IV-2.4　小水力

小水力マニュアルは、小水力による地方電化を望む地方政府などの技術者を対象とする。本マニュアルでは、候補地点の発掘および地方において検討を実施するために必要な基礎的情報を提供することを目的とする。

Mini-Micro Hydropower Manual for Rural Electrification in the Republic of Peru

Dávila, Celso
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DGER/MEM

RURAL ELECTRIFICATION IN PERU

The beginning of rural electrification in Peru comes from the middle of the last century, when in 1955 the new law of Industrial Electricity was created. Its purpose was to encourage private investment in order to promote the electrification in isolated areas.

Complementing this, in the year 1962 the National Electrical Service Law (SEN) was approved, which regulate the supply of electricity in the areas with no private investment, in the same way promote the development of Hydropower Plants by the Government.

In 1992, with a new Law No.19521, Ley Normativa de Electricidad, started the process of the public service of electricity in charge of the government. It was declared the necessity, utility and security of the electricity supply, and the Ministry of Energy and Mines became the entity in charge of the regulation and protection. This new responsibility was entitled to ELECTROPERU S.A which is part of National Electrical Services (SEN), Mantaro Corporation (CORMAN), and Santa Corporation (CORSAN) and other. ELECTROPERU remained in charge of urban and rural electrification in Peru.

Ten years later, in 1982, the General Law of Electricity was created, transferring the energy distribution right given at first to ELECTROPERU, to the Regional Companies, with the purpose that ELECTROPERU stay as the Head company, having all the shares from the government and being responsible of the planning and Electrical equipment by doing the Master Plan of Electricity, Studies and Execution of Generation and Transmission works. This law allowed the development of the electrical sector in all Peru.

In that year, the extension of electricity reached 40%. In ELECTROPERU, was created an organization dedicated exclusively to the electrification in provinces and districts in all rural areas.

In 1992, appeared the Law of Electrical Concessions, Law No.25844 that divided in three parts the activities in the electrical sector: Generation, Transmission and Distribution; giving concessions and authorizations, all of them regulated by the government. With this fact, the government assured more efficiency in electricity matters and also the participation of private sector, but rural electrification was not taken into account. The percentage of national electrification up to that time was 54.8 %.

The Direccion Ejecutiva de Proyectos (DEP) was created under supreme decree No.021-93-EM, in 1993 as part of the Ministry of Energy and Mines with self technical, administrative and financial rights, in charge of the execution of energetic projects with the fund of different sources.

Since August 1993 until the end of 2006, more than 5.6 million people have been benefited with electricity, being the increment of national electrification from 56.8% in 1993, to 78.7% in 2006.

In this period of time, 672 projects were executed, with a total investment of US$ 665 millions. This means: 57 Transmission Systems Projects (Transmission lines and substations), 310 Distribution Projects (Mini hydro, Primary and Secondary

Networks), 63 Hydropower Projects, 207 Thermal Generation Projects, 2 Wind Energy Projects and 4 programs of Solar Panels.

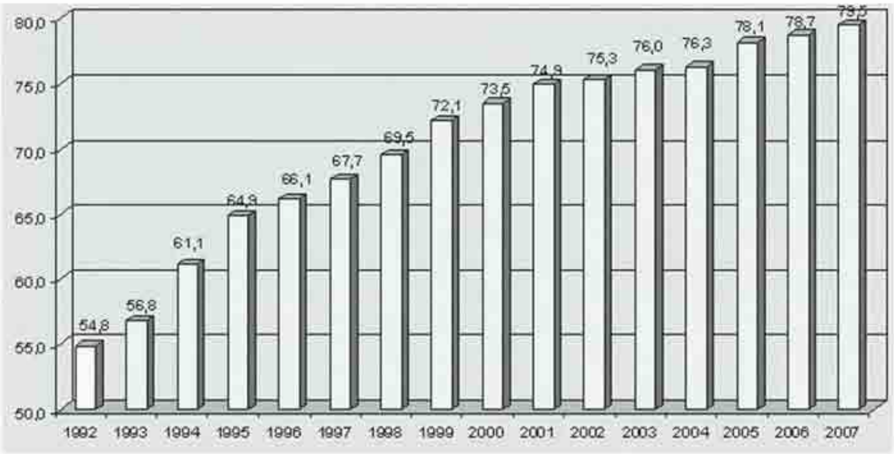
We have commissioned 2, 872 km of transmission lines and 20, 852 km of distribution lines, increasing the isolated generation in more than 150 MW of thermal and hydraulic potency.

The Supreme Decree No.026-2007-EM, dated May 05, 2007 proposed the creation of Dirección General de Electrificación Rural (DGER) as an entity that would be part of the office of the Vice Ministry of Energy and Mines (MEM), through the joint of DEP and FONER.

Likewise, the Supreme Decree No.031-2007-EM, dated June 26, 2007 that approved the Regulations of the Scopes and Organization of MEM declared that: DGER/MEM is responsible for the execution of the National Plan for Rural Electrification which is a duty of the Energy and Mine sector. Also encloses the execution or coordination of electromechanical projects having as priority the rural areas and extreme poverty places.

This legal item declares that DGER/MEM is conformed by the following entities: Dirección de Proyectos (DPR) and Dirección de Fondos Concursables (FONER).

NATIONAL EVOLUTION CHART FOR ELECTRIFICATION



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JICA

Founded in 1974, the Japan International Cooperation Agency is an implementation agency for technical assistance, focusing on systems building, organization strengthening and human resource development that will enable developing countries to pursue their own sustainable socio-economic development. JICA's work is broad in scope and reflects international concerns and changing needs in developing countries. To traditional sectors such as agriculture and social infrastructure, JICA has recently added assistance to combat infectious diseases, support to encourage free market economies or set up legal systems, and support for the peace-building and reconstruction efforts in countries.

JICA uses an issue-based approach to comprehensively analyze issues to be resolved and to expedite various types of programs. "Development Studies" is one of their programs, and this assistance is for formulating development plans at the national or regional level in various social and economic fields. It includes drawing up master plans to act as blue-prints for medium- and long-term development programs, and also includes studying the technical, economic or environmental aspects of proposed project implementations as the basis for feasibility studies.

In the Republic of Peru, JICA implemented "the Master Plan Study for Rural Electrification by Renewable Energy" from February 2007 to July 2008 as one of the supports to Peru based on the above.

Preface

This mini-micro hydropower manual (hereinafter referred to as "the manual") was drawn up for rural electrification by mini/micro hydropower by Japan International Cooperation Agency (JICA) in cooperation with Dirección General de Electrificación Rural (DGER), Ministry of Energy and Mines (MEM) in the Republic of Peru.

JICA implemented "the Master Plan Study for Rural Electrification by Renewable Energy in the Republic of Peru" from February 2007 to July 2008 and the manual was prepared as part of this study. The objective of the manual is to make a practical guideline for procedure of planning and construction of mini/micro hydropower so that persons such as regional government personnel and local residents who want to electrify their region by mini/micro hydropower, but having no experience can obtain knowledge of hydropower.

A kind of study for hydropower planning can be done because some of case examples are shown in the manual. However, in a general there are a lot of methods of planning and design for hydropower plant, therefore, those who want to plan for hydropower plant should consult with appropriate organizations that have sufficient experiences such as DGER/MEM (contact address: refer to the end of the manual) after finishing rough study by using the manual.

In addition, drawing up the manual was carried out with the collaboration of Soluciones Prácticas-ITDG, Peru.

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Mini/ Micro Hydropower Scheme

1

1.1 Rural Electrification

Access to energy

Access to energy is a fundamental element for human development; institutions like the World Bank, United Nations, the European Economic Community and the World Energy Council consider energy to be essential for promoting or improving basic services, such as lighting, safe water, health, education and communications. There is also a general consensus that the Millennium Development Goals will only be achieved if universal access to energy is achieved.

Electricity is a fundamental source of energy. Nevertheless, to achieve a universal access to electricity is a huge challenge. According to the statistics of organisations like the International Energy Agency (IEA), the World Bank and others, about 1.6 billion people in the world have no access to this service and despite government efforts in developing countries, providing access to electricity is a slow and uneven process.

In urban areas, the electricity coverage has increased thanks to the investments made by both the State and the private sector, the latter having enjoyed the benefit of reforms in recent decades. In rural areas, progress is slow because State investments have been slow or non-existent and private investments are not viable because the market is poor and isolated. Even though approximately 480 million rural dwellers gained access to electricity during the seventies and eighties (World Bank, 1996), the number of inhabitants without electricity increased during the same period by about 150 million between 1970 and 1990 and it has been impossible to cover this growing population.

According to recent literature, the energy requirements of poor rural people are very small, between 30 kWh and 50 kWh a month. Field data also reveal that a large proportion of the population consume much less than these figures; for example, in the majority of the communities in the Peruvian Andes, users require less than 10 kWh (Sánchez, 2006). The energy they use is mainly for basic lighting purposes, which inhibits the improvement of children's education, access to information and entertainment.

1.2 Brief Outline of the Use of Hydraulic Energy

Hydraulic energy has been used since ancient times, generated by small and simple machines like hydraulic wheels, which were later used for grain mills and other activities. It is currently one of the most important sources of energy, contributing to the generation of electricity to feed national grids. Systems as large as the Itaipu scheme in Brazil which generates about 13,000 MW or the Three Gorges in China which generate more tan 18,000 MW, provide an idea of the hydroelectric power-generating capacity, the progress of technology and the confidence that investors have in this source of energy.

Despite the great technological progress, there are still enormous resources in many of the world's countries that remain untapped, as occurs in the majority of Latin American countries. For example, Peru has the potential to produce an estimated 58,000 MW of hydropower, yet so far there is only an installed capacity of 3,000 MW, i.e. slightly more than 5% of the existing capacity, representing about 50% of the total installed capacity in the country and supplying 93% of the electricity consumed in the national grid.

Mankind's activities require some degree of energy or other and it has been proved that generating energy based on hydrocarbons will be unsustainable in the medium term, as oil reserves are being depleted and the same will occur with gas and coal within a few dozen years. Moreover, hydrocarbons produce greenhouse gases that are seriously contaminating the environment[1].

Hydraulic energy provides one of the best sources for generating electric and mechanical energy in a clean and renewable manner, particularly in Latin American countries where the rural demand could be covered by small scale hydraulic power plants, with minimum effects on the environment .

Hydraulic energy can be an important source of clean energy, as long as a respect for the environment and for the different communities in the respective watersheds is taken into consideration during the implementation. However, perhaps its most important feature is that it can be used conveniently to generate energy on a small scale and in an isolated manner for rural electrification purposes, this being one of the most appropriate and financially competitive alternatives. During the last few years, rural electrification promotion organisations have indicated that electrification costs in isolated areas through the grid are becoming increasingly more expensive. For instance, according to the MEM (Peruvian Ministry of Energy and Mines), grid connection costs for each new family were about US$1,100 at year-end 2003, becoming more expensive the further away they are from the grids.

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[1] Many claims have been filed worldwide during the last few decades, due to the damages caused by large hydroelectric schemes, particularly flooding in productive valleys and the displacement of entire communities, in some cases resulting in an irreversible loss of species and affecting ethnic groups, sometimes even causing their extinction.

1.3 Small-Scale Hydraulic Energy and its Social Development Potential

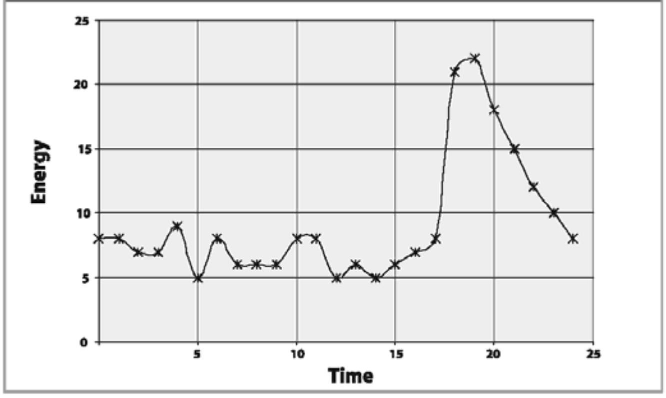
Hydroelectric schemes usually require a large initial investment compared to other sources, but once installed, they contribute favourably to social development. They have the following advantages: (a) they are a clean and renewable source of energy for generating power on a small scale without any major alterations to the environment; (b) they generate energy 24 hours a day; (c) the source of energy costs nothing; (d) operation and maintenance costs are low; (e) small-scale power plants can gain access to local or national spares and technical assistance.

It is a well-known fact that the electricity consumption in rural areas is very low during most of the day, except during the evening (the so-called "peak hours"), when the consumption is relatively "high". As can be appreciated in figure 1 showing the daily consumption in the Conchan district of the Chota province in the department of Cajamarca, Peru, the average consumed by 170 families in 2001 was approximately 7.5 kW, whereas the consumption during peak hours (between 5:30 and 10:30 p.m.) was approximately 22 kW[2].

In view of this rural demand characteristic, a large quantity of energy can be used for the socio-economic development of the user community, because the marginal power-generating costs are insignificant. In fact, various development promotion organizations and governments are promoting the implementation of energy programmes for productive purposes.

Under the context of this great potential for generating low-cost energy, hydraulic energy has become the most appropriate source of energy for productive uses and for adding value to local products like handicrafts, micro industries and other income-generating activities. Hydraulic energy offers more advantages for promoting development than any other source of energy.

FIGURE 1. DIAGRAM SHOWING THE DEMAND OF THE CONCHAN MICRO HYDROELECTRIC PLANT IN CAJAMARCA, PERU, 2000 (170 FAMILIES)



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[2] The demand diagram in figure 1 corresponds to the stage after the implementation of an efficient management model, when all the families had power meters. The consumption before the implementation of that model was high due to the inefficient use of energy.

1.4 Risks of Hydropower Plant-Based Business

Hydroelectric projects usually require long implementation periods, both in the pre-investment and investment stages. The installation of a hydropower plant usually involves several stages, from pre-feasibility studies to engineering designs. Normally, investment decisions are taken based on feasibility studies, once the actual potential has been identified through accurate power estimates on the one hand and the demand for energy on the other. The construction of a plant may be technically feasible and suitable, but unless there is a sure market, or a buyer for the electricity generated, the decision to set up the scheme cannot be taken.

Once the decision to invest is made, the next step is the final engineering design, which consists of an accurate scaling of each component of the scheme, the sizing of every sub-component of the civil works, the dimensions of the pipes and powerhouse and the identification of the detailed technical specifications and origin of each piece of equipment to be used. Well known calculation methods and the corresponding standards must be employed during this process.

Nevertheless, the success of a hydroelectric scheme does not depend as much on the technical aspects as on the feasibility of the market and the investment costs required for the implementation. As mentioned previously, long periods are required for the installation of hydroelectric schemes, therefore the recovery is slow. However, since these schemes do not consume fuel, their marginal costs are usually lower than other energy alternatives and, therefore, they are more viable.

Mini, micro and pico hydroelectric schemes are usually aimed at meeting a specific demand for energy in isolated towns where electricity is not normally a profitable business. However, they are a good alternative for this purpose, as they do not require fuel. Hydroelectric schemes that take advantage of local resources are more familiar for users and easier for local agents to operate and maintain.

The following are the main risks that a hydropower plant is exposed to:

a) **The risk of a shut-down of the hydroelectric system, caused by:**

- Inadequate estimates of water resources, i.e. a deficient hydrological study and therefore the flow design was overestimated, causing problems in the turbines due to the shortage of water.
- Inadequate selection of the turbine, due to the overestimation of the existing flow, as a result of which it would operate deficiently and could even come to a standstill. Flaws of this nature occur more frequently when reaction (Francis and Axial) turbines are used, as impulse turbines have a more regular performance, even with relatively low partial flows.

b) **Maintenance and/or operating flaws:** Poor maintenance of the plant as a whole or any of its parts could cause the plant to shut down. For example, a cave-in or obstruction of the canal or any part of the civil engineering work could leave the plant without water and therefore cause it to stop. Likewise, if a bearing or any other mechanical element should break, the plant could also shut down. Stoppages due to mechanical failures can take longer to solve when no spares are available. Operating failures are caused by human error and occur when the operator is unprepared or not properly trained to operate the entire system correctly. The consequences of this can be greater than those of mechanical flaws.

c) **Flaws in the quality of the equipment:** The quality of the equipment depends mainly on the manufacturer. That is why in larger than mini/micro hydropower plants, consideration should be given to the manufacturer's background, the materials used, the manufacturing process, etc.

d) **Quality of the installation of the machinery:** For larger than mini/micro hydropower plants, the quality of the installation is important. A good assembly implies that the machines must be well aligned with each other, particularly the turbine with the generator and the intermediate components to be used.

The suppliers of the machines usually install them as well, which is advisable to a certain point because it prevents arguments between the suppliers and the installers of the machines in the event of any flaws. It is therefore recommended that for larger than mini/micro hydropower plants, priority should be given to turnkey contracts.

1.5 Designing a Project for Hydropower Plant

Technically speaking, designing a hydropower plant involves a group of documents that contain processed calculations and a detailed description of the results, including explanatory tables and other elements to verify the accuracy of the data and methods used. Each section usually consists of at least one volume; the majority of the studies require detailed plans (civil works, equipment and grids) therefore each volume also contains the corresponding detailed plans. The following studies are usually considered in the project:

a) Electricity market surveys (demand)
b) Geological studies
c) Hydrological study
d) Civil Works: Scaling of the civil works and detailed calculations of the physical dimensions of each of the components mentioned above (intake weir, headrace channel, scouring sluice, head tank, powerhouse, tailrace), as well as complementary works like the access road, camp, etc.
e) Electromechanical equipment (including the technical characteristics of each of the machines and auxiliary equipment)
f) Primary grids (usually medium or high voltage)
g) Secondary grids

1.6 Design of Installed Capacity for Mini/ Micro Hydropower Plant

The installed capacity of a mini/micro hydropower plant is estimated based on the demand and the evaluation of existing hydropower resources, an aspect that is not the object of this publication as there is already enough bibliography on the subject.

The two most important parameters for generating electricity are the flow (Q) and the head (H). A quick way of estimating the power of a hydropower plant is with the following equation:

$$P = kQH$$

Where

P, Installed capacity of the hydropower plant (kW)

k, Factor that includes the effect of the water density, gravity and efficiency parameters

$$k = \gamma \cdot \eta_p \cdot \eta_t \cdot \eta_g$$

γ, specific weight of the water

η_p, efficiency of the piping

η_t, efficiency of the turbine (including the efficiency of the transmission system)

η_g, efficiency of the power generator

H, gross head, measured or estimated (m)

Q, flow (m3/s)

For these quick estimates, average k values were used, which usually differ slightly depending on the size of the plant and the type of turbine, as can be appreciated in table 1.

TABLE 1. TYPICAL VALUES OF K

Power range	K Values
Pico power plants	3.5 – 5
Micro power plants	5 – 6.5
Mini power plants	6 – 7
small and larger power plants	7 – 7.5

The power range corresponds to the classification of hydropower plants. Until a decade ago, this classification was comprised of micro, mini, small, medium and large hydropower plants; now the range has increased to include pico turbines, incorporating the group of the smallest machines. There are two international standards, one used by Europeans and North Americans and one used by OLADE (Latin American Energy Organisation).

TABLE 2. CLASSIFICATION OF HYDROPOWER PLANTS BY THEIR POWER RANGE

Classification Power range	OLADE	United States of America and Europe
Pico power plants	Up to 5 kW	Up to 10 kW
Micro power plants	5 kW – 50 kW	10 kW – 100 kW
Mini power plants	50 kW – 500 kW	100 kW – 1 MW
Small power plants	500 kW – 5 MW	1 MW – 10 MW
Medium power plants	5 MW – 50 MW	10 MW – 100 MW
Large power plants	More than 50 MW	More than 100 MW

Pipes with a good internal finish and little rugosity permit a more efficient flow and therefore fewer losses. The type of material also has an influence on this; for example, in the smallest ranges, plastic pipes are used, which are highly efficient compared to steel pipes. The turbines also have a specific efficiency, depending on the finish, the manufacturing process and the model and size of the machines. Similar factors influence the efficiency of the power generator.

When selecting the machinery for the plant, the manufacturing quality, the background of the manufacturers and the type of turbine selected must be taken into account, in order to avoid unnecessary risks.

1.7 Components of a Mini/ Micro Hydropower Plant

In large hydropower plants, the reservoir is an important component for regulating the use of water throughout the year. In mini/micro hydropower plants, this component is not normally used, other than in exceptional cases when the cost of this structure justifies the investment. Consequently, the following are the main components of mini/micro hydropower plants:

- Intake weir
- Headrace channel
- Settling basin
- Conveyance Ditch
- Flushing gate
- Head tank
- Penstock
- Powerhouse: Turbine, Generator, Regulator
- Tailrace
- Electricity Grids, Transmission grids, Distribution grids

The electricity grids correspond to conventional electrical engineering works, therefore they are not dealt with in this text.

FIGURE 2. COMPONENTS OF A TYPICAL HYDROPOWER PLANT

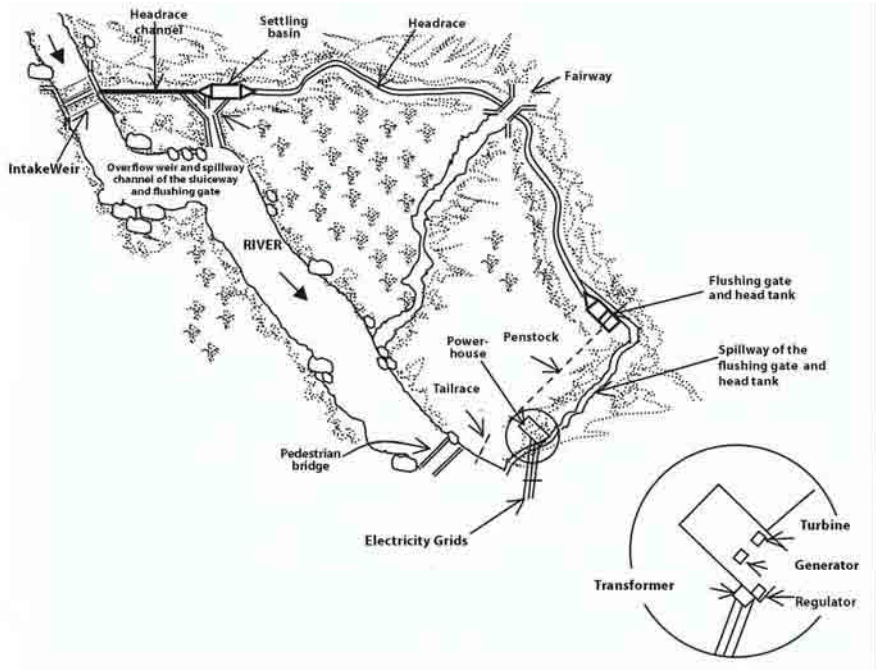


FIGURE 2 COMPONENTS OF A TYPICAL HYDROELECTRIC PLANT.
(Based on the "Tambomayo" MHS
built by Practical Action in Cajamarca-Peru)

Source: Rodríguez and Sánchez

Similarly, it is customary to analyse a hydropower plant in accordance with the following components: civil works, electromechanical equipment, electricity grids and management of the system in operation. This manual will mainly cover the first two components.

The Hydropower Potential in Peru

2

There is a great hydropower potential for generating electric power in Peru, through the installation of hydropower plants. The main conditions for determining this potential are the availability of water, particularly in the eastern watersheds, and the differences of elevation in Andean watersheds.

There are two ways of measuring the hydroelectric potential:

a) The theoretical potential. The resources of a watershed are measured in a hypothetical manner, in their natural form, without calculating the works required to develop them. Only the water and the differences of elevation are considered.

b) The technical potential. The resources are measured in accordance with current and potential uses and the cost of each power unit installed. According to studies conducted in 1979, Peru has a total technical potential of 206,107 MW and a technical potential of 58,346.4 MW, which is the potential that can actually be exploited.

The national technical potential is concentrated in the Atlantic watersheds (east Andean watersheds), representing 78.4% (45,741.7 MW) of the electric power. This indicates that the higher jungle areas and the inter-Andean valleys of these watersheds have an enormous electric power-generating potential.

TABLE 3. HYDROELECTRIC POTENTIAL IN PERU

Watershed	Hydropower potential		National hydropower potential			Installed versus potential power %
	kW	%	Theoretical MW	Technical MW	%	
Pacific	835,709	36.9	29,256.5	12,604.7	21.6	6.63
Atlantic	1,425,448	63	176,286.5	45,741.7	78.4	3.12
Titicaca	352	0.1	564	-	-	-
National total	2,261,509	100	206,106	58,348.4	100	3.88

The hydropower potential is distributed in the following watershed areas:

IN THE EASTERN WATERSHED

- ✓ The Mantaro hydropower plant, which generates nearly 63% of the national energy.
- ✓ Machu Picchu, in the Urubamba valley
- ✓ Carpapata, in the Tarma river
- ✓ Yaupi, in the Paucartambo river (Pasco)
- ✓ Sandia, in Puno

IN THE WESTERN WATERSHED

- ✓ The Huampaní, Moyupampa, Matucana, Barbablanca and Huinco hydropower plants in the Rimac river basin
- ✓ Cañón del Pato in the Santa river
- ✓ Charcani, in Arequipa
- ✓ Gallito Ciego, in the Jequetepeque river

Considering that the current installed capacity is 3,000 MW (3,000,000 KW), the available capacity exceeds 58,000 MW, which means that a mere 5% of the technical potential is used. Nearly 50% of the technical potential is in the departments of Cajamarca, Apurimac, Junin and Huanuco.

The country has a large enough potential to cover its long-term energy requirements and certain regions have a tremendous capacity to generate hydroelectric power. The following measures need to be taken now so as not to compromise this potential in the future:

- ▸ The conservation of the higher reaches of the rivers with the greatest potential
- ▸ Areas in which the hydroelectric power potential is developed should receive some compensation or income to provide funds for watershed management and water conservation purposes
- ▸ Power production costs should be included in the watershed management costs

In rural areas, where enough water and adequate differences of elevation of at least 4 meters are available, it is possible to set up mini/micro hydropower plants to drive machines and generate electric power (mini and micro hydropower plants).

Evaluation of the Resources for Mini/ Micro Hydropower Plants

3

Hydroelectric resources are usually evaluated in two stages. Stage one is the preliminary stage when hydrographic charts and meteorological data are used to evaluate the existence of resources, estimate the potential and make a preliminary calculation of the power, without the need for a field visit. Stage two comprises the definitive evaluation and consists of taking field data, visiting the area and measuring the head and the flow, using statistical methods to evaluate river flows. This will be covered in chapter 4.

The Executive Projects Office of the Peruvian Ministry of Energy and Mines (MEM) has a Geographic Information System (GIS) and a preliminary evaluation of hydroelectric resources can be obtained from their web page, thus ensuring an optimum use of maps.

Maps are usually charts that provide important geo-referential information for different projects, such as the location of urban areas with different population density rates (cities, districts, towns, settlements), road infrastructure (roads, trails, bridges, airports), boundaries between towns, relief characteristics (levels, sheer depressions), drainage (rivers, gorges, ditches, ponds), hydraulic infrastructure (dikes, dams, canals), vegetation (forests, reservation parks, barren areas), etc. The maps are drawn to scale and edited by State institutions like the National Geographic Institute (IGN) in Peru. They are published on a scale of 1:100.000, which means that 1 cm. on the chart is equivalent to 1,000 metres on the ground. This scale can be expanded for office work.

In the study on micro hydropower plants, maps provided preliminary information on the location of the river or watershed to be used for generating power, as well as the location of appropriate areas for the different components: intake weir, headrace channel, scouring sluice, head tank, powerhouse, tailrace channel, the route for the transmission line and, in particular, the area and shape of the watershed selected for the hydrological study. See figure 3.

FIGURE 3. THE MULLIOC RIVER AND THE TOWN OF MOLLEPATA, WITH LEVEL CURVES SHOWING DIFFERENCES OF ELEVATION EVERY 20 M

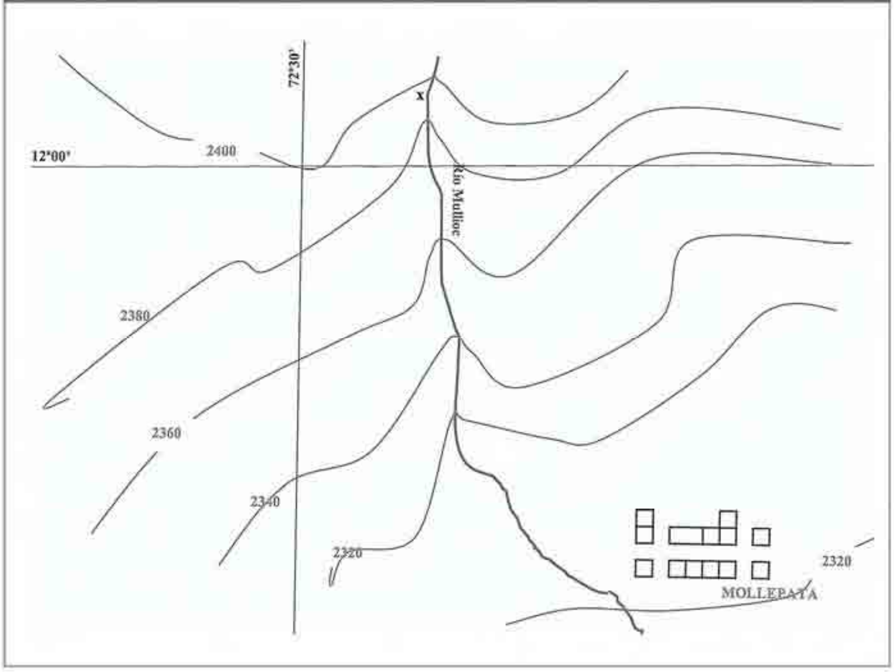
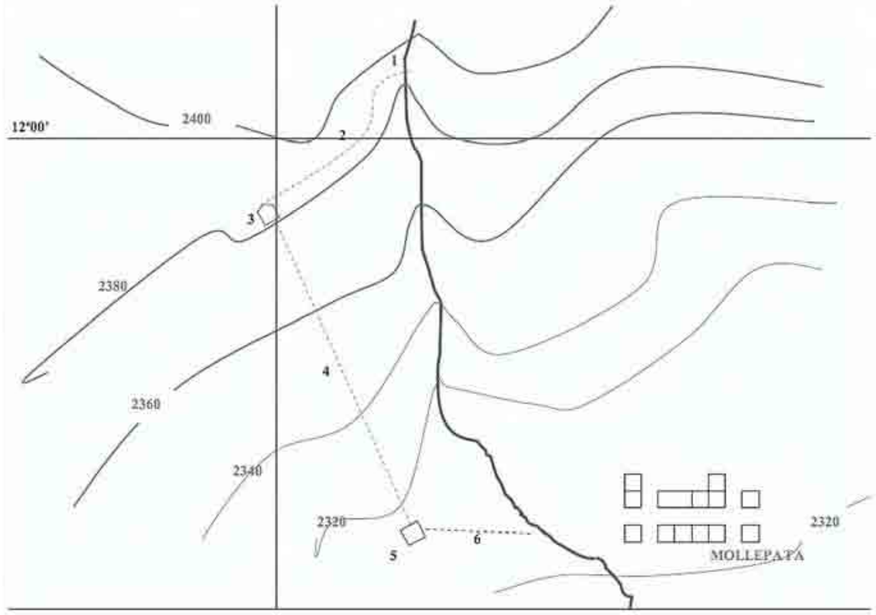


Figure 3 shows a part of the map or national chart with an extended scale, showing the Mullioc river and the town of Mollepata, with level curves showing differences of elevation at every 20 m. For preliminary reference purposes, the catchment area could be at point x and the civil works would be installed on the right bank.

3.1 Head Evaluation

Based on figure 3 and preliminary data, outline the location of the canal, the head tank, the penstock and the powerhouse as shown in figure 4.

FIGURE 4. DETERMINATION OF THE HEAD WITH RESPECT TO THE LEVEL CURVES



1 = Intake weir, 2 = Canal, 3 = Head tank, 4 = Penstock,
5 = Powerhouse, 6 = Tailrace channel

The head to be determined on the map can be obtained with the following steps:

a) Locate the intake weir and make a note of the approximate level in accordance with the level curves on the map. Let us suppose that the level is 2,385.00 metres above sea level.

b) Draw the canal, bearing in mind the length and slope to obtain a head value lower than the intake weir. The length of the canal can be obtained based on the drawing made on the map and the scale. Supposing the scale is 1:5,000; this means that 1 cm. on paper is equivalent to 50 m. on the ground. If the canal measures 4.89 cm on the map, then it will be 4.89 × 50 = 244.50 m long on the ground. Considering that the canal slope is no more than 3 x 1,000, then the difference in elevation between the intake weir and the head tank is 244.5 × 0.003 = 0.7335 m. For practical reasons, 1.00 m can be considered. Consequently, the referential level of the head tank will be de 2,385.00 – 1.00 = 2,384 metres above sea level.

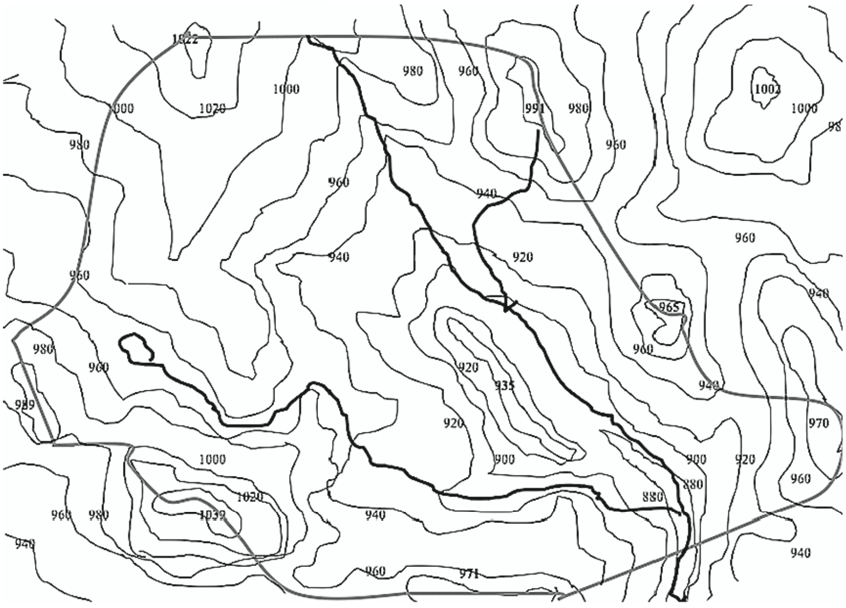
c) The referential head to be developed and determined in a preliminary manner on the map, will be the difference in elevation between the level of the head tank and the powerhouse. The powerhouse is very close to the 2,320.00 level curve, therefore H = 2,384.00 – 2,320 = 64.00 m.

d) It is advisable for the penstock to follow a straight line both on the map and on the ground, from the head tank to the powerhouse, following the convex part of the level curves.

3.2 Intake Area Evaluation

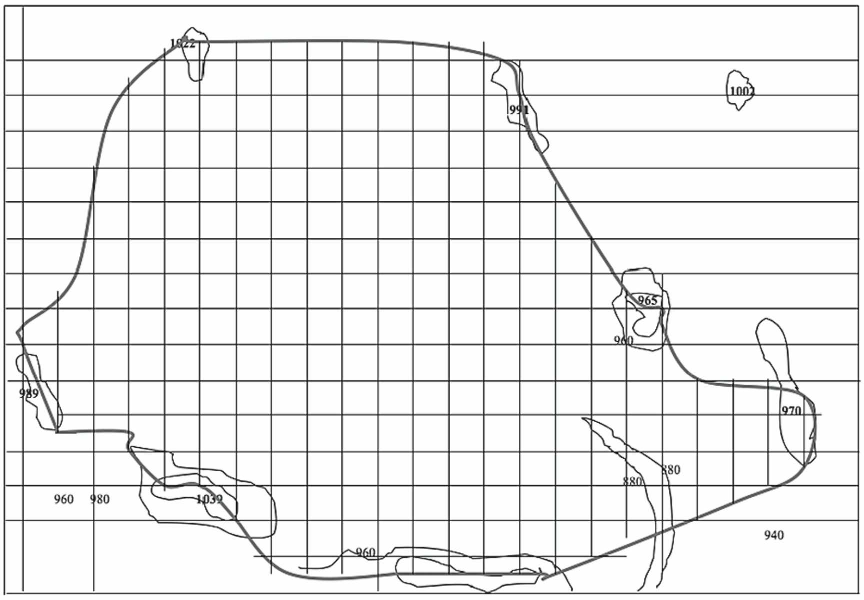
The hydrologist evaluates the catchment area and determines the probable maximum and minimum flows by studying the river or the watershed and the climatologic parameters (dampness, temperature, rainfall, evaporation, run-off, etc.). It is important to know the maximum flow, also known as the high flow level, so that the elements of the intake weir can be designed (guiding walls, spillway, catchment area, headrace channel) to make sure they are stable and work properly. The minimum flow corresponds to the low-stage of the river and is useful for deciding the minimum catchment flow for the year-round operation of the mini/micro hydropower hydroelectric power plant. See figure 5.

FIGURE 5. DETERMINATION OF THE WATERSHED



The watershed area is drawn on a map with level curves. Outline the watershed boundaries, crossing the level curves in the upper reaches of the river or watershed where the rain water flows towards the watershed being studied. Then draw squares in the delimited area in accordance with the scale on the map, count the number of squares and then, in accordance with the scale, express the area in km^2.

FIGURE 6. OUTLINE OF THE WATERSHED AREA



Scale 1: 100.000 1 cm on paper = 1 km on the ground. N.ª of squares = 218,5 the area of the watershed is 218,50 km2

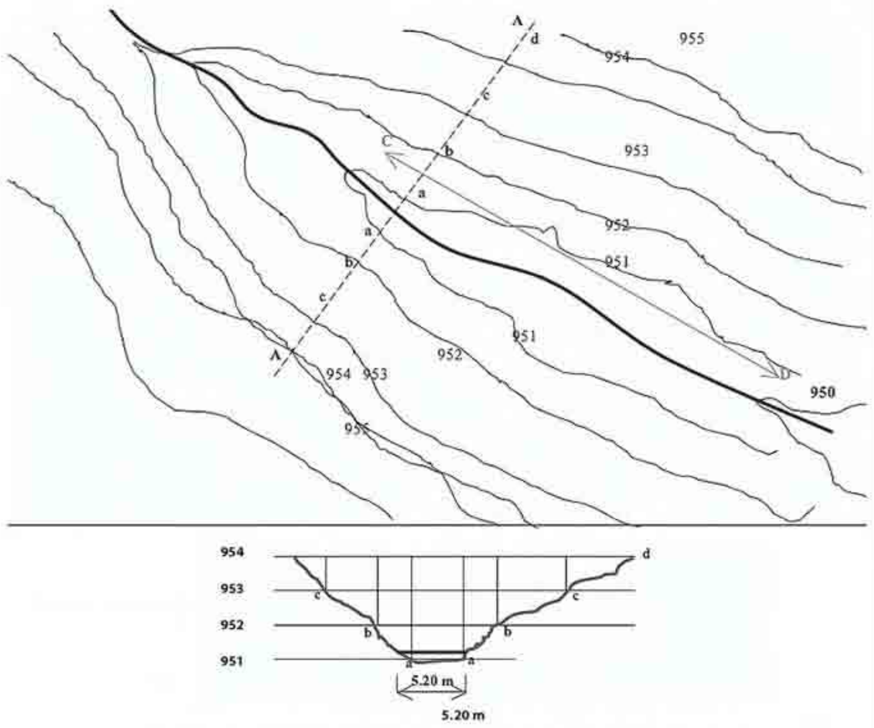
There are various methods for conducting a hydrological study; for example, the method of the National Rural Electric Cooperative Association (NRECA) of the United States of America, which uses data on the monthly precipitation and evapo-transpiration potential, whereby three parameters are determined to characterize the watershed being studied: (a) nominal (indicator of the ground's capacity to store water and the direct or underground run-off; (b) Psub (fraction of the run-off which flows underground and (c) GWF fraction of the total volume of water stored in the subsoil which reaches the river all year round). The permeability of the soil is also an important aspect. Following the guidelines and the calculation sequence, the total run-off is obtained in mm/month. This value is multiplied by the area of the watershed, which may be in m^2, then it can be easily converted into m^3/s as the volume for the month covered by the study. The study must be conducted at least once a month throughout the year.

For this method, information recorded in stations located in the respective watershed are required; however, in the case of mini/micro hydropower plants, such stations do not exist. Consequently, the hydrologist must apply the method referred to as similar or equivalent watersheds, whereby records are available on the conditions of the soil, run-off, climate, altitude, etc. dating back at least 20 years. Both methods are based on probabilities in an effort to obtain reliable results.

3.3 Calculation of the Discharge (Dry Season)

To calculate the discharge, the location of the inlet weir in the section of the river must be obtained, as well as the slope, the depth of the water during the low stage and the discharge.

FIGURE 7. AREA OF THE INTAKE WEIR. SCALE: 1:500



According to scale: water surface = 5.20 m; depth of the river in the low stage = 0.21 m; CD = 35.80 m

Slope of the river in section CD S = 2.7%

River section on intake zone

According to the approximate data on the map and the river section obtained,

$$Q = 5.20\ \text{m} \times 0.21\ \text{m} \times 0.60\ \text{m/s} = 0.655\ \text{m}^3/\text{s}.$$

These figures, which can be obtained from the map, must be verified or modified by means of a direct on-site evaluation.

3.4 Estimating the Demand and the Electricity Supply Potential

3.4.1 Demand for Electricity in Rural Areas

a) The current demand can be estimated with the following table:

TABLE 4. CURRENT DEMAND OF DIFFERENT POPULATIONS

POPULATIONS (INHABITANTS)	POWER DEMAND
500 – 1.000	15 kW – 35 kW
1.000 – 2.000	35 kW – 80 kW
2.000 – 4.000	80 kW – 180 kW
4.000 – 10.000	180 kW – 500 kW
10.000 – 20.000	500 kW – 1.200 kW

It is presumed that the installed capacity per capita is between 30 and 60 W per person. First of all, consider the current demand provided in table 4 based on the number of inhabitants. Secondly, correct this demand according to the social level and special demands, such as mines, industries and farming.

b) Estimating the future demand. The demand is calculated for a future period of 20 years. The rate of increase in the demand for electricity can be estimated at between 2% and 5% a year, in accordance with the annual population growth rate, social lifestyles and the development projects in the study area.

c) Example: The demand in a town with a population of 750 people

$$\text{Current demand} \quad \frac{15 + 35}{2} = 25 \text{ kW}$$

Annual increase in the demand for energy 4%

Demand for a future period of 20 years 25 kW x (1 + 0.04)20 = 55 kW

3.4.2 Comparing the Power Generated With the Demand

The power generated should be equivalent to the estimated demand, i.e. the demand for a future period of 20 years. In the previous example, it was determined that the power for 20 years would be 55 kW. Therefore, the power generated should be equivalent to 55 kW.

3.5 Study on the Electrification of Rural Areas

Background information

In general, the supply of energy depends on the resources available in the target supply area, both in terms of energy resources as well as the financial resources needed to acquire sources of energy.

As regards the electricity supply, power can be supplied through a connection to the conventional electricity distribution grid (if there is one), unconventional self-generating systems (photovoltaic power, wind power or hydraulic power) or generators. In most cases, a transmission-distribution system is required to transport electric power from the generating system to users.

Statistics from the last national census should be used for the study, in order to obtain relatively recent and comparable information throughout the country. With regard to certain specific issues, particularly in the target area and the pre-selected communities, officials of State institutions involved in the census, statistics, electricity, etc. should be interviewed. When compiling information, it is also advisable to visit and interview staff from NGOs operating in the target area and involved in environmental and indigenous issues.

3.5.1 Determining the Influence Area

The steps below should be followed to determine the influence area:

a) Mention the region, province, district and areas benefited and indicate their location; geo-referencing is recommended using the Universal Transverse Mercator system (UTM) of the Global Positioning System (GPS).

b) Location of the project's influence area on the map in the national chart.

c) Description of the economic, productive and social characteristics, the ground relief and the climate in the project's area of influence; access roads, number of houses in each area, energy alternatives used and estimates of possible productive uses of energy.

3.5.2 Methodology for Selecting the Communities

The preliminary selection of the target communities takes place in three stages, in which objectively and quantifiably verifiable indicators related to the objectives of the sustainable rural electrification project are analyzed and the values made available for the entire country and can be compared with each other.

In each stage, the area is selected by adding the most unfavourable relevant indicators. In stage one, a region in the country is selected, to which end the selected indicators on the department are compared. In the second stage, only the department is analyzed, adding the most unfavourable relevant indicators, then the same procedure is followed for the districts comprising the department. In the third stage, the communities are selected and the most specific criteria related to the project are analyzed.

(1) Comparison Indicators for Selecting the Target Area

SELECTION OF INDICATORS

The indicators must reflect the project's main aspects, i.e. the rural nature of the target area, the native aspect, the energy situation, the level of human development, the level of education, the population's economic situation and gender equality aspects.

For the first two stages of the process, seven indicators were selected, which we consider to be the most relevant and on which sufficient objective and coherent data on the entire country are available. These are:

a) Percentage of rural population. This is the ratio between the population living in rural areas and the total population.

b) Percentage of native population. This is the ratio between the native population and the total population of the same area.

c) Percentage of rural dwellings with no electricity. This is the ratio between the quantity of rural homes without electricity and the total number of rural dwellings in the same area. This is determined with the information on sources of domestic lighting obtained during the census.

d) Percentage of the population lacking in at least one basic need. This is the ratio between the population lacking in at least one basic need and the total population in the same area. Four basic needs are considered: quality of housing, sanitary facilities, access to education and subsistence capacity.

e) Human development index. The human development index (HDI) is a composite index that measures the average progress in the three basic dimensions of human development: a long and healthy life, knowledge and a dignified standard of living. It is calculated based on the life expectancy at birth, the adult literacy rate, the combination of the gross registration rate in primary, secondary and tertiary educational establishments and the gross domestic product per capita. Its maximum value is 1 and the minimum is 0. Values below 0.5 are considered low, between 0.5 and 0.8 are considered average and more than 0.8 are considered high.

f) Gender-related index. The gender-related index, like the HDI, is a composite index that measures the average inequality between men and women in the three basic dimensions comprising the HDI, adjusted to reflect the inequalities. The maximum value is 1 and the minimum 0 and it follows the same scale as the HDI.

g) Percentage of people living in poverty. This is the ratio between the population living in poverty and the total population in the same area. The definition of the poverty limit is related to the cost of a family shopping basket, calculated periodically by the corresponding entity.

(2) Establishing the Scale for Defining the Target Area

The following process is used to establish the areas to which electricity will be supplied:

a) The area with the highest percentage value and the lowest value of the corresponding indicator will be awarded three points.

b) The area with the second highest percentage value and the second lowest value of the corresponding indicator will be awarded two points and the area ranking third will be awarded one point. The remaining areas will gain no points.

c) The area gaining the highest score after adding the units of all seven indicators will be considered the selected area.

(3) Comparison Indicators for Selecting the Target Community

The indicators to be used for the initial selection of three communities in the district and then for deciding which of those three will be the target community, must directly reflect the exigencies related to the objectives and feasibility of the project and be objectively verifiable.

Table 5 shows the technical, legal, social and economic indicators that fulfil this requirement and were used in the selection process. Two distinct types of indicators are shown, with respect to their influence in the selection.

a) The first type can be referred to as categorical; that is, the reply is either yes or no, existing or non existent, respectively. In this category, some indicators are excluding as far as the selection of the community is concerned.

b) The second type can be referred to as relative; the reply is a numerical value which may be absolute or relative, or a relative qualification of the quality of a situation. For the selection of a community, a ranking of preferential values can be established, as well as a minimum or maximum limit for excluding the community.

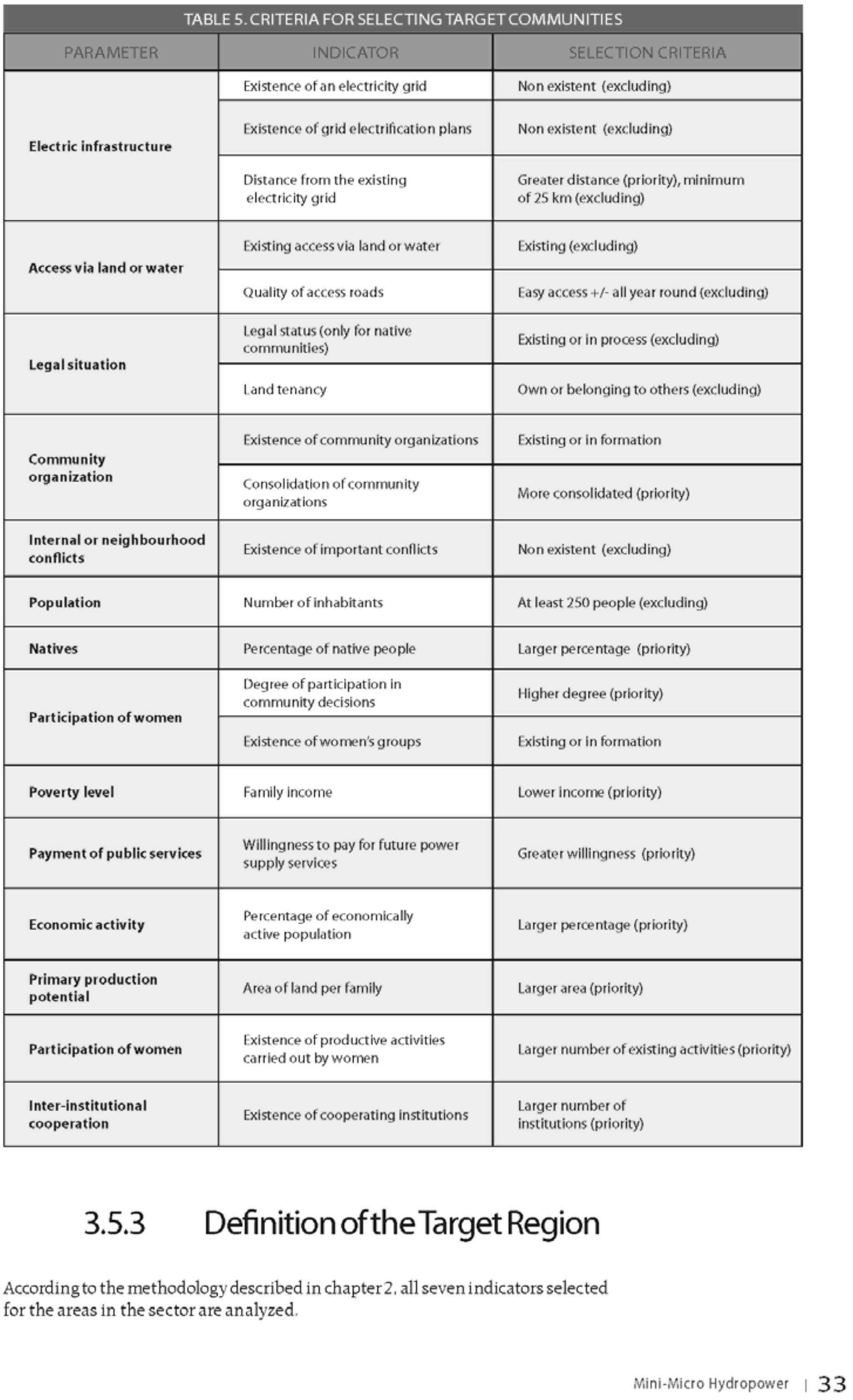


TABLE 5. CRITERIA FOR SELECTING TARGET COMMUNITIES

PARAMETER	INDICATOR	SELECTION CRITERIA
Electric infrastructure	Existence of an electricity grid	Non existent (excluding)
	Existence of grid electrification plans	Non existent (excluding)
	Distance from the existing electricity grid	Greater distance (priority), minimum of 25 km (excluding)
Access via land or water	Existing access via land or water	Existing (excluding)
	Quality of access roads	Easy access +/- all year round (excluding)
Legal situation	Legal status (only for native communities)	Existing or in process (excluding)
	Land tenancy	Own or belonging to others (excluding)
Community organization	Existence of community organizations	Existing or in formation
	Consolidation of community organizations	More consolidated (priority)
Internal or neighbourhood conflicts	Existence of important conflicts	Non existent (excluding)
Population	Number of inhabitants	At least 250 people (excluding)
Natives	Percentage of native people	Larger percentage (priority)
Participation of women	Degree of participation in community decisions	Higher degree (priority)
	Existence of women's groups	Existing or in formation
Poverty level	Family income	Lower income (priority)
Payment of public services	Willingness to pay for future power supply services	Greater willingness (priority)
Economic activity	Percentage of economically active population	Larger percentage (priority)
Primary production potential	Area of land per family	Larger area (priority)
Participation of women	Existence of productive activities carried out by women	Larger number of existing activities (priority)
Inter-institutional cooperation	Existence of cooperating institutions	Larger number of institutions (priority)

3.5.3 Definition of the Target Region

According to the methodology described in chapter 2, all seven indicators selected for the areas in the sector are analyzed.

3.6 Calculating the Power Generated by Mini/Micro Hydropower Plants (Installed Capacity)

Once data based on the level curves is obtained to calculate the head and delimitation of the watersheds in order to identify the discharge flow, preliminary calculations are made of the power generated in the mini and micro hydropower plants, using the following formula:

$$P = kQH$$

Where

P, represents the capacity in kW

k, is a value which depends on the capacity and efficiency of the turbine, as shown in item 1.6 (table 1)

Q, is the available flow in m^3/s

H, is the difference in elevation in metres

3.7 Selection of the Electromechanical Equipment

In the preliminary phase, the components of the electromechanical equipment are selected based on the head and the flow: the turbine, the generator and the speed regulator.

1. Hydraulic turbines

A hydraulic turbine is a turbo machine mechanically driven by the variation of the quantity of water flowing through a system of revolving blades called the runner, in which a simple deviation of the water flow can occur or, in other cases, a deviation and acceleration of that flow.

(1.1) Classification of hydraulic turbines

Hydraulic turbines can be classified based on different criteria:

a. Depending on the variation of static pressure through the runner:

- Impulse turbines, in which the static pressure remains constant between the input and output points of the runner:
  - ✓ Pelton turbines with one or more injectors
  - ✓ Turgo turbines
  - ✓ Michell Banki turbines
- Reaction turbines, in which the static pressure decreases between the input and output points of the runner:
  - ✓ A rotodynamic pump that operates as a turbine
  - ✓ Francis turbines, slow, normal and fast
  - ✓ Deriaz turbine
  - ✓ Kaplan and propeller-type turbines
  - ✓ Axial turbines in tubular, bulbous and peripheral generator variations

b. Depending on the direction of the flow through the runner:

- ✓ Tangential flow turbines
- ✓ Radial flow turbines
- ✓ Semiaxial flow turbines
- ✓ Axial flow turbines

c. Depending on the degree of admission of the runner and considering the alternative that the runner blades are partially or simultaneously submitted to the action of the water flow:

- ✓ Partial admission turbines
- ✓ Total admission turbines

(1.2) Fundamental parts of a hydraulic turbine

Distributor. This is a static element that adopts different shapes depending on the type of turbine. Its functions are to:

- Accelerate the water flow by transforming the potential energy in the water into kinetic energy, either totally (impulse turbines) or partially (reaction turbines)
- Conduct the water in an adequate direction towards the runner
- Regulate the flow

Runner. Also called the wheel, this element is the fundamental organ of hydraulic turbines. It consists of a disc equipped with a system of blades with a certain tangential speed. Hydraulic energy is transformed into mechanical energy in the runner by accelerating and diverting the water flow as it hits the blades.

Aspiration tube. This is a common element frequently used in reaction turbines and occasionally in impulse turbines like the Michell Banki, in which case it will have a cylindrical shape and is installed after the runner, usually taking the form of a straight or elbow-shaped diversion pipe. It fulfils three functions:

It recovers the head between the exit point of the runner and the level of the discharge channel.

It recovers the part of the kinetic energy corresponding to the residual speed of the water at the exit point of the runner, as it is designed to disseminate the flow.

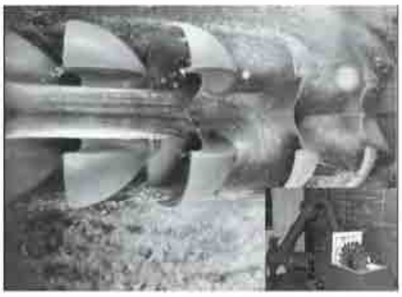
Casing. The function of this element is to cover and support the turbine parts. In Francis and Kaplan turbines, for example, it is shaped like a spiral.

(1.3) Characteristics of the main hydraulic turbines

Pelton Turbine

Invented by Lester A. Pelton (United States, 1829-1908) and patented in 1880. It can be defined as a tangential flow and partial admission impulse turbine. It operates efficiently in high head and low flow conditions, as well as with partial loads. The flow process is produced with atmospheric pressure.

FIGURE 8. PELTON TURBINE WITH TWO INJECTORS



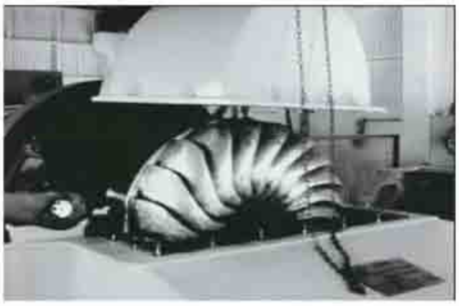
Distributor. This is comprised of between one and six injectors. An injector usually consists of a circular tube with a regulating needle that moves axially, varying the flow section. When it is necessary to cut off the flow of water quickly, the deflectors are used to divert the jet away from the blades. In the small turbines of micro hydropower plants, the needle may not be necessary as they can operate with one or more tubes with a constant flow.

Runner. It is a partial admission runner, which depends on the number of jets or injectors. It consists of a disc equipped with a number of blades or vanes mounted around it, welded or smelted to form a single piece with the disc. The Pelton turbine can be installed with a horizontal hub and one or two injectors and with a vertical hub with three to six injectors.

Turgo Turbine

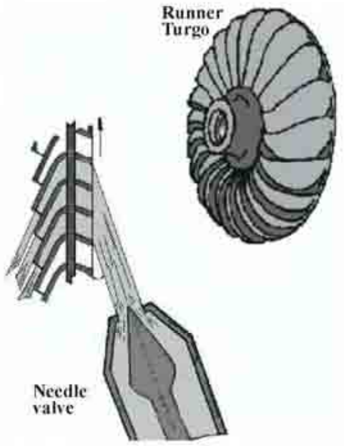
The Turgo turbine was invented by Eric Crewdson (United Kingdom) and patented in 1920. Subsequently, it was perfected by E. Jackson (United Kingdom) in 1936 and between 1961 and 1968. It can be defined as an axial flow and partial admission impulse turbine.

FIGURE 9. TURGO TURBINE



Distributor. It basically consists of a Pelton type injector that spurts out water at a 20 to 22.5° angle from the flat part of the runner.

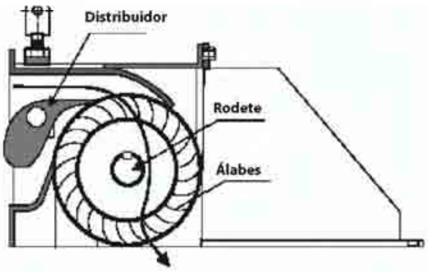
Runner. It resembles a half runner of the Pelton turbine, as though it had been split through the edge of the blades, at right angles with the hub. It is a partial admission turbine and can be installed with either a horizontal or a vertical hub. It is usually used in small power plants. Compared to the Pelton turbine, it has the advantage that it can operate with a larger flow with a runner of the same diameter, as the water jet enters through one side and exits through the other. This turbine covers the field of application of fast Pelton turbines, Michell Banki and slow and normal Francis turbines. It has the same characteristics as the Pelton turbine, operating efficiently with partial loads and little risk of cavitation; however, the axial thrust is a drawback.



Michell Banki Turbine

This turbine was invented by A. G. Michell (Australia) and patented in 1903. Subsequently, between 1917 and 1919, it was studied by Donat Banki (Hungary) in the University of Budapest. It is a centripetal-centrifugal radial flow impulse turbine with a two-way cross-flow and partial admission. However, recent tests have indicated that there is a small reaction in the first step due to the pressure being slightly higher than the atmospheric pressure, caused by the proximity of the injector to the runner.

FIGURE 10. MICHELL BANKI TURBINE



Distributor. This consists of a rectangular tube that covers the runner at a certain partial admission angle. It is equipped with a guide vane to regulate the flow. It can operate manually or automatically.

Runner. It is shaped like a drum or cylinder and is comprised of a pair of discs around which a certain number of rounded blades with a simple curvature are usually welded on. For high flows and low heads, it is built with intermediate discs. The cylindrical shape of the runner allows the turbine to work with a large variety of flows, to which end only the length needs to be adjusted accordingly. The characteristic of the Michell Banki turbine is that a large water jet from the rectangular section hits the runner blades twice. It differs fundamentally from other turbines in that the jet flows over the blades at right angles with the hub. The turbine usually operates with atmospheric pressure. Nevertheless, for high heads, it can be equipped with a cylindrical aspiration tube to recover part of the height of the fixture. This creates a depression inside; therefore, the water must not be allowed to flood the runner. The efficiency is good within a wide range of flows, although not too high compared to Pelton and Francis turbines. Nevertheless, given its low cost and the facility to build it locally, it is an interesting alternative for small power plants.

Pumps that operate as turbines

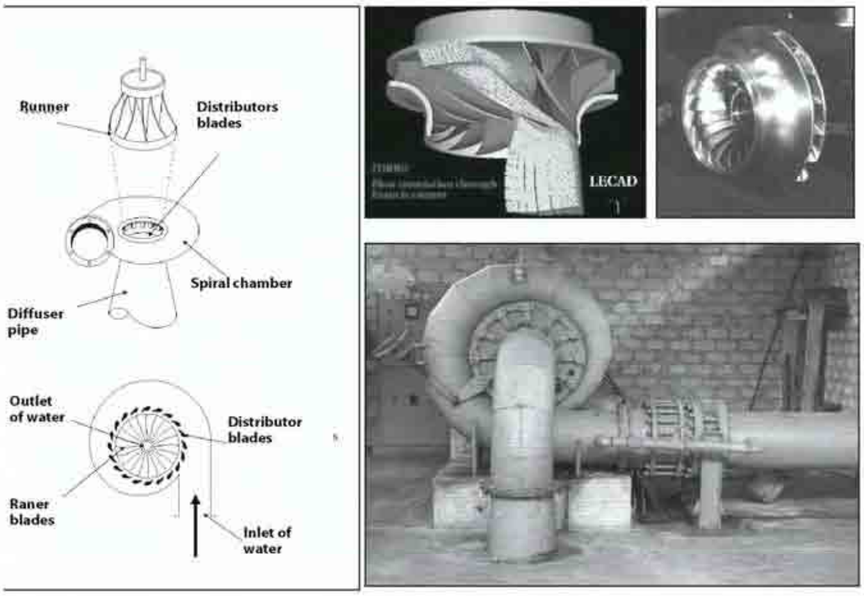
FIGURE 11. PUMP OPERATING AS A TURBINE

There has been a tendency in recent years to use rotodynamic pumps as turbines in plants, which operate by inverting the direction of the flow and rotation. As the pumps have no distributor, they can operate at full load: they are regulated with an electronic load regulator to dissipate the power. The advantage of using pumps instead of turbines is their low cost, since they can be easily acquired and repaired as they are produced in series. However, it is worth pointing out that an adequate selection is required. They are not highly efficient, but their use is recommended for generating low power.

Francis Turbine

The Francis turbine was invented in 1838 by Samuel Howd (United States) and was subsequently perfected in 1848 by James B. Francis (United Kingdom, 1815-1892) in the Untied States. This can be defined as a mixed flow centripetal and total admission reaction turbine

FIGURE 12. FRANCIS TURBINE



Distributor. Invented by Fink (Germany, 1860). It consists of a series of blades with an aerodynamic profile and changeable positions, forming converging tube-type conduits that speed up the water flow and guide it towards the runner at different angles, so that the flow can be regulated. The distributor blades can be operated by hand or by means of an automatic regulator.

Runner. This consists of a series of fixed blades placed between a disc and an outer rim, usually with a double curvature. The radial flow enters through the outer edge and leaves the runner in an axial direction towards the aspiration tube.

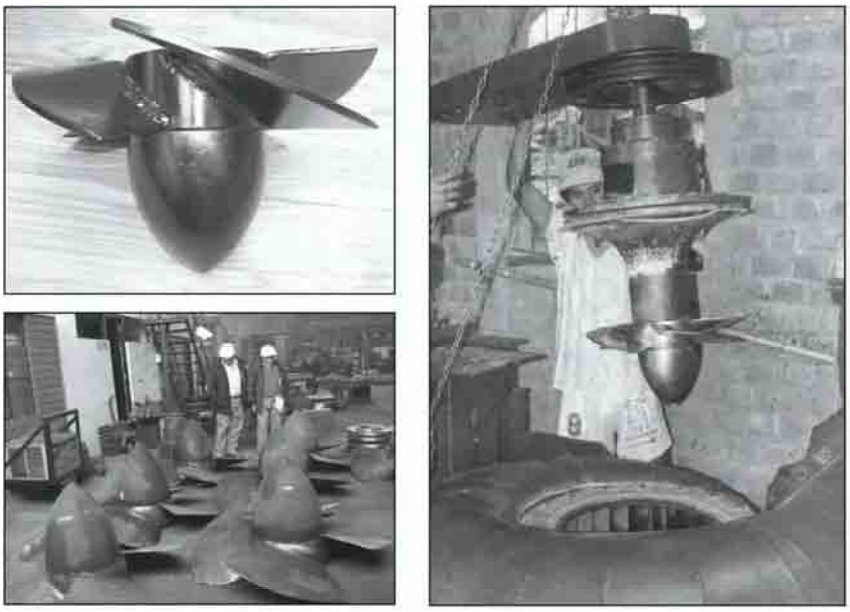
Aspiration tube. It is basically like a straight or elbow-shaped disseminator pipe, depending on the so-called aspiration head, the value of which is calculated in accordance with the cavitation theory.

Casing. This is a spiral chamber that can be smelted in a single piece or with welded sheeting segments.

Kaplan and Propeller-type Turbine

Kaplan and propeller-type turbines were designed by Victor Kaplan (Austria 1876-1934) at the University of Brno (Czechoslovakia) and patented in 1912. They can be defined as axial flow, total admission reaction turbines.

FIGURE 13. KAPLAN AND PROPELLER-TYPE TURBINE



Runner. This is the main characteristic of the Kaplan turbine. Its blades are shaped like the wing of an aeroplane, guided by a mechanism located inside the cube. It can therefore operate efficiently within a wide flow range.

Distributor. It is a Fink type distributor similar to that of Francis turbines. In addition, it consists of a spiral casing with a circular or rectangular section and a straight or elbow-shaped aspiration tube, depending on the required aspiration height.

The propeller-type turbine is a variation of the Kaplan turbine, with a Fink distributor adapted to the axial flow. Instead of the spiral chamber it has a cone-shaped chamber with a converging section in the direction of the flow. There are three versions:

- Tubular turbine

- Bulbous turbine

- Peripheral generator turbine

Quick selection of the turbine

A turbine for a mini/micro hydropower plant can be selected quickly with the application of the following diagram, in which various turbines currently used appear, located by application zones related to the net head, flow, capacity and average efficiency. For heads in excess of 500 meters, the manufacturers must be consulted.

The following diagram is based on this equation:

$$P = \frac{\gamma QH\eta}{K} = \frac{P_E}{\eta_{TR} \cdot \eta_G} = \frac{QH\eta}{102}$$

from which the net head is cleared, so that

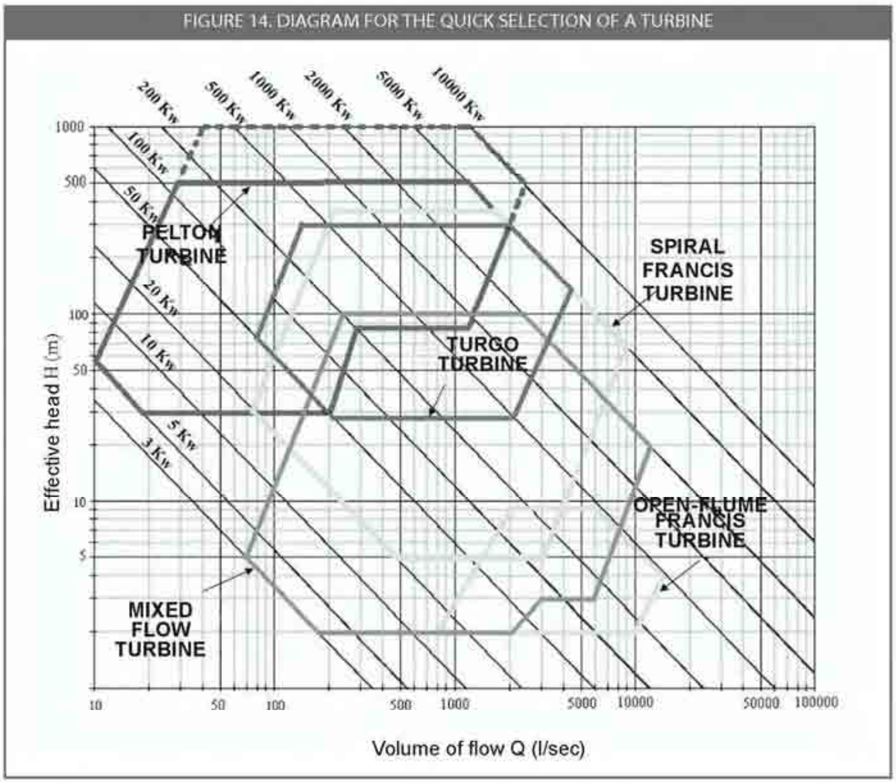
$$H = \frac{P}{\gamma\eta} \, x \, \frac{1}{Q}$$

Taking logarithms:

$$logH = log(\frac{P}{\gamma\eta}) - logQ$$

Assuming an average efficiency, a lineal relation between H and Q is obtained for constant installed capacity P in logarithmic coordinates, as shown in the following figure.

FIGURE 14. DIAGRAM FOR THE QUICK SELECTION OF A TURBINE



2. Power generators in mini/micro hydro-power plants

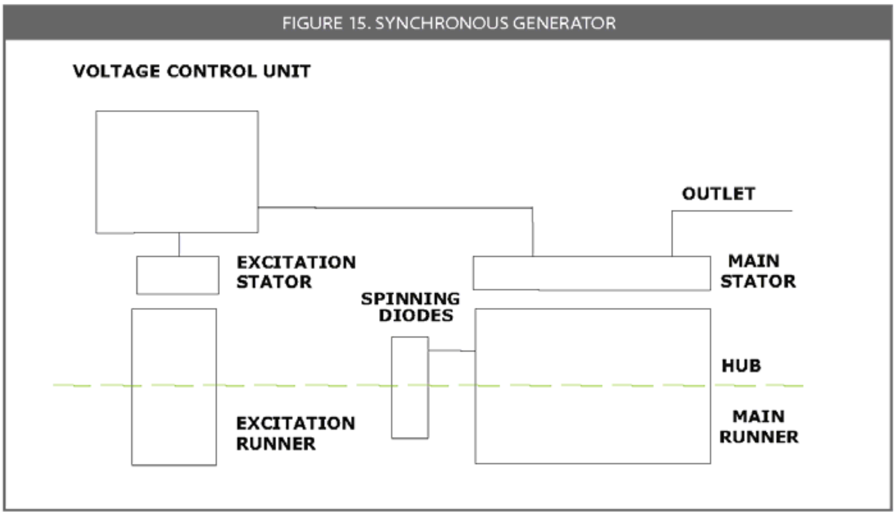
General construction

An alternating current generator mainly consists of:

- ✓ A magnetic circuit
- ✓ A continuous current winding inductor
- ✓ An induced winding alternating current
- ✓ A mechanical structure including the refrigeration and lubrication systems

The use of a synchronous generator is a priority in power generating units and over time its power magnitude and cooling methods have evolved. Nevertheless, its basic structure is still the same as it was when it was introduced in the XIX century.

FIGURE 15. SYNCHRONOUS GENERATOR



Synchronism speed

The synchronism speed is the spinning speed of the machine in RPM, which remains invariable and creates a normalized synchronous frequency in the alternating current of 50 Hz and 60 Hz.

$$f = \frac{PN}{120}$$

Where:

f = induced voltage frequency in Hz
N = runner speed in RPM
P = number of runner poles

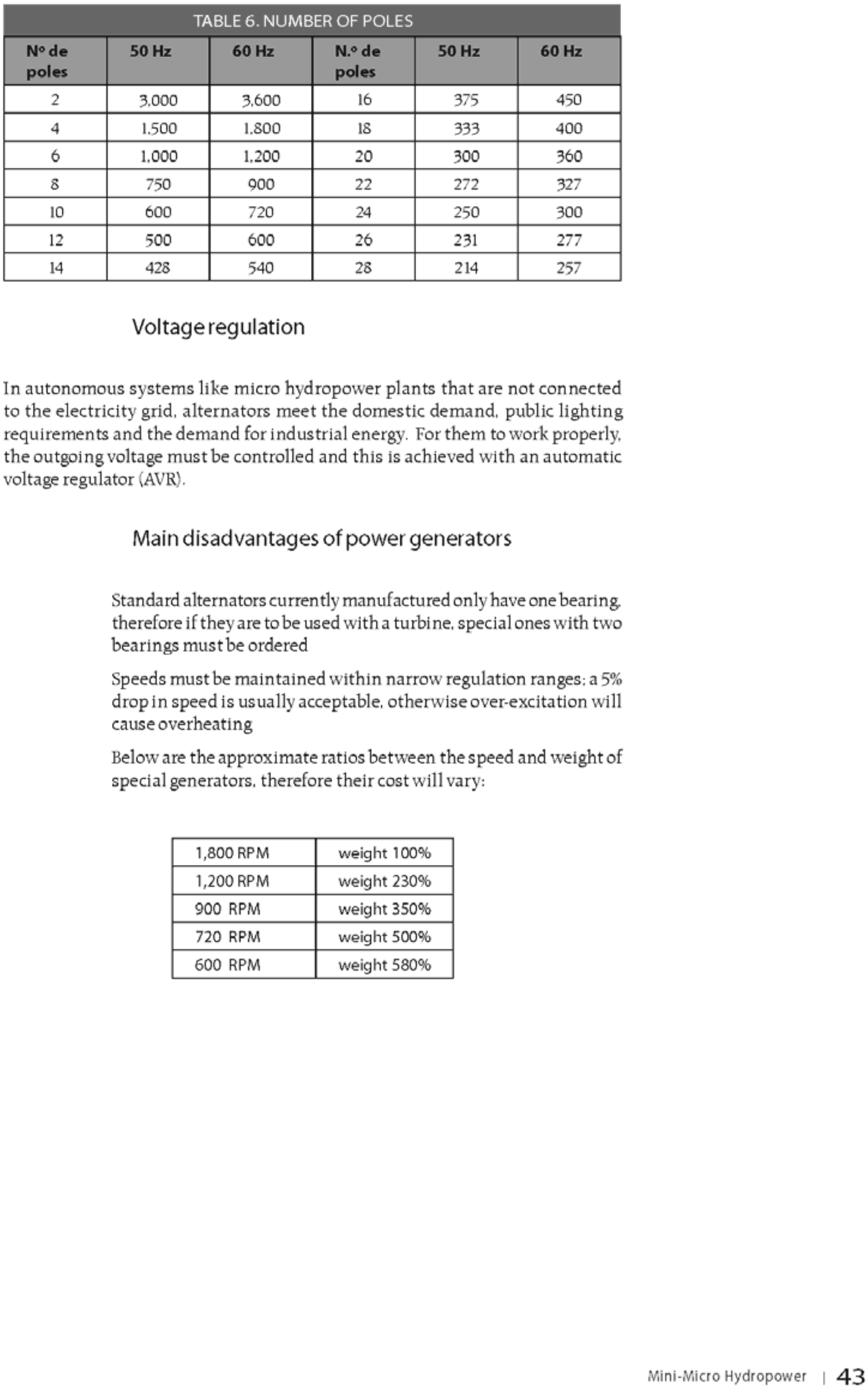


TABLE 6. NUMBER OF POLES

Nº de poles	50 Hz	60 Hz	N.º de poles	50 Hz	60 Hz
2	3,000	3,600	16	375	450
4	1,500	1,800	18	333	400
6	1,000	1,200	20	300	360
8	750	900	22	272	327
10	600	720	24	250	300
12	500	600	26	231	277
14	428	540	28	214	257

Voltage regulation

In autonomous systems like micro hydropower plants that are not connected to the electricity grid, alternators meet the domestic demand, public lighting requirements and the demand for industrial energy. For them to work properly, the outgoing voltage must be controlled and this is achieved with an automatic voltage regulator (AVR).

Main disadvantages of power generators

Standard alternators currently manufactured only have one bearing, therefore if they are to be used with a turbine, special ones with two bearings must be ordered

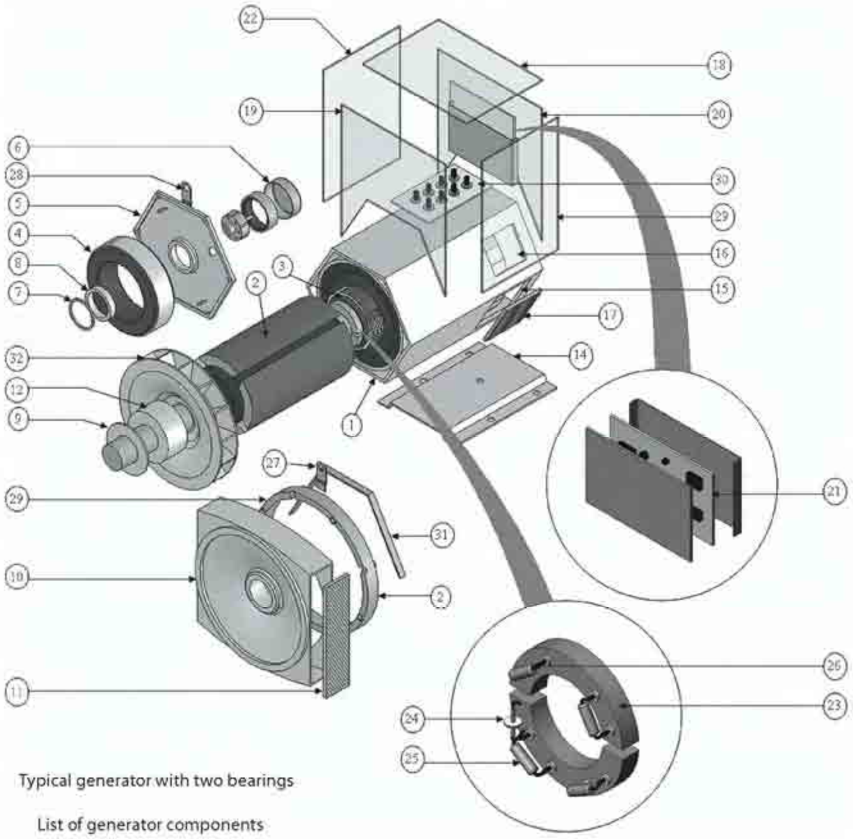
Speeds must be maintained within narrow regulation ranges; a 5% drop in speed is usually acceptable, otherwise over-excitation will cause overheating

Below are the approximate ratios between the speed and weight of special generators, therefore their cost will vary:

1,800 RPM	weight 100%
1,200 RPM	weight 230%
900 RPM	weight 350%
720 RPM	weight 500%
600 RPM	weight 580%

Generator parts

FIGURE 16. PARTS OF AN ELECTRIC POWER GENERATOR

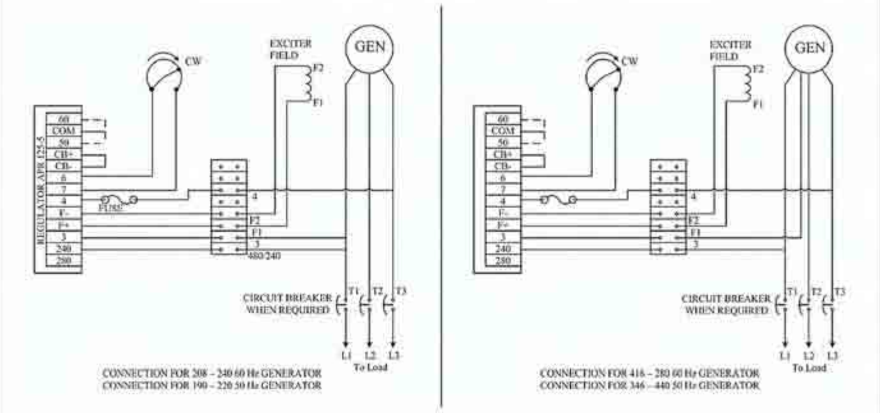


Typical generator with two bearings

List of generator components

1. Stator
2. Runner
3. Excitation runner
4. Excitation stator
5. Support on the non-driving side
6. Cylindrical top on the non-driving side
7. Thoric bearing ring on the non-driving side
8. Bearing on the non-driving side
9. Ondulated bearing washer
10. Support on the driving side
11. Screen on the driving side
12. Bearing
14. Support
15. Casing panel, lower part
16. Casing panel, upper part
17. Air screen
18. Lid of the terminal box
19. Front panel of the driving side
20. Back panel of the non-driving side
21. Control equipment and rectifying kit
22. Side panel
23. Reverse part rectifying kit
24. Varistor
25. Positive diode
26. Inverse diode
27. Lug for the driving side
28. Lug for the non-driving side
29. Adjustment ring between the casing and support on the driving side
30. Main terminal plate
31. Edge strip
32. Fan

FIGURE 17. DIAGRAM FOR THE VOLTAGE REGULATOR (AVR) CONNECTION



Factors affecting generator sizes

The nominal power or the size of generating units vary depending on the type and size of the power plant, the installed capacity of the system it will be connected to and certain design restrictions. It is safe to say that the greater the capacity, the more efficient the machine will be and the power output per kilo of the machine will also increase.

When the capacity or size of the generators increases, they should have efficient cooling systems to prevent unacceptable rises in temperature. In fact, the evolution to large generators is closely related to the evolution of cooling techniques.

FIGURE 18. LOW-POWER GENERATORS DO NOT REQUIRE COMPLEX COOLING SYSTEMS

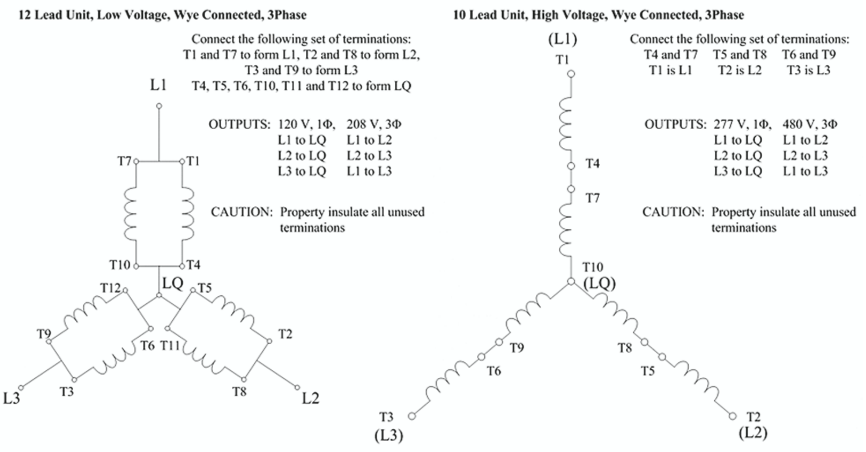
Preferable voltage

When the plant must cover an important pre-existing load, the most suitable voltage to be generated is that of the load in question. Depending on the distance of the load, a double transformation of energy will be required, or a direct voltage discharge from the generator. The recommended tension is the standard 0.38 Y / 0.22 D kV.

Usual connections

Generators producing 380 and 220 volts with a direct feed capacity usually have a simple Y connection, with four terminals for single phase load connections between phases and neutral loads.

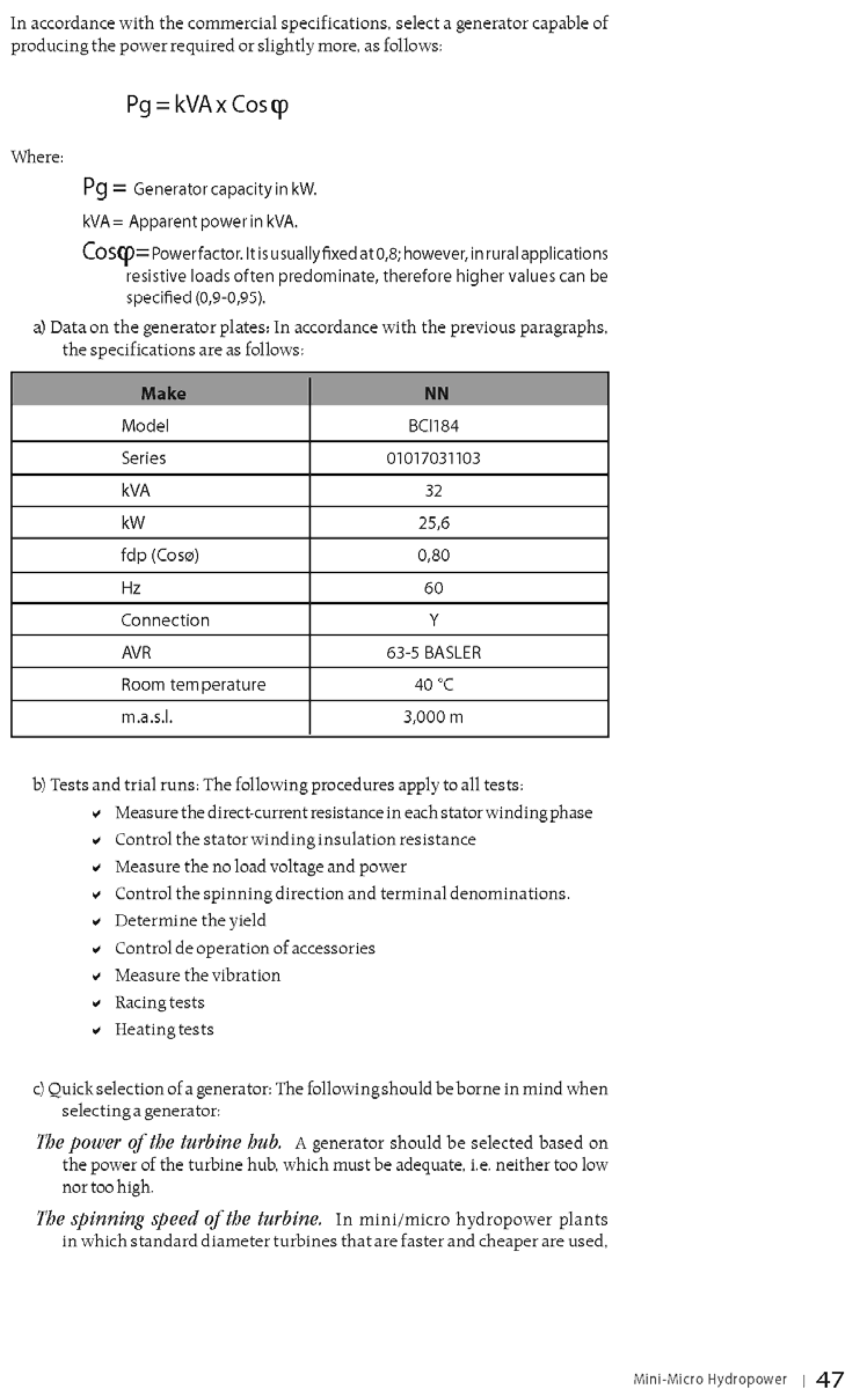
FIGURE 19. USUAL CONNECTIONS



Generator capacity

Considering the installed capacity requirements determined during the analysis of the demand and after taking into account transmission and distribution losses, the power required in the generator terminals is established. Then a preliminary selection of the generator should be considered, based on commercial specifications.

For mini/micro power plants, it is advisable to use generators with two, four and six poles (3,600, 1,800 and 1,200 RPM, respectively at 60 Hz).



In accordance with the commercial specifications, select a generator capable of producing the power required or slightly more, as follows:

$$Pg = kVA \times Cos\varphi$$

Where:

$Pg =$ Generator capacity in kW.

$kVA =$ Apparent power in kVA.

$Cos\varphi =$ Power factor. It is usually fixed at 0,8; however, in rural applications resistive loads often predominate, therefore higher values can be specified (0,9-0,95).

a) Data on the generator plates: In accordance with the previous paragraphs, the specifications are as follows:

Make	NN
Model	BCI184
Series	01017031103
kVA	32
kW	25,6
fdp (Cosø)	0,80
Hz	60
Connection	Y
AVR	63-5 BASLER
Room temperature	40 °C
m.a.s.l.	3,000 m

b) Tests and trial runs: The following procedures apply to all tests:

- ✓ Measure the direct-current resistance in each stator winding phase
- ✓ Control the stator winding insulation resistance
- ✓ Measure the no load voltage and power
- ✓ Control the spinning direction and terminal denominations.
- ✓ Determine the yield
- ✓ Control de operation of accessories
- ✓ Measure the vibration
- ✓ Racing tests
- ✓ Heating tests

c) Quick selection of a generator: The following should be borne in mind when selecting a generator:

The power of the turbine hub. A generator should be selected based on the power of the turbine hub, which must be adequate, i.e. neither too low nor too high.

The spinning speed of the turbine. In mini/micro hydropower plants in which standard diameter turbines that are faster and cheaper are used, the spinning speed of the turbines is determined by the diameter and the altitude. The synchronism generator speed does not always coincide with the turbine speed, therefore speed multiplying transmission systems are used.

The altitude. The altitude varies the efficiency of the generator. For every 1,000 m above sea level, the generator loses about 10% of its efficiency.

Bearing these considerations in mind, an adequate synchronous generator can be selected in accordance with the technical specifications established by the manufacturers.

(2.1) Regulating the speed

Why is it necessary to regulate the speed?

There are many ways of taking advantage of the energy generated when water hits the vanes or blades of a wheel or hydraulic turbine. Some of these systems operate with the turbine spinning at a constant speed at all times, whereas others operate with the turbine working at different speeds. This depends on what the energy is used for and whether or not the generator has a speed control device.

Some examples of small-scale hydro power schemes that operate with variable speeds are traditional water-driven stone mills, wheel-driven sugarcane mills, battery charges that use pico turbines coupled to automobile generators, small turbines coupled to circular saws or lathes, and so on. In these systems, variable speeds will not harm the system and more advantage is taken of mechanical energy. For instance, grain mills can work adequately at different speeds. The same applies to the other cases, as the speed is only affected by the load imposed on the machine.

On the other hand, systems that operate with a constant speed are typically represented by mini/micro hydropower plants that supply alternating electric current. These systems require a constant speed so as not to damage the electric generator or the equipment and machinery using this electricity. As the frequency of the electric current is directly proportional to the spinning speed of the alternator, a change in the spinning speed would change the frequency of the electric system, which should have a value of 60 to 50 Hz, depending on the country.

Some negative effects of working with a different frequency from the nominal in low frequency operations:

The electric motor will not start or could even be damaged by the excess current in the coil

Fluorescent bulbs may not switch on

Incandescent bulbs will provide less light due to the lower voltage.

The alternator may cause the voltage in the system to drop and overheat

Some negative effects of working with other than the nominal frequency in high frequency operations:

Incandescent bulbs can fail or will not last as long

Motors can be damaged

The alternator could be damaged by excessive speed

In mini/micro hydropower plants that do not have a speed regulation system, a change in the demand for energy would immediately change the spinning speed of the turbine, therefore the alternator would start spinning at a different speed from the synchronous speed. This would cause a change in the frequency and voltage of the line, resulting in the above-mentioned negative effects. That is why if continuous changes in the demand are anticipated, it is necessary to install a compensation system to ensure that the turbine speed remains constant.

There are basically two ways of controlling the speed of the power generator:

Regulating the water flow in the turbine

Regulating the load

Regulating the speed with the water flow in the turbine

So that the generator maintains a constant speed if the demand is variable, it is essential that the power input is the same as the power output, plus the internal losses. This can be expressed as follows:

$$\text{Input power} = \text{Output power} + \text{Losses}$$

This balance is obtained by regulating the volume of water entering the turbine, so that when the demand increases a valve is opened to allow more water to enter the turbine, causing the generated power to equal the demand. This can be regulated manually or automatically.

Manual regulation

Traditionally, manual regulation is mainly done in mini/micro power plants producing less than 50 kW of power, because their initial cost is low. This type of regulation is suitable when there are no great fluctuations in the demand for energy. This system requires an operator in the powerhouse to observe the changes in frequency and compensate them by varying the water flow in the turbine. The flow is varied by means of a needle valve or guide vanes, depending on the turbine employed.

Automatic regulation

Regulating the speed automatically by regulating the flow provides a system with a stable voltage and frequency. This system is used when large instant fluctuations in the demand are anticipated. For this type of regulation, oleo-mechanical speed regulators are used, or their variations like electromechanical and electro-hydraulic tachometers, among others. Due to its high cost, this system is inappropriate for mini/micro power plants and is used more often in plants that produce more than 100 kW of power.

Regulating the speed by regulating the load

Unlike the water flow regulation system, when the turbine regulates the water constantly to ensure that the power generated is equivalent to the demand in order to maintain a constant speed, in load regulation systems the generator produces constant power, which means that the water flow is not regulated. Nevertheless, care must be taken to ensure that the power generated is equivalent to or more than the maximum power expected from the demand. Excess power will be dissipated in the form of heat through a resistance in the air or submerged in the water. This can also be done manually or automatically, the latter being the most frequently used system.

Regulating the load automatically

In order to find more economical and simpler solutions for the maintenance and operation of automatic speed regulators, the electronic load regulation system was recently developed. This system is applicable in mini/micro hydropower plants that produce less than 100 kW of power.

This system does not consist of regulating the water flow; instead, the alternator produces constant power and the electronic load regulator, through electronic valves known as 'tiristors', diverts the energy not consumed by the demand to a power dissipation system.

The following are the main advantages of these regulators compared to oleo-mechanical and similar regulators

The design of the turbines is simpler as there is no need to regulate the flow

Lower cost

Simple operation and maintenance

No excess pressure is produced in the penstock

Easy to assemble or manufacture

Responds more rapidly to load changes

At the present time, there are two electronic load regulation systems: continuous or analogical regulation and scaled or digital regulation

Manufacturers of electronic regulators usually provide the following specifications for their electronic regulators:

Response to the application or removal of 100% of the load: transitory diversion of the frequency: less than 0.25 s

Statism: 0 to 3% (digital regulation)

Maximum operating temperature: 55 ºC

Type of alternator to be used: any that work with nominal voltages and frequencies of between 100 and 500 volts and between 45 and 65 Hz

Type of demand: indifferent (capacitive, inductive or resistive)

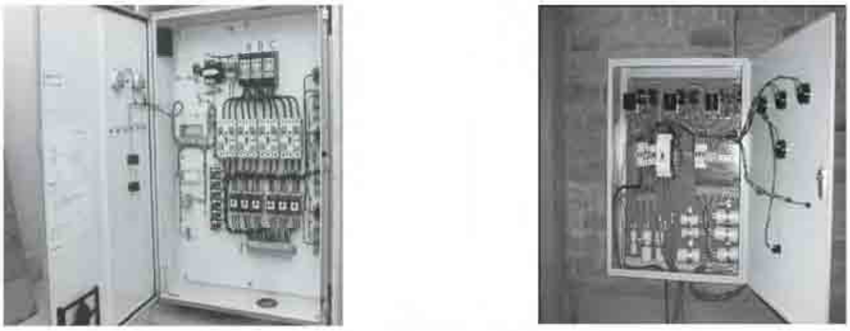
Type of ballast load to be used: resistive, 10% to 20% more than the maximum expected demand

Demand power factor: greater than 0.7

Most frequently used power dissipation systems:

Air heating resistances. Care must be taken to ensure that the resistances are installed in a large, well ventilated area.

FIGURE 20. SPEED ELECTRONICAL GOVERNOR FOR AND MINI/MICRO HYDROPOWER



Resistances submerged in water. These should be placed in a specially adapted small tank. At all times the resistances must be submerged in constantly circulating water, which can be achieved with a diversion from the penstock. The water tank or deposit can be built of steel sheets, concrete or any other appropriate material.

Comparison between the different regulation systems

Prior selection of the speed regulator

The regulator is selected in accordance with the characteristics of the generated power; it could be a flow regulator, a load regulator or a mixed regulator. The design power must be consistent with the power of the generator and the connection system.

TABLE 7. COMPARISON BETWEEN THE REGULATION OF THE FLOW AND THE LOAD

Parameter	**Regulation of the flow**		**Regulation of the load**	
	Manual	**Automatic**	**Manual**	**Automatic**
Initial cost	Very low	High	Low	Average
Frequency regulation accuracy	Depends on the operator	High	Depends on the operator	Very high
Installation problems	None	High	Low	Low
Operation and maintenance problems	Very low	Low	Very low	Low
Supervision by the operator required	Yes	No	Yes	No

3. Mechanical power transmission systems

In a mini/micro hydropower plant, a continuous conversion of mechanical energy is produced in the turbine and the mechanical energy is converted into electric energy in the generator.

In electric systems with alternating current and a 60 Hz frequency, generators with speeds of $n = 7{,}200/p$ (RPM) are available, where "p" is the number of poles in the generator. Therefore, speeds of 3,600, 1,800, 1,200, 900 RPM and less can be obtained, from 2, 4, 6 and 8 poles, respectively. A low speed generator is the most expensive.

The turbine's spinning speed is related to the net head, the flow and the dimensions of the runner. In large hydropower plants, the construction of turbine runners with dimensions that guarantee a spinning speed the same as that of the generator, so that they can be coupled directly, is justified. In mini and micro hydropower plants, on the other hand, only runners with standard manufacturers' dimensions can be used, therefore the operating speed for net head and available flow conditions rarely coincides with that of the generators. For this reason, mechanical power transmission systems between the turbine and the generator should be used in micro hydropower plants, as long as this is justified from technical and economical points of view.

Elements of a mechanical power transmission system

All mechanical power transmission systems contain the following elements:

- ✓ The driving element (in this case, the hydraulic turbine)
- ✓ The driven element (electric generator)

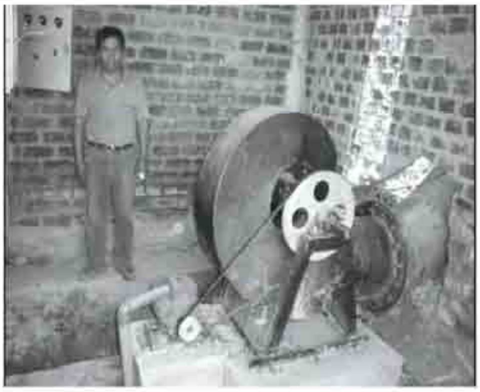
The following are the mechanical elements involved in a transmission:

- ✓ A driving wheel
- ✓ A driven wheel
- ✓ Hubs that support the wheels and spin with them
- ✓ Hub supports (roller bearings)
- ✓ Couplings

These elements can be observed in the following figures. It must be appreciated that the transmission of mechanical power will occur continuously with the participation of the different mechanical elements. In the example, the main hub transmits movement to the wheel through a keyed joint, the wheel moves the belt by friction, the belt moves the driven wheel and finally, the latter moves the driven hub.

FIGURE 21. 25 KW AXIAL TURBINE WITH A VERTICAL HUB AND A 2:1 BELT AND PULLEY TRANSMISSION SYSTEM

FIGURE 22. 5 KW AXIAL TURBINE WITH A HORIZONTAL HUB AND A 4:1 BELT AND PULLEY TRANSMISSION SYSTEM



Types of transmissions

The following are the most important types of mechanical transmission systems:

- Flexible belt transmissions, which could be:
  - Flat
  - Trapezoidal or V-shaped
  - Ribbed.
- Gear transmissions, which could be:
  - Straight toothed cylindrical
  - Helicoidally toothed cylindrical
  - Straight toothed conical
  - Spiral toothed conical
  - Endless screw with cogged Wheel

Speed and transmitted power

When transmitting movement in a system, the idea is to increase or reduce the angular speed and transmit power from one hub to another. For a better understanding of this, below are some concepts and fundamental relations.

a) Peripheral speed: Peripheral speed is also called tangential speed and is equivalent to:

$$V = \pi . D. N/60 \ [m/seg]$$
$$V = w D/2$$

Where:

D = diameter of the wheel [m]
N = RPM of the wheel
w = angular speed [rad/s] ($2\pi . N/60$)

b) Transmission ratio: The transmission ratio is the ratio between the speeds of the driving wheel and the driven wheel. This ratio is identified by the letter "I" and is equivalent to:

$$I = N1/N2 = D2/D1$$

Where:

N_1 = RPM of the driving wheel
N_2 = RPM of the driven wheel
D_1 = diameter of the driving wheel
D_2 = diameter of the driven wheel

If high transmission ratios are required, successive stages can be used. In these cases:

$$i_t = \frac{RPM\ input}{RPM output}$$

$i_t = i_1 x i_2 x \ldots.. x in$

Where:

$i_1, i_2 \ldots$: transmission ratios of each stage.

c) Torque: The torque indicates the capacity of a spinning hub to develop a tangential force "F" at a radial distance "r" from the centre of the hub. It is equivalent to:

$$T = F . r \ [kg.m]$$

d) Power: Power is the energy per time unit transmitted by a hub. It is equivalent to:

$$P = T x w/102 = T . N/974 \ [kW]$$

Also:

$$P = F \, . \, V/102$$

It can be appreciated that the power is directly proportional to the torque output and the angular speed, which means that for the same power value, the torque and the speed are inversely proportional to each other. Therefore, in a system in which mechanical power is preserved, an increase in speed would reduce the capacity to develop torque and vice-versa.

e) Transmission ratios obtained in a stage depending on the type of transmission

The following are the transmission ratios obtained in a stage, depending on the type of transmission:

Gearing	i = 4 to 20
Screw and wheel	the highest values
Roller bushing chain	Up to 6 – 10
Toothed chain	Up to 15
Trapezoidal belt	Up to 8 – 15
Flat belt with idler	Up to 10
Open flan belt	Up to 5

f) Maximum speeds recommended for transmissions

The following are the maximum speeds recommended for transmissions:

Ordinary flat belts	$V_{max} < 25$ m/s
Special artificial fibre belts	$V_{max} < 50$ m/s
Standard trapezoidal belts	$V_{max} < 25$ and 30 m/s
Special trapezoidal belts with a steel core	50 m/s
In chain transmissions V max = 25-40 m/s, and in toothed belts	$V_{max} = 80$ m/s
Straight toothed gears at V > 10 m/s, helicoidally toothed gears at V > 15 m/s should be manufactured with a 6 degree precision	$V_{max} = 150 – 180$ m/s
In screw and wheel transmissions	$V_{max} < 20$ m/s

g) Characteristic yields for one transmission stage

Toothed transmissions	99%
Chain transmissions	97 – 99%
Flat belt transmissions	95 – 97%
Trapezoidal belt transmissions	96%
Screw and wheel transmissions	75 – 90%

Belt transmissions

Belt transmission systems are the most applicable in mini and micro hydropower plants. In this system, the power transmission capacity depends on the friction between the belt and the wheels, which in turn depends on the friction coefficient and the angle of contact between the belt and the smaller pulley.

The following are the main advantages:

The possibility of joining the driving shaft with the driven shaft, placed at alternatively large distances

Apart from the bearings, no lubrication is required

Since the transmission is by friction, an overload will cause the belt and pulleys to slip, protecting the other transmission elements and the equipment involved

The operation is relatively smooth, with no knocking caused by the transmission

Simplicity

Relatively low initial cost

Criteria for the sizing of transmission systems

The following information is required for the sizing of a transmission system:

Power to be transmitted

Input and output speeds

Conditions of the service

The conditions of the service are related to the type of machines driven in terms of the vibrations they create in the transmission. They also depend on the hours of service, environmental conditions and so on. These service conditions have been experimentally evaluated for different transmission systems and are referred to as the "service factor".

For practical purposes, the selection is made with the power design $_{(Pdis)}$, defined with the following formula:

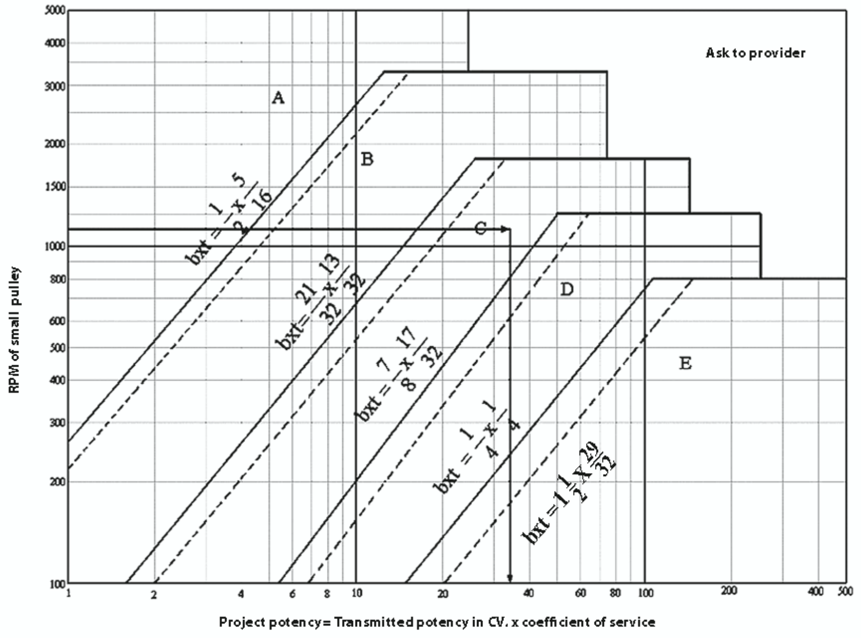
$$P_{dis} = T_{trans} \, x \, F_{serv}$$

Where:

P_{trans}: transmitted power
F_{serv}: service factor

Specific sizing should be made with the help of manufacturers' tables and catalogues.

FIGURE 23. NUMBER OF BELT SECTIONS BY POWER AND SPEED



The selection of V-shaped belts can be made with the general procedure applied to different power transmission systems. It is an essential requirement to have all the initial data on the power to be transmitted, the transmission ratio and the service conditions, as well as any space restriction.

Sections selected for more industrial purposes are designated the letters A (½" × 5/16"), B (21/32" × 13/32"), C (7/8" × 17/32"), D (1/4" × 1/4") and E (1 ½" × 29/32"). There are also more compact sections: 3V (3/8" width), 5V (5/8") and 8V (1"). Through experiments, the appropriate range of use for each section were determined in accordance with the power and speed.

Various criteria are taken into consideration for determining the diameter of the pulleys including the following:

The speed ratio to be obtained

The minimum tolerable diameter of the different sections

The convenience of using standard diameters

The influence that the diameter of the smaller pulley has on the capacity to transmit power from the belts

The influence of the diameters on the tension and force in the hubs and rollers

Some engineers prefer to use the smallest possible diameters, based on the theory that costs will be saved on the pulleys and shorter belts will be obtained.

However, this will reduce the capacity to transmit power and the forces in the hubs and rollers will be greater than for a pulley with a larger diameter. Consequently, solutions will be obtained with a larger number of belts, wider pulleys, thicker hubs and larger rollers. It is necessary to study various alternatives and select the lightest and cheapest of all the transmission components.

3.8 Study of the Distribution Line

Whereas power generating points can be far removed from consumer centres, long medium voltage aerial lines will be necessary to ensure the continuity of the service in the event of various contingencies.

For the study, design and development of a medium voltage aerial line, the following considerations can be established:

a) The general nature of the ground in which the line will be placed must be determined. This can be a determining factor for selecting the conductor and the type of supports. The line must be established in easily accessible areas for inspection and maintenance purposes. In rugged or populated areas, it is not advisable to lay a direct line or to try and adapt to long tangents. Small diversions of a few degrees cost slightly more and only slightly lengthen the line. It is recommended to establish lines with diversions of between 5º and 15º, which are not very costly. High peaks should be avoided, as this would lead to more protection against the wind and atmospheric discharges. It is recommended to take advantage of existing accesses, such as roads, highways or lines already installed. Flood-prone land, ground with fragmented rocks and expansive clay and land with a high level of ground water should be avoided.

b) Every effort should be made to obtain the best maps available. A general land survey should be conducted and all the maps and information available should be evaluated. Once the preliminary works are completed, the main difficulties must be determined in order to establish policies for dealing with aerial routes, crosses with existing lines, crosses with private land, nearby vegetation, type of land, rights of way, etc.

c) The following general terms must be established: (1) an access to each support; (2) permission to install all the supports and guys; (3) the elimination of trees and branches within an area at least three metres wider than the area in which the conductors will be located, so that there will be enough free space for the installation; (4) the elimination of all trees that do not permit the free oscillation of the conductor, in case it should start oscillating under maximum wind conditions; and the elimination of all trees that do not allow the conductor to drop freely.

d) Establish the plant plans and profile, which are key drawings for building the lines. The vertical scale should be considerably exaggerated and the horizontal scale should be no higher than required to determine distances with the necessary accuracy. If no plans of the area are available, a planimetric survey should be conducted. A horizontal scale of 1/2.000,000 (length) and a vertical scale of 1/500 (height) are often used, providing a compact drawing accurate enough for most conditions. Larger scales may be preferable for short vanes, but a smaller scale is not recommended.