Guideline and Manual for Hydropower Development Vol. 2

Small Scale Hydropower

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TABLE OF CONTENTS

Part 1

Introduction on Small Scale Hydropower for Rural Electrification

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Significance of Small Scale Hydropower Development

Chapter 1 Significance of Small Scale Hydropower Development

(1) Contribution to rural electrification

More than two billion people in the world, mostly in developing countries, are still living without benefit of electricity. For these people, access to electricity, even if limited in capacity, should improve the quality of life dramatically as a heat and light source. The daily life would be enriched, and the level of medical equipment and services as well as the safety of stored vaccines would be upgraded. In spite of an obvious need for the electrification in these regions, the majority cannot enjoy electricity because they live in localities which are away from the national power grid. High construction costs for the extension of transmission lines from the grid make the governments in developing countries unable to respond to the needs of the local people.

Small scale hydropower can become an optimal distributed power source for the electrification of remote regions. Costs associated with the construction and operation of the plants and distribution lines can be reduced by having local organizations take responsibility for the small scale hydropower projects.

And also improvement of livelihood and empowerment of the local people can be achieved by making use of hydropower which is stable energy and regional resource.

(2) Global environmental issues

Hydropower is a renewable energy which offers excellent advantages against the negative factors of environmental contaminants such as carbon dioxide (CO_2) and other flue gases. With the increasing use of energy in recent years, the combustion of fossil fuels has resulted in an increasing volume of carbon dioxide causing urgent global warming and other environmental problems. The increase has also resulted in acid rain caused by gaseous pollutant (Sox & NOx) emissions into the atmosphere. In developing countries, wood and charcoal fuels are the major energy resources, resulting in deforestation, soil erosion and ever-advancing desertification. Under these circumstances, the development of non-fossil energy sources like hydropower is growing in demand.

(3) Use of local people and technology

Training local people properly so that they can manage the power plants themselves is a huge advantage. Through more than 100 years of practical application, hydropower generation technology is already well- established. Transfer of the appropriate technologies to the engineers in developing countries enables the production of safe, reliable electric energy, since small scale hydropower does not need such an advanced technology as large scale hydropower and can utilize traditional technology such as irrigation facilities.

(4) Stable electricity rate

Energy generated by small scale hydropower plants is domestic and renewable, and the plants incur no fuel costs. In recent years global, economic development tends to increase prices for fuels such as oil and coal. Major forms of power are reliant on fuels and their operating costs rise significantly year after year. However, once a hydropower plant is completed, it will provide stable low-priced power for a long period, and be unaffected by any changes in fuel prices.

Chapter 2

Objectives and Scope of Manual

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2.1 Objectives

This guideline and manual (hereinafter referred to as "Manual") describes the small scale hydropower projects as electric power supply sources for the rural electrification. Manual includes the contents from planning to operation of the small scale hydropower plants.

Manual is intended to provide persons involved in hydropower with general information about the electrification of local regions by hydropower. Manual covers the following topics.

- To provide central and local government officials with basic information and knowledge about hydropower, in order to get them to be familiar with the schemes for development and the processes of a project from planning to operation. Such information should familiarize them with how a project becomes materialized to be operated and maintained for a long period of time.
- To provide persons who support government officials regarding the rural electrification by hydropower with basic information and knowledge about project planning, design, construction, operation and maintenance, collection of electricity rate as well as other important matters. The persons include engineers in power utilities, universities and local consultants, and local people experienced in hydropower.

2.2 Definition of Small Scale Hydropower and Coverage of Manual

2.2.1 Definition

Local areas which are far from national grid are obliged to have independent electric power grid systems. Manual defines the small scale hydropower as that whose capacity ranges between 10 kW to 500 kW. Power plants within this range are prevalent in the rural electrification.

2.2.2 Coverage of Manual

Manual covers small scale hydropower with respect to surveying, planning, design (civil structures, electrical and distribution equipment), construction, operation and maintenance.

Power demand immediately after the electrification is in general limited initially, however it tends to increase progressively as more and more local people become aware of the convenience of electricity. Although the small scale hydropower plants in Manual are assumed not to be connected to the national grid, the extension of national grid to the local community in the future would provide any increased power for it. Manual covers the topics that deal with the future variability in power demand.

There are several methods for investigation, study and approach to go forward small scale hydropower projects. One of the typical methods is introduced from Chapter 5 to 16 in this Manual, however different methods from the Manual could be used depending on the condition concerned.

Chapter 3

Outline of Hydropower Generation

Chapter 3 Outline of Hydropower Generation

3.1 Energy of Hydropower

3.1.1 Hydro Power Generation

(1) Hydropower

The waters of lakes, reservoirs located at high elevation and water flowing in a river all provide potential energy or kinetic energy. The energy produced by water is termed water power. Power generation methods which produce electric energy by using water power are called hydropower generation.

(2) Water cycle and hydropower

Figure 3-1 shows a schematic figure of water cycle which consists of cloud, rainfall, river flow, ground water, evaporation from oceans and lakes, transpiration from vegetation. The raindrops fall from clouds and reach to the earth, and then the water returns to the atmosphere. Hydropower generation is renewable energy utilizing the phenomenon of water cycle.

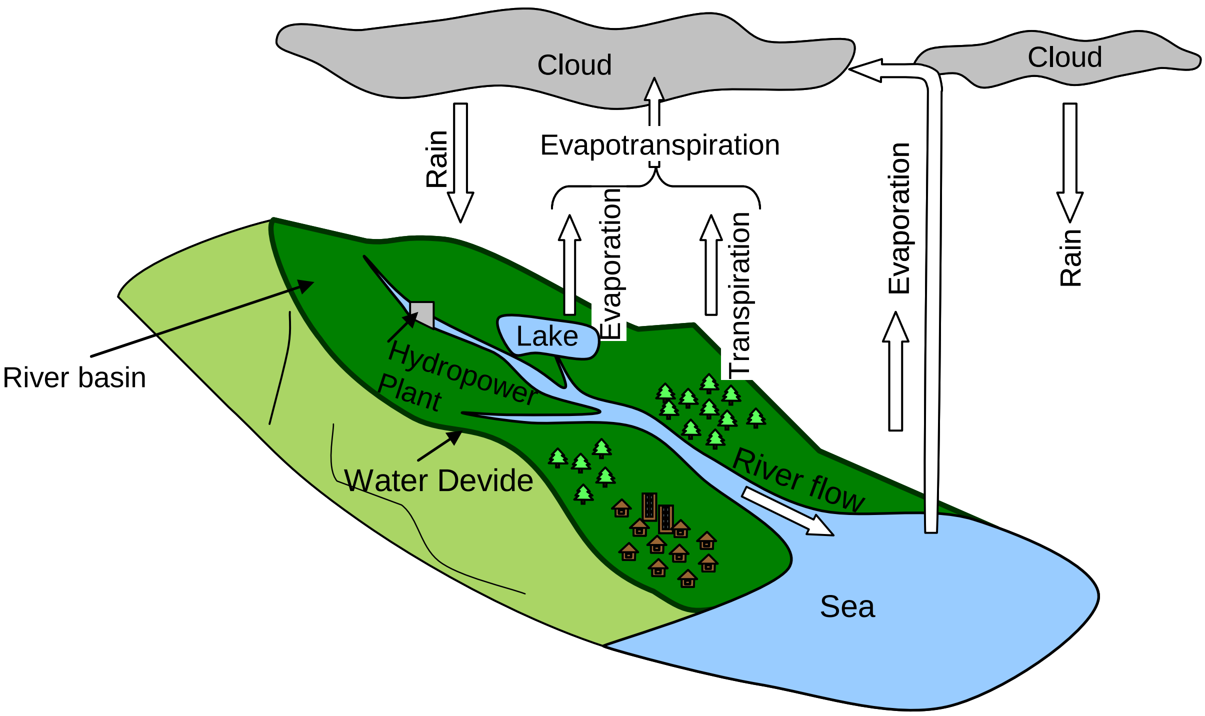


Figure 3-1 Schematic Figure of Water cycle

3.1.2 Electric Power Output

Hydro power plants are equipped with turbines and generators which are turned by water power to generate electric power. Here, the water power is first converted into mechanical energy then into electric energy. In this form of energy conversion process, there is a certain amount of energy loss due to the turbine and generator. The power output is expressed by the following equation. Water density is not written after Chapter 4.

$$P=\rho 9.8 Q H_e \eta$$

where,

P	: Power output (kW)
ρ	: Water density = 1,000 kg/m^3
	(1,000 kg/m^3 at 4°C, elevation 0m and 1atm)
9.8	: Approximate value of gravity acceleration (m/sec^2)
Q	: Plant discharge (m^3/sec)
H_e	: Effective head (m)
η	: Combined efficiency of turbine and generator

The MW unit is also used to express the power output. 1,000 kilowatt (kW) is equal to 1 megawatt (MW).

Installed capacity, maximum output, rated capacity, firm output, and firm peak output[1] are used to express the performance of the power plant.

3.1.3 Energy Generation

Power output (P) is the magnitude of the electric power generated. The electric energy (P×T) generated by continuous operation of P (kW) for T (hours) is termed generated energy and is expressed by kilowatt hour (kWh).

The electric energy generated for one year at the power plant is called annual energy generation or annual energy production.

3.2 Types of Hydropower Plant

3.2.1 Classification from Viewpoint of Power Supply Capability

(1) Run-of-river type

This type takes water from the natural runoff directly to generate electricity; therefore it has no reservoir or pond to adjust river runoff to the generation. A waterway type mentioned in 3.2.2 (1) is a category of this type. Most of the small scale hydropower adopts a run-of-river type.

[1] Maximum output is the power output which power plants generate at maximum level, and the term is used as rated capacity.in a same context. Firm output is the output which plants of-run-of-river type is able to generate almost every day of the year. Firm peak output is the output which the power plant is able to produce almost every day of the year for the specified time during of peak demand.

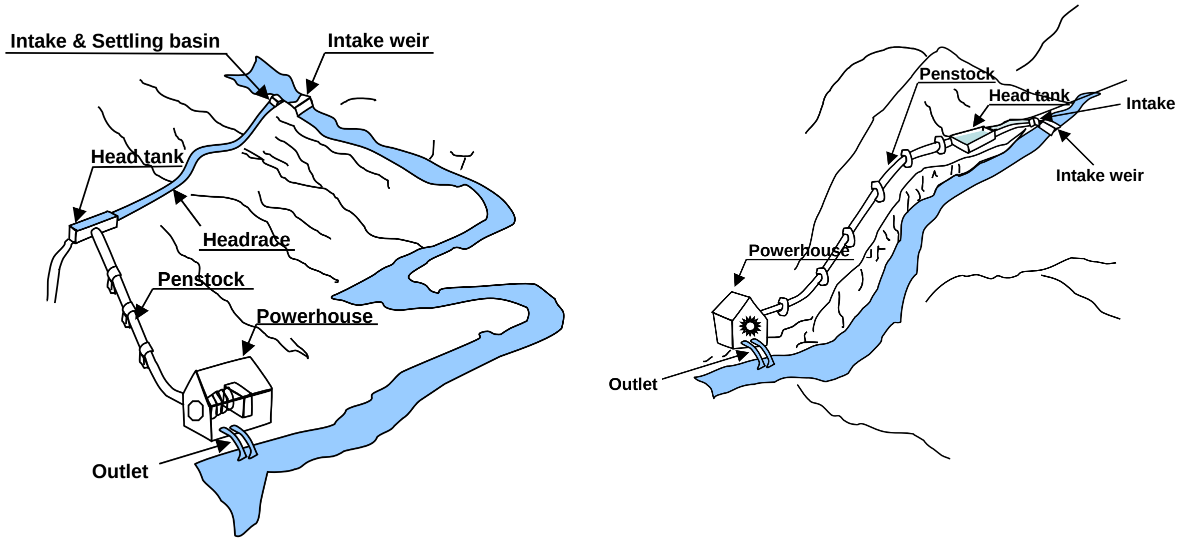


Figure 3-2 Run-of-River Type

(2) Pondage type

A pond type has a pond which can regulate the river runoff for one to several days. Power demand changes in a day depending on time, and hydropower of a pond type can follow the change in power demand.

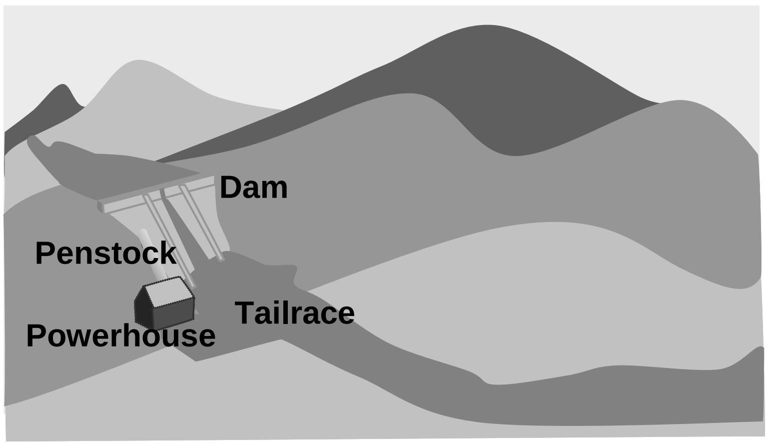


Figure 3-3 Pondage Type and Reservoir Type

(3) Reservoir type

A power plant with a reservoir which can regulate annual or seasonal river runoff is called a reservoir type. Since river runoff changes depending on seasons, a reservoir stores water in a rainy season and releases it in a dry season. The reservoir will release an even flow throughout the year as much as possible. This type has the same function as a pond type to be able to follow the change in power demand and is used for large scale hydropower plants.

3.2.2 Classification by Method of Head Acquisition

(1) Waterway type

As shown in Figure 3-2, an intake weir is constructed at the river and the river water is led to a powerhouse through waterway (headrace, penstock). The head between the intake weir and the outlet is utilized for power generation. This type is commonly used with a run-of-river type mentioned in 3.2.1 (1). Most of the small scale hydropower adopts this type.

(2) Dam type

As shown in Figure 3-3, a head is acquired mainly by the height of a dam (intake weir). The powerhouse is installed near a dam site.

(3) Dam and waterway type

This is a combination of the two types described above to create an increased head of both a dam (intake weir) and a waterway. This type is commonly used with a reservoir type or a pondage type.

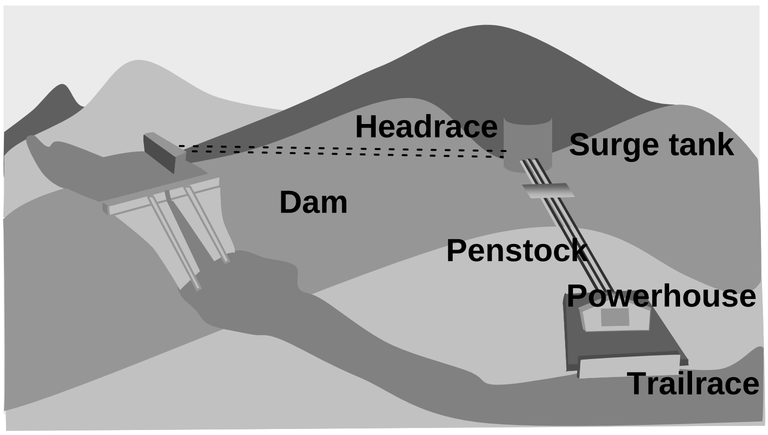


Figure 3-4 Dam and Waterway Type

3.3 Development Pattern and Level of Electrification

3.3.1 Relation between Electricity Demand and Level of Electrification

The situation of electricity demand greatly varies according to living standards of the target areas of electrification. And speed of progress of electrification varies according to deferent characteristic of the target area. Table 3.1 shows the characteristics of electricity demand that normally gradually increase after the electrification.

Table 3-1 Characteristics of Electricity Demand of the Rural Electrification

Stage of electrification		Using time	Daily Load Factor (%)	Monthly comsumption per household	purpose of use
↓	Non electrification	(Night)	-	-	lighting
	Initial period after electrification	Early evenig	15~25%	10~30kWh	lighting
	Next stage	Evening for dinner	25~35%	20~50kWh	Lighting and radio or TV
	General	24 hour use	About 50%	More than 50kWh	Lighting and radio or TV, motor tools

Secular variations of daily load curve are shown in Figure 3-4.

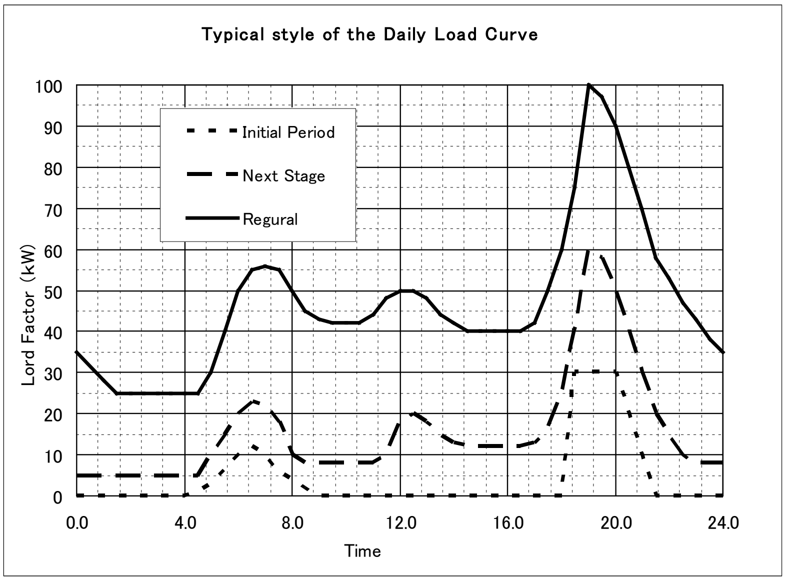


Figure 3-5 Secular Variations of Daily Load Curve

As the above figure shows, it is likely that the daily load will change along with the advancement of electrification.

Since living standards of the areas to be electrified are in general low, immediately after the electrification the electricity demand will stay low for just a few hours per day mainly for uses of lighting, listening to radio, etc. However once they start to benefit from the electricity, the demand for it will increase as long as there are no economic limitations.

At first there are uses for lighting and listening to radio, and when the economic strength grows television is used and the duration of using electricity becomes longer. In addition, dining halls and markets in town will start using refrigerators to preserve their foods, leading to a 24-hour continuous use of electricity.

And, the transition speed to the next step is depending on the speed of development of the region.

The implementing organization of the project needs to pay attention to the points below

i) The scale of a power supply facility is greatly different depending on which step in Table 3-1 is targeted when the electrification is decided.

ii) To foresee the development and change of the area and decide the period that an initial facility can provide electricity

3.3.2 Relation between Level of Electrification and Combination of Auxiliary Generating System

In a case where hydroelectric energy is a main power source for the rural electrification, the role of hydropower will depend on whether only hydropower will be an electricity source or an auxiliary generation system will be applied in combination.

Table 3-2 Scale of Electrification and Combination of Auxiliary Generating System

Item	Case: Supply by Hydropower Only	Case: Combination of Auxiliary Generating System
1. Electrification Scale	Scale of Village (2~3 hundred households)	Scale of small town (One thousand households)
2. Type of Energy Source	By hydropower only	Hydropower with auxiliary system
3. Suppy Parts toward Demand	Hydropower shall cover all demand	- In the case of a run-of river type, hydropower supplies base load - In the case of a daily regulation pond type, hydropower supplies both peak demand and base load.
4. Scale of Installed Capacity	Relatively small (10~100kW approximately)	Relatively large (200~300kW and more)
(Main reason)	The facility scale is set to the level of firm discharge in the dry season, since the constant electricity supply will be required for demand.	An auxiliary generating system is available during the dry season, so there is less restriction on the facility scale. Comparing to supplying only hydropower, a bigger output is expected because there is enough river discharge during the rainy season.
5. Annual Plant Factor	95% approximately	60~75% approximately
(Main reason)	As the facility scale is set as above-mentioned, it can produce its maximum output most of the time.	In the rainy season hydropower can supply a maximum output. In the dry season the hydropower supply becomes less due to the less river discharge. In general the annual plant factor is around 60 to 75%.
6. Surpuls Energy	50~80%	Allmost nothing
(Main reason)	Since electricity is particularly used during the dinner time and early nighttime, there is little use during the daytime.	The electricity output is relatively small comparing to the maximum demand, so it hardly has a surplus.
7. Accutal Annual Plant Factor	15~45% approximatery	60~75% approximatery

Chapter 4

Rural Electrification Project by Small-Scale Hydropower

Chapter 4 Rural Electrification Project by Small-Scale Hydropower

4.1 Development Flow

A rural electrification project by small-scale hydropower consists of the following 5 stages: i) Preliminary Survey, ii) Basic Plan Survey, iii) Implementation Plan, iv) Construction and v) Operation and Maintenance.

Figure 4-1 shows the standard process of the rural electrification project by small-scale hydropower.

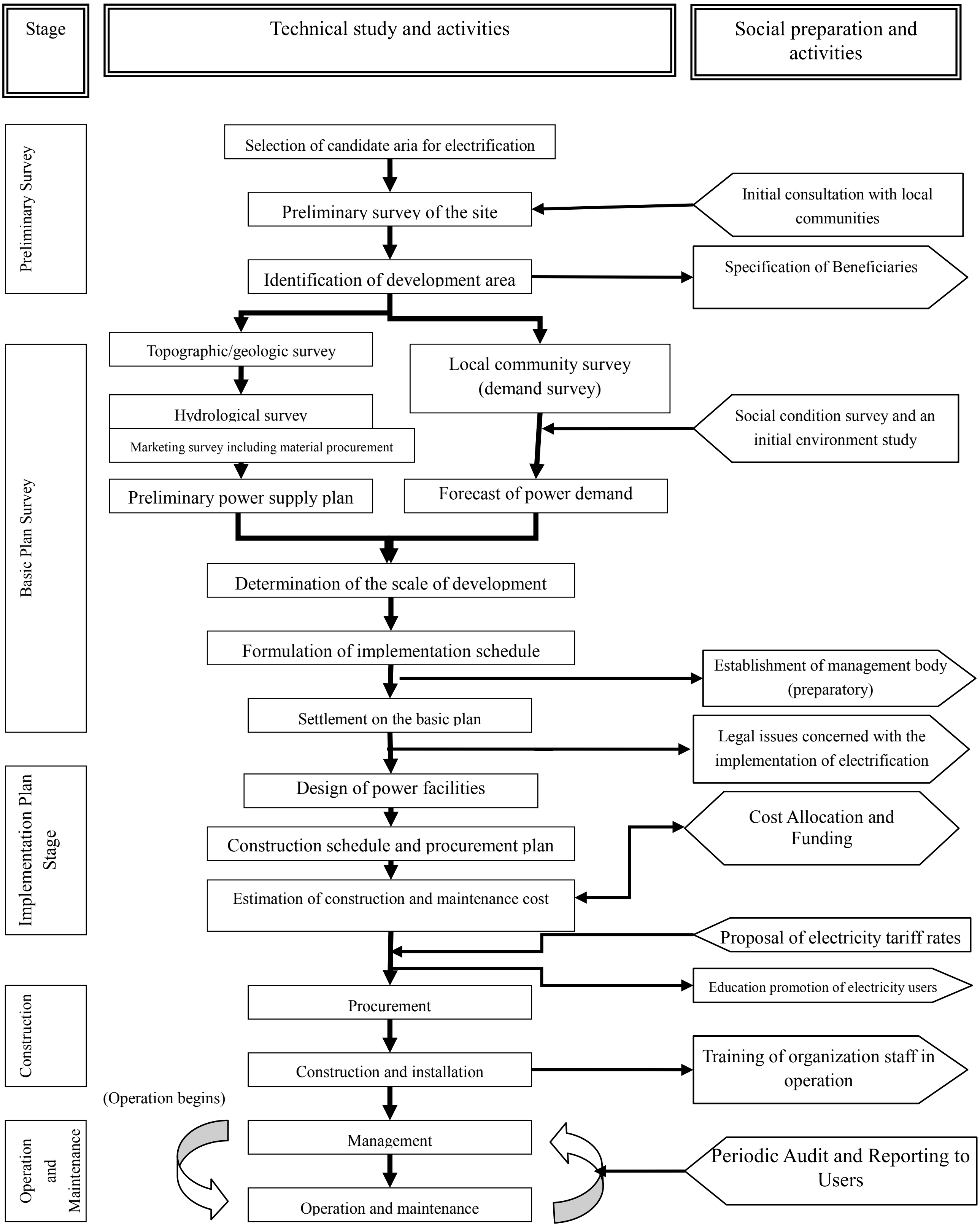


Figure 4-1 Standard Process of The Rural Electrification Project by Small-Scale Hydropower

4.1.1 Preliminary Survey Stage

When designating the area to be developed, suitable areas should be narrowed down for rural electrification development by small-scale hydropower, considering such conditions as hydropower potential, distance to the site of demand, system expansion plan and the surrounding environment.

Table 4-1 Tasks During the Preliminary Survey Stages

	Tasks	Outline	Reference
1	Selection of candidate area for electrification	Candidate site for electrification is selected on paper.	5.1
2	Preliminary survey of the site	A reconnaissance survey of the hydropower potential is carried out, and the existence of possible sites of demand, possibility of grid connection, access conditions and laws and regulations are confirmed.	5.1, 5.2
3	Initial consultation with local communities	After explaining the electrification planning and the study contents for that planning, open a consultation with the community representatives as to obtain its consent to enter into the site study.	5.2
4	Identification of development area	The suitable area is surveyed and selected considering the following condition: the area has a site suitable for small-scale hydropower near a local community and away from an existing distribution network.	5.3, 5.4
5	Specification of beneficiaries	The residents in the selected planning area (future users of electricity) shall be beneficiaries of the project.	5.4

4.1.2 Basic Plan Survey Stage

The basic electrification plan of the selected area is determined during the basic plan survey. This manual includes preparatory items for the next stage.

Table 4-2 Tasks During the Basic Plan Survey Stage

	Tasks	Outline	Reference
1	Topographic/geologic survey	Basic technical data is collected and the area is surveyed with the future structure design in mind.	7.2, 7.3, 7.5
2	Hydrological survey	Basic data is collected and the area is surveyed to determine a structure design, calculate potential generating electric energy and assess the environmental impact.	7.1
3	Marketing survey including material	Procurement method is an important item in cost estimation. As rural electrification is carried out at	7.4

	procurement	remote locations, in most cases each place has its own various labor market conditions, commodity market and transportation conditions, etc. Thus, at this stage it is necessary to carry out a cost estimation survey etc.	
4	Preliminary power supply plan	The scale of power output is preliminarily planned.	
5	Local community survey (demand survey)	Present condition of energy consumption in the target area is surveyed.	7.4
6	Social condition survey and an initial environmental study	Present condition of life style, awareness of electrification and the local industry are surveyed. Also, an initial environmental study is carried out in relation to the plan for small-scale hydropower.	7.4, 8.4
7	Forecast of power demand	Power demand after electrification is estimated in consideration of the life style of the local community and scope of electrification.	8.2
8	Determination of the scale of development	Using the results of the surveys above, power generation and distribution are planned and the balance of supply and demand is confirmed. And project cost and operation and maintenance cost are estimated to determine a possibility of project implementation from the standpoint of finance. In addition, the impact of the project on the social and natural environment is assessed. After verifying these items, the scale of development is determined.	8.3
9	Formulation of implementation schedule	Arrange the procedure schedule and the detailed tasks such as financial procurement, implementation design, procurement, construction and the generation operation opening, etc. to materialize the project.	12.1
10	Establishment of management body (preparatory)	In the future, the operation of the power plant is to be carried out mainly by the local residents. As soon as the basic plan has been determined, a management body or its preparatory organization, including those local residents is established.This organization also serves as the local support office until project completion.	6.5
11	Settlement on the basic plan	The electrification plan is agreed on among the project participants.	8.3
12	Legal	Rural electrification is to be in accordance with the	8.4

	concerned with the implementation of electrification	of the country. Regulatory matters, such as those related to the electric utility services and to environmental development are to be extracted and any development it to be in support of those policies.	
13	Construction financing plan	Unlike a case where construction is carried out with own funds, when the cost is covered by external assistance or a loan, the approaches to the related organizations are necessary and are to be planned.	12

4.1.3 Implementation Plan Stage

Based on the basic plan above, this stage focuses on more detailed work items such as design, construction schedule, procurement, construction, and operation plan, etc. of project implementation.

Table 4-3 Tasks During the Implementation Plan Stage

	Tasks	Outline	Reference
1	Design of power facilities	Design implementation for the procurement of facilities such as power plants and distribution lines (detailed design) is carried out.	9. 10. 11
2	Construction schedule and procurement plan	A construction schedule and procurement method is prepared.	12
3	Estimation of construction and maintenance costs	Construction costs are estimated. The estimated costs of power facilities maintenance after the commencement of operation are used to establish electricity tariff rates.	13
4	Cost Allocation	If the beneficiaries can share the costs, the rate of costs sharing is to be agreed upon among those who are to benefit from the project.	
5	Proposal of electricity tariff rates	Based on the construction costs, and the operation and maintenance costs, electricity tariff rates are calculated. Depending on the regulators of the electric power sector, the proposal of electricity tariff rates may be submitted prior to construction. Also, rate sharing is explained to the local beneficiaries before completion.	14

4.1.4 Construction Stage

This stage includes procurement procedure for selecting/contracting the contractor specializing in construction, production and installment of the small-scale hydropower station. It also includes construction of facilities.

Table 4-4 Tasks During the Construction Stage

	Tasks	Outline	Reference
1	Education promotion of electricity users	Before the beginning of construction, the electrification project is explained through activities such as meetings to seek local cooperation during the construction period. In addition, it is important at this early stage for the local community to fully understand the rate sharing policy after electrification.	
2	Procurement	Tender documents are prepared based on the design and specifications of the facilities that are prepared during the designing stage. A series of procurement procedures to invite a bid, assess, select, negotiate and conclude a contract are followed.	9~13
3	Construction and installation	Civil engineering works such as construction of the intake weir, waterway and powerhouse foundation, and installation of electrical equipment such as the turbine and generator, and distribution line construction are carried out.	13
4	Training of organization staff in operation	In preparation for the commencement of operation, engineers training for power station operation and distribution line maintenance, and training for basic clerical work such as the collection and aggregation of electricity charges are carried out. Moreover, it is possible to increase the effectiveness through study tours of the facilities under construction and/or through partial involvement of the construction, in order for those participants to understand the structure and mechanism of the actual equipment.	16

4.1.5 Operation and Maintenance Stage

During this stage, electrical facilities such as the power plant, distribution lines, etc. are completed and electric power is actually supplied.

Table 4-5 Tasks During the Operation and Maintenance Stage

	Tasks	Outline	Reference
1	Management	The management and operation of the organization of power utility services consists mainly of clerical works including aggregate billing, collection of electricity charges, accounting, procurement, etc	14
2	Operation and maintenance	Operation and maintenance of civil facilities, electrical facilities, distribution line, etc. are carried out.	15
3	Periodic Audit and Reporting to Users	Electric power usage condition and the details of the management body administration are impartially checked by a certified auditor and a report is issued to electricity users.	16

4.2 Relationship between the Project and Local Community

A rural electrification project by small-scale hydropower has a closer relationship with the local community than conventional hydropower and pumped storage power generation projects. As the size of power station is small, in many cases the local community is responsible for management of electric utility services, and for operation and maintenance of the power station after construction. Therefore, it is necessary to create a good relationship with the local community from the preliminary survey stage as a joint developer and a manager to be of the facilities after completion.

Furthermore, it is necessary to conduct consultation meetings from the preliminary survey stage for implementation of sustainable project. Because the local community (beneficiaries) should understand advantages and disadvantages of using electricity, proper management of facilities, proper use of electricity, electricity tariff, operation and maintenance costs etc., and should have a sense of ownership.

Table 4-6 Relationship with Local Community

	Stage	Activities	Objectives/Details
1	Preliminary survey	Prior consultation with the local communities of the candidate area for electrification	Agreement on entering into a site survey is obtained.
2	Early stage of basic plan survey	Social condition survey	A basic study is carried out to collect data for planning, including local awareness of electrification, economic strength and potential power demand.
3	Late stage of basic plan survey	Establishment of a steering body	When the promotion of electrification is specifically decided, a parent body to promote the project, in which local residents participate, is established.
4	Implementation plan stage	Funding Plan for Construction Cost and Cost Allocation	The roles of a local community are decided, including cost sharing of the project sites and any other convenience provisions required.
5	Same as above	Consensus on electricity tariff rates	Promote the education and understanding of the role of the electric utility services to electricity users.
6	Construction stage and the beginning stage of operation	Operation training	Future employees of the management body take part in the lectures on the facilities structures and the operation methods during the construction stage.
7	Same as above	Business management training	Future employees of the management body learn the charging process including billing, collection and accounting of electricity charges through training before the commencement of operation.
8	Operation stage	Management monitoring and reporting to users	Management condition is supervised through regular operational and financial reporting from the management body. As needs arise, users are requested to share the costs.

4.3 Development Scheme

4.3.1 Japanese Development Aid Program

(1) Types of Japanese development aid

The aid for the economic development of developing countries is in general called “economic cooperation”. It is classified into three types as set-in below. Among these, ODA is known as government-based, and broadly speaking the other two as private sector-based economic cooperation.

- Official Development Assistance (ODA)
  Japanese government grant aid, technical cooperation, investments/contributions to international organizations, ODA Loans, etc.
- Other Official Flows (OOF)
  Financial assistance such as exports credits and direct investments by Japan International Cooperation Agency (JICA)
- Private Funds (PF)
  Export credits and direct investments, etc. by the private sectors

(2) Official development assistance (ODA)

1) Definition of ODA

The government-based assistance meets the following three requirements corresponding to the definition by ODA (Organization for Economic Cooperation and Development (OECD): Development Assistance Committee (DAC).

- Assistance is provided by a government or a governmental organization.
- The main objective is to contribute to economic development and improvement of welfare in developing countries.
- With regard to financial assistance, the grant element[1] of grant conditions is more than 25%.

2) Bilateral assistance

Japanese Official Development Assistance (ODA) is broadly divided into bilateral assistance and multilateral assistance as is shown in Figure 4-2. Bilateral assistance consists of technical cooperation, grant aid, and ODA loans (yen loans).

[1] The grant element is an index to show the level of relief of the loan condition. The lower interest rates are, and the longer a loan period is, the higher and more favorable the grant element becomes to the borrower (developing country). In the case of grant assistance, the grant element is 100%.

(a) Grant aid

Grant aid imposes no obligation to repay on the developing countries. This provides a developing country with i) materials and equipment necessary to prepare an economic and social development plan and ii) funds necessary for the procurement of equipment and services. Among developing countries, focusing on those with low income, grant aid supports the creation of social and infrastructural foundations such as the construction of bridges and hospitals, and cooperates directly to improve the living standards of people through education, HIV prevention and treatment, child health care, environmental preservation, etc.

Grant aid mainly assists from the viewpoint of equipment and materials in the basic fields such as medical service, water supply, rural development, transportation and rural electrification; it includes i) "the construction of facilities", such as hospitals, schools and road facilities and ii) "procurement of equipment", such as medical and training equipment.

Grant aid is divided into such types as general project grants and non-project grants. The rural electrification by small scale hydropower falls under the general project grant.

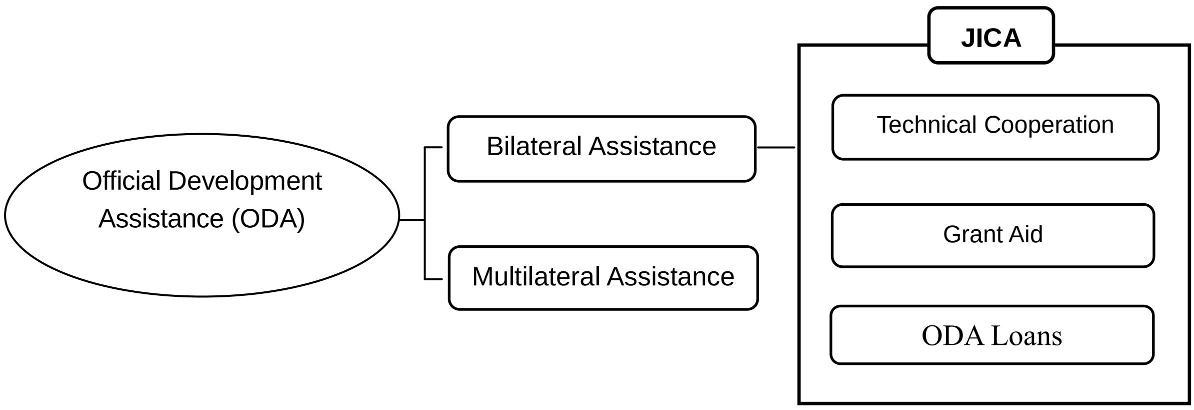


Figure 4-2 Japan's ODA Scheme

(b) Technical cooperation

Technical cooperation trains human resources who fill the role to develop the society and economy of the developing countries by using the technology, knowledge and experience of Japan. Furthermore, it creates a custom-made cooperation plan together with the counterpart country based on the actual conditions of the country and assists in the technological development and improvement suitable to the realities of the country. In addition, Problem-solving skills are enhanced through the improvement of the technical level and contribution to the establishment and development of the organizations. To be more specific, various surveys (technical cooperation through development plan surveys) are carried out in order to support the acceptance of trainees, dispatch of experts, provision of equipment, formulation of a policy, planning of public works, etc. The “technical cooperation project” is implemented during a certain period of time as one project to be planned in a flexible combination of “acceptance of trainees”, “dispatch of experts”, and “provision of equipment”, etc. corresponding to the challenges facing the developing countries.

(c) ODA loans

ODA Loans are a financial method to support the development efforts of developing countries through lending funds required by them, which are long term soft, concessionary loans with low rates of interest repayment. Such assistance forms as “yen loans” and “overseas investments/loans” come under this category. Especially, yen loans have been used for the purpose of large-scale infrastructure development in developing countries, as it is usually possible for the loans to be taken out at a larger amount than those under the technical cooperation and/or grant aid.

Unlike grant aid, ODA Loans oblige developing countries to repay, and this condition thereby underlines why they need to assess the importance and priority of projects and try to allocate and utilize the funds as effectively as possible. Thus, ODA Loans have a major objective to support various development activities while encouraging the self-help efforts of developing countries.

(3) Grant aid

1) Small-scale hydropower for rural electrification

Small-scale hydropower for the rural electrification at which this manual aims, targetsan isolated system that cannot be extended. In rural areas like this, ODA Loans (yen loans) repayment obligations cannot be met by reason of little profitability of the project, and thus, except for special cases, grant aid is provided. Accordingly, the explanation here is based on JICA’s grant aid. (ODA Loans are described in the First Volume.)

2) Implementation flow of grant aid

As shown in Figure 4-3, the activity of a grant aid package includes the following steps: i) recipient country’s request for assistance, ii) preparatory survey for cooperation, iii) project appraisal, iv) consultation within the government, v) decision by the Cabinet, vi) signature on Exchange of Notes, vii) conclusion of grant agreement, viii) implementation supervision and ix) ex-post facto monitoring.

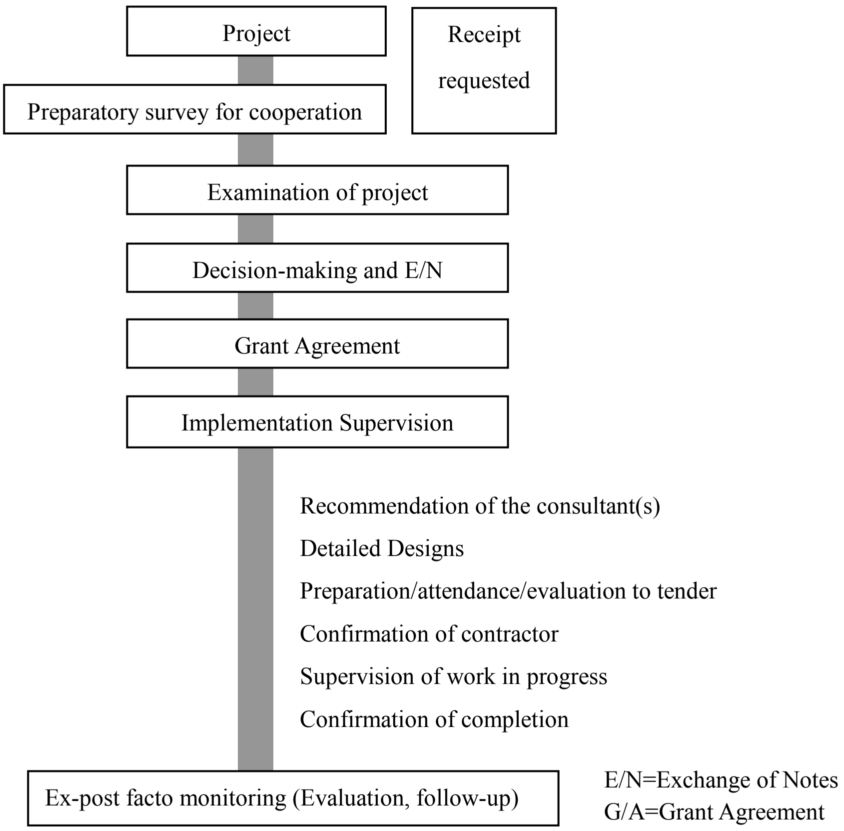


Figure 4-3 Implementation Flow of Grant Assistance

(a) Identification and formulation of the project

Through a preliminary survey for the possibility of cooperation and other preparatory surveys, examined are the degree of public services, organization of operation and management, collaboration with technical cooperation. The following are basic points to check the above.

i) the contents of the development plans including project objectives, backgrounds and effects

ii) the contents regarding the project implementation including the appropriate scale of grant aid, environmental considerations, etc.

The aim of the preparatory survey is to provide a basic document necessary for the appraisal of the grant aid project made by the GOJ and JICA. The contents of the survey are as follows.

- Confirmation of the background, objectives, and benefits of the Project and also institutional capacity of relevant agencies of the recipient country necessary for the implementation of the Project
- Evaluation of the appropriateness of the Project to be implemented under the Grant Aid scheme from a technical, financial, social and economic point of view
- Confirmation of items agreed on between both parties concerning the basic concept of the Project.
- Preparation of an outline design of the Project
- Estimation of Project costs.

The contents of the original request by the recipient country are not necessarily approved in their initial form as the contents of the Grant Aid project. The Outline Design of the Project is confirmed based on the guidelines of the Japan's Grant Aid scheme.

(b) Examination

By request for assistance from the governments of the developing countries, JICA examines the contents of the assistance based upon the investigation reports and other relevant materials.

Based on the results of the review by JICA, the Ministry of Foreign Affairs discusses the matter with the Ministry of Finance in order to ensure the necessary budget. After the necessary formalities, in the end the Japanese Government will make a decision to implement the cooperation plan through a Cabinet meeting.

Under Japanese Grant Aid, in principle, Japanese products and services including transport or those of the recipient country are to be purchased. When JICA and the Government of the recipient country or its designated authority deem it necessary, the Grant Aid may be used for the purchase of the products or services of a third country. However, the prime contractors, namely, constructing and procurement firms, and the prime consulting firm are limited to "Japanese nationals".

(c) Exchange of notes and the grant agreement

After the Project is approved by the Cabinet of Japan, the Exchange of Notes pledging assistance (hereinafter referred to as “the E/N”) is singed between the GOJ and the Government of the recipient country, and is followed by defining the necessary articles to implement the Project that will conclude the Grant Agreement (hereinafter referred to as “the G/A”) between JICA and the Government of the recipient country

(d) Project implementation

After the E/N is signed and G/A is concluded, the project operator will be the government (organization) of recipient country, while JICA guides and supervises the project to ensure the smooth implementation. To ensure the proper and smooth construction of the facilities and procurement of equipment and materials, JICA advises, contacts and instructs both the government of recipient country and consultants throughout the entire process of contract, including construction completion, and the delivery of equipment and materials

A recipient country must carefully consider the social and environmental impacts caused by the Project and must comply with their environmental regulations as well as with the JICA socio-environmental guidelines.

(e) Evaluation and follow-up

After the project has been completed and a certain period of time has passed, JICA carries out an “evaluation” to confirm the effectiveness of the project. The effect clarified through the analysis, which is carried out by comparing and examining the conditions at the time of initial examination and at the completed stage, is to be reflected in the future cooperation projects in respect of planning and implementation method.

After the cooperation is completed, each individual project is maintained by each government of developing country. However, when initially unexpected problems occur, including failure of equipment and lack of funds, etc., project operation may be interfered with. Depending on the situation, JICA carries out follow-up cooperation and supports the developing country to maintain the goals of the project. Follow-up cooperation will include a follow-up survey, procurement of materials and equipment, crew dispatch for repair work and emergency countermeasure work.

4.3.2 Policy to Promote Rural Electrification

(1) Promotion of rural electrification

In the area where the electrification by extending the existing system is difficult, the rural electrification as an isolated system is being promoted under the support of donors. The promotion measures such as establishment of the rural electrification funds (REF), and institutions for it are taken in many countries. t In addition, funds from donors are used for supporting: i) connection of customers (households) that have a new demand created by renewable energy, ii) introduction of the solar home systems (SHS), iii) introduction of an electric power system with renewable energy (including small-scale hydropower), iv)implementation of the pilot project, etc.

(2) Rural electrification fund

REF is operated by the funds of each government and donors. Some countries collect a percentage of electricity rates as a power generation surcharge and appropriate it back to REF.

Below is an example of REF, which is established as an independent organization under the support of the World Bank (WB).

1) The goals of the establishment are as follows:

- Regionally unbiased, impartial promotion of the rural electrification
- The promotion of sustainable rural electrification projects, and participation of private sectors in them
- Making the most of renewable energy

2) Specific activities of the REF office are as follows:

- Presentation of project information
- Review and approval of application forms for financial support such as subsidies
- Planning and preparation of projects
- Monitoring and evaluation of the performance of the project under the support of the REF
- Database management and maintenance of the rural electrification

Reference of Chapter 4

[1] Guide Manual for Development Aid Programs and Studies of Hydro Electric Power Projects, New Energy Foundation, 1996

[2] Guidebook on Small-medium-scale Hydropower (in Japanese), New Energy Foundation, 1997

[3] Guidebook for adopting micro-hydropower, New Energy and Industrial Technology Development Organization, 2003

[4] Guide on Social Preparation for Renewable Energy-based Electrification Projects Department of Energy, Philippines, JICA 2009

Part 2

Designation of the Area of Electrification

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 5

Selection of the Area of Electrification and Finding of the Site

Chapter 5 Selection of the Area of Electrification and Finding of the Site

5.1 Desk Study

5.1.1 Preliminary Survey

When selecting a candidate area for the electrification by small-scale hydropower, the effectiveness of the rural electrification by such a plant needs to be thoroughly examined. For this purpose, total evaluation is required considering the amount of hydropower reserves (namely electricity generating output, hereinafter referred to as "hydropower potential") that the candidate site has, as well as the distance to the demand area, the electric power system extension plan and the surrounding environment, etc.

A preliminary survey is carried out regarding the following items based on the materials available near at hand as well as some basic fieldwork.

- A preliminary survey of hydropower potential
- Existence of a potential demand area
- Confirmation of the possibility to extend the transmission and distribution lines of the electric power system
- Confirmation of the access conditions
- Confirmation of laws and regulations

Materials necessary for the preliminary survey are as follows:

- Topographic maps (scale: 1/50,000 - 1/10,000)
- River flow data and rainfall data, including river flow observation data around the candidate area, isohyets maps and nearby precipitation observation data
- An electric power system extension plan (a transmission line extension plan)
- Laws and regulations concerning the natural environment

(1) Preliminary survey of hydropower potential

Since hydropower potential is determined by the river flow and the water head between an intake weir and an outlet, these two factors must be estimated when a candidate site for hydropower development is examined.

1) Estimation of river flow

In case, the rural electrification is carried out by only small-scale hydropower, it is necessary to provide power almost constantly throughout the year. It is important to estimate plant discharge which is available during the period of 95% in a year. To this end, the flow duration curve shown in Figure 5-1 can be used.

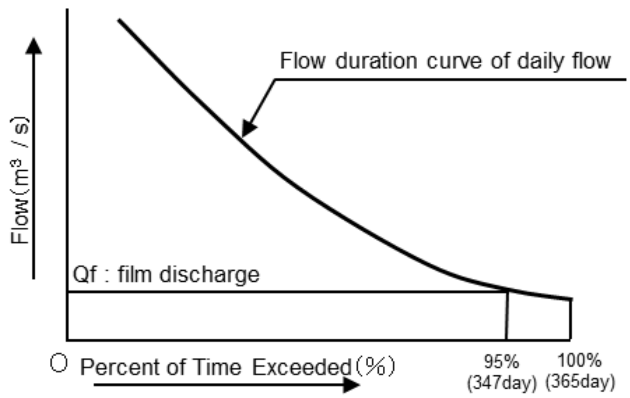


Figure 5-1 Flow Duration Curve and Firm Discharge

The flow in the dry season of a small-sized river, which is the target of small-scale hydropower, is largely influenced not only by the precipitation of the basin but also by the regional geology in terms of water retention characteristics. Existing flow gauging stations (hereinafter, gauging station) are in general placed alongside large and medium- sized rivers. Attention should be given to the fact that significant errors will occur when calculating the small-sized river flow by utilizing those existing data simply in proportion to the respective catchment areas (conversion by catchment area ratio).

This manual regards 95% of the flow in the annual flow duration curve shown in Figure 5-1 above as the basic flow required for electric power planning and defines it as "firm discharge". The following formula determines the regular plant discharge per unit catchment area and defines it as "specific flow during the dry season".

$$q = Qg/Ag$$

where,

q	: Specific unit flow during dry season ($m^3/sec/km^2$)
Qg	: Firm discharge at the gauging station (m^3/sec)
Ag	: Catchment area of the gauging station (km^2)

Based on the flow data of any gauging station in the vicinity, the flow of the project site is estimated by the method given below. However, if a gauging station does not exist in the vicinity, the specific flow during the dry season of a small/medium-sized river in the area that has a similar climatic condition should be consulted.

- Catchment area ratio conversion method

$$Q = q \times Ap$$

where,

Q	: Firm discharge at intake weir (m^3/sec)
Ap	: Catchment area at intake weir (km^2)

- Method taking into consideration the average precipitation in the catchment area

$$Q = R_r \times q \times Ap$$

$$R_r = R_d / R_g$$

where,

Q	: Firm discharge at intake weir (m^3/sec)
Rr	: The ratio of the average precipitation in the catchment area between intake weir and the existing gauging station
Rd	: The average precipitation in the catchment area at intake weir (mm)
Rg	: The average precipitation in the catchment area at the gauging station (mm)
Ap	: Catchment area at intake weir (km^2)

- As described in 5.2.1 below, simplified flow measurement is carried out at promising sites for small-scale hydropower.

2) Estimation of head

The head can be estimated through the specification of the point of the intake weir and outlet.

When the topographic map is available to estimate the hydropower generation, even more desirable is to select the site with a higher head with as short a waterway as possible. It becomes easier to select the promising sites, when the longitudinal section of the river is arranged using the topographic map as in Figure 5-2 below. In the case a small stream meets the river under study, a downstream sites of the confluence might be a candidate weir site because of the increase in river flow.

Specific information from the local government and residents should be considered on the natural topography such as waterfalls and existing agricultural intake facilities, if any.

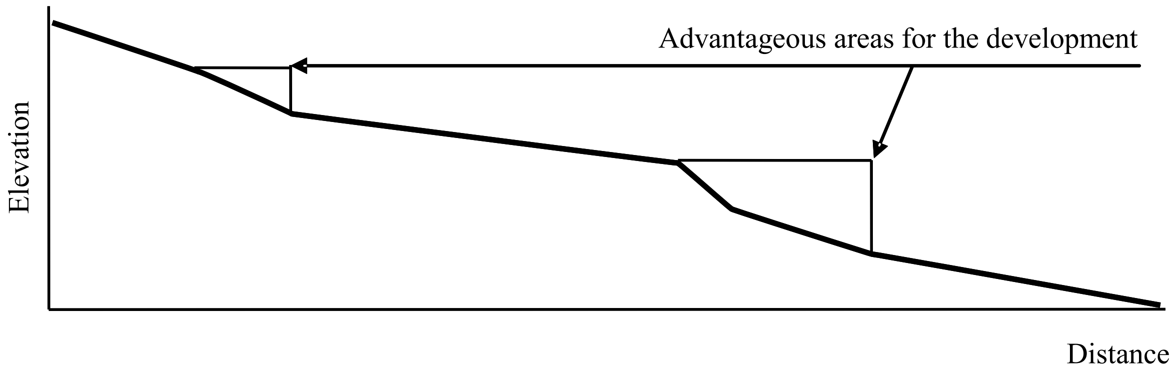


Figure 5-2 Longitudinal Profile

(2) Existence of a potential demand area

In the case of the rural electrification by small-scale hydropower, the power plant needs to be located at the nearer point to the area of electric power supply. In a case where a local community does not exist within the range of about 20km around the power plant, even if hydropower potential exists, transmission/distribution line loss increases compared to the demand, and also the construction cost of the transmission line increases.

When demand areas are separated into several local communities and located over a relatively wide area, sometimes it is more advantageous to construct some small-scale power stations separately than to supply electric power to all the areas by a single power plant. This approach might reduce the transmission cost, ensure ease of operation and maintenance, and reduce the overall impact of power outage, etc.

When the candidate area for the electrification is a rural community, the distance between the power plant and the demand area should be within several kilometers. Even when the candidate area is a town, the distance should be within about 20km.

(3) Confirmation of the possibility to extend the distribution lines of the electric power system

When selecting the candidate area for the electrification, priority should be given to an isolated area that is not expected to have a distribution line extension plan for quite some time. However, regarding the area where there are future plans to extend the existing distribution lines to the vicinity, though the period of construction is not fixed, the extension work of the distribution lines and an isolated small-scale hydropower project are to be compared and examined in terms of economic efficiency.

(4) Confirmation of access conditions

Since the materials and equipment of a small-scale hydropower station are small and lightweight, it is possible to carry them by a simple vehicle or by manpower during construction and operation. However, if available the access road is the best to haul them. On the other hand, since power generation by the small-scale hydropower plant is minimal, construction of a new access road causes a significant reduction in the overall economy of the project. Thus, it is necessary to examine a transportation method using existing roads or without using vehicles.

(5) Confirmation of laws and regulations

When an adverse effect on the lives of the local residents is assumed or when an effect on precious natural species and scenic areas is expected due to the construction of electric power facilities and distribution facilities, it is necessary to conduct a preliminary survey on the laws and regulations related to the social/natural environment in the affected areas.

5.1.2 Selection of the Area for Site Reconnaisance

Utilizing the desk study outlined above, several promising candidate areas for the electrification are examined to evaluate if they are worth a site reconnaissance.

5.2 Site Reconnaisance

With regard to the candidate areas for the electrification and the sites for small-scale hydropower identified through the desk study, a stream flow survey (hereinafter, flow survey), a topographical/geological survey, and a survey on the local community are then carried out. In the case of the rural electrification by small-scale hydropower, the determinant of success or failure of the project depends on the balance between electric supply and demand. The flow survey and topographical/geological survey are carried out to figure out the size of the power plant and to grasp the power supply in general. The survey of the local community aims to determine the amount of power demand in the area to be electrified.

5.2.1 Flow Survey

(1) Simple flow survey by the float measurement method

The float measurement method can be used to calculate the flow rate of the river with a float that measures the velocity, together with the cross section of the river flow separately measured. Pieces of wood available on site are used as the float. Figure 5-3 below and the following explain how to measure the velocity.

- Measurement is carried out in an almost straight river direction and a uniform river cross-section. The float travel length should be longer than the water surface width.
- Traverse lines (A-A’ and B-B’) are created at the upper and lower ends of the measurement interval at right angles to the center of the flow (float travel length = L).
- The flow sectional area at the upper and lower ends of the measurement interval is measured to calculate the average flow sectional area (A).
- The float is dropped into the upper side (O-O’) of the upstream traverse line. The travel time from A-A’ to B-B’ (Ti) is measured.
- The river section is divided into three appropriate divisions (i =1,2,3), and a float is dropped into each of these 3-divisions.
- The average velocity of the 3-divisions is calculated by the following formulae.

$V_i = L/T_i$

$V_m = (V_1+V_2+V_3)/3$

where,

V_i : Velocity in division i (m/sec)

L : Length of traverse line A-A’ to B-B’ (m)

T_i : Float travel time from traverse line A-A' to B-B' in division i

V_m : Average velocity of the three divisions (m/sec)

(Note) In each block of the 3-divisions, measurement is carried out more than twice.

- Flow measurement formula is given as below.

$$Q = C \times V_m \times A$$

where,

C : Coefficient of average velocity (ordinary river = 0.8; concrete waterway with uniform cross section = 0.85; small river with smooth riverbed = 0.65;shallow (about 0.5m deep) stream = 0.45; shallow river with uneven riverbed = 0.25)

V_m : Average velocity (m/sec)

A : Cross sectional area of river flow (m^2)

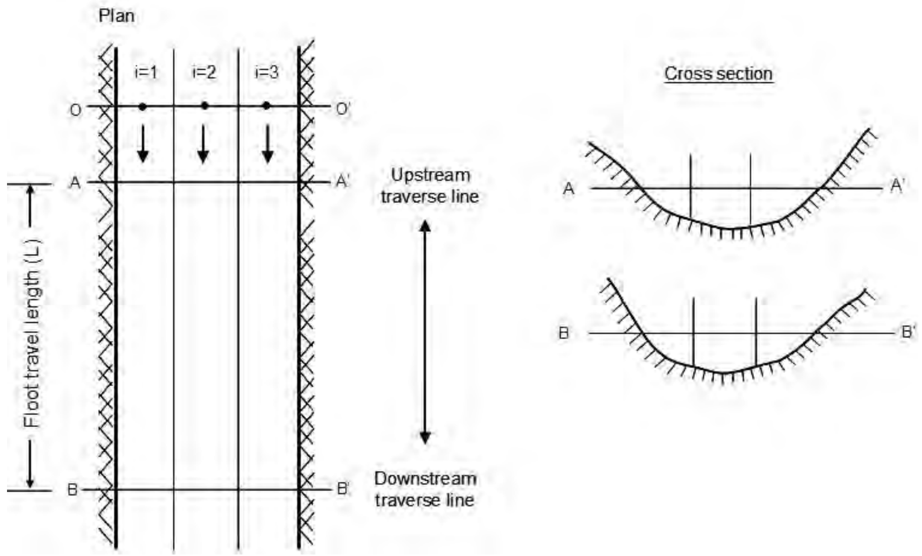


Figure 5-3 Flow Survey by the Float Measurement Method

(2) Simple flow measurement by the current meter

The flow measurement method by the current meter is explained more precisely in Section 7.1. As a simple flow measurement for small rivers, this method is used to calculate the flow based on the surface velocity measured by the electromagnetic current meter or propeller type current meter, and the cross sectional area of the river. It is a variation of (1) above; surface velocity is measured at A-A' line in Figure 5-3. Flow measurement formula is the same as that of (1) above.

Electromagnetic Current Meter

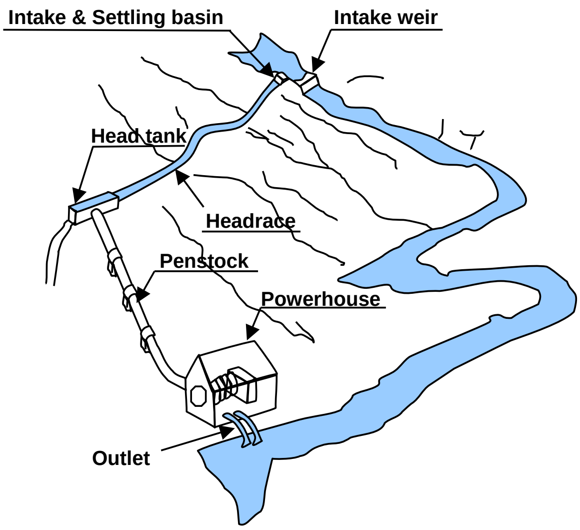
Propeller Type Current Meter

Figure 5-4 Electromagnetic Current Meter and Propeller Type Current Meter

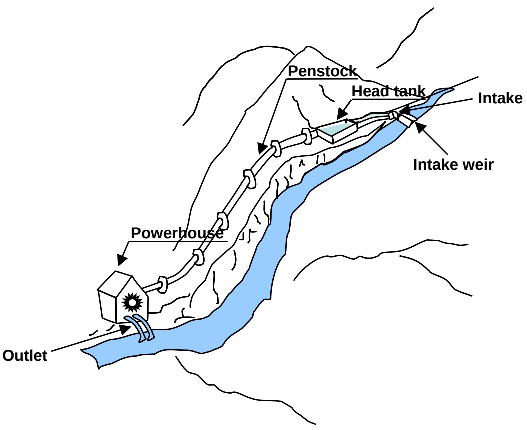
5.2.2 Topographical and Geological Survey

(1) Topographic and geologic features to be considered in planning and designing

As shown in Figure 5-5 below, a small scale hydropower station consists of an intake weir, an intake, a waterway (headrace, head tank and penstock), a powerhouse and a tailrace outlet. As the hydraulic head between an intake and a powerhouse is used for power generation, it is important to estimate the head when planning. It is also required that design considerations set these structures to be built at a low cost and in a safe way from the viewpoint of maintenance in the long run. A site reconnaissance is conducted to confirm the topographical and geological conditions related to the planning and designing of the station.



Facilities with a headrace



Facilities without a headrace

Figure 5-5 Hydropower Generation Facilities

(2) Installation locations for structures

In hydropower planning, natural topographic feature is utilized so that larger head for power generation is gained by shorter waterway of the plant. From the viewpoint, location of each structure is studied and determined on the map as explained in Section 5.1. However, the topographic maps that are available at this stage are on a scale of 1/50,000 to 1/10,000 mostly and are not accurate enough, and thus it is necessary to confirm the validity of each location on site.

For this purpose, the position of each structure can be pinpointed on the topographic map by using a GPS (Global Positioning System) positioning technology for a site reconnaissance. The GPS is a space-based global navigation satellite system that can provide reliable measurements including latitude, longitude and elevation almost anywhere on the earth, and is commonly used today when and where there is an open line of sight to four or more GPS satellites.

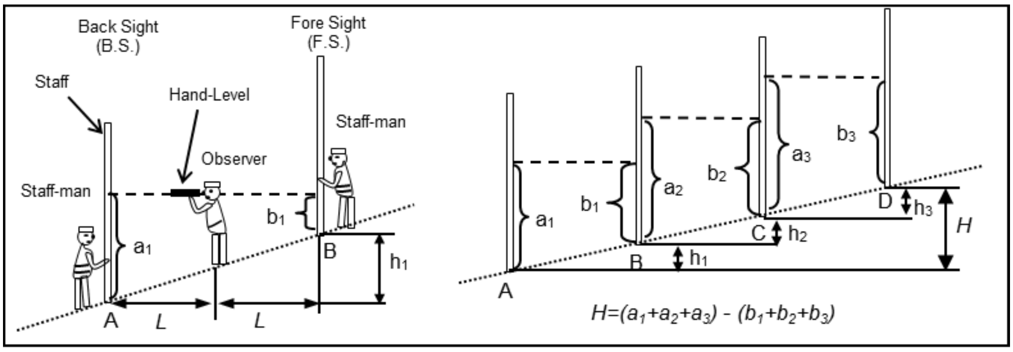
(3) Measurement of a head

In hydropower planning, together with the flow measurement, the measurement of a head is one of the most important survey items. Since topographic maps commonly available for potential small scale hydropower are on a scale of 1/50,000 to 1/10,000, and are not accurate enough, through site reconnaissance measurements are conducted for the head from the intake to the outlet using such tools as a hand-level, an altimeter and a GPS tuner. The measurement methods with these tools are explained below.

1) Use of a hand-level

A hand-level method is a most commonly used way and is recommended for the measurement of the head. Figure 5-6 shows the outline of the measurement, and the usage of the hand-level.

a) The observer who is standing in the middle of observation points A and B holds the hand-level horizontally and reads the scale (a_1) of the staff that stands vertically at the point A.
b) Then, in the same way, the observer turns the hand-level to B, and reads the scale (b_1) of the staff at the point B.
c) This measurement is repeated at several points between the proposed intake and outlet .
d) The difference of elevation (gross head) between A & D is calculated by the formula shown in Figure 5-6 below.



Source: JICA's report

Figure 5-6 Head measurement with a hand-level

2) Use of a barometric altimeter and GPS

Measurements by a barometric altimeter and a GPS technology are easy and effective to roughly estimate the head. However, changes in the atmospheric pressure decrease the accuracy of the barometric altimeter. Also, when there is an obstruction in the line of sight to GPS satellites like in a mountainous area, the accuracy of the GPS declines. The weaknesses of these measurement methods are to be taken into consideration when they are used.

(4) Ascertaining the geologic conditions with regard to the stability of the main structures

Since most of the main structures in small-scale hydropower plant are of an open type (not underground type), and the waterway passes on the slope of the mountain, a geological reconnaissance survey of the ground surface is required.

A geological reconnaissance survey is carried out at the site of the intake weir, in the area where the waterway passes, and at the site of the powerhouse. Then an outline of the geologic features is drawn-up. Based on the results of the reconnaissance survey, it is to be confirmed that there are no crucial geologic issues to deny the installation of these structures.

(5) Situation of the river water usage

If there arises flow reduction in the area affected by river diversion, irrigation water, inland water fisheries and local sightseeing sites such as waterfalls, could be affected. Also, if the intake facilities, such as irrigation facilities exist upstream of the intake weir, the flow available for power generation may be reduced during the irrigation season. Thus, it is important to fully understand the upstream and downstream water use conditions (including future plans).

(6) Existence of important local public places and rare plants and animals

Local residents in the proposed area are to be queried if there are any rare plants and/or animals as well as if there are any important local public structures/places such as monuments and cemeteries in and around the planned main structures including the waterway.

5.2.3 Local Community Survey

(1) Preliminary demand survey

The following are the items to be quarried when undertaking a preliminary demand survey.

- Name(s) and location(s) of the local community
- Population and number of households
- Public facilities (clinic, school, assembly hall, dining hall, etc.)
- Major industries (sawmill, thresher, etc.)
- Use period of the main facilities (seasonal variation, day to day variation)
- Expected use of electric appliances (lamps, radios, television, electric fans, refrigerators, etc.)

This fact-finding survey is based on the field hearings from the local residents, and is carried out under the cooperation of the local consumers. Also, the type of facilities in demand for electricity such as electric lamps and electric motors needs to be fully understood.

(2) Local community distribution survey

During the planning of the rural electrification, in order to examine the size of power generation and plan the power distribution line achieving a balance between the electricity supply and demand in the electrification area, it is necessary to understand the supply capacity of the candidate small-scale hydropower site and to specify the supply area.

It is best if the topographic maps on a scale of 1/2,000 to 1/1,000 are available when carrying out a local community distribution survey. However, such maps are not available for most of the targeted rural electrification areas. Therefore, a site reconnaissance is carried out using those maps that are available, usually drawn on a scale of 1/50,000 to 1/10,000, and at the same time a fact-finding survey on the number of households, etc. is carried out through a field hearing.

The local community distribution survey utilizes the topographic map and such instruments as shown in Figure 5-7 below. Also below are survey methods, contents, and accuracy. A laser range finder (measurement of horizontal distance and slope distance, height, vertical angle) in combination with the GPS can be efficiently used for the mapping tasks, which also enables the surveying work to extend the range from the point where one can stand.

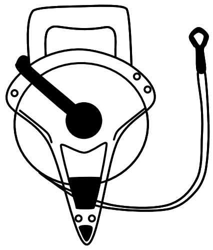
1) Survey methods

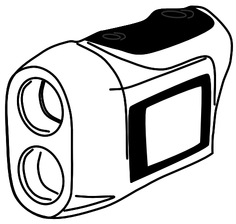
Use of pacing, tape measure, laser range finder, car trip meter, GPS, etc.

2) Survey contents

- Center location of the local community and the number of households
- Topographic features of the surroundings/areas where the waterway passes (mountains, flatlands, etc.)

- Land use conditions of the surroundings/areas where the waterway passes (cultivated fields, forests, wastelands, etc.)





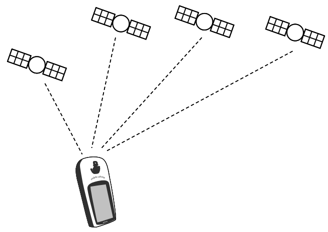


Figure 5-7 Instruments Used for the Local Community Distribution Survey

5.3 Formulation of the Preliminary Plan

5.3.1 Supply Plan (Power Generation Plan)

Based on the desk study (Section5.1 above) and site reconnaissance (Section5.2 above), the location of each structure is decided and the power generation plan is made.

(1) Selection of the intake site

When selecting the intake site based on the topographic map and the results of a site reconnaissance, a head is obtained effectively when the intake site is selected at the point where a gentle river gradient turns steep or downstream of the confluence of the mainstream and its tributary, or upstream of a waterfall, if any.

The intake site is to be selected in consideration of the following points.

- A section of the most linear course of the river both upstream and downstream
- A site where the ground is naturally stable not to cause any problems with the intake function due to possible landslides etc.
- A site where the existing structures such as an intake facility and a waterway can be used to reduce the development cost
- A site where natural features such as a pool and a pond can be used to reduce the development cost and to preserve the river environment
- A site which allows the construction of the intake, settling basin, etc.
- River use conditions in the area affected by river diversion, including intake of irrigation water and inland fisheries
- Effect of back water upstream of the intake weir

(2) Selection of the headrace route

The small-scale hydropower generation plan is generally a waterway type, and basically has a layout as illustrated in Figure 5-5 (5.2.2) above. In this type of plan, the construction cost of headrace accounts for a large portion of the total construction cost. Therefore, the plan should aim at a certain head with as short a waterway as possible.

Usually a non-pressure headrace (open/covered channel) is placed from the intake point on the slope of a mountain, while a head tank, set at the lower end of the headrace, conducts water through a penstock (Short Penstock Type). Sometimes, omitting the headrace, the penstock is set from the point of a settling basin (cum head tank) along a river or a road; thereby it conducts water to the power plant to generate electricity (Long Penstock Type). The latter approach has fewer topographical restrictions related to the waterway installation.

(3) Selection of the head tank location

In general, a head tank is installed at the end of a headrace, while the head tank and a power plant are connected by a penstock. The location of the head tank is to selected in such a way that the length of the penstock is as short as possible. Nevertheless, it is necessary to avoid installing the head tank on an unstable and protruding place such as a narrow ridge.

Also, the point of the spillway discharge needs to be examined to prevent not only such problems as collapse of natural ground due to the discharge from the spillway of head tank but also any human damage caused by a sudden change of the water level in the area affected by a diversion of the river.

(4) Selection of the powerhouse site and outlet site

Location of powerhouse and outlet are almost same site for small scale hydropower plant. Therefore, the location is determined taking into account the following points.

In case a powerhouse site is selected at the point where a steep river gradient turns gentle, shorter water way can gain higher head.

The powerhouse should be selected as follows;

- Enough space is available for installation main electrical/ mechanical and auxiliary equipments.
- Securing of a road carry in heavy objects.
- Availability of the countermeasure against submergence and/or water leakage during flood.

Especially when the site is located at a narrow part of the river, correspondingly it becomes difficult to ensure an area necessary for power house construction. In addition, due to greater fluctuations of the river water level during a flood, there will be the cost increase in the waterproof wall or in the treatment of natural ground.

Outlet site is selected as follows;

- Discharge is not disturbed by sediments accumulated in front of the outlet.

- The riverbed and surrounding natural ground is not scoured by the discharge.
- The direction of the tailrace is set so as not to disturb the smooth flow of the river.

(5) Maximum plant discharge (Q_{max}) study

When the power source is small-scale hydropower only, the maximum plant discharge in the power generation plan is set to be the firm discharge. If the power source is combined with other sources, the maximum plant discharge needs to be determined from the viewpoint of economic efficiency.

(6) Effective head (H_e) study

The following is the calculation method to determine the effective head.

H_e = total head – (intake loss + headrace loss + penstock loss + tailrace loss + other loss(es))

where,

Intake loss (intake, settling basin, inlet/outlet of headrace, etc.) = approx. 0.05m
Headrace loss = 1/1,000 (gradient of headrace) x headrace length
Penstock loss = 1/200 x penstock length
Tailrace loss = 1/1,000 (gradient of tailrace) x tailrace length
Other losses (inlet valve of turbine, etc.) = (0.5m +α)

(7) Calculation of maximum output

In brief the calculation method of the electric power is as follows:

$$P = 9.8 \times Q_{max} \times H_e \times \eta$$

P : maximum output (kW)
Q_{max} : Power discharge (m^3/sec)
H_e : Effective head (m)
η : Combined efficiency of turbine and generator η=0.6～0.7

5.3.2 Demand Plan (Demand Estimation)

(1) Estimation of maximum power demand

Basically, existing demand information should be referred. The general method to estimate the power demand in the local community is to calculate the power demand (unit) of the average household in the local community, which is then multiplied by the number of households to estimate the total demand.

(2) Estimation method when the ratio of the income groups can be estimated

The estimated demand for electricity in the non-electrified local community cannot be generalized sweepingly, due to the difference of economic indicators, electrification policy, local characteristics, etc. However, past surveys have shown that there is a close relationship between the income level and power demand and the willingness to pay electricity rates. Table 5-1 below outlines the relationship between annual income and unit of power demand.

Table 5-1 Average Annual income and unit of Power Demand

Income Group	Average Annual Income (US$/year)	Unit of Power Demand (W/household)
High income	1,000 ~	200 ~ 300
Middle income	500 ~ 1,000	150 ~ 200
Low income	~ 500	100 ~ 150

When the ratio of income groups can be estimated through site reconnaissance, unit of power demand by the high/middle/low income groups is calculated separately. Each unit is multiplied by the ratio of each income group and then totaled to estimate the demand of the entire local community.

(3) Estimation when the ratio of the income groups cannot be estimated

Demand is roughly assumed on condition that the average power demand is between 150 – 200W per household.

5.4 Small-scale Hydropower Site Selection

As a result of the aforementioned summary supply and demand plan, the balance between supply and demand can be identified. Considering this result and the feasible size of supply, the supply area is determined.

As mentioned before, when the candidate electrification area is at a local community level, the distance between the planned site for the power plant and the demand area should be limited to several kilometers, and even when the area is at a town level, the distance should be within about 20km.

Reference of Chapter 5

[1] Guidebook on Small-medium-scale Hydropower (in Japanese), New Energy Foundation, 1997

[2] Manual on Distributed Small-scale Hydropower (Draft), Ministry of Economy, Trade and Industry, New Energy Foundation, 2001

[3] Report on Social Environment Needs Survey of Distributed Small-scale Hydropower (in Japanese), Ministry of Economy, Trade and Industry, Japan Electric Power Civil Engineering Association

[4] Guide Manual for Development Aid Programs and Studies of Hydro Electric Power Projects, New Energy Foundation, 1996

Part 3

Investigation, Planning, Designing and Construction

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 6

Social Economic Research

Chapter 6 Social Economic Research

The rural electrification by small scale hydropower is assumed to be able to continue on condition that the management of the power plant should be done by the local residents. In order to enhance the understanding, awareness, and independence of the local residents, it is very important for them to participate the project from an early stage of the plan.

The matters for the local residents (stake holders) to understand are as follows.

- Benefits of life by use of electric energy
- Understanding of the advantage and disadvantage of the rural electrification by small scale hydropower
- Operation and maintenance of the small scale hydropower and the role of local residents
- Appropriate use of electricity
- Understanding of electricity rate

6.1 Prior Consultation with Local Residents

In an electrified region to be, it is necessary to obtain a prior approval of the entry for the investigation from local representatives in order to advance it smoothly.

Indispensable items to be explained and approved at an earlier stage of the investigation are shown in the table below.

Table 6-1 Prior Consultation Items with Local Residents

Item	Content
1. Prior consultation with representative.	
1) Target person	District chief, village chief, and leader level.
2) Indispensable explanation item	Outline of principle mechanism etc. of small scale hydropower. Purpose of investigation. Flow of development procedure. Management method after development.
3) Approval acceptance matter	Comprehensive approval to investigation.
2. Entry approval of investigation	
1) Target person	Landowner of place to be entered (The concerned organization in case of public place)
2) Indispensable explanation item	Purpose of investigation. Period of investigation. Range of investigation and influence level. With or without compensation.
3) Approval acceptance matter	Entry and partial changing of land etc.

At this stage the possibility of electrification by small scale hydropower is studied. The electrification is not yet decided to be executed, so that it is necessary not to give an excessive expectation to the people.

6.2 Electricity Demand Forecasting for Target Area

In the case of forecasting an electricity demand for the whole country, the past electricity demand is expressed by a regression formula using the past time-series data such as GDP, population, income, electricity tariff, etc., and a future electricity demand is estimated. However, in the case of the rural electrification by small scale hydropower, it is difficult to use a regression analysis because there are no time-series data available in the rural area. In order to estimate an electricity demand in the rural area, the electricity demand for a household is estimated first by applicable electric appliances and then that in a target area is summed up. Therefore, it is necessary to conduct a social and economic survey for the target area in advance. It is conducted by interview or questionnaire sheet. To collect more accurate information, a door-to-door interview survey is recommended. There are several methods for the study and approach. One of the typical methods is introduced here, however different methods could be used depending on the condition concerned.

6.2.1 Classification of Target Village

It is important to prepare a proper questionnaire to meet the current situation of the target village. There are many kinds of non-electrified villages such as a high income village in which they own portable generators or a village for which their children send money back. If you estimate the electricity demand based on lighting and TV only and decide accordingly the installed capacity for hydropower, it will be running short because of increasing electric appliances year by year. Therefore, to estimate an appropriate installed capacity for hydropower, it is very important to conduct a social and economic survey for the target village in advance. Villages are classified into three categories as follows.

(1) Low income village

In general, a low income village is usually seen away from city with limited crop acreage, and advanced aging society. Electricity demand in low income villages is limited to lighting and TV, and the annual growth rate of electricity consumption is small.

(2) Middle income village

In general, a middle income village is usually seen in which they cultivate cash crop and livestock. Some households in the village already had automobile batteries for watching TV. A proliferation of mobile phones provides a good indication of income level for the village. In non-electrified villages in a newly industrializing economy such as in Thailand, many people have mobile phones. In such villages, the annual growth rate of electricity consumption will be rapidly increasing.

(3) High income village

Some households in a high income village own portable generators and vehicles. If such a village is electrified, people will purchase electric appliances such as refrigerator, washing machine, karaoke machine, etc. and electricity supply will be running short and frustration may arise. In high income villages, the villagers prefer electrification by grid extension rather than independent power supply such as small scale hydropower.

6.2.2 Questionnaire Sheet

(1) Household survey

An interview for a questionnaire survey is with the residents who live in a non-electrified village. They have limited access to information because of no television etc. It is important to prepare a simple questionnaire sheet and not to use difficult words such as a disposable income. Also it is necessary to ask a question that is simple to answer because they do not record energy consumption and expenditure. For example, when you would like to know monthly rice consumption;

[Bad example]

How much do you buy rice a month?

[Good example]

Is staple food rice? How much do you cook rice a day?

Questions by the month and/or year should be avoided and daily questions are recommended because they will answer based on their memory. If you distribute the questionnaire sheets to the residents, multiple choice questions are also recommended because they are easier to answer. Moreover, it is important to analyze the willingness to pay for electricity charges. When an electrification plan is explained in a public gathering, the residents expect to use electricity. However, it is different from payment capability. In general, the amount of willingness to pay for electricity is corresponding to alternative energy cost such as those of kerosene lamp, automobile battery, etc.

(2) Industry survey

It is envisaged that there is no large industry in non-electrified villages. However it is necessary to check the existing cottage industry using a portable generator or to check the possibilities of electricity usage for the industry after electrification.

Table 6-2 Sample of Socio-economic Survey for Household (Questionnaire)

Date:____________________

1. Occupation ____
2. Number of people in a family____
3. Age composition in a family____
4. Number of Room

   ☐ one ☐ two ☐ three ☐ four ☐ five
5. Kind of light at present

   ☐ Kerosene lamp ☐ Gas lamp ☐ Candle ☐ Other
6. Number of lights

   ☐ one ☐ two ☐ three ☐ four ☐ five
7. Above (#6) consumption per day ________________________________
8. Fuel price____
9. Using time of lighting per day

   ☐ 2 hours ☐ 3 hours ☐ 4 hours ☐ 5 hours ☐ 6 hours ☐ Other
10. Wake-up time and time for bed_____________________________________
11. Do you have a battery?

    ☐ Yes ☐ No
12. If you answer to #11 is Yes,

    12.1 Battery price____

    12.2 Capacity of battery_______________________________________

    12.3 What is purpose of battery?

    ☐ TV ☐ Radio ☐ Lighting ☐ Other

    12.4 If you answer to #12.3 is TV,

    12.4.1 How many hours do you watch TV a day?

    ☐ 1 hour ☐ 2 hours ☐ 3 hours ☐ 4 hours ☐ more than 5

    12.4.2 What wattage is power consumption of TV?

    12.5 If you answer to #12.3 is lighting,

    12.5.1 How many hours do you use lights a day?

    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ more than 6

    12.5.2 What wattage is lights?___________________________

    12.6 Battery charge price_______________________________________

    12.7 How many times do you charge battery per week?

    ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

    12.8 Battery life

    ☐ less than 1 year ☐ 1 year ☐ 2 years ☐ 3 years ☐ 4 year

    12.9 How many times do you fill in distilled water?

    ☐ 1/ month ☐ 1/ 2 months ☐ 1/3 months ☐ Other

    12.10 Price of distilled water_________________________________

13. What kind of electric appliances will you purchase after electrification?
☐ Lighting ☐ TV ☐ CD player ☐ Fan ☐ Washing machine
☐ Refrigerator ☐ Others

Table 6-3 Sample of Socio-economic Survey for Cottage Industry (Questionnaire)

Date:___________________

1. Products____
2. Capacity of diesel or gasoline generator_______________________________________
3. Operation hours per day____
4. Operation time per day____
4. Operation days per week ____
5. Fuel price____

6.3 Social Economic Study

The attitude survey of the electrification is carried out to the residents. And their needs for electric energy are clarified. The results of survey will be reflected in the plan and the design.

Table 6-4 Item of Social Economic Study

Item	Content
I Key informant study	
1. Operation period	Time to begin social economic study (Concurrently with prior consultation)
2. Target person	District chief, village chief, and leader level.
3. Matters for study	Basic information on population, number of household , and industries, etc.
4. Usage and purpose	Collection of basic information Scale of household research and material for fixation of item
II Workshop (briefing)	
1. Operation period	Before operating the household research
2. Target person	Local representative and regional resident
3. Purpose	Explanation of outline about rural electrification by small scale hydropower. Explanation of household research operating
III Household research	
1. Operation period	After Workshop (briefing)
2. Target person	About 20% or more of number of regional households. (Reliability and the target accuracy in statistical study are considered.)
3. Method	Interview
4. Main research item	1. Number of family composition. 2. Job and income. 3. Presence of use of electric apparatuses (current situation). 4. Recognition and consideration to electrification. 5. Demand level of electrification. 6. Amount of energy expense (lighting and power and others). 7. Willingness to pay for electricity charges. 8. Number of people getting benefit from electrification geographic distribution situation.

Table 6-5 Questionnaire for Village Officer / Key Informant Interview

Name of Village, Union, District:	
Date:	
Name of Respondent:	
Name of interviewer	

1. Number of household

2000	2005	2010

2. Population

2000	2005	2010

3. Number of households moving in or out of the village

Year	In	Out
2006		
2007		
2008		
2009		
2010		

4. Communication system between outside

   1) Cell-phone 2) Telephone 3) Others:___________________________

5. Means of transportation (ex. Motorbike, bus)

   ____

6. What kinds of village organizations are exist? (e.g. youth group, cooperative, farmers group)

Name of Organization	Activities
1	
2	
3	
4	
5	

7. Education: Primary and Secondary

	Primary	Secondary

Educational Ratio (%)		
Educational Expenses (Currency/Year)		

8. What kind of facilities are in your village?

Types		Number
1.	Hospital	
2.	Village hall	
3.	Tap water	
4.	Well	
5.	Elementary school	
6.	Secondary school	
7.	Daily Market	
8.	Restaurant	
9.	Motorbike/bike repair shop	
10.	Carpenter	
11.	Saw mill	
12.	Rice mill	
13.	Mosque / Church	
14.	Pharmacy	
15.	Other (Specify)	

9. Cropping calendar

	1	2	3	4	5	6	7	8	9	10	11	12
Rice												
(harvest, plant)												
Sugarcane												
(harvest, plant)												
Jute												
(harvest, plant)												
Other ( )												
(harvest, plant)												

Priority needs; list and prioritize the needs felt by the village for improvement of livelihood (e.g. water, road, sanitation, medical care services, electricity etc.)

Rank	Need	Remark

10. Needs for electrification (Do the village people want to have electricity? Do they want to use it for machine or public facility lighting?)

    ____

11. Decision making mechanism (How do the village people decide the thing? How do they proceed with the decision making?)

    ____

12. Past and on-going development projects;
    1) Has your village ever had any development projects in the past and at present?

       ____

    2) If your village has, how was it financed and who managed the project?

       ____

    3) How were the villagers involved in the process of identifying, planning, implementing, operating and maintaining the project?

       ____

13. Land ownership system;
    1) Is the land ownership based on registration or customary right?

       ____

    2) In the case of customary right, what is the content of the ownership (e.g. the right to farm the land only?)

       ____

    3) What is the inheritance system of land ownership?

       ____

    4) Was there any dispute on the land ownership (e.g. construction of public facility on private land)?

       ____

14. How do you get water for drinking, bathing, washing clothes and irrigation?

Item	How do you get water?
Drinking	
Bathing	
Washing clothes	
Irrigation	
Other (specify)	

15. Wealth gap in a community
    1) Are there any criteria to distinguish the rich and the poor (e.g. income, property, house material, educational level etc.)?

       ____

    2) Based on the criteria above, could you estimate approximate percentage of the households in each category (rich, middle and poor)?

	Estimate (%)
Poor	
Middle	
Rich	

Thank you very much for your kind cooperation!!

Table 6-6 Questionnaire for Household

<Questionnaire for Household>

Name of Village, Union, District:	
Date:	
Name of Respondent:	
Name of interviewer	

1. No. of family who live under one roof: __________ persons

2. Does one of your family works away from home?
   1) Who a: husband b: wife c: son d: daughter e: __________
   2) Where a: Capital b: Center of nearest district c: Overseas d:_____
3. How many years have you been living here?
   a: under 5 years b: 5 years to 10 years c: 11 years to 20 years d: over 21 years
4. No. of room: __________rooms
5. Family Income Source
   1) Main source of cash income of the household and annual cash income
   *if you have a certain amount of agricultural products for selling, please answer it. But if you consume them for your own family, you don't have to answer.

Items	✓	Annual Cash Income (currency)
a. Agriculture		
b. Own business		
c. Government employee		
d. Migrant labor		
e. Private employee		
f. Other (Specify)		
TOTAL(currency/year)		

   2) Do you receive any remittance from your family who works away from home?
   a: Yes. If yes, how much do you receive? ______________ currency/year
   b: No.

Expenditure

	Item	Amount (currency/year)	Remarks
A	Food		
B	Housing		Housing loan repayment/house rent, etc.
C	Water		For cooking, drinking and washing.
D	Irrigation water		Agricultural use.
E	Education		Enrolment fee, books, uniforms etc.
F	Transportation		Bus fare, oils for your cars/bikes.
G	Health care		Medical treatment, medicines.
H	Social cost		Cash contribution to social events & ceremony
I	Others		Other costs not specified in the above
	TOTAL (currency/year)		

6. Debt or Credit
   1) Do you borrow money? a: Yes b: No
   2) From which do you borrow? a: Cooperative b: Bank c: Relatives
      d: Other
   3) How much is the interest rate? /month, /year
   4) Do you save money? a: Yes b: No

7. Own Properties
   1) I have my own land (ha)
   2) I'm an agricultural laborer wage: currency/day
   3) How many days do you work as an agricultural laborer for a year? Days
   4) I'm a tenant farmer Rent for tenancy currency/month or year
   5) List the property owned by your family (e.g. house, livestock, bike, tools)

Property	Contents
A. House	a: Own house b: Rental house
B. Livestock	a. Cow Number of head ________________ b. Duck Number of head ________________ c. Chicken Number of head ________________ d: Goat Number of head ________________ e: Sheep Number of head ________________ f: Fish Amount (kg) ________________
C. Car or motor bike	
D. Other	Specify: ________________________________

8. Agricultural products

   If your family has been engaged in agricultural farming, let us know the kind of agricultural products and the volume.

	a. Volume/year	b. Where to sell (Market, factory etc.)	c. Selling Unit Price (Rs/kg)
1) Rice	kg		
2) Sugarcane	kg		
3) Maize	kg		
4) Jute	kg		
5) Vegetable	kg		
6) Fruits	kg		
7) Others ( )	kg		

9. Does your household use electricity now?

   a: Yes → **go to question No.15**

   b: No → **go to question No.10**

10. (for *non-electrified household*) What are the current energy sources in your household?

	a. Amount/month	b. Unit Price (currency)	Remarks
1) Kerosene	litter		Purchase cost. Do not include car, bike, and tractor, but include lamp.
2) Gasoline	litter		For diesel generator
3) Fuel wood	kg		Purchase cost
4) Dry batteries	pieces		Purchase cost
5) Candles	pieces		Purchase cost
6) Matches	pieces		Purchase cost
7) Car battery charging	units		Charging cost per unit
8) Charcoal	kg		
9) Others			Specify
TOTAL			

11. *(for non-electrified household)* Do you want to get electricity?

    a: Yes   b: No   Reason: ______________________________

12. (*for non-electrified household)* If you can use electricity in future, what kind of electric appliances do you want?

    a: Light   b: Television   c: Radio   d: Video player   e: Refrigerator   f: Fan

    g: Ironing   h: Water pump   i: Other (Specify) ______________________________

13. (*for non-electrified household)* If you can use electricity in future, what kind of productive activities will you start by using electricity?

a: Irrigation　b: Sawmill　c: Chicken farm　d: Rice milling
e: Handicraft　f: Home industry (making cake or bread)　g: Shop
h: Restaurant　i: Other (specify: ____________________)　j: No idea

14. (*for non-electrified household)* If your house can get electricity, are you willing to pay for new electricity services?

1) for initial cost　a: Yes　b: No
2) for monthly charge　a: Yes　b: No

This is the end of interview for non-electrified household.
Thank you very much for your cooperation!!

15. *(for electrified household)* What kind of electric appliances does your family have?

a: Light　b: TV　c: Radio　d: video player　e: refrigerator　f: fan　g: ironing
h: water pump　i: Other (Specify) _________________________________

16. *(for electrified household)* How much do you use electricity for a month? Could you show us the latest three (3) month electric bill?

(Unit: currency/month)

Month	a. 2 month before	b. 1 month before	c. Recent month
1) Demand Charge			
2) Service Charge			
3) Electricity Charge			
4) 10% VAT			
5) Late payment			
TOTAL			

17. *(for electrified household)* Do you plan to start house industry and/or small industry by using electricity?

a: Irrigation　b: Sawmill　c: Chicken farm　d: Rice milling
e: Handicraft　f: Home industry (making cake or bread)　g: Shop
h: Restaurant　i: Other (specify: _______________________)　j: No idea

This is the end of interview for electrified household.
Thank you very much for your cooperation!!

6.4 Understanding and Role of Persons to get Benefit

The public consultation shall be held at each stage of a small scale hydropower project. Then, an implementation body and the regional residents are able to exchange opinions with one another to achieve a mutual understanding.

The following table shows the indispensable explanation items to the public.

Table 6-7 Explanation Items to the Public

Item	Contents
1. Target person	Regional resident
2. Operation period	i) Basic plan survey stage ii) Implementation and construction stage: Before and during construction iii) Operation and maintenance stage: Before commencement of operation
3. Method of operation	Public consultation
4.Reguired explanation items	-Outline of electrification plan -Electric power facilities as community property -Technically and financially independent management from power grid -Payment of electricity bill -Cooperation on utility pole and distribution line, etc. in respect of site occupation -Initial cost such as wattmeter and lead-in

6.5 Establishment of Preparatory Management Organization

The management organization of the electric power supply is depending on the scale of electrification and the electric power administration of the country. But in general the local residents constitute a main body to be organized. Therefore, it is necessary to establish a preparatory management organization including the local residents from a stage where a basic plan was fixed to some degree.

The preparatory organization requires succeeding to the business organization which describes in Chapter 14, and finally becomes an organization which shows in Figure 14-1.

The activity during the preparation period is shown in Table 6-8 though the concrete content of the activity of the management organization is described hereinafter in Chapter 14.

Table 6-8 Activity Items of Preparation Organization

	Matter	Outline
1. Members	- Administrative official at central level for project's promotion. - Administrative official at provincial level for project's promotion. -Related administrative organizations in regions. -Candidates of operation and maintenance work (in village, and group, etc.)	Development promotion administrative officials are mainly involved in implementation of the project.
2. Operation period	Stage when basic plan was almost set.	
3. Method of operation	Committee and public consultation	
4. Indispensable matter	1. Acknowledgment of the promotion of the Project	The public consultation is held for the local representatives or all members.
	2. Planning of organization of management body(preparation)	Members will make it by themselves.
	3. Local bearing of the cost (Cost allocation)	Adjustments between members are carried out and approval from local residents is obtained.
	4. Employment and recruiting of staff for operation and maintenance work	Those who will work at site for the operation and maintenance are to be selected locally.
	5. Training of operation and maintenance staffs	Technical training is started from the construction period for those who will work continuously at site and prepares for the operation and maintenance management.

Reference of Chapter 6

[1] Basic design study report on the project for rural electrification micro-hydro power in remote province of Mondul Kiri in the Kingdom of Cambodia, JICA, 2005

[2] The project for Project for Operation and Maintenance of the Rural Electrification on Micro-hydropower in Mondul Kiri, JICA、2011

Chapter 7

Technical Survey

Chapter 7 Technical Survey

7.1 River Flow Measurements

7.1.1 Flow Data Required for Hydropower Planning

In this chapter the following terms are defined and used to express river runoff. “Runoff” means a phenomenon of running water in a river. “Flow” means water volume flowing in a river per second (m^3/sec). “Discharge” means water volume flowing in the power plant per second (m^3/s).

River runoff changes daily as well as yearly, with flows higher and lower during the rainy and dry seasons respectively. Figure 7-1 shows a flow duration curve for a year (365 days) plotted in descending order of daily flows. For small scale hydropower generation for the rural electrification, the flows from 90% to 100% in the curve are important. The flows thus obtained characterize runoff in the dry season, and at the same time, determine the firm output of a plant. As stated in Section5.1 Chapter 5, a flow at 95% in the curve is chosen as the basic flow to determine the firm discharge of the hydropower plant.

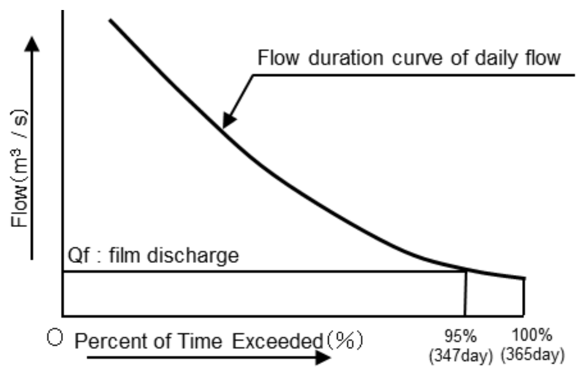


Figure 7-1 Flow Duration Curve

On the other hand, the combination of small scale hydropower with other power sources such as diesel power allows stable and constant power generation independent of the dry and rainy seasons. In this instance, the hydropower plant is allowed to reduce its power during the dry season, and the deficit power demand is complemented by diesel or other means of generation. Here the maximum plant discharge is chosen at a point greater than the 95% flow.

For these reasons, the river runoff data mentioned in this chapter should cover runoff throughout the year, not just the dry season.

Additionally, since the water levels in the river increase during the floods, estimate of flood discharge is also necessary to protect the plants adequately against the inundation.

Figure 7-2 shows the procedure for flow duration curve required for planning a small scale hydropower plant, including the development of rating curve and estimation of daily discharges.

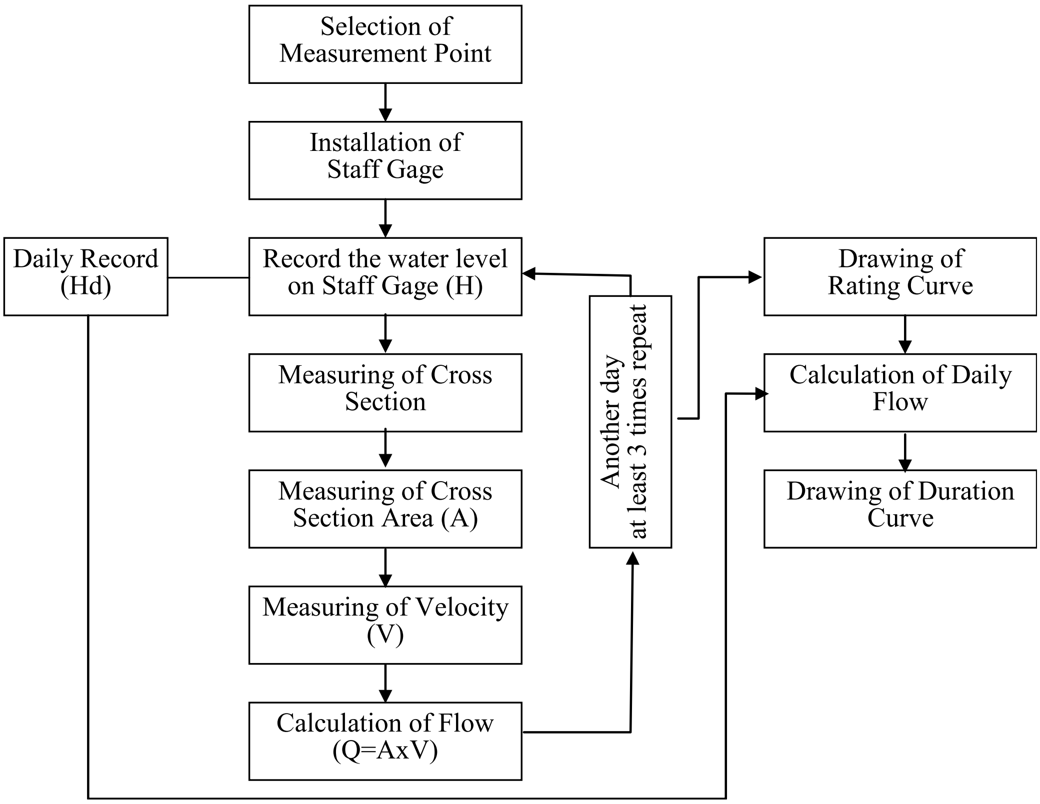


Figure 7-2 Procedure for Flow Duration Curve Preparation

7.1.2 Flow Measurement and Data Collection by Staff Gage

In section5.2, "Simple flow survey by the float measurement method" is explained for preliminary planning. However, more detailed survey should be conducted for basic plan survey (feasibility study level) as mentioned below.

(1) Runoff measurement and observation of river water level by staff gage

River flow measurements need both the flow velocity and cross section of a river. Since the number of labors involved for the work is quite large, it is impractical to carry out a 24-hour continuous measurement for 365 days. For this reason, the following approaches are adopted.

- Carry out river flow measurements at the site a minimum of three times a year.
- Carry out daily observations of the water level by staff gage.
- Estimate daily flows from the rating curve (the curve for flows and water levels) and daily observations of the water level.

(2) Setting of gauging station

1) Selection of gauging station

A gauging station shall be chosen close to the planned intake weir site and needs to satisfy the following conditions.

- Curved portions and locations of abrupt cross sectional changes should be avoided, and straight waterways should be selected.

- The flow should not be too fast or too slow.
- The waterway and riverbed should be stable.
- Flow measurements should not be impeded by either large or small river flow.

2) Positioning of staff gage

Staff gages shall be positioned and set up at a gauging station (See Figure 7-3) to be marked every 1cm on the plate surface with meter indications clearly printed with large digits for easy reading. The gages shall be set up in consideration of the following requirements.

- Set up the staff gages during the dry season and position them such that the zero (0) points are below the lowest water level in the season.
- Embed the staff gages firmly into the ground and fix them vertically using concrete to prevent them from being disturbed by the currents.
- Place the staff gages in directions so as to allow easy reading from the river bank.
- After installation, record the coordinates and elevation of the zero points.
- When placing the plural number of staff gages, overlap about 50 cm with each other.

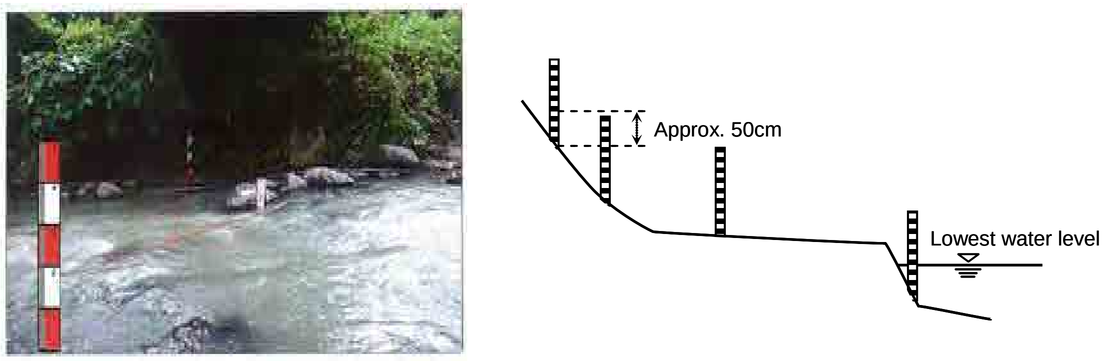


Figure 7-3 Positioning of Staff Gages

(3) Flow measurement

1) Calculation of flow

A flow is calculated by multiplying a cross sectional flow area and an average flow velocity.

$$Q = A \times Vm$$

Where,

Q	: river flow (m^3/sec)
Vm	: average flow velocity (m/sec)
A	: cross sectional flow area (m^2)

2) Surveying cross section of river

The figure of a cross sectional flow area at a gauging station is obtained by surveying. Where a change in the cross sectional area is suspected due to floods, the measurement is repeated and the figure should be modified. Figure 7-4 shows actual field work for the measurement, and Figure 7-5 shows cross sectional areas of a river thus determined.

Figure 7-4 Measurement of Cross Sectional Area

3) Flow measurement by current meter

Small scale hydropower projects target small rivers or tributaries. A flow measurement is repeated at a minimum of three to ten times. A simultaneous observation of water level by staff gages is carried out, since it is needed in developing the rating curve mentioned in the item 4).

The cross sectional areas of the river shown in Figure 7-5 (top) are divided almost evenly and the flow velocity for each divided section is estimated. Here, the average velocity for each section ((1), (2) …) is calculated by the following simplified methods.

3-point method: method to measure flow velocity at 20%, 60% and 80% of the water depth

$$Vm = 0.25\times(V_{0.2} + 2V_{0.6} + V_{0.8})$$

2-point method: method to measure flow velocity at 20% and 80% of the water depth

$$Vm = 0.50\times(V_{0.2} + V_{0.8})$$

1-point method: method to measure flow velocity at 60% of the water depth

$$Vm = V_{0.6}$$

where,

V_m : average flow velocity (m/sec)

$V_{0.2}$: flow velocity at 20% of the water depth from water surface (m/sec)

$V_{0.6}$: flow velocity at 60% of the water depth from water surface (m/sec)

$V_{0.8}$: flow velocity at 80% of the water depth from water surface (m/sec)

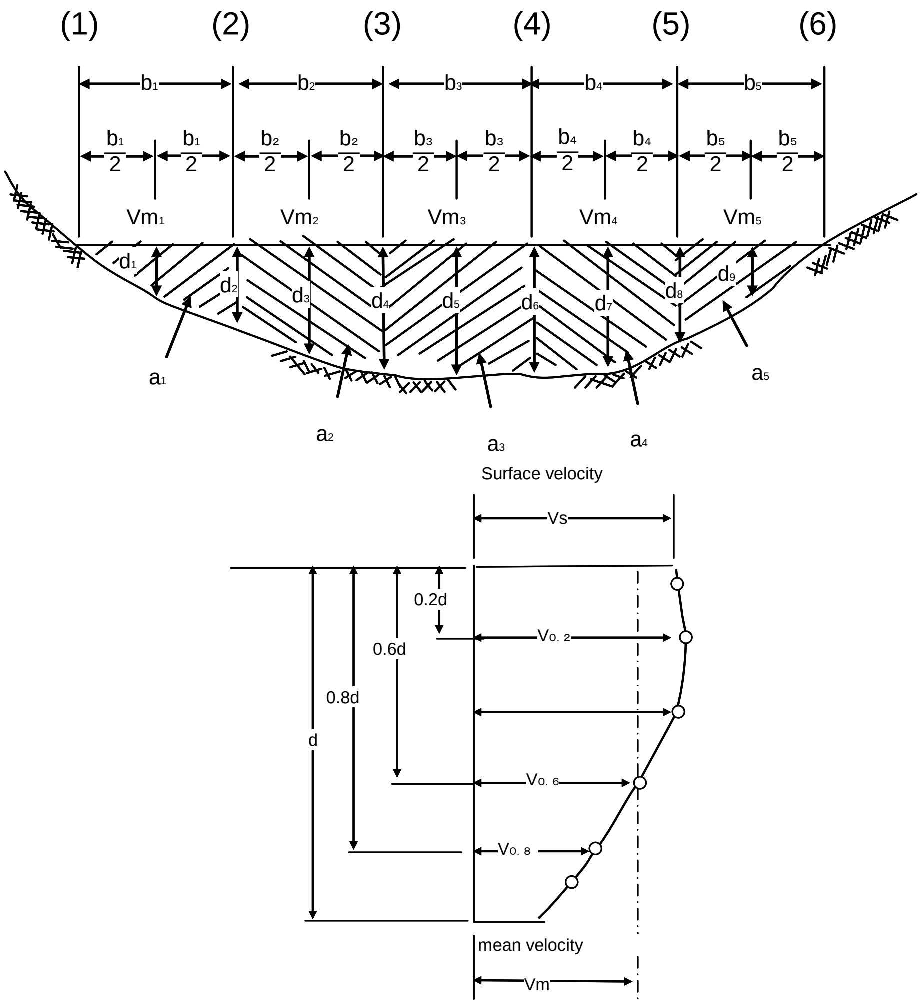


Figure 7-5 Flow Measurement by Current Meter

Once the average velocity for Figure 7-5 is obtained, the total river flow is determined by the following equation. Figure 7-5 is the example where the river cross-section is divided to 5sub-sections

$$Q = a_1 \times V_{m1} + a_2 \times V_{m2} + a_3 \times V_{m3} + a_4 \times V_{m4} + a_5 \times V_{m5} \quad (a_i = b_i \times d_{2i-1})$$

where:

a_i	: flow area of each sub-section (m^2)
b_i	: width of each sub-section (m), ($b_1=b_2=b_3=b_4=b_5$)
d_i	: average depth of each sub-section (m)
V_{mi}	: average velocity of each sub-section (m/sec)
Q	: total flow (m^3/sec)

Propeller type current meter and electromagnetic type current meter are generally used for flow measurement of small river / tributary. Figure 7-6 shows photographs of the propeller type current meter and the demonstration of measurement in a stream. The electromagnetic type current meter is described in Section 5.2.1. Calibration of current meters and electromagnetic flow meters at reliable institutions is essential for obtaining reliable measurement data.

Propeller type Current meter

Measurement

Figure 7-6 Propeller Type Current Meter and the measurement

4) Determination of rating curve

Using the flows and water levels obtainable as above, a flow rating curve shown in Figure 7-7 is developed. The curve is prepared by plotting the flow horizontally, the water level vertically, and then applying the least-square method to the plots. It is generally expressed by a parabola equation.

$$Q = a + b \times h + c \times h^2$$

where:

Q	: flow (m^3/sec)
h	: water level (m)
a, b, c	: constant

Where a single curve is deemed to be an inadequate representation of the relationship between the water level and flow for the river, the plural number of curves should be used depending on the water levels. When changes of river bed conditions or other parameters are suspected after flooding, appropriate surveys shall be conducted to revise the rating curve when necessary.

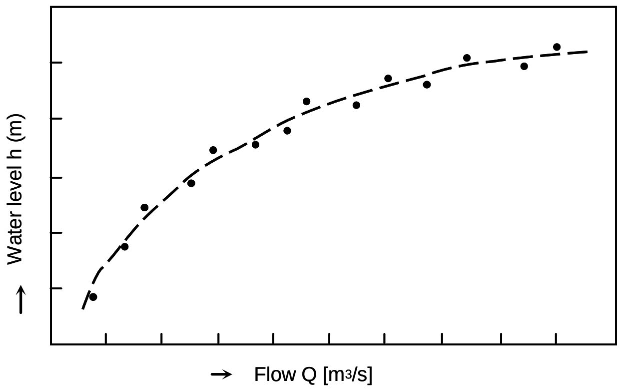


Figure 7-7 Rating Curve

5) Observation of water level

Observation of the water level is repeated by staff gage once or twice a day at fixed time. Automatic recording is not necessarily a requirement. The observation and recording may be outsourced to the local residents.

Although not directly linked to daily flow measurements, the water levels during the floods are important because they constitute important records for the design of civil structures.

6) Development of flow duration curve

River flows are estimated by putting the water levels from item 5) into the rating curve of item 4). An example of daily flows (hydrograph) thus obtained is shown in Figure 7-8. Then the duration curve shown in Figure 7-1 is developed using the daily flows.

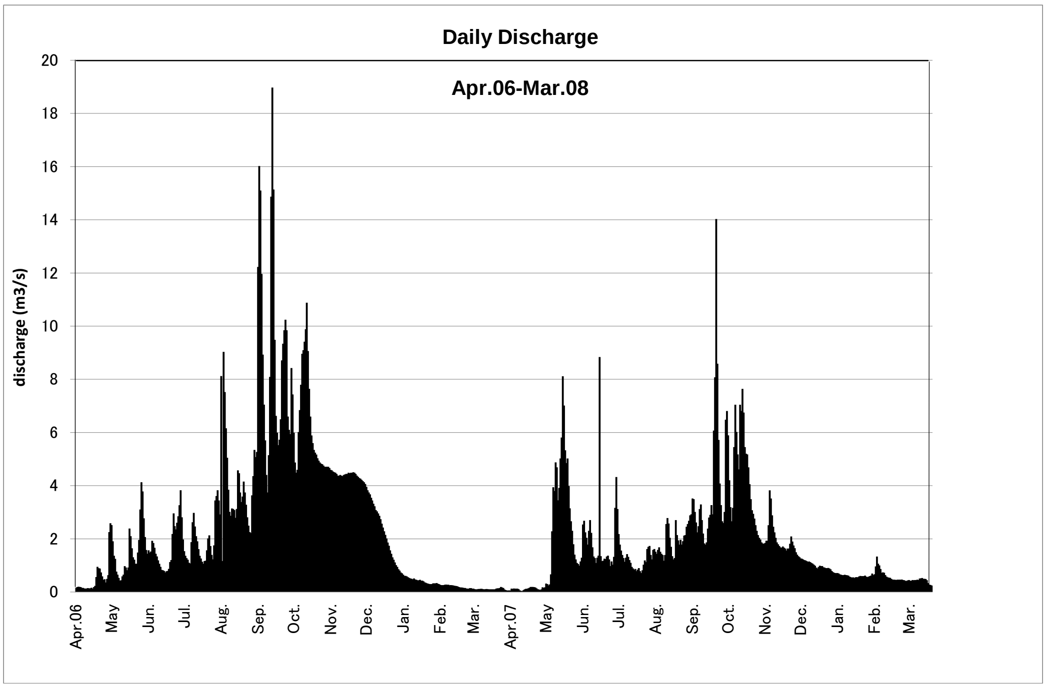


Figure 7-8 Example of Hydrograph

7.1.3 Runoff Data Measurement by Weir

For rivers whose flows are too small for the measuring instruments such as current meters and electromagnetic flow meters, weirs as shown in Figure 7-9 are used for flow measurements. A wear is placed perpendicular to the flow centerline and the depth of overflow is measured. The location of weirs site is selected where the flow is stable and the flow velocity upstream is small.

Various equations are available for the flow calculation, and here the "Francis formula" is used.

$$Q = 1.84 \times (b - 0.2 \times h) \times h^{1.5}$$

where,

Q : river flow (m^3/sec)

h : overflow depth (m)

b : width of opening (m)

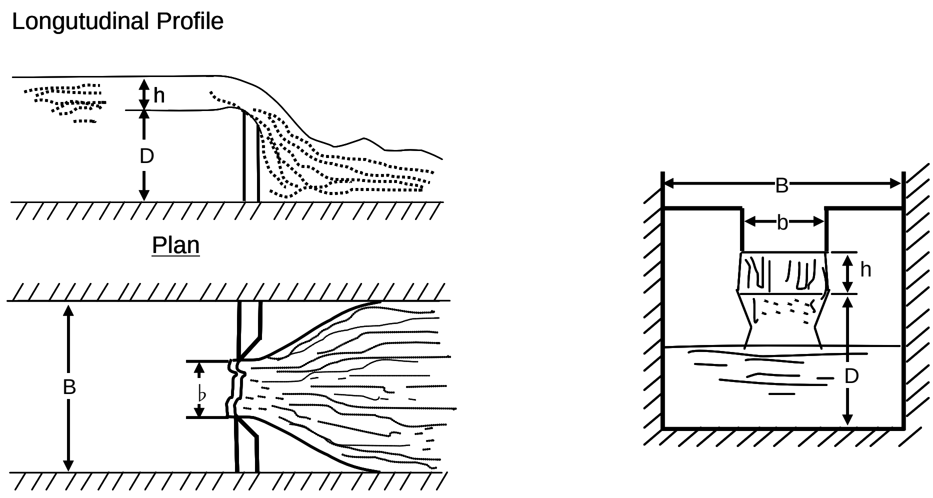


Figure 7-9 Rectangular Weir

In weir-based flow measurements, a combination of fixed weir and complete overflow is recommended.

7.1.4 Salt and conductivity meter method

It is not possible to measure a river cross section and flow velocity in the case the river water flows in the stream dotted with boulder stones and under or in the boulder stones. Salt and conductivity meter method is applied for the condition, which a bucket of heavily salted water is continuously poured into the stream. The salty water starts to spread out while traveling downstream. Electricity conductivity is measured at the downstream measurement point, then the river flow is calculated.

7.2 Topographical Survey

For small scale hydropower projects, a topographical survey is important because most of the major civil structures are on the surface. For facilities and structures with respective footprints, such as intake weir, waterway, head tank, penstock and powerhouse, the survey is necessary to assure the accuracy of designing.

A map of about 1:500 – 1:1000 scale is adequate taking into account civil structures of small scale hydropower plants, and the relation between potential errors in the map and the estimate accuracy of quantities of the works for civil structures.

Route survey data (setting of centerline, cross sectioning) can be used for planning and design of waterways and access roads. The survey is specifically recommended where a project involves a long waterway and long access roads.

7.3 Geological Survey

(1) Geological ground surface survey

Most of the major structures of small scale hydropower plants are placed on the ground surface. Since a waterway such as headrace passes mainly on the mountain slope, a geological ground surface survey is required in order to inspect the stability of the ground surface. Geological outlines should be grasped by surveying on site such as rock categories of ground surface, and strata seen in cliffs as well as topography.

Generally rocks are covered with top soil on which many grasses and trees grow thick. The geological survey should not be finalized by checking only gullies and outcrops, and it should be carried out by removing the top soil if necessary. Since the geology is generally complicated, the geological structure should be grasped widely for the project area.

A sketch as shown in Figure 7-10 should be made as a result of the ground survey, and it leads to the basic design of each structure.

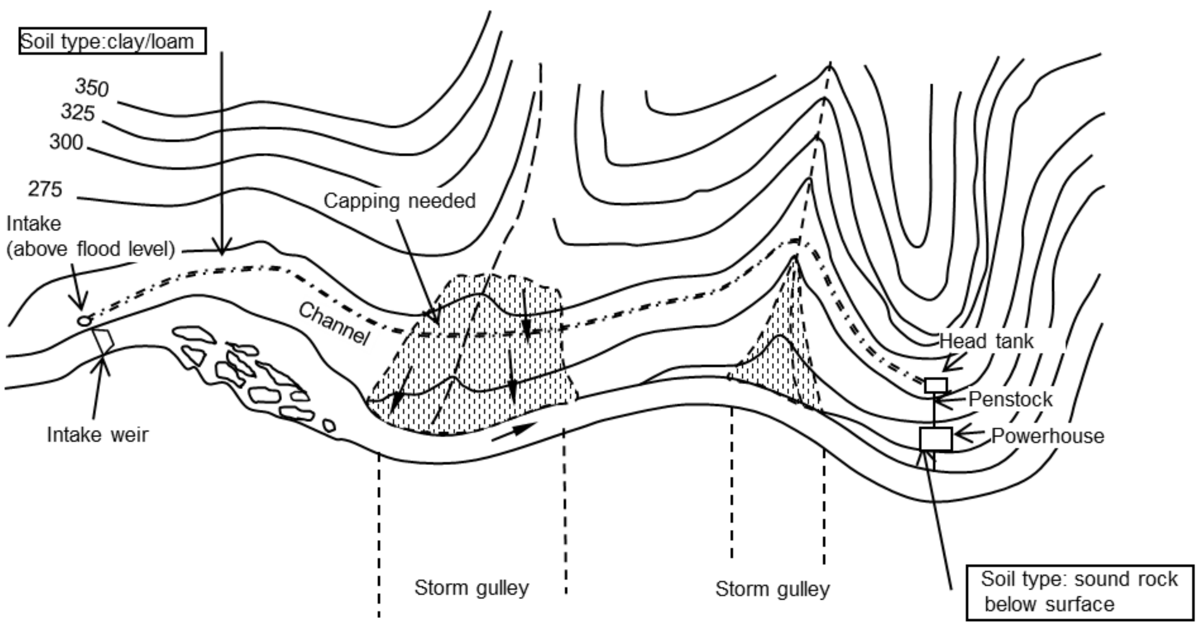


Figure 7-10 Geological Map by Ground Surface Survey

(2) Interpretation of aerial photograph

A geological ground surface survey can reveal the local geology of ground surface along the surveying route, however it is not easy to establish a link with a wide range of geology. In a case where aerial photographs for mapping are available, it should be considered that they may be very well utilized for geological interpretation.

7.4 Environmental and Social Considerations

7.4.1 Relevant Laws and Regulations

Small scale hydropower projects must follow laws, regulations and guidelines of each country, and guidelines of donors for the projects' development. The names and contents of the relevant laws and regulations to be considered depend on the countries, and typical ones are as follows.

- National environmental act
- Environmental impact assessment law
- Public health act
- Water act
- Agriculture land act
- Natural resources conservation act
- National heritage conservation act
- Lands act
- Fishery act
- Wildlife conservation act
- Forestry act

7.4.2 Environmental and Social Impact

(1) Physical impact

1) Change in downstream water flow

For most of small scale hydropower of a run-of-river type, which does not store and regulate the river flow, the change in river flow downstream from the outlet does not occur. However in a case where a pondage type, which regulates the river flow, is adopted, it does change from the natural river conditions downstream from the outlet as well.

2) Emergence of area affected by river diversion

As shown in Figure 7-11, river flow between the weir and outlet decreases because the flow is diverted through a long waterway for power generation in both "waterway type" and "dam and waterway type" mentioned in Section 3.2.2. There is a possibility to affect people using the river flow, and the flora and fauna.

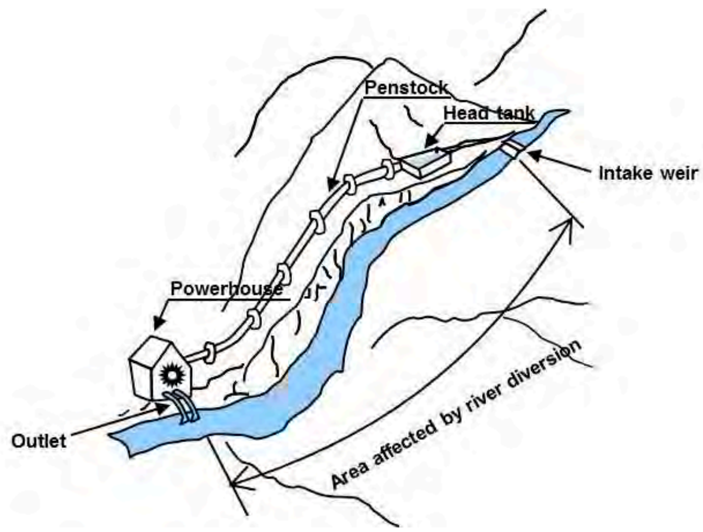


Figure 7-11 Area Affected by River Diversion

3) Water pollution

The water pollution such as turbid water might occur and affect drinking water and/or aquatic organisms during construction of the civil structures such as intake weir, waterway and powerhouse. Fuels for construction equipment, lubricating oils and other chemical materials might spill out to the river during construction. Water contamination might also occur due to leakage of electro-mechanical equipment.

(2) Impact on natural environment

1) Land alteration

The construction of a power plant needs land for generating and distribution facilities, and access roads. Tree cutting and clearing are carried out at the operation stage in order to secure the necessary height and passage under the distribution line.

2) Habitat loss caused by inundation

The terrestrial habitat in the inundation area is lost due to the construction of intake weir. The ecosystem will be influenced and paid a careful attention to if the area is a wildlife habitat for rare and endangered species. In addition, aquatic gene biodiversity will be influenced because of reduced opportunities of genetic interaction caused by the weir as migration barrier. Migratory fishes in particular, which move between the upstream and downstream areas or sea, would suffer seriously due to the blockage of migration and reproduction. Open channel of headrace, access roads and temporary roads for construction have a possibility to obstruct movement of prowling animals.

(3) Impact on social environment

1) Positive impact by projects

Since the small scale hydropower changes a non-electrification area to electrification one, a plus effect to improve living conditions of the people is large. The positive impact contributes to not only health, education, agriculture but also development of new small industries. However the users should pay the electric rates, and a supporting approach to draw out the possibility might be necessary.

2) Resettlement, loss of agricultural land

People who live in the project area for power plant development have to move to the outside of the area. People who live in the areas such as disposal areas, site offices, work houses, stockpile yards of construction materials might have to move only temporarily. It might be necessary to resettle the people who live under or along the distribution line even though the route is carefully planned. There is also a case where such areas as farm lands and important public facilities are inundated.

3) Loss of intangible cultural assets

It might happen that an archaeological site and an ancient dwelling site are discovered without anticipation during construction.

4) Water utilization, water right and communal land

In a case where the area affected by river diversion is utilized for inland water fisheries, the project might affect the fisheries. The construction of a power plant and distribution facilities might destroy a landscape and bereave a potential development of tourism, and then it might cause the local society a negative social and economical impact. In the case of the picturesque place as shown in an example of Figure 7-12, it is necessary to consider the effect of the project on water fall, swale and the like.

Source: JICA

Figure 7-12 Example of Waterfall

5) Increase of disease

Disease of malaria might break out as an intake weir crates a pond and malarial mosquito comes out. A matter of safety for the people to use electricity for the first time is important in the villages which have been newly electrified.

6) Influence to local community

Introduction of electricity to a non-electrification area brings a change to the living of villagers. The amount of lamp oil usage decreases drastically by changing oil to electricity, and the merchant's business chance to sell oil and lamp equipment is missed. The oil refrigerator changes to electric one, then again the service misses a business chance.

Concerning the distribution line newly planned, there might be a concern that it may trigger the potential friction between the fighting regions and renew the fighting. If the project is designed to be unfair, there might raise an issue that the electrification will bring about the advantage to a limited part of higher socioeconomic groups.

7) Influence to transportation

Although serious traffic problems might not occur for small scale hydropower projects, attention should be paid in the case where the road is used for school road and daily life.

(4) Environmental check list for proposed small scale hydropower projects

A reconnaissance survey is to be conducted concerning the above mentioned physical, ecological, and social impact. The entire environmental check list is attached in Table 7-1.

Table 7-1 Check List for Proposed Rural Electrification Projects

1. General Information
   1.1 Name of the proposed project:
   1.2 Name of project owner/proponent
       Project execution organization:
           Name of the responsible office:
           Name of contact persons:
           Address:
           E-mail:
           Tel/Fax No.:
           Cell phone no.:
       Name of Authorized Person(s) Responsible for the Project:
           Name:
           Position:
           Address:
           E-mail:
           Tel/Fax:
           Cell phone:
           Signature:
   1.3 Information regarding the project site
       Name of the village, commune, district and province

Address:

Other information regarding the village(s) the project site area belongs

2. Outline of the Proposed Project

2.1 Information on project characteristics

(1) Needs involuntary resettlement		
	Yes	Scale: households, persons
	No	
(2) Groundwater pumping		
	Yes	Scale: m^3/year
	No	
(3) Land reclamation, land development and land cleaning		
	Yes	Scale: hectors
	No	
(4) Logging		
	Yes	Scale: hectors
	No	

2.2 Description of the project

Main design specifications:

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

2.3 Is the project consistent with the higher program/policy?

	Yes	(outline of the higher program/policy)
	No	

2.4 Any alternatives considered before the project ?

	Yes	(outline of the alternatives)
	No	

2.5 Did the project proponent have meetings with related stakeholders during the project planning?

	Yes	(mark the corresponding stakeholders)	
			Administrative body/local government
			Local residents/villagers
			NGOs

			Others (to specify)
	No		

2.6 Are any of the following areas located inside or around the project site?

	Yes	(mark related items listed below)	
			National park, wildlife sanctuary, protected area designated by the government
			Virgin forests, tropical forests
			Ecological important habitat areas
			Habitat of valuable species protected by domestic laws or international treaties
			Likely salt cumulus or soil erosion areas on a massive scale
			Remarkable desertification trend areas
			Archaeological, historical or cultural valuable areas
			Living areas of ethnic, indigenous people or nomads who have a traditional lifestyle or specifically valuable areas
	No		

2.7 May the project have potential negative impacts to the environment and local communities?

	Yes	(brief description of the potential negative impacts)
	No	
	Not identified	

2.8 Mark the related potential environmental and social impacts and describe briefly the contents of the impacts, if any.

Items of potential impacts		Items of potential impacts	
	Air pollution		Local economy, employment, livelihood, etc.
	Water pollution		Land use and utilization of local resources
	Soil pollution		Existing social infrastructures and services
	Waste (liquid and/or solid)		Poverty issue
	Causing noise and vibration		Ethnic and /or indigenous people
	Ground subsidence		Misdistribution of benefits
	Offensive odors		Local conflict of interests among villagers
	Geographical features		Gender issue
	Bottom sediment		Children’s rights
	Biota and ecosystem		Natural and/or cultural heritages

	Potential conflict on water use rights		Infectious diseases such as HIV/AIDS, etc.
	Public health and hygiene		Global warming
	Involuntary resettlement		Others if any

Outline of related impacts marked as above:

(1) (2)

(3) (4)

2.9 Key Results of the Environmental Screening

7.5 Distribution Line Route Survey

First of all, regarding the geographical survey to plan the distribution line route, the skeleton plans should be made by the map of 1/10,000 and the satellite photograph etc. on the desk. A standard route is the shortest route between the small scale hydropower plant and the houses of customer and along the road. Several plans should be usually prepared.

Afterward, a field survey should be conducted to check that whether there are steep geographical features, trees that become a trouble in the distribution line and big rivers or not. If there is such kind of matter and the distribution route has to be extremely changed due to the matter, you should return to the map study on the desk and make an alternative. In the field survey, the GPS, the laser rangefinder and the tape measure, etc. are used. As a result of the field survey, the plan, which distribution length is the shortest and the number of problem is few, is the best one because the cost of distribution construction is in proportion to the distance of the distribution line.

After a rough distribution line route is decided, the transformer installation places should be examined based on selecting the optimum number and the optimum capacity of the transformers from the load based on the demand forcast, and setting up the transformers at the load center position to supply the customers. Then medium voltage lines from power plant to transformers and low voltage lines between transformers and customers should be drawn. It is calculated that the voltage to all customers is within acceptable value (±10% of the nominal voltage usually). Finally the pole position should be decided under the consideration of the operation and maintenance as well as distribution line. Please refer the following Chapter 11 Design of Distribution Facilities.

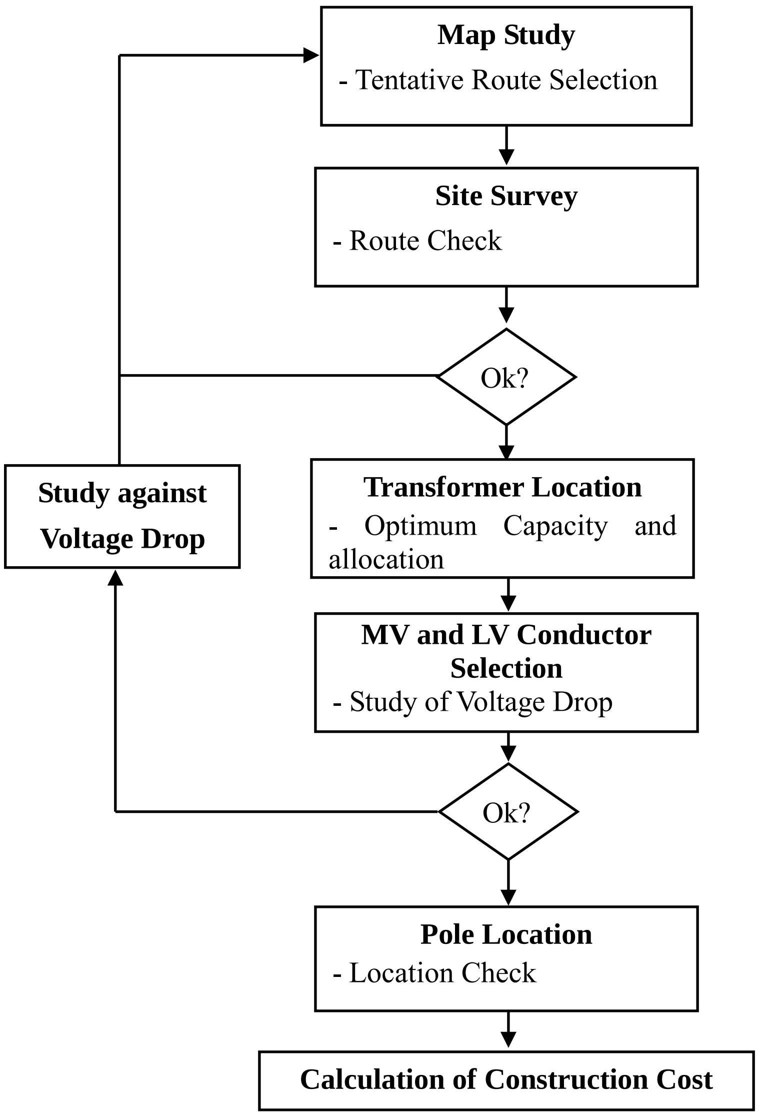


Figure 7-13   Flowchart of Distribution Line Route Survey

Reference of Chapter 7

[1] Guide Manual for Development Aid Programs and Studies of Hydro Electric Power Projects, New Energy Foundation, 1996

[2] Guidebook on Small-medium-scale Hydropower (in Japanese), New Energy Foundation, 1997

[3] Guidebook for adopting micro-hydropower (in Japanese), New Energy and Industrial Technology Development Organization, 2003

Chapter 8

Generation Plan

Chapter 8 Generation Plan

8.1 General

A generation plan with main characteristics, such as type of power generation, head, plant discharge and maximum output, is set at the feasibility study level (Basic Plan Study in Figure 4-1) based on the result of preliminary study level mentioned in Chapter 5.

Figure 8-1 shows the flow chart of the power generation planning. The column of "Power Supply Capacity″ means supplying energy by not single power plant but a combination of other power sources.

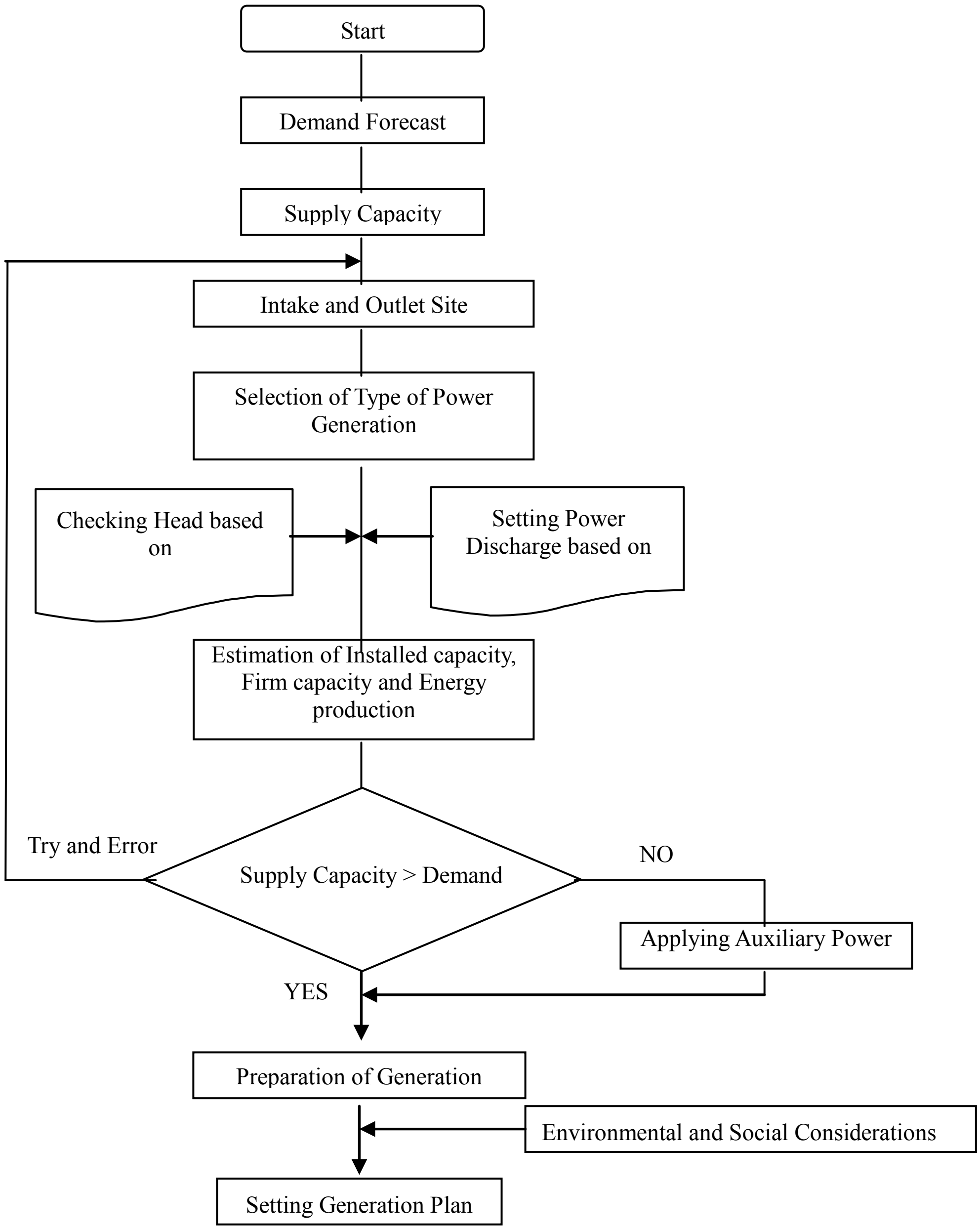


Figure 8-1 Flowchart of Generation Planning

8.2 Study on Electricity Demand

8.2.1 Electricity Demand per Household

The electricity demand in the village is calculated by the following equation.

Electricity demand in the village = (Average electricity demand per household) × (Number of households + Electricity demand for industry)

However, it is necessary to assume what kind of electric appliances will be purchased in the future in non-electrified villages. Electric appliances that will be purchased are assumed based on the results of a socio-economic research as mentioned in Chapter 6.

The electricity demand per household can be calculated by number of electric appliances, power consumption, and operating time. In general, in the early stage of electrification in developing countries, lamps, television, and a CD player are purchased in the village. Owing to the increasing income, a fan and a washing machine will be purchased. With more increasing income, luxury electric appliances such as a refrigerator, a clothes ironing, a rice cooker, and so on will be purchased. The most important thing for the estimate of the electricity demand is a choice of lamp for lighting that all households are using. There are three types of lamps, filament lamp, bulb-type fluorescent light, and LED[1] bulb.

(1) Lighting

Filament lamp is cheaper than other two lamps. But filament lamp consumes a lot of electricity because of low efficiency and the useful life is shorter than other two lamps. In the case of filament lamp, only 10% of power consumption turns to light and the rest is consumed as heat. As a result, the temperature of filament lamp reaches over 300 degrees centigrade in some case. Where brightness is concerned, filament lamp is 10-20 lm/W compared with 60-80 lm/W, and 60-85 lm/W for bulb-type fluorescent light and LED bulb respectively. Brightness of LED bulb is almost the same as bulb-type fluorescent light and is 3-5 times that of filament lamp. Regarding the useful life, filament lamp is 1,000 hours, bulb-type fluorescent light is 10,000 hours, and LED bulb is 40,000 hours. As for these prices, filament lamp is 100-300 Japanese Yen (US$1-3), bulb-type fluorescent light is 500-1,000 Japanese Yen (US$5-10), and LED bulb is 3,000-7,000 Japanese Yen (US$30-70)

Accordingly, in the case of filament lamp, the efficiency is one-forth and the useful life is 10% and 2.5% compared with bulb-type fluorescent light and LED bulb respectively. The price of filament lamp is very low. However, considering the power consumption and useful life, bulb-type fluorescent light and LED bulb are more economical than filament lamp. In the future, it is expected that prices of bulb-type fluorescent light and LED bulb will be further decreased by mass production.

[1] A light-emitting diode (LED) is a semiconductor device that emits visible light when an electric current passes through it.

In general, people in developing countries do not like to purchase such an expensive lamp. When there is a limit of power supply capability like in a small scale hydropower system, a high efficiency lamp with less power consumption is recommended considering the total economy.

Table 8-1 Comparison of Lamps

	Filament lamp	Bulb-type fluorescent light	LED bulb
Power consumption	60W	12W	9W
Brightness	10-20 (lm/W)	60-80 (lm/W)	60-85 (lm/W)
Price	100-300 Yen	500-1,000 Yen	3,000～7,000 Yen
Useful life	1,000 hours	10,000 hours	40,000 hours
			

(2) Television (TV)

TV poses greatly different power consumption depending on the size, cathode-ray tube type, and liquid crystal type. For example, the power consumption of small black and white TV is about 10W and that of 25-inch screen color TV is about 150W. Therefore, it is necessary to survey what type of TV is widespread in general.

(3) CD Player

Power consumption of a general CD player is about 15W. A CD player is often used in the young generation in the daytime of holidays.

(4) Fan

Power consumption of a general electric fan is 30-50W. The fan is used in the daytime.

(5) Washing Machine

Power consumption of a washing machine is also depending on the size. A capacity of a washing machine is measured in kilograms ranging from 3 to 10 kg. The most common size of machine for a small family (two adults and two children) is 6-7 kg. Power consumption of a small washing machine (5 kg or less) is 400W, that of a medium size (6 kg) is 470W, and that of a large size (7 kg or more) is 500W. However, the actual power consumption (Wh) is smaller than the product of power (W) and operating hours (hour) because the driving of motor of a washing machine is not continuous. Roughly, the electricity consumption during one washing (for 40 minutes) is 60Wh.

(6) Refrigerator

Even if the maximum power is displayed as 250W, the actual electricity consumption (Wh) is small because the driving of motor of a refrigerator is not continuous like a washing machine. In the calculation, electricity will be consumed at 55W on the average continuously. Though a big refrigerator seems to consume more electricity than a small refrigerator, it is not necessarily so as shown in Table 8-2.

Table 8-2 Annual Electricity Consumption of Refrigerator by Size

Size	Annual power consumption (kWh)	Average power (W)
140 litters or less	362	41
141-200 litters	363	41
201-250 litters	508	58
251-300 litters	469	54
301-350 litters	469	54
351-400 litters	441	50
401-450 litters	376	43
451-500 litters	318	36
501 litters or more	434	50

Source: The Energy Conservation Center, Japan

Table 8-3 shows the assumption of daily electricity consumption per household. The electric appliances of a low income village are lighting, TV (black & white), and a CD player and a daily electricity consumption is 151Wh/day. In the case of a middle income village, the electric appliances are lighting, TV (color), a CD player, a fan, and a washing machine with 861Wh/day of daily electricity consumption. In the case of a high income village, the electric appliances are lighting, TV (color), a CD player, a fan, a washing machine, and a refrigerator with 2,181Wh/day of daily electricity consumption. This electricity consumption is calculated based on the data from Japanese electric appliances. Therefore, it is necessary to check the electricity consumption data for electric appliances in each country.

Table 8-3 Assumption of Daily Electricity Consumption per Household (Using Bulb-Type Fluorescent Light)

(Wh)

	Low income village	Middle income village	High income village	Note
Lighting	96	96	96	12 W×2 unit×4 hours
TV	40	600	600	4 hours
CD player	15	15	15	1 hour
Fan		90	90	3 hours
Washing machine		60	60	40 minutes
Refrigerator			1,320	24 hours
Total	151	861	2,181	

If the electric light is changed from bulb-type fluorescent light to filament lamp, daily electricity consumption per household in a low income village increases from 151Wh/day to 535Wh/day as shown in Table 8-4.

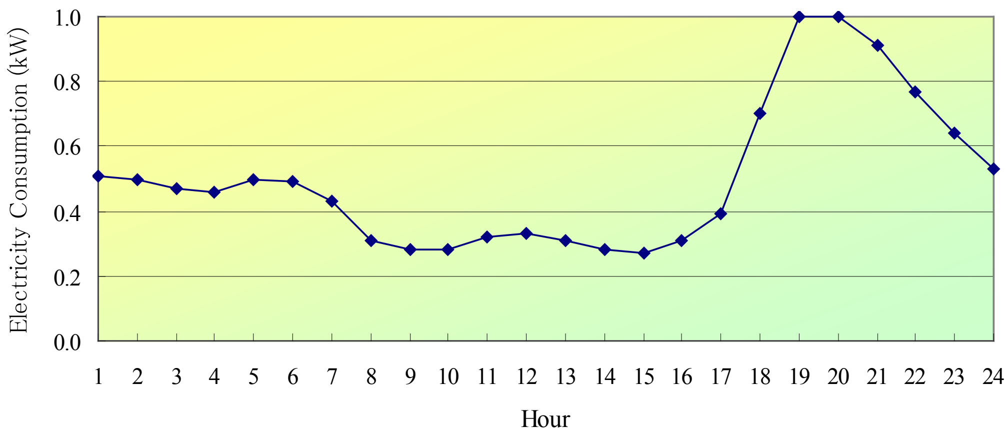
Table 8-4 Assumption of Daily Electricity Consumption per Household (Using Filament Lamp)

(Wh)

	Low income village	Middle income village	High income village	Note
Lighting	480	480	480	60 W×2 unit×4 hours
TV	40	600	600	4 hours
CD player	15	15	15	1 hour
Fan		90	90	3 hours
Washing machine		60	60	40 minutes
Refrigerator			1,320	24 hours
Total	535	1,245	2,565	

8.2.2 Electricity Demand by Village Types

The electricity consumption that is explained in Section 8.2.1 was daily electricity consumption per household. However, it is necessary to estimate the maximum load in the village when examining the supply capacity of small-scale hydropower. Usually, the peak demand in the village appears at night for lighting demand. Figure 8-2 shows daily load curve in the village that was measured in the past electrification project and the peak load appears in the night-time. The electricity demand in the daytime is low with about 30% of that at the peak time.



Source: Hydropower Study in Southeast Asia/Study on Decentralized Small Hydropower, METI

Figure 8-2 Daily Load Curve in Village

The daily load curve of the village having 100 households is estimated based on electric appliances and the operating hours as mentioned in Table 8-4. It is necessary to consider the diversity factor when estimating daily load curve. The diversity factor is the ratio of the sum of the individual maximum demands to the maximum demand of the system. The diversity factor is always greater than

1 and is defined by the following formula.

$$\text{Diversity Factor} = \frac{\text{Sum of Individual Maximum Demand}}{\text{Maximum Demand on Power Station}}$$

If two or more equipment are operated at the same time, the diversity factor becomes small. For example, there are three factories, X, Y, and Z with the maximum demand of 200 kW each. If three factories are operating at the same time from 9:00AM to 5:00PM, the power supply of 600 kW is necessary. In this case, the diversity factor is 1 (200×3/600). If three factories shift the operation time by eight hours and the operation time doesn't overlap with one another, a power system of 200 kW is just enough. In this case, the diversity factor is 3 (200×3/200).

If each household owns lighting (12W×2 units), TV (10W), a washing machine (400W), and a refrigerator (250W), the maximum demand per household reaches 684W. If these electric appliances are used by 100 households at the same time, a power supply system of 68.4kW is needed. However, actually the motor of the refrigerator and washing machine of 100 households won't be driven at the same time.

(1) Assumption of the diversity factor for low income village

The electric appliances of a low income village were assumed to be lighting (12W×2), TV (10W), and a CD player (15W). The maximum demand per household is 49W when three electric appliances are used at the same time. The sum of individual maximum demand reaches 4.9kW (49W×100). The maximum demand in the village becomes 3.4kW at 8:00PM when assuming that 100 households do not use all the electric appliances at the same time. The diversity factor is 1.44 (4.9/3.4). Figure 8-3 shows assumption of daily load curve for low income village

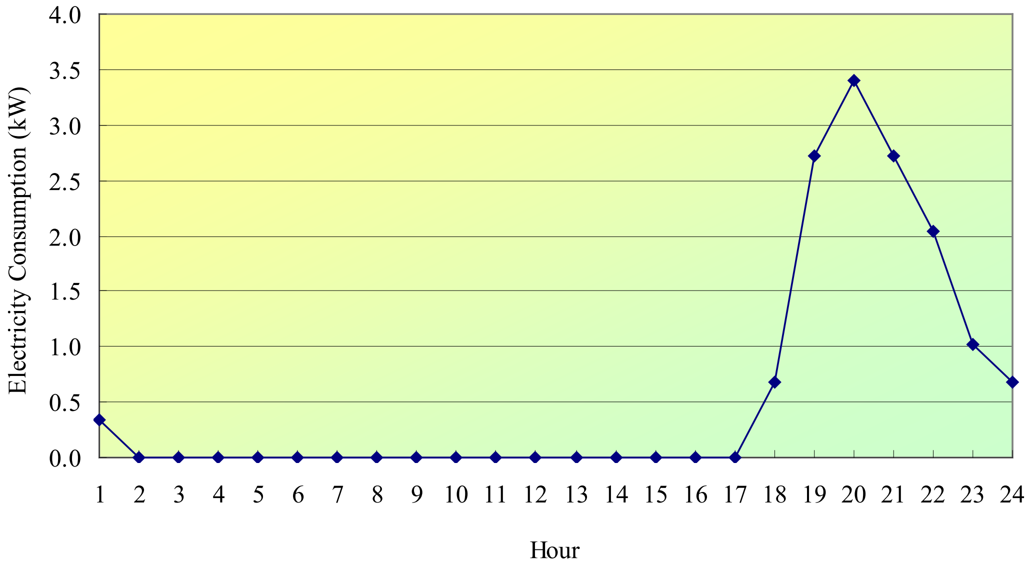


Figure 8-3 Assumption of Daily Load Curve for Low Income Village

(2) Assumption of the diversity factor for middle income village

The electric appliances of a middle income village were assumed to be lighting (12W×2), TV (150W), a CD player (15W), a fan (30W), and a washing machine (400W). The maximum demand per household is 619W. But all the electric appliances are not used at the same time. When assuming that a washing machine is used from 8:00 to 10:00 AM, a fan and a CD player are used afterwards, and lighting lamps and TV are used at night, the maximum demand per household becomes 174W at night. Assumption of daily load curve for a middle income village is shown in Figure 8-4. The maximum demand in the village becomes 17.4kW at 8:00PM and the diversity factor is 3.55 (61.9/17.4).

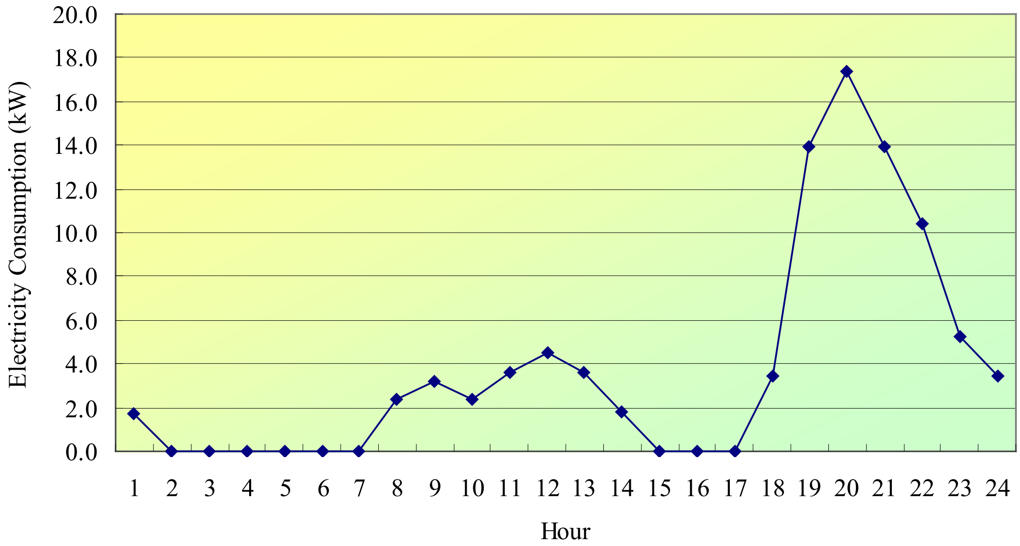


Figure 8-4 Assumption of Daily Load Curve for Middle Income Village

(3) Assumption of the diversity factor for high income village

The electric appliances of a high income village were assumed to be lighting (12W×2), TV (150W), a CD player (15W), a fan (30W), a washing machine (400W), and a refrigerator (250W). The maximum demand per household is 869W. But all the electric appliances are not used at the same time. The power consumption patterns of electric appliances except a refrigerator are assumed in the same way as a middle income village. Adding a refrigerator demand for 24 hours, the maximum demand per household becomes 229W at night. Though the maximum power demand of the refrigerator is 250W, the average daily power demand of the refrigerator is assumed to be 55W because its motor doesn't continuously drive as before- mentioned. Assumption of daily load curve for a high income village is shown in Figure 8-5. The maximum demand in the village becomes 22.9 kW at 8:00PM and the diversity factor is 3.79 (86.9/22.9).

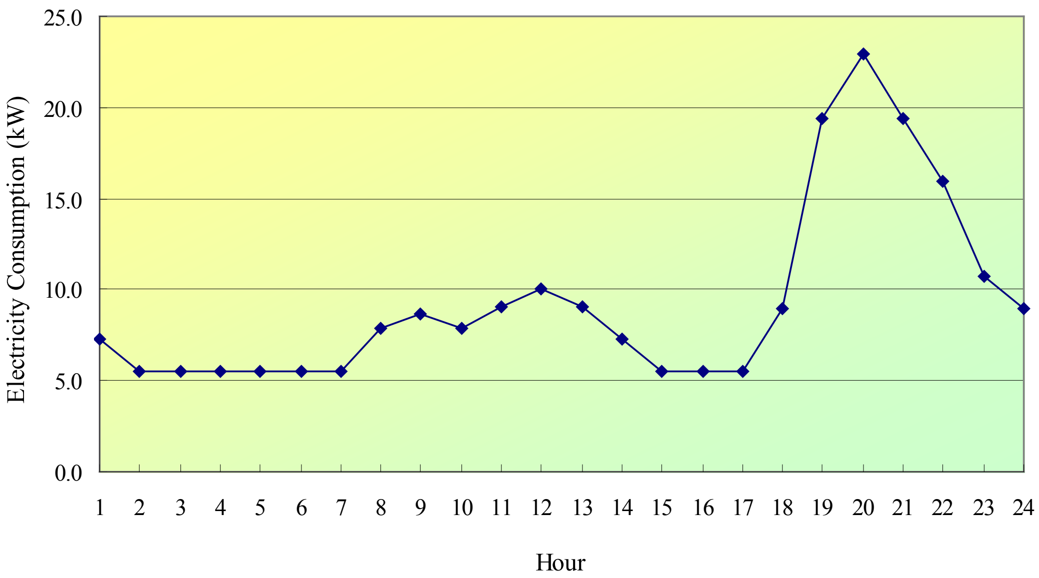
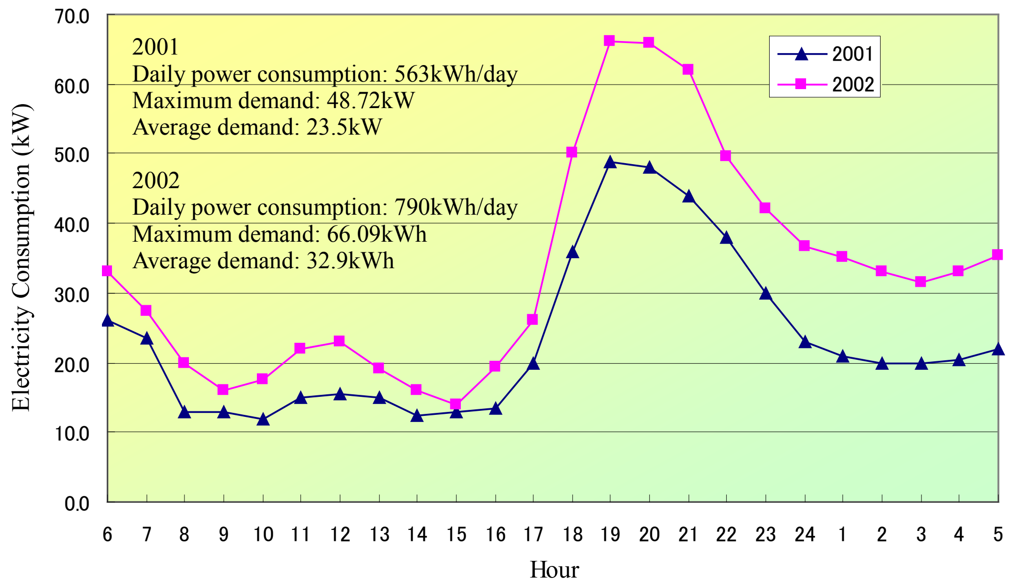


Figure 8-5 Assumption of Daily Load Curve for High Income Village

As mentioned above, the diversity factor of the village with only light demand at night is small because much of the load is borne at the same time. Anyway, in the case of village electrification, the peak demand appears at night as long as there is no industry. The power generation capacity is decided by estimating the peak demand. To estimate the peak demand in un-electrified village, daily load curve of adjacent electrified villages will serve as a useful reference. As past experience shows, the growth rate of electricity demand in the village at an early stage of the electrification is very high and the maximum demand increased by 35% in only one year as shown in Figure 8-6.



Source: Hydropower Study in Southeast Asia/Study on Decentralized Small Hydropower, METI

Figure 8-6 Comparison of Electricity Demand Between The First and The Second Year

8.2.3 Consideration of Electricity Demand Assumption in the Future

In the case of a village in developing countries, the peak demand appears at night due to lighting demand. Therefore, the number of households multiplied by the electricity demand at night per household becomes the maximum demand in the village. The supply capacity of small-scale hydropower has only to be designed to cover it. The electricity demand of the village just after the electrification is limited to lighting demand and the maximum demand is also small as already described. However, it will increase rapidly in a small village to double within several years. There is no definite answer how long such a high growth rate of electricity demand will continue. In order to estimate the future electricity demand in a non-electrified village, the actual electricity demand in the neighborhood area that has already been electrified will serve as a useful reference.

8.3 Supply Capacity

8.3.1 Combination Study of Energy Source

As mentioned above, the speed of increasing demand per household is much different depending on the type and condition of the villages in the first period of the electrification. The development scale of small scale hydropower becomes within the range of the potential for both head and discharge.

It is necessary to check the scale of the demand for electricity in connection with the potential for the head and discharge at the project site selected in Chapter 5, and to confirm whether there is any necessity of the auxiliary power system.

The relation between supply by hydropower and demand is shown in Figure 8-7.

$$D_{max} = P_{h\,firm} - P_{\ell}$$
$$= P_{h\,firm}\,(1-\alpha)$$

where,

D_{max} : Maximum demand (kW)

$P_{h\,firm}$: Firm output of hydropower (kW)

$P\ell$: Distribution loss (kW)

α : Distribution loss rate of hydropower ($=P\ell/ P_h$ firm)

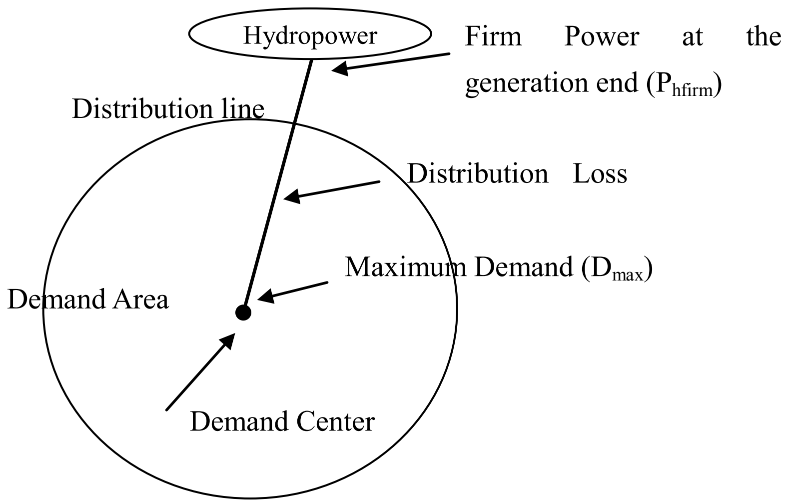


Figure 8-7 Relation Between Supply and Demand by Hydropower

It is possible to supply energy by hydropower only if the firm power (*3) of hydropower is enough for the maximum demand.

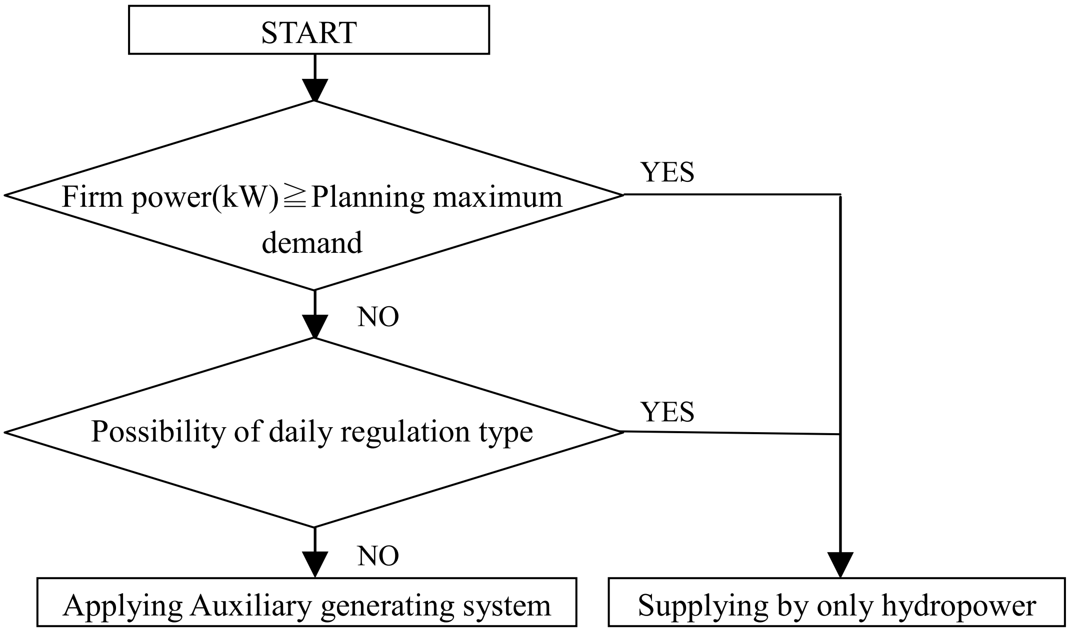


Figure 8-8 Study Flow for Necessity of Auxiliary Generating System

8.3.2 Supply by Hydropower Only

(1) Run-of- river type

1) Installed capacity

The maximum demand is, in most cases, set equivalent to the firm output. The relation between the flow duration curve and the maximum plant discharge is indicated in Figure 8-9.

However, the installed capacity may be set equivalent to the value of demand in a case where the firm output is extremely smaller than the demand.

$$P_{max} = 9.8 \times Q_{max} \times He \times \eta_t \times \eta_g$$

where,

P_{max}	: Maximum output (kW)
Q_{max}	: Maximum plant discharge (m^3/sec) = Q_{firm} (Firm discharge)
He	: Effective head (m)
η_t	: Turbine efficiency
η_g	: Generator efficiency

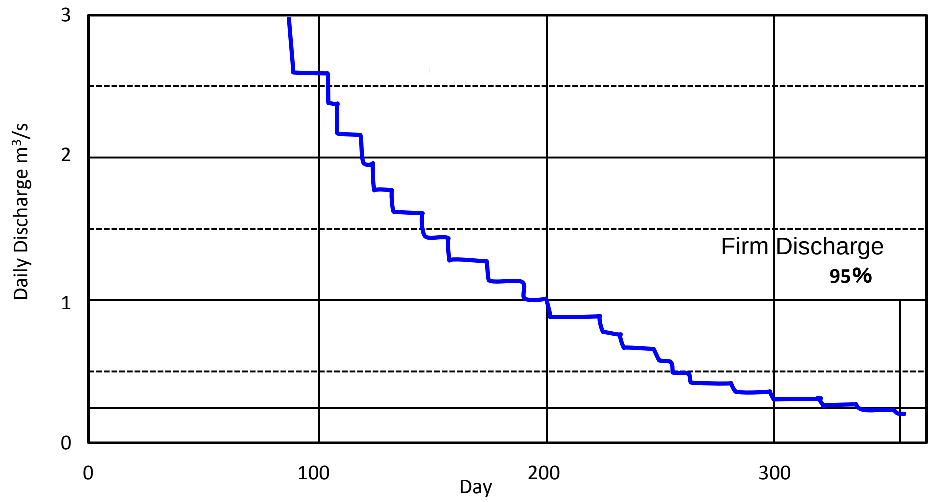


Figure 8-9 Flow Duration Curve and Maximum Plant Discharge (Run-of -River Type)

2) Head Loss and Effective Head

Figure 8-10 shows a schematic diagram of effective head in the case of a Pelton turbine type. An effective head is estimated by a gross head minus a total head loss. Equation for effective head is indicated below.

(a) In the case of Pelton turbine type

$$H_e = H_g - (H_{L1} + H_{L2} + H_{LP} + H_{L3})$$

where,

H_g	: Gross head (between intake water level and tailwater level)
H_e	: Effective head
H_{L1}	: Total head loss between intake and head tank
H_{L2}	: Head loss of penstock between head tank and entrance of turbine
H_{L3}	: Head loss of tailrace and outlet
H_{LP}	: Installation height of Pelton turbine

Figure 8-11 shows a schematic diagram of an effective head in the case of a Francis turbine type and propeller type.

An effective head is estimated by a gross head minus a total head loss.

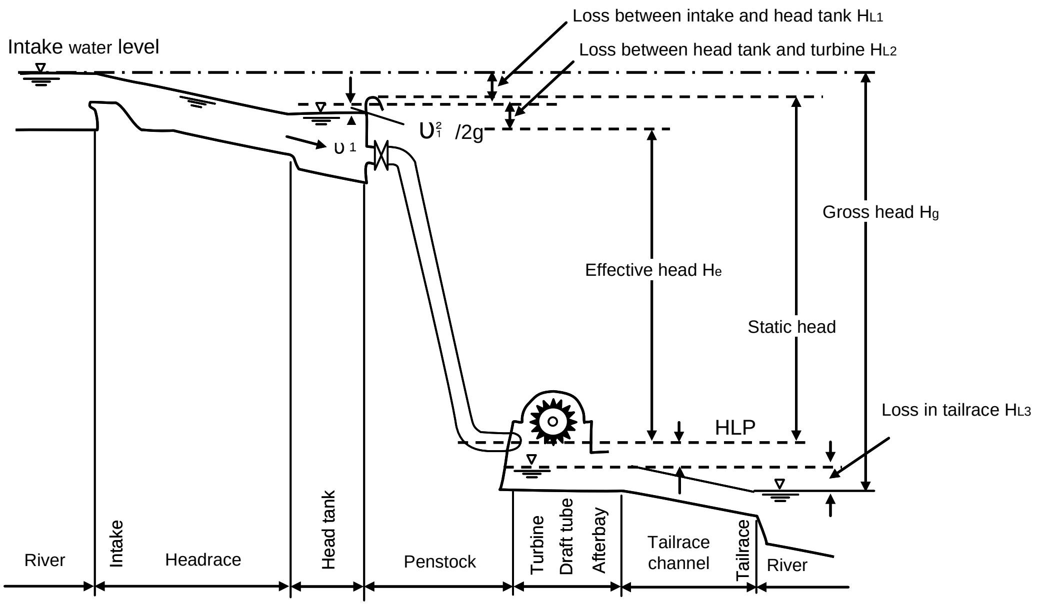


Figure 8-10 Schematic Diagram of Effective Head (Pelton Turbine Type)

(b) In the case of Francis turbine type

$$H_e = H_g - (H_{L1} + H_{L2} + V_2^{\,2}/2g + H_{L3})$$

Where,

Legends are the same as those of Pelton turbine type except a velocity head as below.

$V_2^{\,2}/2g$: Velocity head (flow velocity V_2) of draft tube outlet

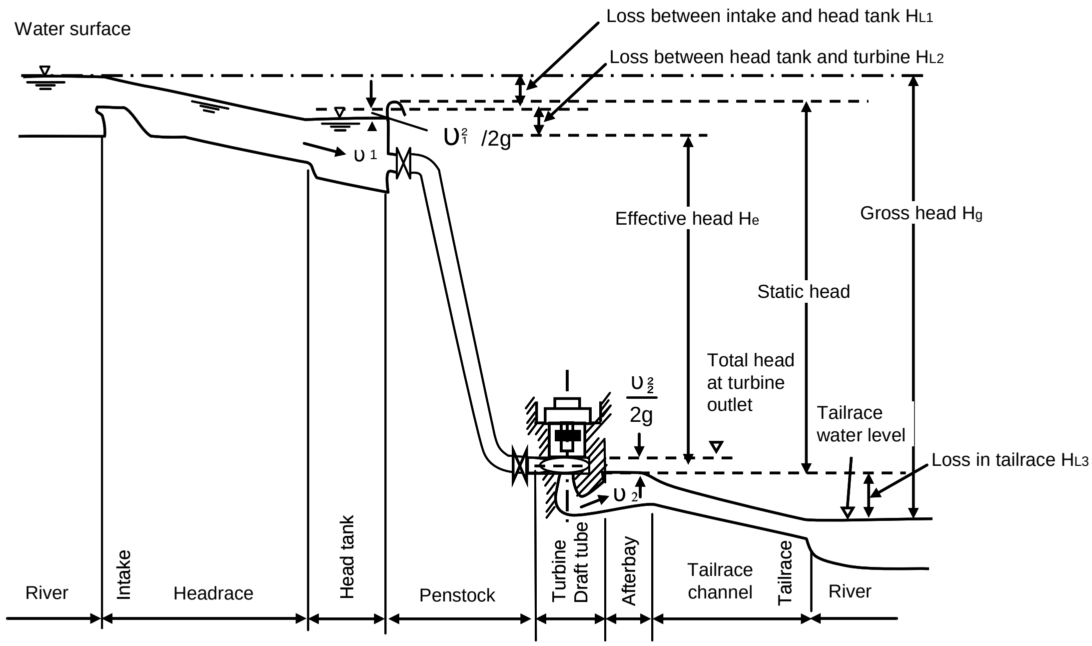


Figure 8-11 Schematic Diagram of Effective Head (Francis Turbine Type)

3) Firm output

Firm output of hydropower is indicated as below.

$P_{max} = P_{firm}$

$P_{firm} = 9.8 \times Q_{firm} \times H_e \times \eta_t \times \eta_g$

where,

P_{max}	:Maximum output(kW)
P_{firm}	: Firm output(kW)
Q_{firm}	: Firm discharge at the intake site (m^3/sec)
H_e	: Effective head (m)
η_t	: Turbine efficiency
ηg	: Generator efficiency

(2) Pondage type with Daily Regulating Pond

A pond for daily regulation is used to reserve the inflow during low demand hours such as daytime and midnight. The reserved water is used for the generation at the peak time. This type is accordingly able to generate the maximum output more than double of a run-of-river type during the dry season.

1) Condition for Applying Daily Regulation Type

Generally, the construction cost of this type of hydropower is relatively high because of the dam cost. Moreover an environmental impact caused by constructing the dam should be taken into consideration.

2) Maximum Output and Regulating Capacity of the Pond

The equation of output is the same as a run-of river type.

$P = 9.8 \times Q_{max} \times H_e \times \eta_t \times \eta_g$

However, the calculation method of a maximum plant discharge of this type is different from that of a run-of-river type as mentioned before.

$Q_{max} = Q_{firm} \times 24$ hours/peak duration time

Here, peak duration time means the hours that electric energy of the peak time divided by the maximum output. Generally, a range of the peak duration time of the electrified village at the initial period is three to six hours. (See Figures 8-3, 8-4 and 8-5) It should be selected according to the actual conditions of the project area.

The required available regulating capacity of the pond is estimated by the following equation.

$V_e = (Q_{max} - Q_{firm}) \times T \times 3{,}600$

where,

V_e	: Available regulating capacity (m^3)
Q_{max}	: Maximum plant discharge (m^3/sec)

Q_{firm} : Firm discharge (m^3/sec)
T : Peak duration time (hour)

In theory, a volume of the available regulation capacity becomes the maximum in a case where a peak duration time becomes 12 hours.

The relation among daily load curve, maximum plant discharge and available pond capacity is indicated in Figure 8-12.

Maximum discharge will be more or less double of firm discharge if daily load factor is 50%. And Available pond capacity needs the amount of water corresponding with six hours of the maximum discharge.

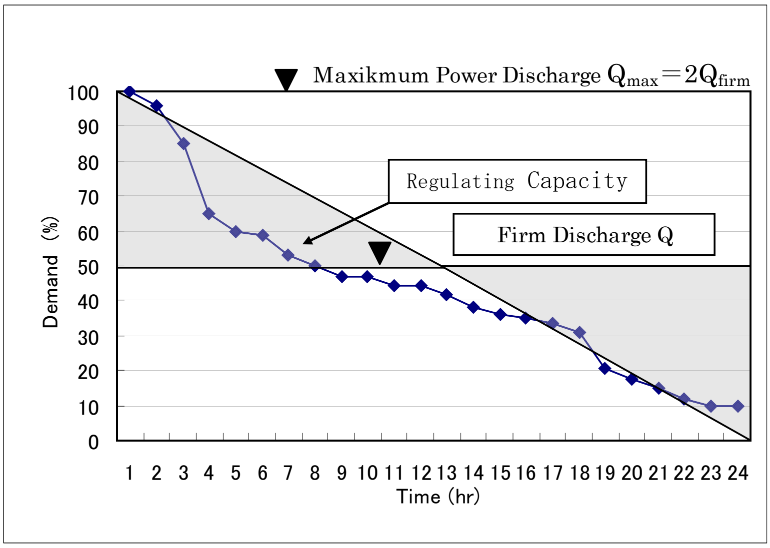


Figure 8-12 Relation Among Daily Load Curve, Maximum Power Discharge and Regulating Capacity

3) Head loss and effective head

The calculation method is the same as a run-of-river type.

8.3.3 Combination of Auxiliary Generating System

(1) General

In a case where supply capacity of hydropower does not meet the demand, an auxiliary generating system such as diesel power, bio gas generation, and solar power together with the connection with the network is required. Here in the case of hydropower as a main supply, the following points should be considered.

- The hydropower and other auxiliary power must be operated at the same time.
- The auxiliary facilities must be able to correspond with the load variations.

➢ The auxiliary facilities must be easily operated and maintained.

(2) Allotment of Power Supply

1) Dry Season

The entire power supply capacity including the auxiliary generating system must meet the planned maximum demand. Figure 8-13 shows the typical example of the supply range due to the daily load pattern and combined power sources.

The hydropower is intended to correspond to the base load in 24 hour operation, while it is the most economical method to make an auxiliary generating system correspond to the peak load like dinner time, etc.

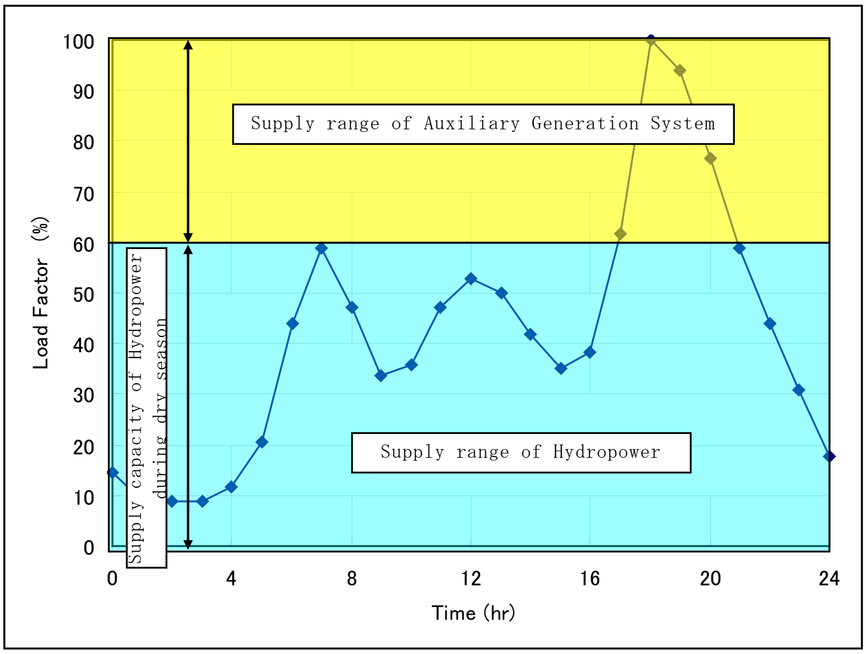


Figure 8-13 Combination of Auxiliary Generating System (In Dry Season)

2) Rainy Season

Allotment of power supply in the dry season with little river discharge is shown in Figure 8-13. On the other hand in the rainy season, it is possible to supply energy by hydropower only because of enough river discharge. Figure 8-14 shows allotment of power supply in the rainy season.

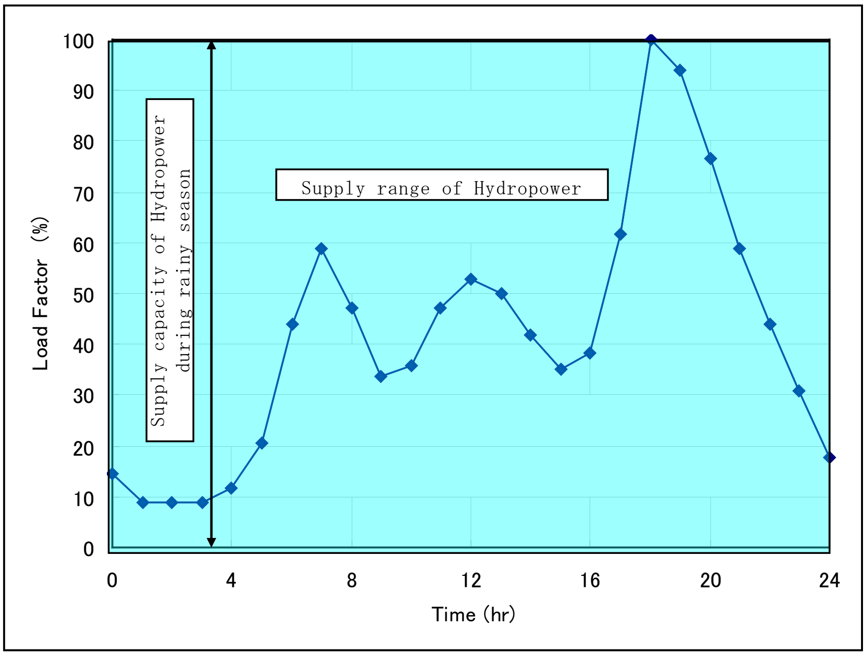


Figure 8-14 Energy Source in Rainy Season

(3) Total Installed Capacity

1) Auxiliary Generating System

The installed capacity of an auxiliary generating system needs to be that of the maximum demand deducted by the output of hydropower as shown in Figure 8-13.

$$Po\,(1-\beta) = D_{max} - P_{h\,firm}\,(1-\alpha)$$

where,

Po	: Output of auxiliary generating system (kW)
D_{max}	: Maximum demand (kW)
$P_{h\,firm}$	: Firm output of hydropower (kW)
α	: Distribution loss by hydropower ($=P\ell/\ P_{h\,firm}$)
β	: Distribution loss by auxiliary generating system

2) Hydropower

The installed capacity of hydropower is between the maximum demand and the firm output. It is possible to scale up the maximum output of hydropower if a maximum discharge is adopted to be larger than the firm discharge. Then hydropower may be able to supply energy without an auxiliary generating system during the rainy season. The installed capacity of hydropower is to be determined based on the optimization study considering both cost and benefit of the combined system.

8.4 Environmental and Social Considerations

8.4.1 Screening and scoping

(1) Screening

Screening is the procedure to decide whether the proposed project should conduct EIA (Environmental Impact Assessment. Concerning small scale hydropower projects for the rural electrification, a necessity of EIA depends on countries. In the case of the country having the legal system, the necessity is judged in accordance with the defined procedure.

JICA Guidelines show that JICA conducts a screening on the basis of a check list prepared by the country concerned.

JICA categorization consists of the following categories A, B and C. IEE (Initial Environmental Examination) should be done for category B and EIA should be done for category A.

- Category A

  Proposed projects are classified as Category A if they are likely to have a significant adverse impact on the environment and society. Projects with a complicated or unprecedented impact that is difficult to assess, or projects with a wide- ranging or irreversible impact are also classified as Category A. These impacts may affect an area broader than the sites of the work or facilities subject to a physical change. Category A, in principle, includes projects in influential sectors, projects that have characteristics that are liable to have an adverse environmental impact, and projects located in or near sensitive areas.

- Category B

  Proposed projects are classified as Category B if their potential impacts on the environment and society are less adverse than those of Category A projects. Generally, they are site-specific; few if any are irreversible; and in most cases, normal mitigation measures can be designed more readily.

- Category C

  Proposed projects are classified as Category C if they are likely to have a minimal or few adverse impacts on the environment and society.

(2) Scoping

When the project is decided as “EIA needed” or “IEE needed”, the next step is scoping. Scoping identifies relatively large-impact items and decides survey methods, survey time, a survey area, and prediction methods. Many EIA regulations require disclosure of the scoping results and stakeholder meetings in order to collect its views. The opinions obtained in the meetings should be included in the survey and assessment to the maximum possible extent.

8.4.2 Impact Assessment and Mitigation

Compensation should be considered for a remaining social and environmental impact after taking the mitigation. Even though the problem is permanent or temporary, any loss of houses and land/farmland, agricultural products, trees, households account, community, business should be compensated.

Drawing up transparent and equitable compensation principles and procedures is very important to form a trustworthy relationship with people and community influenced by the project.

8.5 Setting Up of Basic Plan

(1) Determination of development scale

The scale of electricity demand for the target of electrification area is examined in Section 8.2. In Section 8.3, supply capacity of small scale hydropower is studied considering a scale of electricity demand. And if supply capacity of hydropower is not enough for electricity demand, an auxiliary generating system is adopted.

The plan of the project is made final based on these, and the basic project plan is shown as in Table 8-5.

Table 8-5 Example of Basic Plan

Item	Unit		
Catchments Area	km^2		
Annual Average River Flow	m^3/sec		
Average Flow during Rainy Season	m^3/sec		
Firm Discharge (95%, 347th Flow)	m^3/sec		
Intake Water Level	E.L.m		
Tailrace Water Level	E.L.m		
Gross Head	m		
Effective Head	m		
Maximum Power Discharge	m^3/sec		
Installed Capacity	kW		
Number of Turbine	Unit		
Type of Turbine			
Headrace			
Section	m		
Length	m		
Penstock			
Section	m		
Length	m		
Annual Available Energy	MWh		
Plants factor of above	%		
Operation period by Maximum output	day		
Firm Output	kW		
Annual Energy Consumption at Demand End	MWh		

(2) Formation of implementation schedule

The implementation schedule consists of the following steps:

1) Site acquisition and law permission

Issues of law permissions such as environment and electric utility should be conducted. And site acquisition is carried out.

2) Finance

In a case where an aid fund and a financing fund are applied, you must draw up a planning report because you need to appeal to those related organizations.

3) Designing electric facilities

Detailed design of the electric facilities such as civil, electro-mechanical and distribution facilities is conducted.

4) Cost estimation of construction work, operation and maintenance, and construction schedule

5) Procurement

Tender documents including drawings and technical specifications are prepared for electric facilities as above 3). And all the procedure for procurement such as tender calling, evaluation, selection, negotiation and contract is conducted.

6) Construction

Construction of the electric facilities such as civil, electro-mechanical and distribution facilities is carried out.

Reference of Chapter 8

[1] Guide Manual for Hydropower Development, New Energy Foundation, 1996

[2) Basic design study report on the project for rural electrification micro-hydro power in remote province of Mondul Kiri in the Kingdom of Cambodia, JICA, 2005

[3] The project for Project for Operation and Maintenance of the Rural Electrification on Micro-hydropower in Mondul Kiri, JICA, 2011

Chapter 9

Design of Civil Structures

Chapter 9 Design of Civil Structures

9.1 Intake Weir

An intake weir is a structure designed to dam up a river to draw water from the river creating a waterway type (run-of- river type) power plant.

The following conditions are to be met when selecting an intake weir site.

i) The foundation should be a solid rock with little or no sediment deposit.

ii) In the case of the foundation rock lying deep, a relatively small amount of excavation may be enough to provide a suitable foundation for the structure.

iii) After the intake weir construction, it is not likely that there occurs a scour on the banks or in the riverbed immediately downstream. (The river course upstream/downstream is to be as straight as possible)

iv) There are no landslides nor slope instability near the intake weir: the natural ground around the intake weir is stable.

v) River diversion and cofferdam closure during construction are easy.

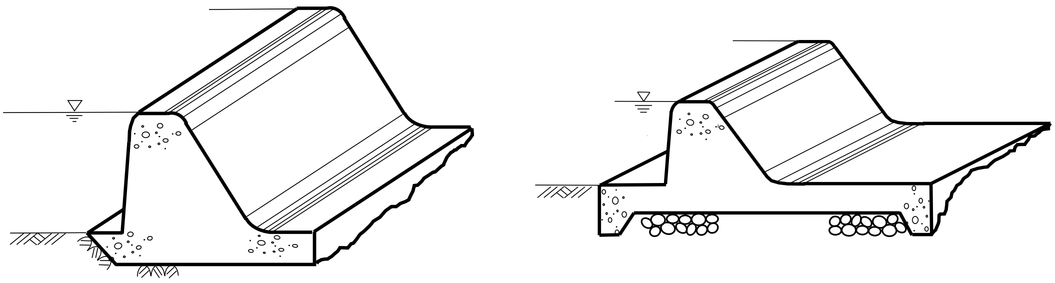
vi) With all future sedimentation, the cross-section is safe enough to release the design flood discharge.

vii) The intake weir is to be constructed at right angles to the river. Where it is unavoidable to have it at an angle, preventive measures are to be taken against the scouring of the banks downstream during floods.

In general, to reduce the construction cost of the intake weir body, a narrow section of a river is selected as the intake weir construction site. However, in the case of a small-scale hydropower plant, if an intake weir is constructed at a narrow section of the river, inevitably the floodwater level is likely to become high and the weir section and the height/length of bank protection work are thereby increased. It should be noted that such a selection is not always advantageous.

9.1.1 Weir Body

In general, a concrete structure is used for the intake weir of the small-scale hydropower plant construction. A concrete gravity type structure is set upon the bedrock. When the river deposit is thick and the bedrock is located deep below, a floating type structure is to be adopted located on the gravel layer of the riverbed. In this case, to prevent sand and gravel from being taken away by water leakage at the bottom of weir, water cutoff is engineered. Also, to prevent the riverbed from being washed away by a flood discharge downstream of the weir, particularly at its directly hitting area, a protective apron is added.



Concrete gravity type　　　　Floating type

Figure 9-1　Concrete Gravity Dam

In order to reduce the construction cost, a concrete-faced reinforced gabion dam is constructed.

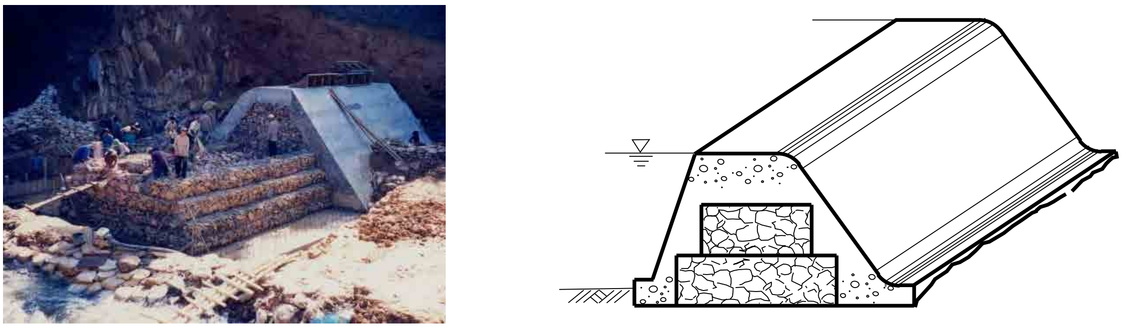


Figure 9-2　Concrete Reinforced Gabion Dam

The intake weir height is determined considering the following conditions.

i) Installation height restrictions on the waterway
ii) Possibility of rise of the riverbed downstream
iii) Conditions to remove sediment in front of the weir and in the settling basin
iv) Impact on power generation
v) Influence of backwater

(1) Conditions restricting waterway height

It is rare that a waterway as a headrace is planned as a tunnel waterway for a small scale hydropower plant; an open channel and a culvert are commonly used instead. The construction cost of these types of waterway is dependent on the topographical and geological conditions of the area where the water channel is to pass.

Thus, to determine the intake weir height, the topographical and geological conditions of the waterway route are considered in addition to the conditions at the intake weir construction site itself. Careful examination is necessary particularly at the site where the construction cost of a waterway accounts for a large portion of the total construction cost.

(2) Possibility of downstream riverbed rise

Since the intake weir height for a small-scale hydropower plant is generally as low as several meters, there is a possibility that the normal function of the plant could be impaired by a rise in the downstream riverbed.

Accordingly, a possible rise of riverbed in the future should be considered when determining the intake weir height if the planned site falls under any of the following cases:

i) A low-gradient river having a large amount of sediment delivery

ii) Existence of check dams downstream of the planned intake weir

iii) Presence of land failure with the possibility of continuous failure in the future

iv) Existence of a narrow section downstream which obstructs the flow of sediment and/or driftwood

(3) Conditions to remove sediment in front of the intake and in the settling basin

Under normal circumstances, to ensure the smooth removal of sediment in front of the intake and in the settling basin, the height of the weir should be greater than the value calculated by the following methods (See Figure 9-3):

1) In the case of side intake

A higher value of either (a) or (b) below is to be adopted.

(a) Height (D_1) determined in relation to the sill elevation of the sand flush gate of the intake weir

$$D_1 = d_1 + h_i$$

(b) Height (D_2) determined in relation to the settling basin slope

$$D_2 = d_2 + h_i + L \times (i_c - i_r)$$

where,

d1	: Height from the sill of the sand flush gate of the intake weir to the intake sill (usually approximately 1.0 m)
d2	: Difference between the sill of the sand flush gate of the settling basin and the riverbed at the same location (usually approximately 0.5 m)
hi	: Water depth at intake sill (usually with a flow velocity of 0.3 to 1.0 m/sec)
L	: Length of the settling basin
ic	: Bed gradient of settling basin (usually approximately 1/20 to1/30)
ir	: Current river gradient

2) In the case of Tyrolean intake

Power discharge is taken from the bottom of Tyrolean intake. Assuming that the front of the weir is filled with sediment, the weir height is determined by D_2 as explained in 1) (b) for a side intake.

$$D_2 = d_2+h_i+L(i_c-i_r)$$

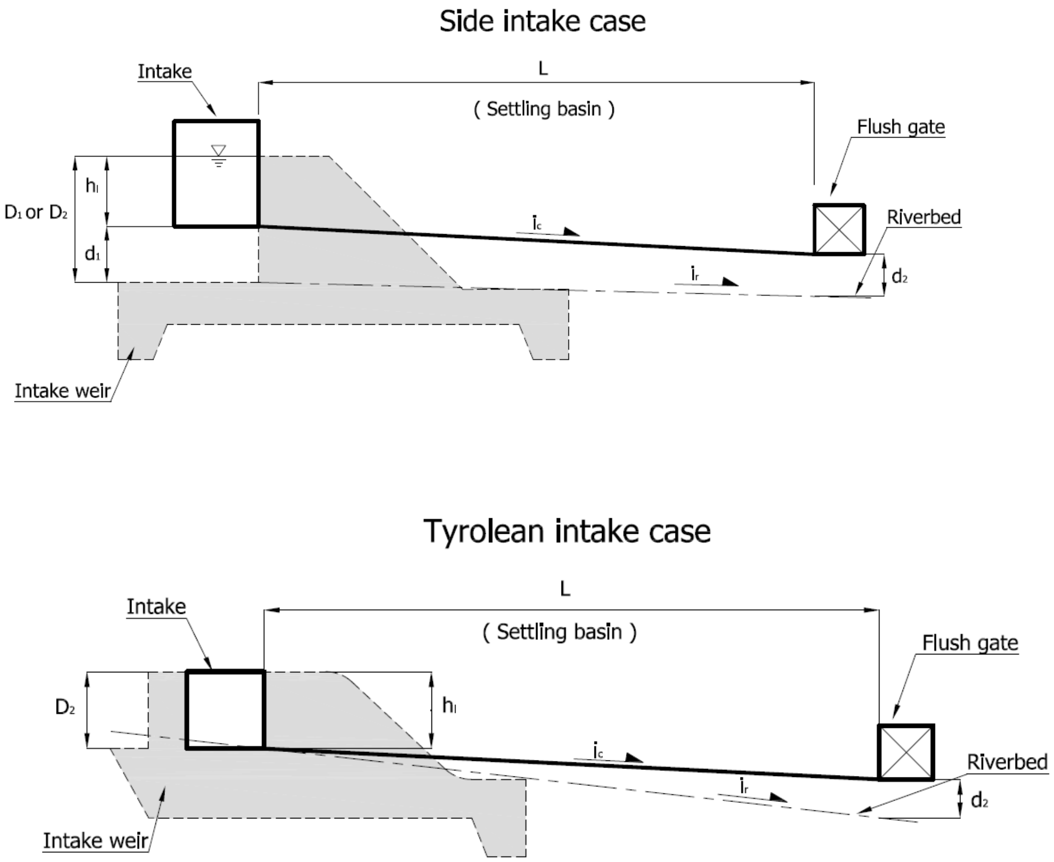


Figure 9-3 Intake Method and Weir Height

(4) Impact on power generation

At a site where the usable head is limited or where it is planned to secure the necessary head by the construction of an intake weir, the weir height will significantly influence power generation.

Accordingly, it is necessary to determine the weir height at such a site by comparing the expected changes in both the construction cost (Cost) and the power generation (Benefit), which vary according to different weir heights.

(5) Backwater effect

When roads, residential areas, farmlands, bridges, check dams, etc. existing in the upstream area of a planned intake weir site are subject to flooding, it is necessary to determine the weir height to prevent the flooding due to the backwater effect of the weir.

Particularly at a site with a significant weir height, the degree of impact on the above facilities must be checked by means of backwater calculation or other such methods.

9.1.2 Sediment Flushing Facility

Sediment deposits in a relatively short time when an intake weir is constructed on a river with steep gradient. A sand flush structure is, therefore, required to ensure the enough intake of water and to prevent sediment from entering the waterway.

A sand flush structure is generally constructed near the intake adjacent to the intake weir. Sand flush gate is opened and water is discharged, at the subsiding stage of floods for example, to flush out the sediment. The sand flush gate must have the dimensions to obtain a flow rate enough to flush out the sediment. Because of a lot of wear and tear on the watercourse surface, construction may provide a stone or steel-clad structure.

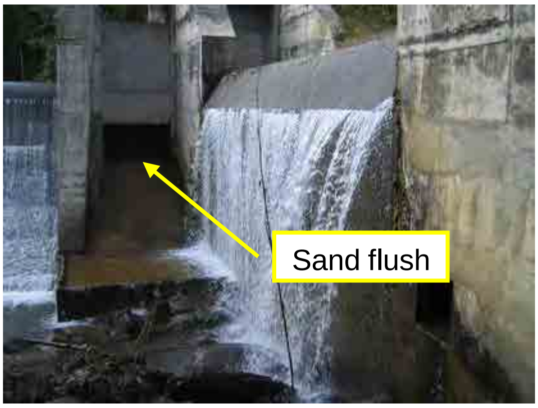


Figure 9-4 Sand Flush

A slide gate is adopted for sand flush for the reason not only that it can be raised up with reliability even when sediment has been accumulated behind the gate but also that it can be shut down with ease even under the flushing conditions.

9.2 Intake

(1) Essential points to be considered for designing

An intake structure leads river water into a waterway, and is designed to meet the following conditions.

- i) The maximum plant discharge is taken in constantly and is adjusted as required.
- ii) The head loss is small.
- iii) Inflow is smooth and does not have any air intrusion vortex
- iv) Sediment, driftwood, leaves, etc. do not flow into the intake.
- v) The intake is not susceptible to damage due to flooding or landslide.
- vi) Maintenance work after completion is easily carried out.

(2) Intake method

In general, the following intake methods are used for small scale hydropower plants.

1) Side intake method

The intake is generally constructed near the intake weir. The site of the intake should be selected so that the design discharge can be drawn from the river without being affected by sedimentation behind the weir, and that it is not subject to damage by a flood flow and driftwood. The intake site should also provide adequate space for a settling basin between the intake and headrace inlet. The intake should be designed to take in the water at a right angle to the river course or at a slightly less angle.

Figure 9-5 Side Intake

The intake must be designed with an inflow velocity of approximately 1.0m/sec and under. The intake sill height should be approximately 1 m higher than the sill height of the sand flush gate to prevent the entry of sediment into the waterway. A screen with bars spaced between 5 cm to 15 cm is to be set in the front of the intake. At the junction of the waterway, a control gate (a stop log may be substituted for it in the case of the small scale hydropower plant) is provided to adjust the discharge and to close the waterway for inspection and repair.

The cross section from the intake to the waterway should be clear of sudden changes to minimize the head loss.

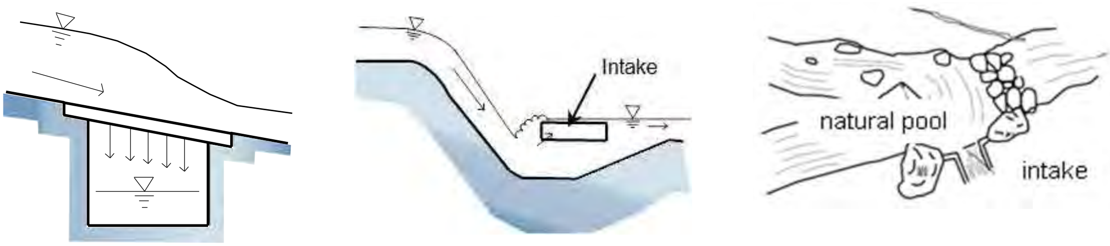
2) Tyrolean intake method

The Tyrolean intake method collects river water from a channel constructed across the river as shown in Figure 9-3 and 9-6. Screen bars are placed at the upper part of the intake, and in the same direction as river flow.

3) Other intake method

Other intake methods are water cushion type and weir-less type. (See Fig. 9-6)

The intake of water cushion type is installed at the level where water level rises due to water cushion. Weir-less type utilizes natural topography forming a natural pool.



Tyrolean type (Cross section)	Water cushion type (Section)	Weir-less type (Plan)

Figure 9-6 Tyrolean intake and other simplified intake types

(3) Omission of intake gate

In the case of the small scale hydropower plant, the headrace is usually an open channel, a covered channel or a culvert. When one of these types is employed, it is essential to avoid an inflow which exceeds the maximum plant discharge (for example, during flood), as it will directly do damage to the headrace. However, the use of an automatic control gate for the small scale hydropower plant results in an increase in construction cost. The following method is a possibility to control the inflow at the time of flooding without the use of the gate.

1) Consideration for designing

This method is to design the intake so as to function as orifice with a rise of river water level during flooding. This method is often used for the Tyrolean intake.

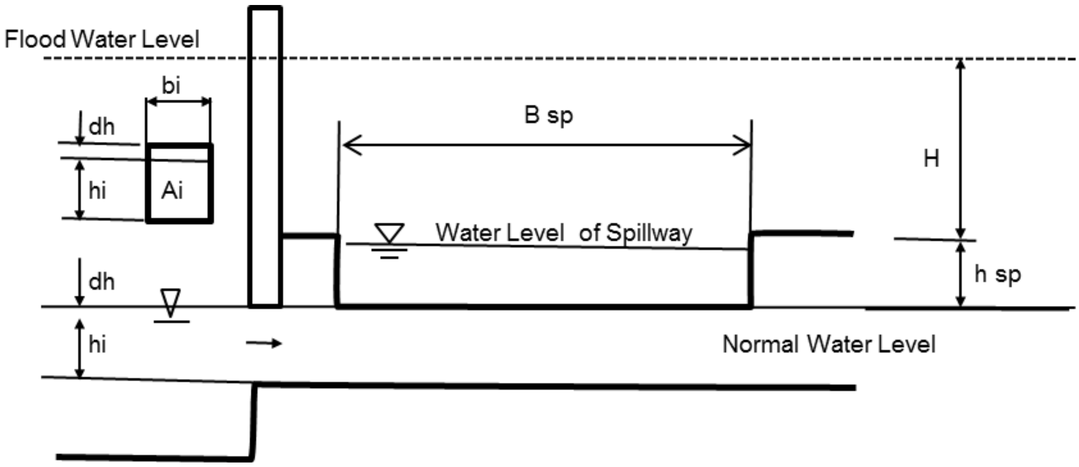


Figure 9-7(1) Water levels for designing

The important points for designing are listed below:

- The upper part of the intake is to be designed as a closed structure instead of an open structure so that it becomes a pressure intake when the river water level rises.
- The intake should be placed at as right angles as possible to the river flow so that the approaching velocity head can be minimized at the time of flooding.

- As a water inflow at the time of flooding exceeds the design discharge, the spillway capacity of the settling basin or at the starting point of the headrace should be fairly large.

The inflow during floods is to be calculated by trial and error with regard to the following conditions:

- Velocity at the sectional area of the intake should be lower than 1m/sec during the maximum plant discharge. At that time, the clearance needs to be 10 – 15 cm.
- Regarding the water level downstream of the orifice, the overflow depth should be calculated estimating the overflow length of the spillway. Design spillway discharge is to be an entire inflow assuming that the power generation stops.

The inflow from the orifice is calculated by the following formula:

$$Q = A_i \times C_v \times C_a \times (2 \times g \times H)^{0.5}$$

where,

Q	: Submerged orifice inflow (m^3/sec)
A_i	: Intake area (m^2) $Ai=bi \times (dh+hi)$, d_h=0.10~0.15m
h_i	: Water depth at the intake opening (m)
b_i	: Width of the intake opening (m)
d_h	: Clearance between highest water surface and top of the intake (m)
C_v	: Velocity coefficient: $C_v=1/(1+f)^{0.5}$
f	: Inflow loss coefficient (see the Figure below)
C_a	: Contraction coefficient (approximately 0.6)
g	: Gravity acceleration (9.8m/sec^2)
H	: Difference in water level between upstream and downstream of orifice during a flood (m)

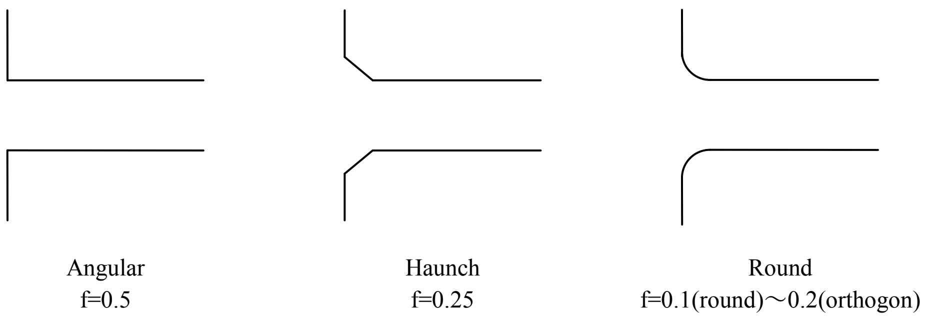


Figure 9-7(2) Inflow Loss Coefficient

9.3 Settling Basin

Sediment concentration of river water increases substantially during floods. In the case of the hydropower plant of waterway type, sediment deposits in the waterway and chokes its sectional area. It is also a cause of wear and tear of the penstocks and turbines. To settle and flush this sediment, it is necessary to construct a settling basin close to the intake.

The settling basin should also have a spillway to prevent an excess inflow of water into the headrace.

The basic configuration of a settling basin is illustrated in Figure 9-8.

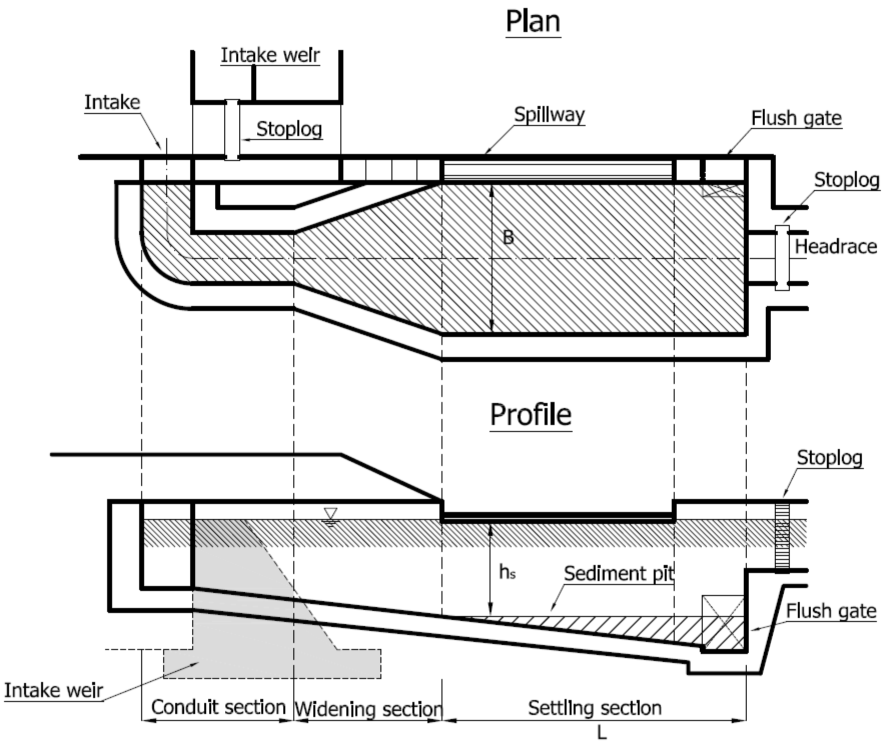


Figure 9-8 Settling Basin

(1) Widening section

The widening section regulates the water flow from the conduit channel to prevent the occurrence of whirlpools and a turbulent flow and to reduce the flow velocity inside the settling basin to the velocity of 0.3 to 0.6m/sec.

(2) Settling section

The settling section functions to steadily settle sediment over a certain grain size. The minimum length (ℓ) is calculated as below based on the relation between a settling speed, a flow velocity in the settling basin and a water depth.

The length of the settling basin (L) is usually determined by doubling the minimum length calculated by the following formula:

$\ell \geq h_s/v_g \times u$

$L \approx \ell \times 2$

where,

L	: Length of settling basin (m)
ℓ	: Minimum length of settling basin (m)
h_s	: Water depth of settling basin (m)
Vg	: Critical settling velocity for sediment to be settled (m/sec)

usually around 0.1 m/sec for a target grain size of 0.5 to 1mm.

u : Average flow velocity in settling basin (m/sec)

usually around 0.3m/sec, but up to 0.6m/sec can be acceptable in the case where the width of the settling basin is restricted.

$u = Q/(B \times h_s)$

Q	: Maximum plant discharge (m^3/sec)
B	: Width of settling basin (m)

(3) Sediment pit

This is the area in which sediment is deposited. In the river which has substantial sediment, a large area is to be created to reduce the frequency of the removal work.

(4) Spillway

The settling basin spillway is required to release an excess inflow of water.

Especially when the intake control gate is omitted as explained in 9.2(3), the design for an excess inflow of water during floods is required. In this case, the relation between the length of spillway (b) and overflow depth of spillway (h) is as follows.

$h = \{Q_f/(C \times b)\}^{2/3}$

where,

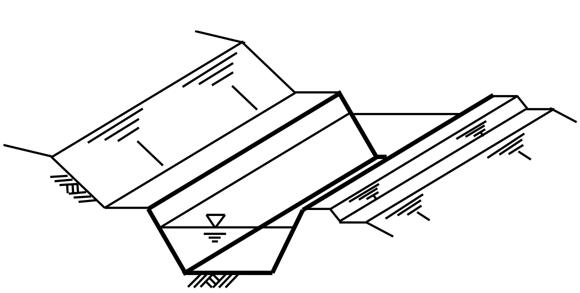
h	: Overflow depth of spillway in the settling basin (m)
Q_f	: Inflow of excess water volume during flood (m^3/sec)
C	: Coefficient of overflow (1.84: coefficient of discharge for sharp-edged full-width weir)
b	: Length of spillway in the settling basin

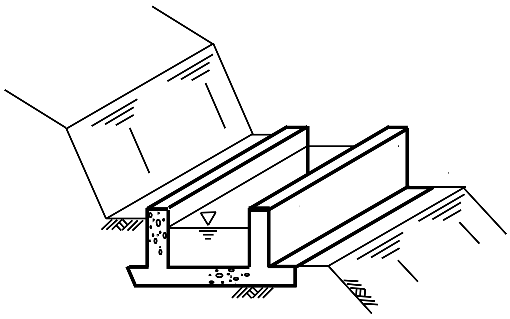
9.4 Headrace

A headrace is a structure to conduct water from an intake to a head tank. It is classified into a non-pressure headrace and a pressure headrace .

In general, a small scale hydropower plant uses a small volume of discharge, and the headrace is usually a non-pressure one which is classified into an open channel and culvert as shown in Figure 9-9. The open channel has types of unsupported channel and concrete channel including wet masonry one. The culvert has types of box culvert channel and pipe channel. As these are generally open structures, topographic features of the waterway route need to be duly surveyed. In addition, the waterway route is basically placed nearly in parallel with a contour line. When the headrace is constructed on the slope of mountain, the gradient of the waterway needs special attention, and the method of passing a stream and/or mountain ridge are also to be examined when selecting a waterway route.

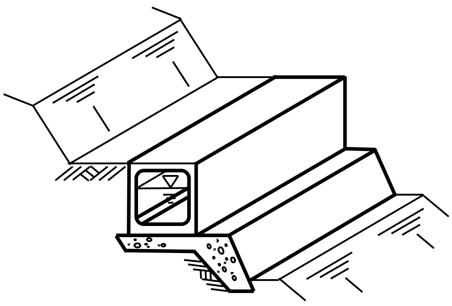
Depending on the topographic conditions, it is sometimes more advantageous to conduct water from a settling basin (cum head tank) directly to a turbine through a penstock without a headrace. Simply, all approaches need to be compared when examining waterway routes.

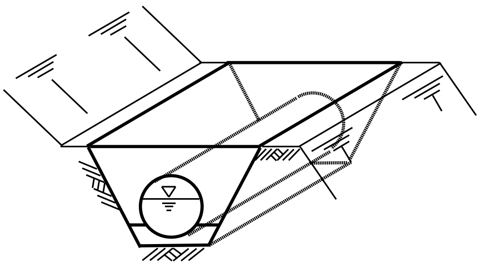




(Unsupported channel) (Concrete channel)

Open channel





(Box culvert channel) (Pipe channel)

Culvert

Figure 9-9 Non-Pressure Waterways

(1) Gradient and cross section of headrace

The cross-section of the headrace channel is determined correlatively with the gradient of the headrace.

When the discharge is fixed, a steep headrace gradienr provides a smaller channel cross section, thereby reducing the headrace construction cost. This is, however, not always economical because the friction loss of the headrace increases and the electricity generated decreases. Conversely, a gentle headrace gradient causes the cross section of the channel to be larger and the energy generation increases due to the decrease in friction loss, however, the headrace construction cost increases.

Therefore, taking into account both the construction costs of the waterway and power output (kW) or energy generation (kWh), the channel gradient and channel cross-sections are to be determined in the most economical way.

In general, the velocity in a headrace is about 1 to 3m/sec and the headrace gradient is 1/500 to 1/1,000. The headrace gradient is to be determined considering the engineering level of the local surveyors and contractors.

(2) Discharge in headrace

Manning's formula is generally used to calculate the discharge in the headrace.

$$V = 1/n \times R^{2/3} \times I^{1/2}$$

$$Q = V \times A$$

where,

- V : Average velocity in headrace (m/sec)
- n : Coefficient of roughness
- R : Hydraulic radius (m) ($R = A/S$, S: Length of wetted perimeter (m))
- I : Hydraulic gradient of headrace
- Q : Discharge (m^3/sec)
- A : Cross-sectional area of flow (m^2)

Table 9-1 Manning's Roughness Coefficient (Reference)

Lining material	n
Unlined waterway (artificial waterway dug in deposit ground)	0.017～0.025
Wet masonry waterway (waterway lined with stones on both banks)	0.025
Concrete waterway	0.013～0.018

Source: Homma and Ogiwara, "Keiryo Keisanho (new edition)"

9.5 Head Tank

A head tank supplies water when the power plant load increases rapidly, and absorbs excess water when the load decreases. The head tank regulates accordingly the difference of flow between the penstock and the headrace due to load change. It also settles and removes sediment from the running water to prevent turbine damage.

Besides the main structure, the head tank has other attached facilities, such as the regulating gates, sand flush gates, screens, air supply pipes and other fixtures.

When designing the head tank, the following points are to be considered.

i) Avoidance of sudden changes in the cross-section to prevent the vortex of water flowing into the head tank.

ii) To remove sediment in the head tank, a 1/15 to 1/50 downward gradient is used for the bottom. A groove is provided at its end and a flush gate is attached to wash out the sand.

iii) To prevent a sand inflow to the penstock, the elevation of the inlet sill of the penstock is 1.0 to 1.5 m higher than the lowest part of the head tank.

iv) The front of the intake sill is provided with a trash screen.

v) The spillway channel is designed to safely release the maximum plant discharge at full load interruption.

Also, with regard to the design of head tank, the following matters in particular are to be noted.

(1) Volume and water surface area of head tank

The volume of a head tank is to be usually equivalent to 1 to 2 minutes plant operation of the maximum plant discharge. However, when an electric governor or a dummy load governor is used for the operation of power plant, the head tank can have a smaller volume.

To minimize the change of the water level of the head tank, the water surface area (As) is to be approximately 5 to 10 times as much as the maximum plant discharge.

$$As \geq Q_{max} \times (5 - 10)$$

Where,

As: storage volume per unit height (m^3/m)

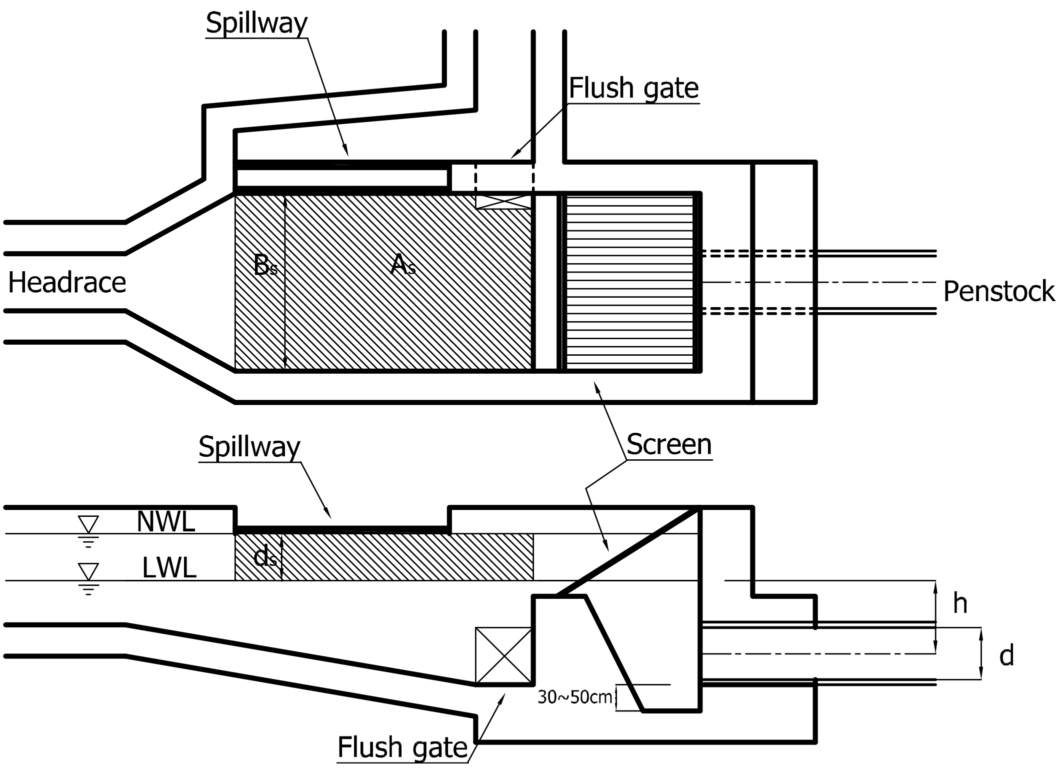


Figure 9-10 Head Tank

(2) Elevation of penstock installation at the penstock inlet point

The minimum water depth at the penstock inlet must be over the following value to prevent the occurrence of inflow turbulence.

$h \geq d$ for the condition of $d \leq 1.0$m

$h \geq d^2$ for the condition of $d > 1.0$m

where,

d : Inner diameter of the penstock (m)

h : Water depth from the center of the penstock to the lowest water level of the head tank (m)

The elevation of bottom edge of the penstock inlet is to be 30 to 50 cm higher than the apron sill of head tank (See Figure 9-10).

(3) Screen bar space for trash rack

The spacing of the trash rack screen bars (effective screen mesh size) is roughly determined by the inlet valve diameter, but is to be finalized in consideration of the type and dimensions of the turbine, and the quantity as well as quality of the trash.

The following provides reference values for an effective screen mesh size.

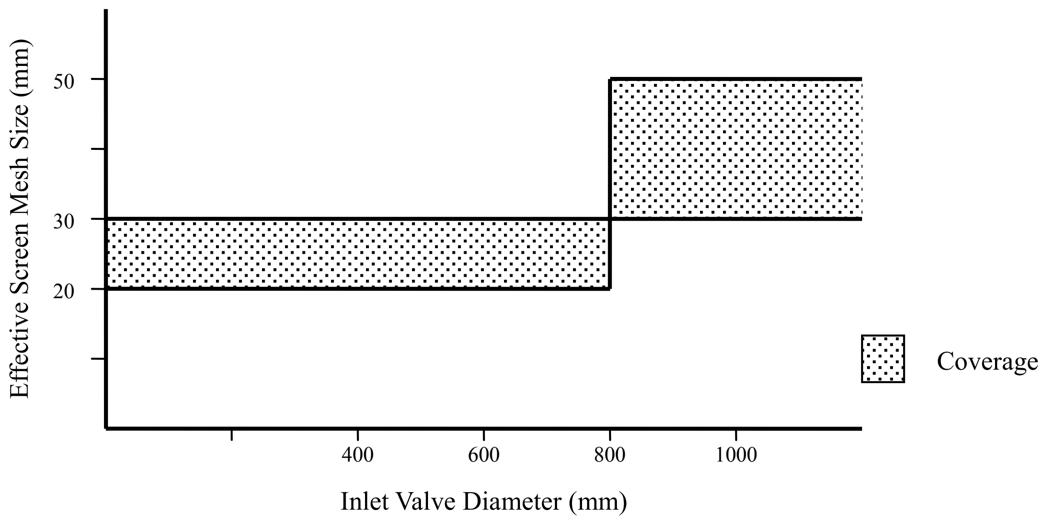


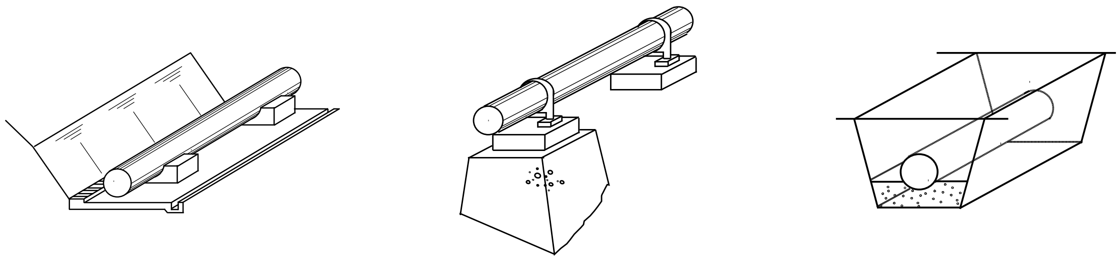
Figure 9-11 Space of the trash rack screen bars (Reference)

9.6 Penstock

A penstock conducts water from a head tank to a turbine.

The penstock is roughly divided into an exposed type and a buried type as shown in Figure 9-12. In the case of a small scale hydropower plant, as the diameter of penstock is small and the required conditions of foundation are not strict, it is possible to adopt the penstock without a concrete mat and as buried/ or semi-buried type.

A steel pipe is usually used for the material of the penstock. In the case of a small scale hydropower plant, as the diameter of penstock is small and internal pressure is relatively small, FRP(M) (Fiberglass Reinforced Plastic (Mortar)) pipes, ductile iron pipes, spiral welded pipes and hard vinyl chloride pipes can be alternatively used.



Exposed type (normal type) | Exposed type (without concrete mat) | Buried/semi-buried type

Figure 9-12 Penstock

(1) Plan of penstock

1) Expose type

It is desirable that the exposed type of penstock is designed to run straight over a short distance along a ridge with a thin surface deposit and is not affected by landslides etc.

The penstock is fixed in bends with concrete anchor blocks. In general, when a steel pipe is used, the distance of the anchor blocks is usually at 50 to 100 m intervals. In the case of a steel pipe, the straight sections between the anchor blocks are supported by concrete saddles. The support interval is about 3 to 5 times the pipe diameter and, in many cases, it is 6 m.

When joint pipes such as FRP(M) pipe are used, more bends are provided than those of a steel penstock in order to minimize the excavation and to maintain the stability of the natural ground. However, the size of the anchor blocks is smaller than that of a steel penstock, because saddles support the thrust of the inclined pipe's length.

Figure 9-13 Example of Penstock

2) Buried type

This type is used when a pipeline is laid under an existing road or when the water is conducted through a penstock directly from a settling basin (cum head tank) to a powerhouse (turbine) without a headrace. It is possible to design the alignment of the penstock without being much influenced by topological features, but the route with a relatively gentle incline should be selected in order to stabilize loose soil backfilling.

3) Longitudinal alignment

When designing the longitudinal alignment of the penstock, it is inevitable to locate it lower than the minimum hydraulic gradient line (minimum pressure line) to avoid negative pressure in the penstock. Special attention needs to be given to its layout, in particular at the site where the penstock is long compared with the head.

(2) Design of penstock

1) Determining diameter of penstock

When selecting the most economical pipe diameter, the changes in construction cost in relation to pipe diameter and changes in electric power output and energy due to the loss are taken into consideration, in the same way as the most economical headrace cross section is determined as mentioned in section 9.4.

Flow velocity in the penstock is usually 2 to 4 m/sec. In the case of a power plant with a low head, it is generally more economical to increase the pipe diameter and consequently to decrease the velocity as well as head loss. In the case of a power plant with a high head, it is generally more economical to decrease the pipe diameter.

2) Determining thickness of pressured iron penstock

Thickness of pressured iron penstock is calculated by the following formula.

$$t = p \times D / (2 \times \sigma_a \times \eta) + \varepsilon$$

where,

t	: Thickness of pipe (mm), $t \geq 6$ (mm) and $t \geq (D+80)/40$
ε	: Margin for corrosion (mm) (usually 2 mm)
p	: Maximum design water pressure of the target point (N/mm^2)
(design water head: h (m), $p = 0.1h$)	
D	: Inner diameter of pipe (mm)
σ_a	: Allowable tensile stress (N/mm2)
η	: Efficiency of axial joint (plant welding: 80 to 90%, on-site welding: 75 to 90 %)

Table 9-2 Type and Feature of Penstock Pipe

Type	Resin Pipe		Iron Pipe		
	Hard Vinyl Chloride Pipe	FRP(M) Pipe	Steel Pipe	Ductile Iron Pipe	Spiral Welded Pipe
Characteristics	-Most popular material for a pipeline; frequently used for water supply and sewer lines -Effective for a pipeline with a small discharge -Wide variety of ready-made irregular pipes -Often buried due to weak resistance to impact and large coefficient of linear expansion	<FRP pipe> -Plastic pipe reinforced by fiber glass -An exposed pipe that can be made lighter than FRPM pipe with a thinner wall; not subject to external load other than snow <FRP(M) pipe> -Highly rigid pipe reinforced with silica sand mortar that has the same amount of resin as FRP between internal and external surface -Resistant to both internal and external pressure; reliable as penstock material and effective as buried pipe	-Popular choice as penstock for pressure pipes of the typical hydropower plant -Reliable material due to established design techniques	-Often used in agricultural water supply and the industrial water and sewerage sectors -Generally used as a buried pipe although exposed used is also possible -High resistance to both external and internal pressure	-Well proved for use as a penstock pipeline; as an underground pipe on the landscape as spiral welding line hidden -Used as non-pressure pipe and steel pipe piles -Regarding thickness of pipe, negative allowable error (-12.5%)
Maximum Pipe Diameter	Thick pipe: ϕ 300 Thin pipe: ϕ 800	ϕ 3,000	approx. ϕ 3,000	ϕ 2,600	ϕ 2,500
Permissible Internal Pressure	Thick pipe: 0.98N/mm^2 Thin pipe: 0.58N/mm^2	Maxi 2.20 N/mm^2	13.05N/mm^2	approx. 3.92N/mm^2	1.47N/mm^2
Roughness Coefficient	n = 0.009 – 0.010	n = 0.010 – 0.012	n = 0.010 – 0.014	n = 0.011 – 0.015	—
Workability	-Easy design and work due to light weight and wide variety of irregular pipes	-Good workability due to lightweight. On-site welding not required as a specially formed rubber rings are used for pipe connections -Steel pipes are used for irregular sections because of the limited availability of irregular FRP pipes	-Inferior workability compared to FRP pipes	-Inferior workability to resin pipes; twice or more heavy than FRPM pipes	-Inferior workability compared to FRP(M) pipes
Water-tightness	-Good water-tightness; bonding connection is possible	-Water-tightness not an issue; joint connection method is well established	-Water-tightness not an issue; joint connection method is well established	-Good	-No mentionable issues

9.7 Spillway Channel

A spillway channel discharges an overflow from its outlet of a settling basin or a head tank into the river. An open channel, a covered channel, and a pipe conduit (steel pipe, reinforced concrete pipe, reinforced plastic pipe, etc.) are used for spillway channel.

As the spillway channel for head tank is often located on a steep slope, considerations are given to the following items in the design.

i) The spillway channel route and its structure are determined by a survey of the topographic and geologic conditions from the head tank to the river, together with the surrounding environmental conditions.

ii) As the flow in the spillway channel is very rapid in a steeply sloped channel, it could cause an impulse wave or cavitation at bends or at discontinuous parts of the channel, and therefore it should be as linear as possible.

iii) As the water surface may swell due to air intrusion, the cross section of the spillway channel must be designed with due attention to this phenomenon.

iv) In a case where the spillway channel is a pipe conduit, air holes are added at the pipe bends to replenish the air to be carried away by high-speed water flow.

v) Even when the spillway channel is an open type or a covered one, cut-off projections are provided on the bottom of the channel, which are required as well on the anchor blocks of the pipe conduit, in order to prevent the slide and erosion due to leakage of water.

vi) An energy dissipater is constructed at the end of the spillway channel to safely discharge water downstream.

vii) When water from the spillway is discharged directly into the river, due attention is to be paid to its alignment to avoid any negative affect on the river including a scour of the riverbed.

viii) In general, the spillway channel is located adjacent to the penstock. When a stream or gully near the head tank can be used, the spillway channel is shortened, however the route and the location of outlet needs to be considered to avoid scouring the stream or gully by spilling discharge.

9.8 Powerhouse

The powerhouse of the small-scale hydropower plant should have the size and capacity to contain the turbine, generator, switchgear, control panel and ancillary equipment. The placement of the equipment is to allow for easy installation, operation, maintenance, and overhaul.

The powerhouse location is decided by considering the following:

i) A location with a good foundation

ii) Riverside parallel to the river flow and unsusceptible to floods

iii) A location without fear of landslide etc.

iv) A location easy for transportation of construction materials and equipment, and future operation/maintenance

Especially, the design flood discharge is to be calculated through a probability analysis and/or a rational formula in order to design the powerhouse coping with the possible water level during floods. It is noted that important information about it can be gathered by interviews with local residents.

An impulse turbine (Pelton turbine, Turgo impulse turbine, Cross-flow turbine, etc.) and a reaction turbine (Francis turbine, propeller turbine, etc.) are generally used for a small scale hydropower plant.

Among these, especially a Cross-flow turbine is used as impulse turbine, and a Francis turbine as reaction turbine.

The following points should be considered when designing the powerhouse.

(1) Powerhouse substructure for impulse-type turbine

In the case of the impulse turbine, as the water that passes through a runner is directly discharged into the tailrace as shown in Figure 9-14, the water flow under the turbine will be turbulent. Therefore, the clearance between the powerhouse slab and water surface at the afterbay needs to be secured at least 30 to 50cm.

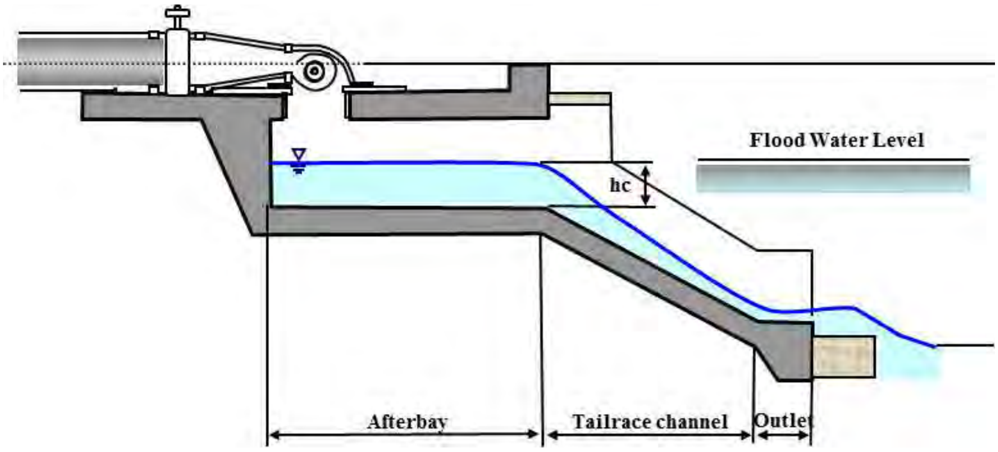


Figure 9-14 Powerhouse substructure for impulse-type turbine

The water depth at the afterbay can be calculated by the following equation.

$$h_c = \{(1.1 \times Q_d^2)/(9.8 \times b^2)\}^{1/3}$$

where,

h_c : Water depth at afterbay (m)

Q_d : Maximum plant discharge (m³/sec)

b : Width of tailrace channel (m)

The water level at the tailrace bay should be higher than the estimated flood water level.

(2) Powerhouse substructure for reaction-type turbine

As a draft tube is used in the reaction turbine, the tail-water level should be designed not to be lower than the outlet of draft tube even during the minimum discharge.

In the case of the reaction turbine, the head between the center of turbine and tailwater level is called draft head (Hs) which is an important factor to determine cavitation phenomenon. The head can be used to generate power for the reaction turbine. The Hs value is described precisely in in Chapter 10. So it is possible to set the tailwater level lower than the design flood water level by installing a tailrace channel gate. In this case, the powerhouse requires a watertight structure and drainage pumps.

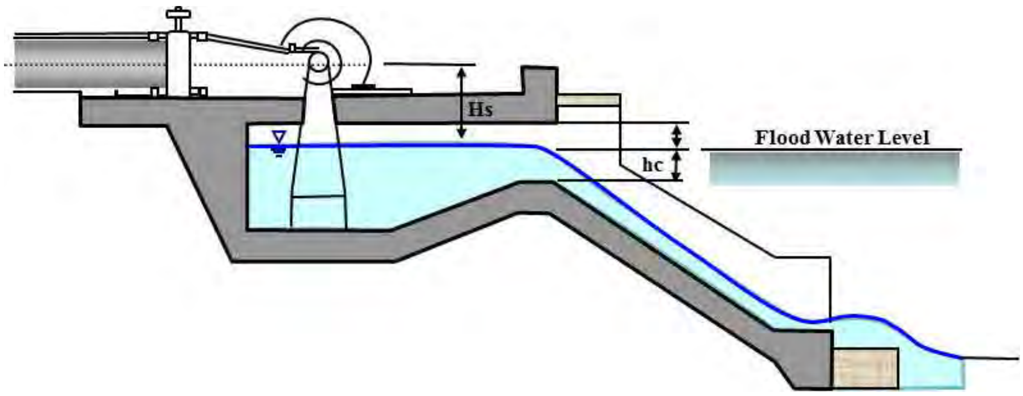


Figure 9-15 Powerhouse substructure for reaction-type turbine

9.9 Tailrace Channel and Tailrace Outlet

A tailrace channel is a part of waterway that conducts the water discharged from the turbine to the river. It consists of afterbay, tailrace channel and tailrace outlet.

The velocity in the tailrace channel is usually set at 1 to 2 m/sec.

The tailrace outlet is the exit to the river and is protected with concrete and/or wet masonry from the river flow and sediment according to surrounding topographic features.

The tailrace outlet location must be selected by considering the following factors.

i) There will be no risk that the exit is blocked by the accumulation of sediment in the river .

ii) The river flow does not directly hit the tailrace

iii) The water level does not rise sharply during floods and there is no riverbed movement caused by floods. There is no risk of the tailrace being damaged by floods.

iv) The river width does not decrease near the downstream of the tailrace outlet.

Reference of Chapter 9

[1] Guidebook on Small-medium scale Hydropower (in Japanese), New Energy Foundation, 1997

[2] Guide Manual for Development Aid Programs and Studies of Hydro Electric Power Projects, New Energy Foundation, 1996

[3] Manual on Distributed Small-scale Hydropower (Draft) in Japanese, Ministry of Economy, Trade and Industry (METI), New Energy Foundation, 2001

[4] Manuals and Guidelines for Micro-hydropower Development in Rural Electrification, Department of Energy, Philippines, JICA, 2009

Chapter 10

Design of Electro-Mechanical Equipment

Chapter 10 Design of Electro-Mechanical Equipment

10.1 Selection and Design of Turbine

Design parameters such as water levels of intake and tailrace (Maximum, Normal, and Minimum), and maximum generating discharge, etc. are to be selected as shown in Table 10-1 followed by general design for electro-mechanical equipment. The following describes selection and design methods for turbines, generators, auxiliary equipment and electrical circuits.

Table 10-1 Design Parameters for Electro-Mechanical Equipment

Item	Unit	Planned		
Maximum generating discharge	m^3/sec			
Normal effective head	m			
Number of Unit	unit			
Power System Frequency	Hz			
		Maximum	Normal	Minimum
Water level of Intake	EL. m			
Water level of Tailrace	EL. m			

10.1.1 Classification of Turbines

Turbines to be applied for small scale hydropower projects can be classified, according to fundamental mechanism of utilizing water energy, into an impulse turbine and a reaction turbine. Turbine classification can be further organized as shown in Figure 10-1. The electrical designer selects a turbine that can produce as much generating electricity as possible taking into consideration the effective head and available maximum discharge of the project site.

- Hydro Turbine
  - Impulse Turbine
    - Pelton Turbine
    - Turgo Impulse Turbine
    - Cross-Flow turbine
  - Reaction
    - Francis Turbine
    - Propeller Turbine
      - Kaplan Turbine
      - Diagonal Flow Turbine
      - Tubular Turbine (S-shaped, Package Submerged pump Type, etc)
      - Straight Flow Turbine

Figure 10-1 Classification Tree of Turbine

(1) Impulse turbine

In an impulse turbine, water having the pressure head is ejected from the nozzles to convert all of its energy into the velocity head, and the turbine runner is driven by the velocity of the water jet.

(2) Reaction turbine

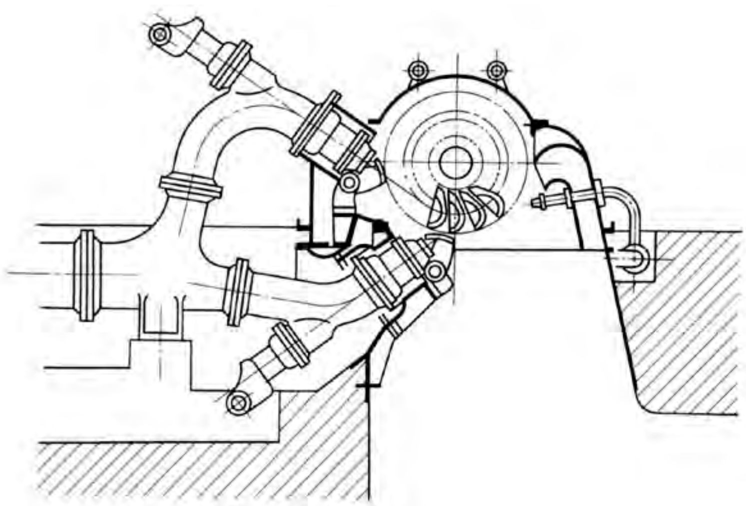
In a reaction turbine, water having the pressure head acts on the turbine runner and the water pressure drives it directly.

(3) Pelton Turbine

A Pelton turbine is classified into an impulse turbine. High velocity water that jetted from the nozzle is made to collide with the bucket arranged in the runner outer part, and this reaction force is used as a rotating torque. Revolving speed of the turbine can be regulated by adjusting the discharge through the opening of the needle valve of jet nozzle, or by adjusting the direction of jet water with the deflector so as not to collide with the bucket.

Pelton turbines are generally applied to the head of 200m and over. In recent years, for small scale hydropower, they have also been adopted for the less head than that, in a case where it is difficult to apply a Francis turbine because of too low a river flow, or in a case where there is too wide a variation in river flow. Now the minimum head of Pelton turbines is as low as 75m. The Pelton turbine reduces its efficiency significantly when the head changes, but it can regulate the output efficiently by changing the operating number of nozzles when the river flow changes. Therefore the Pelton turbine is suitable for a run-of-river type hydropower plant with small variations in the head and wide variations in the plant discharge. The coverage of small scale hydro- Pelton turbines is roughly as follows.

Generating output : 100~5,000 (kW)
Discharge : 0.1~3 (m^3/sec)
Effective Head : 15~500(m)



Source: JIS-B0119 Hydraulic turbines and reversible pump turbines-Vocabulary

Figure 10-2 Horizontal Pelton Turbine(2 Jet Nozzles)

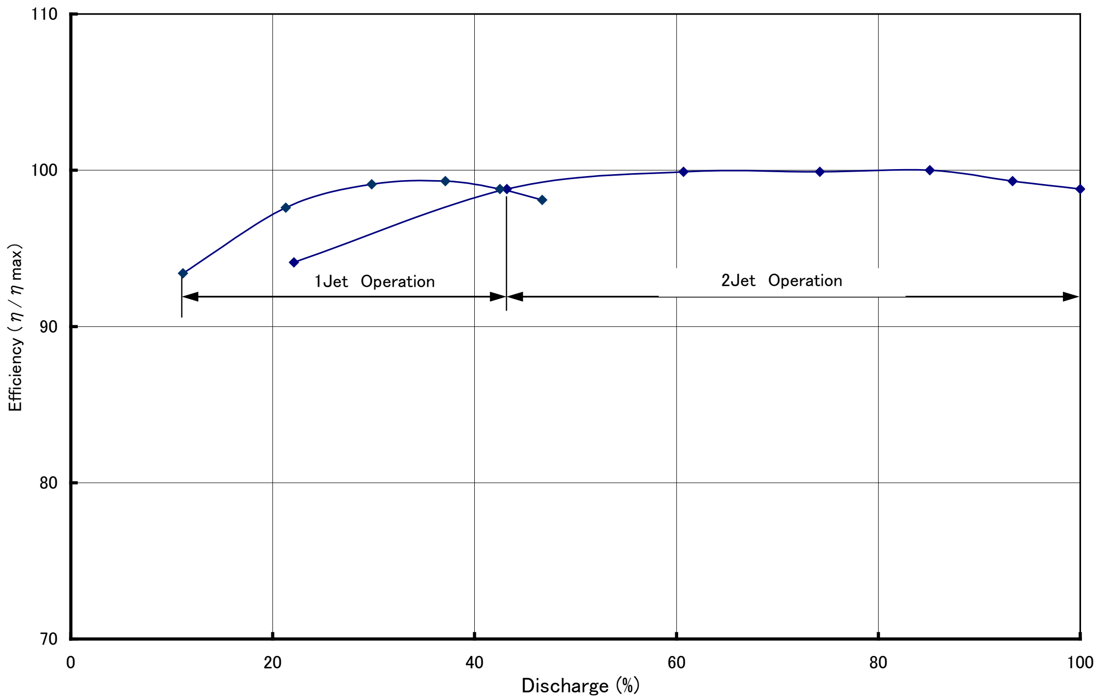


Figure 10-3 Efficiency vs. Discharge of Pelton Turbine (at 1 to 2 Jet Operation)

The horizontal Pelton turbine has generally one or two nozzles. Even if the turbine has been designed as a 2 jet nozzle type, a single nozzle operation technology is developed in response to a low river flow in the dry season, which ensures efficient operation at low flow rate as well.

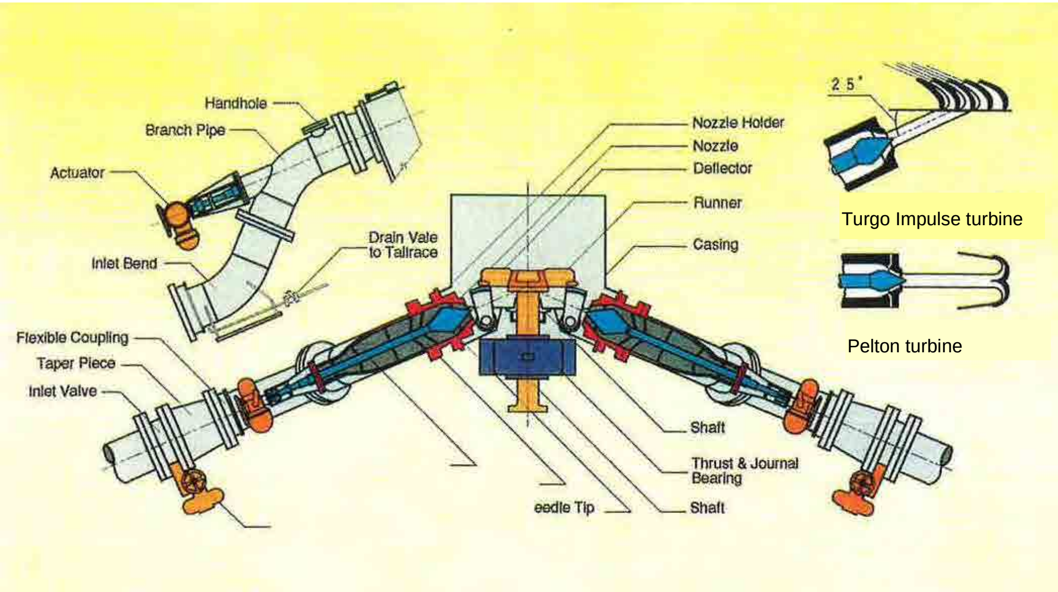
Water jetted from the nozzles collides with the Pelton turbine runner in the air. Therefore, the installation height of the Pelton runner must always be higher than the tailrace water surface. The difference between the tailrace water surface and the Pelton turbine runner center is a head loss and it is not utilized for generation. It is advantageous on this point to set the installation height of the turbine as closer to the tailrace water surface as possible, however, it is necessary to keep a safe height not to have the turbine runner inundated during floods.

The Pelton turbine equipped with the deflector, in a case where the control or shut- off of the generator output is required due to a sudden load change or a transmission line failure, can respond to it with the deflector as well by changing the direction of the jet water acting on the turbine runner, by which a similar effect to that by closing the nozzle is achieved. It is also possible for the Pelton turbine to close the plant discharge rather slowly using the deflector. This will mitigate a pressure increase inside the penstock as well as a revolving speed increase in the turbine when the plant discharge is cut off rapidly, which are the problems with the Francis turbine. In addition, a technology to omit the spillway in a head tank has been also developed through the deflector discharge for a considerable period of time. It is said that the Pelton turbine is suitable for a run-of-river hydro generating scheme that has a large effective head and a large change in river flow.

(4) Turgo impulse turbine

A Turgo impulse turbine is classified into an impulse turbine which a British turbine manufacturing company, Gilkes (Gilbert Gilkes & Gordon Ltd.) has developed. The turbine is composed of a runner and nozzles as well as a Pelton turbine. Water jets from the nozzles are diagonally sprayed on three or four blades simultaneously at a flat surface of the runner to drive the turbine runner. Shown in Figure 10-4 is the turbine structure including the relationship between the nozzle and the runner compared with a Pelton turbine. This turbine is used for a hydropower scheme with a little lower head than that for a Pelton turbine. The coverage of a Turgo impulse turbine is roughly as follows.

Generating output	: 100~10,000 (kW)
Discharge	: 0.2~8.0 (m^3/sec)
Effective Head	: 20~250 (m)



Source: Gilkes Co.,Ltd. TURGOIMPULSE TURBINE Catalog

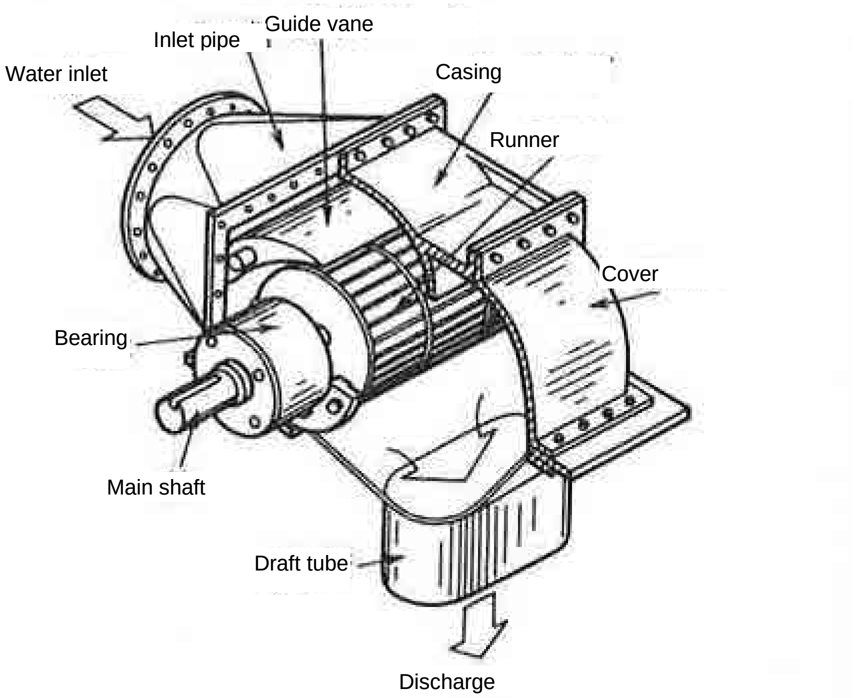
Figure 10-4 Turgo Impulse Turbine(Comparison of Nozzle Flow between Pelton Turbine and Turgo Impulse Turbine)

A Turgo impulse turbine, as compared with a Pelton turbine with the same head and the same discharge, can set a higher revolving speed, which decreases not only the turbine dimension and weight but also the generator weight. As a result it is probable to reduce the overall cost. This turbine, like a Pelton turbine, enables highly efficient operation at a partial load by switching the nozzles, reduction of the water hammer pressure and rotation speed due to a sudden closure of the plant discharge, and the omission of the spillway in a head tank through the deflector discharge.

(5) Cross flow turbine

A cross flow turbine is simple in structure and easy in production to be applied to many cases of small scale hydropower development. This turbine is also called Ossberger turbine from the name of the manufacturer developed. This turbine is suitable for a run-of-river type hydropower plant with the medium to low effective head, and the low plant discharge with a large change in river flow. The coverage of cross flow turbines is roughly as follows.

Generating output : 50~1,000 (kW)
Discharge : 0.1~10 (m^3/sec)
Effective Head : 5~100 (m)

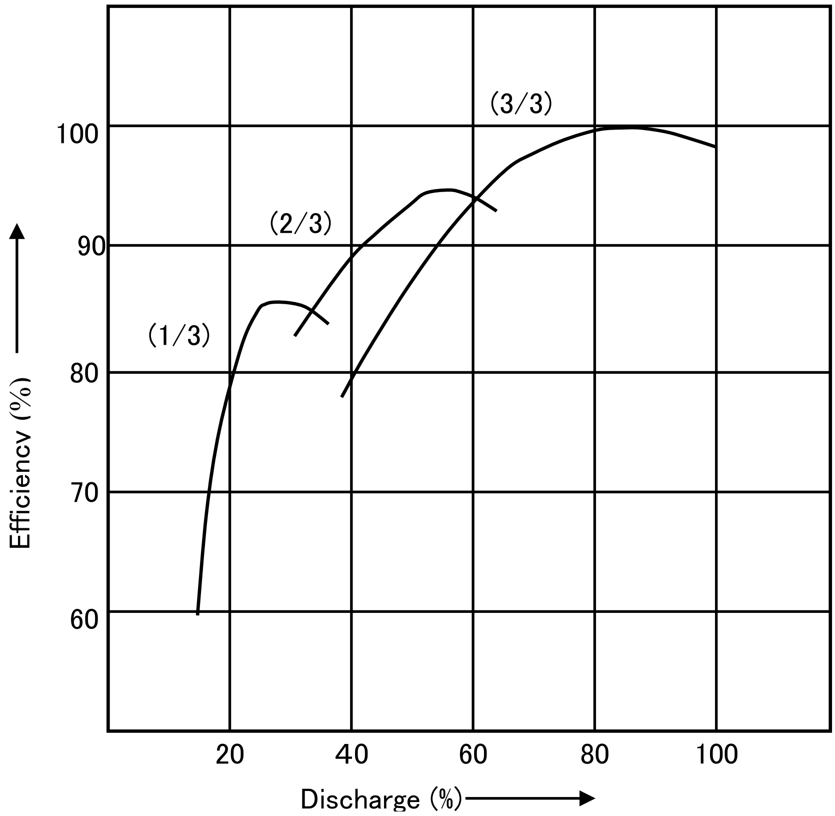


Source : NEF Medium and small Scale hydropower guidebook (5th revised edition)

Figure 10-5 Cross Flow Turbine

A cross flow turbine is featured by easy operation and maintenance from its simple structure, improved efficiency during partial operation with the two-part split guide vanes, and an inexpensive price for the equipment. A water flow from the penstock is adjusted in quantity by the guide vanes and acts on the runner blades before and after running through the center of the runner. The guide vanes 1/3 and 2/ split are manipulated individually in response to the flow and load. As a result, keeping high efficiency for a wide range of the discharge as shown in Figure 10-6, the cross flow turbine can be operated as well as the Pelton turbine under the nozzle switching operation. However, the maximum efficiency of cross flow turbine is approximately 80% regardless of the specific speed.

A cross flow turbine is classified into a impulse turbine and the installation height of the runner must always be higher than the tailrace water surface like a Pelton turbine. The runner length and diameter ratio (aspect ratio) of the cross flow turbine is larger in proportion to the specific speed. Therefore, if a designer selects a large specific speed for the cross flow turbine, the long runner may pose the problems of deflection etc., which needs to be carried out carefully.



Source : NEF Medium and small Scale hydropower guidebook (5th revised edition)

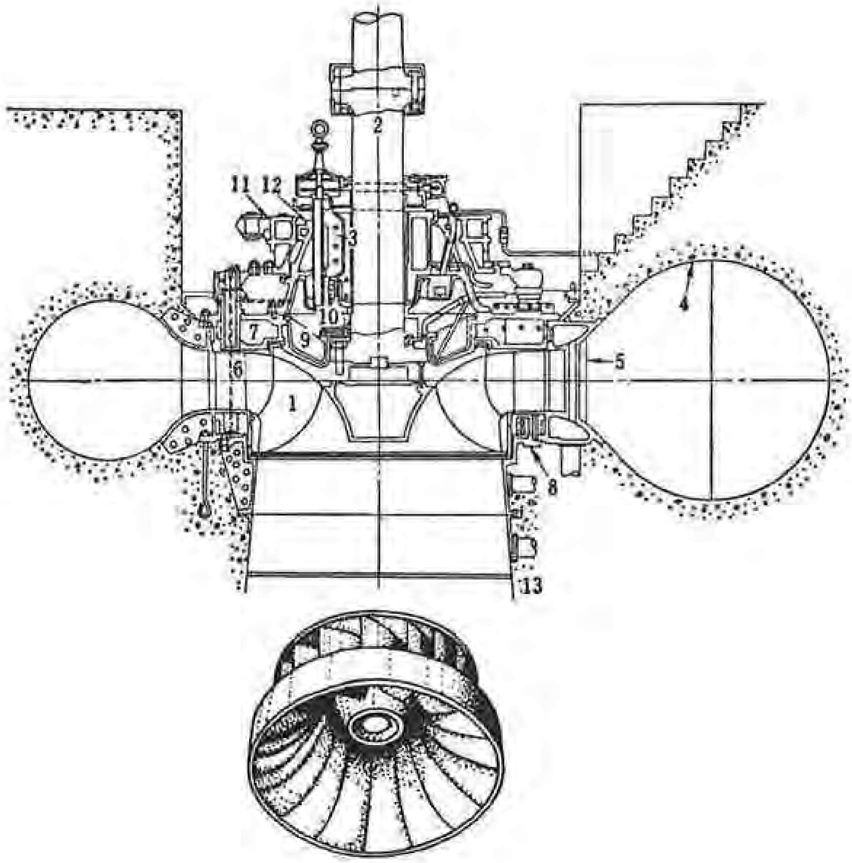
Figure 10-6 Cross Flow Turbine Efficiency with two Guide Vane Paces

(6) Francis turbine

A Francis turbine is the most popular hydro- turbine, which has been used for a wide range from large to small capacity and from a high to low effective head. Because the structure is simple, a Francis turbine has often been adopted for a small scale hydropower generation scheme.

Water flows from the entire periphery toward the center of the runner in a spiral casing, rotates the runner, runs through a draft tube and leads to the tailrace. The Francis turbine is always filled with water from the turbine inlet to the draft tube, and unlike the Pelton turbine, it can utilize effectively the head from the turbine runner to the tailrace water surface. This turbine has both types of vertical shaft and horizontal one. Often used for small scale hydropower development is a horizontal Francis turbine. A Francis turbine has been used for many schemes and is under study for the standardization of the design by the manufacturers. In recent years, due to the advancements in a computer-based flow analysis technology, a low load runner with improved efficiency during partial operation is being developed rather than the improvement of the maximum turbine efficiency itself. The coverage of Francis turbines is roughly as follows.

Generating output : 100~5,000 (kW)
Discharge : 0.3~20 (m^3/sec)
Effective Head : 15~300 (m)



Source : NEF Medium and small Scale hydropower guidebook (5th revised edition)

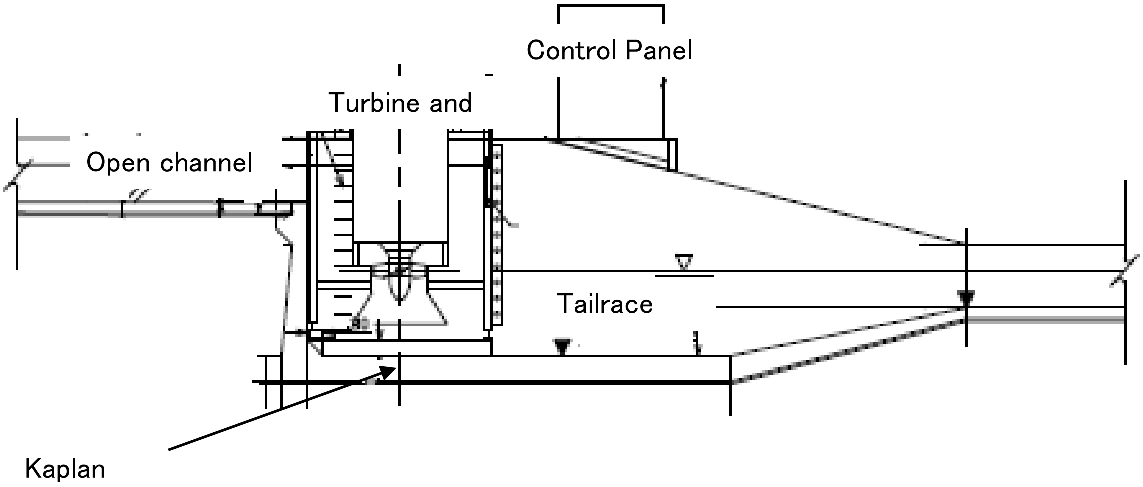
Figure 10-7 Vertical Francis Turbine

(7) Propeller turbine

A propeller turbine is applied in an area of 80m or less low effective head. The shape of runner looks like a screw of ship, and the runner vanes vary from 3 to10 in less number with the lower head. Water flows axially and drives the turbine runner. A propeller turbine is classified into a Kaplan turbine, a diagonal-flow turbine, a tubular turbine, and a straight flow turbine in terms of structure.

1) Kaplan turbine

A Kaplan turbine is a type of a propeller turbine which can adjust correlatively the opening angles of guide vanes and runner vanes so that optimal efficiency can always be obtained in response to the effective head and plant discharge. This turbine is applied to a range of head from 5m to 80m. Most of the propeller turbine is a Kaplan turbine, some of which exceed 200,000kW. For small scale hydropower, this turbine is not used much because of the complicated structure and the expensive price. In recent years, small capacity Kaplan turbines are applicable in which an electric drive mechanism has been developed for the runner vanes.

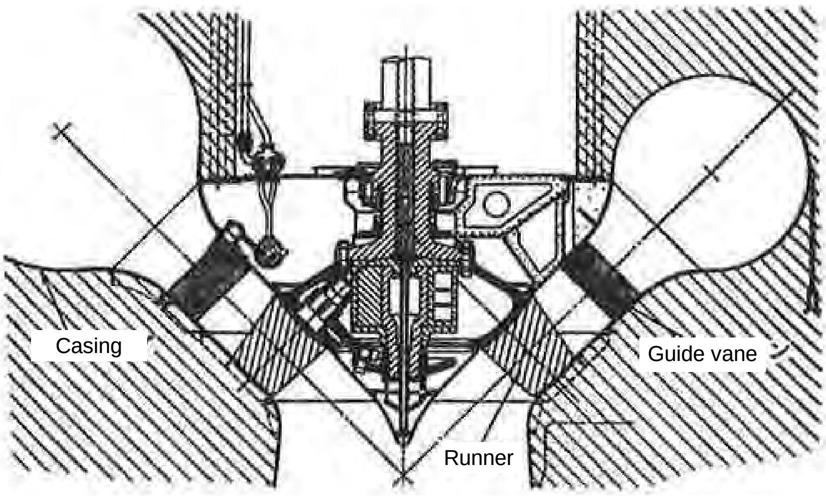


Source: Hydro Aguri turbine construction plan document

Figure 10-8 Propeller Turbine (Kaplan Turbine)

2) Diagonal-flow turbine

Another type of a propeller turbine, in which the axis of the runner blades is diagonal with the main shaft, is called diagonal flow turbine. The runner blades and the guide vanes are generally adjustable like Kaplan turbine in response to the effective head and discharge. This turbine is applied to approximately 40 to 130m of effective head, some of which exceed 50,000kW. For small scale hydropower, this turbine is hardly used because of the too much complicated structure and the expensive price.



Source: NEF Medium and small Scale hydropower guidebook (5th revised edition)

Figure 10-9 Diagonal-Flow Turbine

3) Tubular turbine

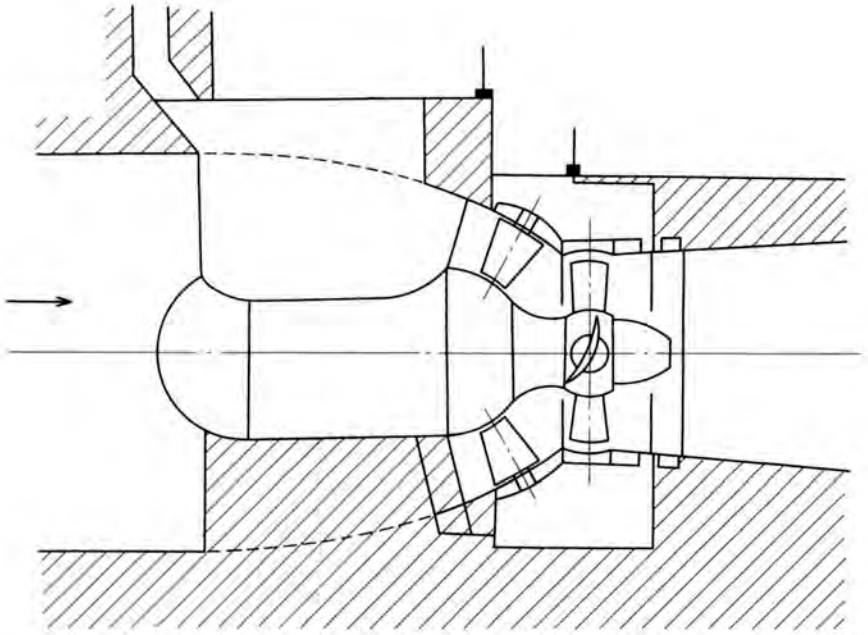
One of propeller turbines that have a cylindrical casing (tubular) instead of a spiral casing is called a tubular turbine. This turbine is applied to the range of low effective head from 3 to 25m, the output of which varies from a few hundred kW to more than 60,000kW. The large capacity tubular turbine is equipped like Kaplan turbine with an adjustable system of guide vanes and runner blades in response to the effective head and plant discharge. .

(a) Bulb turbine

This is one of tubular turbines which install a generator inside the bulb in a waterway. This turbine is often applied to the low effective head generating scheme, the output of which varies from a few hundred kW to more than 60,000kW. The coverage of a bulb turbine for a small scale hydropower scheme is roughly as follows.

Generating output : 100~5,000 (kW)
Discharge : 3.0~40 (m^3/sec)
Effective Head : 3~18 (m)

A diameter and a flywheel effect of the generator are restricted due to its installation in the bulb in the waterway. In addition, a cooling system may be required in order to release the heat from the generator.



Source: JIS-B0119 Hydraulic turbine and reversible pump turbines-Vocabulary

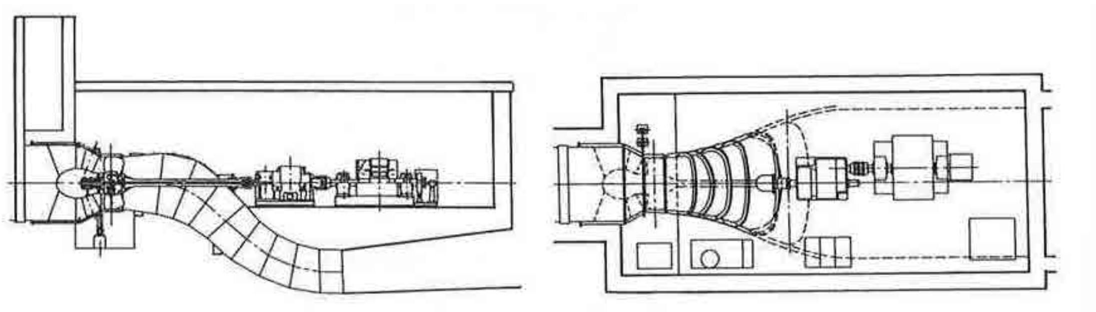
Figure 10-10 Bulb Turbine

(b) S shaped tubular turbine

S shaped tubular turbine is to be applied for the scheme of large change in the water flow and low effective head, the coverage of which is shown below.

Generating output : 50~5,000 (kW)
Discharge : 1.5~40 (m^3/sec)
Effective Head : 3~18 (m)

S shaped tubular turbine has a S shaped waterway in order to install the generator outside the waterway. The runner part is the same structure as other tubular turbines. But the turbine shaft penetrates the channel to be connected to the generator located above the draft tube with S shaped bend. This configuration has advantages in easy maintenance easy installation works for flywheel, speed-up gear, etc., and almost no restriction on the generator design, compared with other tubular turbines to have a generator installed in a tube or a bulb.



Source : NEF Medium and small Scale hydropower guidebook (5th revised edition)

Figure 10-11 S Shaped Tubular Turbine

(c) Vertical Shaft tubular turbine

A vertical shaft tubular is a S shaped tubular turbine installed vertically (or diagonally), and the basic performance and turbine structure are the same. The application area of the turbine is shown below.

Generating output : 100~2,000 (kW)
Discharge : 2~20 (m^3/sec)
Effective Head : 5~18(m)

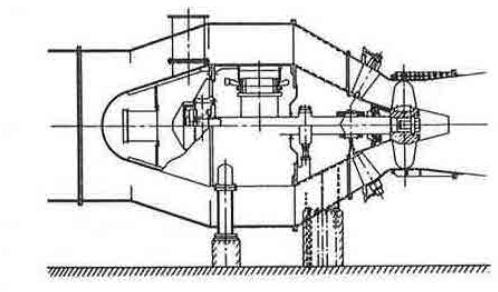
By adopting the vertical shaft tubular turbine, a generator and a speed-up gear can be placed on the top of the cylindrical casing, which may reduce the size of power plant building. In recent years, there has appeared an example of a new technology where the bulb turbine coupled with the elbow draft tube is installed in a vertical position for the purpose of reducing the power house dimensions.

(d) Package Bulb turbine

A package bulb turbine is classified into a Bulb turbine, and they are the same structure. A package bulb turbine is applied to a small capacity bulb turbine. Here, a channel, a bulb, a generator, a turbine, and support structures are integrally assembled into a unit in a factory, which is to be joined to the waterway with a flange in the construction site. Thus, the package bulb turbine is aimed at shortening the construction period, streamlining civil works, and saving installation space. It is suitable for a relatively low head and large discharge scheme and is applied to the idle head of water lines such as waterworks, industrial water service, etc. The application area of the turbine is shown below.

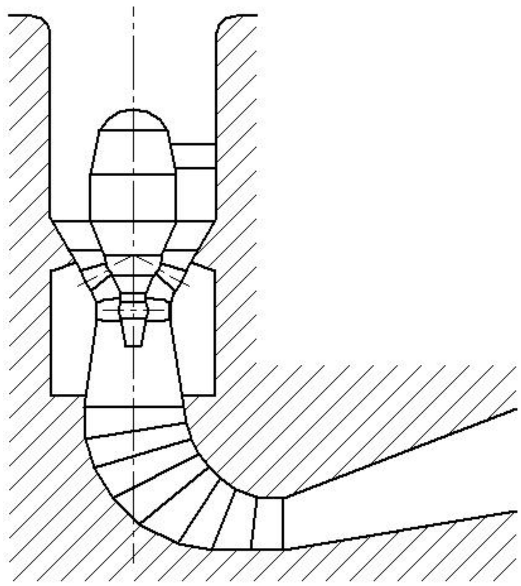
Generating output : 150~3,500 (kW)
Discharge : 4~25 (m^3/sec)
Effective Head : 4~20 (m)

A diameter and a flywheel effect of the generator are restricted due to its installation in the bulb. In addition, a cooling system (such as groove or corrugation) may be required to release the heat from the generator.



Source : NEF Medium and small Scale hydropower guidebook (5th revised edition)

Figure 10-12 Packeage Bulb Turbine



Source: JIS-B0119 Hydraulic turbine and reversible pump turbines-Vocabulary

Figure 10-13 Vertical Shaft Tubular Turbine

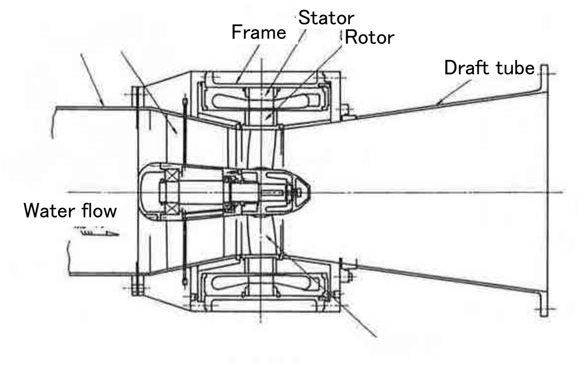
(e) Straight Flow turbine

It is a water turbine which has been adopted for a long time historically in Europe when there is a relatively large river flow and a low effective head. It is the structure that a generator is installed in the outer periphery of the runner of tubular turbine. Because a generator is installed outside of the waterway, it is advantageous in easy maintenance, no restriction on the flywheel effect, and a compact plant building compared with bulb turbine and Kaplan turbine. Each set of seal devices is necessary at the outer periphery of the turbine upstream and downstream between fixed parts of the turbine and the peripheral ring where a generator rotor is set. This is disadvantageous in its technical difficulty coping with a high circumferential speed of the generator rotor, and the time-consuming maintenance works. The improvement of seal materials has recently been advanced, and an adjustable runner vane system of the straight flow turbine has been developed. An application area of the straight flow turbine spreads to 20,000kW in output and 120m^3/sec in discharge.

An integrated water turbine generator has been developed for a small scale hydropower scheme by adopting an induction generator and omitting the outer ring seal systems. An application area of the integrated water turbine generator is shown below.

Generating output : 10~600 (kW)
Discharge : 0.5~4.0 (m^3/sec)
Effective Head : 3~20 (m)

The turbine of this type has fixed guide vanes and runner vanes, and it may be necessary for a few turbines to be installed to respond to the varying discharges by operating number of units. A start- up and a stop of this turbine are controlled by either inlet valve or intake gate.



Source : NEF Medium and small Scale hydropower guidebook (5th revised edition

Figure 10-14 Straight Flow Turbine

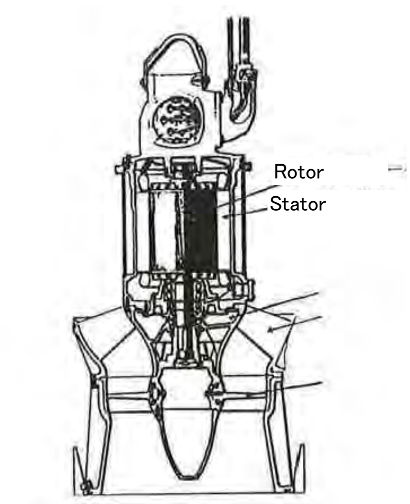


Figure 10-15 Submerged Pump-Type Turbine

(f) Submerged pump-type turbine

A Submerged pump-type turbine is compact in structure encasing an induction generator, speed- up gear, and a fixed runner vane propeller turbine without guide vanes. This turbine is also called Flygt turbine from the name of the manufacturer developed. An application area of the turbine is shown below.

Generating output : 30~850 (kW)
Discharge : 0.4~10 (m^3/sec)
Effective Head : 2.5~20 (m)

Being compact and modularized, this turbine does not need the complicated turbine control. If a waterway from an intake to a tailrace is modularized and manufactured in a factory, and then it is possible for all the components including a turbine and a generator to be assembled in the construction site as a prefabricated scheme.

The turbine of this type does not have a discharge control system, and another unit is required, where appropriate, to control the varying discharge. When quantity of an available discharge is higher than 2.0m^3/sec, it is possible to adjust it by making the runner vanes movable.

4) Reverse pump turbine

A reverse pump turbine is a ready-made pump used in reverse as a turbine. Consequently this turbine has more limitations on discharge adjustment, efficiency, etc. than one designed as a water turbine. But the procurement and installation cost for the turbine and generator may be reduced. There are examples in which the turbine is combined with an induction generator, or the speed control of the turbine is omitted by the adoption of an inverter. An application area of the turbine is shown below.

Generating output : 1~300 (kW)
Discharge : 0.02~0.9 (m^3/sec)
Effective Head : 6~100(m)

Source: Reverse Pump Turbine Catalog Kubota Corporation

Figure 10-16 Reverse Pump Turbine(Double Suction, Single Stage, Volute Pump)

10.1.2 Turbine Type Selection

The turbine type is selected on the basis of the effective head and turbine discharge, while considering such factors as a river flow, operation of the reservoir and regulating pond (head fluctuation and flow fluctuation) and distributing demand. When two or more turbine types are available, the best one is selected by a comprehensive study of cost, efficiency, maintenance, etc.

Various turbines have limitations on their respective heads and applicable specific speeds. The application range is determined by their adaptability, strength, and characteristics including cavitation with respect to head and discharge variations. Shown in Figure 10-17 below is the coverage of water turbines including the turbines of the foregoing paragraphs. Generally, the Pelton turbine is applied to a high head with a small flow and the propeller turbine to a low head with a large flow. The Francis turbine is applied to a medium to high head with a large to medium flow.

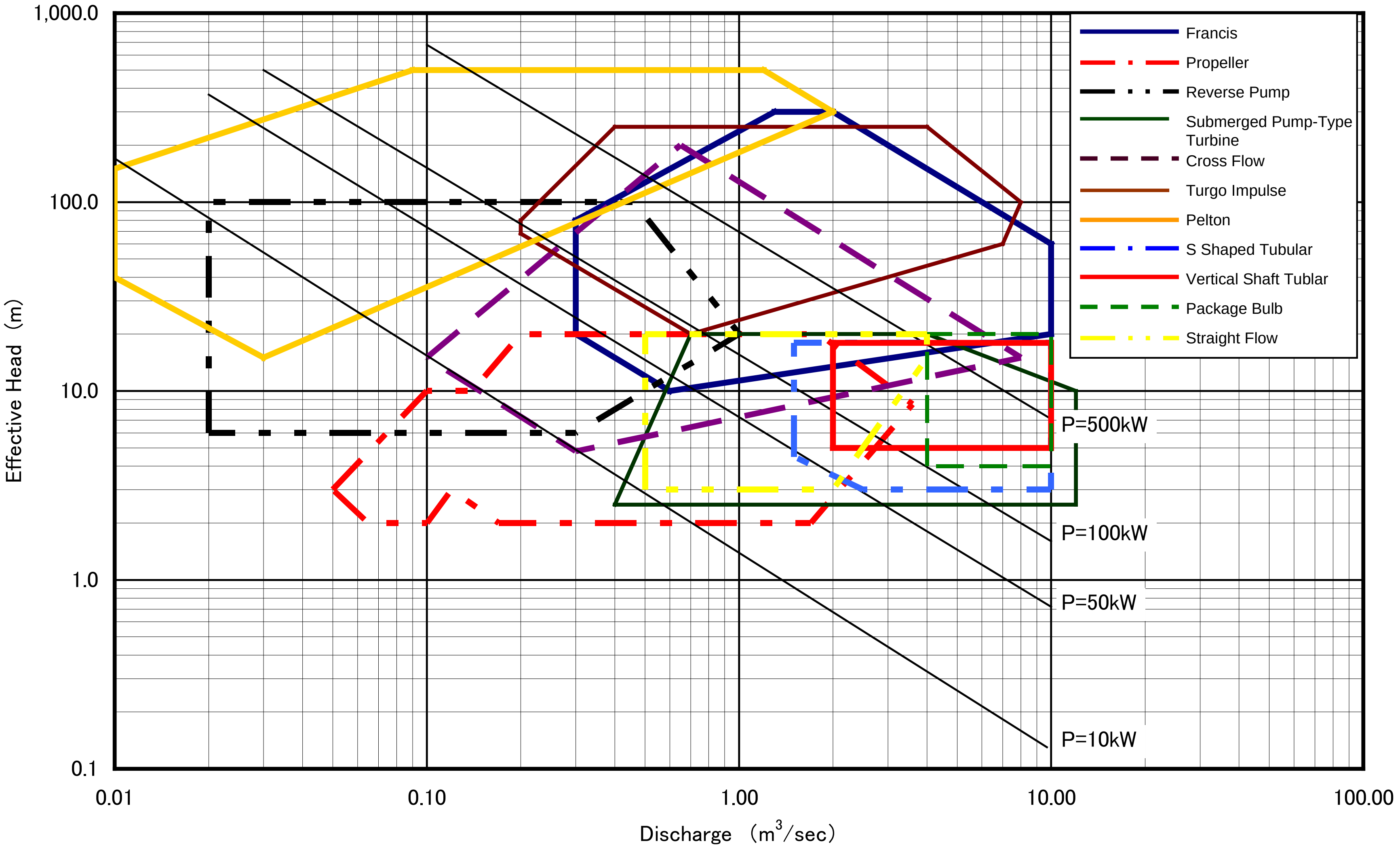


Figure 10-17 The Coverage of Water Turbines

10.1.3 Designing the Water Turbine

The turbine design in a feasibility study stage can be carried out by the following flow.

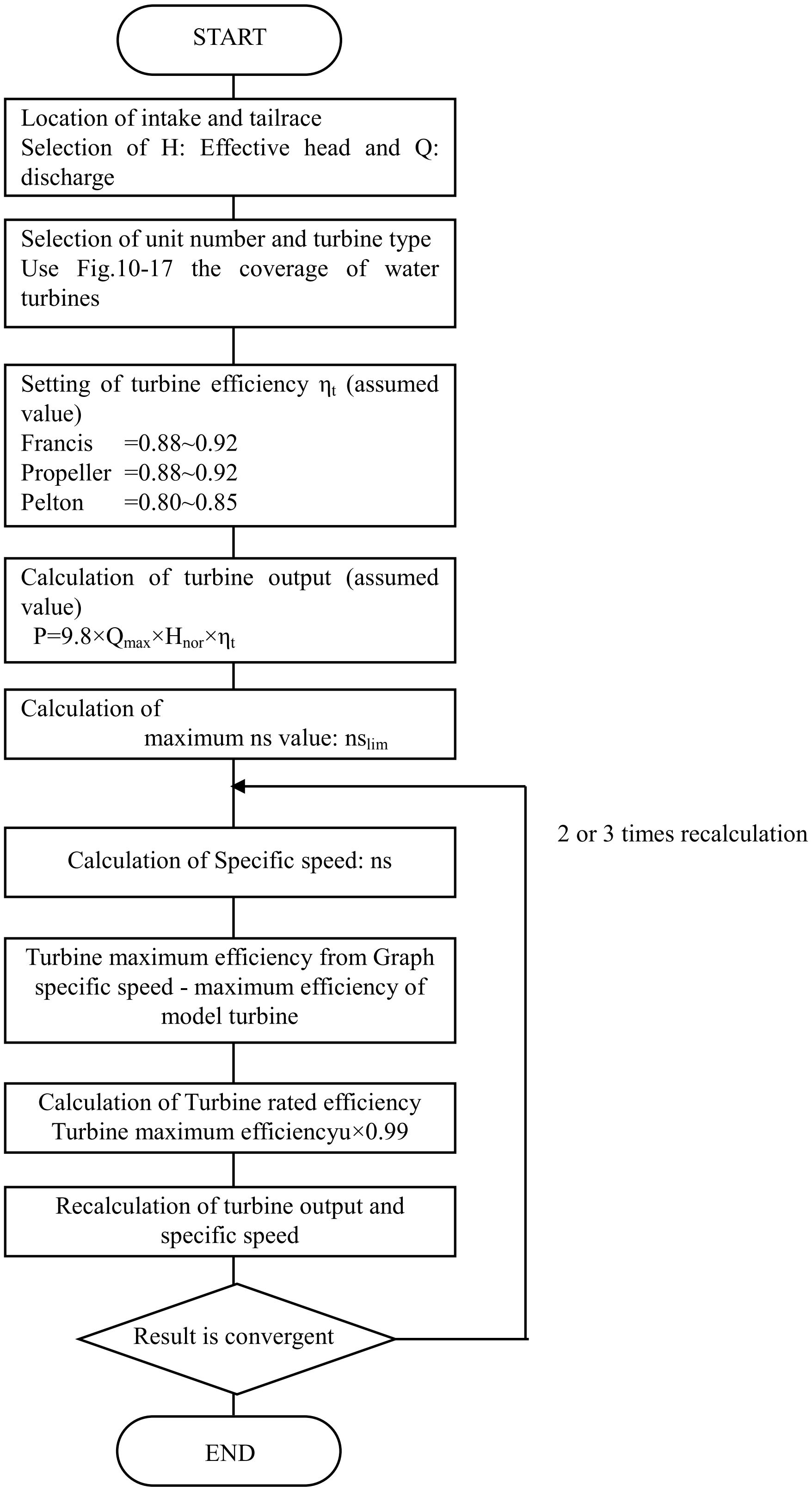


Figure 10-18 The Design Flow of Water Turbines

(1) Set of water turbine output (assumed value)

In the first estimation, it is necessary to set the water turbine output for the calculation of specific speed, rotary speed, and efficiency. Therefore, the designer sets an assumed efficiency shown below for an initial value for each water turbine type, and calculates the water turbine output, specific speed, revolving speed. And the designer recalculates them from calculation results again as needed and improves the accuracy. A theoretical formula for water turbine output is shown below.

$$P_t = 9.8 \times Q_{max} \times H_e \times \eta_t$$

where,

P_t : Maximum turbine output at the effective head H (kW)

Q_{max} : Maximum discharge at the effective head H (m^3/sec)

He : Effective Head (m)

η_t : Water turbine efficiency

Assumed water turbine efficiency

Pelton turbine	: 0.88~0.92
Francis turbine	: 0.88~0.92
Diagonal flow Turbine	: 0.88~0.92
Propeller turbine	: 0.80~0.85

(2) Calculation of the Specific speed of water turbine

The specific speed of a certain turbine is the rotating speed of a hypothetical turbine which is homologous to the original turbine and produces unit output (1kW) under unit head (1m). When the effective head and turbine output are kept constant, it is called the specific speed because this expresses the pitch (small or large) of the revolving speed of the turbine. The specific speed is given by the following formula.

$$ns = n \times \frac{\sqrt{P_t}}{H_e^{5/4}} \qquad n = \frac{ns \times H_e^{5/4}}{\sqrt{P_t}}$$

where,

ns : Specific speed (m-kW)

n : Revolving speed (min^{-1})

H_e : Effective Head (m)

P_t : Maximum turbine output at the effective head H (kW)

Given the head and output, the specific speed is proportional to the revolving speed and the selection of a higher specific speed or higher revolving speed of the turbine makes it smaller together with a generator and a powerhouse building. There is, however, a limit to the specific speed because of cavitation occurrence and equipment strength. The maximum specific speed is given by statistics according to the following formulae.

Pelton turbine $ns \le \dfrac{4,300}{H_e + 200} + 14$

Francis turbine $ns \le \dfrac{23,0\,00}{H_e + 30} + 40$

Diagonal flow Turbine $ns \le \dfrac{21,0\,00}{H_e + 20} + 40$

Propeller turbine $ns \le \dfrac{21,000}{H_e + 16} + 50$

Cross Flow turbine $ns \le \dfrac{4,000}{H_e + 14} + 16$

The maximum output per one runner is used to calculate the above specific speed of the Francis turbine, diagonal-flow turbine and propeller turbine and the maximum output per one nozzle is used for the specific speed of the Pelton turbine. The output defined by the following equation is used for the cross-flow turbine.

$$P_t = \frac{P_r}{B_g / D_1}$$

where,

P_t : The output used for calculation of the specific speed of cross flow turbine (kW)

P_r : Output per one runner (kW)

B_g : Width of the guide vane flow part (m)

D1 : Runner diameter (m)

(3) Calculation of water turbine revolving speed

The designer selects a water turbine type, sets its assumed efficiency and calculates the revolving speed from the maximum specific speed. The revolving speed of water turbine and generator is estimated by the following formula with the frequency of the distributing power system and the number of magnetic poles of the generator except when adopting a speed-up gear or a direct current generator. It is common that the revolving speed is chosen among the standard revolving speeds of a generator shown in Table 10-2, which is originally obtained in terms of the generator design.

$$n = \frac{120 \times f}{p}$$

where,

f : Power system frequency (Hz)

p : Number of Poles

The upper limit of the revolving speed of the water turbine is calculated by the formula below using the maximum specific speed of each water turbine type as shown in the foregoing paragraph. Then the designer chooses a value from the table below which is close to the calculated value.

$$n = \frac{ns_{lim} \times H_e^{5/4}}{\sqrt{P_t}}$$

where,

n : Revolving speed (min^{-1})

P_t : Water turbine output used for calculation of the specific speed (kW)

ns_{lim} : Maximum specific speed (m-kW)

H_e : Effective Head (m)

Table 10-2 The Standard Revolving Speed of a Generator (JEC-4001)

Pole	50Hz	60Hz	Pole	50Hz	60Hz	Pole	50Hz	60Hz
4	1,500	1,800	28	214	257	60	100	120
6	1,000	1,200	30	200	240	64	94	113
8	750	900	32	188	225	70	86	103
10	600	720	36	167	200	72	83	100
12	500	600	40	150	180	80	75	90
14	429	514	42	143	171	84	71	86
16	375	450	48	125	150	88	68	82
18	333	400	50	120	144	90	67	80
20	300	360	54	111	133	96	63	75
24	250	300	56	107	129	100	60	72

Source: IEEJ standard JEC-4001 Hydro turbine and pump turbine

An estimation example is shown below.

Effective head H_e=100 (m)

Maximum discharge Q_{max}=0.5 (m^3/sec)

Turbine Type: Francis

Efficiency ηt=0.9 (assumed)

Turbine output Pt=9.8×Qmax×He×ηt=9.8×0.5×100×0.9=441 (kW)

Maximum specific speed $$ns_{lim} = \frac{23{,}000}{H_e + 30} + 40 = 217(m - kW)$$

Revolving speed $$n = \frac{ns_{lim} \times H_e^{5/4}}{\sqrt{P_t}} = \frac{217 \times (100)^{5/4}}{\sqrt{441}} = 3{,}267\ (min\text{-}1)$$

Therefore, from the standard revolving speeds of a generator of Table 10 -2, 1,800 (min^{-1}) or 1,200 (min^{-1}) becomes the choice candidate of the water turbine revolving speed if it is a 60Hz district, and 1,500 (min^{-1}) or 1,000 (min^{-1}) if it is a 50Hz district. Using the revolving speed selected, the specific speed is calculated again and the estimate of the turbine efficiency is made.

(4) Turbine efficiency estimation (Francis and Kaplan turbine)

The ratio of output and input of the water turbine is called turbine efficiency, and it is given

$$\eta_t = P_t/(9.8 \times Q_{max} \times H_e).$$

where,

Pt	: Turbine output (kW)
Qmax	: Discharge (m3/sec)
He	: Effective head (m)

Generally, in consideration of partial to full load operation, a turbine is designed so that it can attain the highest efficiency at around 80% of the maximum discharge. In this case, the efficiency decreases as the discharge becomes higher or lower than that point. The efficiency curve is different depending upon the turbine type and the specific speed. The relations between the specific speed and model turbine efficiency for each major turbine types are shown in Figure 10-19 to Figure 10-21.

Homologous to the actual water turbine is the model turbine, which is made in a factory after the design of actual turbine for the designer to inspect its hydraulic performance, and validity of the design. Usually a performance curve of the model turbine is organized with respect to effective head of 1m and specific runner dimension of 1m.

By the specific speed calculated from the revolving speed selected from Table 10-2 as explained in a foregoing paragraph, the maximum turbine efficiency is set. The designer reads a maximum turbine efficiency of the similar (the same specific speed) model turbine and converts it into the value of actual planning project with the following conversion formula.

$$\eta_{tmax} = \frac{2 \times (\eta_{mmax} - 0.5(1 - (P_t/H_e^{1.5})^{0.1})}{1 + (P_t/H_e^{1.5})^{0.1}}$$

where,

P_t	: Turbine output (kW)
H_e	: Effective head (m)
η_{mmax}	: Model turbine maximum efficiency
η_{tmax}	: Maximum turbine efficiency

Because it is estimated that the turbine efficiency at the rated output (the maximum output) is at around 0.99 of the maximum turbine efficiency. Then the efficiency at the rated turbine output is given in the next formula.

Turbine efficiency $\eta_t = 0.99 \times \eta_{tmax}$

When water turbine efficiency is estimated, the water turbine output is calculated again. Therefore, the designer recalculates the specific speed and sets the efficiency again in the same way. This procedure is carried out until a value of the turbine efficiency does not change greatly. Calculations are usually done around three times.

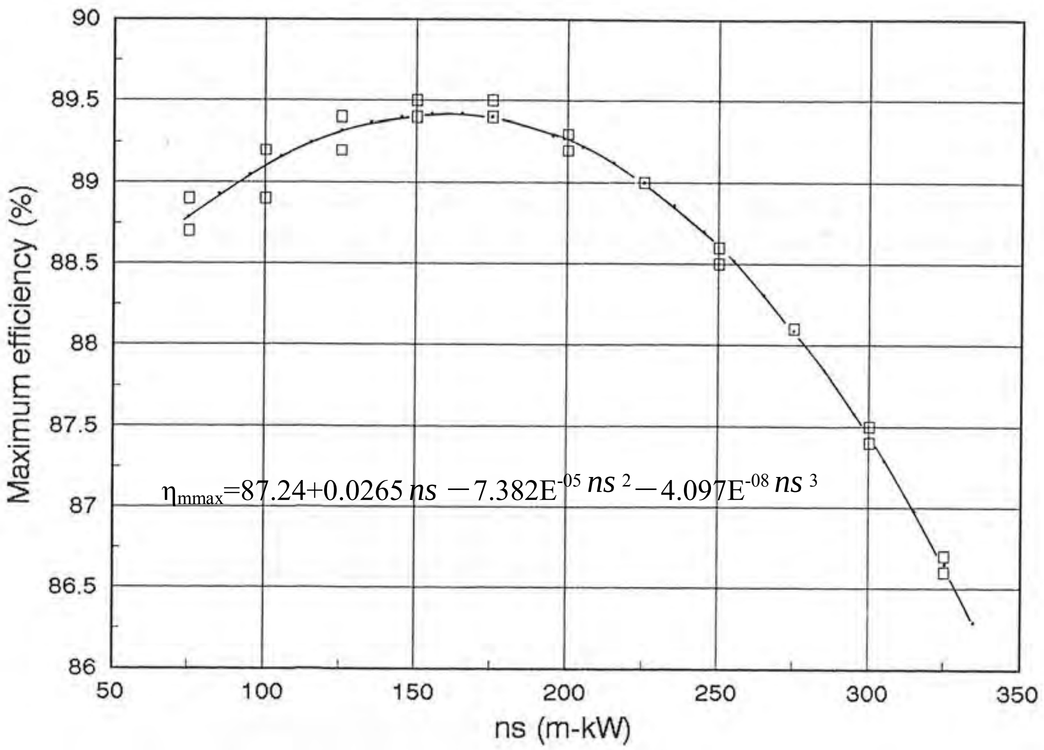


Figure 10-19 Relation of Maximum Model Turbine Efficiency and Specific Speed (Francis Turbine)

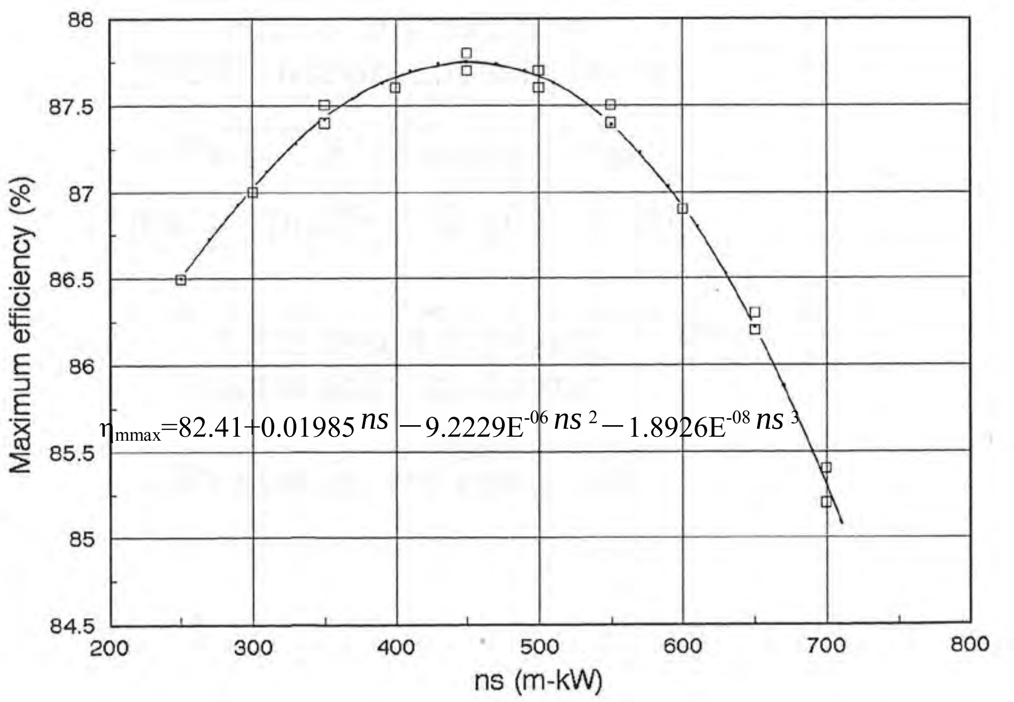


Figure 10-20 Relation of Maximum Model Turbine Efficiency and Specific Speed (Kaplan Turbine)

The estimation example is shown below.

Water turbine type	: Francis
Effective Head	: H_e=100 (m)
Maximum discharge	: Q_{max}=0.5 (m^3/sec)
Efficiency	: η_t=0.9 (assumed)
Frequency	: 50 (Hz)

First calculation,

Turbine output $P_t=9.8\times Q_{max}\times H_e\times\eta_t=9.8\times0.5\times100\times0.9=441$ (kW)

Maximum specific speed $ns_{lim} = \dfrac{23{,}0\,00}{H_e + 30} + 40$ =217(m-kW)

Revolving speed $n = \dfrac{ns_{lim} \times H_e^{5/4}}{\sqrt{P_t}} = \dfrac{217 \times (100)^{5/4}}{\sqrt{441}}$ =3,267 (min^{-1})

Standard revolving speed of 1,500 (min^{-1}) is chosen from the system frequency 50Hz district of Table 10 -2, and calculate specific speed.

Specific speed $ns = n \times \dfrac{\sqrt{P_t}}{H_e^{5/4}} = 1500 \times \dfrac{\sqrt{441}}{100^{5/4}}$ = 99.6(m-kW)

The model turbine efficiency η_{mmax} = 0.899 is given from Figure 10-19. Maximum actual turbine efficiency is converted from the model turbine efficiency.

$$\text{Maximum actual turbine efficiency} \quad \eta_{tmax} = \frac{2\times(\eta_{mmax} - 0.5(1-(P_t/H_e^{1.5})^{0.1})}{1+(P_t/H_e^{1.5})^{0.1}}$$

$$= \frac{2\times(0.899 - 0.5\times(1-(441/100^{1.5})^{0.1})}{1+(441/100^{1.5})^{0.1}}$$

$$= 0.895$$

Rated turbine efficiency $\quad \eta_t = \eta_{mmax}\times0.99=0.895\times0.99=0.886$

Second calculation,

Turbine output $\quad P_t=9.8\times Q_{max}\times H_e\times\eta_t = 9.8\times0.5\times100\times0.886 = 434.1\approx434$ (kW)

$$\text{Specific speed} \quad ns = n\times\frac{\sqrt{P_t}}{H_e^{5/4}} = 1{,}500\times\frac{\sqrt{434}}{100^{5/4}} = 98.8 \text{ (m-kW)}$$

The model water turbine efficiency ηmmax = 0.899 is given than Figure 10-19. Maximum actual turbine efficiency is converted from the model turbine efficiency.

$$\text{Maximum actual turbine efficiency} \quad \eta_{tmax} = \frac{2\times(\eta_{mmax} - 0.5(1-(P_t/H_e^{1.5})^{0.1})}{1+(P_t/H_t^{1.5})^{0.1}}$$

$$= \frac{2\times(0.899 - 0.5\times(1-(431/100^{1.5})^{0.1})}{1+(431/100^{1.5})^{0.1}}$$

$$=0.895$$

Rated turbine efficiency $\quad \eta_t = \eta_{mmax}\times0.99=0.895\times0.99=0.886$ (Convergent)

Because the calculation is convergent, the designed turbine ratings become as follows.

Turbine type	: Francis turbine
Effective head	: H=100 (m)
Maximum discharge	: Q=0.5 (m^3/sec)
Rated turbine Efficiency	: 0.886
Turbine output	: 434 (kW)
Revolving speed	: 1,500 (min^{-1})

(5) Turbine efficiency estimation (Pelton turbine)

The efficiency estimation of a Pelton turbine is carried out by a similar method of a Francis and a propeller turbine. However, a conversion formula from a model turbine to an actual one is different from the above turbines and the specific speed of the Pelton turbine is calculated using the maximum output per nozzle. The conversion formula of the maximum turbine efficiency from a model turbine to an actual one of the Pelton turbine is shown below. The relation between the specific speed and the maximum turbine efficiency of the Pelton turbine is shown in Figure 10-21.

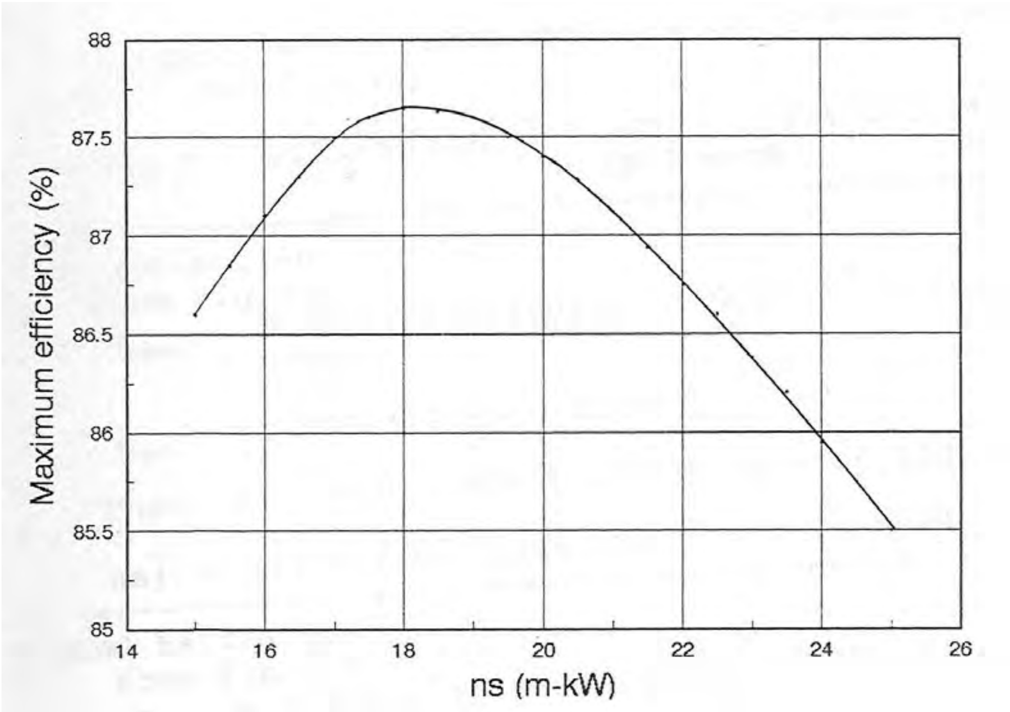


Figure 10-21 Relation of Maximum Model Turbine Efficiency and Specific Speed (Pelton Turbine)

$$\eta_{tmax} = \eta_{mmax} \times \left(\frac{P}{Noj \times 2500}\right)^{0.01375} \times \left(\frac{Noj}{4}\right)^{0.01475}$$

where,

P	: Turbine output (kW)
Noj	: Number of nozzles (jet)
η_{mmax}	: Maximum efficiency of model turbine
η_{tmax}	: Maximum turbine efficiency

The estimation example is shown below.

Turbine type : 2jet Pelton turbine
Effective head : H_e=150 (m)
Maximum discharge : Q_{max}=0.4 (m^3/sec)
Efficiency : η_t=0.85(assumed)
Frequency : 50 (Hz)

First calculation,

Turbine output $P_t=9.8\times Q_{max}\times H_e\times\eta_t$ = 9.8×0.4×150×0.85 = 499.8≈500kW

4 jet Pelton turbine is adopted in the example, and the turbine output per nozzle Pj is calculated.

Turbine output per nozzle $Pj = P_t/Noj = 250kW$

Maximum specific speed $$ns_{lim} = \frac{4{,}300}{H_e + 200} + 14 = 26.3 \text{ (m-kW)}$$

Revolving speed $$n = \frac{ns_{lim} \times H_e^{5/4}}{\sqrt{Pj}} = \frac{26.3 \times (150)^{5/4}}{\sqrt{250}} = 873 \text{ (min}^{-1}\text{)}$$

Standard revolving speed 750 (min-1) is chosen from Table 10-2 for the system frequency 50Hz district, and calculate specific speed.

Specific speed $$ns = n \times \frac{\sqrt{Pj}}{H_e^{5/4}} = 500 \times \frac{\sqrt{250}}{150^{5/4}} = 22.5 \text{(m-kW)}$$

The model water turbine efficiency η_{mmax} = 0.866 is given from Figure 10-21. The maximum actual turbine efficiency is converted from the model turbine efficiency

Maximum actual turbine efficiency
$$\eta_{tmax} = \eta_{mmax} \times \left(\frac{Pj}{Noj \times 2500}\right)^{0.01375} \times \left(\frac{Noj}{4}\right)^{0.01475}$$
$$= \eta_{mmax} \times \left(\frac{Pj}{2500}\right)^{0.01375} \times \left(\frac{Noj}{4}\right)^{0.01475}$$
$$= 0.866 \times \left(\frac{250}{2500}\right)^{0.01375} \times \left(\frac{2}{4}\right)^{0.01475}$$
$$= 0.830$$

Rated turbine efficiency $\eta_t = \eta_{mmax}$×0.99=0.830×0.99=0.821

Second calculation,

Turbine output $P_t=9.8\times Q_{max}\times H_e\times\eta_t$ = 9.8×0.4×150×0.821
= 482.7 ≈ 482 (kW)

4 jet Pelton turbine is adopted in the example, and the turbine output per nozzle Pj is calculated.

Turbine output per nozzle $\quad Pj = P_t/Noj = 241kW$

Specific speed $\quad ns = n \times \frac{\sqrt{Pj}}{H_e^{5/4}} = 750 \times \frac{\sqrt{241}}{300^{5/4}} = 22.1(\text{m-kW})$

The model water turbine efficiency η_{mmax} = 0.866 is given from Figure 10-21. The maximum actual turbine efficiency is converted from the model turbine efficiency

Maximum actual turbine efficiency
$$\eta_{tmax} = \eta_{mmax} \times \left(\frac{Pj}{Noj \times 2500}\right)^{0.01375} \times \left(\frac{Noj}{4}\right)^{0.01475}$$
$$= \eta_{mmax} \times \left(\frac{Pj}{2500}\right)^{0.01375} \times \left(\frac{Noj}{4}\right)^{0.01475}$$
$$= 0.866 \times \left(\frac{241}{2500}\right)^{0.01375} \times \left(\frac{2}{4}\right)^{0.01475}$$
$$= 0.830$$

Rated turbine efficiency $\quad \eta_t = \eta_{mmax} \times 0.99 = 0.830 \times 0.99 = 0.821$(Convergent)

Because the calculation is convergent, the designed turbine ratings become as follows.

Turbine type	: Pelton turbine
Effective head	: H=150 (m)
Maximum discharge	: Q=0.4 (m^3/sec)
Rated efficiency	: 0.821
Turbine output	: 482 (kW)
Revolving speed	: 750 (min^{-1})

(6) Draft head

A Pelton turbine and a Turgo Impulse turbine is an impulse turbine that uses the effective head at the nozzle exit entirely as a velocity head. Unlike the reaction turbine, the head from the nozzle to the tailrace level becomes ineffective. When the runner is installed near the tailrace water level, the water running outside the runner may be up with in the housing by water foaming to hit the bottom of the runner and causes the output reduction. The runner installation height from the tailrace water level varies depending on the runner shape and the specific speed, and is set generally at 2 to 3m.

When the tailrace water level rises only temporarily during a flood, the installation elevation of the Pelton turbine can be set at the normal water level. In such a case, however, compressed air may be sent inside the housing to lower the downstream water level and continue the operation throughout a flood.

As the cross-flow turbine runner receives water in the air in the same way as the Pelton turbine, the runner is installed higher than the tailrace water level. The runner installation height and an effective head vary depending on the presence or absence of a draft tube. When a draft tube is not installed and water running through the runner is discharged directly into the air, the runner installation height is determined to ensure that the foaming water does not strike against the bottom of the runner, similarly to the Pelton turbine. The head from the runner center to the tailrace water surface then becomes ineffective. If a draft tube is installed, a part of the head mentioned above is recovered.

A reaction turbine such as a Francis turbine, a diagonal flow turbine, and a Kaplan turbine is equipped with a draft tube to minimize the turbine loss and use the head between the runner center and the tailrace water level effectively, head which is called a draft head. It is desirable that the turbine be installed as high as possible in view of flood protection and reduction of foundation excavation in powerhouse. However, if the draft head is raised above a certain level, negative pressure on the back of the runner vanes increases and causes cavitation as well as noise, vibration, efficiency drop, etc. Moreover it accelerates cavitation erosion of the runner itself.

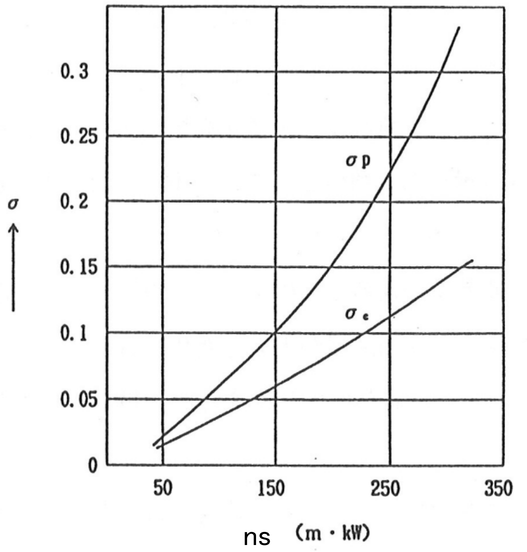
A cavitation coefficient is used as an index to quantitatively express the conditions causing cavitation. The turbine draft head (Hs) is expressed by the following formula.

$$Hs = Ha - Hv - \sigma H$$

where,

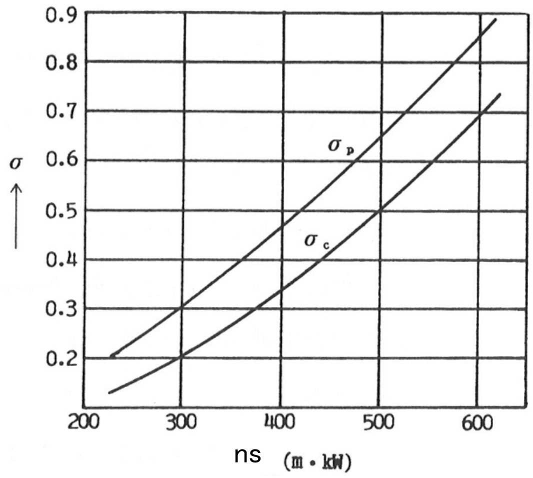
Hs : Draft head (m)
Ha : Atmospheric pressure (water column m)
Hv : Saturated vapor pressure (water column m)
σ : Cavitation coefficient
(Obtained from the turbine specific speed (Ns in Figure 10-22 and 10-23)
H : Effective head (m)

The cavitation coefficient is classified into a critical cavitation coefficient to indicate the point where the efficiency begins to drop during turbine operation and a plant cavitation coefficient to indicate the turbine draft head for the runner to be actually installed. The relations between σand turbine specific speed ns of Francis and Kaplan turbines are shown in Figure 10-22 and Figure 10-23. The turbine draft head (Hs) is specified as difference of elevation between a specific position of the runner and the tailrace water surface. The positions of several types of turbines are shown in Figure 10-24. They are not necessarily in the center of the turbines and on the rather safe side against cavitation.



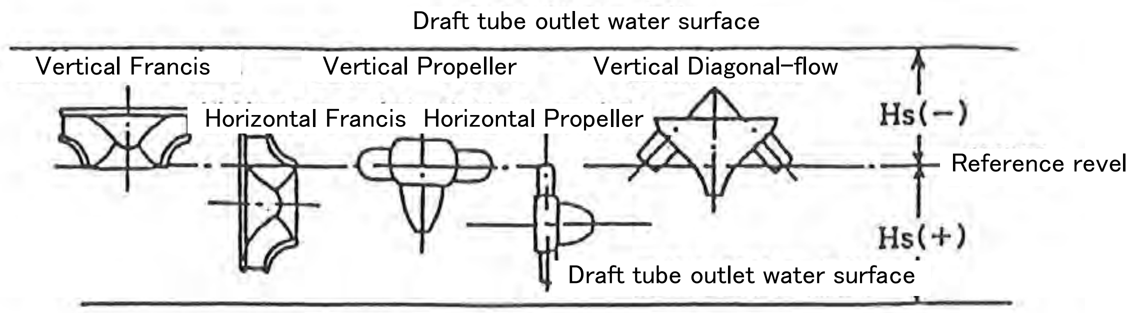
Source: IEEJ standard JEC-4001 Hydro turbine and pump turbine

Figure 10-22 Cavitation Coefficient of Francis Turbine



Source: IEEJ standard JEC-4001 Hydro turbine and pump turbine

Figure 10-23 Cavitation Coefficient of Kaplan Turbine

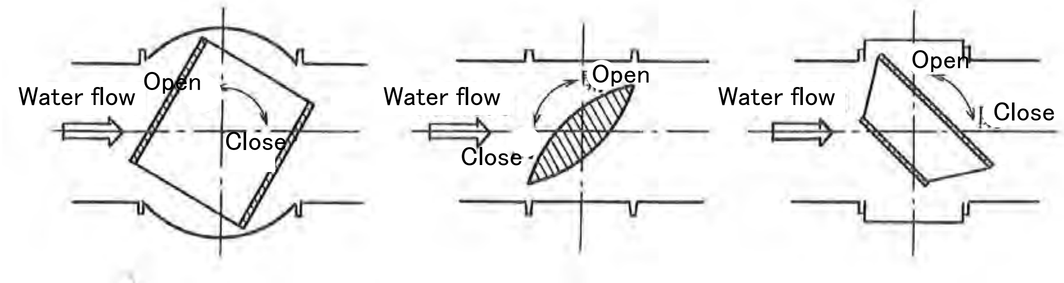


Source: IEEJ standard JEC-4001 Hydro turbine and pump turbine

Figure 10-24 The Specific Point of Runner and Static Suction Head

10.1.4 Inlet Valve

The inlet valve is located between the turbine casing and the end of the penstock. It is a water stop valve which is opened/closed when the turbine is operated/stopped. Ordinarily the inlet valve is operated when the guide vanes are completely closed and there are no flows at all. In an emergency, however, such as when the guide vanes are not closed, the inlet valve is sometimes designed to shut off the entire turbine inflow. Three types of inlet valves are presently employed, which are a spherical valve, a butterfly valve and a through valve. Figure 10-25 shows the structure of these valves.



Spherical valve Butterfly valve Through valve

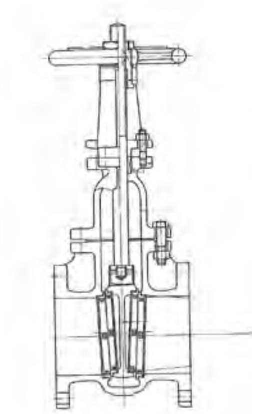
Figure 10-25 Outline Structure of Inlet Valves

A spherical valve has a cylindrical valve inside the spherical valve body. When the valve is fully closed, water is stopped by a ring shaped sealing surface installed on the side face of the cylinder. When the valve is fully opened, the hollow cylinder connects the penstock and the turbine casing to be one single continuous pipe.

A butterfly valve has a lens-shaped valve inside the cylinder body. When the valve is fully closed, the erect valve cuts off the passage and stops the flow. When the valve is fully opened, the lens-shaped valve remains flat in the flow passage to connect the penstock and the turbine casing.

A through valve contains within a cylindrical body a water stop disc and a reinforcing plate connected by several ribs. The flow is cut off by the disc. When the valve is fully opened, the valve itself remains in the passage. The disk, plate, and ribs stand against the water flow, but water can pass through the valve.

Generally, spherical valves are used when the head is over 250m. Butterfly valves are used when the head is less than 200m and through valves less than 350m. In the case of the low head less than around 70m, it is possible to omit an inlet valve when the upstream waterway is short and there are not two or more units or other water utilization. In that case, however, the intake gate is designed to function as emergency flow interruption. In case of small scale hydropower plant, there are examples that a ready made sleuth valve is applied for the inlet valve.



Source: JIS-B2031 Gray cast iron valves

Figure 10-26 Sleuth Valve

10.1.5 Turbine Auxiliary Equipment

(1) Speed governor

The speed governor automatically adjusts the guide vanes opening according to the change of rotating speed to control the turbine speed and output. The speed governor adjusts the rotating speed to synchronize at the time of turbine start up, and then controls the output connected to the power system during synchronous operation. During single operation with a limited load, the output is adjusted according to the variations of the load to control the frequency. When operation is disconnected due to a fault or breakdown of the distribution line, the turbine is immediately shut down by closing the guide vanes to prevent an abnormal speed rising of the turbine and generator.

Water level regulators which regulate the turbine discharge depending on the waterway inflow are installed in run-of-river hydropower schemes. In this case a speed governor responds to changes in the head tank water level and adjusts the guide vanes opening. In recent years, a digital type of the speed governor has become the mainstream. To give an example at a small scale hydropower station, PLC (Process Logic Controller) is applied as a package control panel integrating not only the start stop sequence control but also the excitation control and speed control of the generator and is controlled by software.

When the hydro- turbine and generator are connected to an independent power system, the governor regulates the discharge of the turbine so that the generator output and load demand do not become unbalanced, and the power system frequency keeps the rating value. When the designer adopts the turbine which does not have the discharge adjustment functions such as a reverse pump turbine, the dummy load governor can be adopted aiming at the prevention of wear due to partial load operation of the water turbine, or the cost reduction by simplification of water turbine structure and turbine control. The dummy load governor can regulate the dummy load electrically according to a change in surplus electric energy without adjusting the output of the water turbine. The dummy road-type governor adjusts a waterwheel at a most suitable operating point, and it is a method to consume the surplus electricity by the dummy loads (resistors) that is the generation output and a difference with the demand. An example of control system figure of a dummy load governor is shown in Figure 10-27, and a water-cooling dummy load is shown in Figure 10-28. The turbine carries out only operating depending on a flow quantity control, and the dummy load performs the adjustment of the demand. It is advantage in that the mechanical wear of the turbine can be prevented. The limitation of dummy load governor is applicable to turbine less than about 200kW.

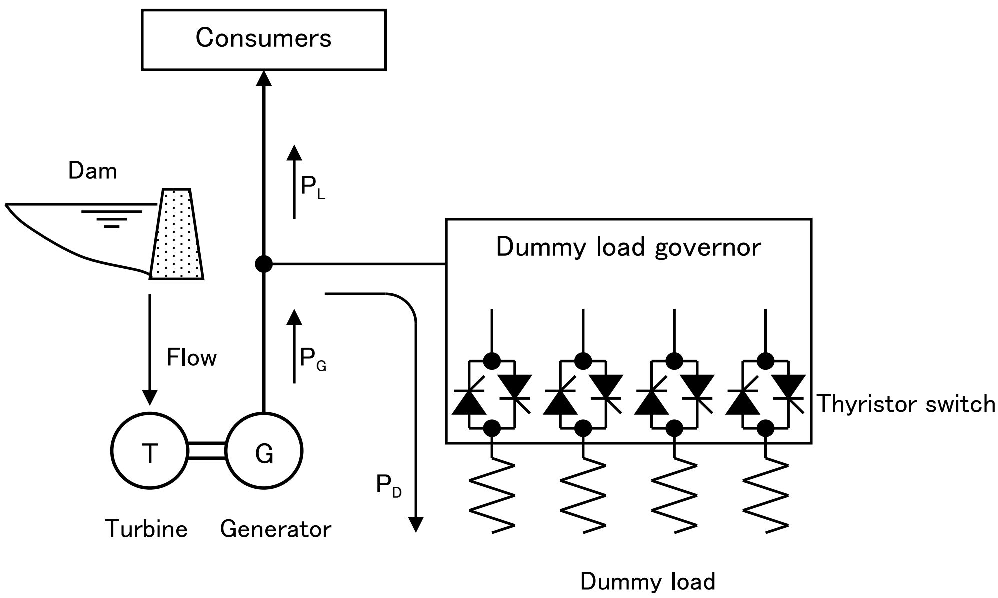


Figure 10-27 System Figure of The Dummy Load Governor

The dummy load governor adjusts the number of the connection of the dummy road resistor with a thyristor switch to become $P_G = P_L + P_D$. However, the differences between demand electricity and generation electricity detect it as a change of the revolving speed of the generator or frequency and adjust it.

where,

P_G : Generating output (kW)
P_L : Demand electricity (kW)
P_D : Consumption electricity of the dummy loads (kW)

Figure 10-28 Construction of Water Cooling Dummy Load

(2) Cooling water supply system

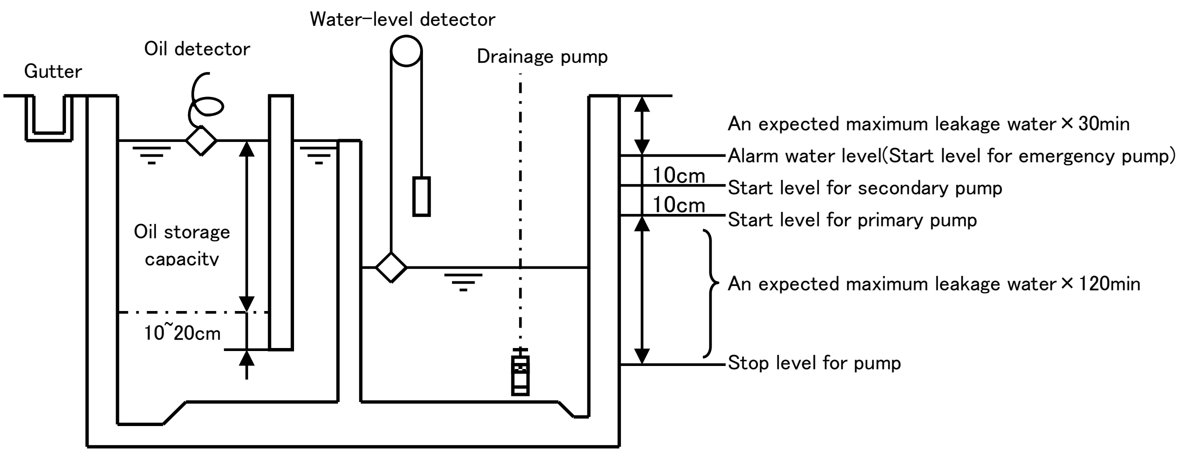
This system supplies cooling water to the turbine and generator bearings, and generator itself as well as firewater. Generally, in power plants where the head is 30 to150 m, the water is supplied from a penstock by an automatic valve via a pressure reducer. In power plants where the head is less than 30m and where there is insufficient feed water pressure, and in power plants where the head is over 150m and where it is uneconomical to use high pressure water, the water is fed from the tailrace by a feed water pump. When feeding water from the penstock, a feed water tank is generally installed at an appropriate height to reduce the pressure, and settle the sediment. The tank capacity is of a size to supply water for about five minutes at a water failure. The feeding water passes through an automatic strainer and then it fed to each cooler. Sand separators and rapid filters are used where purified water is needed as main bearings seal water, etc.

For a turbine and a generator for a small scale hydropower generation around a few hundred kW, the cooling water supply system is omitted by adopting air-cooling for generator with air duct, plastic packing for main shaft sealing, air cooling with the heat radiation fin, heat piping of the main bearings, etc. It aims at simplification of the equipment and future maintenance works.

(3) Water drainage system

Coming into a power plant are leakage from building walls and foundations, leakage from turbine seals, water remaining in the penstock, casing, and piping during works, and general service water. All water is collected in a drainage pit provided at the lowest level and the drainage pump automatically operates depending on the level of collected water to discharge it to outside the power plant. Jet pumps and small turbine pumps are used as countermeasures against a station blackout. However, jet pumps cannot be used in power plants where the effective head is less than 40m. A capacity of the drainage pump is estimated from the volume of the building and quantity of leakage water. A capacity of the drainage pit is estimated from how long it takes for a member of maintenance to arrive at the power plant and carryout effective measures when power fails, etc.

Even if lubricating oil or turbine oil leaks from equipment or piping in a power station, an oily water separator pit is installed in the drainage pit not to directly release it in the river. When it is a Pelton turbine and the installed height of water turbine is higher than river flow surface, leakage water can naturally flow down from the power station, but it is necessary even in this case to install a drainage pit and an oily water separator pit so that leakage oil does not flow out into the river outside. A design example of a drainage pit and an oily water separator pit is shown in Figure 10-29.



Source: Denki kyodou kenkyu Vol42-2 Design guide for water turbine auxiliary equipment

Figure 10-29 Example of a Drainage Pit

10.2 Generator

10.2.1 Generator Types

The water turbine generators mainly used are salient-pole rotating-field type 3-phase alternators. Induction generators are sometimes used in small scale hydropower plants in consideration of cost reduction. Recently, new type generators which combined an inverter (a power conditioner) with a permanent magnet alternator or a direct current alternator have been developed. It is necessary to choose the most suitable generator type in consideration of the scale of the power station, relations with the demand, and its construction cost and future maintenance cost. Conventional synchronous generators may be classified as follows depending on the shaft axis and cooling system.

(1) Classification by shaft axis

Turbine generators may be classified into two types by shaft orientation, a horizontal shaft type and a vertical one. A horizontal shaft type is generally applied to high speed generators and a vertical type is suited to low speed generators. Shaft axis is selected considering the turbine type and speed, topography, an amount of excavation required, building design, and maintenance, etc.

(2) Classification by generator cooling system

Generator Cooling systems are classified, depending on the combination of the following three items.

i) Used coolant (air, water, hydrogen).

ii) Coolant passage and heat dissipation method (free circulation type, inlet and outlet pipe ventilation type, heat exchanger type)

iii) Coolant feed method (self-cooled, unaided, aided)

In generators for water turbines, generally, air is a primary coolant to directly cool a stator and a rotor, with water as a secondary coolant. These are roughly categorized into the following types. There is a method to directory cool by water the inside of a rotor and a stator in a large-capacity generator as an extremely rare example.

- Open type (free circulation type): Used for small capacity units. In general, ordinary induction motors are classified in this.
- Full enclosed, air duct ventilation type {pipe cooling type): Used for small to medium-capacity units. Most are outlet pipe cooling types. Generally used up to 20MW.
- Full enclosed, air duct circulation type (water cooling heat exchanger type): Circulation types need an air cooler inside the duct and a cooling water system. Because it provides a high cooling capability, it is used for mid-and large-capacity generators.

(3) Classification by bearing arrangement

1) Horizontal shaft generator

For a horizontal shaft generator, it is classified into a bracket type and a pedestal type by the placement of the bearings. The bracket type has the structure that integrates a bearing with the main body of a generator as shown in Figure 10-30, and the pedestal type puts away guide and thrust bearings in each case placed in the front and behind the main body of a generator as shown in Figure 10-31. There are a lot of adoption examples of the bracket type for small capacity generators, and its installation and adjustment works are easy.

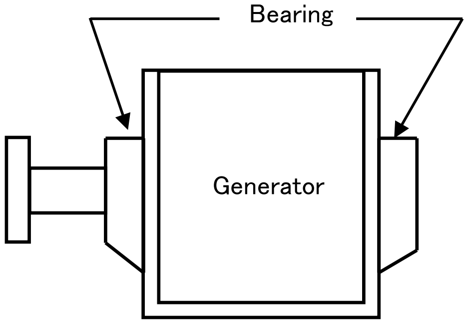


Figure 10-30 Bracket Type

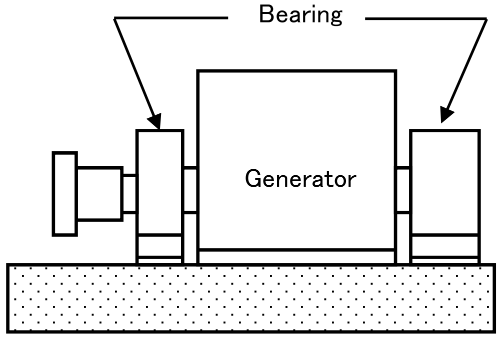
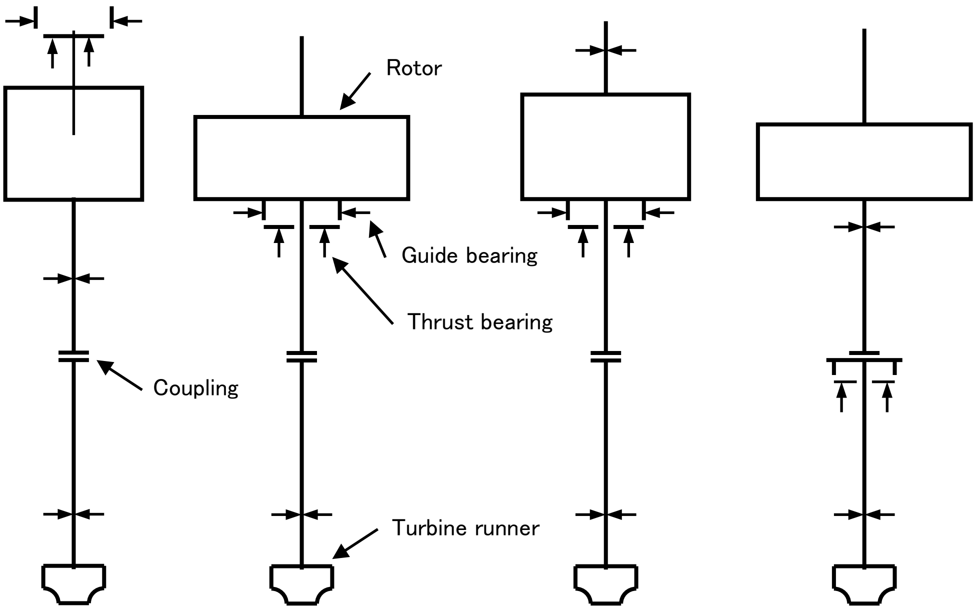


Figure 10-31 Pedestal Type

2) Vertical shaft generator

Vertical generators are classified by their bearings arrangement. A suspended type has the thrust bearings above the rotor and is provided with two guide bearings, one above the rotor and the other below it. An umbrella type has the thrust bearings below the rotor and one guide bearing also below the rotor. A semi-umbrella type, which is also called as a modified umbrella type, has an additional guide bearing above the rotor. For very large capacity generators or for generators to be applied for a low head and large discharge hydropower generation scheme, the thrust bearings may be supported from the turbine head cover to achieve more compact arrangement. Figure 10-32 shows the bearing type arrangement.



Suspended type Umbrella type Semi-Umbrella type Head cover supported type

Figure 10-32 Bearing Arrangement Type of Vertical Shaft Generator

10.2.2 Designing the Generator

The design works for a generator is carried out as follows.

(1) Capacity and power factor

It is common that the rated capacity of a generator assumes water turbine maximum output, and generator output at a rating power factor, and the rated capacity is calculated using the generator loss curve shown in Figure 10-34 by the following flow.

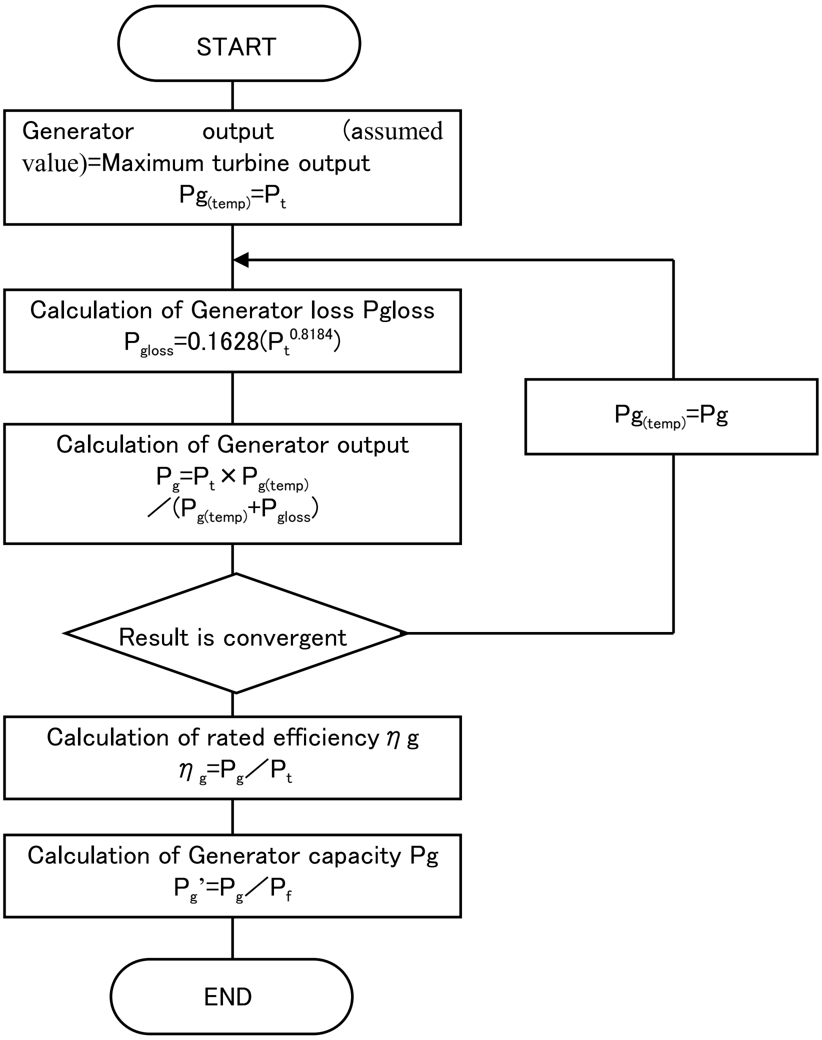


Figure 10-33 Design Flow of a Generator

where,

P_t	: Turbine maximum output (kW)
$P_{g(temp)}$	: Generator output (assumed value) (kW)
P_{gloss}	: Generator loss (kW)
P_g	: Generator rated output (kW)
η_g	: Generator rated efficiency
P_g'	: Generator rated capacity (kVA)
P_f	: Generator rated power factor

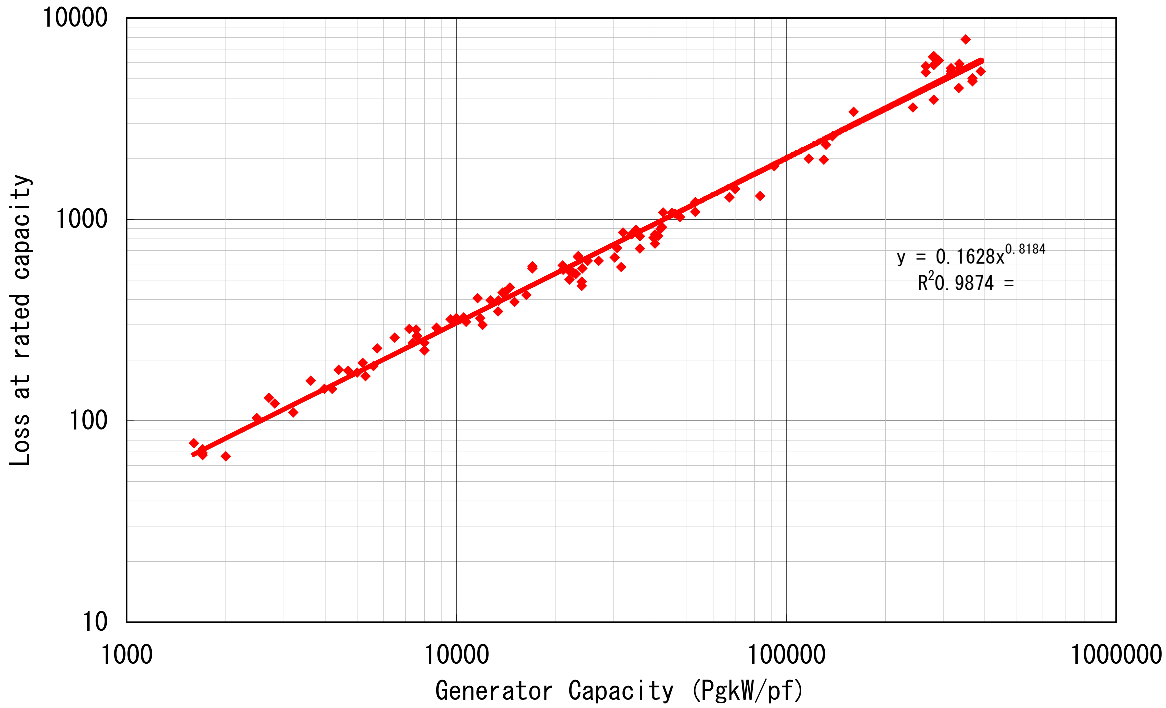


Figure 10-34 Generator Loss at the Rated Capacity (P_{gloss})

A calculation example is shown bellow.

First calculation

Turbine rated output P_t=434kW, The generator output is assumed $P_{g(temp)}$=434kW

Generator loss $P_{gloss}=0.1628(P_{g\,(temp)}{}^{0.8184})=23.5(kW)$

Generator output $P_g=P_t\times Pg\ (temp)/(P_{g\,(temp)}+P_{gloss})$

$=434\times434/(434+23.5)$

$=414kW$

Second calculation

Generator output (assumed value) $P_{g\,(temp)}$=414kW

Generator loss $P_{gloss}=0.1628(P_{gkW(temp)}{}^{0.8184})=22.6(kW)$

Generator output $P_g=P_t\times P_{g\,(temp)}/(P_{g\,(temp)}+P_{gloss})$

$=434\times414/(414+22.6)$

$=412kW$

Third calculation

Generator output (assumed value) $P_{g\,(temp)}$ =412kW

Generator loss $P_{gloss}=0.1628(P_{gkW(temp)}{}^{0.8184})=22.5(kW)$

Generator output $P_g=P_t\times P_{g\,(temp)}/(P_{g\,(temp)}+P_{gloss})$

$=434\times412/(412+22.5)$

$=412kW$ (convergent $P_g=P_{g\,(temp)}$)

From estimated generator output P_g=412kW

Generator efficiency $\eta_g=P_g/P_t$=412/434

=94.9%

Therefore, if the designer adopts P_f=0.95(95%) of rating power factors.

Generator rated output is, $P_g'=P_g/P_f$=412/0.95

=434kVA

Generator efficiency is basically determined by the generator output and power factor. The generator power factor is determined in consideration of the characteristics of the load and power system. A rated power factor of approximately 98% to 85% is usually adopted. A rated power factor as near to 100% as possible can reduce generator capacity if the generator is not connected to an independent power system to be operated with an independent load. As a result, the cost reduction of the generator is achieved. If there are not requirements of voltage control of the power system etc., a power factor of around 98%may be selected.

(2) Frequency, revolving speed and poles

Power transmission system frequencies are usually 50 Hz and 60 Hz. The frequency used depends on the area. As is described in a clause of calculation of water turbine revolving speed, alternator revolving speed is also selected in accordance with the frequency and is determined by the following formula, which is not applied to a direct current generator, an induction generator or a combination system of an induction generator and an inverter.

$$n = \frac{120 \times f}{p}$$

where,

n : Revolving speed (min^{-1})

f : Power system frequency (Hz)

p : Number of the poles

Revolving speed is determined by the maximum specific speed which depends on the turbine type. Generators become smaller as the revolving speed increases, which serves to reduce the manufacturing cost. However, the draft head of the turbine becomes higher and it requires more excavation, which in turn serves to reduce the economic merits. The revolving speed is, therefore, determined considering the overall plant cost. Table 10-3 shows the standard revolving speed of turbine generator.

Table 10-3 The Standard Revolving Speed of a Generator (JEC-4001)

Pole	50Hz	60Hz	Pole	50Hz	60Hz	Pole	50Hz	60Hz
4	1,500	1,800	28	214	257	60	100	120
6	1,000	1,200	30	200	240	64	94	113
8	750	900	32	188	225	70	86	103
10	600	720	36	167	200	72	83	100
12	500	600	40	150	180	80	75	90
14	429	514	42	143	171	84	71	86
16	375	450	48	125	150	88	68	82
18	333	400	50	120	144	90	67	80
20	300	360	54	111	133	96	63	75
24	250	300	56	107	129	100	60	72

Source: IEEJ standard JEC-4001 Hydro turbine and pump turbine

(3) Voltage

The higher the voltage is, the thicker and heavier the generator coil insulation becomes at a lowered occupation ratio of the conductor. Low voltage is more advantageous in this aspect. However, selecting low voltage has a disadvantage of a large current rating which requires a larger capacity of the cables and connecting conductors as well as breaking devices. It may reduce the overall economy when considering the main bus leading to the transformer, the circuit breakers and other switching equipment.

Considering these aspects, the rated voltage is to be selected. Generally, however, the following rated voltage is used with generator capacity as shown in Figure 10-35.

Generator capacity	Less than 3MVA	: 400 (V)
	3 - 10MVA	: 6.6(kV)
	10 - 50MVA	: 11 (kV)

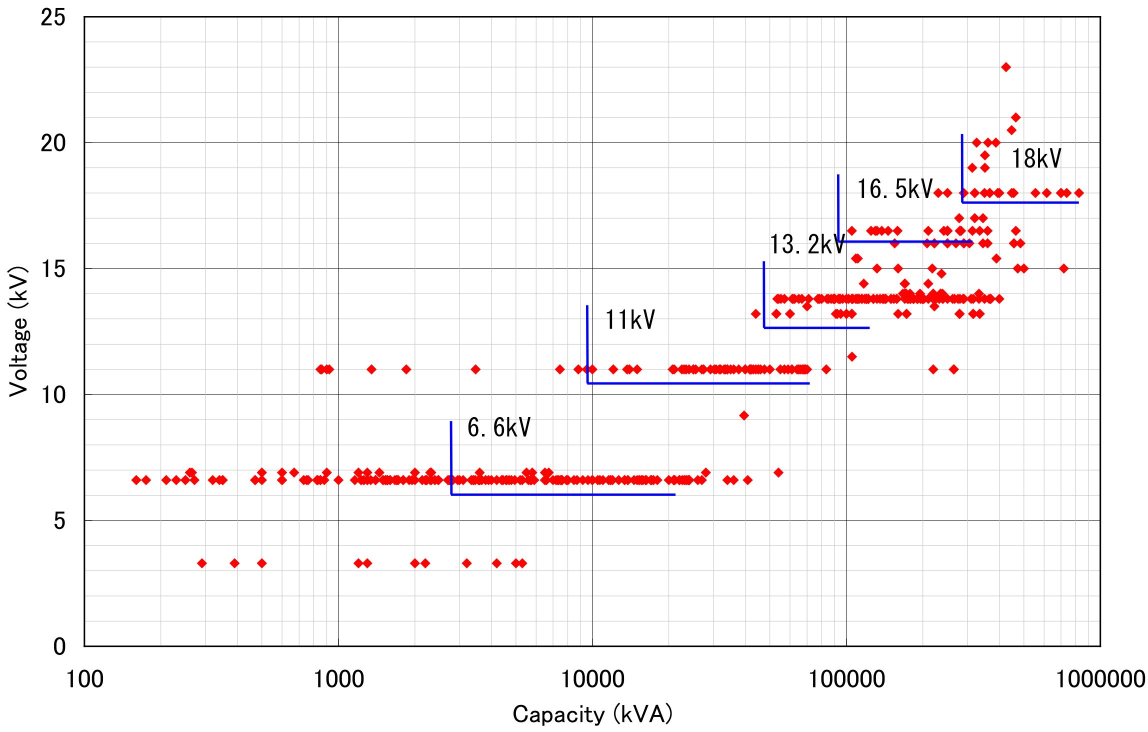


Figure 10-35 Relation between Rated Generator Capacity and Rated Voltage

(4) Current

The generator current is important in determining the specification of the generator itself, and the circuits and switch gears connected to the transformer. The generator rated current is calculated by the following formula.

$$Ig = \frac{P_g'}{\sqrt{3}E}$$

where,

I_g : Generator rated current (A)

P_g' : Generator rated capacity (kVA)

E : Generator rated voltage (kV)

(5) Excitation System

The excitation circuit supplies a field current for the rotor of generator, and adjusts its output and voltage, which consists of a thyristor, an exciter power transformer, a slip ring, and an automatic voltage regulator. In recent years, for a small scale hydropower station, the integrated control panels have been operated by software which incorporated the excitation control of the generator in PLC (Process Logic Controller).

1) Excitation method

The following methods are now mainly used.

- DC Excitation system

  It is a method for supplying a field current by installing a direct current dynamo. Nowadays there becomes rare adoption, and the existing DC excitation systems are often replaced with other methods because a direct current alternator is expensive and it needs the maintenance of a rectifier.

- Thyristor excitation system

  The output of an exciter transformer or an AC generator is converted to DC by a thyristor rectifier, and a field current is then supplied being regulated by thyristor phase control. This method is now used in most cases because of easier maintenance without a rectifier and quicker control speed.

- Brushless excitation system

  The output current of a revolving armature type AC generator directly connected to the rotor of the main shaft is converted to DC by a rectifier attached to the same revolving shaft, and a field current is directly supplied without using a slip ring. Brush maintenance is not needed in this method which is applied to a small scale hydropower plant.

2) Exciter capacity and voltage

Exciter capacity is determined as follows: the exciting power required to operate the generator at the rated output/rated power factor, plus a 10% margin. In most instances, the exciter voltages are 110 V, 220 V, and 440 V.

3) Automatic voltage regulator (AVR)

An automatic voltage regulator (AVR) regulates the field current automatically to keep the generator voltage constant. To set the generator voltage, firstly constant voltage power is regulated by a voltage-adjustment resistor. This being the reference voltage, secondly it is compared with the generator terminal voltage, and the field current is regulated according to the deviation signal.

4) Automatic power factor regulator (APFR)

When a comparatively small capacity generator is connected in synchronism to a large capacity power system, the reactive power required to stabilize the generator voltage may cause the generator over-current. In this case, it is better to operate the generator, with a fixed power factor, at the voltage corresponding with the varying voltage of the power system. To do this, an automatic power factor regulator (APFR) is used. It is general for a small scale hydropower station to carry out the constant power factor operation with this APFR except independent operation of the generator.

10.3 Transformer

Hydropower plant transformers are classified into three types, a main transformer used to step up generator voltage to line voltage, a station service transformer to lower the generator voltage to house voltage, and a station low-voltage transformer to lower the house voltage to equipment voltage.

10.3.1 Main Transformer

Outdoor three-phase transformers are normally used in hydro-electric power plants. Regarding the cooling method, a self-cooling type is used in small capacity units. When the transformer of small scale hydropower station is to be installed indoors, in many cases dry-type is used considering the limited installation space.

The rated capacity of the main transformer is set at the rated output (kVA) of the generator. Primary voltage is normally set at about 5% lower than the rated voltage of the generator. However, as a system becomes ultra-high voltage, the power factor comes near to 1. In this case, primary voltage is set at the rated generator voltage.

In addition, in a small scale hydro power station, if transmission line voltage and the generator voltage are chosen at the same voltage, an insulation transformer of the same voltage is installed as a main transformer to protect the generator from an external attack such as a thunder surge from a transmission line and to reduce the short circuit capacity in the power plant.

10.3.2 Station Service Transformer and Station Low-Voltage Transformer

Transformer capacity is determined after a full study of the required power for plant equipment such as a water supply pump, a water drainage pump, lighting for the plant and a crane for the installation and maintenance works. Generally, a dry transformer is used for a small capacity unit installed indoors to avoid the danger of fire. It is installed in the same place parallel to the metal enclosed switchgears in consideration of the safety. The impedance of a station service transformer and a main transformer influences the short circuit current of the station service circuit. Therefore, at the time of the purchase of these transformers, it is necessary to study so that both impedance and short circuit electric current may become appropriate values.

10.4 Main Circuit Connection and Electrical Equipments

10.4.1 Main Circuit Connection

The following are considered when selecting the main circuit connection system: the number and capacity of generators, the number of transmission lines and the connection method, restrictions on power plant space, a station power receiving method and the existence or non-existence of distribution lines, the construction cost and transportation conditions of the transformers and switchgears, the range of power failure caused by in-station accidents, and the safety and ease of repair and maintenance. These aspects are considered in perspective from the viewpoint of reliability of the power plant as well as economy and technology. Typical main circuit connections are shown below.

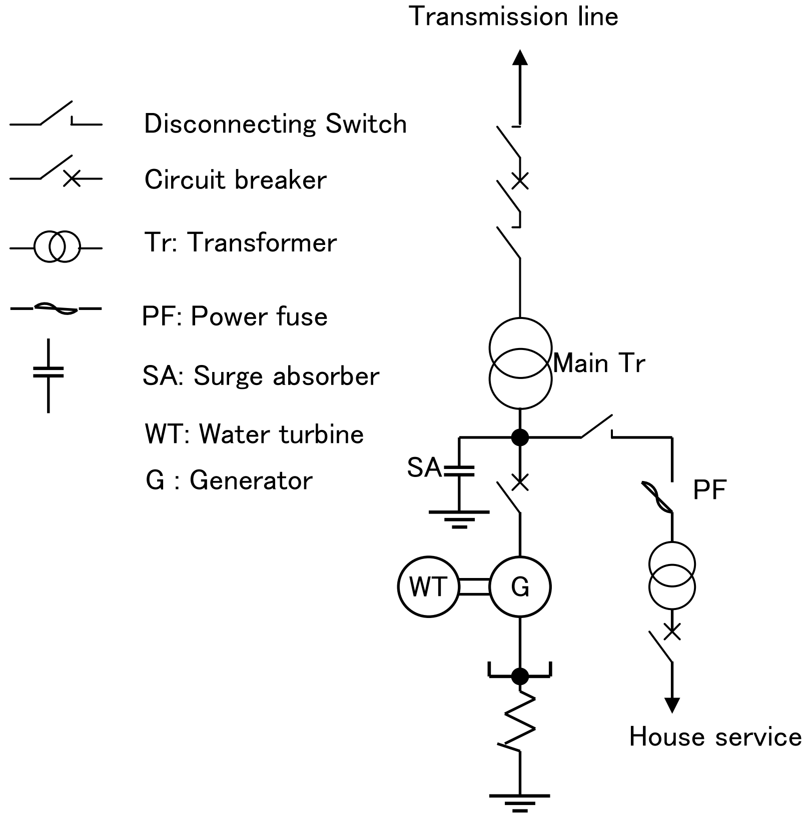


Figure 10-36 1 Unit of Turbine Generator, Single Transmission Line

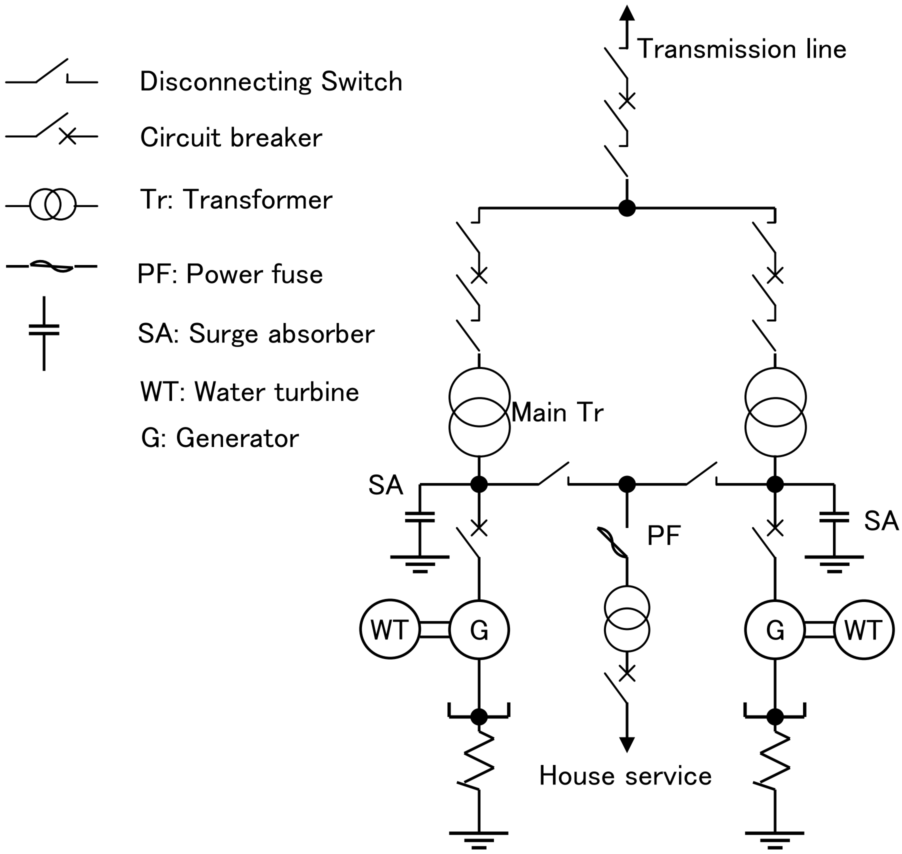


Figure 10-37 2 Units of Turbine Generator, Single Transmission Line

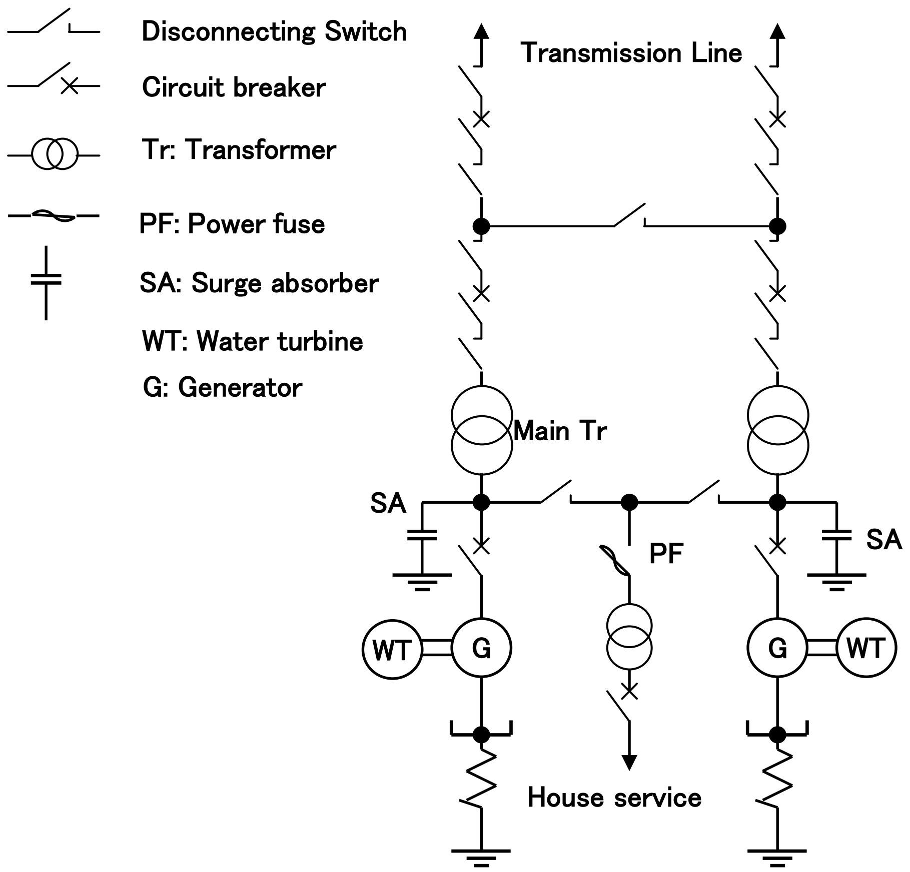


Figure 10-38　2 Units of Turbine Generator, 2 Circuits of Transmission Line

10.4.2　Circuit Breaker

Circuit breakers switch the load currents and also interrupt short circuit fault and ground fault currents. The types are shown in Table 10-4.　Circuit breakers are operated by air, oil or an electric motor and a spring.　At small scale hydropower stations, there are many designs that do not use compressed air, and there is much adoption of oil pressure operation or electric motor spring operation.　The circuit breakers used depend on the rated voltage as shown in Table 10-5, which is referred to when selecting the circuit breakers.　The following should also be considered when making a selection.

(1)　Rated voltage

The maximum voltage of the circuit used should not exceed the rated voltage of circuit breaker.　In Japan, normally used are circuit breakers with a rated voltage of 1.1 to 1.2 times nominal power system voltage.　For example, 72 kV circuit breakers are used for 66 kV nominal power system voltages.

(2)　Rated current

The maximum value of the load current which passes the circuit breaker should not exceed the rated current. A slightly overloaded current may pass it without problems, which should be limited for a short time only.

(3) Rated breaking current

The rated value of the breaking capacity is expressed by the breaking current value. Calculate the maximum fault current of the circuit used and then circuit breakers with a rated breaking current exceeding the value are to be used. When calculating, the impedance of the rotating alternator will be the sub-transient value. Normally, it is enough to calculate the three-phase ground current as the maximum, but for circuits where the zero-phase impedance is smaller than the positive/negative phase impedance, one-line-to-ground current becomes the maximum and it is necessary to use the maximum fault current.

Table 10-4 Circuit Breaker Types Classified by Arc Control Principle

Type	Symbol	Arc Quenching method
Oil breaker	OCB	The current is interrupted by the blast of the gas generated by decomposition of insulation oil in the arc quenching chamber.
Air circuit breaker	ACB	This is in the air and cooled in the arc quenching.
Magnetic circuit	MBB	The arc in the air is induced into the arc quenching chamber by magnetic force, and extended and cooled for quenching.
Air blast circuit breaker	ABB	Compressed air is blasted to the arc for quenching.
Vacuum circuit breaker	VCB	This is quenched by quick diffusion of electrons in vacuum.
Gas circuit breaker	GCB	Special gas (SF6) having high insulation is blasted for quenching

Table 10-5 Circuit Breaker Types Classified by Rated Voltage

Type	Rated Voltage(kV)		
	7.2	12	24
MBB	○		
ACB		○	
ACB	○	○	○
GCB			○
VCB	○	○	○

10.4.3 Disconnecting Switch

A disconnecting switch is not used to switch the load current on or off. It is used to disconnect electrical machinery and apparatus from circuit. A disconnecting switch is also used to switch the circuit which is charged at the rated voltage such as the bus and transmission line charging current and the transformer exciting current.

Disconnecting switch types and applicable voltages are shown in Table 10-6. Bus construction and installation methods and other aspects must be considered as a whole when making a selection. The rated voltage and rated current are determined in approximately the same way as the circuit breaker.

Table 10-6 Disconnecting Switch Types and Applicable Voltage

Method of operation	Type	Applicable voltage class
Manual	Vertical, 1 contact	Less than 7.2kV
Motor drive, Air driven	Horizontal, 2 contacts	7.2kV – 300kV

10.4.4 Instrument Transformer

Instrument transformers can be classified into potential transformers (PT or PD: Potential Device) and current transformers (CT). They are used to measure high voltage large current electric circuits. They supply voltage/current, in proportion to the circuit voltage and current, to instruments, relay and watt-hour meter based on the principle of the power transformer.

(1) Potential transformer (PT, PD)

Potential transformers can be classified into indoor and outdoor types depending on the installation site, and into a dry type and an oil immersed type by insulation construction and into a winding type and a capacitive type by principle. The winding type is structured based on the same principle as the power transformer and is generally called a PT. The capacitor voltage transformer is generally called a PD and uses a capacitor's potential divide principle. The dry type is used when the voltage is less than 22kV. When the voltage is over 66kV, the capacitive oil immersed sealed type which provides high insulation reliability is used. PD and PT of a gas insulation type combined with gas insulated switchgears (GIS) are developed.

(2) Current transformer(CT)

Classification by used location and insulation construction is about the same as the potential transformer. When classified by coil type, there are a winding type, a through type and a bushing type. The winding type is used for the generator main circuit or for measuring the house circuit bus. The oil or gas immersed type is used for higher voltages.

10.4.5 Arrester

Lightening protective devices are the general term for devices which protect the insulation of electric facilities and equipment from over- voltage. Lightening protective devices include arresters, protective gaps and protective condensers. The arrester is a typical lightening protective device. When over- voltage (impulse over voltage or switching surge voltage) with a high crest value caused by lightening or operation of circuit breakers and other switching devices, an accompanying electric current is discharged to limit over- voltage and protect electric facility insulation. The arrester also cuts dynamic current in a short time and automatically recovers system voltage. There have been various types of arresters. Today, however, a zinc oxide type (gapless type) arrester which enables easier serviceability is used.

10.4.6 Metal Enclosed Switchgear

Put away in steel boxes in consideration of safety and security are circuit breakers, disconnecting switches and instrument transformers of each power supply (400V, 200V, 100V and a 6.6kV circuit of the power station), which are called metal enclosed switchgears in a lump. The metal enclosed switchgears bear electricity supply functions for the auxiliary equipment, ventilating devices, and a DC power supply system, etc. These should be divided properly into a charge and a no- charge part at the time of maintenance work to carry out the safe work efficiently.

10.4.7 Control Panel

Operation, control and protection of turbine, generator, main circuit, main transformer, transmission line, short circuit etc. are carried out through control panels. The control panel is designed according to number of equipment and transmission lines, control method, number of operators, and the scale and importance of the power plant. In recent years, for a small-scale hydroelectric power station, the integrated control panel is used to be used for cost reduction. The panel is equipped with PLC (Process Logic Controller) which integrates functions of not only start stop sequence control but also excitation control and speed control of the generator by software. An example of an integrated control panel is shown in Figure 10-39.

Control and protection
1 Human interface (LCD touch panel)
2 Automatic synchronizer
3 Alarm and fault indicator
4 Lockout relay and alarm reset button
5 Emergency stop button
6 Control switch for circuit breaker
7 WH Meter

Control and protection (internal alignment)
1 Power supply unit
2 CPU unit
3 GOV interface unit
4 AVR interface unit
5 Protective relay (over current)
6 Protective relay (grand short over voltage)
7 Power switch and Remote switch

Auxiliary relay (internal alignment)
1 Auxiliary relay and timer
2 Speed detector
3 Lock out relay
4 Terminals for control cables

Source: Integrated control panel Catalog Toshiba Corporation

Figure 10-39 An Example of Integrated Control Panel

10.4.8 Protective Relay System

Protective devices are installed to limit damage caused by faults and the following to a minimum.

➢ Cost of damage and repair

- Expansion of damage caused by faults
- Outage period
- Loss to electric utilities and customers

For effective protection, protective systems in hydropower plants are divided into turbine generator protection, transformer protection, bus protection and transmission line protection. A list of protective items of turbine, generator, transformer, etc. is provided in Table 10-7.

Table 10-7 Turbine Generator Protection Items

Protection category	Failure item
Emergency stop	Generator internal short circuit, Generator internal ground, Generator circuit short circuit, Generator circuit ground, Generator over voltage, Generator over current, Lost of excitation, Main transformer internal short circuit, Main transformer internal ground fault, Excitation system failure, Control equipment failure
Quick stop	Excess bearing temperature (failure level), Governor failure, Excess speed
Normal stop in alarm mode	Excess bearing temperature (alarm level), Low oil level of bearing oil tank, Cooling water supply failure, Excitation system malfunction, Stator coil high temperature
Alarm	High oil level of bearing tank, Air cooler outlet high temperature, Excitation circuit grounding, Cooling water cut off, Start-up impeded, Auxiliary machine malfunction (or breakdown), Drainage pit high water level, Drainage pit oil detection, Main transformer high temperature

1) Emergency stop

An electrical fault occurs on the generator. The synchronizing circuit breaker is opened instantly in order to prevent the adverse effect on power system, and at the same time, the excitation power is cut off to stop the fault current from generator and prevent aggravation of the fault.

2) Quick stop

A mechanical fault occurs on the turbine or generator. Although a prompt shutdown is required, the mechanical failure could be aggravated if the load is suddenly shut off by a synchronizing circuit breaker similarly to the case of an emergency stop because this would result in a turbine speed rise and a water pressure rise which may have a severe effect on the turbine generator and structures. In this case, the guide vanes are completely closed soon after the failure is detected, then the synchronizing circuit breaker is opened to stop the turbine and generator under the condition of no loads.

Recently at small scale hydropower stations, there have been examples that a quick stop mode is omitted and integrated into an emergency stop mode in order to simplify the control equipment.

3) Normal stop in alarm mode

Although there is no need to urgently shut down the machines as in the case of an emergency stop or a quick stop, there is a risk of aggravating the breakdown, failure, etc. if operation is continued. The machines are shut down automatically according to the normal stop sequence.

4) Alarm

An operator or an inspector confirms the equipment conditions and various measurement data, and exercise a judgment on continuous operation. They either reduce the generator output or shut it down according to the circumstances.

10.4.9 DC Power Supply System

A DC power supply system is supplying a direct current for controlling the control panels, switchboards, protective system; it is comprised of a battery charger, a battery and an inverter. At a small power station less than 100kW, a DC power supply system is occasionally omitted and then AC power is applied for the plant controlling, as long as the water turbine and generator are specified that they should not operate at the outage of the power plant and that they should absorb its run-away speed. In addition, as simplified DC power supply facilities, general-purpose uninterruptible power supply equipment such as UPS, and CVCF (UPS: Uninterruptible Power Supply, CVCF: Constant Voltage Constant Frequency) is adopted.

10.4.10 Operation Control System

An operation control system is selected from the following systems considering the scale of the power plant, its duty within the power system, geographical conditions, the number of operators, etc. Figure 10-40 shows: an example of a generator start control system.

(1) One-man control system

This is an automatic operation system. Turbine and generator operation, load/voltage regulation, gauging and monitoring can be done by one operator using the control panel. In the event of a failure it automatically shuts down or issues a warning signal, depending on the nature of the fault.

(2) Remote supervisory control system

Operation of the turbine and generator, load/voltage regulation, monitoring, etc., are done from a remote control center. In the event of a fault, it automatically shuts down or issues a warning signal depending on the nature of the fault. In many cases, this system is being aggressively adopted due to the advancements in communication and computer technologies as well as operator savings. There are cases where more than ten power plants are collectively controlled by one control station.

(3) Fully automatic control system

This is a fully automatic control system. When the pre-set starting conditions are ready, the turbine and generator start automatically. The load is regulated automatically and operation is continued. The generator is automatically shut down when the set shutdown conditions are formed or in the event of a fault. Conditions of full automatic operation are mainly the time or load set in advance, and water level in a pond or a head tank at a run-of- river hydropower station.

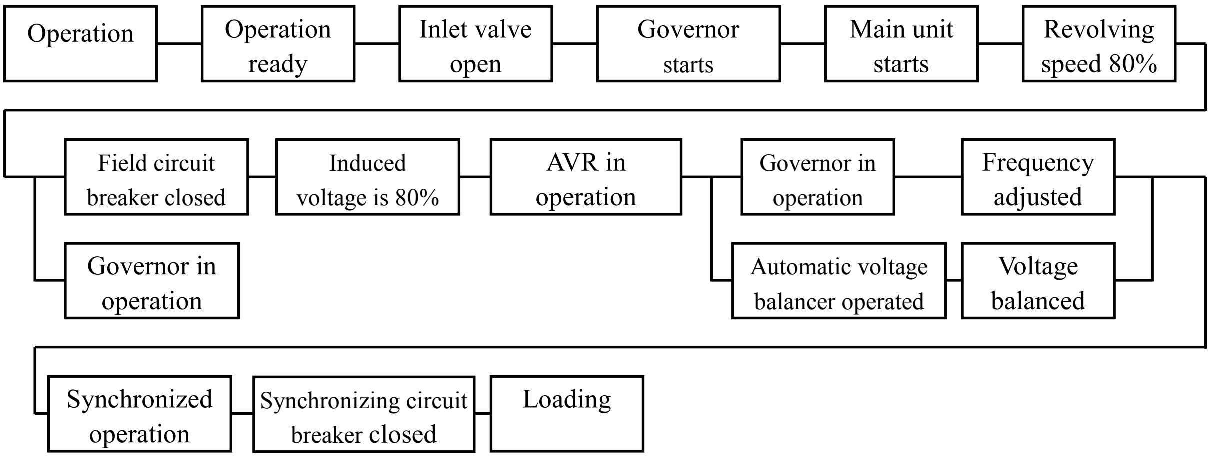


Figure 10-40 Examples of Water Turbine and Generator Start Sequence

10.5 Other Equipment

10.5.1 Crane

An overhead traveling crane or a gantry crane is installed for installation works and maintenance works of the water turbine and generator in a hydropower station. In this case there are many examples that the maximum hoisting load of the crane is designed to be the hoisting load of the generator rotor. In addition, a crane for carrying-in works of the apparatus and materials may be installed separately from an assembling crane when a power station is installed underground or in a deep vertical shaft. At small scale hydropower schemes, there are examples that a truck crane, a small electric hoist, a hand-operated hoist and a chain block are applied as a substitute for an assembling crane.

10.5.2 Grounding Wire

At the time of a ground fault of a transmission line or a generator, an electric current flows to a ground fault point from the power station. Therefore, a grounding mesh is installed in and around the power station area in order to lower the ground resistance at or less than the specific value, and it is necessary for a safety problem not to occur by the step voltage or the touch voltage. It is indispensable to connect all the electrical equipment such as a water turbine, a generator, auxiliary equipment, metal enclosed switchgears, control panels, etc to a grounding mesh surely.

The designer measures or estimates resistivity of the ground such as local bedrock and designs the

area that meets the necessary ground resistance. It is important that grounding wires should be installed like a mesh after excavation works down to the bedrock foundation, and before concrete placement works of the foundations, walls and floors in the power station. And, it is necessary to make ready the ground wire taps to be connected to all the required equipment. The cooperation with the civil constructor is important to adjust the complicated works of reinforcement bar and concrete. Similarly, it is necessary for the grounding wires to be embedded after foundation excavation works in the outdoor switchyards. The ground resistance is measured after the installation of all grounding wires to be confirmed. An additional grounding wire is necessary when the ground resistance does not meet the specific design value.
Target values of the ground resistance are specified in the electrical preservation standard of the country, and the following values are referred to as well.

A power station under the directly grounded neutral system
(Neutral of the main transformer directly grounded) : Less than 1Ω
A power station under the non directly grounded system (Neutral of the main transformer non grounded, resistance grounding, reactor grounding, etc.) : Less than 10Ω

Reference of Chapter 10

[1] Medium and small scale hydropower handbook (5th revised edition) in Japanese, New Energy Foundation, 1997

[2] Guide manual for Development Aid Programs and Studies of Hydro Electric Power Project, New Energy Foundation, 1996

[3] Hydro turbine (in Japanese), Turbomachinery Society of Japan, 1991

[4] Electrical Engineering Handbook 6th Edition (in Japanese), IEEJ

[5] TURGOIMPULSE TURBINE Catalog, Gilkes Co.ltd.

[6] Reverse pump turbine Catalog, Kubota Corporation

[7] Design guide for water turbine auxiliary equipment (in Japanese), Electric Technology Research Association Vol.42-2

[8] Hydro turbine and pump turbine (Standard JEC-4001), IEEJ

[9] Gray cast iron valves (in Japanese), JIS-B2031

Chapter 11

Design of Distribution Facilities

Chapter 11 Design of Distribution Facilities

11.1 Mini-Grid Plan

Consideration of the following points is generally required when designing the distribution facilities for a mini-grid. It is necessary for planning and designing the distribution facilities to consider the safety and the life cycle cost. Therefore the facilities for a mini-grid are technically the same as the facilities for the conventional distribution system.

- Has the design satisfied the technical standards required for power facilities in the target country?
- Has the design satisfied the safety standards for the target country?
- Can you supply electrical power for all consumers at or above the quality of the electrical power standards of the target country?
- Has the cost of the equipment been minimized over the life cycle, not only of an initial investment but also of maintenance?

There is a limit of the amount of electrical power that can be supplied locally by a small scale hydropower station. Therefore, there is little need to consider the future expansion based on the long-term planning required for a large-scale system.

11.2 Distribution Methods

11.2.1 Distribution Voltage

Basically, the distribution voltage of the target country is specified by electrical power technical standards, with which both low and medium voltages must comply. If no particular specifications have been set, voltages specified by IEC (International Electrotechnical Commission) 60038 are preferred to. In general, 20kV/230 - 400V distribution methods are commonly used.

Table 11-1 Standard Voltages (Medium Voltage)

Series I (50Hz and 60Hz)			Series II (60Hz)	
Highest voltage for equipment (kV)	Nominal system voltage (kV)		Highest voltage for equipment (kV)	Nominal system voltage (kV)
3.6[1]	3.3[1]	3[1]	4.40[1]	4.16[1]
7.2[1]	6.6[1]	6[1]	-	-
12	11	10	-	-
-	-	-	13.2[2]	12.47[2]
-	-	-	13.97[2]	13.2[2]
-	-	-	14.52[1]	13.8[1]
(17.5)	-	(15)	-	-
24	22	20	-	-
-	-	-	26.4[2]	24.94[2]
36[3]	33[3]	-	-	-
-	-	-	36.5[2]	34.5[2]
40.5[3]	-	35[3]	-	-

Source: IEC60038, July 2002

Note: These systems are generally three-wire systems unless otherwise indicated. The values indicated are voltages between phases. The values indicated in parentheses should be considered as non-preferred values. It is recommended that these values should not be used for new systems to be constructed in future.
1) These values should not be used for public distribution systems. 2) These systems are generally four-wire systems. 3) The unification of these values is under consideration.

Table 11-2 Standard Voltages (Low Voltage)

three-phase four-wire or three-wire systems		Single-phase three-wire systems (including single-phase two-wire systems)
Nominal voltage (V)		Nominal voltage (V)
50Hz	60Hz	60Hz
-	120/208	120/240
-	240	-
230/400	277/480	-
400/690	480	-
-	347/600	-
1,000	600	-

Source: IEC60038, July 2002

Note: Where only a single value is shown, it is the line voltage for a three-wire system. Where two values are shown, they are voltage to ground/line voltage.

11.2.2 Medium Voltage Distribution Methods

Medium voltage distribution methods can be classified broadly by the neutral grounding method. They include a neutral point solidly grounding method; a neutral point resistively grounding method, an arc suppression coil compensated grounding method, and a non-grounding method. These are further classified as single or multiple grounding methods, according to the number of grounding locations. Table 11-3 shows the various neutral grounding methods and their characteristics. There are a lot of differences such as abnormal voltage at the grounding fault, inductive interference in telecommunication lines, and the rise of low-voltage electric potential when medium voltage lines come in contact with low-voltage lines. Therefore selections of the neutral grounding method are made primarily based on the distribution voltage and facility conditions. Generally, a non-grounding method is used for 11kV or less, and a neutral point resistively grounding method is used for 20kV or more.

Three-phase loads may be used for the distribution methods listed above. A SWER (Single Wire Earth Return) method can also be used if it is for the rural electrification of single-phase load only and the demand is small. As shown in Figure 11-3, the SWER method uses only a single medium voltage conductor, and an earth return system is used for the return circuit. Although the cost of the insulating transformers is high, the cost of the conductor drops as the distance becomes longer. Therefore, this method is used to where there are points of load across large areas, such as in New Zealand, Australia, and Africa. The advantages include a low initial investment and low maintenance costs. However, there are many problems, such as a possibility of an accident to the public caused by an electric current passing through large areas of the land, a large amount of electromagnetic induction in the communication equipment compared to other distribution methods, and a necessity to change to a single-phase two-wire method or other distribution methods in the case of the SWER method being unable to handle the load that exceeds a certain volume.

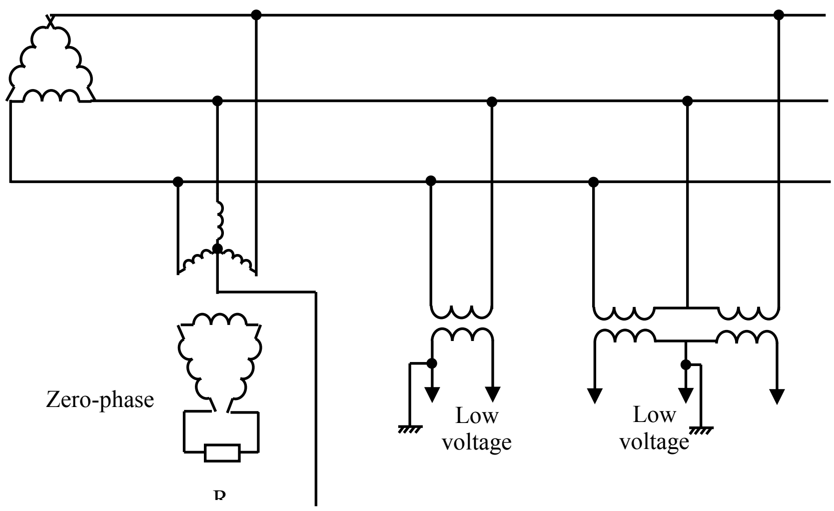
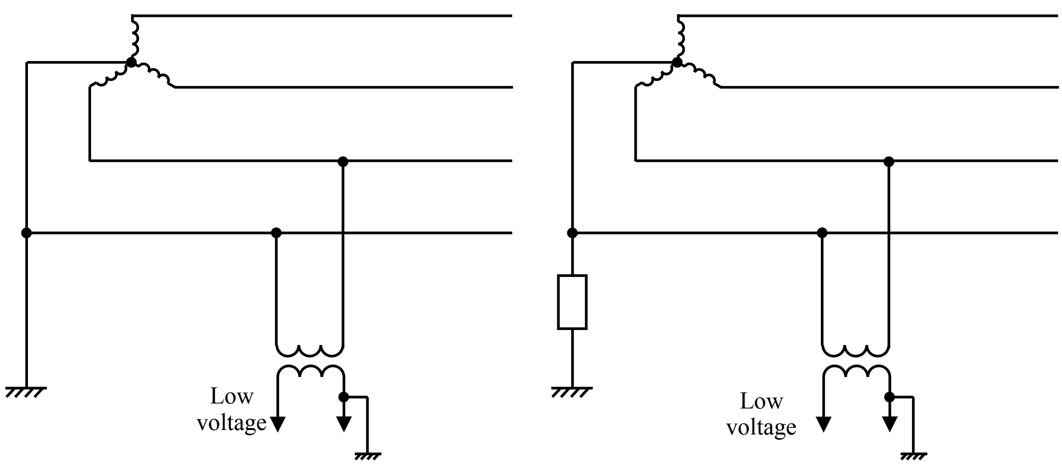


Figure 11-1 Non-grounding Method



(a) Single neutral point solidly grounding method (b) Single neutral point resistively grounding method

Figure 11-2 Neutral Grounding Method

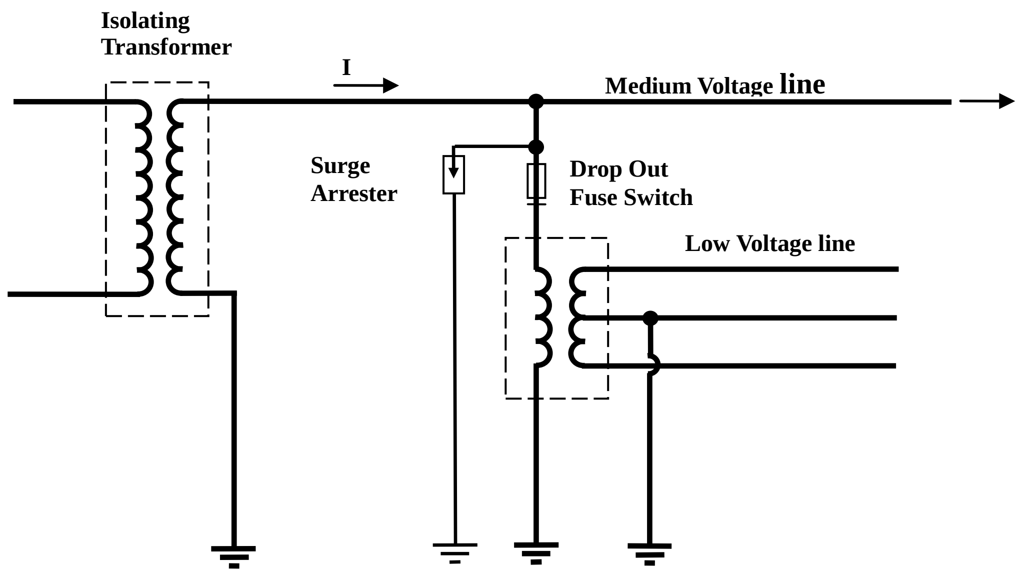


Figure 11-3 SWER Method

Table 11-3 Comparison of Grounding Methods

<table>
<tr><td colspan="3">Grounding method</td><td rowspan="2">Solidly grounding method</td><td colspan="3">Resistively grounding method</td><td rowspan="2">Arc suppression coil compensated grounding method</td><td rowspan="2">Non-grounding method</td><td rowspan="2">Remarks</td></tr>
<tr><td colspan="3">Item</td><td>40 to 90Ω</td><td>Around 200Ω</td><td>500Ω (22kV)
950Ω (33kV)</td></tr>
<tr><td rowspan="4">Abnormal voltage</td><td colspan="2">Switching surge</td><td colspan="6">There is a problem with input surge, and the size is not directly affected by the grounding method.</td><td rowspan="4">There are no grounding methods that are difficult to use for insulation design.</td></tr>
<tr><td rowspan="2">Single-line grounding fault</td><td>Steady state</td><td>1.3 times or less</td><td colspan="3">If R_0/X_1>10, 2.0 times or less
・Impedance of earth capacity that satisfies conditions of 2.0 times or less
R_N 50 190 950
X_C>250Ω>300Ω>600Ω
・X_C of model system
City 150 to 1,500Ω
Urban 180 to 6,700Ω
Rural 3,700 to 10,000Ω</td><td>If overcompensated, $\sqrt{3}$ times or less</td><td>If X_0/X_1<-10, 2 times or less</td></tr>
<tr><td>Transient</td><td>1.5 times or less</td><td colspan="3">If R_0/X_1>10, 3.0 times or less</td><td>If overcompensated, 2.5 times or less</td><td>If X_0/X_1<-10, 3 times or less</td></tr>
<tr><td colspan="2">One line disconnected</td><td colspan="4">No problem</td><td><table><tr><td>α</td><td>0.1</td><td>0.2</td><td>0.3</td><td>0.5</td></tr><tr><td>V_0</td><td>$5E_a$</td><td>$2.5E_a$</td><td>$1.7E_a$</td><td>E_a</td></tr></table>where α = overcompensation rate
$= (3X_L-X_C)/3X_L$</td><td>No problem</td></tr>
<tr><td>Induction toward communication line</td><td colspan="2">Single-line grounding fault Normally</td><td>Large
For multiple groundings, there might be interference from earth branches of load unbalance current.</td><td colspan="3">Medium
No problem</td><td>Small
No problem</td><td>Small
No problem</td><td rowspan="2">Neutral point solidly grounding cannot be used. Neutral point resistively grounding becomes more difficult to use for lower resistances.</td></tr>
<tr><td colspan="3">Rise in electrical potential on low voltage side when mixed with low voltage</td><td>Excessive</td><td>Large</td><td colspan="2">Medium</td><td>Small</td><td>Small</td></tr>
<tr><td rowspan="3">Grounding fault protection</td><td colspan="2">Wave distortion</td><td>No problem</td><td>Small</td><td colspan="2">Medium</td><td colspan="2">Large</td><td></td></tr>
<tr><td colspan="2">Applicable relays</td><td>OC</td><td>3CT+DG</td><td colspan="2">ZCT+DG
3CT+DG might also be used.</td><td colspan="2">CT+OCG, GPT+OVG, ZCT+DG
ZCT+DG might malfunction depending upon conditions at the fault point, and careful consideration of DG performance is required.</td><td>Although the development of a relay might be required, resolution of the problem is not difficult.</td></tr>
<tr><td colspan="2">Fault detection sensitivity</td><td>Cannot be set very high</td><td>100 to 900Ω (10 to 30%)</td><td>2,000Ω (10%)</td><td>4,500 to 8,500Ω (10%)</td><td colspan="2">About 10,000Ω</td><td>Figures shown in ( ) are the minimal detection sensitivity for DG.</td></tr>
</table>

Source: "20kV Distribution Method (Overhead Edition)", Vol. 30 No. 3, Electric Technology Research Association

Notes R_0: zero-phase resistance, X_1: positive-phase reactance, V_0: zero-phase voltage, OC: over current relay, OVG: grounding over voltage relay, 3CT: items using residual circuitry for 3 CT units of each phase, X_0: zero-phase reactance, X_C: earth capacity reactance, OCG: grounding over current relay, DG: directional grounding fault relay, ZCT: zero-phase current transformer, X_L: reactor reactance

11.2.3 Low Voltage Distribution Methods

Low voltage distribution methods include a single-phase two-wire method and a single-phase three-wire method for a lighting load, and a three-phase three-wire method for a dynamic load. In general, a three-phase four-wire method is used to supply both a lighting load and a dynamic load, and a star- connection three-phase four-wire method is common for the standard of 230/400V. The most suitable method is selected based on the configuration and density of demand in the area.

11.3 Distribution Line Planning

Distribution line planning requires consideration for not only construction but also maintenance in relation to the facility location, topography, the route, and the relationship with other structures. Specifically, the following should be considered when selecting the route.

- The route preferably follows roadways.
- There are fewer trees that would require cutting or clearing.
- The area is not susceptible to natural damages, such as land slides, avalanches, and flooding.
- Swamps and steep mountainous areas should be avoided.
- There are fewer river and roadway crossings. When the crossing is required, it can be done at a right angle.
- The route is straight and level as much as possible between the supports with equal spans on both sides.
- The supports can be built on risers firmly when passing through rice paddies and agricultural fields.

11.4 Electrical Design

11.4.1 Line Constants

As shown in Figure 11-4, distribution lines are electric circuits with four line constants: resistance, inductance, capacitance, and leakage conductance. These line constants must be known in order to calculate the electric properties of the distribution line. They are determined by the type, thickness, and layout of conductors, and they are mostly unaffected by voltage, current, and power factor. In addition, since the distribution lines have lower voltage and shorter lengths than the transmission lines, therefore normally only resistance and inductance need to be considered here.

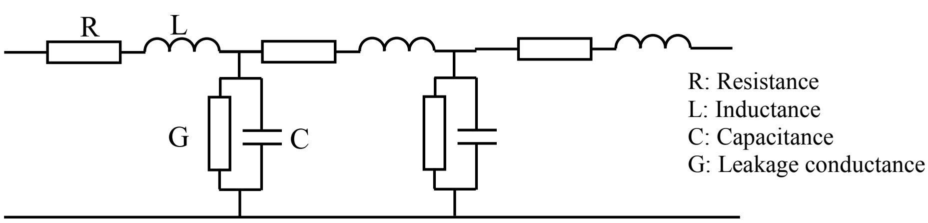


Figure 11-4 Line Constants

11.4.2 Voltage Drop

A voltage drop is the difference between the delivered voltage and the received voltage, occurring when there is a load current on a distribution line. The voltage drop is calculated in order to check the maximum and minimum voltages at each point to finally examine whether it is within a standard range. Normally, the standard range is stipulated in the electric power technical standards for the target country, and is generally within ±10% of the nominal voltage. Since the load of distribution lines is dispersed variously depending on the location, capacity, and type, it is difficult to calculate the voltage drop. Therefore, a normal method for determining an approximate value of voltage drop is to refer to the scattering loss coefficients for common forms of load distribution. However, it is also difficult to use this method when there are multiple power sources, making it necessary to use a software program to perform a load-flow calculation to find the voltage at each point.

11.4.3 Power Loss

A power loss in distribution lines is primarily a resistive loss in lines, an iron loss (no-load loss) and a copper loss (load loss) in transformers. A resistive loss in distribution lines is proportionate to the resistance and the square of current. A power loss W (W) is expressed with the following formula, where load current is I (A), resistance per one km of lines is r (Ω･km), length of line is L (km), and the number of lines is N:

$$W = I^2 rLN \text{ (W)}$$

Since the loss in transformers is determined according to the specifications of the transformer itself, a power loss in a transformer is one indicator of the quality of the transformer. A power loss P (W) in a transformer is expressed with the following formula, where an iron loss is Wi (W), a copper loss is Wc (W), and usage rate of the transformer is F:

$$P = Wi + WcF^2 \text{ (W)}$$

11.4.4 Fault Current

Electric faults can be classified into a grounding fault and a short circuit. A grounding fault occurs when trees or other objects come into contact with lines, or when lightning causes discharge in insulators, resulting in the flow of current into the ground and a grounding fault current value differs depending on the neutral grounding methods. As for a short circuit, the impedance of electric line becomes nearly zero at the point of the short circuit, and generally the current flows from the power source through the impedance of the line or transformer. Therefore, the value of a short circuit current is huge. A short circuit current causes the temperature of the line to rise and can do damage to the line, making it necessary to prevent the temperature from exceeding the allowable temperature for the line (the maximum temperature at which the usage is not impaired). It is accordingly necessary to cut off the current with an over current relay at the substation when a short circuit occurs, and to use electric lines that can resist the rise in temperature until such cut off occurs. Specifically, the allowable current for the shortest amount of time must satisfy the short circuit current. It is inversely proportional to the line impedance (distance from the power source) at the short circuit, growing larger as the power source approaches. Therefore the length of distribution line should be limited and it is necessary to put a switch to detect and cut the fault current such as reclocer in the middle of the feeder when the fault current is too small to detect it by the relay such as a short circuit between lines at the terminal.

Regardless of which type of fault, it is necessary to cope with the faulty current (short circuit current in particular) through the use of protection relays to detect the fault and circuit breakers to cut off the current, in order to prevent the fault from spreading to the entire power system as well as to protect the equipment on the load side.

11.4.5 Allowable Current

An allowable current is a maximum current, in accordance with the standards, that can pass through electric facilities such as electric lines. Physical objects have resistance to electricity, which results in the generation of heat when voltage is applied to and current flows through the objects. Even conductors such as electric lines have a small amount of resistance, which can generate sufficient heat to melt insulation and cause a short circuit, or possibly start a fire. Therefore, the allowable current is specified for electrical materials such as electric lines, and fuses and circuit breakers are used for protection. There are two types of allowable current: a constant allowable current regarding the continuous flow of current, and a short-time allowable current regarding the flow of current over a short period of time, such as a short circuit current.

The allowable current changes based on the following:

- Type of insulating body (because allowable temperature for insulation differs depending on insulating body)
- Electric line laying method (because the ease of thermal diffusion differs depending on laying method)
- Ambient temperature (when ambient temperature is low, the current required to reach the allowable temperature for insulation increases)

11.4.6 Inductive Interference

Inductive interference is a phenomenon by which electromagnetic induction in the current flowing through transmission lines and electrostatic capacitance in electric lines generates an electric current in other electric lines or communication lines, causing an injury to the people and interfering with telecommunications.

In general, there is electrostatic capacitance between the conductors located near each other. Such nearby conductors act accordingly as a kind of condenser, so that the charge in one of the lines will induce voltage in the other, even if they are not directly connected. This is called electrostatic induction. The size of the voltage occurring in the other conductor is determined based on the mutual electrostatic capacitance and the voltage of the first conductor.

Electromagnetic induction occurs when a fluctuating magnetic field caused by the current in one conductor intersects with another conductor, resulting in inductive voltage in the second conductor. The size is determined based on the mutual inductance, the current, and a parallel route length of the two conductors.

Normally, inductive interference almost never occurs because distribution voltage is small, and ground current is also small if a non-grounding method is used. However, inductive interference must be considered when distribution voltage is 20kV or greater, and it must be controlled below the allowable inductive interference value stipulated in the standards.

11.4.7 Insulation Design

Targets for insulation design can be broadly classified as follows: i) commercial frequency voltage, ii) internal abnormal voltage generated by internal factors, such as switching surges, and iii) external abnormal voltage caused by lightning surges. The basic concept for insulation design includes sufficient resistance of line insulation against internal abnormal voltage and no equipment insulation damage or flashover due to external abnormal voltage, and the use of lightning surge suppression in order to dramatically reduce flashover faults. Since the external abnormal voltage caused by lighting surges is much greater than that of i) or ii), suitable measures against the external abnormal voltage will be effective for all cases. Therefore, designs resistant to lightning form the basic concept for insulation design in distribution lines.

Arrestors are required to satisfy the following performance to meet the insulation level of the distribution line and protective coordination.

- The voltage level at which arrestors operate must be higher than the internal abnormal voltage that occurs in the distribution line.
- The lightning impulse limit voltage of arrestors must be lower than the insulation level of the insulators and equipment in the distribution line, with sufficient margin to allow protective coordination.
- The continuous cutoff voltage for arrestors must be higher than the maximum voltage occurring in the distribution line circuitry.

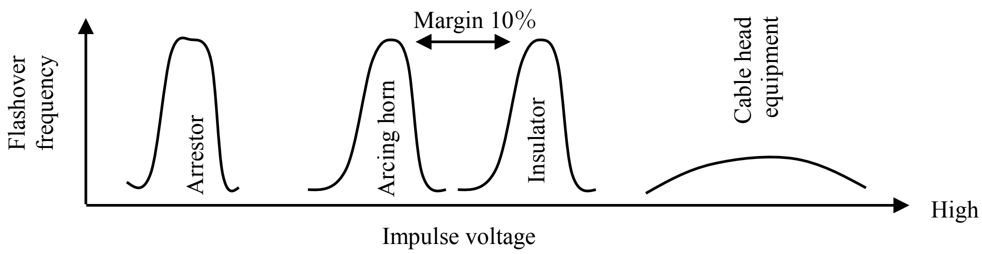


Figure 11-5 Example of Coordination of Insulation

11.5 Mechanical Design

11.5.1 Load on Distribution Lines

The loads on distribution line supports, electric lines, etc. include wind load, uneven tension between electric lines on both sides, own weight, and the weight of other supporting structures. Since these loads have a compounded effect on distribution lines, they must be classified separately when designing them according to the direction of action. They can be generally categorized into the following three:

- Vertical load (load acting upon a structure in the vertical direction)
- Horizontal lateral load (load acting upon a structure in the horizontal direction, perpendicular to electric lines)
- Horizontal longitudinal load (load acting upon a structure in the horizontal direction, parallel to electric lines)

Since supports for distribution lines are normally strong enough against a vertical load, it is necessary to consider during the design stage whether they can withstand horizontal loads.

11.5.2 Support Strength

Support strength refers to the moment of resistance for support against stresses such as the moment of bending. In other words, it refers to whether supports will break under such stresses. In general, supports must be designed so that the safety factor against a breaking load is the defined number in the standards of the target country or greater, and guys and struts must be used to distribute the load.

11.5.3 Guy and Strut Strength

Guys and struts can be used to distribute the load acting on supports for distribution lines. They are necessary to ensure the required safety factor against uneven tension generated when hanging conductors, the combined tension resulting from directional angles with conductors, and also uneven tension due to different span lengths on both sides of the support.

11.5.4 Support Foundation Strength

The support foundations must be set so that the moment of resistance for the ground on which the foundations sit is greater than the moment of rotation caused by external forces under the worst load conditions acting on the support. The strength of the foundations of the support will vary depending on the embedded length, the usage of guy anchors, and soil factors based on a type of soil.

11.5.5 Dip in Electric Lines

Although the tension on electric lines themselves is reduced and the safety is improved through a greater (deeper) dip in the lines, the height of the supports must be increased to keep the low-hanging lines up from the ground. This results in lateral oscillation caused by wind, increasing the possibility of faults due to tangled lines, etc. Therefore, the dip and tension that satisfy the safety factor must be considered during the design stage.

11.6 Design that Fits Local Features

11.6.1 Lightning Resistant Design

Lightning damage is done when lightning strikes a distribution line and causes an over voltage that damages the insulation. Such strikes that actually occur in the system are called lightning surges, and man-made ones for testing purposes are called lightning impulses. Lightning surges that damage distribution lines can be classified into three categories:

i) Induced lightning

Overvoltage generated by changes in the electromagnetic field near distribution lines caused by the flow of current when lightning strikes trees or structures near the lines

ii) Direct lightning

When lighting directly strikes a distribution line, causing an extremely large inflowing current and generating voltage

iii) Reverse lightning (reverse lightning current that occurs when lightning strikes a load structure)

When lightning strikes a structure or an antenna, high grounding resistance in the structure will cause a high grounding potential, and a portion of the lightning current will flow in the reverse direction along the distribution line to the power source. This phenomenon is called reverse lightning. Depending upon the composition of the electrical circuitry in the structure, it might escape from any harm with the damage only to the distribution line.

When creating lightning-resistant designs, it is necessary to understand the types and frequency of lightning surges occurring in distribution lines in order to come up with effective measures against lightning. Common methods used as measures to resist lightning include the following:

- Installation of arresters
- Installation of ground wires
- Installation of arcing horns
- Use of equipment with zinc oxide elements

11.6.2 Salt Resistant Design

Distribution lines in areas along coastlines are easily damaged by salt from seawater. Salt damage reduces electric insulation properties and leads to rust and corrosion in chemical metals. When the wind is strong, in particular, salt content adheres to distribution facilities, reducing the insulation properties over a wide range, and interfering greatly with the electric power supply.

Common measures against salt damage include the use of salt-resistant material to which salt will not adhere easily, and which resists interference even when some salt does accumulate. Salt-resistant material has the following properties: i) leakage distance is increased to reduce leakage current, ii) surface resistance is increased to limit leakage current, iii) shielding is added to prevent ingress of salt and moisture, iv) airtight seal to prevent exposure of charging areas, and v) surface treatment to prevent the adherence of salt on the surface of insulation.

11.7 Overhead Distribution Lines

There are overhead and underground distribution lines. Overhead distribution lines are common with mini-grids due to the low construction costs and the possibility of quick recovery in the event of a fault.

11.7.1 Supports

With overhead distribution lines, supports must be used to ensure that the lines remain at a height from the ground that is safe for both motorists and pedestrians. If a support should collapse, there is a high possibility of a personal injury and property damage due to the proximity between distribution lines and residential areas. Further, the reconstruction of the collapsed supports involves an additional cost and would require a service interruption in the surrounding area. Therefore, the avoidance of such problems requires the selection of supports that are strong enough against the load acting on them and durable enough for the use for a long time. Different types of supports include reinforced concrete poles, wooden poles, steel poles, and iron poles.

Reinforced concrete poles are economical and strong, and a most commonly used type of support. There are two types of reinforced concrete poles: cylindrical hollow poles compacted through centrifugal force, and rectangular poles made of concrete poured into the mold. These can be further divided into prestressed concrete pillars whose resistance to cracking is improved by applying compressive stress (prestress) to concrete with reinforcement bars that are under prior tension to increase nominal tensile strength, and concrete pillars that are not prestressed. Generally, prestressed pillars are more widely used due to their resistance to flexure and cracking.

Wooden poles are used in areas such as mountainous regions where it is difficult to bring in concrete poles or construct new poles. These poles require the injection of creosote or other wood preservatives to prevent a reduction in strength due to the decomposition of the wood in the portion of the pole to be embedded in the ground. The strength of wooden poles will vary depending upon the material used.

Figure 11-6 Reinforced Concrete Pole (Cylindrical)

Figure 11-7 Reinforced Concrete Pole (Rectangular)

11.7.2 Guys and Struts

Guys and struts are used in areas where the tension on electric lines acts unevenly on supports, such as at the ends of distribution lines and sections where lines curve. Tables 11-4 and 11-5 show different types of guys organized by function and structure. Struts are used where it is not possible to use guys for a land-related reason, and they are installed in the direction opposite to the guys to be installed if possible.

In general, galvanized steel stranded conductors are used for guys. In addition, anchors that can withstand the guy tension must be embedded in the foundation of guys.

Table 11-4 Types of Guys by Function

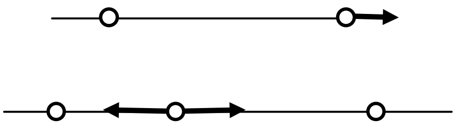
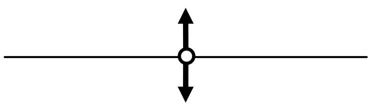
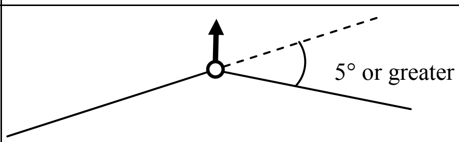
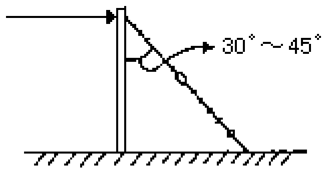
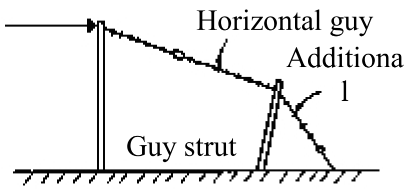
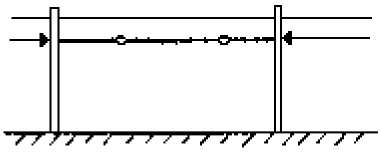
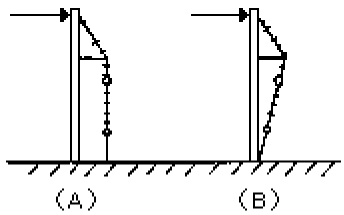
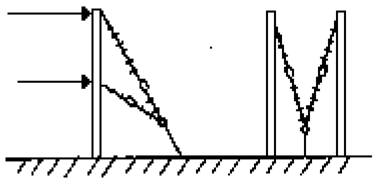
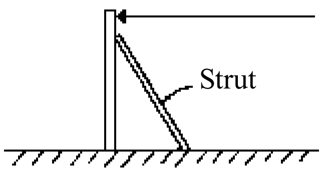
Type of guy	Structure	Function
Dead-end guy		Used to withstand uneven tension that occurs normally due to difference in the spans between anchor struts and supports for conductors
Vibration damping guy		Installed perpendicularly to conductors when supports are unable to withstand the wind load at right angles to conductors. Installed in appropriate areas along straight connections.
Angle guy		Installed to withstand combined tension generated when the angle of directional change of a line at a support is 5° or greater

Table 11-5 Types of Guys by Structure

Type	Structure	Features and description
Normal guy		Common type
Horizontal guy		Used when a normal guy cannot be used due to site conditions
Joint guy		Used to connect two supports
Bow guy		Used when anchoring distance for guys is insufficient due to site conditions, and when the tension of electric lines is below the regulated value
Y guy		Used to disperse the tension in electric lines
Strut		Used when a normal guy cannot be used due to site conditions

11.7.3 Crossarms

Crossarms are used to mount electric lines on supports. Wooden crossarms are used on wooden poles, and also need to be treated with creosote or other wood preservatives. Metal crossarms are used widely on all types of supports. They are made of rolled steel that is treated with a rust-resistant coating. Rack hardware is primarily used on supports for low-voltage lines.

Figure 11-8 Crossarms

Figure 11-9 Cable Supported by Rack Hardware

11.7.4 Insulators

Insulators are used to maintain insulation and also to mount electric lines when using metal crossarms. Insulators are grouped by voltage and the installation method of electric lines: pin insulators or line post insulators are used for bypass lines and bridle wires, and strain insulators or dead-end insulators are used to mount the ends of electric lines. Although porcelain is generally used for insulators, there are also polymer insulators made of light-weight silicon rubber for the use for medium voltage distribution lines.

Figure 11-10 Insulators (Pin Insulators are Porcelain, Strain Insulators are Polymer.)

11.7.5 Conductor

A single conductor is commonly made up of several individual strands. Copper and aluminum are commonly used as conductors due to their low resistance, and there are a variety of structures including bare conductors or the use of insulation, various materials, and steel cores. Since conductors used in overhead distribution lines are often located near residential areas, insulated conductors are normally used for low voltage lines on safety consideration.

When selecting a conductor, it is necessary to consider a type and a sectional area according to the allowable current required, topography of the route, mechanical strength, resistance to corrosion, economical efficiency, and other factors.

Figure 11-11 Bare Conductor for Medium Voltage

Figure 11-12 Insulated Conductor for Medium Voltage

Figure 11-13 Overhead Cable for Medium Voltage

Figure 11-14   Insulated Conductors for Low Voltage

11.7.6 Transformers

Overhead distribution lines normally have pole transformers to step down the voltage from medium voltage. Most pole transformers are of oil-filled self cooling type in which the main transformer unit (core and windings) is immersed in insulating oil. Silicon steel strips are widely used for the core. Grain-oriented silicon steel strips can be used to reduce loss, and amorphous materials are also sometimes used to reduce loss even further. There are two types of transformers, single-phase and three-phase, and wiring methods vary depending on medium or low voltage distribution. Two single-phase transformers with V wiring can be used for a three-phase load, and single-phase transformers with different capacities and V wiring can be used for a combined single- and three-phase load with a three-phase four-wire method.

The primary indicators of transformer performance are no-load current, no-load loss, voltage regulation, and efficiency. When selecting a transformer, it is necessary to consider not only suitable capacity for the load, but also performance indicators such as no-load loss and efficiency.

Figure 11-15   Three-Phase Transformer

Figure 11-16 Single-Phase Transformers

11.7.7 Switches

Switches can cut off an electric current, and are used to disconnect areas of distribution lines that have been involved in a fault, or to limit the range of power outage when repairs to distribution lines are required. Varieties of arc suppressing media are used, such as oil-filled switches, air switches, vacuum switches, and gas switches. The use of oil-filled switches is not recommended for overhead distribution lines in public areas due to a possibility of fire if a short circuit occurs. There are also some switches with built-in transformers for controlling the system, arrester components, and a variety of other sensors.

Figure 11-17 Switches

Cutouts are switches with built-in fuses that are installed on the primary sides of transformers. If an overload or an internal short circuit occurs on the transformer, they automatically disconnect the transformer from the distribution line and can be used as switches on the primary side. They are also used as switches for branching distribution lines with a small load current. Some also have built-in arresters.

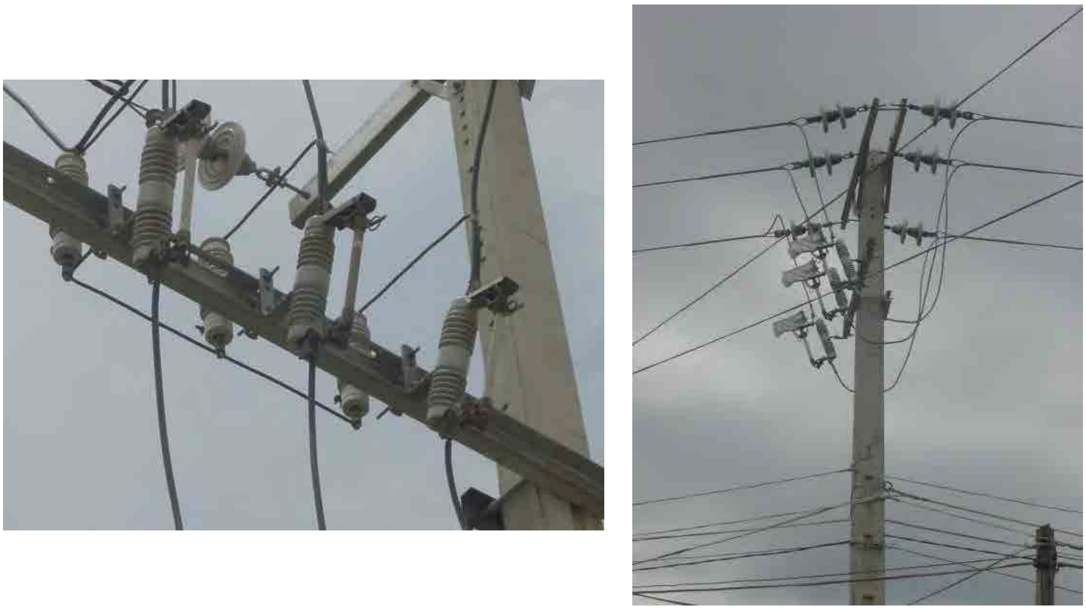


Figure 11-18 Cutouts

11.7.8 Arresters

Arresters are installed between distribution lines and earth to protect distribution facilities from lightning surges. Many are made of zinc oxide (ZnO) components, nonlinear resistive elements. Arresters operate most effectively when installed as near as possible to the equipment to be protected.

Figure 11-19 Arresters (for Cable Head Protection)

11.8 Underground Distribution Lines

Underground distribution lines are used when it is impossible to use overhead distribution lines for a mini-grid (such as when it is impossible to keep the lines safe above the ground).

11.8.1 Cable Laying Methods

There are three methods for laying cable underground: a directly embedding method, a conduit method, and a culvert method. The directly embedding method is used when there are few components to embed, such as few main lines and service drops. Protective case is laid underground, and then the cable is pulled in to be embedded. This method requires excavation when the cable must be replaced. The conduit method is used in areas where there are many cables to spread, and in areas where excavation would be difficult due to large traffic or pavement. Several lengths of pipes are connected with manholes or handholes at intervals. Since all pulling in, pulling out and connection work is performed via manholes or handholes, re-excavation is not necessary. The culvert method involves constructing a tunnel-shaped structure in advance, and then laying cables on the mounts that have been installed along the side walls of that structure. This method is used in areas where there are many cables to spread, and where cables need to be embedded together with telecommunication lines and so on. The directly embedding method is almost always used for mini-grids that supply electricity locally, unless excavation would be difficult such as when the cables cross paved roadways.

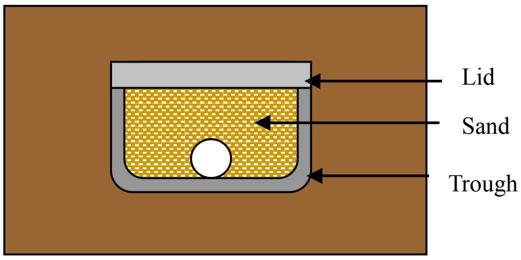


Figure 11-20 Directly Embedding Method

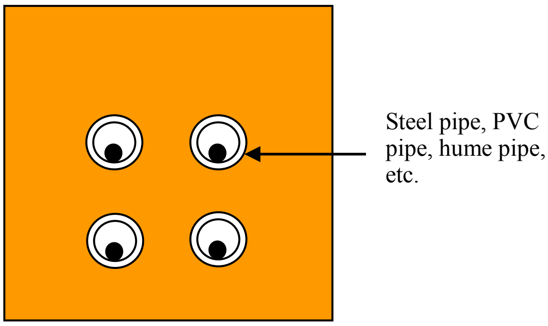


Figure 11-21 Conduit Method

11.8.2 Cables

Most cables used for underground distribution lines are CV cables (cross lined polyethylene insulated PVC sheathed cables).

CV cables are primarily made up of conductors, insulating materials, a shielding layer (medium voltage only), and an exterior (sheath). An additional exterior layer to prevent wear and an anti-corrosion layer can be also added, as necessary. Copper or aluminum is used as a conducting material. Although aluminum is generally less expensive than copper, it also has a lower electrical conductivity, and the cost for insulating materials and a sheath make up a large part of the price when used for medium voltage cables. Therefore, copper is often used to make cables of a smaller diameter.

When selecting cables, it is necessary to consider a type and a sectional area based on the allowable current required, resistance to corrosion, and economical efficiency.

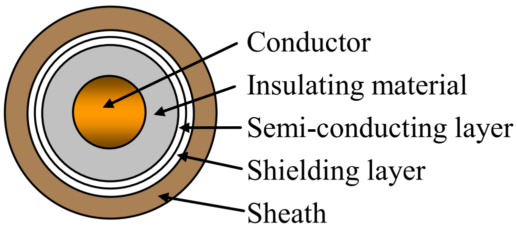


Figure 11-22 Single-core Cable

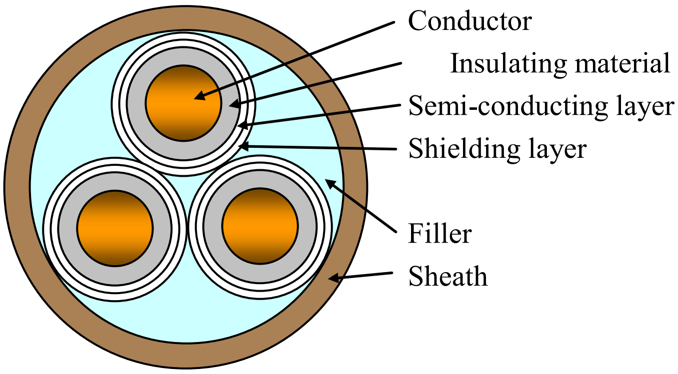
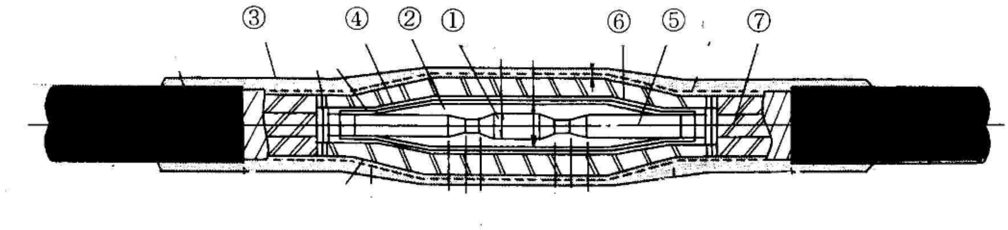


Figure 11-23 Three-core Cable

11.8.3 Interconnection Material, Terminal Connection Material

Interconnections, used to connect different cables, can be classified as direct connections or branched connections (Y branches and X branches). Connections of conductors normally include compressed joints and clamped connections using wedges, which are then covered with a pre-fabricated insulation tube and then waterproofed with tape. In addition, such material as is shrinkable at room temperature has also been developed to reduce labor and make the work easier.

Terminal connections are used to connect cables with overhead lines or electrical machinery. Terminal connection material (cable head) is used to maintain the electric insulation at the terminal of the cable. Although insertion-type terminal connectors made from rubber molds or insulating tubes are normally used, such types as are shrinkable at room temperature are also becoming more common.



① Connecting pipe

② Adhesive polyethylene tape

③ Waterproof tape

④ Lead tape

⑤ Cross-linked polyethylene

⑥ Semi conductive fusion bonding tape

⑦ Cable shielding copper tape

Figure 11-24 Example of Connections in Medium Voltage Cable

11.9 Service Drops

Service drops are electric lines that branch from distribution lines and come into customers' homes. Normally, the point of insertion is the property demarcation point and the obligation demarcation point (demarcation points for maintenance and security between power companies and customers). If watt hour meters are installed on poles to prevent the theft of electricity and the secondary side of a watt hour meter is at the property demarcation point or the obligation demarcation point, the customer will be mostly required to install electric lines as service drops to his/her residence or business.

11.9.1 Selection of Service Drops

In the same manner as when selecting electric lines and cables, it is necessary to select lines with conductors and a sectional area of sufficient mechanical strength for the allowable current that is required, and to keep voltage drops within the allowable range. Since service drops are installed near residential areas, insulated conductors are normally used on safely consideration.

11.10 Watt Hour Meters

Watt hour meters measure the amount of electricity used by customers, to calculate electricity rates based on the contracts between the power company and the customers. The type of watt hour meter used will vary according to a type of contract. There are also some cases where watt hour meters are not installed, such as for public street lighting, and for customers with small-scale demand whose usage conditions are almost always the same. In some instances, load limiters might be used in place of watt hour meters to ensure a more consistent electricity rate when compared with the cost required to calculate the rates by reading meters. Recently prepayment watt hour meters are used by the same reasons.

11.10.1 Types of Watt Hour Meters

Watt hour meters are broadly classified into two types according to operating principle: induction-type mechanical watt hour meters and electrical watt hour meters. Induction-type watt hour meters are commonly used. Electromagnetic induction is used to rotate a circular aluminum plate based on the multiplication of current and voltage. This rotating plate turns the gears on a display panel to mechanically calculate and indicate the amount of electric power used. Electrical watt hour meters use electrical circuitry for calculation or display, or both. The processing components can be either analog or digital.

These devices are also classified into four types according to the method of supplying electric power: a single-phase type, a three-phase type, a type with current transformer, and a type with voltage and current transformer. They are further classified according to measuring precision. For common low-voltage single-phase instruments, most watt hour meters have an error within ±2.0%. Some models are weatherproof, which might be classified depending upon the environmental performance.

Prepayment watt hour meters are classified into an all-in-one type with a keypad for charging the usable amount by inputting certain digit numbers like prepaid cellular phones, a split type with a communication terminal and an IC card for charging the usable amount and monitoring the remaining amount and so on. They are more expensive than others and the installation cost of the system is also high. However they become widely used because there are a lot of advantages such as prevention of nonpayment, costless for reading meters, etc.

Figure 11-25 Watt Hour Meters

(a) All-in-one type

(b) Communication terminal and IC card

Figure 11-26   Prepayment Watt Hour Meters

11.10.2 Types of Current Limiters

Current limiters are used to limit the use of electric current. They are designed for repeated use without consumable parts such as fuses. Current limiters are selected with a rated current that matches the current contracted by the consumer.

Figure 11-27   Current Limiter

Reference of Chapter 11

[1] Overall Manual on Distribution Technique (in Japanese), Ohmsha, Ltd., 1991

[2] Dissemination and Technology on 20kV / 400V Distribution Method, Vol. 56, No. 3 (in Japanese), Electric Technology Research Association, 2000

[3] Handbook on Electrical Engineering 6th Edition (in Japanese), the Institute of Electrical Engineers of Japan

[4] Guide of Lightning Protection Design for Power Distribution Lines (in Japanese), Central Research Institute of Electric Power Industry, 2002

[5] Mini-Grid Design Manual, ESMAP, 2000

Chapter 12

Construction and Procurement

Chapter 12 Construction and Procurement

12.1 General

For the rural electrification by small scale hydropower, it is often difficult to recover construction costs through only income from electrical charge. Therefore, it is necessary to prepare logical and detailed cost estimation data for fund raising from financing or aid organizations because a part or total of construction costs are often a subsidy or an aid from the government or aid organizations.

12.1.1 Component of Project Cost

The project cost consists of construction cost, engineering fee and owner's project management cost. The construction costs of power plant and electricity distribution facility of the rural electrification by small scale hydropower are roughly divided into the costs of civil structures, electro-mechanical equipment and distribution facilities. The cost estimating methods differ from countries and aid organizations but the following methods are generally adopted for facilities.

- Civil structures: a bill of quantity method is applied. Bill, unit cost and quantity which is calculated from the drawings are multiplied and direct construction costs are obtained. And its overhead costs are added.
- Electro-mechanical equipments: a quotation method the costs of which are estimated by the manufacturers according to the technical specification indicated by the client. Quotations usually include the installation work.
- Distribution facilities: a combination type of above two methods

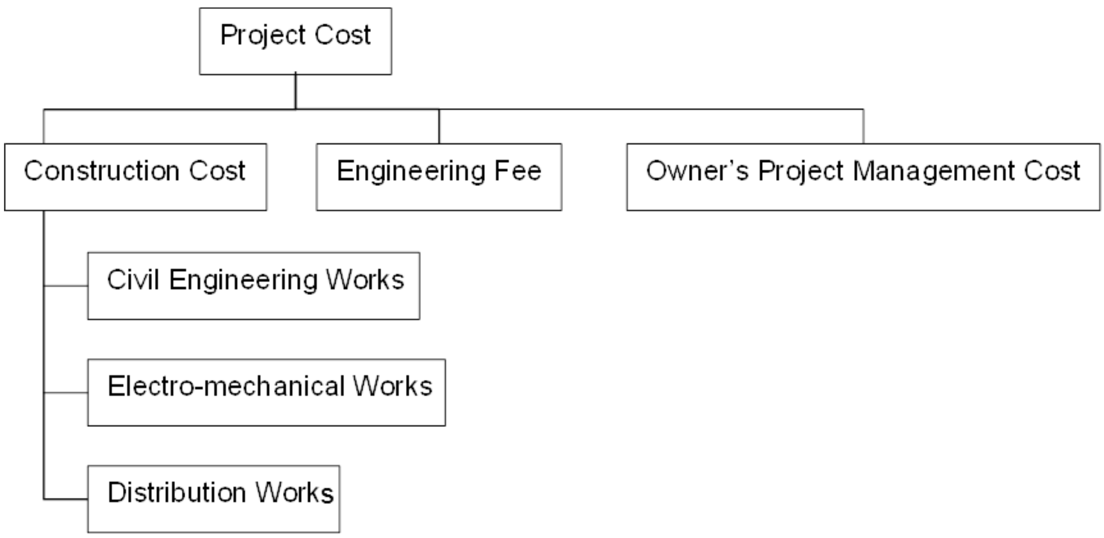


Figure 12-1 Component of Construction Cost

12.1.2 Points to Consider for Cost Estimation

The costs should be estimated including contingency by surveying current market prices etc. in order to avoid the project deadlock at an implementation stage caused by too low a budget estimated for the purpose of promoting the project.

Regarding the estimation of construction costs, it is necessary to prepare estimate data which are clear and logical for a demand of disclosure to a financing or aid organization. The costs should be considered especially for the following 3 points

- Clear basis of estimation
- Being not much different from market prices
- Possibility of local employment
- Possibility of procurement of resources such as materials and equipment

Assumed procurement places of equipment, materials and suppliers are shown in Table 12-1.

Table 12-1 Assumed Procurement Place

Item		At the Site	Domestic	Import
1.	Civil structures; Construction material			
	Sand, Gravel, Stone	○		
	Cement	○		
	Steel		○	
	Other construction materials	○	○	
2.	Electro-mechanical equipment			
	Turbine			○
	Generator			○
	Control panel			○
3.	Distribution line facilities			
	Pole		○	○
	Electric wire, cable		○	○
	Transformer, switch and others		○	○
	Telecommunication system		○	○

Note: Mark of ○ is an example place that is generally adopted, however, procurement place should be selected considering the special condition of the project.

12.2 Civil Structures

A method of construction cost estimate described in this section is not for planning stage but for construction stage which requires precise estimate for actual construction.

12.2.1 Cost Structure

The costs of civil structures consist of generating facilities such as intake weir, settling basin, headrace, head tank, penstock, powerhouse and tailrace, and auxiliary facilities such as maintenance roads and administration buildings. In addition, temporary work for those permanent structures is included.

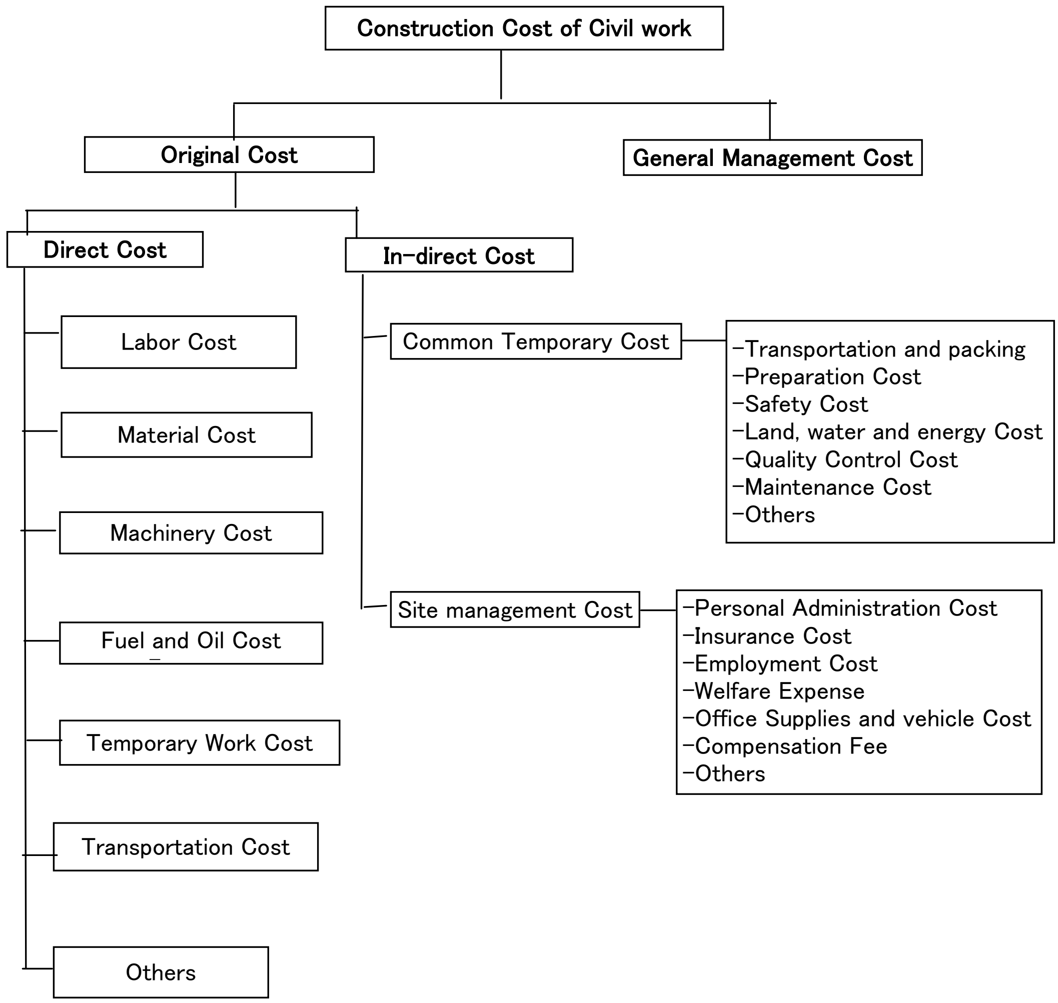


Figure 12-2 Component of Cost for Civil Engineering Works

Figure 12-2 shows an example of the components of the costs for civil engineering works classified by the client's cost estimation.

However, an actual construction contract is often made by defining the unit price of each work type and provisionally deciding the amount as shown in the following equation.

Cost = Quantity × Unit cost

As for most civil engineering works, the bill of quantity (price schedule) is applied.

Calculation method of quantity and unit cost are described in the next section.

12.2.2 Quantity

In order to make a construction planning and estimate the construction costs, it is necessary to estimate at least the amount of main facilities shown in Table 12-2

Table 12-2 Quantity Items of Civil Structures

	Name	Excavation (m^3)	reinforcing (kg)	Concrete (m^3)	Form (m^2)	Scaffolding (m^2)	Supporting (m^3)	Steel (kg)	Others
	(Generatig Facilities)								
1	Intake weir and Intake	○	○	○	○	○	○		
	Gate and Trashrack							○	
2	Settling basin	○	○	○	○	○	○		
	Gate and Trashrack							○	
3	Headrace	○	○	○	○				
4	Head tank	○	○	○	○	○	○		
	Gate and Trashrack							○	
5	Penstock	○	○	○	○				
	Steel pipe							○	
6	Spillway	○	○	○	○			○	
7	Powerhouse	○	○	○	○	○			○
8	Tailrace	○	○	○	○			○	
	(appurtenant work)								
9	Maintenance Road	○	○	○	○				
10	Administration Building	○	○	○	○	○		○	
11	Water and Sanitary system								○
12	Electrical system								○

There might be projects which is necessary to estimate quantity of temporary work as shown in Table 12-3.

Table 12-3 Item of Preparation and Temporary Work

	Item	Rough Indicator
1	Logging and stripping	Area and number of trees
2	Labor camp	Total labor and period
3	Care of river for intake structure	Same as direct cost
4	Care of river for powerhouse and tailrace	Same as direct cost
5	Reclamation for temporary yard	Lease contract is basic.

12.2.3 Unit Cost

Unit cost of construction work corresponding to the quantity mentioned in the previous section is estimated as below:

(1) Components of unit cost

An example of components of unit cost generally applied for the site work is shown in Table 12-4.

Table 12-4 Components of Unit Construction Cost

	Item	Description	Note
i)	Labor cost	Cost for labors who are involved in the construction work directly: special skilled persons such as operators, carpenters, reinforcing bar workers, welding operators, and common workers etc.	
ii)	Material cost	Hire cost for materials such as cement, sand, aggregates, woods, reinforcement, steel, forms, scaffolds, supports, etc.	
iii)	Machinery cost	Hire cost or lease charge for construction equipment such as bulldozer, backhoe, dump track, crane etc.	
iv)	Fuelcost	Fuel and lubricant for construction equipment such as gasoline, diesel oil, electric energy, etc.	
v)	Temporary work cost	Cost for Temporary facilities, equipment, electric energy, water, fences, etc.	
vi)	Transportati -on cost	Cost for transportation and wrapping of construction materials and equipment	In the case of long distance of transportation, this category is separated

(2) Market price survey

For cost estimation mentioned above, special knowledge of construction method and man-days of work is necessary. When without such detailed knowledge, first of all, market price survey is recommended. The following should be also considered.

- Obtaining more than three quotations

  When a request of proposal is offered, details of estimate condition, time schedule, quantity and specification should be defined. And quotations should show not only the total amount but also the details such as material cost, labor cost and machinery cost.

- Selecting reliable procurement companies

  To prevent troubles such as inferior quality, delay of delivery date, cancel due to bankruptcy etc., reliable procurement companies should be selected.

(3) Adopted unit cost

Each result of evaluation of quotations and cost estimation should be summarized in the table. Examples of form of table of unit cost, labor cost, material cost, machinery cost and construction work cost are shown in Appendix A-12-1 to A-12-4 respectively.

Bill of quantity for direct construction cost is made utilizing the quantity and unit price mentioned in the previous sections.

Table 12-5 shows an example of bill of quantity of the direct construction cost for civil works.

(4) Direct construction cost

Table 12-5 Example of Price Schedule of Direct Construction Cost for Civil Engineering Works

Bill of Quantity for Direct Construction Cost

Exchange rate	Local currency/ U.S.$

Item / Name	Class	Specification	Unit	Quantity	Unit Cost	Amount	Note
1 Access Road							
Clearing and Grubbing			m^2				
Excavation	Soil	including slope forming	m^3				
Excavation	Rock	including slope forming	m^3				
Disposal of excavated soil	Soil	including transportation to disposal site	m^3				
Disposal of excavated rock	Rock	including transportation to disposal site	m^3				
Backfill	Soil	Using excavated soil	m^3				
Concrete	18N	For wall structure	m^3				
Concrete	21N	For drainage structure	m^3				
Formwork		Wall	m^2				
Formwork		Drainage	m^2				
Reinforcement work		SD-295A	t				
Scaffolding		For concrete placing	m^2				
Gravel Compaction		T=200 mm	m^3				
Backfill		Clashed stone	m^3				
Sub-total							
2.2 Intake Weir							
Clearing and Grubbing			m^2				
Excavation	Soil	including slope forming	m^3				
Excavation	Rock	including slope forming	m^3				
Disposal of excavated soil	Soil	including transportation to disposal site	m^3				
Disposal of excavated rock	Rock	including transportation to disposal site	m^3				
Backfill	Soil	Using excavated soil	m^3				
Gabion		Wire mesh T=50cm	m^3				
Concrete	18N	For body structure	m^3				
Concrete	21N	For reinforcement concrete	m^3				
Formwork		For weir structure	m^2				
Formwork		For sedimentation structure	m^2				
Scaffolding		For concrete placing	m^2				
Water proofing		T = 200 mm	m				
Concrete Joint		T = 10 mm	m^2				
Reinforcement work		SD-295A	t				
Handrail		h=1000mm	m				
Gate and Trash rack			L.S.				
Care of River			L.S.				
Sub-total							
2.3 Headrace channel							
Excavation	Soil	including slope forming	m^3				
Excavation	Rock	including slope forming	m^3				
Disposal of excavated soil	Soil	including transportation to disposal site	m^3				
Disposal of excavated rock	Rock	including transportation to disposal site	m^3				
Backfill	Soil	Using excavated soil	m^3				
Concrete	18N	For body structure	m^3				
Concrete	21N	For reinforcement concrete	m^3				
Formwork		For weir structure	m^2				
Formwork		For sedimentation structure	m^2				
Scaffolding		For concrete placing	m^2				
Water proofing		T = 200 mm	m				
Concrete Joint		T = 10 mm	m^2				
Reinforcement work		SD-295A	t				
Sub-total							

Table 12-5 Example of Price Schedule of Direct Construction Cost for Civil Engineering Works（Cont.）

Bill of Quantity for Direct Construction Cost

Exchange rate	Local currency/ U.S.$

Item / Name	Class	Specification	Unit	Quantity	Unit Cost	Amount	Note
1 Access Road							
Clearing and Grubbing			m^2				
Excavation	Soil	including slope forming	m^3				
Excavation	Rock	including slope forming	m^3				
Disposal of excavated soil	Soil	including transportation to disposal site	m^3				
Disposal of excavated rock	Rock	including transportation to disposal site	m^3				
Backfill	Soil	Using excavated soil	m^3				
Concrete	18N	For wall structure	m^3				
Concrete	21N	For drainage structure	m^3				
Formwork		Wall	m^2				
Formwork		Drainage	m^2				
Reinforcement work		SD-295A	t				
Scaffolding		For concrete placing	m^2				
Gravel Compaction		T=200 mm	m^3				
Backfill		Clashed stone	m^3				
Sub-total							
2.2 Intake Weir							
Clearing and Grubbing			m^2				
Excavation	Soil	including slope forming	m^3				
Excavation	Rock	including slope forming	m^3				
Disposal of excavated soil	Soil	including transportation to disposal site	m^3				
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Formwork		For weir structure	m^2				
Formwork		For sedimentation structure	m^2				
Scaffolding		For concrete placing	m^2				
Water proofing		T = 200 mm	m				
Concrete Joint		T = 10 mm	m^2				
Reinforcement work		SD-295A	t				
Handrail		h=1000mm	m				
Gate and Trash rack			L.S.				
Care of River			L.S.				
Sub-total							
2.3 Headrace channel							
Excavation	Soil	including slope forming	m^3				
Excavation	Rock	including slope forming	m^3				
Disposal of excavated soil	Soil	including transportation to disposal site	m^3				
Disposal of excavated rock	Rock	including transportation to disposal site	m^3				
Backfill	Soil	Using excavated soil	m^3				
Concrete	18N	For body structure	m^3				
Concrete	21N	For reinforcement concrete	m^3				
Formwork		For weir structure	m^2				
Formwork		For sedimentation structure	m^2				
Scaffolding		For concrete placing	m^2				
Water proofing		T = 200 mm	m				
Concrete Joint		T = 10 mm	m^2				
Reinforcement work		SD-295A	t				
Sub-total							

(5) Adding up of original cost

Quantity is multiplied by unit cost and original costs are obtained. Summary of bill of quantity is shown in Table 12-6.

Table 12-6 Example of Bill of Quantity for Original Cost

	item	Unit	Quantity	Unit cost	Amount	Note
Ⅰ	**Original cost**					
1	Direct cost					
2	In-direct cost					
	(1) Common temporary cost					
	(2) Site management cost					
	Sub-total					
Ⅱ	General management cost					
Ⅲ	Total					

12.3 Electro-mechanical Equipment

Classified as electro-mechanical equipment are a water turbine, a generator, a main transformer, switchgears, control equipment, auxiliary equipment, and other equipment. The price of above equipment is estimated assuming that it is ordered from manufacturers or agencies like general trading companies. Most of the equipment is assumed to be import goods, and it is necessary to make specifications and a contract applying guidelines on FIDIC as a worldwide standard. As a matter of contract, it is not classified for separate bids but in general a package deal is adopted because of a possible cost reduction out of economies of scale as well as a probable reduction of paperwork. An example of the construction cost list of electro-mechanical equipment is shown in Table 12-7.

The construction costs of the equipment are estimated from the contract results of similar equipment and from hearings on the quotations from plural suppliers. In the selection of the cost estimate inquiry, and the decision of the contract, prior investigations should be done regarding the delivery results of a similar product and the operation record as well as the quality and reliability of the product. In this case, a price should not be of the highest priority, and risks of increasing construction costs, damage due to delayed completion, maintenance expense increases after commissioning and price increases of the spare parts should be taken into consideration.

The obligation demarcation of supply and construction with other parts such as civil engineering facilities should be clearly defined and due care must be taken to avoid defects in procurement and construction. It is necessary to pay attention to the interfaces in particular, such as the welding work between a final piece of the penstock and a turbine inlet pipe, the connection of a transmission line feeder and a power station bus bar, and the electricity delivery points to other civil and architectural equipment.

Table 12-7 Example of the Construction Cost List of Electro-mechanical Equipment

Item	FC	LC	Total	Remarks
Turbine Turbine Installation				
Generator Generator Installation				
Main Transformer Main Transformer Installation				
Switchgears and Control equipment High Voltage switchgears Metal Enclosed Switchgears Control Equipment Water Level measurement equipment Transmission Line Protection system Tele-control Equipment Main Circuit Bus (IPB, SPB, CV-cable) Power and Control Cable and Rack Installation				
Steel Structure				
Auxiliary Equipment Station Service Transformers Crane DC Power System and CVCF Arrestor Emergency generator Grounding Wire				
Spare parts				
Other Equipment Testing equipment Plant Communication System				

12.4 Distribution Facilities

12.4.1 Cost Structure

Distribution facilities consist of supports (concrete poles), conductors, cables, transformers, switches, communication facilities, and so on.

Distribution facilities work is in many cases classified into procurement of materials and equipment, and installation/construction work of the procured materials and equipment. Taking a power pole as an example, procurement covers the purchase of a power pole and its transportation to the construction site, and construction work is to install it at the site. Breakdown of unit prices for installation/construction work is the same as for civil engineering works except a power pole itself.

In most cases where the construction contract is made, the unit price of each item is defined and the amount is provisionally decided. The formula is shown as follows;

$$\text{Cost} = \text{Quantity} \times \text{Unit Price}$$

Construction cost of distribution facilities is calculated in the same way as of civil engineering works, which is the total of direct work cost, indirect work cost consisting of common temporary facilities cost and site management cost, and general management cost.

As for procurement, the contract is also based on quantity and unit prices, but indirect work cost is not required with general management cost added only.

12.4.2 Quantity of Construction

It is necessary to understand the type and the amount of the main equipment that are shown in Table 12-8 to establish the construction plan and the costs of construction.

Table 12-8 Main Distribution Facilities

No.	Facility Item	Unit	Remarks
1	MV Overhead Lines	cct-m	line type, cross section
2	LV Overhead Lines	cct-m	line type, cross section
3	MV Underground Cables	cct-m	line type, cross section
4	LV Underground Cables	cct-m	line type, cross section
5	Supports	-	type, length, strength
6	Pole Mounted Transformers	-	type, capacity
7	Switches	-	type, capacity
8	Watt-hour Meters	-	type, capacity

In addition, it is necessary to calculate the incidental costs such as those of cutting trees, etc.

12.4.3 Unit Price of Construction

A general unit price composition is as follows.

i) Materials expenses

ii) Shipping expenses

iii) Labor costs

Table 12-9 shows examples of unit price composition.

Table 12-9 Example of Composing the Unit Price

Item	Total Cost	Local Currency	Foreign Currency		Remarks
		Price Including Tax and Local Transport	CIF	Local Transport	
① Materials					
(a) 22kV Overhead Lines					
(b) Pole Mounted Transformers					
(c) Indoor Substations					
(d) 22kV Underground Cables					
(e) LV Lines					
(f) Watt-hour Meters					
(g) Radio Receivers					
Subtotal					
② Machines and Tools					
(a) Machines					
(b) Tools for Overhead Lines					
(c) Tools for Underground Cables					
(d) Consumables					
Subtotal					
③Installation and Construction					
(a) 22kV Underground Cables					
(b) LV Underground Cables					
(c) 22kV Overhead Lines					
(d) LV Overhead Lines					
(e) Switches					
(f) Watt-hour Meters					
Subtotal					
Total					

12.5 Planning of Construction Schedule

Hydropower utilizes circulating natural water energy; it is better to commence generating hydro-energy as early as possible. It is preferable accordingly to complete the construction in as short a period as possible in which the required safety is secured in terms of quality and performance.

However, actual construction work is affected by not only natural conditions such as climate, hydrology, topography and geology but also resource conditions such as laborer's performance, construction machinery arrangement and equipment procurement procedure. Therefore, a realistic construction schedule shall be planned.

It is necessary to consider especially the following points for planning the construction schedule.

- Traffic conditions in each season including the presence of a detour
- Difficulty of transportation of construction materials and equipment
- Effect on the construction work of the river discharge, rainfall pattern etc.

An example of construction schedule is shown in Table 12-10 which is the rough preparation of a basic construction schedule based on the followings..

(1) Rough indication of total construction period

1) Procurement

A series of procurement procedure such as construction announcement, contractor's estimation, evaluation of proposals and contractor's selection, generally requires 2 to 3 months. However, preparation of tender documents such as technical specifications and drawings for procurement bid, and preparation of contract are not included in the above period.

2) Contract negotiation

In a case where the negotiation failed with the first negotiating contractor, it will generally take around 1 month until the contract is finally signed by one of the next negotiating contractors.

3) Construction period at the site

It generally requires around one year to one and half years from the date of the contract to the date of completion or handover to the client. A construction schedule is different from a fund payment schedule. Those schedules should be separated.

(2) Preparation work

i) Preparation works: 1 to 3 months

ii) Temporary works: about 1 month

iii) Maintenance road and access road: It depends on the site conditions

(3) Civil engineering works

The entire civil engineering works generally take around one year to one and half years.

i) Intake weir and intake: a half year to one year (It depends on the rainy or dry season and flood conditions)

ii) Headrace and head tank: several months (It depends on the length of headrace)

iii) Penstock: several months to a half year (Manufacturing period should be considered separately)

vi) Powerhouse and Tailrace: several months to a half year

(4) Electro-mechanical Works

In the case of small scale hydropower, the following approximate periods are based on the premise that the turbine and generator are relatively ready-made. The entire period of construction for electro-mechanical equipment is in general approximately one year. However, for installation work at the project site, it is necessary for the construction schedule to be adjusted between civil engineering works and distribution works, and electro-mechanical works. In addition, for trial operation, civil engineering works and distribution works must be almost completed.

i) Design for shop drawings and procurement of materials: several months

ii) Manufacturing and transportation: several months

iii) Election of turbine and generator: 2 to 3 months

iv) Trial operation: 1 to 2 months

(5) Distribution facility

The construction period for distribution facilities depends upon the distance of the line. In a case where an electrification scale is 500 to 1,000 households and the distance of electricity distribution line is around 50km, it takes around 8 months to 1 year generally.

i) Distribution line survey: several weeks to one month

ii) Design for shop drawings and procurement of materials: 2 to 3 months

iii) Manufacturing and transportation: 1 to 2 months

iv) Constructing poles, distributing electric wires, installation of watt-hour meters: several months to a half year

v) Trial operation: 1 to 2 months

Table 12-10 Example of Construction Schedule

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Preparation Work																		
Land acquisition and access road	▬	▬																
2. Civil Works																		
1) Intake weir and settling basin			▬	▬	▬	▬												
2) Headrace channel, head tank and spillway					▬	▬	▬	▬	▬	▬	▬							
3) Penstock																		
Manufacturing and transportation						▬	▬	▬										
Instauration work at the site									▬	▬	▬							
4) Powerhouse and tailrace/outlet										▬	▬	▬	▬	▬				
5) Miscellaneous work															▬	▬	▬	▬
3. Electro-mechanical works																		
1) Design and procumbent of materials		▬	▬	▬														
2) Manufacturing and transportation					▬	▬	▬	▬	▬	▬								
3) Instauration work at the site											▬	▬	▬					
4. Transmission and distribution work																		
1) Detailed site survey			▬	▬	▬													
2) Design and procumbent of materials						▬	▬	▬										
3) Installation work at the site									▬	▬	▬	▬	▬	▬	▬	▬		
5. Adjustment and trial operation																	▬	▬

Reference of Chapter 12

[1] The project for Project for Operation and Maintenance of the Rural Electrification on Micro-hydropower in Mondul Kiri, JICA, 2005

Chapter 13

Construction Management

Chapter 13 Construction Management

13.1 General

This chapter describes Construction Management which is on the client side, and it is different from the supervision of works on the contractor side. Furthermore, a term of " Construction Supervision" is used in this chapter by specifying engineering matters of Construction Management.

For the rural electrification by small scale hydropower, it is difficult to cover the construction costs by electric charges only. Therefore, in most cases the fund for the construction is partly or fully provided as a subsidy or aids from the government or from aid agencies respectively.

Depending on aid agencies or financial institutions, there are cases that the implementation of the construction work is asked to be reported in order to clarify whether the fund is being used properly.

The construction work for the rural electrification by small scale hydropower is a small scale, but one needs to supervise 3 main different types of the work such as civil structures, electro-mechanical equipment and distribution facilities. It is necessary to adjust them during the construction period.

Because the supervision of construction work needs the complicated technical knowledge, we suggest that it be implemented under the leading of the experts, or be entrusted to consultants.

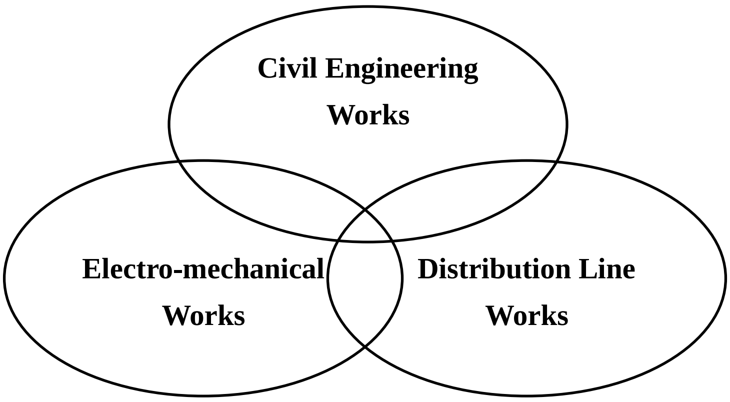


Figure 13-1 Component of Supervision of Works

General work items of the construction supervision are shown in Table 13-1.

Table 13-1 Work Items of the Construction Supervision

1. Overall Control	General management for the project
2. Program Management	Program management for construction work.
3. Project Quality Management	A method of quality control and preparation of a check list.
4. Document control	Rules for forms and procedures of documents should be defined.
5. Control of Amount of the work performed	A control method of amount, the forms and procedures.
6. Variation Order	It is conducted in the case of necessity of change in design due to varied circumstances of the project.
7. Safety and health control	Management is for minimization of accidents and troubles during the construction work.

13.1.1 Overall Control

The items related to overall construction management of the project are as Table 13-2.

Table 13-2 Items of Overall Control

	Type of Documents	Description
1	Organization management	Construction supervision team is organized.
2	Submission control	It means managing the submissions by Contractors according to the Contracts.
3	Safety and Health control	Establishment of system of management for safety and health, and the control of the system.
4	Progress report	Detailed items and methods of the procedure shall be prepared in advance.
5	Completion report	The construction supervisor team is required to prepare a completion report which describes the records of the construction and completed facilities, and submit it to the financial institutions or aid agencies.

Before starting construction work, a construction supervision team (C/S Team) is organized and execution strategy of the project is confirmed. The construction supervision team is formed from consultants and/or direct management of relevant organizations. Figure 13-2 is an example of Organization chart of C/S Team for a rural electrification project based on small scale hydropower which was implemented on the JICA's grant aid basis. Because the construction scale is small, one resident engineer stayed at the site with several visiting experts in each field according to the construction progress.

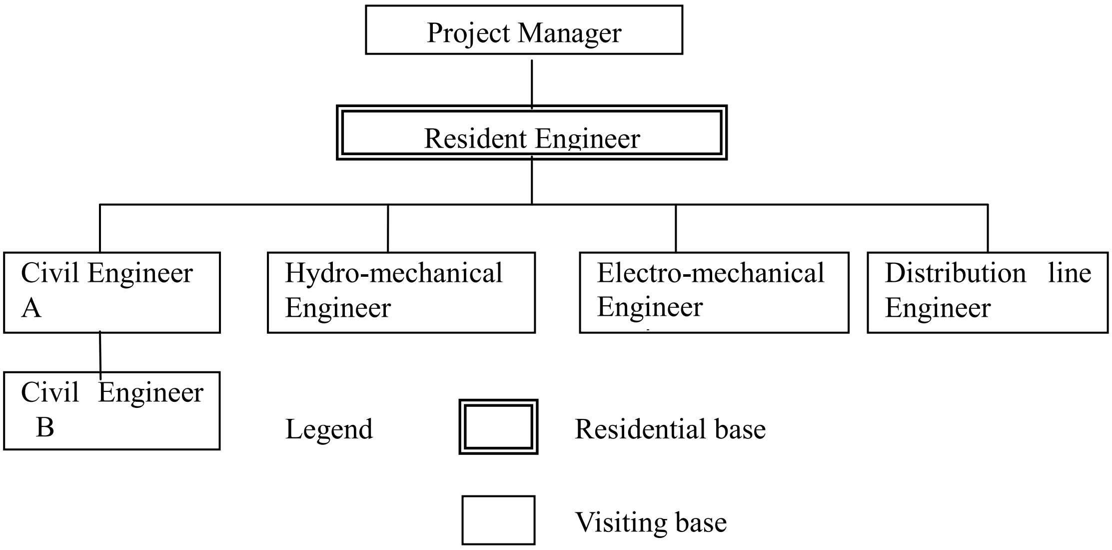


Figure 13-2 Example of Organization for Construction Supervision Team

13.1.2 Program Management

This is a task to manage the progress of the whole construction by adjusting the related construction progress between the civil engineering works, electro-mechanical works and distribution line works in consideration of respective contractual construction programs. The program management is classified to three items shown in Table 13-3.

Table 13-3 Program Management

	Item	Description
1	Construction Program	Setting contract program and its modification.
2	Management of key-dates and milestone	Controlling key-dates
3	Schedule control, Adjustment of construction program	Coordinating and organizing plural schedules to prevent troubles

(1) Construction Program

1) Construction Program

Construction Programs planned in the Contracts between Client and Contractors are basic.

2) Revised Construction Program

Construction Programs will be revised officially as revised construction programs when a necessity of change is acknowledged due to different conditions of the project.

3) Updated Construction Program

This construction program indicates an actual progress of the construction. The program is updated on the actual basis.

(2) Management of key-dates and milestones

Starting or delivering dates of the main structures, equipment, etc. are set as milestones, and they are designated as key dates which have to be kept as a matter of contract.

If a key date is scheduled backward or forward, not only its work but also the subsequent relevant works are influenced. Therefore, work progress and the schedules should be confirmed and notified between the concerned parties.

(3) Adjustment of the construction program between civil, electro-mechanical and distribution works

Since the construction scale of the rural electrification is small, the contractors are relatively small as well; however, since civil works, electro-mechanical works and distribution works are mutually related, it is necessary that the adjustment of the programs be made reciprocally according to the progress.

Especially, regarding the work which is connected to key dates, it is necessary to confirm the progress at all times, and the supervisor must hold regular contruction program meetings as follows.

- A weekly construction program meeting: a meeting normally held on the last weekday to clarify the results of the week and the plan of the coming week, and to adjust the related works.
- A monthly construction program meeting: a meeting normally held at the end of the month to clarify the results of the month and the plan of the coming month.

13.1.3 Project Quality Management

Items of project quality management are shown in Table 13-4.

Table 13-4 Items of Project Quality Management

Item	Description
1) Quality of Construction Materials	This is a quality control for construction materials such as filling materials, aggregates, concrete, rock bolts, shotcrete and others which are used for permanent structures. Construction materials for temporary works are not the target of this item.
2) Progress Control of completion form	This is to control and check whether the permanent structures have been constructed in line with drawings and specifications.
3) Supervision of Construction methods	This is to control and check the validity of the construction methods, and safety and health.
4) Management of Equipment and Facilities for construction work	This is to control and check the quality and performance of equipment and facilities used for the construction work.

13.1.4 Documents Control

Documents control is one of the most important methods to manage not only construction program but also detailed expenses of construction cost which are reported toward the client and financing institution.

Type of documents is shown in table 13-5.

Table 13-5 Type of Documents

	Type of Documents	Description
1	Letters	Communications with Client and Contractors are to be established by official letters basically.
2	Minutes of meetings	Minutes of meetings should be filed after confirmation by concerned parties.
3	Technical reports	Design report, Clarification report and other technical reports, etc.
4	Drawings	Original drawings as contract drawings, revised drawings, shop drawings, instruction drawings, as built drawings, etc.
5	Onsite Instructions	Onsite instructions describing practical construction methods etc. within or out of a scope of work are issued to Contractors.
6	Onsite Approval	Onsite approval is issued for the inspection to be requested by Contractor.

(1) Letters

Numbering of letters should be defined before issuing the first letter. Items such as number of letter, issuing place and date, sending address and name of person should be simple and clear in order to organize the record of letters. Issuing and receiving records should be filled separately.

(2) Meetings and Minutes of meetings

- Joint meeting

  Client, Supervisor of C/S Team (hereinafter, Supervisor) and each individual Contractor participate in the joint meeting periodically to discuss mainly construction program.

- Coordination Meeting

  Supervisor turns out Contractors for the coordination of the programs which are related to one another.

- Meeting between persons in charge of discussing daily practical issues.

(3) Technical Reports

Technical reports are submitted to Client. The reports show clarification and analysis of special technical issues of the project.

(4) Drawings

1) Drawings issued by supervisor

These drawings issued by Supervisor are called Construction Drawing.

It is better that the numbering system be defined before starting construction. Basically, new number is added at the end of the number of the tender drawing. And the record of revision should be mentioned there.

2) Approval for construction drawing

A person in charge working on the client side checks on the detail of approval for construction drawing submitted by Contractor.

The following items should be defined before starting construction work.

- Size and title's format of drawings
- Number of the submitting drawing to Client and number of the returning approved drawing to Contractor
- Procedure of submitting for approval from Contractor.
- Final signer of Client

3) As-built drawings

Generally, as-built drawings are prepared and submitted to Supervisor by Contractor according to the contract.

(5) Onsite Instructions

Supervisor issues on-site instructions. The original is kept by Contractor while Client and Supervisor keep copies respectively. On-site instructions should also mention about the payment terms and the influence on the construction program. It is recommended that there should be the number, the name of structure and the issuing date and year in the instruction form.

(6) Onsite Approval

Contractor makes a request for inspection which describes the objective structure, inspection date and inspection contents. Supervisor approves the inspection to keep the original inspection form, while Contractor keeps the copy. Whether Client might sign it or not is depending on its daily presence of the inspection and it is to be discussed and decided preferably before the construction work.

13.1.5 Progress Control of Work Amount Performed

In a case where a progress payment method is adopted according to the contract with Contractor, it is necessary to confirm the progress of the construction work by the work amount performed.

(1) Progress control of working amount performed by progress measurement of working form

Set up the progress control standard of working form in advance. Bared on the standard, a graph comparing measured value with designed one is drawn, and the construction performance is managed to go well with the design.

Generally, the following items are controlled and supervised.

- Base line survey

  Contractor carries out a base line survey which indicates the starting figure of construction in the presence of Supervisor. The survey determines starting figure to calculate construction quantity.

- Check of working form

  Dimension of the structures so far performed by the time of the inspection is measured and confirmed.

- Check of calculation sheet and work amount performed

  Quantities written in the calculation sheet is checked by the data of the measurement of working form and baseline survey.

(2) Progress control of work amount performed by inspection at the time of accomplishment of milestone

A certain amount of payment is done when a milestone has been carried out.

Examples of setting milestones are as follows.

- A certain percentage of the costs are paid when concrete placing work is commenced at the intake weir.
- A certain percentage of the costs are paid when 30 percentage of the concrete is cased for headrace channel.
- Methods of inspection and confirmation are the same as mentioned before in (1) above.

13.1.6 Variation Order

There are many cases where a necessity arises during construction to modify the original design. If it is the case, it is necessary to follow the procedure of the design change with Contractor. In most cases, it is also necessary to confirm and report it to the aid agencies or the financial institutions. The Variations include 3 actions which are Alterations, Additions, and Omissions. Included in them are variations of work volume, alterations of characteristics/quality and types of the work, modifications of the elevation/base lines/positions and sizes of the structures, variations of the construction order/ work additions, and work omissions.

13.1.7 Safety and Health

In the construction work, there are lots of primary factors that cause accidents. Moreover, because the construction work like the rural electrification is done in the remote rural areas, it needs lots of time and energy to deal with them when accidents or any other fatal disasters occur. Therefore, we need to take steps to cope with all kinds of situations in order to prevent accidents as mentioned above.

Supervisor is to manage whether Contractor is surely executing the safety and health control, and instruct it if necessary.

- Usual safety and health control; site patrol as needed
- Confirmation of the points of indication and improvement; at the weekly and monthly meetings

And, contractor is instructed on the following items.

- Convening a daily morning safety assembly before working for confirmation of the daily tasks, confirmation of awareness of the precautions and physical exercise
- Indicating safety targets (priority issues of the safety corresponding with the progress and characteristics of the work should be set up on a monthly basis for awareness-building of the labors.)
- Preparation of a daily safety report; the report should be perused by Supervisor as needed.

13.2 Civil Structure

13.2.1 Work Items for Construction Supervision

General work items of civil structures are shown in Table 13-6.

Table 13-6 General Work Items of Civil Structures

	Name of Structure	Description	Timing
1	Confirmation of right of way and control points survey	Joint inspection for confirmation of borders and reference points by owners, Contractor and Supervisor	Before commencement of construction work
2	Confirmation of temporary accommodations and areas	Joint inspection for confirmation of borders and reference points by owners, Contractor and Supervisor	Before or after of mobilization of Contractor
3	Intake weir and Intake		
a)	Care of river for intake works	Diversion work of river flow is necessary in accordance with the progress of the work.	As needed during intake work
b)	Main structures	The most important thing is to protect water leakage from the foundation ground.	Dry season is recommended.
c)	Trashrack and gates	Protection of water leakage	During construction work
4	Settling basin		
a)	Main structure	Foundation without unequal settlement	During construction work
b)	Trashrack and gates	Protection of water leakage	During construction work
5	Headrace		
	Main structure	Management of headrace gradient Protection of water leakage	During construction work
6	Headtank		
a)	Main structure	Foundation without unequal settlement	During construction work
b)	Trashrack, Gate	Protection of water leakage	During construction work
7	Penstock		
a)	Foundation structure	Foundation without unequal settlement	During construction work
b)	Steel pipe work	Factory inspection and site inspection of welding	During construction work
8	Spillway	Same as penstock method	During construction work
9	Powerhouse		
a)	Civil works	Foundation without unequal settlement and Protection of water leakage	During construction work

	Name of Structure	Description	Timing

b)	Connection points with Electro-mechanical works	Arrangement and confirmation with electro-mechanical works regarding connection points; anchor bars are required where appropriate	
c)	Building	Arrangement and confirmation with electro-mechanical works regarding connection points; anchor bars are required where appropriate.	
d)	Care of river for powerhouse and outlet	Diversion work of river flow is necessary in accordance with the progress of the work.	During construction work
10	Outlet or tailrace		
	Gate and stoplog	Protection of seepage	During construction work
11	Maintenance roads	There are many cases where roads are used for access roads during the construction period.	
12	Administartion bulding		
a)	Building	Foundation without unequal settlement	During construction work
b)	Water supply and sanitary facilities	Protection of water leakage	During construction work
c)	Electrical facility		During construction work

13.2.2 Quality of Materials

Quality control of construction materials is specified as below:

Table 13-7 Items of Quality of Materials

Specified Item		Example of Form
1)	Required quality of materials and its standard	Refer to Table 13-4
2)	Detail of the control such as control item and frequency, etc.	Refer to Table 13-4
3)	Format of record sheet on quality control test	Refer to Table 13-4
4)	Format of report which describes the test results	
5)	Method of filing and storing of the test records	
6)	Evaluation method of the test results	
7)	Manner of utilization of quality control results	
8)	Implementation structure of the tests	

General items of construction materials used for civil structures are shown in Table 13-8 and the details are in Appendix A-13-1 and A-13-2.

13.2.3 Control of Dimension

An example of a standard of dimension control is shown in Table 13-8. And an example of control sheet is shown in Appendix 13-3.

Table 13-8 Example of Dimension Control

Work Item	Item of Measurement
Access Road	Road Width, Formation height
Stone Foundation	Width, Thickness
Leveling Concrete	Width, Thickness
Intake Weir, Settling Basin, Head Tank	Height, Width, Thickness, Formation height
Water Way, Spillway	Height, Width, Thickness, Formation height
Steel Penstock (Anchor Block)	Height, Width
Steel Penstock (Sand Foundation)	Width, Thickness
Powerhouse (Under Ground Pit)	Height, Width, Thickness, Formation height
Administration Office, Powerhouse (Building)	Height of column, Cross-sectional dimension of member, Formation height
Retaining Wall	Height, Width
Stone Masonry	Slope length, Thickness of strut, Thickness of backing concrete, Thickness of backing crusher run

13.2.4 Procedure of Approval and Confirmation at the Construction Site

To carry out the confirmation and inspection by all the same methods including the detail parts of the construction implemented by Contractor takes a great considerable time and labor not only for Supervisor but also for Contractor, and as a result it has an influence on the construction program and construction costs. It is efficient and time-saving for Supervisor and Contractor that methods of inspection and confirmation are decided in advance according to the importance of the works.

There are some examples: Table 13-9 shows 4 grades, A, B, C and D, of approval and confirmation formats according to the importance. An example of a transmittal form and an application for approval are shown in Appendix 13-4 and 13-5 respectively.

Table 13-9 Procedure for Approval and Confirmation

Class	Form	Application	Process by Supervisor	Examples
A	Covering letter with the transmittal	Approval item by Supervisor written in the contract document Milestone for payment Design Change Minutes of meeting of important issue	Supervisor fills signature in the transmittal at the time of approval. If some defects are found there, re-submission is required. Finally, a copy is returned to Contractor.	Quality of Concrete, and steel, Commencement of work such as excavation at the waterway.
B	Application for Approval Type-B	Approval item which is relatively minor issue written in the contract document Minutes of meeting Other issues without mentioned above required by Contractor	Stamp of approval is sealed on the application form, and a copy is returned to Contractor.	Approval of construction material, Approval of form, concrete placement etc,. excluding milestones. Minutes of meeting Concerning the confirmation on site
C	Covering letter only	Issues which are written in the specification as “submission”	Receipt stamp is sealed on the letter, and a copy is returned to Contractor.	Submission of weekly and monthly reports
D	Oral request	Confirmation at the site without approval	Person who check and confirm at the site. If some issues occur, minute of meeting is prepared by Contractor and submitted for approval.	Concrete test at laboratory, Confirmation of land border etc.

13.3 Electro–mechanical Equipment

For electro-mechanical equipment, the construction management concerning design documents, approval documents, final documents, completion documents and manual of equipment is performed by the same rules for civil works in principle. It is determined in the contract how to authorize the payment for fabrication and installation, and it is common that the payment of the costs of electro-mechanical equipment is authorized at the time after witness test in the factory, on the delivery or installation date at the construction site, and on acceptance of the commissioning test. For a small scale hydropower scheme, there is an example that the construction costs of electro-mechanical equipment are paid in a lump sum at the time of acceptance of the commissioning test.

One of important aspects of the construction management and supervision is an interface with other sections such as civil works. Good examples are blockouts in the floor concrete and foundation metal or anchor bars embedded in it for the electrical apparatus and cables to be installed later. Those are to be reflected in approval drawings of civil works, and the scope of supply for those materials are to be allocated appropriately between an equipment supplier, an installation contractor, and a civil contractor.

About the quality of electro-mechanical equipment, it is important to control the turbine and generator efficiency, the error allowance of fabrication and installation of equipment. Tests and measurements procedures based on application standards to control them should be made by the designer or submitted for approval by Contractor. Such tests and measurements are carried out correctly in the factory and at the construction site. It is important for quality control of electro-mechanical equipment that the various tests and measurements are enforced fairly and correctly.

13.3.1 Acceptance of the Turbine Efficiency

Water turbine efficiency is an important parameter for a hydropower generation scheme. The procurement specification or the tender specification of turbines generally stipulates that the supplier ensure a guaranteed performance. When the supplier cannot satisfy the guaranteed efficiency, it will be charged money of penalty for it. Therefore, the model test of water turbine is carried out in the factory after fluid design of the water turbine is completed and before fabrication of the turbine is commenced. A smaller similar model of the actual turbine is used to confirm the performance such as efficiency, runaway speed, cavitation characteristics, etc.

The turbine model test method is prescribed by international standards such as IEC (International Electrical Committee), and the model test is carried out applying these standards. After the contract, fluid design, model test, and fabrication of turbine draft tube require about one year and the draft tube to be installed during foundation concreting of the power plant might be possibly critical. The turbine model test is important to confirm the turbine performance, but test expenses are very high, which influences construction costs of small scale hydropower. Therefore, owing to recent advancement of CFD analysis technology using a computer, there have been examples of omitting a turbine model test. Instead, CFD analysis is carried out for the purpose of estimating and confirming the design turbine efficiency. If the designer adopts a finished type of turbine developed in series, and submerged pump-type turbine or reverse pump turbine generally in use, the model test will also be omitted applying the performance data during product development by the manufacturer.

It is possible to calculate the real turbine efficiency by efficiency measurement on site where turbine discharges, effective head, and amount of actually generated power are measured. However, it is common not to carry out it for small scale hydropower, because it requires much preparation for the measurement devices causes a considerable error of the discharge measurement and cost a lot.

13.3.2 Acceptance of the Generator Efficiency

Like turbine efficiency, generator efficiency is an important parameter to control the economy of a hydropower scheme, and the efficiency stipulated in the contract is guaranteed by Contractor. There are two generator efficiency measurement methods, one is measured in the factory with generator assembled, carrying out a revolving test, the other is measured on site using an actual machine at the time of a filed acceptance test. The test method is prescribed by international standards such as IEC, which are applied to this test as well. For small scale hydropower, the revolving test in the factory is omitted aiming at cost reduction, and it is common to measure it using an actual generator on site.

13.3.3 Shop Test

A shop test is important to check whether a generation apparatus is produced according to the specifications, the contract and the approval drawings. Confirmation of the factory test data and all witness tests must be carried out carefully to perform quality control closely. An example of witness tests is shown below. In the purchase of a finished product or a general purpose product, witness tests may be omitted, but it is necessary that a manufacturer should submit its factory test data for Supervisor to confirm them.

Table 13-10 An Example of Witness Test for Generation Apparatus

Turbine	- Model turbine test - Dimension measurements of draft tube liners. - Dimension measurements and nondestructive test of a spiral casing - Nondestructive test of a runner (before finish machining) - Nondestructive test of a runner (after finish machining) - Nondestructive test of guide vanes (before finish machining) - Dimension measurements of guide vanes - Dimension measurements and nondestructive test of a top cover, a bottom cover and a guide ring - Turbine main shaft alignment test and nondestructive test - Turbine temporary assembly test - Governor performance test - Performance tests for turbine auxiliary equipments
Generator	- Dimension measurements and nondestructive test of a top and bottom bracket - Dimension measurements and nondestructive test of guide bearings and a thrust bearing - Generator main shaft alignment test and nondestructive test - Combination and revolving balance alignment test of rotor spoke, turbine and generator main shaft - Dimension measurements and withstand voltage test of stator coils - Dimension measurements and withstand voltage test of rotor coils - Dimension measurements and withstand voltage test of a stator - Dimension measurements and withstand voltage test of a rotor - Performance test and withstand voltage test of an exciter - Dimension measurements, withstand voltage test and performance test of a NGR
Main transformer	- Dimension measurements - Withstand voltage test - Measurements of various fixed number
Control panels, Switchgears and other equipments	- Dimension measurements - Performance test (open-close test, interlock system test, sequence test, etc) - Withstand voltage test

13.3.4 Site Test (Acceptance Test)

The site test is performed in order to determine the acceptance of the generation apparatus. Attention is paid to performance of the power plant, purchase conditions, and construction quality in particular. As for factory test data, measurements at the time of the site installation, and site test data, those are necessary as initial values for a comparative observation of a change due to the aging of generation facilities. An example of site tests is shown below.

Table 13-11 An Example of Acceptance Test for Generation Apparatus

Turbine	- General structural inspection - First revolving test - Bearing running in test - Revolving balance alignment test - Protection system test - Load rejection stop test - Emergency stop test - Quick stop test - Quick stop test by power source (oil pressure, voltage) drop of guide vane servomotor - Load test (continuous operation test with full output) - Remote control and supervision test (include alarm test)
Generator	- General structural inspection - First revolving test - Bearing running in test - Revolving balance alignment test - Measurements of insulation resistance and withstand voltage test - Measurements of various fixed number of the generator - Check of phase sequence - No-load saturation test - 3 phase short-circuit test - Calculation of short-circuit ratio and voltage regulation - Measurements of deviation factor of voltage waveform - Operation test combined with excitation system - Shaft voltage/current measurements - Protection system test - Load rejection stop test - Emergency stop test - Quick stop test - Load test (continuous operation test with full output) - Remote control and supervision test (include alarm test)
Main Transformer	- General structural inspection - Measurements of various fixed number of the transformer - Measurements of insulation resistance - Withstand voltage test
Control panels, Switch gears, etc.	- General structural inspection - Performance test (open-close test, interlock system test, sequence test, etc) - Withstand voltage test - Remote control and supervision test (include alarm test)

13.4 Distribution Facilities

13.4.1 Supervision Items for Construction

Supervision items and the checking contents for distribution facilities construction are shown in Tables 13-12.

Table 13-12 Supervision Items and Contents for Distribution Facilities

	Items	Checking Contents	Time
1	Pole positions and Wiring routes	- To confirm pole positions with landowner, contractor and supervisor	Before construction
2	Supporting Structures	- To plumb the pole up - To check pole length under ground - To check foundation - To check backfill and disposal of waste soil	During and after construction
3	Guys	- To check the linkage of anchor - To check the height of guy wire	During and after construction
4	Grounding	- To check the depth of grounding electrode and grounding wire installation - To check grounding resistance	During and after construction
5	Cross arms	- To check the installation of cross arm, arm tie and band	During and after construction
6	Insulators	- To check insulator type and installation method	During and after construction
7	Conductors	- To check dip of conductor - To check ground height and distance between conductor and object - To check fixing of conductor - To measure insulation resistance	During and after construction
8	Transformers	- To check the installation of transformer	During and after construction
9	Switches	- To check the installation of switch - To check fuse value of cutout	During and after construction
10	Watt-hour Meters	- To check the place and height of installation - To check the wiring - To measure insulation resistance	After construction

13.4.2 Quality Control of Materials

Quality control of materials for distribution construction should be chosen from witness test at the factory, quality inspection and sampling test according to the level of importance and quantity.

13.4.3 Procedures of Authorization and Confirmation on Site

In the same way as civil works, it is efficient to define the inspection and confirmation method according to the level of importance and construction stage.

Reference of Chapter 13

[1] Basic design study report on the project for rural electrification micro-hydro power in remote province of Mondul Kiri in the Kingdom of Cambodia, JICA, 2010

[2] The project for Project for Operation and Maintenance of the Rural Electrification on Micro-hydropower in Mondul Kiri, JICA, 2005

Part 4

Management of Electric Utility

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 14

Management Body and Electricity Rate

Chapter 14 Management Body and Electricity Rate

14.1 Component of Organization

14.1.1 Establishment of Organization

To supply and manage electric energy, firstly a management body needs to be established. For smooth operation of a power plant, it is good to make it a main organization to advance the construction at the stage of a preparatory survey mentioned in Chapter 6. A method of the formulation of organization and capacity building for staff is different from country to country; therefore, an appropriate support by experts is necessary as described in chapter 16.

It is desirable that the organization be established following the basic policies below:

(1) Basic policies

The structure of the management body shall be legally established according to the laws of the concerned country.

- In general, an electricity association or a state-run company will be employed.
- In principle the member of the structures should be local residents.
- Establishing a system of management and operation that can ensure transparency. It is desirable that the system be established to report, after the commencement of operation, the operational situation to the aid organizations or supporting agencies for assisting the project.
- Management should be based on the result of social survey.

(2) Organization form

Roughly there are three cases as the organization form for a rural electrification.

1) Directly operated by a state-run corporation/company

It is operated by a branch office of a public electricity corporation/company. From a sustainability point of view, it is an optimal organization form due to its strong structure.

2) Operated by a local community

It is for the small scale electrification of around 200 households in a case where it is hard to employ several full staff members due to financial matters or in a case where it is difficult for it to be operated under the direct management of a state-run corporation/ company.

3) Operated by an independently established public corporation

For the case of relatively large-scale electrification of 500 to 1,000 households that is hard to be directly operated under the direct management of a state-run corporation/company by a central government’s public corporation

One of examples in which a new organization is established is described below:

The organization consists of a management body which performs business practically and a committee which manages and audit the management body.

Figure 14-1 shows an example of the organization form for electricity operation.

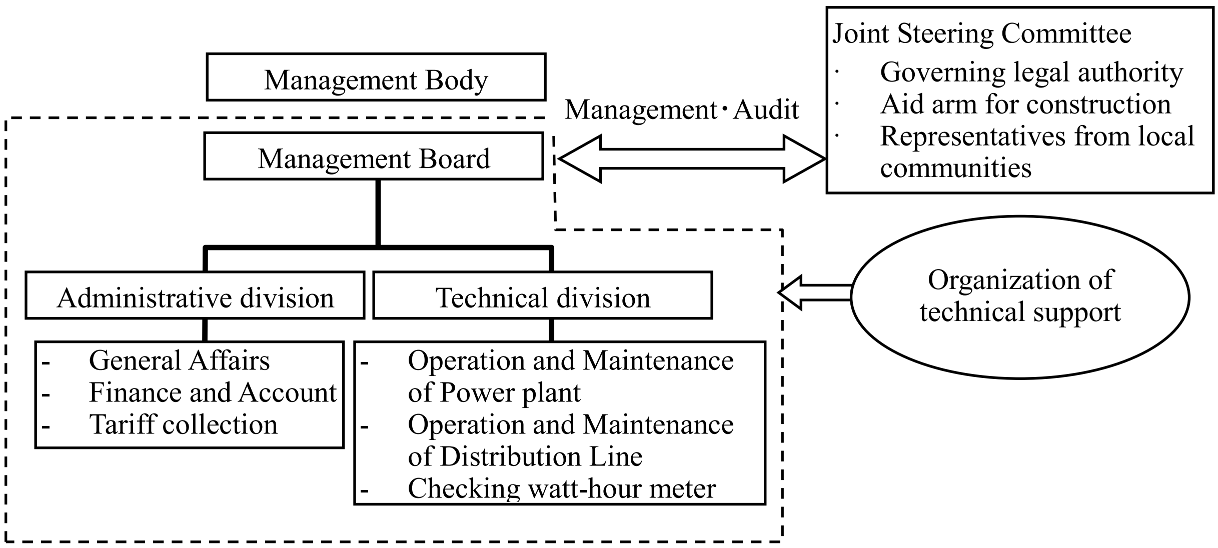


Figure 14-1 Example of Structure of the Organization

(a) Joint steering committee

The joint steering committee (JSC) has the power on the project management in general and the responsibility as below. Its members consist of officials from local authorities, beneficiaries of the rural electrification as well as representatives from the agencies financially supporting the construction.

- Establishing management policies
- Assigning and removing officers executing the management
- Setting an electricity rate (submitting an electricity rate to a superior institution, if any, for approval)
- Approving important repairing and renovation plans.
- Making a financial audit

The JSC should hold a meeting every quarter to one year to supervise and guide the operation situation.

(b) Management body

Administrative members of the management body are assigned by the JSC to execute the operation. It consists of 2 divisions, the administration division for collecting electricity bills and other operational work, and the technical division for operation and maintenance of electric power facilities such as civil structures, electro-mechanical equipment and distribution lines.

(c) Technically supporting organization for operation and maintenance

Since it will be operated by staff members with poor technical experience, it is important to have support from a special organization such as public electricity corporations with specialized experiences in operation and maintenance of electricity facilities.

- Handling the trouble-shootings occurring at the initial stage after the commencement of operation
- Regular checking and repairing
- Instruction for replenishing spare parts

If the above is neglected, the equipment may often be out of order and its life span will considerably become short. Therefore it is desirable to enter into an umbrella agreement with the organization to get technical support since the construction stage.

14.1.2 Management Body

(1) Task items

Tasks for the management body in charge of the entire operation are divided into operational matters and technical ones.

The tasks of the administration division are as follows:

- Personnel and labor affairs (employment, pay control, working control)
- General affairs (Meeting, document control, control of office equipment & consumables, safety control, miscellaneous affairs)
- Budget control (Business planning, fiscal budget, control of revenues and expenses)
- Accounting (Bookkeeping, account settlement, asset management)
- Fund administration (Cashier, fund administration)
- Customer management (Customer management, bill collection)
- Procurement (Contract for construction work, contract for maintenance work, purchases)
- Inventory control (Warehouse control, control of inventory goods and fuels)

Table14-2 indicates more detail of the work.

In implementing the above-mentioned tasks, they shall be simplified according to the order of priority to be established.

The technical division has the principal tasks as below. The details are mentioned in Chapter 15.

- Operating the hydropower plant as well as maintaining and controlling the facilities.
- Maintaining and checking the distribution facilities as well as controlling and repairing spare parts.
- Understanding well about the operation condition of the power plant and giving instructions for startup or shutdown
- Checking watt-hour meters

(2) Scale and size of staff members of management body

The scale of the management body varies by the scale of power supply.

Table 14-1 indicates the size of staff members varying according to the scale of electricity supply.

Table 14-1 Rough indication of the scale of Management Body

<table>
<tr><th colspan="2" rowspan="2">Job description</th><th rowspan="2">Unit</th><th colspan="4">Rough scale of number of users(households)</th></tr>
<tr><th>Under 200</th><th>200 to 500</th><th>500 to 1,000</th><th>Over 1,000</th></tr>
<tr><td colspan="2">Scale of Power generation</td><td>kW</td><td>~40</td><td>40~100</td><td>100~300</td><td>Over 300</td></tr>
<tr><td colspan="2">Minimum Number of persons</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1</td><td>Director</td><td>P</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>2</td><td>Deputy Director, Administration and Technical Matters</td><td>P</td><td></td><td></td><td>1</td><td>2</td></tr>
<tr><td>3</td><td>Administrator</td><td>P</td><td>1</td><td>2</td><td>2</td><td>4</td></tr>
<tr><td>4</td><td>Operator for power plants</td><td>P</td><td rowspan="2">4</td><td>4</td><td>4</td><td>5</td></tr>
<tr><td>5</td><td>Distribution staff (Checking Wh meters and invoices)</td><td>P</td><td>2</td><td>2</td><td>More than 3</td></tr>
<tr><td></td><td>Total</td><td>P</td><td>6</td><td>9</td><td>10</td><td>More than 15</td></tr>
</table>

Table 14-2 Task Description for Administration Matter

I. General Affairs Matter	II. Financial Matter	III. Procurement Matter
1 Personnel and Labor Affairs Group	1 Budget Group	1 Procurement Group
1) Employment	1) Business planning	1) Conti Contracts for construction works
i) recruit	i) Long & mid-term planning policy	
ii) promotion	ii) Long & mid-term planning	
iii) dismissal	iii) Report to JSC	
iv) retirement	iv) Power rate change	
2) Pay control	2) Fiscal budget	2) Contracts for maintenance works
i) pay regulation	i) budgeting policy	
ii) pay raise	ii) budgeting	
iii) payroll	3) Control of revenues and expenses	
3) Working control	i) check of receivables & payables	3) Purchases
i) working regulation	ii) examination of expenses	
ii) attendance sheet	2 Accounting Group	
2 General Affairs Group	1) Bookkeeping	2 Inventory Control Group
1) Meeting affairs	i) journal	1) Warehouse control
i) meeting arrangement	ii) ledger	i) warehouse bookkeeping
ii) minutes of meeting	2) Account settlement	ii) record of carrying-in and - out
2) Document control	i) Balance sheet	2) Control of inventory goods and fuel
i) internal regulations	ii) Income statement	i) periodical inventory check
ii) filing & storing	iii) Financial report to JSC	ii) inventory count for account closing
	3) Asset management	
3) Control of office equipment & consumables	i) Fixed asset register	
i) office equipment & furniture	ii) Inventory book	
ii) consumables	3 Fund Group	
iii) car dispatch	1) Cashier	
4) Safety control	i) cash receipt	
i) power plant	ii) cash payment	
ii) working safety	iii) cashbook keeping	
iii) safety regulation	iv) cash safekeeping & bank deposit	
iv) disciplinary code	2) Fund administration	
5) Miscellaneous affairs	i) cash planning	
i) entrusting works	ii) borrowing	
ii) mail operations	4 Customer Management Group	
iii) public relations	1) Customer management	
iv) others	i) customer book	
	ii) billing book	
	2) Bill collection	
	i) record of meter measurements	
	ii) issue of electricity bill & receipt	

14.2 Setting Electricity Rate, Collecting Electricity Bills and Financial Control

14.2.1 Policies of Setting Electricity Rate

The policy of electricity rate should consider: that tariff setting should be based on cost recovery principle and full charges should be paid by beneficiaries. However, a small scale hydropower project will not be financially feasible if the construction cost shall be recovered. Therefore, it is considered to be wise to exclude the unacceptable cost of consumers out of rate calculation by obtaining financial aid for the construction.

Electricity rate is a most important financial resource for a management body. To ensure sustainable operation in the future, the management body should employ basic policies as below:

i) All the consumers shall bear electricity charges without exception and the management body shall be operated with the income from it.;
ii) Priority shall be given to maintaining the financial balance of the corporate operation for stable management.
iii) The replacement expense of the power facilities is not included in the operation costs; however the expenses for inspection, maintenance and repair shall be secured in order to maintain the functions of the power facilities.
iv) Promotion of electrification for a low-income group shall be made as long as the above conditions are satisfied.

14.2.2 Calculation of Maintenance and Administration Costs

It is necessary that the income from electricity energy cover all the expenses except the payback of initial facilities investment (cost depreciation). Those expenses are as below:

(1) Personnel expenses

Calculate personnel costs on salaries and allowances of persons in charge of office management, operators and other employees.

(2) Administrative expenses

Calculate all the administrative expenses excluding the personnel expenses of the management body. Included are expenses for office's fuels and light, administrative commodities and others. It is estimated that administrative expenses amount to about 60 to 120 % those of personnel ones.

(3) Power facilities operation and maintenance expenses

Calculate the expenses for power facilities maintenance needed for normal operation including the costs of machinery tools, oils, spare parts, etc.

(4) Cost depreciation

Cost depreciation includes the costs of fixed assets such as electricity facilities; however normally the construction costs, initial expenses and so on are supported by aid or a subsidy.

If the electricity rate is calculated including cost depreciation, the price will be very high which makes subscribers hard to afford it. This would make the electrification project difficult to be realized.

Therefore, when the electricity rate is set, the expenses need not to include the cost depreciation of fixed assets to make it affordable for subscribers.

If the cost depreciation is not adopted as mentioned above, the facilities renewal costs will not be accumulated. In other words, if the facilities break down, it is impossible to provide electric power and the areas will have a blackout as before. In order to prevent such a problem, reserved fund for overhaul mentioned next item should be necessary.

This method is a controversial matter among countries and organizations. Therefore, consensus should be necessary.

(5) Reserve fund for overhaul

For the sustainability of the electrification project, it is important to set up and accumulate a fund to inspect and overhaul the hydro-electrical machine and equipment. Since the inspection and overhaul will be conducted every several years by foreign engineers or manufacturers, a large amount of budget is needed.

(6) Other expenses

Expenses of taxes, insurances, loyalty, etc. shall be calculated.

14.2.3 Selection of Type of Electricity Rate

For a sound management, it is important to set the electricity rate that will not cause a deficit. It is desirable to employ a rate system that ensures fairness and transparency and is simple and easy to operate.

Generally, rate is divided into two charges, a constant charge and a charge according to consumption. The constant charge is a charge for no relations to the amount of the electric power use and paying. In case of small scale electrification, a constant rate is commonly accepted to save an operation and maintenance costs of hydropower plant. In case of relatively large scale electrification, a constant rate is sometimes called a basic rate which depends on the capacity of watt-hour meter.

Table 14-3 indicates some types of electricity rate in accordance with electrification scales.

Table 14-3 Type of Electricity Tariff

Scale of Electrification	Component of consumers	Watt–hour meter	Application of Constant charge	Charge according to consumption	Rough indication of monthly consumption (kWh/household)
～100 households	farm households	No use	Yes	N.A	10～20
～200	Mixed with small shops	Installed	Eitheris available	Unit price of kWh is constant	20～30
～1,000	Mixed with shops and factories				50～80
500～1500	Mixed with shops and factories			variable in some cases	80～100

14.2.4 Setting Electricity Tariff

It is necessary to set the electricity tariff on the average of kWh higher than the cost price per kWh to be sold or consumed. The energy demand is unstable for about one year after starting operation. Therefore, an amount of energy consumption which is used for estimation of the electricity tariff should be adopted as a value of two or three years after starting operation.

An example of breakdown of the unit generation cost, which is basic data for setting electricity tariff, is shown in Table 14-4.

Table 14-4 Example of Breakdown of The Unit Generation Cost

Item	Unit	Middle Scale	Large Scale
Condition of Electrification			
1 Number of Household	number	300	1000
2 Distance of Distribution Line	km	15	35
3 Monthly Energy Consumption per Household	kWh/M/house	15	40
4 Installed Capacity	kW	55	300
5 Total Annual Energy Consumption	MWh/year	54	480
6 Total Monthly Energy Consumption	MWh/month	5	40
7 Number of Employees		6	12
Cost Estimation on Monthly Bases			
1 Employment Cost	Lumpsum	300	1,020
2 Overhead Cost	Lumpsum	300	1,020
3 Operation and Maintenance Cost	Lumpsum	200	200
4 Depreciation Cost	Lumpsum	0	0
5 Provision for Overhaul	10%	80	224
6 Other Expenses	5%	40	112
7 Total		920	2,576
Unit Cost per kWh	US Cent/kWh	20.4	6.4
Monthly Expenses for Electric Energy per Household	US$/Month	3.1	2.6

Unit generation cost shown in Table 14-4 is based on 100% of collection of electric charges. However, there are some commercial losses such as nonpayment and lifting of energy. Therefore, such losses should be considered in the setting of electricity tariff.

14.2.5 User Responsibility for Enrolment

Generally an electricity user is required to pay the following expenditures at the time of enrolment.

(1) Cost of service drop installation

In a case where a wattmeter is installed on a power pole, a service drop from the power pole to the subscribed house is needed. The line extension shall be around several meters to tens of meters, depending on the location.

(b) Cost of indoor wiring work

It is the cost of indoor wiring with smaller cords and installing a circuit breaker box.

(c) Wattmeter installation cost

It is the cost of equipment to measure kWh which a subscriber consumes. In some cases, it is installed at the expense of a management body.

(d) Deposit

There are cases that deposit equivalent to one-or-two month electricity fee is needed as a guarantee for the payment of electricity bills. There could be a view that the management body uses it for the operation expenses for the initial period of electrification.

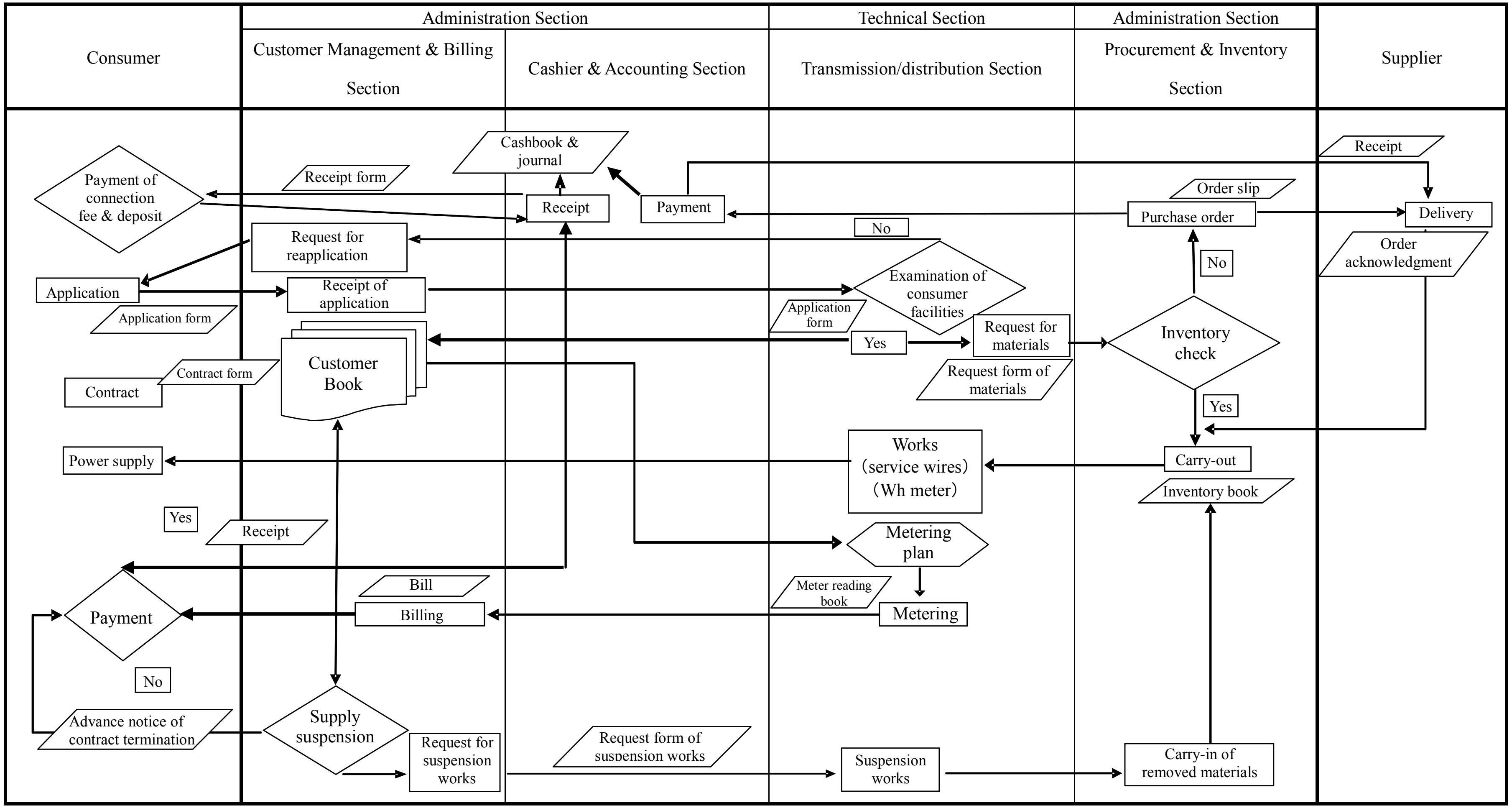
14.2.6 Establishing Billing System

A normal accounting system of the rural electrification is called MBC (Metering-Billing-Collection). A series of procedures need to be established for it including application from subscribers, subscription contract singing, checking electricity energy consumed at subscribers' houses, and issuing and paying electricity bills. In a case where subscribers fail to pay their bills, measures how to cope with it should be taken into consideration, for it is important from not only an income aspect but also a discipline aspect of the management, which is also a part of the management of the accounting system.

Drawing 14-2 indicates the flow of an accounting system.

Following method is a standard type. However different methods could be used depending on the condition concerned.

Figure 14-2 Flow of Billing and Business processing System



14.2.7 Management with Balanced Income and Expenditure

For a sound management, a manager of the management body needs monthly to calculate the balance between income from electricity tariff and the operation expenditures, compare the estimate with the actual achievements, find out the reasons of difference if any, and make an estimate for the next few months.

An example of a simple sheet to check the monthly balance between income and expenditures is shown in Table 14-5. It is necessary to have separate breakdowns carefully calculated to account for the entire financial balance.

By inputting the expecting values for the next one year and updating them when the actual achievements are available, the operation situation can be managed easily without having to wait for the results through complicated totaling calculation.

Necessary items for the table are as follows.

(1) Column of Energy

(a) Energy Generation (kWh/month): Value at the end of generator
(b) Energy Consumption (kWh/month): Value at the User end, watt-hour meter value
(c) Distribution Losses: Technical energy loss by distribution line (1 − (b)/(a)) × 100)

(2) Column of Revenue

(d) Amount of invoice (Monetary Unit) : Corresponding to item (b), monthly sales of energy.
(e) Amount of revenue (Monetary Unit): Corrected amount by due date of the month to be revised when the payment is made
(f) Uncollected ratio (%): When the payment is made, table shall be revised.

(3) Column of Expenditure

(g) Salary (Monetary Unit): Monthly salary Cost
(h) Administration Cost (Monetary Unit): Expenses for operation of the office
(i) Operation and Maintenance Cost (Monetary Unit): Spare parts, repair, maintenance cost
(j) Other Cost (Monetary Unit): Taxes, royalty
(k) Deposit (Monetary Unit): Reserve fund for overhaul
(l) Total: (g)+(h)+(i)+(j)+(k)

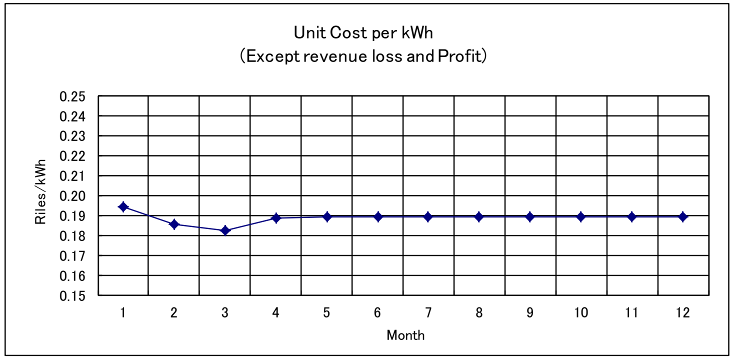
(4) Column of Generation and Profit

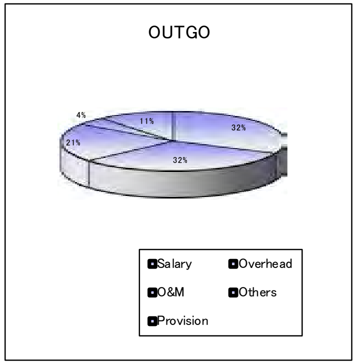
(m) Unit Cost per kWh (Monetary Unit/kWh): (l)/(b)
(n) Monthly Balance (Monetary Unit): (e) – (l)
(o) Profit-earning ratio (%): Monthly Basis

Table 14-5 Example of Monthly Check Sheet for Financial Management

Monthly provision 10 % of Revenue Tariff Rate 22 cent/kWh
Miscellaneous 5 % of Salary + Overhead + O&M cost

	Month	Energy: Generation kWh	Energy: Consumption kWh	Energy: Loss %	Income: Invoice	Income: Revenue	Income: Loss %	Outgo: Salary	Outgo: Overhead	Outgo: O&M	Outgo: Miscella-neous	Outgo: Sub-total	Outgo: Provision for Overhaul	Outgo: Total	Cost/kWh $/kWh	Profit	Profit %
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)		(k)	(l)	(m)	(n)	(o)
1	Jan	5,869	4,850	21%	1,067	1,014	5%	300	300	200	40	840	101	941	0.19	72	7%
2	Feb	6,081	5,110	19%	1,124	Record		300	300	200	40	840	107	947	0.19	121	11%
3	Mar	6,344	5,200	22%	1,144	1,087	5%	300	300	200	40	840	109	949	0.18	138	13%
4	Apr	5,924	5,020	18%	1,104	1,049	5%	300	300	200	40	840	105	945	0.19	104	10%
5	May	6,000	5,000	20%	1,100	1,045	5%	300	300	200	40	840	105	945	0.19	101	10%
6	Jun	6,000	5,000	20%	1,100	1,045	5%	300	300	200	40	840	105	945	0.19	101	10%
7	Jul	6,000	5,000	20%	1,100	Plan	%	300	300	200	40	840	105	945	0.19	101	10%
8	Aug	6,000	5,000	20%	1,100	1,045	5%	300	300	200	40	840	105	945	0.19	101	10%
9	Sep	6,000	5,000	20%	1,100	1,045	5%	300	300	200	40	840	105	945	0.19	101	10%
10	Oct	6,000	5,000	20%	1,100	1,045	5%	300	300	200	40	840	105	945	0.19	101	10%
11	Nov	6,000	5,000	20%	1,100	1,045	5%	300	300	200	40	840	105	945	0.19	101	10%
12	Dec	6,000	5,000	20%	1,100	1,045	5%	300	300	200	40	840	105	945	0.19	101	10%
Total		72,217	60,180	17%	13,240	12,578	5%	3,600	3,600	2,400	480	10,080	1,258	11,338	0.19	1,240	9.9%





14.2.8 Management for a Period of 1 to 2 Years After Start of Operation

For a period of 1 to 2 years after the actual operation of the small scale hydropower plant, electricity users by the electrification are still on the increase, which does not satisfy the planned demand for electricity. As a result, in most cases at this stage, revenue from electricity charges does not meet operation expenses. Financial measures are accordingly required, the methods of which are not definitely determined, but there are some ideas as below.

i) To allocate security deposits from subscribers at their signing-up to operation funds for the time being

ii) To borrow from a lending institution

iii) To obtain financial assistance from an aid agency and/or a governmental institution

i) and ii) above are liabilities which need to be compensated and repaid. Allotted to the sources are, first of all, a profit and a surplus of the management body. In the case of a further lack, electricity rates need to be changed.

Reference of Chapter 14

[1] Basic design study report on the project for rural electrification micro-hydro power in remote province of Mondul Kiri in the Kingdom of Cambodia, JICA, 2005

[2] The project for Project for Operation and Maintenance of the Rural Electrification on Micro-hydropower in Mondul Kiri, JICA, 2011

Chapter 15

Operation and Maintenance

Chapter 15 Operation and Maintenance

15.1 General

Electric power supply is based on 24-hour continuous supply. Operation and maintenance of the facilities accordingly need to be secured around the clock. This chapter describes items on management of technical matters, such as electro-mechanical equipment, civil structures and transmission line facilities.
Technical affairs of electric power facilities largely consist of operation and maintenance.
The diagram below shows main tasks of the operation and maintenance. Table 15-1 shows the list of items of service by technical working groups.

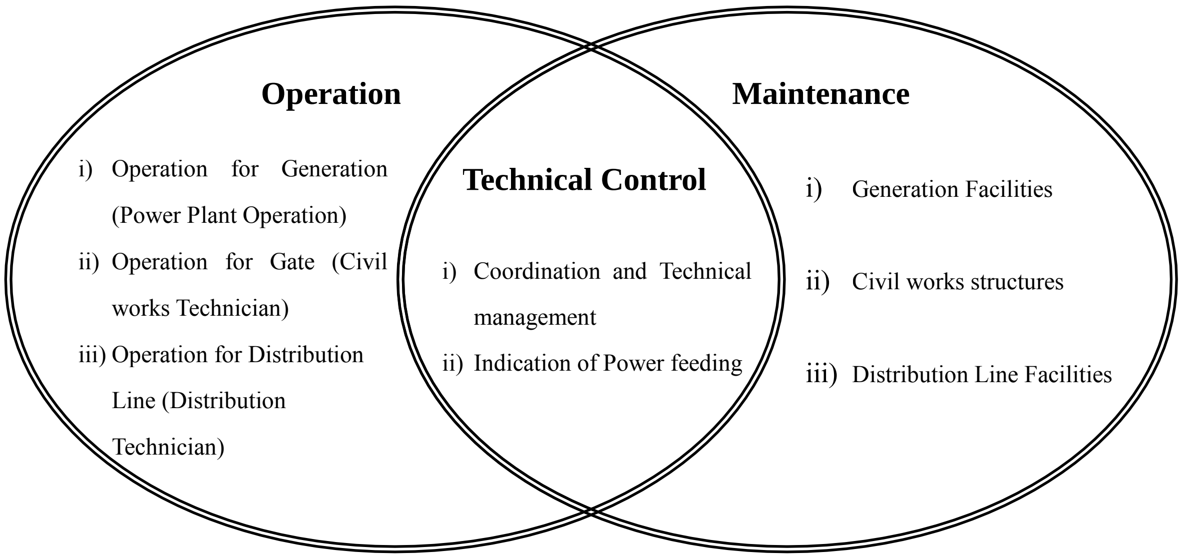


Figure 15-1 Main Tasks of the Operation and Maintenance

Each item above should be run through mutual coordination. Lack of any one item causes troubles and normal operation is interrupted. Below is an example of how to share services. In case technical standards for electricity are already established or under preparation, tasks of operation and maintenance must follow such standards.

15.1.1 Technical Administration and Coordination

(1) General affairs

1) Labor management: work management for technical staff, such as work shift
2) Operational coordination: providing places and opportunities for coordination among those in charge
3) Safety control: Managing the safety of electric power facilities from a technical point of view

(2) Document control

1) Operation record: storage and compiling of operation records, such as daily/weekly/monthly /annual reports
2) Maintenance and repair record: storage and compiling of maintenance and repair records
3) Accident and emergency record: storage and compiling of accident and emergency response records
4) Daily/monthly/annual operational plan: storage and compiling of daily/weekly/monthly/annual operational plan

(3) Mid-/long-term plan/budget (comparatively large-scale case with increasing demand)

1) Repair plan: plan for repair for up to 5 years and estimate of the budget
2) Inspection plan: plan for periodic inspections according to facilities and equipment and estimate of the budget
3) Tool and part replacement plan: plan for part replacement to maintain the performance and quality of equipment, parts and oil of facilities, and estimate of the budget

(4) Asset management (assistance to those in charge of office management from a technical point of view)

1) Equipment ledger: while an administration division is basically in charge of the management, a technical division is responsible for reporting in a case where any change happens due to a disaster or a repair.
2) Inventory book of parts: while an administration division is basically in charge of the management, a technical division is responsible for reporting a utilization schedule of parts and their prospects.

(5) Complaint and request response

1) Accidental service interruption: since the working group that supervises the equipment causing the fault handles the restoration, the group in charge of power feeding or system control often leads the fault restoration.
2) Abnormal voltage: since the working group that supervises the equipment causing abnormal voltage takes charge of the investigation and countermeasures, the distribution group often handles the case.
3) Malfunction of watt-hour meters: this is about responses to complaints and requests to the malfunction of watt-hour meters, such as problems with the circular plate. The distribution group in charge of watt -hour meters often handles the case.
4) Check of watt hour-meters: It is important to check a watt-hour meter in a case where a large error is suspected. The distribution group in charge of watt-hour meters often handles the case.

(6) Customer support

1) Technical review of application from electricity subscribers: it is to check the need for additional distribution facilities in the case of the increase in electronic products of current customers. The distribution group controlling voltage of customers often handles the case.
2) Connection setup: construction work in response to customer's application for electric power receiving, such as setting a watt- hour meter and a service drop for new customers or replacement of a watt-hour meter in response to current customers. The distribution group in charge of watt- hour meters often handles the case.
3) Meter reading: it is to read a number of watt- hour meters every month or at agreed intervals. The distribution group in charge of watt- hour meters often handles the case.
4) Issue of invoice: based on the meter reading, invoices are to be issued to customers.
5) Temporary connection and removal: it is to set up and remove a watt-hour meter in the case of a temporary use of electricity, such as construction work. The distribution group in charge of watt- hour meters often handles the case.
6) Removal of watt- hour meters: it is to remove watt-hour meters when customers stop the use of electricity such as service cancellation. The distribution group in charge of watt- hour meters often handles the case.

15.1.2 Power Feeding Direction

Electric power must be supplied in accordance with electricity demand, particularly with right frequency and voltage for the stable supply. Because the demand is changing at all times, the role is required to observe the change and direct power plants to change the output accordingly. Those in charge of power feeding indication play a central role in operation.

Table 15-1 Task Description of Technical Matter

General Technical Matter	Power Plant	Distribution Line (D/L)
1 General matter	1 Safety and quality control of operation and maintenance work	1 Safety and quality control of operation and maintenance work of D/L facilities
i) employment	2 Working control	2 Working control
ii) evaluation of staff activities	i) working regulation	i) working regulation
iii) working control	ii) attendance sheet	ii) attendance sheet
iv) safety control	iii) operators shift schedule	3 Planning of D/L activity
	3 Data/records control	i) long & mid-term plan, budget
2 Document control	i) operation records	ii) daily activity plan (Operation, Maintenance and Construction)
i) operation records	ii) water levels at intake weir, hradrace channnel and head tank	4 Check of D/L operation
ii) maintenance records	iii) maintenance records	i) Analyzing of operating condition (Load, D/L Loss, Voltage drop)
iii) fault & emergency records	iv) fault & emergency records	ii) Measuring of Current & Voltage
iv) daily, monthly and yearly operation plan	v) daily, monthly and yearly operation plan	5 Scheduled Outage Operation
3 Long & Mid-term plan and budget	vi) long & mid-term plan	i) making a switching procedure
i) maintenance plan	4 Operation and maintenance(O&M) of civil structures and electro-mech	ii) notification to customers
ii) scheduled inspection plan	i) daily operation	iii) ordering switching operations
iii) tool & spare parts procurement plan	ii) daily, monthly and yearly maintenance	iv) doing switching operations
4 Asset management	iii) trouble shooting	v) record of result
i) fixed asset register	5 O & M of civil structures	6 Fault Outage Operation
ii) inventory book	i) operation: intake gate, sand flush gate	i) decision of the method how to restore
	ii) maintenance: removing the garbage in front of the	ii) ordering each action to restore
5 Customer's request or claim	iii) patrol for the civil structures	iii) searching and restoration of fault
i) interruption of power supply		iv) record of result
ii) abnormal voltage	6 O & M of electro-mechanical equipment	7 Maintenance of D/L facilities
iii) Watt-hour meter broken	i) turbine, apeed governer,inlet valve, oilpressure supply	i) patrol & Inspection
iv) Watt-hour meter checking	ii) exterbal inspection, internal inspection	ii) record of result
6 Customer contract issues		iii) negotiation with owner of obstruct close to D/L line
i) technical review of supply application	7 Repairment planning of civil structures and electro-mechancal equipme	iv) Control of spare parts
ii) connection work		v) Maintaining of working tools
iii) metering		8 Construction of D/L facilities
iv) delivery of invoices		i) making a specification of constructions
v) temporary disconnection & re-connection		ii) constructing
vi) removal of Wh meter from ex-customers		iii) supervising construction work
		iv) inspection of the result
		v) revising facility book

15.2 Civil Structures

Civil structures of electrical facilities consist of intake weir, intake, settling basin, headrace, head tank, penstock, powerhouse, tailrace or outlet and maintenance road etc. To prevent troubles and keep safety operation, proper maintenance shall be performed.

15.2.1 Operation Work

(1) Item of operation

Main items for operation of the civil structures are as follows:

Table 15-2 Operation Task of Civil Works Structures

	Item	Discription
1	Gate Control	Sand flush gate at intake weir, Intake gate, Sand flush gate at settling basin, Sand flush gate at head tank, Tailrace gate and others.
2	Record and Report of Operation	Keeping a record of operated gates in line with the format and reporting it to a manager
3	Water Level Measurement	Periodic measuring and recording of water level at Intake and waterway
4	In an Emergency	Urgent matters such as accidents regarding civil work structures

(2) Gate control

1) Intake weir

This gate is to be open to flush sedimentation in the pond or in the front of the intake in order to keep the stream for power discharge. The gate is usually closed under operation for generating energy.

2) Intake gate

This gate is open during operation for generating energy, and closed when inspection and/or maintenance work is conducted in headrace.

3) Sand flush gate at settling basin

This gate is to be open to flush sediment deposit in settling basin and/or to carry out the inspection. The gate is usually closed under operation for generating energy.

4) Sand flush gate at head tank

This gate is to be open to flush sediment deposit in head tank and/or to carry out the inspection. The gate is usually closed under operation for generating energy.

5) Outlet gate

This gate is usually open under operation for generating energy, and closed when an inspection and/or maintenance work is conducted in powerhouse and tailrace channel.

6) Gate in headrace

In the case of a long headrace, a gate or a valve may be installed to empty it for maintenance work. It is usually closed.

(3) Record and report of operation

All operation work of the above gates shall be recorded and reported to a technical manager every time.

(4) Measurement of water level

Water level in head tank or headrace is periodically measured to suppose a power discharge at the time. Rating curves at the intake and the outlet shall be developed in advance.

During the dry season when an amount of river flow is small, a daily water level should be measured and an operation condition of the next day is able to be forecasted. In addition, a long period of the observed data is clarified and analyzed for developing a seasonal and annual operation plan

15.2.2 Maintenance Work

(1) Task Items

Principle task items for maintenance work of civil structures are as follows:

Table 15-3 Maintenance Task of Civil Structures

	Item	Discription
1	Documents Control	Recording and compiling maintenance and inspection work
2	Maintenance Patrol for Civil works structures	Patrol for maintenance of civil structures to be carried out periodically in order of importance
3	Study and inspections for maintenance and repairing	Planning improvement and repair excluding large scale work
4	Others regarding civil structures	Maintenance work for civil structures excluding above items

(2) Item and frequency of inspection patrol

Items and frequency of general inspections are shown in Figure 15-4.

Ordinary, weekly patrol is conducted in the beginning of week and monthly one is in the beginning of month. Results of inspection shall be filled in the format of an inspection report and reported to a technical manager. Examples are shown in Appendix A-4-1 to A-4-3.

(3) Maintenance and improvement

When trouble or abnormal condition is found out, countermeasures shall be immediately taken in line with an improvement plan. Plan for maintenance and/or improvement shall be prepared according to the results of inspection and additional survey. First priority shall be placed on safety and daily operation. Detailed points of repair and improvement shall be filled in the documents such as an equipment list, drawings, and specifications practically.

(4) Inspection patrol

1) Intake weir and intake

Intake weir and intake shall be maintained in as good a condition as is able to take a maximum plant discharge for generating energy.

(a) Trash screen

Trash on the screen shall be plowed out on a timely basis. If difference in water level between both sides of the screen is observed visually, it will affect generating output seriously. Then the trash shall be removed immediately.

(b) Sedimentation in the front of intake

Sedimentation is taking place in the pond and sedimentation level shall be measured periodically, in particular in the front of intake. Generally, sediment particles is transported from upstream by flood discharge. For that, inspection is required after flooding. If there is a possibility that sedimentation will close the water way to intake or if it has already closed it, sand flush gate in intake weir shall be open to flush sedimentation to downstream. If there is much sedimentation in the pond, heavy equipment like an excavation machine will be used.

(c) Gate

For smooth operation, periodic inspection and maintenance such as filling grease oil shall be conducted.

(d) Locking steering wheel

Steering wheels for gate control shall be properly locked against intruders.

(e) Concrete structure

Periodic visual observations shall be conducted to find out water leakage from joint positions and/or concrete surface cracks.

2) Settling basin

Function of settling basin shall always be kept because sand contained in the discharge will do damage to turbine.

(a) Trash screen

Trash on the screen shall be plowed out on a timely basis. If difference in water level between both sides of the screen is observed visually, it will affect generating output seriously. Then the trash shall be removed immediately.

(b) Settling basin

The process of sedimentation in the basin would be surveyed and measured periodically to envisage the required frequency of flushing sand. Flushing shall be carried out at least before and after the rainy season.

(c) Concrete Structure

Periodic visual observations shall be conducted to find out water leakage from joint positions and/or concrete surface cracks

3) Headrace

Generally, an open channel type is adopted in the case of small scale hydropower.

If unequal settlement occurs at headrace, it will possibly cause serious damage to the functions such as water leakage or overflow from the channel.

4) Head Tank

(a) Trash screen

Countermeasures are the same as those of settling basin.

(b) Settling tank

Countermeasures are the same as those of settling basin.

(c) Concrete structure

Countermeasures are the same as those of settling basin.

5) Spillway at head tank

(a) Concrete structure

Countermeasures are the same as those of headrace.

(b) Outlet

If some sediment particles is deposited around the outlet, it shall be taken off from there.

6) Penstock (in the case of steel lining)

(a) Vibration

Periodic inspections shall be conducted to find out abnormal vibration or noise. If some abnormal condition is found out, the consultation with an expert is recommended.

(b) Bolt

Periodic inspections shall be conducted to find out loosening of the bolts.

7) Powerhouse and tailrace

(a) Concrete foundation structure

Periodic visual observations shall be conducted to find out water leakage from joint positions and/or concrete surface cracks.

(b) Building

Periodic visual observations shall be conducted to find out water leakage from joint positions and/or concrete surface cracks, leaking of rain from the roof or wall.

(c) Tailrace

If some sedimentation is deposited around outlet, it shall be taken off from there.

8) Maintenance road

(a) Maintenance road

A visual observation shall be conducted after a heavy rain for checking cracks or erosion on the slope.

(b) Side ditch

A visual observation shall be conducted after a heavy rain if trash or soil has been deposited in the side ditch. Side ditch shall be cleared where appropriate after a heavy rain.

(c) Road surface

If there is undulation or furrows on the road surface, maintenance work shall be carried out.

Table 15-4 Example of Check items for Civil Structures

Check items of civil structures

Name of facility	Item	Maintenance point	Daily	Weekly	Monthly	Remarks
Intake weir	Intake screen	Remove the trash on the screen	○			If necessary
	Sedimentation	Flush out the accumulated sand in front of the intake			○	Rainy season, if necessary
	Gate	Check the function of the gate If necessary, put the oil on the gear			○	
	Locking	Check the locking of gate handle and guard fence	○			
	Structure	Water leakage, deformation and crack, etc		○		
	Appearance	Check the appearance, others	○			
Setting basin	Screen	Remove the trash on the screen	○			
	Sedimentation	Flush out the accumulated sand in front of the intake			○	If necessary
	Structure	Water leakage, deformation and crack, etc		○		
	Appearance	Check the appearance, others	○			
Headrace	Structure	Water leakage, deformation and crack, etc		○		
	Appearance	Check the appearance, others	○			
Head tank	Screen	Remove the trash on the screen	○			
	Sedimentation	Flush out the accumulated sand in front of the intake			○	If necessary
	Structure	Water leakage, deformation and crack, etc		○		
	Appearance	Check the appearance, others	○			
Spillway	Structure	Water leakage, deformation and crack, etc		○		
	Appearance	Water leakage, deformation and crack, etc	○			
Penstock	Vibration	Check the abnormal vibration or noise from the structure			○	
	Bolt	Clench the bolt			○	If necessary
	Appearance	Check the appearance, others	○			
Powerhouse	Retaining wall	Deformation or depression of the structure		○		
	Appearance	Check the appearance, others	○			
Outlet	Sedimentation	Remove the sand or mad in front of the outlet			○	If necessary
	Appearance	Check the appearance, others	○			
Access road	Side ditch	Clean the side ditch		○		If necessary
	Weeding	Weeding around the path			○	If necessary
	Road surface	Check the condition of road surface		○		
	Slope protection	Check the condition of slope or guard fence		○		
	Appearance	Check the appearance, others	○			

15.3 Electro–Mechanical Equipment

Maintenance works of electro-mechanical equipment for small scale hydro power plants can be classified into main equipment such as turbines and generators, and other equipment such as main transformers, switching devices for power station buses and transmission lines. To main transformers, and switchgears for power buses and transmission lines, the maintenance rule of powerhouse is also applicable. Below is a description about the maintenance of turbines, generators and auxiliary equipment peculiar to small scale hydropower plants.

15.3.1 Operation Patrol

The purpose of plant operation patrol is to check for general abnormalities of the equipment and to check the operational conditions of electro-mechanical components. The key detection factors are abnormal noise, smell and vibration. The operation patrol is to be conducted daily or weekly, setting a patrol course and a check list beforehand, and recording the readings of indicators such as a meter, a pressure gauge, an oil gauge, and an opening angle meter. An example of daily operation record for hydropower plant is shown in Appendix A-15-4.

15.3.2 Inspection

In general, inspections of electro-mechanical equipment are classified as follows:

- Inspection
  - Periodic inspection
    - External inspection
    - Internal inspection
  - Emergency inspection

An external inspection is conducted periodically approximately once every one to three years. The turbine and generator are shut down during this inspection to check for abnormalities and to check their performance. An internal inspection is conducted periodically approximately once every five to ten years. The turbine and generator are overhauled, thoroughly cleaned and repaired to restore their performance. It is recommended that the inspection cycle be so set as to reflect the inspection results and the operation conditions. For example, from cavitation measurement of water turbine runner to be carried out once for 1to3 years, the repair works are set at the time of the internal inspection depending on the progress of and damage due to cavitation.

An emergency inspection is conducted when an abnormal event or a problem occurs in electro-mechanical component. The turbine and generator are shut down during this inspection. The major periodic inspection items of electro-mechanical equipment are listed in Table 15-5. An example of weekly inspection for Electro-mechanical Equipment is shown in A-15-5. An example of intervals and items of ordinary maintenance is in A-15-6 and A-15-7. And an example of fault record of electro-mechanical equipments is shown in A-15-8.

Table 15-5 Inspection Items for Electro-mechanical Equipment

Component	Periodic inspection	
	External inspection	Internal inspection
Turbine	(Turbine internal) Inspect and measure for abrasion, cracks, erosion and rust on the runner, guide vane and casing interior. Measure the runner gap and guide vane gap. Check the bearing lubricant quality * Test: automatic start/stop	(Turbine overhaul) Measure abrasion loss at each part. Inspect the sliding area and packing for damage and fine cracks. (Bearing overhaul) Measure the damage and gap on the sliding surface. Calibrate the cooling water pipe pressure resistance, thermometer and oil gauge. * Replace worn parts * Test: load rejection, vibration measurement, stroke output, automatic start/stop
Speed governor	(Mechanism) Inspect for abrasion of movable parts. Loose wiring/lever, and strainer overhaul (Controller) Inspect the conditions of the printed circuit board and position transducer. Measure the insulation resistance	(Mechanism overhaul) Overhaul movable part and SSG. Replace worn parts. * Test: characteristics measurement and load rejection
Inlet valve	(Inlet valve internal) Measure leakage. Inspect for abrasion and erosion and erosion. Measure sheet surface clearance. Inspect position indicator conditions.	(Operation mechanism overhaul) Inspect damage to movable part and sliding area. (Valve body overhaul) Inspect for abrasion and erosion. Inspect for damage to the packing and the sealing condition. Replace worn parts.
Oil pressure supply and lubrication oil system	(Performance) Measure load operation time. Test oil quality (Oil filtration) Test oil quality	(Oil pressure supply and lubrication oil system overhaul) Inspect for abrasion and damage to internal movable part and sliding area, and motor insulation resistance. (Performance test) Measure pump discharge and grease feed volume Performance test of sensors, detectors, and protection relays
Water supply and drainage system	(Strainer overhaul) Inspect abrasion and erosion	(Pump overhaul) Inspect for abrasion and damage to internal movable part and sliding area, and motor insulation resistance. (Performance test) Measure water supply and drain volume

Component	Periodic inspection	
	External inspection	Internal inspection
Generator	(Generator internal) Inspect for loose electric circuit terminals, discolored, peeled or loose coil, abrasion and damage to slip ring, loose and rusted revolving part. Measure brush contact pressure and insulation resistance of electric circuit. (Brake equipment) Inspect for shoe abrasion loss and operation condition (Neutral grounding resistor) Measure resistance and insulation resistance	(Rotor lifting) Inspect for loose rotor core and winding. Measure winding deterioration. Inspect loose wedge, flaking varnish, and rust. (Brake equipment, bearings and air cooler overhaul. * Measure shaft current * Exciter characteristic test
Control panels etc	(Performance test of all relays)	(Performance test of all relays)

15.3.3 Spare Parts

Spare parts are stored for the quick corrections of and recover from abnormalities and breakdowns. The variety and quantity of these spare parts are determined considering their frequency of breakdowns, the manufacturing period and the importance level of the parts. The storage location is determined based on the haul distance and other conditions. The required quantity of consumables such as brushes and fuses are stored separately. Examples of spare parts for hydro power station are listed in Table 15-6.

Table 15-6 Common Spare Parts

Component	Part name	Quantity	Remarks
Turbine			
Main unit	Main bearing metal	For 1unit	
	Guide vane weak point pin	For 1unit	
	Searing packing	For 1unit	During repairs, the damaged parts are required and stored as auxiliary parts.
	Runner	For 1unit	
	Guide vane	For 1unit	
	Nozzle tip	For 1unit	
	Bucket		
Governor	Printed circuit board	1 each	
	Moving coil	1	
	Various springs	1 each	
Oil pressure supply and lubrication oil system	Oil pressure lubricant pump	1unit	Only where an auxiliary system is not installed.
	Un-loader spring	1	
Air compressor	Safety valve spring	1	When not included in the auxiliary equipment as a set.
	Pressure reduction valve	1	
Automatic control system	Solenoid for electromagnetic valve	1	
Generator	Thrust bearing metal	For 1unit	
	Guide bearing metal	For 1unit	
	Stator coil	5～10	
	Brush holder	For unit	
Exciter	Printed circuit board	1 each	
	Field breaker coil	1	
	Semiconductor rectifier	For 1phase	
Transformer	Bushing	For 1phase	Not stored if available from other power plant stocks.
	Bursting board	1	
Switchgear			
Breaker	Bushing	For 1phase	Not stored if available from other power plant stocks.
	Fixed/movable contact	For 1phase	
	Switching coil	1 each	
Disconnecting switch	Switching coil	1 each	
Control panel	Printed circuit board	1 each	
Others			
Generator main circuit	Current transformer (per model)	1 each	Not stored if available from other power plant stocks.
	Instrument transformer (per model)	1 each	

15.4 Distribution Facilities

Distribution facilities to maintain, which are poles, conductors, transformers, watt- hour meters etc., are widely distributed. It is necessary to maintain distribution facilities efficiently and properly in order to operate the system safely and prevent the accidents.

15.4.1 Operation

(1) Item of operation

Main items of distribution facilities operation are as follows.

Table 15-7 Main Items of Distribution Facilities Operation

	Items	Contents
1	Scheduled Outage	To stop power supply in order to repair and check distribution facilities or to cut trees close to hot line.
2	Fault recovery	To recover the fault such as grounding fault, etc.
3	Measurement	To measure voltage, current etc.

(2) Scheduled outage

It is necessary to preliminarily decide the procedure of the installation and operation of the switches and grounding short-circuit equipment etc. based on minimizing the outage range and ensuring the safely work. It is also important to inform the customers of the scheduled outage in advance according to its procedure. Table 15-8 shows an example of the procedure.

(3) Fault recovery

When the fault occurs, it is preferable to restore it as soon as possible. In many cases the fault may cause damage to the equipment, it is necessary to consider carefully both public and worker's safety. Therefore it is recommended to train for the fault restoration and to prepare materials and the tools on a routine basis. An example of the fault recovery is shown below.

1) Power cut

Protection relay detects the fault. Then circuit breaker automatically opens and power supply stops.

2) Checking the present situation

Check the status of protection relays (such as which relay is operated), switches and load etc.

3) Estimation of the fault cause

Estimate the cause of the fault according to the present situation. (Example : overload, short-circuit, grounding fault, the fault in power plant, etc)

Table 15-8 Example of Scheduled Outage Procedure

	DATE OF WORK		24-Feb-09			
	WORK OUTLINE		Installation of 10kVA Transformer to OR-066			
	Place		OR-066			
	Purpose		To supply electricity to a new customer			
	Responsible person at the site		Mr. A			
	Deenergized MV Line		From	Hydro P/S		
			To	Hospital S/S F1		
	Outage PMT		PMT01, PMT02, PMT03			
	Date of notification*		24-Feb-09			
	Method of notification		loudspeaker			
	PROCEDURE		Outage PMT	TIME		
				Scheduled	Result	
1	Hydro P/S MCB	OFF	–			
2	Hospital S/S F2	OFF	PMT01,PMT02,PMT03	13:00	13:05	
3	Hospital S/S F2	Earthing	PMT01,PMT02,PMT03			
4	OR-065	Check voltage	PMT01,PMT02,PMT03			
5	OR-065	Earthing	PMT01,PMT02,PMT03			
6	OR-067	Check voltage	PMT01,PMT02,PMT03			
7	OR-067	Earthing	PMT01,PMT02,PMT03			
8	OR-066	10kVA TR Installation	PMT01,PMT02,PMT03			
9	OR-066	Meter Box Installation	PMT01,PMT02,PMT03			
10	OR-065	Detach Earthing Tool	PMT01,PMT02,PMT03			
11	OR-067	Detach Earthing Tool	PMT01,PMT02,PMT03			
12	Hospital S/S F2	OFF	PMT01,PMT02,PMT03			
13	Hospital S/S F2	ON	–	16:00	15:30	
14	OR-066	Check the New Equipment	–			
15	OR-066	Check voltage	–			
16	Hydro P/S	Syncronizing	–			
17	Hydro P/S MCB	ON	–			
	Result of outage period**		PMT01	2:25		
			PMT02	2:25		
			PMT03	2:25		

4) Pre-energizing

If the fault point can not be detected, open all switches and pre-energize each section from power plant in order to search the fault section.

5) Fault detection

After fixing the fault section, find the fault cause by extraordinary patrol checking facilities in the fault section. The insulation–resistance meter (meg-ohmmeter) other fault detection equipment to charge the direct-current pulse voltage to the overhead distribution conductor is also common to find fault point.

6) Fault recovery

Remove the fault cause and repair the facilities if necessary. Be sure to attach the grounding short-circuit equipment in order to make the work section safe.

7) Energizing and recording

After removing the fault cause, energize and restore the system. Then record the fault data in order to use it for improvement for the fault prevention.

Table 15-9 shows an example of a fault outage record.

(4) Measurement

It is important to measure voltage, current, and ground resistance, etc. for checking the status and maintenance of the distribution line.

It is necessary to measure or analyze voltage and current of the system at the peak and off-peak, and when they are out of the permissible ranges it is also necessary to take measures to make them within the ranges.

When it comes to management of electricity loss, a watt- hour meter should be set up on the secondary side of the transformer in order to detect a technical loss and a non-technical loss such as stolen electricity Stolen electricity can be found by comparing the indication of the meter to a total amount of power supplied by the transformer.

Table 15-9 Example of Fault Outage Record

	Date	**Outage time**		**Weather**		
	3-Apr-09	13:10		Rain with thunder		
	Customer Report	Name		-		
		Date & Time		-		
		Contents		-		
	P/S Situation (Output before outage)	A P/S		V0=21kV, Overcurrent, MCB Shutdown (60kW)		
		Diesel P/S		V0=22kV, V0-Overvoltage (100kW)		
		B P/S		Scheduled Stopping (0kW)		
	Responsible Person	Order of Operation		Mr. A		
		Transmission		Mr. B		
		DG P/S		Mr. C		
	Procedure			**Date**	**Time**	**Condition(P/S, Site)**
1	Diesel P/S MCB		OFF	3-Apr	13:10	
2	District S/S F1,F2,F3		OFF	3-Apr	13:20	
3	Hospital S/S F1,F2,F3		OFF	3-Apr	13:25	
4	Diesel P/S MCB		ON	3-Apr	13:28	GOOD
5	Hospital S/S F1		ON	3-Apr	13:28	GOOD
6	Hospital S/S F2		ON	3-Apr	13:28	GOOD
7	Hospital S/S F3		ON	3-Apr	13:28	GOOD
8	District S/S F2		ON	3-Apr	13:34	GOOD
9	District S/S F3		ON	3-Apr	13:35	GOOD
10	District S/S F1		ON	3-Apr	13:36	GOOD
	Inspection		Date	From	To	Result
	MV Line of A P/S Side		3-Apr	13:50	15:00	GOOD
	MV Line of B P/S Side		3-Apr	13:50	15:00	GOOD
	From OM108 to OM135		4-Apr	14:30	15:00	GOOD
	Reason for Fault					
	Unkown --- Probably thunder shock					
	Comments by Chief					
	The person who are responsible to order operations should stay DG P/S, and order operations to Distribution team by radio, so that DG P/S Indicator can be observed and do the next action quickly if Distribution team finds some Distribution equipment's abnormal condition. Distribution staff should be devided to 2 teams. One is to go to Hospital S/S, and the other is to go to District S/S. So Electricity Unit can go through the switch operation quickly, and reduce power outage duration to customers.					

15.4.2 Maintenance

It is necessary to remove the fault causes through patrol and inspections in order to prevent faults.

(1) Patrol and Inspections

Basically, patrol and inspections of distribution facilities are carried out without interruption of power supply. The patrol and the inspections are classified into the following three.

1) Periodic patrol (weekly or monthly)

Rough Patrol for the whole Distribution Facilities for finding flying-obstacles, facilities broken, trees fell down, obstructive building construction, etc.

2) Annual inspection (yearly)

A detail Inspection for observations of degradation and damage

3) Incidental Patrol (when the fault has occurred)

Patrol for finding a fault point

The examples of the maintenance check sheets for each equipment inspection are shown in Appendix A-6-1 to A-6-14.

The check results should be described in the form and reported to the person in charge.

Reference of Chapter 15

[1] Basic design study report on the project for rural electrification micro-hydro power in remote province of Mondul Kiri in the Kingdom of Cambodia, JICA, 2005

[2] The project for Project for Operation and Maintenance of the Rural Electrification on Micro-hydropower in Mondul Kiri, JICA, 2011

Chapter 16

Assistance in Management Electrical Utility Services

Chapter 16 Assistance in Management of Electrical Utility Services

16.1 General

A new management body established for the rural electrification is operated by local people, as most part of the pursuers, who has no experience in and no knowledge of electrical utility services. Once an electrical supply service is started, it is difficult for a limited number of staff to have a long-period of technical training. Therefore, it is required from the commencement of the services to develop human resources with the minimum ability of operation and maintenance of electrical facilities. For that purpose, OJT, on the job training, is indispensable. This training is through the practice of management, operation, and maintenance of the existing hydropower plants.

It is desirable that the technical training be carried out by experts who are working for state institutions or aid agencies related to electric power.

The following items should be effectively considered for planning and practicing the assistance program.

i) It is desirable to have the candidates engaged in the construction work as much as possible. Having been engaged in the construction work as an assistant gets the candidates to increase the depth of understanding of facilities and mechanisms, and to make use of the experience for operation and troubleshooting.

ii) It is recommended that a training center or vocational training school of public corporations be utilized. It is necessary for amateurs in electric power to learn the basic electrical knowledge and safety matters before actual operation of the plant. For a training site, it is preferable to choose either a public corporation of the country or a vocational school for electrical facilities in the urban areas, where there is no language problems.

iii) A monitoring system should be adopted for checking the learning level of skills even after the commencement of operation. Also it is necessary to implement periodical audits on the management and operation by related government authority.

16.2 Guidance before Starting Operation

A management body should be established in due advance together with proper corporate structure and basic regulations in order to start electric supply soon after the completion of the construction. For that purpose, it is desirable that guidance and training be introduced with the assistance of experts who have rich experience in and knowledge of operation of electrical utility services.

(1) Establishment of the Management Body

On the electrical business management shown in Table16-1, guided are managers who execute the establishment management, administration work and technical work.

Table 16-1 Guidance before Starting Operation

Activities	Description
1) Establishment of Management Body	To provide technical guidance on development of rules during the preparation period and on how to operate the organization when the Management Body is established, and help it establish Joint Steering Committee.(See; Figure 14-1)
2) Establishment of Joint Steering Committee	
3) Arrangements to obtain license for electricity business and approval for electricity tariff rate	To provide technical guidance on how to prepare an application form for business license and a statement on electricity rate during the preparation period, and to help them become capable of obtaining the license
4) Start-up of power supply business	To check management of power utilization during test operation, advise on points for improvement, and help the local staff continuously carry out their own management

(2) Formulation of office work management system

On the items shown in Table16-2, guided are workers in the administration section who are in charge of the collection of the electricity rate, and the revenue and expenditure management, in the operating management section, and in the distribution line maintenance section.

Table 16-2 Activities on Administration

Activities	Description
1) Outline and functions of power facilities	To help the trainees learn the basics of power plant facilities and understand the roles of the staff through lectures, including visits to the site
2) Lecture on electricity charge system	To hold a lecture on the concept of electricity charge and its system so that the trainees can learn the background of the work of 3) and 4)
3) Development of office management manuals	To help the trainees complete the office management manuals based on the draft prepared in advance and establish the work flow through workshops
4) Guidance on recording energy consumption, issuing and sending invoices, and collection of electricity charges	To help the trainees memorize the work procedures (described left) through lectures and field practice
5) Guidance on documentation (meter reading, invoicing, collection of charges)	To help the trainees memorize the work (described left) through lectures and field practice

(3) Establishment of the maintenance and operation method of civil structures

On the items shown in Table16-3, guided are the staff of the operation and maintenance works of the civil structures.

Table 16-3 Activities on Operation and Maintenance for Civil Structures

Activities	Description
1) Outline and functions of power plant facilities	To help the trainees learn the basics of power plant facilities and understand the roles of the staff through lectures, including visits to the site
2) Guidance on functions and structures of civil engineering facilities	To help the trainees understand the functions and structures of the civil engineering facilities through lectures and field visits
3) Preparation of operation and maintenance manuals for civil engineering facilities	To help the trainees complete the manuals based on the draft prepared in advance and establish the work flow through workshops
4) Guidance on inspection, maintenance and repair of civil structures	To help the trainees learn how to make a daily inspection, mainly through field practice, and be capable of judging repair necessity
5) Guidance on documentation of maintenance of civil structures (operation, shut-down, inspection and repair)	To help the trainees be capable of filling in inspection sheets, mainly through field practice

(4) Establishment of the maintenance and operation method of electro-mechanical equipment

On the items shown in Table16-4,guided are the staff of operation and maintenance work of the electro-mechanical equipment.

Table 16-4 Activities on Operation and Maintenance for Electro-mechanical Equipment

Activities	Description
1) Guidance on functions and structures of electro-mechanical equipment	To help the trainees learn the basics of power plant facilities and understand the roles of the staff through lectures, including visits to the site
2) Guidance on inspection, maintenance and repair of electro-mechanical equipment	To help the trainees learn how to make a daily inspection, mainly through field practice, and to be capable of judging repair necessity
3) To prepare operation and maintenance manuals for electro-mechanical equipment	To help the trainees complete the manuals based on the draft prepared in advance and establish the work flow through workshops
4) Guidance on operation, shut-down, and condition monitoring of power electro-mechanical equipment	To help the trainees learn the basic operation of electro-mechanical equipment, mainly through field practice
5) Guidance on documentation (operation, shut-down, inspection and repair)	To help the trainees be capable of filling in inspection sheets mainly through field practice

(5) Establishment of the maintenance and operation method of distribution facilities

On the items shown in Table16-5, guided are the staff of the operation and maintenance work of the distribution facilities.

Table 16-5 Activities on Operation and Maintenance for Distribution Facilities

Activities	Description
1) Guidance on functions and structures of distribution facilities	To help the trainees learn the basics of power plant facilities and understand the roles of the staff through lectures, including visits to the site
2) Guidance on inspection, maintenance and repair of distribution facilities	To help the trainees learn how to make a daily inspection, mainly through field practice, and to be capable of judging repair necessity
3) To prepare operation and maintenance manuals for distribution line facilities	To help the trainees complete the manuals based on the draft prepared in advance and establish the work flow through workshops
4) Guidance on trouble shooting of operation and maintenance work for distribution line facilities	To help the trainees learn troubleshooting for the basic operation of distribution line facilities, mainly through field practice
5) Guidance on documentation (operation, shut-down, inspection and repair)	To help the trainees be capable of filling in inspection sheets mainly through field practice

16.3 Items for Operation Support after Starting Operation

For the same items as above mentioned such as management, and operation and maintenance work, coaching is carried out in the manner of practice. It is also required to check if the workflow created beforehand fits the reality and modify the regulations and approaches if needed.

(1) Items for operation support

i) Advice and guidance for management & operation to the management body shown in Figure 14-1

ii) Advice to a regulatory agency of the government concerning the monitoring method for the performance of the management body

iii) Practical guidance for office work management system and modification as appropriate

iv) Practical guidance for operation and maintenance of civil structures and modification as appropriate

v) Practical guidance for operation and maintenance of electro-mechanical equipment and modification as appropriate

vi) Practical guidance for operation and maintenance of distribution facilities and modification as appropriate

(2) Assistance period

Operation assistance by experts is necessary at least for 2 to3 years for the following reason.

i) First year: Practice of tariff charging system and operational method, and modification as needed

Hydro power often differs in the manner of operation between the rainy season and dry season due to its utilization of natural river flow. Demand for electric power also differs according to the seasons. Thus, the combined cycle pattern of demand and supply requires at least one year. For the first year, everything is new for a management body and the managers of electrical utility services. In addition since there are many cases where they start commercial operation just after the completion of electrical facilities without adequate trial operation, initial troubles will often occur during the operation within the first one year. This is why elaborate assistance by experts is indispensable for the first year in particular for maintaining steady supply of electric power.

ii) Second year and afterward: Audit and guidance of electrical utility services, and technical training and improvement of operation and maintenance

Audit should be carried out on a quarterly basis for proper business management by checking the status of charge collection and expenses. Repeated training is also required for the staff to acquire technical skills on inspection, operation and maintenance, troubleshooting etc. of the electrical facilities.

Reference of Chapter 16

[1] Basic design study report on the project for rural electrification micro-hydro power in remote province of Mondul Kiri in the Kingdom of Cambodia, JICA, 2005

[2] The project for Project for Operation and Maintenance of the Rural Electrification on Micro-hydropower in Mondul Kiri, JICA, 2011

APPENDIX

Appendix Contents

A-12-1 Example of Unit Price of Labor

1	Year, Month		5	Exchange Rate	Local currency/ U.S.$
2	Country				
3	Project				
4	Sector				

	Name	Unit	Applied Rate					
			Basic Rate	Allowance			Total	Note
				Insurance	Bonus	Retirement		
1	Forman	day						
2	Specialist worker	day						
3	Common worker	day						
4	Earth worker	day						
5	Scaffolder	day						
6	Re-bar worker	day						
7	Driver-heavy Vehicle	day						
8	Driver-light vehicle	day						
9	Carpenter（form work)	day						
10	Carpenter	day						
11	Plaster man	day						
12	Mason	day						
13	Painter	day						
14	Welder	day						
15	Electrician	day						
16	Mechanic	day						
17	Plumber	day						
18	Watchman	day						
19	Concrete worker	day						
20	Steel frame worker	day						
21	Block layer	day						
22	Plaster man	day						
23	Window fitter	day						
24	Tile worker	day						
25	Roof worker	day						
26	Glazer	day						
27	Site supervisor	day						
28	Quality surveyor	day						
29	Store keeper	day						
30	Machinery operator	day						
31	Surveyor	day						
32	Office clerk	day						
33	Accountant	day						
34	Typist	day						
35	Secretary	day						
36	Office boy	day						
37	Cook	day						
38	Maid	day						
39	Driver	day						
40	Watchman	day						

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-12-2 Example of Unit Price of Construction Materials

1	Year, Month		5	Exchange Rate	Local currency/ U.S.$
2	Country				
3	Project				
4	Sector				

	Name-1	Name-2	Specification	Unit	Adopted Unit Price			Procurement Place
					Local	U.S $	Converted in US$	
1	Steel Bar	Deformed bar	SD295A,10-16mm	t				
		Deformed bar	SD295A,19mm & over	t				
2	Steel Pipe	Steel pipe	φ600×6,000mm	kg				
		Steelpipe	φ800×6,000mm	kg				
		Steel pipe	φ1,000×6,000mm	kg				
3	Wire Mesh	Welding wire mesh	2m×1m×0.5m	m				
4	Concrete	Cement	White Portland cement	kg				
		Fine aggregate	for Concrete	t				
		Coarse aggregate	for Concrete	t				
		Sand	for Concrete	m3				
		Crushed stone	25-150	m3				
		Rock for slope protection	20-50kg/pc	m3				
5	Wood	Plywood for finishing	t=12mm	m2				
		Timber for structure	50mm×50mm	m				
		Timber for structure	100mm×100mm	m				
		Hard wood	1st Class	m3				
		Hard wood	2nd Class	m3				
6	Asphalt		t=50mm	m2				
7	Fuel and Oil	Gasoline		l				
		Oil		l				
		Diesel Oil		l				

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-12-3 Example of Unit Price of Construction Machine and Equipment

1	Year, Month		5	Exchange Rate	Local currency/ U.S.$
2	Country				
3	Project				
4	Sector				

	Name	Specification			Unit	Adopted Unit Price		
		Class	Output	Weight		Local	US $	Converted in US$
1	Backhoe excavator	0.4 m3			day			
2	Backhoe excavator	0.6 m3			day			
3	Giant breaker	1,300 kg			day			
4	Wheel loader	0.8 m3			day			
5	trailer	20 t			day			
6	Bulldozer	11 t			day			
7	Bulldozer	15 t			day			
8	Dump truck	10 t			day			
9	Truck	4 t			day			
10	tire roller	8-16 t			day			
11	Motor grader	2.5 t, 4.0m			day			
12	Truck with crane	2 t			day			
13	Truck with crane	4 t			day			
14	Truck crane	16 t			day			
15	Crawler crane	20 t			day			
16	Vibro hammer	232 kW			day			
17	Vibration Roller	5-8 t			day			
18	Plate compactor	60-100 kg			day			
19	Generator	45 kVA			day			
20	Generator	60 kVA			day			
21	Re-bar bender	Electric			day			
22	Pick up truck	2,000 CC			day			
23	Four wheel drive car	2,500 CC			day			
24	Minibus	12 Persons			day			
25	Air compressor	2.5 m , 3 /min			day			
26	Concrete mixer car	4 m3			day			
27	Vibrator for concrete	50 φ			day			
28	Water lorry	10 m3			day			
29	Engine welder	150 A			day			
30	Mortar mixer	0.5 m3 25ps			day			
31	Water pump	80mm, h=20m			day			
32	Water pump	100mm, h=20m			day			

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-12-4 Example of Samary of Original Cost

	Name-1	Name-2	Specification	Unit	Adopted Unit Price			Procurement Place
					Local	U.S $	Converted in US$	
1	Water way	Sealing compound	Polysulfide	m				
		Sealing compound	Silicone	m				
2	Roofing work	Corrugated aluminum sheet		m2				
		Metal roofing sheet		m2				
3	Doors and Window	Steel single swing flush door set	W=0.9,H=2.1	set				
		Aluminum double slide window	W=2.0, H=1.0	set				
		Cylinder lock		pc				
4	Glass work	Plate glass	t=4.5mm	m2				
		Float glass	t=2mm	m2				
5	Metal work	Anchor bolt	L= 250 dia=13	pc				
		Checkered plate	t=3mm	m2				
		Checkered plate	t=5mm	m2				
		Galvanized grating	W=300, Loading Capacity=1.0t	m				
		Electric Welding Rod	3.2 mm	kg				
		Electric Welding Rod	4.0 mm	kg				
		Light Gage Steel Partition Frame		m2				
		Light Gage Ceiling Frame		m2				

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-13-1 Example of Quality Control Sheet

Item	Measure Item	Standard	Frequency	Remark
Sand	Sieve analysis test	-	before commencement of work	
	Specific-gravity test	MLIT standard	before commencement of work	
	Water Absorption test	MLIT standard	before commencement of work	
	Unit Weight test	-	before commencement of work	
	Moisture Content test	-	Each casting day	
Aggregate	Alkali aggregate reaction test	(No reaction)	before commencement of work	
	Sieve analysis test	-	before commencement of work	
	Specific-gravity test	MLIT standard	before commencement of work	
	Water absorption test	MLIT standard	before commencement of work	
	Unit weight test	-	before commencement of work	
	Test for resistance to abrasion of coarse aggregate by use of the Los Angeles machine	MLIT standard	before commencement of work	
	Moisture content test	-	Each casting day	
Cement	Catalog	-	before commencement of work	
	Compressive strength test	JIS R 5210	before commencement of work	
Water for Mixing	Water examination	-	before commencement of work	
Batching Plant	Weighing accuracy test	(±3%)	every 3 months	
Concrete	Compressive strength test	Technical specifications TS3.2.5	Each casting day	
	Slump test	Technical specifications TS3.2.1	Each casting day	
	Air content test	Technical specifications TS3.2.1	Each casting day	
	Chloride content test	MLIT standard	every 150m^3	
Crushed Stone	Specific-gravity test	Technical specifications TS2.6.1	before commencement of work	
	Sieve analysis test	-	before commencement of work	
	Proctor Compaction test	-	before commencement of work	

* MLIT standard: Standard for civil works by Ministry of Land, Infrastructure and Transport Japan.

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-13-2 Example of Quality Control of Concrete Materials

THE PROJECT FOR THE RURAL ELECTRIFICATION ON MICRO-HYDROPOWER IN REMOTE PROVINCE OF MONDUL KIRI

Checed by Contractor	Checed by Consaltant

Concrete Control Chart

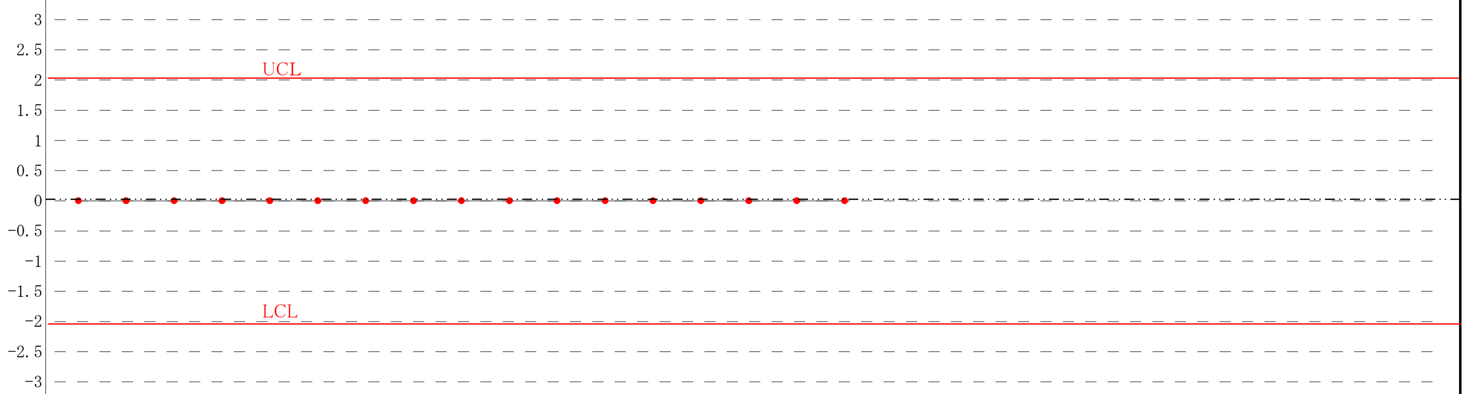
Strength: 18 N/mm^2

Frequency of mejurement: ____________

Mesured by ____________

Date																															
Item / No.																														
Design	cm																													
Actual	cm																													
Difference	cm																													

Allowable Error
Standard
±2.0



Note	

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-13-3 Example of Control Sheet

Site:

Location:

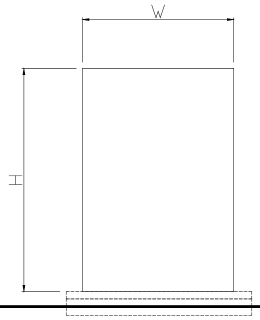
Control Item :

Interval of Measurement :

Item / Station	Width (W)			Height (H)			Remark
	Design (mm)	Actual (mm)	Differential (mm)	Design (mm)	Actual (mm)	Differential (mm)	
							Allowable Error Standard W≧-**mm ≦+**mm H≧-**mm ≦+**mm

The Upper: Checked by Contractor

The Lower: Checked by Consultant



Measured by Contractor

Date: / /

Signature:

Checked by Consultant

Date: / /

Signature:

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-13-4 Example of Transmittal Form

Application for Approval

Subject	
Data	
Comments	
Attached	
Project Name	THE PROJECT FOR THE RURAL ELECTRIFICATION ON MICRO-HYDROPOWER
Contractor	Construction Co.,Ltd.
Name	
Signature	

or Consultant use

Result	☐ Approve ☐ Disapprove ☐ Others（ ）
Comments	
Date	
Consultant	Consortium of Electric Power Development Co.,Ltd. And Nippon Koei Co., Ltd
Name	
Signature	

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-13-5 Example of Application for Approval (Type-B)

Project Name	xxx Micro Hydropower Project						
Contractor	xxx Construction Co., Ltd.			Consultant		xxx Consultant Co., Ltd.	
TRANSMITTAL FOR APPROVAL							
Contractor							
NO.							
Date	Date / Month / Year						
Subject	Approval for						
Attached							
Comments;							
Consultant							
Date							
☐	Receipt	☐	Confirmation	☐	Approve	☐	Pending
Comments;							

Signatures:

Consultant	Contractor

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-1 Example of Check Sheet of Civil Structures for Daily Partrol

Check sheet of civil structures for daily patrol

Day ______ Month ______ Year ______ ______

Name ____________________

Name of facility	Item	Condition		Status if "NG"	Remark
Access path	Appearance	☐ OK	☐ NG		
Intake weir	Intake screen	☐ OK	☐ NG		
	Locking	☐ OK	☐ NG		
	Appearance	☐ OK	☐ NG		
Sedimentation basin	Screen	☐ OK	☐ NG		
	Appearance	☐ OK	☐ NG		
Waterway	Appearance	☐ OK	☐ NG		
Head tank	Screen	☐ OK	☐ NG		
	Appearance	☐ OK	☐ NG		
Spillway	Appearance	☐ OK	☐ NG		
Penstock	Appearance	☐ OK	☐ NG		
Powerhouse	Appearance	☐ OK	☐ NG		
Outlet	Appearance	☐ OK	☐ NG		

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-2 Example of Check Sheet of Civil Structures for Weekly Partrol

Check sheet of civil structures for weekly patrol

Day ________ Month ________ Year ________ Name ________

Name of facility	Item	Condition		Status if "NG"	Remark
Access path	Side ditch	☐ OK	☐ NG		
	Road surface	☐ OK	☐ NG		
	Slope protection	☐ OK	☐ NG		
Intake weir	Structure	☐ OK	☐ NG		
Sedimentation basin	Structure	☐ OK	☐ NG		
Waterway	Structure	☐ OK	☐ NG		
Head tank	Structure	☐ OK	☐ NG		
Spillway	Structure	☐ OK	☐ NG		
Powerhouse	Retaining wall	☐ OK	☐ NG		
Outlet	Appearance	☐ OK	☐ NG		

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-3 Example of Check Sheet of Civil Structures for Monthly Partrol

Check sheet of civil structures for monthly patrol

Day ______ Month ______ Year ______ ______ Name ______

Name of facility	Item	Condition		Status if "NG"	Remark
Access path	Weeding	☐ OK	☐ NG		
Intake weir	Sedimentation	☐ OK	☐ NG		
	Gate	☐ OK	☐ NG		
Sedimentation basin	Sedimentation	☐ OK	☐ NG		
Head tank	Sedimentation	☐ OK	☐ NG		
Spillway	Appearance	☐ OK	☐ NG		
Penstock	Vibration	☐ OK	☐ NG		
	Bolt	☐ OK	☐ NG		
Outlet	Sedimentation	☐ OK	☐ NG		

出典：JICA「カンボジア国モンドルキリ州小水力地方電化計画の運営・維持管理プロジェクト」より

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-4 Example of Daily Operation Recprd (Hydropower)

Daily Operation Record (Hydropower) **Name of PS:** **DATE:** / / **Weather:**

Times	Generator (V)			Hz	Speed	Press.	GV	kW	Var	Generator (A)			Cos φ	Line (V)			kW	GWH	SWH	Line (A)			Temperature(℃)						Vo
	RS	ST	TR			Mpa				R	S	T		R	S	T				R	S	T	1	2	3	4	5	6	meter
1:00																													
2:00																													
3:00																													
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20:00																													
21:00																													
22:00																													
23:00																													
24:00																													

Approved by Deputy Director
Technical and Operation Div.
Signature: ____________________

Note: 1)

Confirmed by Chief
T & D Division
____

Note: 1)

Name of Operators
(1) (2) (3)
____

Note: 1)

Total Running Hours: ____________________

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-5 Example of Weekly Inspection for Electro-Mechanical Equipments

HYDROPOWER STATION

Weekly Inspection Report				P.S		
	Date: 01 / 11 / 2008	(Sut.)	Time:	9:00～11:00		Signature by
	Inspector:		Weather:	Fine		Chief:
			Room Temp.:	℃		Operator:
No.	Inspection Items	Unit	Standard Value	Reading values		Remarks
				Previous	This time	
1	**Hydraulic Turbine**					
	Casing and Outer construction	OK /No	Normal			
	water leakage	OK /No	No leak			
	Oil leakage	OK /No	No leak			
	Ground pickings	OK /No	No leak			
	Water outlet temp	℃	15- 35			
	Abnormal Sound or Vibration	OK /No	Normal			
	Bearing temperatures (turbine side)	℃	40- 50			
	Bearing temperatures (generator side)	℃	40- 50			
	Pressure of penstock	mAq	1.0- 1.2			
	Air Breather		Normal			
2	**Guide Vane Mechanism**					
	Casing and Outer construction	OK /No	Normal			
	Servomotor temperatures	℃	40- 50			
	Oil leakage	OK /No	No leak			
	Limit switches	OK /No	No leak			
	Guide Vane handle indicator	mm	Stroke 200			
3	**Speed Increaser**					
	Bearing housing construction	OK /No	Normal			
	water leakage	OK /No	No leak			
	Oil leakage	OK /No	No leak			
	Vibration	OK /No	Normal			
	Sound	OK /No	Normal			
	Smell	OK /No	Normal			
	Oil temperatures	℃	40- 50			
	Bearing temperatures (turbine side)	℃	40- 50			
	Bearing temperatures (generator side)	℃	40- 50			
4	**Inlet Valve**					
	Casing and Outer construction	OK /No	Normal			
	water leakage	OK /No	No leak			
	Abnormal Sound or Vibration	OK /No	Normal			
	Limit switches	OK /No	Normal			
5	**Generator**					
	Casing and Outer construction	OK /No	Normal			
	Oil leakage	OK /No	No leak			
	Abnormal Sound or Vibration	OK /No	Normal			
	Bearing temperatures (turbine side)	℃	40- 50			
	Bearing temperatures (generator side)	℃	40- 50			
	Instruction					
	1)					
	2)					
	3)					
	4)					
	5)					

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-5 Example of Weekly Inspection for Electro-Mechanical Equipments（Continue）

HYDROPOWER STATION

Weekly Inspection Report P.S

Date: 01 / 11 / 2008 (Sut.)		Time:	9:00～11:00		Signature by	
Inspector:		Weather:	Fine		Chief:	
		Room Temp.:	℃		Operator:	

No.	Inspection Items	Unit	Standard Value	Reading values		Remarks
				Previous	This time	
6	**Control Panels**					
	Power system operation					
	Sending power (transmission line)	kW	≦ 185			
	Reactive power	Vary	≦ 138			
	Line voltage	V	22,000			
	Line current	A	6			
	Frequency	Hz	50			
	Power factor	%	lag 1.0～0.8			
	Wh-meter (Sending)	kWh	total Wh			
	Generator operation	kW				
	Generator output	kW	≦ 185			
	Generator voltage	V	400			
	Generator current	A	333			
	Wh-meter (generation)	kWh	total Wh			
	Running hours	h	total hours			
	Status indicator	OK /No	Normal			
	Fault indicator	OK /No	Normal			
	Lamp test	OK /No	Normal			
	Switches lamps	OK /No	Normal			
	Dummy load	OK /No	Normal			
	AVR	OK /No	Normal			
	Cooling fans (inside panel)	OK /No	Normal			
7	**400V/22kV Step-up Transformer**					
	Cut out switches, Arrester, Transformer	OK /No	No leak			
	Oil leakage	OK /No	No leak			
	Vibration	OK /No	Normal			
	Sound	OK /No	Normal			
8	**Power Station**					
	Penstock (leakage, vending, landslide, etc.)	OK /No	Normal			
	Powerhouse	OK /No	Normal			
	Dam	OK /No	Normal			
	Gates	OK /No	Normal			
	Access load	OK /No	Normal			
9	**Pole mounted Substations**					
	Load Switches	OK /No	Normal			
	22kV/400V Transformer	OK /No	Normal			
10	**Transmission/Distribution Lines**					
	400V Distribution lines	OK /No	Normal			
	22kV Transmission lines	OK /No	Normal			
	400V Transformer	OK /No	Normal			
	Line materials	OK /No	Normal			
11	**Wiring**					
	Wh-meters	OK /No	Normal			
	Wiring, etc.	OK /No	Normal			
	Instruction					
	1)					
	2)					
	3)					
	4)					
	5)					

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-6 Example of Intervals and Items of Ordinary Maintenance (No.1)

Ordinary Maintenance

Interval of Ordinary Maintenance

Sr. No.	Classification of Equipment	Check Items	Check Interval: weekly	Once/ Month	Once/3 Months	Once/6 Months	Remarks
1	**Hydraulic Turbine**						
	1.1 Hydraulic Turbine	General Visual check	O				
		Check and Cleaning of the inside pit (outlet)			O		
	1.2 Inlet Valve	General Visual Check	O				
		External check and cleaning				O	
	1.3 Speed Changer	General Visual check	O				
		Oil checking of box and cleaning				O	
	1.4 Oil Cooling Unit	General Visual Check	O				
	1.5 Governor						
	1.5.1 Dummy Load Panel	General Visual check	O				
	1.5.2 Dummy Load Element	General Visual check				O	
	1.5.3 Servo motors	General Visual check	O				
2	**Generator**						
	2.1 Generators	General Visual Check	O				
	2.2 Automatic Voltage Regulator	General Visual check	O				
	(AVR)	External checking			O		
	2.3 Excitation equipment						
	2.3.1 Brushless Exciters	General Visual Check	O				
	2.3.2 Exciter Transformer	General Visual Check	O				
	2.3.3 Exciter rectifier	General Visual Check	O				
	2.3.4 Field Controller	General visual check	O				
	Reactor Field breaker Field Resistor	External checking			O		
	2.3.5 Tacho-generator	General visual check	O				
3	**Transformer**						
	3.1 400V/22kV Transformer	General visual check	O				
		Changing of Taps (before dry season)				O	
	3.2 Cut out switches	Cut out switches				O	
	3.3 Arrestor	General visual check				O	
4	**Breaker**						
	4.1 Circuit Breaker	General Visual check	O				
		Check of the operation				O	
	4.2 Load Switch	General Visual check	O				
5	**Instrument Transformer (VT and CT)**	General Visual check	O				
6	**Cubicle**	General visual check	O				
7	**Electrical Wires and cables**						
	7.1 Electrical wire and insulators	General visual check	O				
	7.2 Power cables	General visual check	O				
8	**Protective Relays**						
	8.1 Transmission line protective relay equipment	General visual check	O				
		Automatic oscilloscope operational condition check				O	
	8.2 Generator and Bus Protective relays	General visual check	O				
9	**Automatic Control Unit**						
	9.1 System control unit	General visual check	O				
	9.2 Electronic control Unit	General visual check	O				
		Inspection at every three months			O		
		Inspection at every six months				O	

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-6 Example of Intervals and Items of Ordinary Maintenance (No.1) (Continue)

Ordinary Maintenance

Interval of Ordinary Maintenance

Sr. No.	Classification of Equipment	Check Items	Check Interval: weekly	Once/ Month	Once/3 Months	Once/6 Months	Remarks
10	**Battery**						
	10.1 Battery cells	Measurement of all batteries and uniform charging				O	
	10.2 Converter	General visual check	O				
	10.3 Chargers	General visual check	O				
11	**Crane**	General visual check				O	
	11.1 Gantry crane	General visual check	O				
	11.2 Monorail crane	General visual check	O				
12	**Air Compressor**	General Visual check	O				
		Operational condition check				O	
13	**Transmission and Distribution lines**						
	13.1 400V/22kV Transformer	General Visual check	O				
		Cleaning				O	
	13.2 Distribution Transformers	General Visual check	O				
		Cleaning				O	
	13.3 Load switches	General Visual check	O				
		Cleaning				O	
	13.4 Arrestors	General Visual check	O				
		Cleaning				O	
	13.5 Wiring and Wh meters	General Visual check				O	
14	**Stand by Diesel Engine Unit**	General visual check	O				
	Diesel Generator 300 kW	External check and cleaning		O			
		Startup tests		O			

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-7 Example of Intervals and Items of Ordinary Maintenance (No.2)

PERIODICAL DETAILED MAINTENANCE

Interval for Periodical Detailed Maintenance (Power Station)

No.	Classification of Equipment	Check Interval	Remarks
1	Hydraulic Turbines		
1.1	Hydraulic Turbines	1) General overhauling	Once/ 10 years
1.2	Inlet Valve	1) General overhauling	Once/ 10 years
1.3	Governors (Including dummy load and control units)	1) To be checked using, as a guide, manuals the checking interval half that for hydraulic turbines	
1.4	Hydraulic Turbine operation controller Equipment	1) To be checked using, as a guide, manuals the checking interval half that for hydraulic turbines	
1.5	Speed Changer	1) To be checked using, as a guide, manuals the checking interval half that for hydraulic turbines	
1.6	Oil Cooler unit	Same as for item 1.5 Speed changer	
2	Generators		
2.1	Generators	1) To be checked using, as a guide, manuals the checking interval half that for hydraulic turbines	
2.2	Exciters	Same as for item 2.1 Generator	
		Rotary and stationary excitation equipment	
2.3	Automatic Voltage regulators (AVR)	Same as for item 2.1 Generator	
		1) The control part should be checked at the interval half that for (1) Generators as a guide.	
3	Transformers	1) When it has been confirmed, as a result of the analysis of gas in the oil, that there is an abnormality inside a transformer.	
4	Breaker and Switch		
4.1	Magnetic Circuit Breaker	1) The specified frequency refers to the cumulative number of current interruptions, the number of interruptions of rated current, the number of switching operation of load current and the number of switching operations; and in other words.	As specified
4.2	Vacuum Breaker	1) The specified frequency refers to the cumulative number of current interruptions, the number of interruptions of rated current, the number of switching operation of load current and the number of switching operations; and in other words .	As specified
4.3	Load Switch	1) The specified frequency refers to the cumulative number of current interruptions, the number of interruptions of rated current, the number of switching operation of load current and the number of switching operations; and in other words.	As specified
5	Instrument Transformers (VT & CT)		As required
6	Cubicles		
6.1	Monitoring and control panels		As required
6.2	Relays for protection panels		As required
6.3	Station service panels		As required
6.4	Synchronizing unit		As required
7	Electrical wire and insulators		
7.1	Control cables		As required
7.2	Power cables		As required
7.3	Electrical wire and insulators		As required
8	Automatic control equipment		As required
9	Surge Absorbers		As required
10	Various types of transformers (Including those for station service and those for local power distribution)	Same as for 3. Transformers	
11	DC Power supply unit for controls		
11.1	Battery		As required
11.2	Converter		As required
11.3	Chargers		As required
12	Air compressors		As required
13	Lighting Arrester		As required

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-8 Example of Fault Record of Electro-Mechanical Equipments

FAULT RECORD

(Urgent Report)

	Date		
	Fault time		
	Fault Power station		
	Power System Load	Total: kW	
	Out Put (kW)		
		Output: kW	
1	Status		
	Kind of Fault		
	Fault Indicators		
	Reasons why		
2	Countermeasure		
	Recovery time		
	Temporally recover		
	Normal recover		
3	Operator name		
4	Approved by		Confirmed by
	Note:		Note:
5	Comments by JICA advisors team		

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-9 Example of Check Items for T/D Facility Inspection (No.1)

Detail Check Items for T&D Facilities' Inspection

Overhead					
	Pole Assembly				
		General			
			Concrete Pole		
				Surroundings	EUMP Staff Easy to access Bucket Car Easy to access Easy to climb No dead animal around No trace of rusty water around No new building is near No new construction work is near
				Pole No.	MV Pole No. is clear LV Pole No. is clear
				Ground	Not flow up Not sink down
				Body of a pole	Not incline Not bent Not cracked Not weathered Not broken
				Step bar	Not remain
				TV cable	Attached appropriate
			Guy Wire		
				Height	Height over road Height over building Height over another place
				Clearance	Clearance to MV Lines, LV Lines OK Clearance to another Transmission equipment OK Clearance to a building OK
				Surroundings	No trace of rusty water around No new building around No new construction work around No vine growing along Not Obstruct Traffic
				Ground	Not flow up Not sink down Anchor is Not shown
				Wire	Elemental wire is Not broken Not too rusty Tension is not too loose Wire End is safe for public
				Collier	Installed firmly Not too rusty Not broken
				Parallel groove Clamp	Installed firmly Not too rusty Not broken
				Turnbuckle	Installed firmly Not too rusty Not broken
				Guy Insulator	Not cracked Not broken Not dusty No trace of arc
				Rod	Not bent too much Not cracked too much Not broken Not too rusty
				Guy Wire Cover	Attached at necessary place Not detached Not broken

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-10 Example of Check Items for T/D Facility Inspection (No.2)

Overhead					
	Pole Assembly				
		General			
			Cross Arm		
				Cross Arm & Arm Tie	Not Incline Not bent Not broken Not too rusty
				Bolt & Nut	Not disappeared Not broken Not too rusty Not loose Not bent
				Obstacles	No nest of birds No other obstacles
			Insulator		
				Porcelain	Not broken Not cracked Not dusty No trace of arc
				Bolt & Nut	Not disappeared Not broken Not too rusty Not loose Not bent
			Earthling Wire		
				General Ground	Earth Resistance Good ※Need to measure Not flow up Not sink down Earthling Rod is Not shown
				Earthling wire	Protected enough by pipe Pipe not broken Pipe not cracked Pipe height enough Conductor is Not shown Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt
				Joint to equipment (Transformer etc.)	Jointed tightly Not too rusty Wire stripping Not too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-11 Example of Check Items for T/D Facility Inspection (No.3)

Overhead					
	Pole Assembly				
		Transformer Assembly			
			Transformer		
				Body outside	Height is enough Not incline Not bent Not dent Not bulge Not too rusty No trace of arc No oil leak Spray Coating Not coming off No abnormal noise Not heated too much Fixed tightly
				Bolt & Nut	Not disappeared Not broken Not too rusty Not loose Not bent
				Insulation Resistance ※If Discharge	Insulation Resistance is enough
				Body Inside ※If Open & Discharge	Color of Oil is Clean Tap Position is appropriate Tap tightly fixed
				Terminal (Primary/Secondary)	firmly fixed to Lead Wire & Cable Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Porcelain Not broken Porcelain Not cracked Porcelain Not dusty Porcelain No trace of arc
				Lead Wire to FCO	Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Wire Tension is not too loose Wire Tension is not too tight Clearance enough to other objectives
				Joint of Lead Wire	firmly fixed to Transformer and FCO Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much
				Earthling Terminal	Jointed tightly to earthling wire Not too rusty Wire stripping Not too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-12 Example of Check Items for T/D Facility Inspection (No.4)

Overhead					
	Pole Assembly				
		Transformer Assembly			
			Fuse Cutout Switch		
				Primary Cutout Switch	firmly fixed to Cross Arm firmly fixed to Lead Wire Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Porcelain Not broken Porcelain Not cracked Porcelain Not dusty Porcelain No trace of arc Fuse Size Appropriate
				Lead Wire to MV Line	Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Wire Tension is not too loose Wire Tension is not too tight Clearance enough to other objectives
				Joint of Lead Wire	firmly fixed to MV Line and FCO Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-13 Example of Check Items for T/D Facility Inspection (No.5)

Overhead					
	Pole Assembly				
		Transformer Assembly			
			Lightning Arrester		
				Body	firmly fixed to Cross Arm firmly fixed to Lead Wire Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Porcelain Not broken Porcelain Not cracked Porcelain Not dusty Porcelain No trace of arc Fuse Size Appropriate
				Lead Wire to MV Line	Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Wire Tension is not too loose Wire Tension is not too tight Clearance enough to other objectives
				Joint of Lead Wire	firmly fixed to MV Line Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much
				Earthling Terminal	Jointed tightly to earthling wire Not too rusty Wire stripping Not too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-14 Example of Check Items for T/D Facility Inspection (No.6)

Overhead						
	Pole Assembly					
		Transformer Assembly				
			LV Distribution Board			
				Body		
					Body	Height is appropriate Easy to access for Reading meters Case is Not Charged Front Glass Not Foggy Front Glass Not Dirty Locked Fixed tightly Not broken Not incline
					Lead Cable to Transformer	Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Fixed firmly to the Pole
				Watt-Hour Meter		
					Watt-Hour Meter	Fixed firmly to the Box Not broken Not incline Not too rusty Front Glass Not Foggy Front Glass Not Dirty No trace of arc Not Burned Inside Disk Rotate is smooth No abnormal noise Terminal Cover is Not Charged Terminal Cover is Fixed firmly Wire Fixed to Terminal firmly Terminal Voltage is appropriate Wires connected to correct phase or neutral Not heated too much
					CT	Appropriate Combination to Watt-Hour Meter Fixed firmly to the Box Not broken Not incline Not too rusty Not Burned No trace of arc No abnormal noise Wire Fixed to Terminal firmly Wires connected to correct phase Not heated too much
				MCCB		
					Magneting Switch	Turn On & Off Smoothly Fixed firmly to the Box Not broken Not incline Not too rusty Not Burned No trace of arc No abnormal noise Wire Fixed to Terminal firmly Wires connected to correct phase Not heated too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-15 Example of Check Items for T/D Facility Inspection (No.7)

Overhead		
Pole Assembly		
Transformer Assembly		
LV Distribution Board		
Street Light Control Circuit with Timer		
	Timer	Time Accumulated (Yes/No) Switch Turn On & Off smoothly Fixed firmly to the Box Not broken Not incline Not too rusty Not Burned No trace of arc No abnormal noise Wire Fixed to Terminal firmly Wires connected to correct phase Not heated too much
Wires Inside		
	Wires Inside	No Abnormal Pressure from outside Fixed to the Box firmly Not heated too much Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Wire Tension is not too loose Wire Tension is not too tight
	Joint of Wires	firmly fixed to Watt-Hour Meter etc. Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much
	Earthling Terminal	Jointed tightly to earthling wire Not too rusty Wire stripping Not too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-16 Example of Check Items for T/D Facility Inspection (No.8)

Level 1	Level 2	Level 3	Level 4	Level 5	Item	Check Items
Overhead						
	Pole Assembly					
		LV Assembly				
			Aggregating Meter Box			
				Body		
					Body	Height is appropriate Easy to access for Reading meters Case is Not Charged Front Glass Not Foggy Front Glass Not Dirty Locked Fixed tightly Not broken Not incline
				Watt-Hour Meter		
					Watt-Hour Meter	Fixed firmly to the Box Not broken Not incline Not too rusty Front Glass Not Foggy Front Glass Not Dirty No trace of arc Not Burned Inside Disk Rotate is smooth No abnormal noise Terminal Cover is Not Charged Terminal Cover is Fixed firmly Wire Fixed to Terminal firmly Terminal Voltage is appropriate Wires connected to correct phase or neutral Not heated too much
				CB		
					CB	Turn On & Off Smoothly Fixed firmly to the Box Not broken Not incline Not too rusty Not Burned No trace of arc No abnormal noise Wire Fixed to Terminal firmly Wires connected to correct phase Not heated too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-17 Example of Check Items for T/D Facility Inspection (No.9)

Level 1	Level 2	Level 3	Level 4	Level 5	Item	Check
Overhead						
	Pole Assembly					
		LV Assembly				
			Aggregating Meter Box			
				Wires Inside		
					Wires Inside	No Abnormal Pressure from outside Fixed to the Box firmly Not heated too much Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Wire Tension is not too loose Wire Tension is not too tight
					Joint of Wires	firmly fixed to Watt-Hour Meter etc. Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much
					Earthling Terminal	Jointed tightly to earthling wire Not too rusty Wire stripping Not too much
			Street Light			
					Body	Not Incline Not bent Not broken Not too rusty
					Bolt & Nut	Not disappeared Not broken Not too rusty Not loose Not bent
					Circuit	Connection is correct Bulb Not Broken Glow Lamp Not Broken

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-18　Example of Check Items for T/D Facility Inspection (No.10)

Overhead					
	Pole Assembly				
		LBS Assembly			
			LBS		
				Location	Easy to Access
					Suit Location for Grid's-Operation
				Operating Bar	Locked
					Not Charged
					Move Smoothly
					Fixed firmly to the Pole
					Not broken
					Not incline
					Not Bent
					Not too rusty
					Bolt & Nut Not disappeared
					Bolt & Nut Not broken
					Bolt & Nut Not loose
					Bolt & Nut Not bent
				Body	No nest of birds
					No Obstacles
					Not broken
					Not incline
					Not Bent
					Not too rusty
					Bolt & Nut Not disappeared
					Bolt & Nut Not broken
					Bolt & Nut Not loose
					Bolt & Nut Not bent
					No Abnormal Noise
				Blade	Not broken
					Not incline
					Not Bent
					Not too rusty
					Not too dirty
					No trace of arc
				Porcelain	Not broken
					Not cracked
					Not dusty
					No trace of arc
				Lead Wire to MV Line	Insulating Cover Not broken
					Insulating Cover Not cracked
					Insulating Cover Not melt
					No trace of arc
					Wire Tension is not too loose
					Wire Tension is not too tight
					Clearance enough to other objectives
				Joint	firmly fixed to MV Line and Body
					Joint Not too rusty
					Bolt & Nut Not disappeared
					Bolt & Nut Not broken
					Bolt & Nut Not loose
					Bolt & Nut Not bent
					No Tension to Joint Point
					Not heated too much
					Not melt
					Wire stripping Not too much
				Earthling Terminal	Jointed tightly to earthling wire
					Not too rusty
					Wire stripping Not too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-19 Example of Check Items for T/D Facility Inspection (No.11)

Overhead					
	Pole Assembly				
		Underground Connecting Assembly			
			MV/LV Termination		
				Location	Easy to climb
				Termination	Fixed firmly to the Pole No Compound Leakage Each Termination Not Touched Each Termination Not too close Phase Plate Not Detached No Tracking Winding Tape Not loose Not broken Not cracked Not dusty
				Lead Wire to MV Line	Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Wire Tension is not too loose Wire Tension is not too tight Clearance enough to other objectives
				Joint of Lead Wire	firmly fixed to MV Line Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much
			Cable along the Pole		
				Lead Cable along the Pole	Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Caution: If Finding abnormal condition, Check electric Leakage by MV Voltage Detector AT FIRST before approaching
			Pipe along the Pole		
				Pipe along the Pole	Height is appropriate Fixed tightly to the Pole Not broken Not incline

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-20 Example of Check Items for T/D Facility Inspection (No.12)

Overhead					
	Pole Assembly				
		Underground Connecting Assembly			
			Lightning Arrester		
				Body	firmly fixed to Cross Arm firmly fixed to Lead Wire Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Porcelain Not broken Porcelain Not cracked Porcelain Not dusty Porcelain No trace of arc Fuse Size Appropriate
				Lead Wire to MV Line	Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt No trace of arc Wire Tension is not too loose Wire Tension is not too tight Clearance enough to other objectives
				Joint of Lead Wire	firmly fixed to MV Line Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much
				Earthling Terminal	Jointed tightly to earthling wire Not too rusty Wire stripping Not too much

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-21 Example of Check Items for T/D Facility Inspection (No.13)

Overhead					
	Line				
		Ground Wire			
			Ground Wire		
				Clearance	Clearance to MV lines is enough.
				Sag	Not Unbalanced Not too loose
				Wire	No Kink Elemental Wire is not Broken No Obstacle on the Wire *Kite, Branch, etc.
				Near the pole	Fixed firmly to the Cross Arm
				Earthling Terminal	Jointed tightly to earthling wire Not too rusty Wire stripping Not too much
		MV Wire			
			MV Wire		
				Clearance	Height is enough. Clearance to other things is enough. Clearance to Construction Work is enough. Public cannot touch easily.
				Neighbor	Burned Trees near a wire Dead Animal by electrical shock No Obstacle near the Wire *Inclined TV Antenna or Tree *Tin Roof easy to fly toward, etc
				Sag	Not Unbalanced Not too loose
				Wire	No Kink Insulating Cover is not Cracked Insulating Cover is not Broken No trace of arc on the Insulating Cover Insulating Cover is not burned. No Obstacle on the Wire *Kite, Branch, etc.
				Near the pole	Elemental Wire is not Broken Binding Wire to an Insulator is not Detached Binding Wire to an Insulator is not Loose Bare Conductor is not Touched to other things.
		LV Cable			
			LV Cable		
				Clearance	Height is enough. Clearance to other things is enough. Clearance to Construction Work is enough. Public cannot touch easily.
				Neighbor	Burned Trees near a wire Dead Animal by electrical shock No Obstacle near the Wire *Inclined TV Antenna or Tree *Tin Roof easy to fly toward, etc
				Sag	Not Unbalanced Not too loose
				Wire	No Kink Insulating Cover is not Cracked Insulating Cover is not Broken No trace of arc on the Insulating Cover Insulating Cover is not burned. No Obstacle on the Wire *Kite, Branch, etc.
				Near the pole	Fixed firmly to the Clamp

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA

A-15-22 Example of Check Items for T/D Facility Inspection (No.14)

Underground					
	Cubicle				
		Cubicle			
			Cubicle		
				Location	EUMP Staff Easy to access No dead animal around No new building is near No digging construction work is near
				Foundation	Not sink Anchor Bolt is not Loose No Crack Not Broken Fixed to the Case Not incline Not Slide Not Collapse
				Case	Not broken Not Dent Not bulge Not bent Not too rusty Easy to read Name Plate Spray Coating Coming Off (Yes/No)
				Door	Locked Easily Open and Close Door Stopper works well Gasket of the Door is good Ventilation Opening is not Blocked
				Panel	Easy to read Switch Number and symbol No abnormal noise No trace of entering water No trace of animal No Condensation Not too dirt
				Earthling wire	Earth Resistance Good ※Need to measure Insulating Cover Not broken Insulating Cover Not cracked Insulating Cover Not melt Joint is tight Joint is Not too rusty Wire stripping Not too much
				Operation	Smooth to turn ON/OFF
				Switch	Blade does not Bent Blade is not too rusty Blade is not dirty Charged part is covered well Not Broken inside No trace of arc
				Terminal	firmly fixed to MV Line Joint Not too rusty Bolt & Nut Not disappeared Bolt & Nut Not broken Bolt & Nut Not loose Bolt & Nut Not bent No Tension to Joint Point Not heated too much Not melt Wire stripping Not too much
	Line				
		Cable			
			Cable		
				Location	No digging construction work is along the route
				Cable	Insulating Resistance Good ※Need to measure

Source: Project for the Project for Operation and Maintenance of The Rural Electrification on Micro-Hydropower in Mondul Kiri, JICA