WG2: IPP Project Evaluation Methodology
-Hydropower Plant-
Electric Facilities

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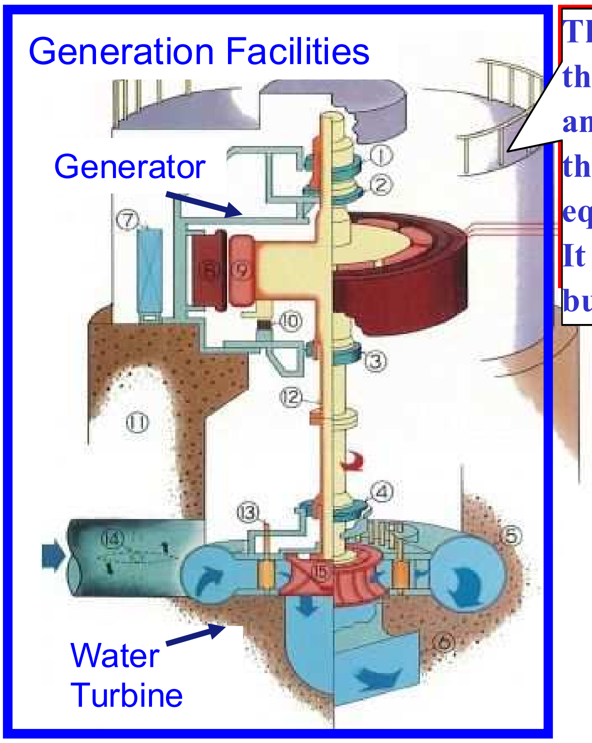
Chapter1 . Outline of Electric Facilities

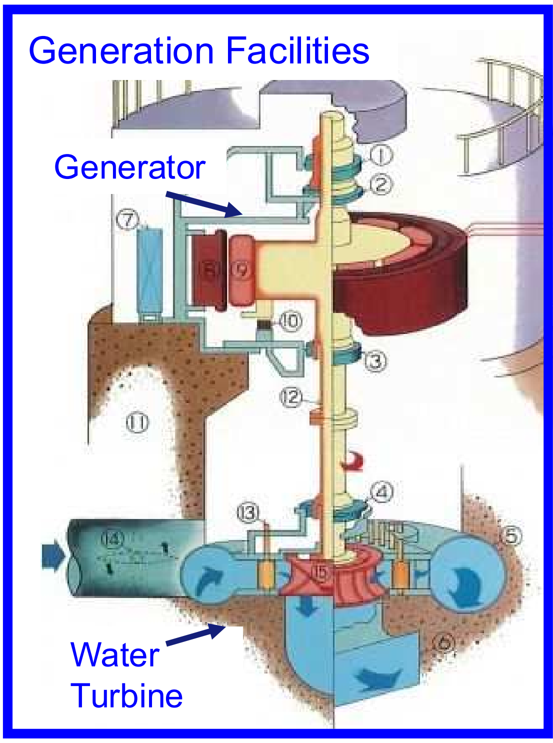
- The electrical facilities of hydro power plants consist of the following equipment.

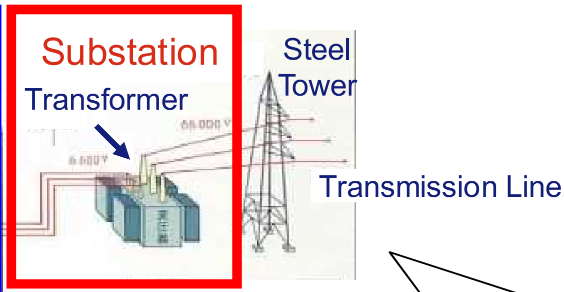


The power generation equipment has a generator that rotates a water turbine powered by water and generates electricity by directly connecting to the water turbine and rotating it, auxiliary equipment to control these, and a control device. It is common for them to be installed in the building.

①	Top bearing	⑨	Rotor
②	Thrust bearing	⑩	Break
③	Lower bearing	⑪	barrel
④	Water turbine bearing	⑫	Shaft
⑤	Casing	⑬	Guide vane
⑥	Suction tube	⑭	Inlet valve
⑦	Cooling system	⑮	Runner
⑧	Stator		

- The electrical facilities of hydro power plants consist of the following equipment.





Main equipment

The substation equipment consists of (1) a main transformer that changes voltage generated by the generator to the same voltage as the power system, (2) a transformer for the in-house power supply, (3) a circuit breaker that opens the load current and fault current, and (4) lightning arresters that protect the equipment from lightning, and (5) control devices that control mentioned equipment. Generally, the equipment is installed outdoors and the control device is installed inside the building.

- In GREPTS, technical standards for turbines and generators are described in Article 28.

In this lecture, we will mainly explain the water turbine and generator equipment among the electrical equipment of hydroelectric power plants. Technical standards for turbines and generators are described in Clause 28 of GREPTS. Therefore, these need to be checked on FS.

PART 3

GENERAL REQUIREMENTS FOR HYDRO POWER GENERATING FACILITIES

Clause 28: Hydraulic Turbines and Generators

28.1 Prevention of Damage to Hydraulic Turbines

1. Hydraulic turbines shall not be remarkably damaged by driftwood, floating debris, or sediment that flows into hydraulic turbines.
2. Vibrations that may damage hydraulic turbines shall not occur.
3. Cavitation erosion that may damage hydraulic turbines shall not occur.

28.2 Equipment to Quickly Shut off the Inflow of Water

Hydraulic turbines or waterways shall be equipped in principle with facilities that can quickly shut off the inflow of water into the turbines.

28.3 Mechanical Strength of Hydraulic Turbines and Generators

1. Hydraulic turbines shall withstand the maximum water pressure in case the load is rejected.
2. Hydraulic turbines and generators shall withstand the maximum speed in case the load is rejected.
3. Generators shall withstand the mechanical shock caused by short-circuit current.

28.4 Thermal Strength of Hydraulic Turbines and Generators

Hydraulic turbines and generators shall withstand the heat generated by hydraulic turbines and generators under normal operations.

28.5 Protective Devices for Hydraulic Turbines and Generators

Hydraulic turbines and generators shall be equipped with devices to disconnect the generators from the electrical circuits and to stop the hydraulic turbines automatically in case any abnormality that may cause significant damage and/or make serious trouble to the supply of electricity occurs.

Chapter2 : Water Turbine

Chapter2. Water Turbine

■ Items required for designing hydro power plants

If the items shown in the table below can be calculated, it is possible to calculate the outline design of water turbine etc.

In addition, it should be confirmed that the river flow conditions obtained by the hydrological survey are calculated appropriately because they are important for calculating the generated power when selecting water turbines.

Table Items which are necessary for designing

Item	Unit	Planned value		
Maximum Amount of Water	m^3/sec			
Effective Head	m			
Number of Generator				
Frequency	Hz			
		Highest	Standard	Lowest
Intake Position	EL. m			
Discharge Position	EL. m			

Check : Are the items necessary for water turbine design selected?
Are the materials such as river flow conditions calculated appropriately?

Outline design flow of water turbine

1. Select the turbine type according to its type selection diagram.
2. Calculate the rotation speed from the specific speed of the selected turbine type.
3. Determine the turbine efficiency and turbine output of the selected turbine type.

Selection of turbine type

- The turbine type is determined in consideration of the effective head, the amount of water used, the flow condition of the river, the operation of the reservoir (head fluctuation, flow fluctuation). If multiple turbine types can be selected, the decision will be made by comprehensively considering economic efficiency and maintainability.
- Each type of turbine has a limit on its head and applicable specific speed. And the range of application is determined by the strength against the head, characteristics, and the cavitation.

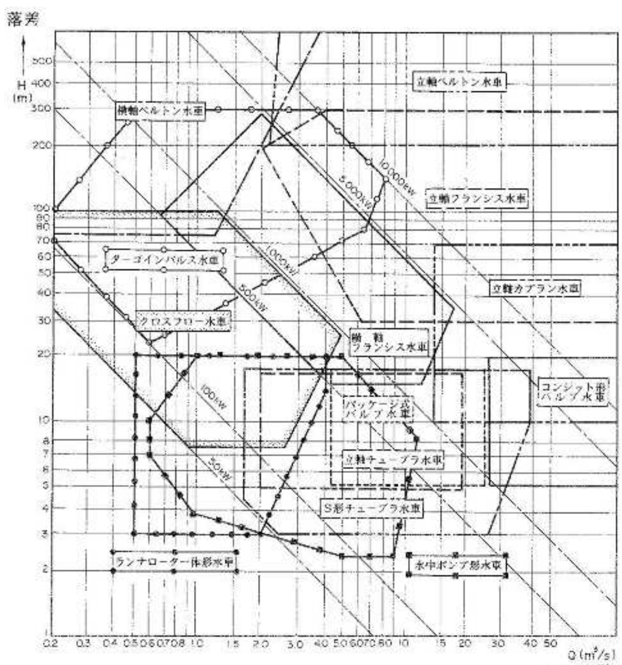


Figure: Water turbine type selection chart

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.14

Check : Are the number and type of turbines selected according to the effective head and the amount of water used?

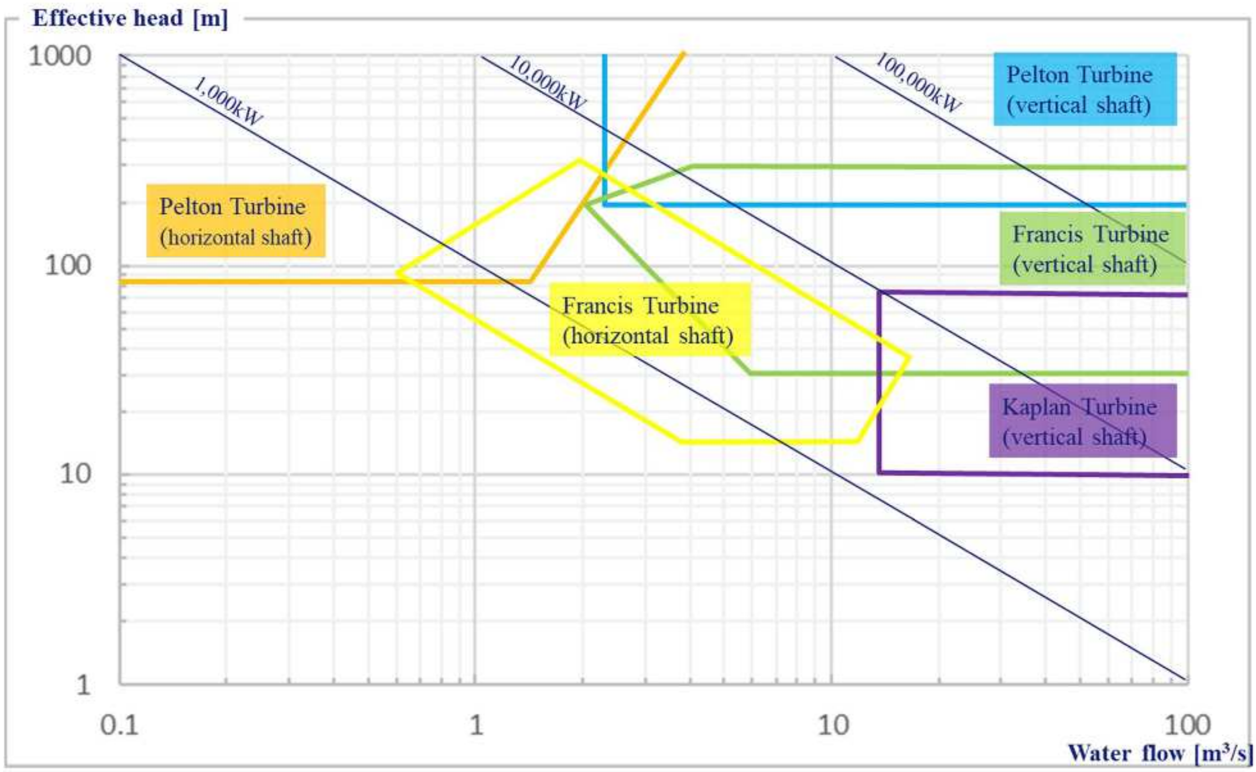
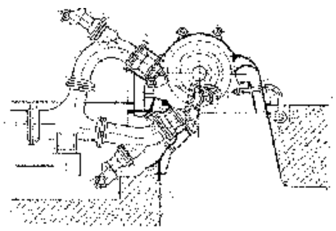


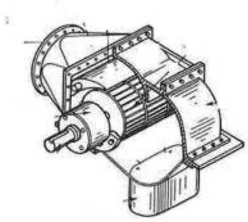
Figure: Water turbine type selection chart

A water turbine is a rotating machine that converts the potential energy of water into mechanical energy.

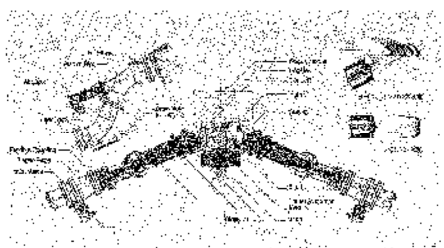
- Impulse Water Turbine — **Impulse water turbine changes the pressure head to the speed head.**



Pelton Turbine

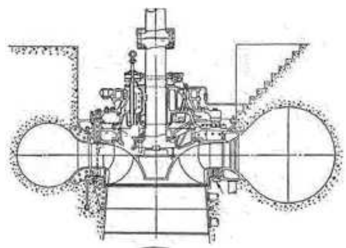


Cross Flow Turbine

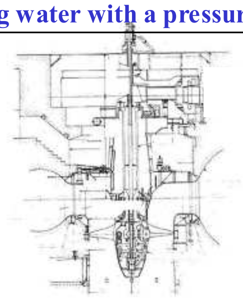


Turgo Impulse Turbine

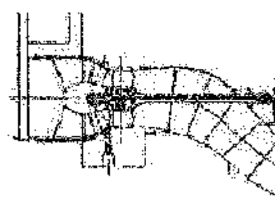
- Reaction Water Turbine — **Reaction water turbine is a turbine with a structure that allows running water with a pressure head to move on the runner.**



Francis Turbine



Kaplan Turbine



Tubular Turbine

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.2,5,6,8,9,11

Chapter2. Water Turbine

Calculation of turbine output

The turbine output is calculated by calculating the specific speed, rotation speed, and efficiency from the turbine model.

Calculation of specific speed

The specific speed is proportional to the rotation speed. Increasing the specific speed can increase the rotational speed, which can reduce the size of the turbine and generator. And the equipment price and power plant dimensions can be rationalized. However, cavitation is more likely to occur when the specific speed is increased. The upper limit and applicable range of the specific speed that can be adopted are as follows.

Type of Turbine	Upper limit and applicable range of specific speed	
Pelton Turbine	$n_s \leqq \frac{4{,}300}{H_e+200}+14$	**8～25**
Cross Flow Turbine	$n_s \leqq \frac{4{,}000}{H_e+30}+16$	**90～110**
Francis Turbine	$n_s \leqq \frac{21{,}000}{H_e+30}+40$	**100～350**
Diagonal Flow Turbine	$n_s \leqq \frac{21{,}000}{H_e+20}+40$	**100～350**
Propeller Turbine Kaplan Turbine	$n_s \leqq \frac{21{,}000}{H_e+16}+50$	**200～900**

Chapter2. Water Turbine

Calculation of turbine output

Specific speed

The specific speed is the rotational speed when the shape of the runner is reduced in a geometrically similar state to make a water turbine that generates an output of 1kW with a head of 1 m. The Specific speed indicates the speed when the head and output are constant.

$$n_S = n \times \frac{P_t^{1/2}}{H_e^{5/4}}$$

n_S : Specific Speed [m-kW]

n : Rotational Speed [min^{-1}]

H_e : Head [m]

P_t : Maximum output of turbine at effective head [kW]

Francis Turbine (Specific Speed =92)

If the specific speed becomes slower, the shape of the turbine becomes closer to the shape of the centrifugal pump.
If the specific speed increases, the water flow will be in the axial flow direction.

Calculation of turbine output

Calculation of rotational speed

The rotation speed of the water turbine is calculated from the limit specific speed by the following formula. Select from a standard rotation speed lower than the rotation speed, but also consider the setting of the suction height of the turbine (To be described later).

$$n = n_{Slim} \times \frac{H_e^{5/4}}{P_t^{1/2}}$$

- n_{Slim} : Limit Specific Speed [m-kW]
- n : Rotation Speed [mim^{-1}]
- H_e : Effective Head [m]
- P_t : Maximum output of turbine at effective head [kW]

The rotation speed of a water turbine / generator is calculated by the following formula based on the frequency of the power system and the number of poles of the generator.

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

- n : Rotation Speed [mim^{-1}]
- f : Frequency [Hz]
- p : The number of poles

Calculation of turbine output

The rotation speed is generally selected from the standard rotation speed due to the generator design.

Table Standard Rotation Speed

P	N	P	N	P	N
4	1,500	28	214	60	100
6	1,000	30	200	64	94
8	750	32	188	70	86
10	600	36	167	72	83
12	500	40	150	80	75
14	429	42	143	84	71
16	375	48	125	88	68
18	333	50	120	90	67
20	300	54	111	96	63
24	250	56	107	100	60

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.19

- n : Rotation Speed [mim^{-1}]
- f : Frequency [Hz] = 50
- p : The number of poles

Calculation of turbine output

Using the initial value of turbine efficiency, the turbine output is calculated by the following formula, and the calculation is repeated to improve the accuracy based on the turbine design flow.

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

Pt : Maximum output of turbine at effective head [kW]
Q_{max} : Maximum water consumption at effective head [m^3/sec]
H_e : Effective head [m]
η_t : Turbine efficiency

Initial value of turbine efficiency and general turbine efficiency curve which are necessary to calculate

〔Initial value of 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

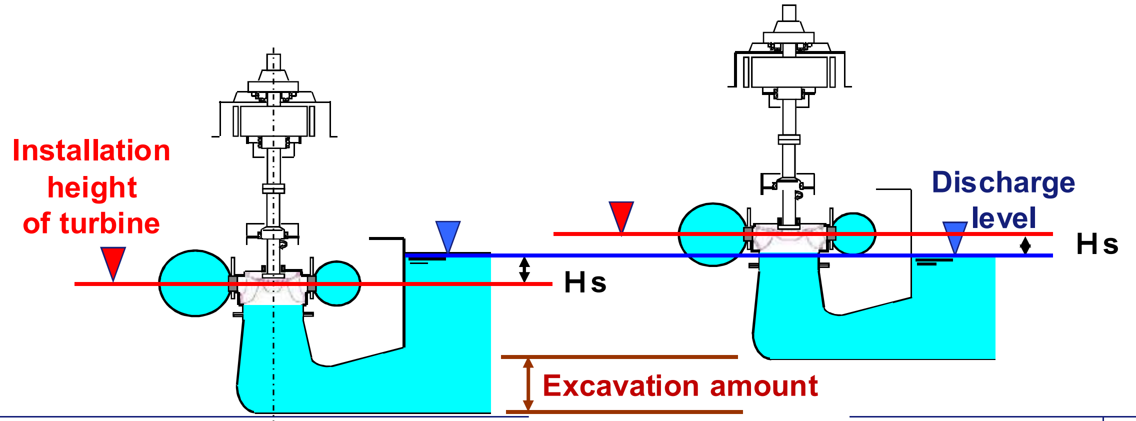
Check : Is the turbine output calculated in consideration of the turbine efficiency?

Setting the suction height of the water turbine

- The suction height of the turbine is the difference between the discharge level and the installation height of the turbine.
- It is desirable to make the installation height of the turbine as high as possible in terms of flood protection and reduction of excavation amount. However, if the suction height is higher than a certain level, cavitation will occur, which causes noise, vibration, efficiency reduction, etc., and also promotes erosion of the runner itself.

By properly designing the turbine rotation speed and suction height, it is possible to satisfy the criteria of 1-2 and 1-3, Clause 28, GREPTS.

【Suction height (Low)】 【Suction height (High)】

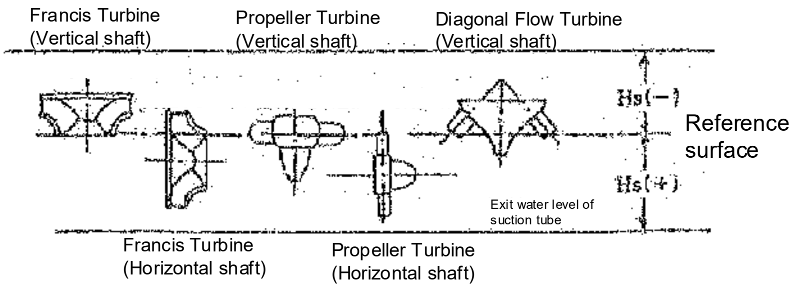


Setting the suction height of the water turbine

- There is a cavitation coefficient σ as an index that quantitatively indicates the conditions under which cavitation occurs, and it is expressed by the following equation.

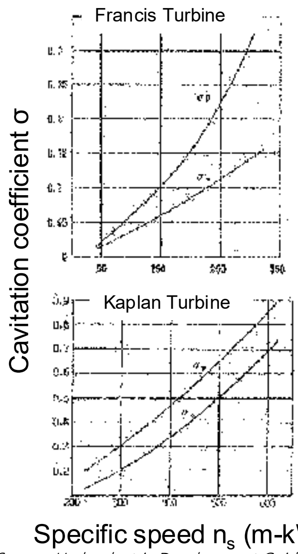
$$Hs = Ha - Hv - \sigma H$$

- Hs : Water turbine suction height [m]
- Ha : Atmospheric pressure [mH_2O]
- Hv : Saturated vapor pressure [mH_2O]
- σ : Cavitation coefficient
- H : Effective head [m]



Relationship between water turbine reference plane and suction pipe outlet water level

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.27



Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.26

Check : Is the optimum water turbine suction height set?

The cavitation coefficient σ varies depending on the characteristics of the turbine runner and is determined by the manufacturer's test, but the relationship between the specific speed and the cavitation coefficient as a guide is shown in the graph below.

Setting the suction height of the water turbine

- What is cavitation?
  When the pressure inside the runner drops below the saturated vapor pressure of running water, the water begins to boil, and the air mixed in the water becomes bubbles and collapses.
- Impact of cavitation
  - ・Significant reduction in turbine efficiency and output
  - ・Shortening the life time of the runner due to surface erosion
  - ・Operational obstacles due to vibration and noise generated from steel pipes, water turbines, and suction pipes
- Precautions of cavitation
  - ・Optimization of turbine suction height and specific speed
  - ・Smooth the surface of parts to contact with the running water
  - ・Select a material that is resistant to erosion
  - ・Introduce an appropriate amount of air to the upper part of the suction pipe

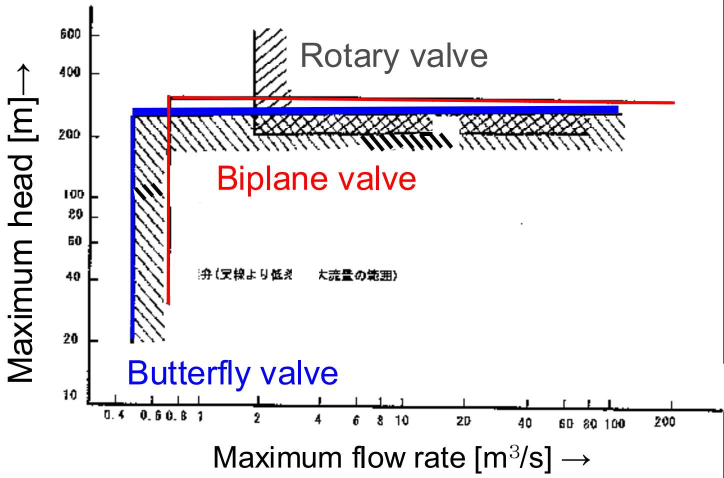
Cavitation erosion in the turbine runner

Roughness on the surface is a mark of cavitation erosion

Energia

Selection of inlet valve

- The inlet valve is a water stop valve that is installed at the end of the penstock and just before the water turbine casing, and opens or closes when the water turbine is operated or stopped.
  Select the type that can be adopted based on the relationship between the maximum head and the maximum flow rate.



The inlet valve normally operates with the guide vanes fully closed and no water flowing.

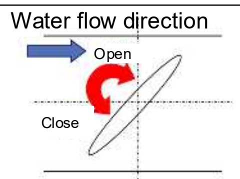
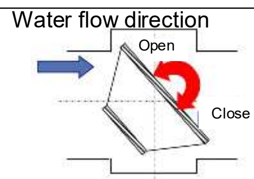
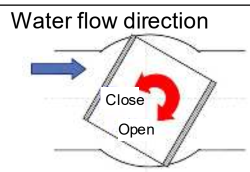
However, in an emergency where the guide vane or the guide vane operation mechanism are not closed, the inlet valve may be provided with the ability to shut off the entire flow rate of the turbine.

The tear blocking of the inlet valve is one of the devices that quickly shuts off the inflow water in Article 28, Paragraph 2 of GERPTS.

Check : Is the inlet valve selected according to the capacity of the power plant?

Type of inlet valve

Economical evaluation is performed based on hydropower loss, water leakage amount, and price, and the optimum inlet valve is selected.

	Butterfly valve	Biplane valve	Rotary Valve
Image			
Picture			
Applicable head	Medium	Medium	High
Applicable Water Flow	Small to medium	Small to big	Medium to big
Hydropower loss	Medium	Small	Almost 0
Water Leakage amount	Medium	Small	Very few
Structure	Simple	Simple	Complex
Cost	Medium	Cheap	Expensive

Chapter2. Water Turbine

Selection of turbine accessories

- Governor

  The governor is a device that adjusts the amount of water by automatically changing the guide vane opening in order to adjust the rotation speed (frequency) and output of the water turbine. In addition, if the generator is disconnected due to a water turbine or generator accident, or transmission line failure, etc., the guide vane will be closed immediately to prevent an abnormal increase in speed of the water turbine and the generator.

Governor Control Panel (Regulator)

Governor (Actuator)

Inside of governor actuator

Chapter2. Water Turbine

Selection of turbine accessories

- Pressure oil device

  The pressure oil device is a device that supplies pressure oil necessary for operating a servomotor such as a guide vane or an inlet valve of a water turbine. It consists of a pressure oil tank, an oil collection tank, a pressure oil pump, an unloader, etc. Some power plants do not use pressure oil to eliminate the risk of oil leaks from hydro power plants to the surrounding environment. For example, in a water turbine of about 30 MW or less, an electric servo motor is used instead of a pressure oil servo motor.

Pressure oil tank

Pressure oil pump

Oil collection tank

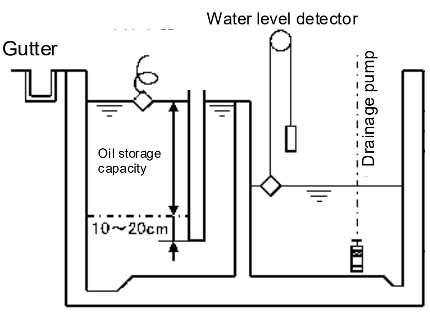
Selection of turbine accessories

- Lubricating equipment for bearings
  Lubricating equipment for bearings are devices that supply lubricating oil to oil-circulating turbine bearings. It consists of an oil pump, an oil tank, a cooling device, etc.

- Water supply device
  It is a water supply facility for cooling the bearings of water turbines and generators, the main body of the generator, and water for fire extinguishing. Water is supplied from a penstock or a flood bypass with a water supply pump.
  For small-capacity water turbines and generators, the water supply device is omitted by air cooling using the ventilation pipe of the generator to streamline the equipment and improve maintainability. For small-capacity water turbines and generators, the water supply device is omitted by air cooling using the ventilation pipe of the generator to streamline the equipment and improve maintainability.

Selection of turbine accessories

- Drainage device
  Water leakage from the area around the building, the foundation, and the water turbine seal is collected in the drainage pit at the bottom of the power plant.
  In addition, an oil-water separation tank will be installed in the drainage pit to prevent oil leaks by equipment from being discharged directly into the river.



(Example) Drainage device

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.30

- Air compressor
  The air compressor is used to operate generator brakes and switches.
  Recently, many small-scale hydro power plants are designed not to use air compressor due to electrification and the adoption of spring operation mechanisms.

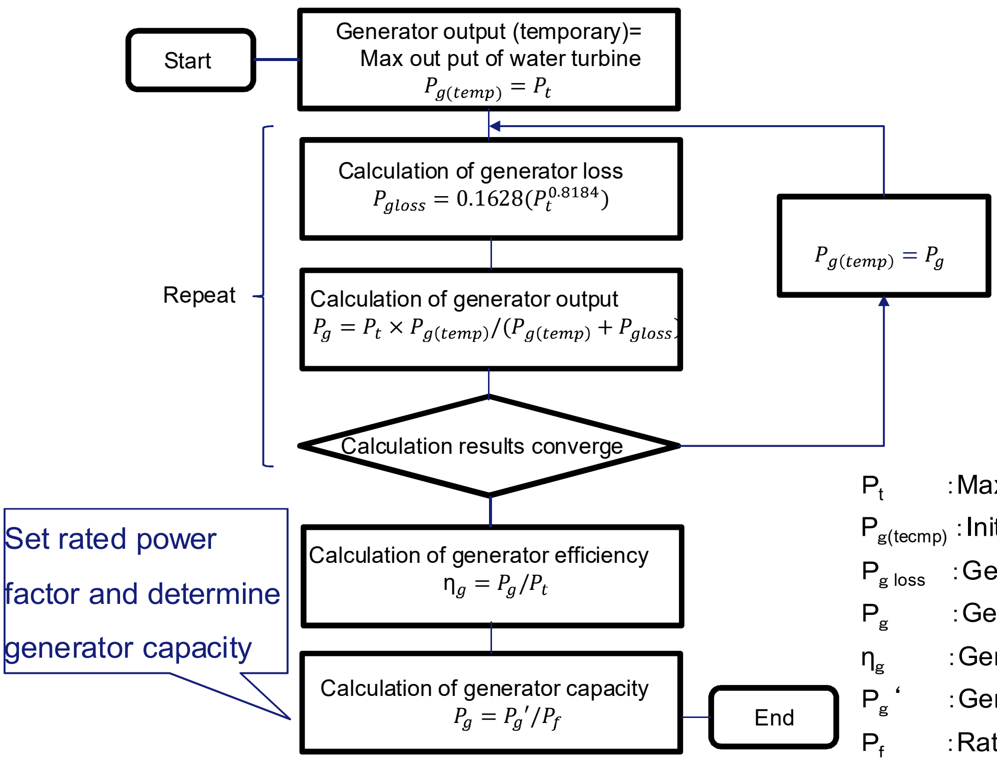
Air compressor

Chapter3 : Generator

Energia

Chapter3. Generator

■ The generator is designed with the following flow



P_t : Max output of water turbine [kW]

$P_{g(tecmp)}$: Initial output of generator [kW]

$P_{g\ loss}$: Generator loss [kW]

P_g : Generator output [kW]

η_g : Generator efficiency

P_g ' : Generator capacity [kVA]

P_f : Rater power factor of generator

Energia

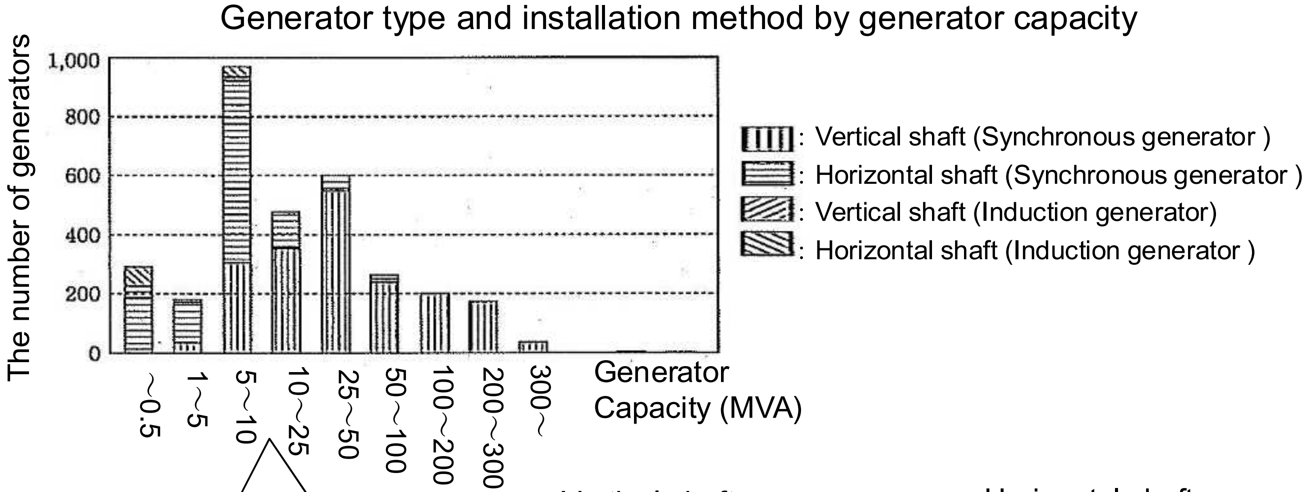
Generator type

- Generator type
  - ・Synchronous generator : Mainly used.
  - ・Induction generator : Adopted in consideration of economy when not operating independently with a small capacity
- Classification by installation method
  The installation method is roughly divided into a horizontal axis and a vertical axis. Select from a comprehensive judgment based on generator capacity, economy, maintenance, etc.
  - Horizontal shaft
    Although the foundation excavation depth is shallow and the height of the building is low, it is generally used for small-capacity machines because the floor area is large.
  - Vertical shaft (Single floor barrel type)
    The entire weight of the generator is supported by a barrel installed on the water turbine, which is used in large-capacity machines. The installation work period will be longer, but the height of the building will be lower than that of the two-floor type.
  - Vertical shaft (Two-floor type)
    The two-floor type installs floors that supports the water turbine and the generator separately. It is applied to small and medium-sized capacity machines because of the strength of the floor. The water turbine and generator can be disassembled and assembled separately.

Check : Are the type of generator and installation method selected according to the scale of the power plant?

Generator type

Generator type and installation method by generator capacity



With a generator capacity of around 10MVA, the installation tends to change from the horizontal type to the vertical type.

Vertical shaft

Horizontal shaft

■ Calculation of generator capacity
The generator capacity shall be the capacity that is the maximum output of the turbine to be the electric output at the rated power factor.

➢ Calculation of generator output and generator efficiency
Assuming the maximum output of the turbine, the generator output is calculated based on the generator design flow, and the generator efficiency is calculated by the following formula.

$$\eta g = Pg / Pt$$

Pg : Generation Output [kW]
Pt : Maximum output of turbine[kW]
ηg : Generator efficiency

➢ Generator rated power factor and generator rated capacity
The rated power factor of the generator is determined in consideration of the load and the characteristics of the power system. Normally, the rated power factor is about 98 to 85%, and it is calculated by the following formula.

$$Pg' = Pg / Pf$$

Pg' : Generation Capacity [kVA]
Pg : Generation Output [kW]
Pf : Generator rated power factor

Check : Are the generator output, rated power factor, and generator capacity appropriate?

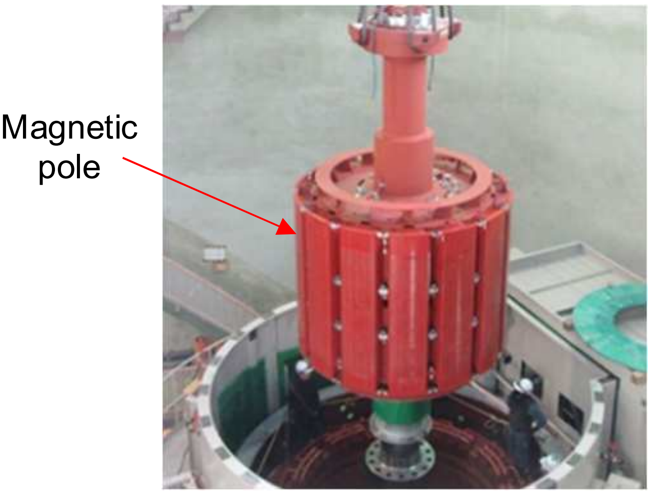
■ Calculation of rotation speed and number of poles

➢ Rotation speed and number of poles

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

n: Rotation speed [min^{-1}]
f:Frequency [Hz]
p:Number of poles

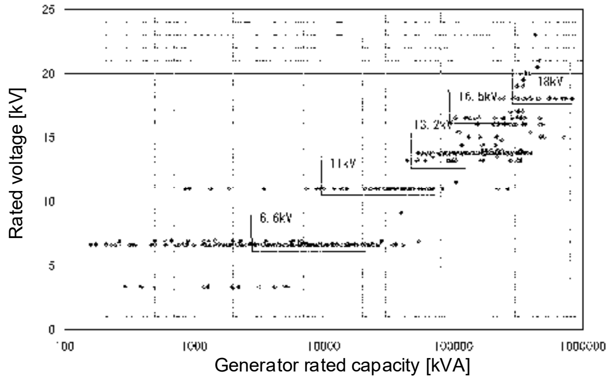
Generator rotor



Generator voltage

- The generator voltage is generally selected as follows for the capacity of the generator.

Generation Capacity [MVA]	Generator voltage [V]
Less than 3	400
3 – 10	6,600
10 – 50	11,000
50 – 100	13,200
100 – 300	16,500
More than 300	18,000



Relationship between generator rated capacity and rated voltage

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.36

The higher the generator voltage, the thicker the insulation of the stator coil and the heavier the weight. This increases the cost, so it is advantageous for the generator to have a low voltage. However, if a low voltage is selected, the current will increase, and the cable size and connecting conductor will increase. Therefore, the generator voltage will be selected to match the generator capacity.

Check : Is the generator voltage selected to match the generator capacity?

Calculation of generator current

- The rated current of the generator is calculated by the following formula. This is an important for determining the specifications of the main circuit from the generator to transformer, and the switching equipment.

$$I_g = P_g' / \sqrt{3} / E$$

I_g : Generator current [A]
P_g' : Generator rated capacity [kVA]
E : Generator rated voltage [kV]

Selection of exciter

- The exciter is a device that applies a field current to the rotor of the generator and controls the output and voltage of the generator. There are three types of exciter.

・DC excitation type

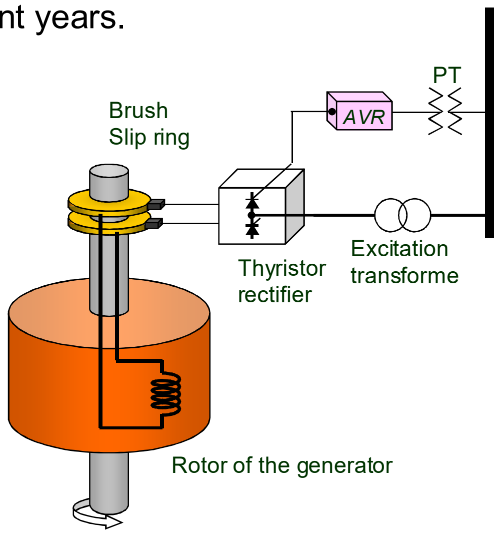
To supply field current by installing a DC generator
[Characteristics] DC generator is expensive and requires maintenance of commutators, so this has not been adopted in recent years.

・Thyristor excitation type

A method in which the output of an excitation transformer or AC generator is converted to direct current by a thyristor rectifier to supply a field current, and the field current is adjusted by phase control of the thyristor.

[Characteristics]

Compared to the DC excitation method, there are advantages such as easy maintenance and high control speed because there is no commutator, and it is used in power plants that require responsiveness such as system frequency adjustment.



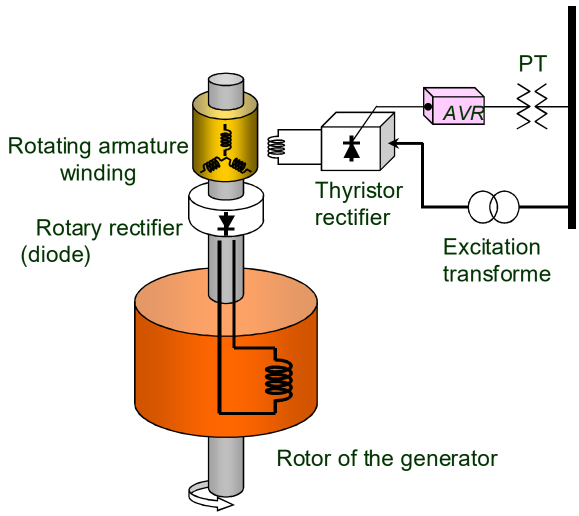
Selection of exciter

・Brushless excitation type

A method in which the output of a rotating electric current type AC generator directly connected to the generator spindle is converted to direct current by a rectifier mounted on the same rotating shaft, and the field current is directly supplied without going through a slip ring.

[Characteristics]

It is used for small and medium-sized machines because it does not require maintenance of the brush.



Check : Is an exciter selected according to the power plant operation method and generator capacity?

Function of excitation

- Automatic voltage regulator (AVR)

  A device that automatically adjusts the field current to keep the generator voltage constant.

- Automatic power factor regulator (APFR)

  A device that adjusts the voltage of the generator to the system voltage and operates at a constant power factor.

  In small-scale hydropower plants, it is common to carry out constant power factor operation with APFR.

Chapter4 : Electrical equipment

Main circuit connection

- The main circuit connection of a hydro power plant shall be determined by comprehensively judging from the reliability, economic efficiency and technical aspects of the power plant in consideration of the following.

  - Capacity and number of generators
  - Number of transmission line lines and withdrawal method
  - Constraints such as power plant space
  - How to receive power from the facility
  - Presence or absence of distribution lines
  - Transport conditions
  - Power outage range in the event of an accident
  - Safety and ease of failure repair and operation maintenance, etc.

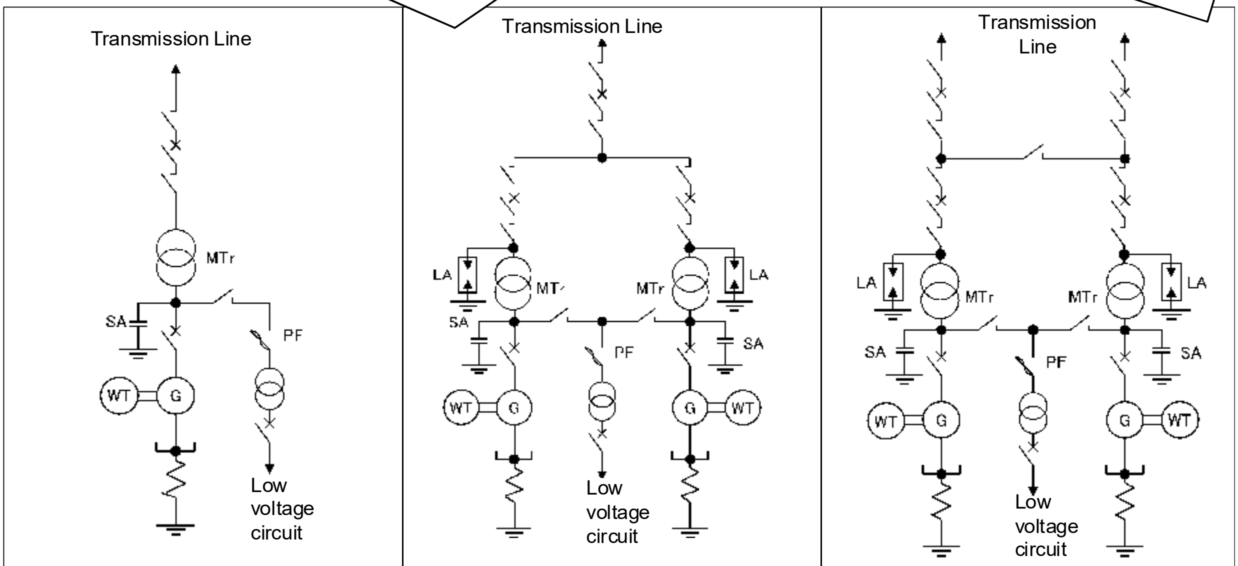
Typical examples of the main circuit connection are shown on the next page.

[Legend]
DS: Disconnecting Switch
CB: Circuit Breaker
Tr: Transformer
PF: Power Fuse
SA: Surge Absorber
LA: Lightning Arrester
WT: Water Turbine
G: Generator

Typical examples of the main circuit connection

Even if one transformer is stopped due to an accident or maintenance work, the remaining one can supply power.

In addition to the left, even if one transmission line is stopped, the remaining one can supply power.



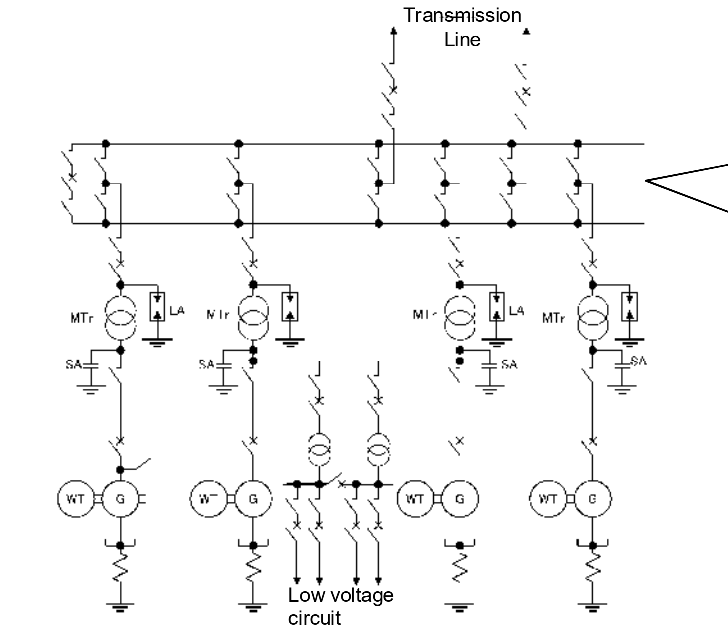
1 Generator
1 Transmission Line

2 Generators
1 Transmission Line

2 Generators
2 Transmission Lines

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.39,40

■ Typical examples of the main circuit connection



4 Generators, 2 Transmission Lines, Double bus bar

This is a double bus type.
It has a large capacity such as a pumped storage power plant, and is an important power plant because multiple turbine generators are connected.

Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.41

Check : Is the main circuit configuration and power plant layout according to the importance of the power plant?

■ Transformer selection

➢ The transformer with the necessary capacity will be installed for the following purposes.

・Transformer

[Application] It is used to transform a generator voltage to a power system voltage.

In a small-capacity power plant, if the power system voltage and the generator voltage are the same, install an insulated transformer to prevent disturbances such as lightning surges from the transmission line to the generator.

[Capacity] The capacity of the transformer shall be the same as the rated capacity of the generator.

Transformer

・House transformer

[Application] A transformer used for stepping down from a generator voltage to a low voltage.

[Capacity] The capacity of the house transformer is selected by calculating the capacity from the power consumption in the power plant.

Check : Is the capacity of the transformer consistent with the rated capacity of the generator?
Does the house transformer capacity matches the capacity of the power consumption in the power plant?

Circuit breaker selection

- Select a capacity that can cut off a short circuit and ground fault current.

・Rated voltage

The circuit breaker should be selected so that the maximum voltage of the circuit used does not exceed the rated voltage of the circuit breaker.

・Rated current

The circuit breaker should be selected so that the maximum value of the load current through the circuit breaker does not exceed the rated current

・Rated breaking current

Since the rated value for the breaking capacity is expressed by the breaking current, calculate the maximum fault current (usually the three-phase short-circuit current) of the circuit used, and select a circuit breaker with a rated breaking current that exceeds this.

Gas Circuit Breaker

Circuit breaker type by rated voltage (Japanese case)

Insulation Type	Rated Voltage [kV]							
	7.2	12	24	36	84	168	300	500
Oil	○	○	○	○	○			
Gas			○	○	○	○	○	○
Vacuum	○	○	○	○	○			

Check : Is an appropriate circuit breaker selected?

Disconnection switch selection

- The disconnection switch does not have a current opening & closing function and is used to disconnect electrical equipment from the circuit. The disconnection switch opens and closes a circuit that is only charged at the rated voltage, such as the charging current and the exciting current of the transformer, and is installed according to the applicable voltage.

・Rated voltage, rated current

Select the rated voltage and rated current in the same way as the circuit breaker.

Disconnection Switch

■ Instrument transformer selection

- There are Voltage Transformer and Current Transformer. The purpose of use is for measuring high voltage and high current of circuits. It supplies electricity proportional to the circuit voltage and current to instruments, relays, etc.

■ Lightning arrester selection

- Lightning arresters are installed to protect electrical equipment from overvoltage due to lightning and switching surges.

■ Metal-clad switch gear selection

- A low-voltage circuit stored in an iron box for safety is called a metal-clad switch gear

Voltage Transformer

Metal-clad switch gear

■ Switch gear selection

- A switch gear for operation, control, and protection of equipment.

In small and medium-sized hydro power plants, there are cases where software is used to reduce costs.

Switch gear

Protective device

- The protective device is installed for the purpose of reducing the following items by minimizing the effect in the event of a failure.
  - Damage recovery costs
  - Possibility that the failure will spread and spread to other parts
  - Period to stop power generation

- The protection of hydro power plants is divided into four categories: generator protection, transformer protection, bus protection, and transmission line protection in order to protect them efficiently.

Check : Are water turbines, generators and other protective devices properly selected?

DC power supply

- DC power supply is a facility that supplies DC power for control to switchboards and protective devices, and consists of a charging device and a battery.

Operation control method

- The operation control method is selected from the following.

・One-person control type

One operator can conduct start & stop operations, load & voltage control, measurement, monitoring, etc. It is designed to automatically stop or give an alarm when a failure occurs.

・Remote supervisory control system

Conduct start & stop operations, load & voltage control, measurement, monitoring, etc. from another nearby power plant or control center. It is designed to automatically stop or give an alarm in the event of a failure.

・Fully automatic control type

The turbine and generator will start automatically according to the set conditions, and the load will be adjusted automatically. It is designed to automatically stop in the event of a predetermined stop condition or failure.

Check : Is the operation control method selected according to the type of the power plant?

Chapter5 :Others

Crane

- Overhead travelling cranes and/or gantry cranes will be installed for the installation and assembly of turbines and generators. The maximum hoisting load of a crane is the hoisting load of a generator rotor. In addition, consider the lifting height and movable range required for installation and assembly.

Overhead travelling cranes

Check : Are the rated load, lifting height, and movable range of the crane appropriate?

Earthing

- When a ground fault occurs in a transmission line or a generator, a ground fault current flows from the power plant to the ground fault point. It is necessary to install a grounding mesh at the power plant and keep the ground resistance below the specified value so that safety problems do not occur. All electrical equipment such as water turbines, generators, auxiliary equipment, and switch gears must be properly connected to the ground mesh.
- The target value of grounding resistance is decided by the electrical safety standard of the country, but it is roughly the following value.
  - ･Power system of direct grounding: less than 1 ohm
  - ･Others (resistance grounding etc.): 10 ohm

■ Emergency electric supply unit

- Hydropower plants are the starting point for blackout starts. Therefore, emergency power generator is installed to start the water turbine generator even during a power outage.
- An emergency generator will be installed so that the power plant will not be submerged or the hydraulic pressure, air pressure, DC voltage for control, etc. will not drop due to a long-term power outage.

The capacity of emergency power generation equipment is calculated from the installed capacity of equipment used in the above situations.

Diesel generator and gas turbine generator are applied to the emergency power generator.

Check : Do you install an emergency power generation facility with an installed capacity according to the operation?

Chapter6 : Summary of FS check points

Points to be checked in FS review

Chapter6. Summary of FS check points

Point to be Checked	Details
Water Turbine	■ Water Turbine ✓ Are the items necessary for water turbine design selected? Are the materials such as river flow conditions calculated appropriately? ✓ Are the number and type of turbines selected according to the effective head and the amount of water used? ✓ Is the turbine output calculated in consideration of the turbine efficiency? ✓ Is the optimum water turbine suction height set? ■ Inlet valve ✓ Is the inlet valve selected according to the capacity of the power plant?
Main facility of generator	■ Generator ✓ Are the type of generator and installation method selected according to the scale of the power plant? ✓ Are the generator output, rated power factor, and generator capacity appropriate? ✓ Is the generator voltage selected to match the generator capacity? ✓ Is an exciter selected according to the power plant operation method and generator capacity?

Chapter6. Summary of FS check points

Point to be Checked	Details
Electrical equipment	■ Facilities ✓ Is the main circuit configuration and power plant layout according to the importance of the power plant? ✓ Is the capacity of the transformer consistent with the rated capacity of the generator? ✓ Does the house transformer capacity matches the capacity of the power consumption in the power plant? ✓ Is an appropriate circuit breaker selected? ✓ Are water turbines, generators and other protective devices properly selected? ■ Operation control method ✓ Is the operation control method selected according to the type of the power plant?
Others	■ Others ✓ Are the rated load, lifting height, and movable range of the crane appropriate? ✓ Do you install an emergency power generation facility with an installed capacity according to the operation?

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References

- SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)

- EXPLANATION SHEET FOR SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)

- 水力開発ガイドマニュアル（第 **1** 分冊 一般水力・揚水式水力発電）
（独立行政法人　国際協力機構（JICA)、電源開発株式会社、株式会社開発設計コンサルタント　2011.3）

Thank you for your attention

IPP Project Evaluation Methodology
- Solar power plant -

The Chugoku Electric Power Co., Inc.

中国電力株式会社
THE CHUGOKU ELECTRIC POWER CO.,INC

Outline

1

- **Objective**

 When you receive the report presented from the IPP developer, you should necessary to check each evaluation items are appropriate or not using the Check List.

- **Main evaluation items of Solar power**

 1.Site Assessment

 2.PV System (Facility, Equipment)

 3.Energy Assessment

Outline

■Main evaluation items of Solar power

1.Site Assessment

2.PV System

3.Energy Assessment

Energia

1.1 Site Location

- The site location is appropriate for PV installation?
  (Compared to the case of flat and plane land, it is necessary to consider the influence when it is on slope in the mountains, or sea breeze close to the sea, etc.)
- In Japan, based on the guidelines, we do preliminary surveys (material surveys / field surveys) for the terrain condition of installing PV equipment, such as soft ground, reclaimed land, embankment, mountains, hills, cliffs, steep slopes etc.

It is prefer to avoid installing on steep slopes as much as possible because avoiding landslides.

If it is close to the coastline, it is susceptible to salt damage due to sea breeze and spray.

1.2 Site Boundary

- Are not there any private houses and/or factories around the site location? (It should be avoid the influence of shade from the building. Also, if it is close to a residential area, it is necessary to check whether there is a complaint due to the reflection of the panel. And if it is close to the factory, it is necessary to check whether the contaminated dusts comes in.)
- At the Fukuyama Solar Power Plant, the experience of cleaning the panel surface by chemical cleaning occurred because the power generation efficiency decreased due to the adhesion of flying objects (mainly iron and calcium) from neighboring factories to the panel surface.

It should be considered the reflected light from the PV panel, and it does not effect to a house or office building.

It should be installed where there is little dust and dirt. Because in particular, chemical contamination cannot be removed with rainwater easily, and which may cause to permanent power reduction.

1.3 Site Connectivity

- Is easy road access to the site location? (It is necessary to confirm the access conditions to carry in and out of sand soil to the site, and such as transportation of equipment under the construction, also operation and maintenance is ease or not.)
- A road is required for transport vehicles such as panels, PCS, transformers, and heavy construction equipment at the construction stage.

Construction of access road

Packages of PV panel

Bulldozer

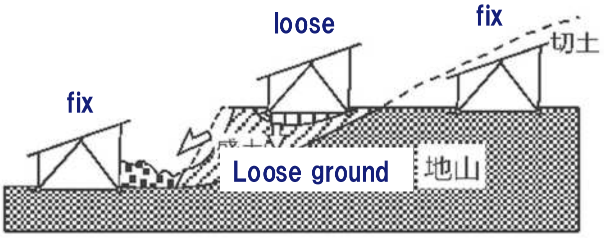
Truck

Package of Foundation Pile

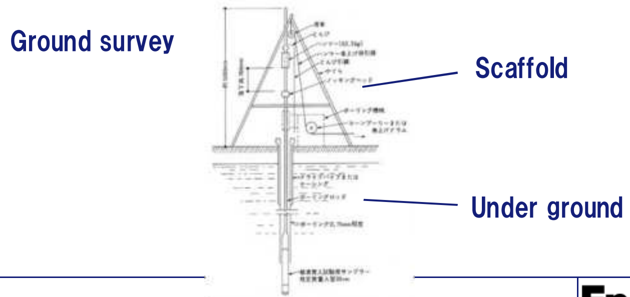
1.4 Geography

- Is the ground condition suitable for PV installation?
  (Because the basic design changes depending on whether the ground condition is hard or soft, it is necessary to check the ground conditions before construction.)
- In Japan, ground surveys and soil tests are conducted.
- There are some method such as Standard penetration test, Simple dynamic cone penetration test, Swedish sounding test (SWS test), etc. If the test result is soft ground, it is necessary to consider the basic design such as improvement of soil condition and/or increase pile driving amount.

An example of Landslide PV array where on loose ground



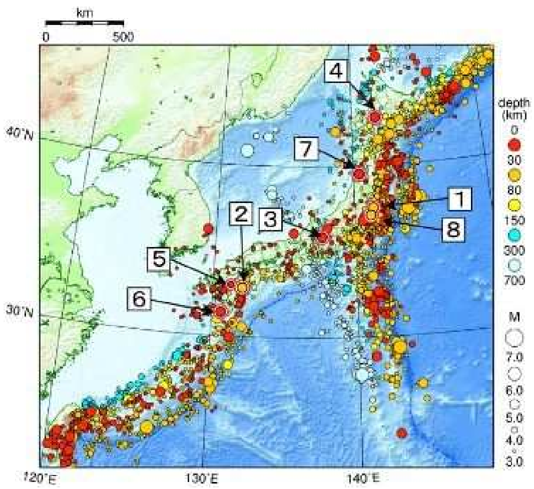
Loose ground causes the foundation move easily



1.5 Natural disaster risks (1.5.1 Seismic)

- Is a low probability of an earthquake?
  (It is necessary to confirm whether the risk of equipment damage due to the occurrence of an earthquake in the area is evaluated as based on the data of the Cambodia Meteorological Agency and various documents. Or are there any appropriate countermeasures taken?)
- It is necessary to confirm whether an appropriate evaluation has been made by IPP using past literature.

An example of a landslide caused by an earthquake



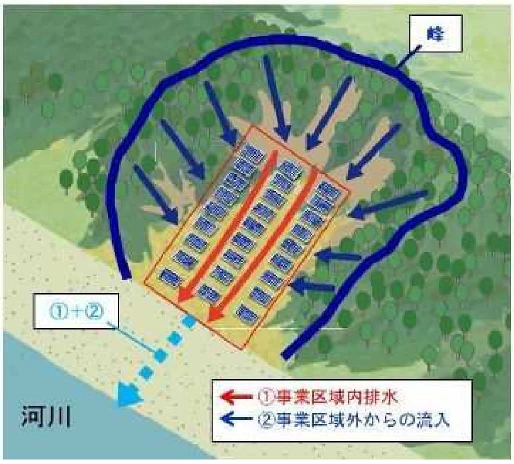
Earthquake possibility distribution map in Japan

1.5 Natural disaster risks (1.5.2 Flood hazard)

■ Is a low probability of flood disasters and landslides such as in the mountains?
(It is necessary to confirm whether the risk of equipment damage due to heavy rain disasters or landslides in the area is evaluated as based on Cambodia Meteorological Agency data and various documents. Or are there any appropriate countermeasures taken?)

An example a landslide caused by flood

An example of flooding river

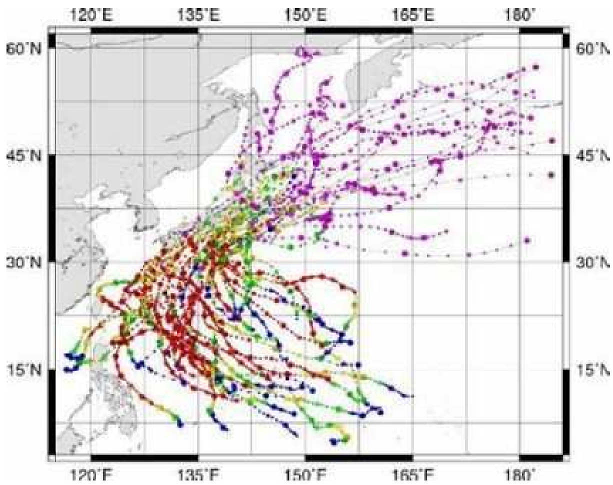


It should be considered Site drainage when planning

1.5 Natural disaster risks (1.5.3 Cyclone)

■ Is a low probability that the cyclone will adverse affect the equipment?
(It is necessary to confirm whether the risk of equipment damage due to cyclone storms, etc. in the area is evaluated as based on Cambodia Meteorological Agency data and various documents. Or are there any appropriate countermeasures taken?)

An example of PV panels damaged by a typhoon

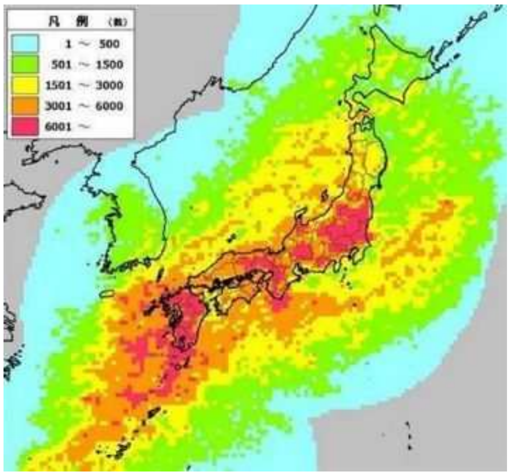


Typical typhoon tracks in Japan

1.5 Natural disaster risks (1.5.4 Lightning)

- Is low probability that the equipment will be affected by a lightning strike? (It is necessary to confirm whether the risk of equipment damage due to lightning strikes in the area is evaluated as based on Cambodia Meteorological Agency data and various documents. Or are there any appropriate countermeasures taken?)
- In Japan, if a lightning surge is expected to electrical facilities, it is necessary to confirm whether installing an appropriate arrester (lightning protection element).
- In addition, for high voltage, it is necessary to secure a certain distance between the arrester and a wooden wall (1 m or more), and the arrester should be grounded (grounding resistance value is 10 Ω or less).

Image of lightning strike on solar panel



Lightning strike distribution map in Japan

Outline

- Main evaluation items of Solar power

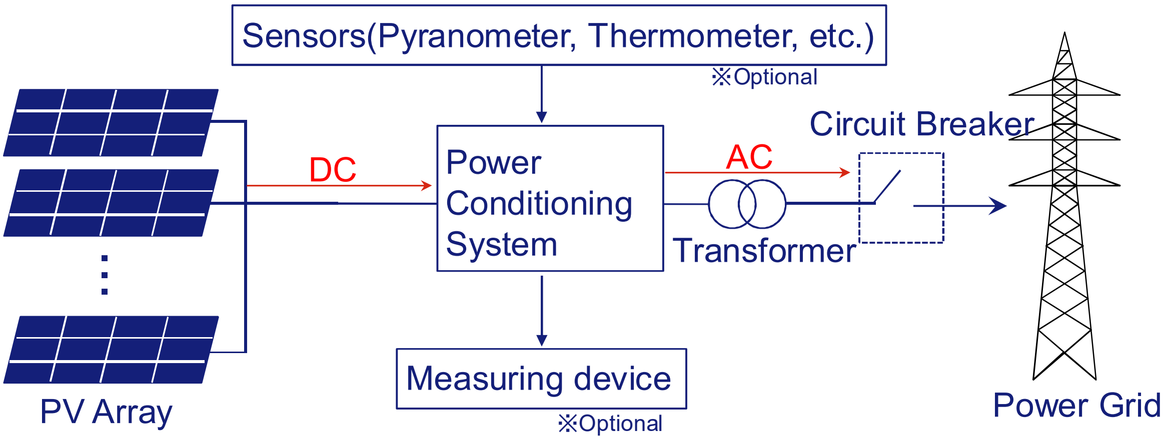
  1.Site Assessment

  2.PV System

  3.Energy Assessment

2.1 Facility Structure

- **Is the equipment design appropriate such as single diagram?**
  (It is necessary to confirm that the single diagram, device configuration, and various device specifications are properly designed or not.)
- **It is necessary to confirm that the equipment configuration is appropriate, such as voltage, capacity, and number of lines.**

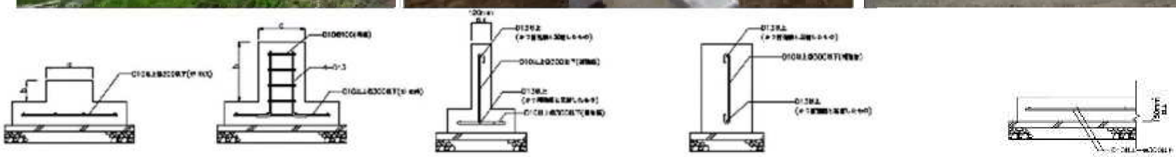


Especially, It is necessary to confirm that the equipment configuration is appropriate, such as voltage, capacity, and number of lines.

2.2 Foundation

- **Is the foundation design appropriate depending on the ground conditions?**
  (It is necessary to confirm whether the foundation is properly designed according to the ground conditions, and how the ground soil improvement if necessary.)
- **It is necessary to confirm whether the load design is appropriate based on the 1.4 results of the ground survey. It is necessary to consider the static load, wind pressure load, seismic load, etc.**

■ Foundation



Laying Foundation　Footing Foundation　Mat Foundation

2.3 Frame structure

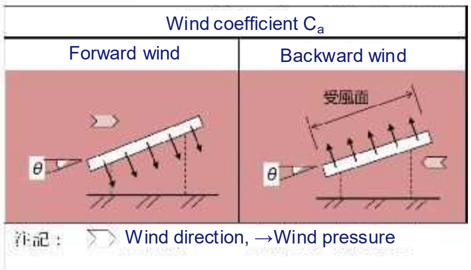
- **Is the mount frame design appropriate depending on the weather conditions?**
  (It is necessary to confirm that the mount frame is properly designed, such as the panel will not fly away when a cyclone storm coming.)
- **In Japan, the standard wind speed is 34 m/s or less for design. (40m/s or less for strong wind specifications).**

■ Frame

[Material]
- Stainless, steel, aluminum

[Feature]
- Stainless: ◎Durability, ×Expensive
- Steel: ◎Cheap, Strength
- Aluminum: ◎Durability, Weight

Wind coefficient of array



Forward wind

C_a=0.35+0.055θ − 0.0005 $θ^2$
ただし、5°≦θ≦60°
If 20° → C_a = 1.25

Backward wind

C_a=0.85+0.048θ − 0.0005 $θ^2$
ただし、5°≦θ≦60°
If 20° → C_a = 1.61

Design for wind load of array

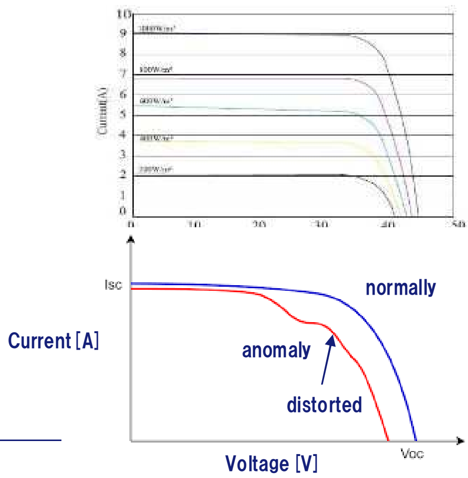
$$W_a = C_a \times q_p \times A_a \ [N]$$

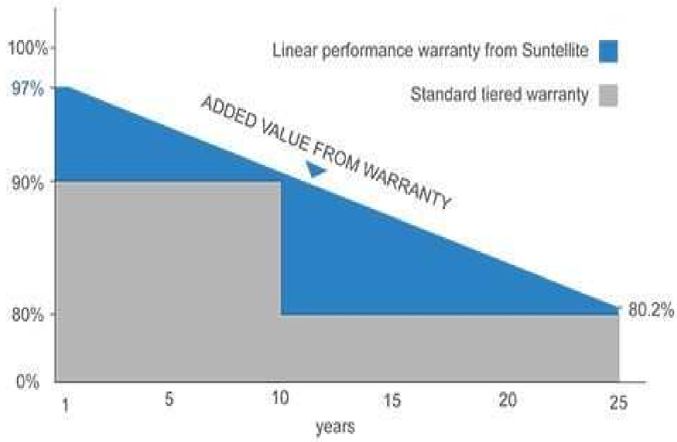
C_a : Wind coefficient
q_p : Design wind pressure [N/m²]
A_a : Area of array [m²]

2.4 Solar PV module

- **Is appropriate the module manufacturer that has much delivered record in other projects, and appropriate the proposed equipment performance and warranty period?**
  (It is necessary to confirm whether the module manufacturer has a lot of experience, and whether the proposed equipment performance and warranty period are appropriate or not.)
- **It is necessary to confirm whether the module manufacturer has much past supply records (generally 10 years or more) and whether the module warranty period is appropriate (generally 20 years or more).**

[I－V characteristic curve]

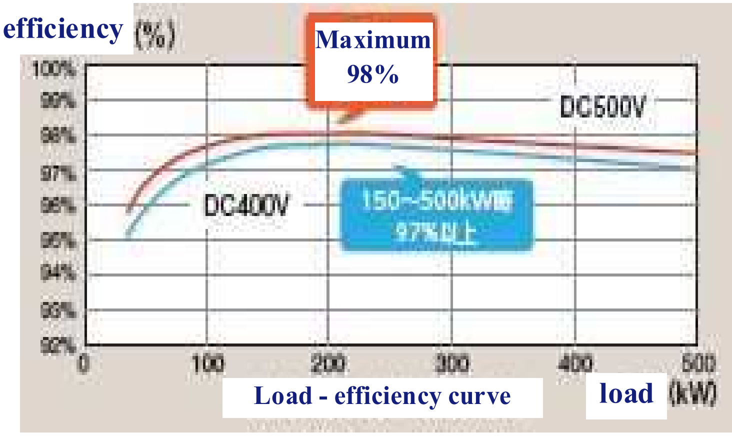




For ex. Output guarantee of 80% for 25 years

2.5 PCS (Power conditioning system)

- Is appropriate PCS manufacturer that has much delivered record in other projects, and the proposed device performance?
  (It is necessary to confirm whether the module manufacturer has a lot of experience, and whether the proposed equipment performance is appropriate or not.)
- It is necessary to confirm whether the PCS manufacturer has much past supply records (generally 10 years or more).

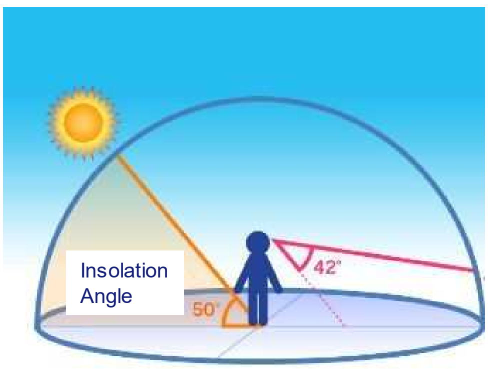


Compartment of PCS

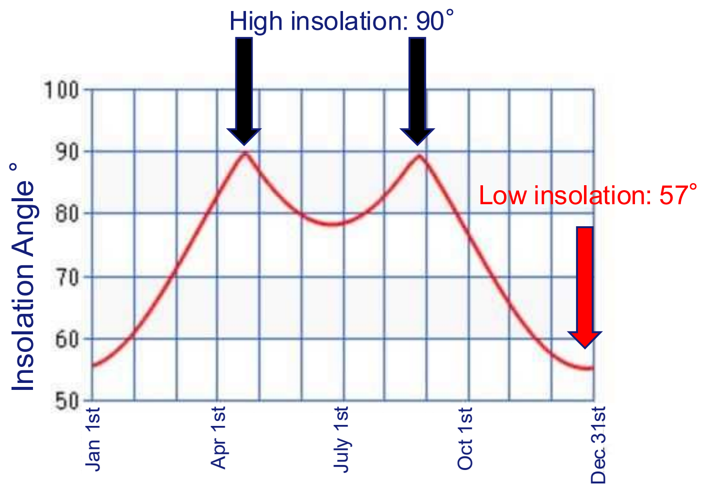
Cooling function affect the PCS efficiency

2.6 Tilt angle optimization

- Is appropriate panel angle depending on the illuminance conditions?
  (It is necessary to confirm whether an panel angle is appropriate according to the illuminance conditions or not.)
- In Japan, the solar panel is designed facing south which aim to power generation amount is large, and the array tilt angle which is designed for maximizes the amount of annual power generation.
- The array tilt angle of Fukuyama and Ube solar power plant was set to 20° .



https://weathernews.jp/s/topics/201807/310135/

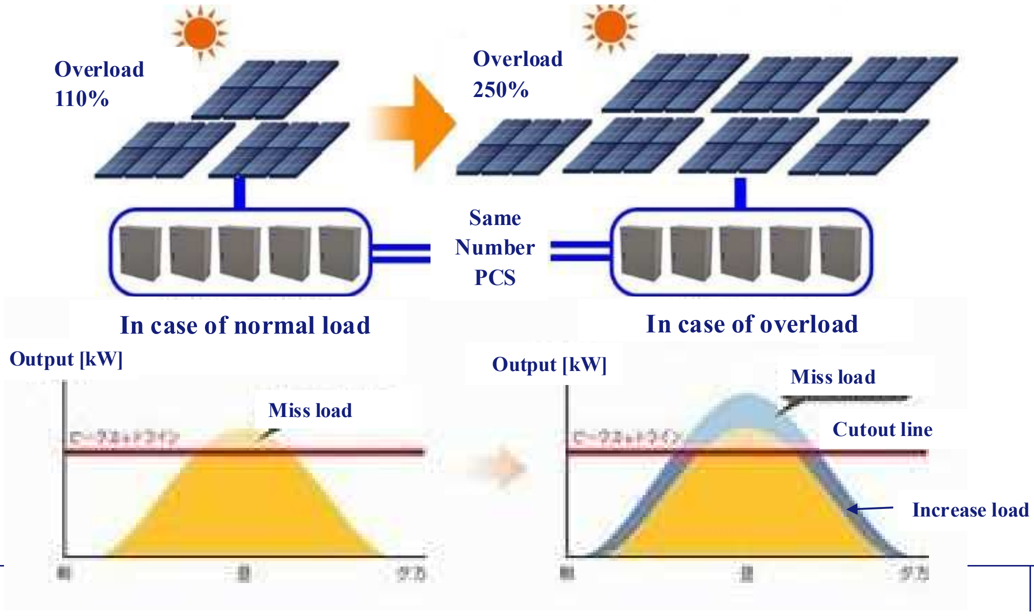


Angle of the sun at 12:00 in Phnom Penh

https://cheerfulsmile.org/life/sun-degree-cambodia/

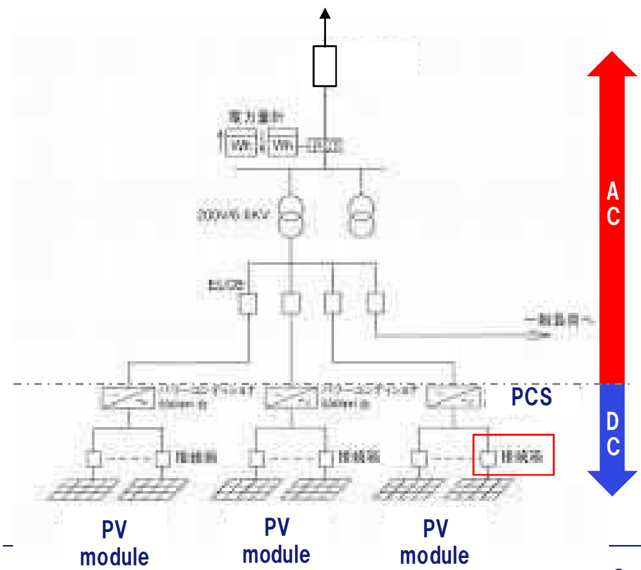
2.7 DC / AC ratio for optimal plant configuration

- **If it is PV panel overloaded, the whole design is appropriate?**
  (It is necessary to confirm whether the proposed overload design is appropriate or not.)
- **It is expected that the annual power generation will be increased by installing a larger DC capacity (panel capacity) than the AC capacity. But there is a possibility of curtailment problem of the power output, so it is necessary to check the design is correct or not.**

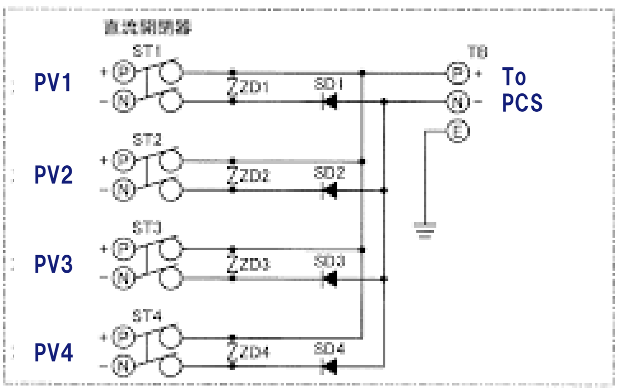


2.8 DC Cabling

- **Are appropriate cable laying design for each string to the CB hub and PCS specification?**
  (It is necessary to confirm whether the cable laying design from the PV panel to each CB and PCS are appropriate or not.)
- **In Japan, it is necessary to use the insulating material should be cross-linked polyethylene when using a high-voltage DC cable in a mega solar, and voltage should be 1.5 kV or less.**



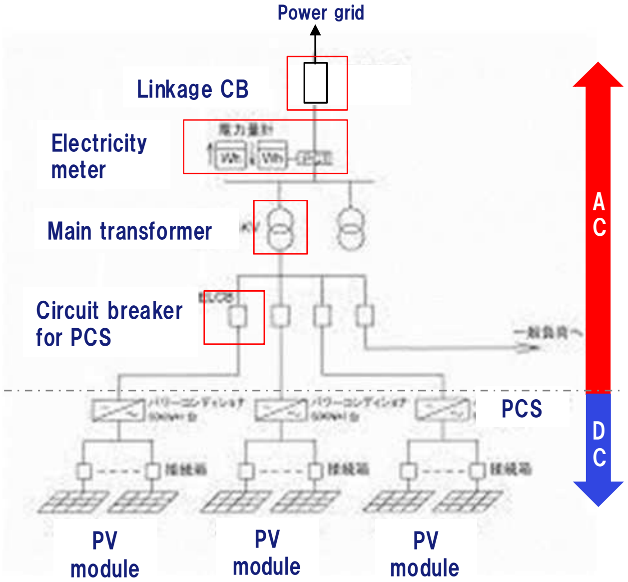
[Single diagram]



[Check items]
- ·Polarity（+, −）, Direction of a diode
- ·Capacity voltage of DC cable that is higher than PV output
- ·The location is depending on SPD class

2.9 AC Cabling, Voltage transformer ,Grid interconnec.

- Are appropriate design for the AC equipment, transformer and circuit breaker? (It is necessary to confirm whether AC equipment, transformer, and circuit breaker design are appropriate or not.)
- It is necessary to appropriately select such as the regular voltage and current, transformer ratio, regular breaking current for the connection circuit.



Check items

CB (Circuit Breaker) for linkage
・The function of CB circuit current is higher than the failure current from the power grid and the facility.
・The coherent action of CB circuit.

Electricity meter
・It is able to measure each current.
・It must locate between the Linkage CB and Main transformer.

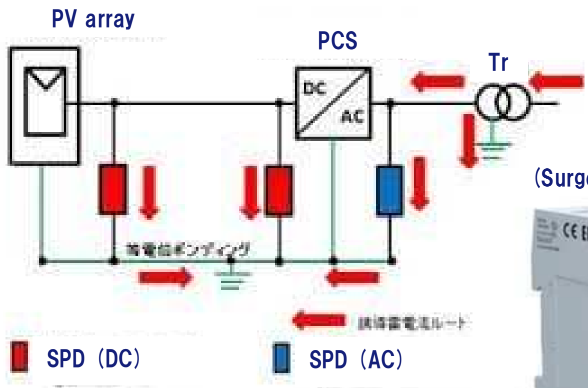
Main transformer
・The transformer capacity is higher than whole output of PCSs.
・It must install the appropriated Cooling system.

CB for PCS
・The function of CB circuit current is higher than each PCSs,
・The coherent action of each CB for PCS.

2.10 Facility protection device

- Are appropriate design and specifications for the protective system in the event of a ground fault, short circuit, or lightning strike? (It is necessary to confirm whether protection system is appropriate or not, when ground faults, short circuits, lightning surges during lightning strikes, etc. are occurred.)
- It is necessary to install a lightning arrester (lightning protection element at an appropriate position in the electrical facilities and circuits for protect from abnormal voltage and current.

Burned PCS (Terminal box)

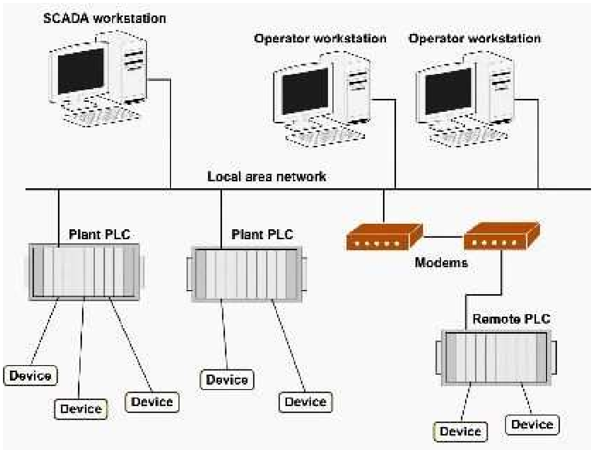


The protection from lightning surge by using SPD

SPD (Surge Protection Device)

2.11 Monitoring and Control Equipment

- Are appropriate design for the specifications of remote monitoring / control system such as SCADA?
  (It is necessary to confirm whether the remote monitoring / control device design is appropriate or not.)
- In Japan, when using the remote monitoring and control system, it is necessary to monitor the operating status ceaselessly and it have to operate the circuit breaker when start and stop of the power plant.



Remote monitor by SCADA
- ･Generation output（whole plant, each PCSs）
- ･Voltage, Current
- ･Insolation, Temperature, Humidity
- ･Condition of facilities（an on/off of switch gears）
- ･Several control signals
- ･Annunciator etc..

2.12 Boundary wall and fencing

- Are appropriate design for the equipment boundaries?
  (It is necessary to confirm whether the design has been made and proposed to prevent electric shock due to the invasion of humans and/or animals, and also equipment damage, etc.)
- In Japan, power plant must be surrounded by gates, fences, etc. to prevent intrusion and for the purpose of ensuring public safety.

It is preferable a fence height is 1.2m or more.

Secure of public safety, Prevent property loss

Prevention of animal damage（deer, wild boar, etc.）

2.13 O&M (Operating & Maintenance)

- **Are appropriate design for the operation and maintenance plan such as checking the power generation, PV panels and mounts, peripheral facility, and weed treatment?**
  (It is necessary to confirm whether the operation / maintenance plan is appropriate or not.)

Device	Inspection items	Remark (Detail)
Module	Any cracks, peeling, breakage and burn	・It should care where lightning strikes frequently.
	Any accumulation of dust, bird's dung or sea salt	・Whether the site is susceptible to ash fall due to eruption, and/or bird droppings dung and salt damage, etc.
Array	Any rust, corrosion, deformation, breakage, and loose bolts	・Where in strong winds, earthquakes.
PCS	Any corrosion, rusting, and wiring damage	・It should be specified by the manufacturer's manual. ・If it is in a corroded environment or in a dusty place, it should Increase the frequency of inspections.
Foundation	Any cracks and erosion	・Areas with frequent heavy rains, floods, and earthquakes. ・Sites soil is unstable or subject to land subsidence.
CB, LS(DS)	Any looseness of fixing bolts	・Management by the manufacturer's recommended torque and eye mark confirmation (not loosen).
	Any dust and rain water invasion	・Not invasion of any dust and water by heavy rain.
Others	Weeding management	・Weeding at a frequency is important that does not interfere with power generation performance reducing.

Outline

- Main evaluation items of Solar power

  1.Site Assessment

  2.PV System

  3.Energy Assessment

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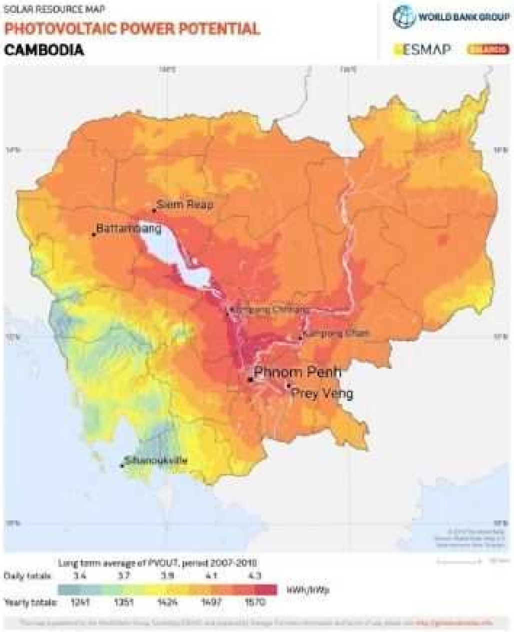
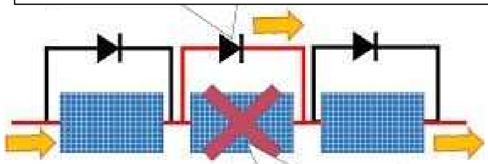
3.1 Evaluation of site

- Are appropriate illuminance conditions at the PV installation site? (It is necessary to confirm whether the appropriate illuminance conditions and whether it is not shaded by trees or building.)
- In Fukuyama and Ube power plant, the array tilt angle was designed from between the tilt angle and the amount of solar radiation. Cambodia is closer to the equator and it might be shallower tilt angle.



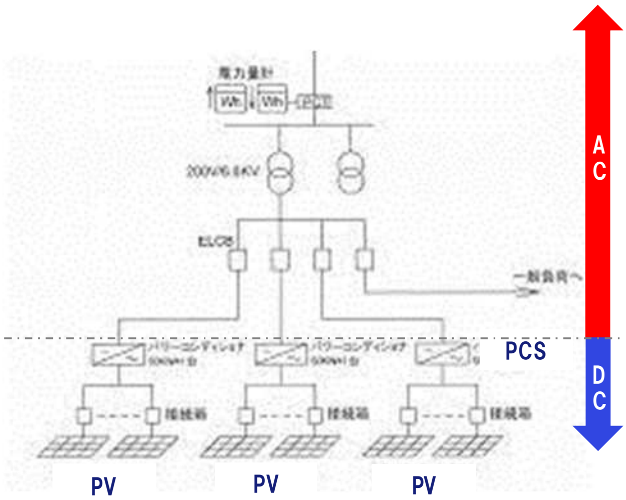
Current is through the bypass diode, and reducing the power generatation.



For example, if the module hides in the shadow of a tree

3.2 Calculation of solar PV system energy yield

- Is appropriate power generation forecast according to the equipment conditions such as illuminance conditions and panel / PCS performance? (It is necessary to confirm whether the appropriate power generation in consideration of illuminance conditions, and including panel / PCS degradation, transmission / transformation loss, etc.)
- It is necessary to check a power generation simulation based on the panel module efficiency, PCS performance and transmission / transformation.
- The general capacity factor in Japan is about 17%.



[Efficiency of each devices]

Main transformer
・Conversion efficiency is about 98-99%.

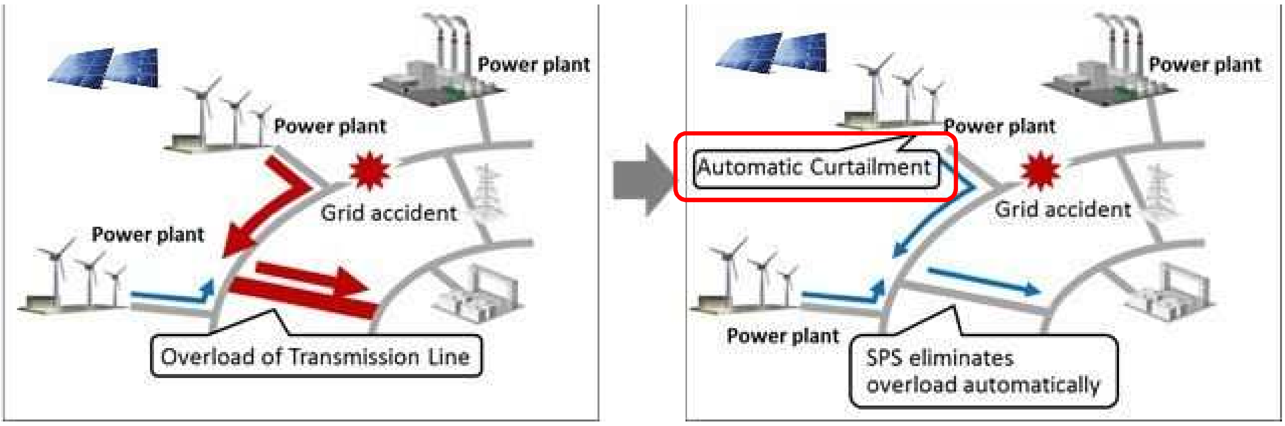
Power Conditioner
・Conversion efficiency about 96 to 98%.
(It is high efficiency from middle load to light load)
・It should be preferable a wide range to perform high efficiency.
・The cooling system has a large effect on the efficiency.

Dc Cable
・Energy loss is about 2-4%.

PV panel
・The amount of power generation depends on the solar radiation, radiation angle and any dirt of the panel surface.
・Conversion efficiency id around 20% (single crystal silicon).
・The general degradation rate is 0.5% / year.

3.3 Evaluation of results of Curtailment

- Is appropriate power output evaluation according to the energy demand, capacity of the transmission, power tidal current, etc.?
  (If curtailment occurs, it is necessary to confirm whether the power output evaluation is appropriate or not.)



[Example of power limitation (SPS: grid stabilization system)]

・In the event of a grid accident, the power plant output is automatic curtailment using SPS for in order to avoiding the overload of transmission line capacity.

・Even if in case of the low demand and the amount of solar power generated is too high when strong sunlight, the power output will be automatic curtailed due to avoiding overload of transmission capacity.

・ It depends on the congestion condition of the power system, it should considered when excessive the curtailment amount is exceeds 5% during the year.

WG2: IPP Project Evaluation Methodology
- Power System -

The Chugoku Electric Power Co., Inc.

中国電力株式会社
THE CHUGOKU ELECTRIC POWER CO.,INC

Interconnection to power grid

1

Evaluation item			Specific elements	Pass	Fail
1.Power System					
1.1	Situation of Power System		Validity of conditions and results of power flow study		
1.2	Necessity of Power Plant based on power development master plan		Type of generator, Capacity, Commencement date of commercial operation		
1.3	Interconnection to Power System				
	1.3.1	Specification	Voltage, Power factor, Operating frequency range of power generation facilities, etc., Frequency adjustment function※1, Neutral point grounding equipment, Electromagnetic induction hazard, Protection device		
	1.3.2	Impact on Power system	Necessity of power system extension (if overloaded), Voltage fluctuation※2, Power plant output [MW] fluctuation※2, Power quality※2, System stability, Automatic load limiter and power generation suppression(only if required)		
	1.3.3	Countermeasures for accident	Short-circuit and ground-fault currents, Fault Ride Through function※2		
	1.3.4	Control and communication requirements	Telephone equipment for security of electric facilities, Power Feed Information Transmission Equipment		
2.Transmission Line					
2.1	Transmission line		Interconnection point with power system, Voltage, Route(Over head and/or under ground), Structures, Wire type, Necessity of Low-loss wire, Number of Circuits, Things crossing transmission lines(e.g. river, railroad, etc.), Matching of power generator and transmission line capacity		

※1 : Thermal power plant, Hydro power plant
※2 : PV power plant, Wind power plant

Specification (1)

Frequency & voltage

- ✓ System Frequency shall be nominally 50 Hz.
- ✓ System Voltage shall be ranged
  - 230kV:207kV～245kV
  - 115kV:103.5kV～123kV
  - 22kV:19.8kV～24kV

(Reference) Grid Code 3.3.1

The NTL shall ensure that the CTS will comply with the following operational criteria.

a. System Frequency shall be nominally 50 Hz and shall be controlled within the limits of 49.5 Hz - 50.5 Hz unless exceptional circumstances prevail. The System Frequency could fall to 47 Hz or rise to 52 Hz in exceptional circumstances.

b. System Voltage at the Connection Point will normally remain within the operating range stated in the table below unless exceptional conditions prevail.

Nominal Voltage	Higher Limit	Lower Limit
230 kV	245 kV	207 kV
115 kV	123 kV	103.5 kV
22 kV	24 kV	19.8 kV

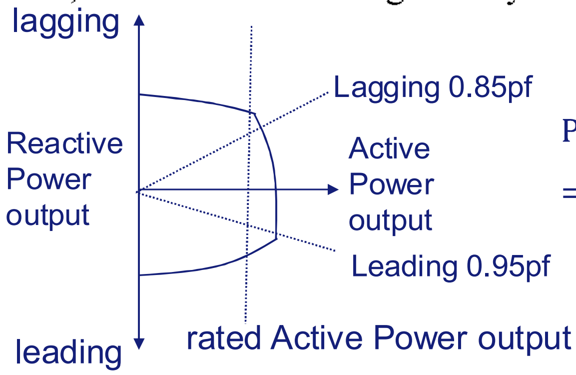
Specification (2)

Power factor

- ✓ Generating Units must be capable of supplying rated Active Power output at any point between the limits 0.85 power factor lagging and 0.95 power factor leading.

(Reference) Grid Code 3.3.3

All Generating Units must be capable of supplying rated Active Power output at any point between the limits 0.85 power factor lagging and 0.95 power factor leading at the Generating Unit terminals, unless otherwise agreed by the NTL.



Power factor

$$= \frac{\text{Active Power}}{\sqrt{(\text{Active power}^2) + (\text{Reactive power}^2)}}$$

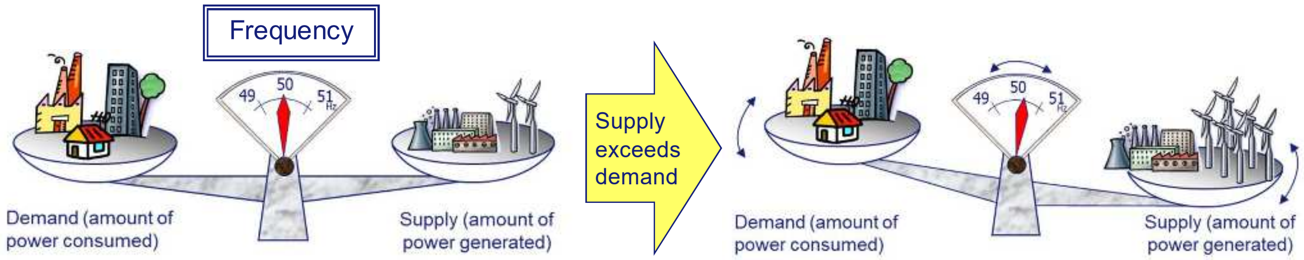
image of generator capability curve

Specification (3)

Operating frequency range of power generating units

- ✓ Continuous operation frequency range: 47.5 to 52 Hz
- ✓ Operation frequency range for a period of 20 seconds: between 47 and 47.5 Hz.

When generated power equals to demand, the power system frequency shall be about 50Hz in Cambodia. If the generated power exceeds the demand, the rotating speed of generating units increases and the power system frequency increases, and vice versa.



Specification (3)

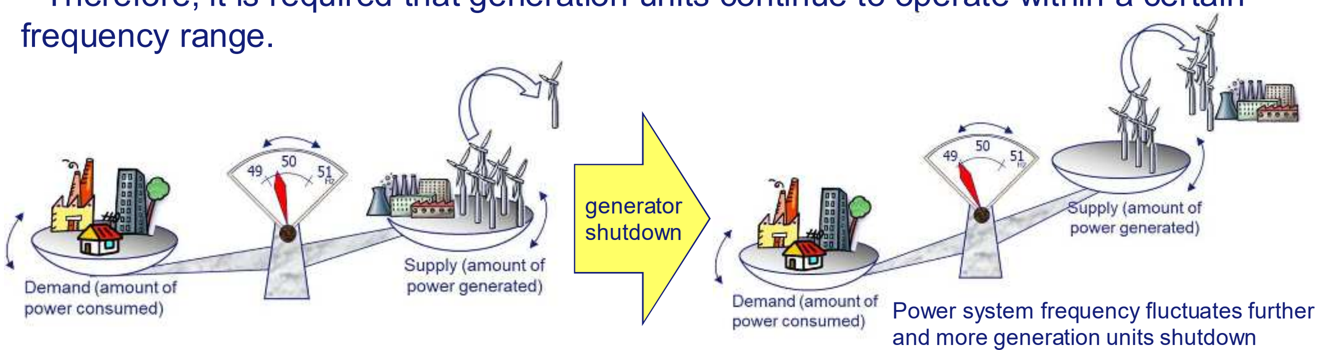
Operating frequency range of power generating units

- ✓ Continuous operation frequency range: 47.5 to 52 Hz
- ✓ Operation frequency range for a period of 20 seconds: between 47 and 47.5 Hz.

If the power system frequency (and so the rotating speed of generating unit) fluctuates widely, the generating units may be stressed and damaged, and so the generation units shall shutdown in such a situation.

On the other hand, if generation units shutdown due to a small fluctuation in frequency, the frequency may fluctuates further due to a drop in power generation and that may cause a chain of generation unit shutdowns.

Therefore, it is required that generation units continue to operate within a certain frequency range.



Specification (3)

Operating frequency range of power generating units

(Reference) Grid Code 3.3.3

A Generating Unit must be capable of continuously supplying its rated Active Power output at the Generating Unit terminals within the System Frequency range 49.5 to 50.5 Hz. Any decrease of Active Power output occurring in the frequency range 49.5 to 47 Hz should not be more than pro rata with frequency.

Design of Generating Unit must ensure continuous operation of the Generating Units for Frequency range of 47.5 to 52 Hz and operation for a period of 20 seconds each time the frequency is between 47 and 47.5 Hz.

Specification (4)

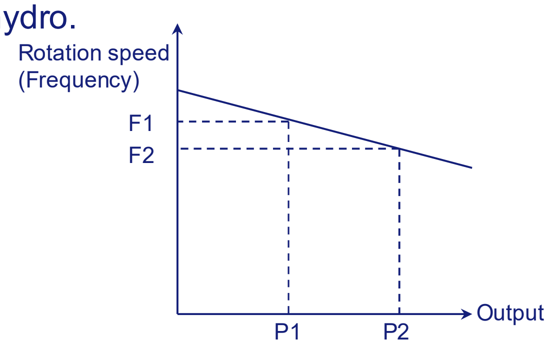
Frequency adjustment function

✓ Generating unit shall operate under the control of a governor.

For very short-period power demand and/or supply fluctuations of a few minutes or less, the "governor-free control" function equipped by a generating unit is used.

The governor is the control device to maintain the rotating speed of generating unit by adjusting the input(e.g. water flow). Under the governor-free control, if the rotating speed decreases (i.e., power demand exceeds generation), the input (and thus output) is increased to raise the rotating speed (and vice versa). Therefore, the governor-free control can contributes to supply-demand adjustment.

Governors are equipped on synchronous generating units such as thermal and hydro.



Speed droop characteristics

Left graph shows the relation between the generating unit output and the rotation speed. Governors operate directly on frequency changes and can respond quickly.

Specification (4)

Frequency adjustment function

✓ Generating unit shall operate under the control of a governor.

(Reference) Grid Code 6.4

6.4 Requirements of Generating Unit Governor system

6.4.1 Other than as permitted in accordance with Section 6.4.2, Generation Units when synchronized to the CTS shall operate at all times under the control of a governor control system (or frequency control device). No time delays other than those necessarily inherent in the design of the governor control system shall be introduced. The design, implementation and operation of the governor control system shall be agreed with the NTL prior to the commissioning of the Generating Unit.

6.4.2 The provisions of Section 6.4.1 may be contravened where:

a. The action is essential for the safety of personnel and/or to avoid damage to Equipment, in which case the Generation Licensee shall inform the Control Center of the restriction without delay; or
b. In order to (acting in accordance with Good Industry Practice) secure the reliability of the Generation Unit; or
c. The restriction is agreed by the Control Center in advance; or
d. The restriction is in accordance with a Dispatch Instruction given by the Control Center.

Specification (5)

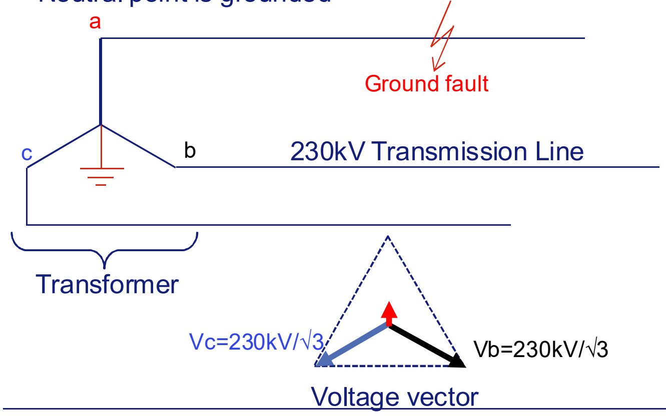
Neutral point grounding equipment

✓ Neutral point shall be grounded if the voltage is 115kV or more over.

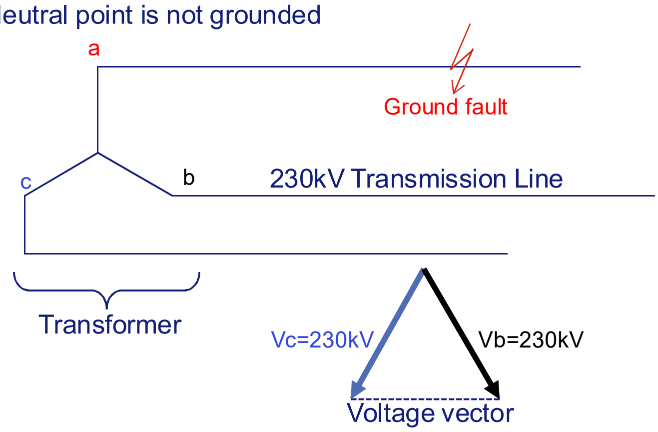
Grounding the neutral point has the following advantages:

- Since the voltage rise during an accident is reduced, the insulation level of the equipment can be lowered, resulting in a more cost reduction of the equipment, especially in equipment with higher voltages.
- In the event of a ground fault, the current flowing to the neutral point is large enough to cause the protective relay to operate quickly and reliably.

Neutral point is grounded



Neutral point is not grounded



Specification (5)

Neutral point grounding equipment

- ✓ Neutral point shall be grounded if the voltage is 115kV or more over..

(Reference) SREPTS for Transmission and Distribution Facilities, Article 23

1.2 Grounding for Neutral Points in High-voltage and Medium-voltage Electrical Circuits

In case where grounding is provided for the neutral point of high-voltage and medium-voltage electrical circuits in power stations, substations, switching stations and high-voltage and medium-voltage users' sites in order to secure reliable operation, to suppress abnormal voltage and to reduce the voltage to ground for protective devices of electrical circuits, the grounding electrode shall be installed to prevent risks of danger to people, domestic animals and other facilities due to the potential difference generated between the pole and the nearby ground when any failure occurs.

(Reference) Grid Code 3.3.4

3.3.4 Distribution Licensees and Consumers connected directly to CTS

b. Neutral Earthing
The upper voltage winding of the three phase transformers connected to CTS at voltages of 115 kV and above shall be star connected with the star point connected to earth as per IEC standards.

Specification (6)

Protection device

- ✓ Maximum Time for Fault Clearance:
  230kV: 100 [ms] / 115kV: 140 [ms]
- ✓ High Voltage line shall have protection consisting of a primary and a back up protection.

	Primary Protection	Backup Protection
230kV	- Current differential protection relay - Optical fiber communication	- Distance protection
115kV	- Distance protection	- Directional three poles over current and earth fault protection

- ✓ Reclosing provision shall be high speed first shot for single phase and three phase re-closing and further delayed multiple shot three phase re-closing.

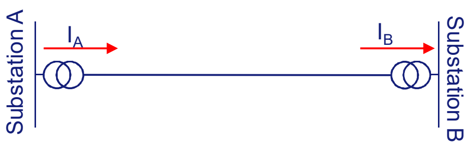
Specification (6)

12

Protection device

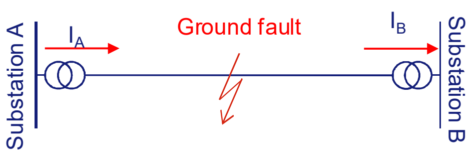
When a fault occurs in the power grid, such as a ground fault or a short circuit, fault current continues to flow from the generator until the fault point is isolated or the cause of the fault is eliminated. If fault clearance takes long time, conductor of transmission lines may melt or transformers and generators may fail. Higher system voltages cause higher fault currents, so higher voltages require faster fault clearing.

The back-up protection is installed in case the primary protection does not operate. The protection stability is enhanced by adopting different protection methods as the primary and back-up. The current differential protection relay used as the primary protection for 230kV line can clear fault rapidly. However, note that, the relay requires the communication with opposite substation, and so the same relay with the opposite substation shall be installed.



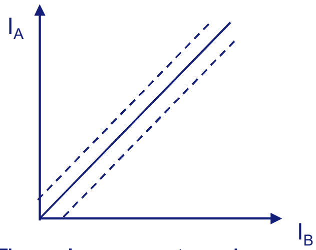
I_A-I_B=0

Normal situation



I_A-I_B=fault current

Fault situation



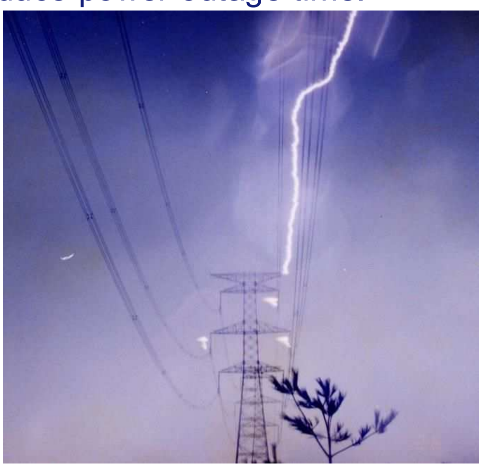
The relay operates above a certain current difference.

Specification (6)

13

Protection device

On overhead transmission lines, since most of the fault incidents are flashover caused by lightning or other reason, turning off the arc will restore the insulation. Reclosing is that the auto closing of the circuit breaker opened by the protection relay. This function is introduced to improve the reliability of the power grid and to reduce power outage time.



https://dbnst.nii.ac.jp/view_image/4486/9274?height=873&width=728

Photo of flashover caused by lightning

It should be noted that the circuit breaker must be capable of reclosing operation.
For example, in the high speed reclosing method, the fault current must be cut off and the circuit breaker recloses again in a very short period of time, and must be cut off again if the reclosing is not successful.

Specification (7)

Protection device

(Reference) Grid Code 10.5, 10.6

10.5 Maximum Time for Fault Clearance

From a stability consideration, the maximum time for clearance of faults (from fault inception to circuit breaker arc extinction) by primary protection on any User's system directly connected to the CTS, or faults on the CTS itself, for different system voltages shall be as follows:

a. 230 kV 100 milliseconds
b. 115 kV 140 milliseconds

Slower fault clearance times for faults on a User's system may be agreed to, but only if, in the opinion of the NTL, system conditions allow this.

The maximum time for clearance of faults by back up protection, on failure of the primary protection, shall be 300 milliseconds.

10.6 Protection Requirements

10.6.2 Transmission Line

Every High Voltage line taking off from a Generating Plant or a substation shall have protection consisting of at least a primary protection scheme and a back up protection scheme. The recommended protection schemes for lines of different voltages are stated below. The Transmission Line owner may provide different protection scheme than stated below only in consultation with and approval of the NTL.

230 kV lines – Primary Protection - Current differential protection relay in conjunction with optical fiber communication from the transmission line. Back up Protection - Three or more zone distance protection with phase fault and earth fault measuring elements and with permissive inter trip for accelerating tripping at remote end in case of zone-2 fault. Reclosing provision shall be high speed first shot for single phase and three phase re-closing and further delayed multiple shot three phase re-closing.

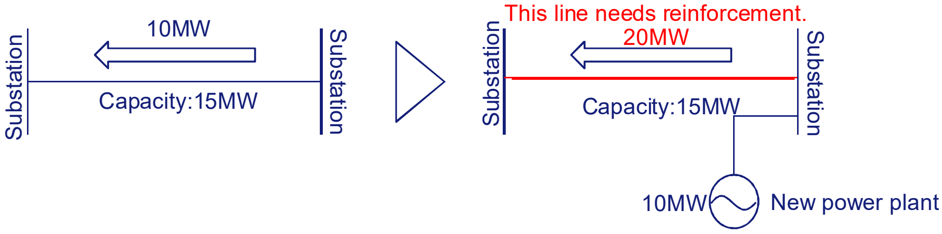
115 kV lines - Three or more zone static distance protection with permissive inter-trip for accelerating tripping at remote end in case of a zone-2 fault shall be provided as primary protection. The backup protection will be directional three poles over current and earth fault protection.

Impact on power system (1)

Necessity of power system reinforcement

✓ For the power flow calculation results, the power flow of each transmission and distribution lines shall not exceed the capacity of the line.

- The capacity of transmission and distribution lines is determined by the thermal capacity of the wires and the capacity of the transformer. These capacities are limited by the heat due to the current, and if the limit is exceeded, the wire will melt or the transformer will fail.
- The interconnection of a new power plant to the power grid changes power flow in each transmission and distribution line.
- The results of power flow studies under various conditions (e.g., season, day/night, outage by maintenance, etc.) shall be confirmed that the maximum power flow for each transmission and distribution line does not exceed its capacity.



Current Situation

After interconnecting power station

Impact on power system (2)

Voltage fluctuation

- ✓ Each Generating Unit must be capable of contributing to frequency and voltage control by modulation of Active Power and Reactive Power supplied to the CTS.
- ✓ On-load tap changing facilities are required on Generating Unit transformer for dispatch of Reactive Power.

The reactive power can be increased or decreased by increasing or decreasing the generator excitation.

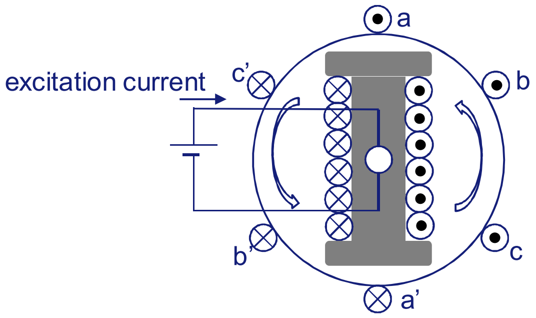
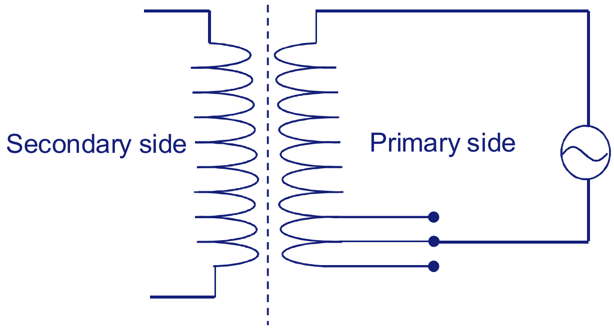


Image of generator

Tap changing facilities adjust the voltage by changing the winding ratio.



Transformer

Impact on power system (2)

Voltage fluctuation

(Reference) Grid Code 3.3.3

3.3.3 Generating plant

The Active Power output at the Generating Unit terminals under steady state conditions should not be affected by voltage changes in the normal operating range specified in Section 3.3.1.b. The Reactive Power output at the Generating Unit terminals under steady state conditions and at rated Active Power should be fully available within the range ±5% of nominal grid system voltage at the Connection Point.

Each Generating Unit must be capable of contributing to, in a manner satisfactory to the NTL, frequency and voltage control by modulation of Active Power and Reactive Power supplied to the CTS.

On-load tap changing facilities are required on Generating Unit transformer for dispatch of Reactive Power. The transformer voltage ratio, tapping range and step sizes must be such that the reactive requirements specified in Paragraph 4 above of this Subsection are fully complied with.
The higher voltage windings of the Generating Unit transformer connecting a Generating Unit to the CTS at voltages of 115 kV and above shall be star connected with the star point earthed in accordance with IEC standards.

Impact on power system (3)

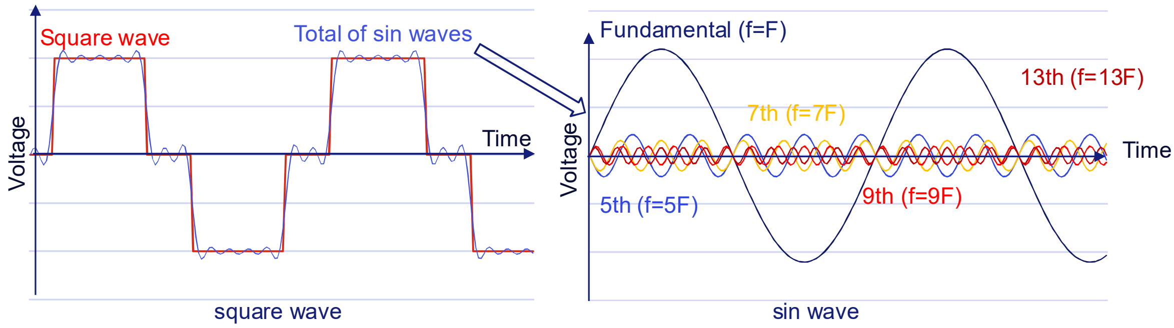
18

Power quality

✓ The maximum total levels of harmonic voltage distortion and the total demand distortion of the current on CTS at a connection point shall be under the amounts specified in Grid Code.

- Harmonics occur when rectifier circuit or AC-DC conversion is used such as Solar power and wind power.
- Harmonics affect phase modifying facility such as phase advance capacitor. Since capacitors are low impedance to high frequency, the high voltage of harmonics cause overcurrent and fail.

Example of wave form converted from DC to AC



Energia

Impact on power system (3)

19

Power quality

(Reference) Grid Code 3.3.1

c. The maximum total levels of harmonic voltage distortion and the total demand distortion of the current on CTS at a Connection Point under normal operating conditions and under both planned and unplanned outage conditions (other than for infrequent short duration peaks) shall be:

Harmonic Voltage Distortion			
Voltage Level (kV)	Total Harmonic Distortion	Individual Distortion	
		Odd	Even
115-230	2.5%	1.5%	1%
22	3%	2%	1%

Harmonic Current Distortion			
Voltage Level (kV)	Total Demand Distortion	Individual Distortion	
		Odd	Even
115-230	2.5%	2%	0.5%
22	5%	4%	1%

The Equipments connected to the CTS should be capable of withstanding the above harmonic distortions.

Energia

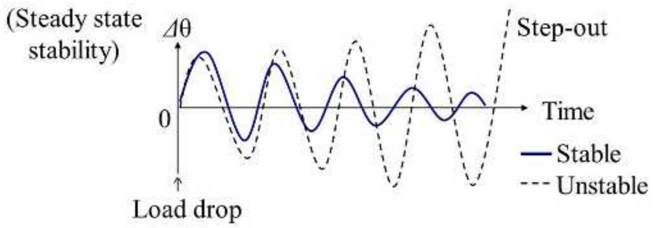
Impact on power system (4)

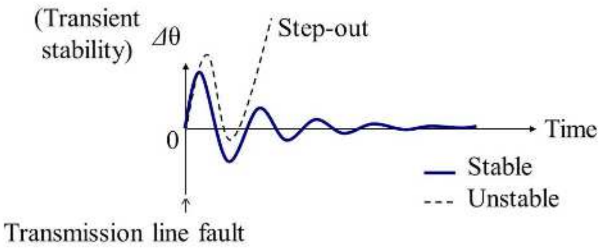
20

System stability

✓ The results of steady state and transient stability studies shall be stable.

- Steady state stability study examines whether the generating unit can operate stably when the situation (load, voltage, and/or system configuration) changes, and transient stability study examines whether the generating unit can operate stably when the system has a fault, etc.
- In Cambodia, EDC conducts these studies by using PSS/E. Therefore, the necessary data to conduct these studies shall be shared with EDC and the results studied by EDC shall be stable.





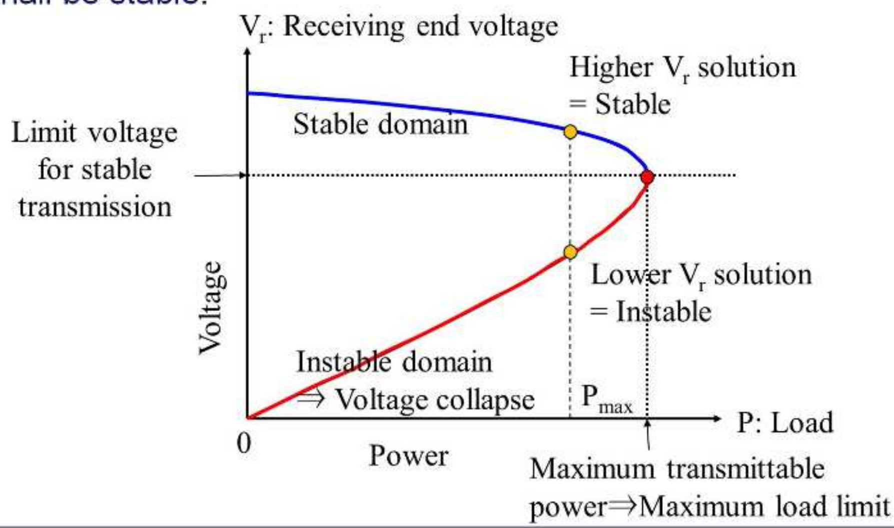
Impact on power system (4)

21

System stability

✓ The results of voltage stability study shall be stable.

- Voltage stability study examines whether the power grid voltage can be maintained stable during load changes or faults.
- In Cambodia, EDC conducts this study by using PSS/E. Therefore, the necessary data to conduct this study shall be shared with EDC and the results studied by EDC shall be stable.



Impact on power system (4)

System stability

(Reference) Grid Code 2.4

2.4 Studies for Transmission System Planning

2.4.1 The CTS should be evolved based on detailed power studies. Subject to Section 2.4.2, the NTL may conduct some or all of the following studies, as it decides to be necessary:

a. Power Flow Studies   Power flow studies are performed to evaluate the behavior of the transmission system for the existing and planned transmission facilities under forecasted maximum and minimum load conditions and to study the impact on the transmission system of the connection of new Generating Plant, loads or transmission lines. For new transmission lines, the load condition that produces maximum power flows through the existing and new lines are identified and evaluated.

b. Short Circuit Studies   Short circuit studies are performed to evaluate the effect on transmission system equipment of the connection of new Generating Plants, transmission lines and other facilities that result in increased fault duties for transmission system equipment. These studies identify the equipment that can be permanently damaged during fault condition due to current exceeding the design limit of the equipment.

c. Stability Studies

Transient stability studies are performed to verify the impact of the connection of new Generating Plants, transmission lines and substations and other changes in transmission circuit configurations on the ability of the Grid to seek a stable operating point following a transient disturbance. This study simulates the outage of critical grid facilities such as major lines and generating units. This study may be performed only when connection of major facilities are done.

Voltage stability studies are performed periodically to determine if the Grid is vulnerable to voltage collapse under heavy loading condition. A voltage collapse can proceed very rapidly if the ability of System's Reactive Power supply to support system voltages is exhausted. The study identifies safe Grid operating conditions where vulnerability to voltage collapse can be avoided until solutions are implemented.

Steady state oscillatory stability studies are performed to determine if the Grid is vulnerable to steady state stability problems. Such problems occur on heavily loaded systems, where small disturbances may cause steady-state oscillations that can lead to major disturbances.

d. Electromagnetic Transient Studies - Electromagnetic transient studies are performed to determine switching/ temporary over voltages which can affect equipment insulation, the thermal dissipation capacity or the clearing capacity of the protection devices.

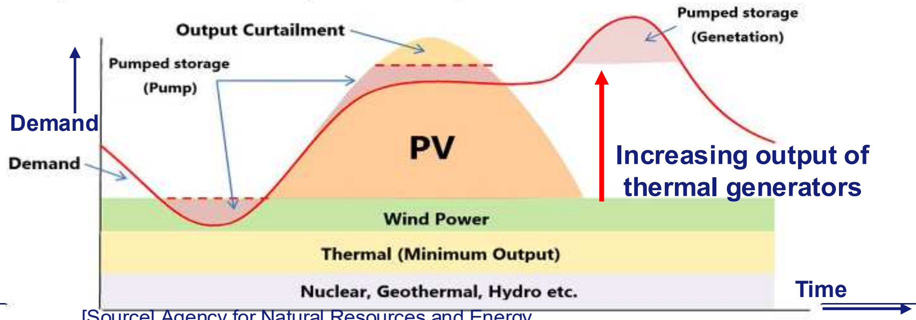
2.4.2 However, when directed by EAC, the NTL shall carry out the studies stated in the direction.

Impact on power system (5)

Power generation curtailment

✓ Generating units shall be capable of curtailing output to balance supply and demand. (For solar power plants and wind power plants, If needed, in Japan)

For frequency stability, the power generation must be balanced with the power demand. Solar and wind power cannot adjust their output because they don't have the governor. Hydro and thermal can adjust their output, but adjustable output range of thermal is about between 50-100% of rated output. Thermal power plants can't start operation rapidly, and so need to keep output over 50% for balancing. If the solar or wind power output increases, the thermal and hydro power output will reduced and/or pumping operation will carried out. If the supply of electricity still exceeds demand, solar and wind power output shall be curtailed.



[Source] Agency for Natural Resources and Energy

Countermeasure for accident (6)

Short circuit current

✓ The short circuit current shall be below the levels specified in Grid Code.

Since a large current flows during a short-circuit, the fault must be removed from the power grid as soon as possible. To remove it from the power grid, circuit breakers should be opened. And the short-circuit current should be less than the rated breaking current of the circuit breakers.
The amount of short-circuit current should be considered for the overall power system, and the capacity of existing circuit breakers at other locations in the power grid should also be checked.
In Cambodia, EDC studies them by using PSS/E. Therefore, the necessary data to study shall be shared with EDC and the results studied by EDC shall be below the levels specified in Grid Code.

(Reference) Grid Code 3.3.1

e. The short circuit current level at a point on the CTS shall be below the levels stated below:
   40 kA on the 230kV system
   31.5 kA on the 115kV system
   12.5 kA on the 22kV system

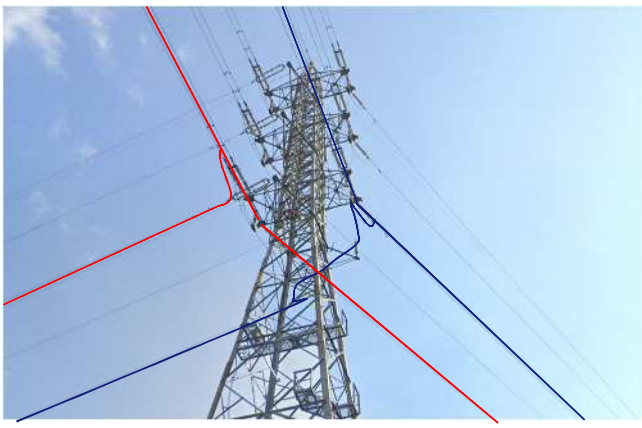
Transmission line (1)

Interconnection point with the power grid

✓ The interconnection point shall be the bus bar of a switching station, substation, or power plant.
✓ If it is lower cost, existing transmission line could be acceptable.

Power System of Cambodia

Modifying or rebuilding existing towers is expensive, but since towers are usually constructed over several hundred meter spans, interconnecting to existing transmission line is inexpensive when switching stations, substations, and power plants are far away.
(Interconnection may not be possible depending on such as the protection method and the capacity of transmission line.)



Branch tower

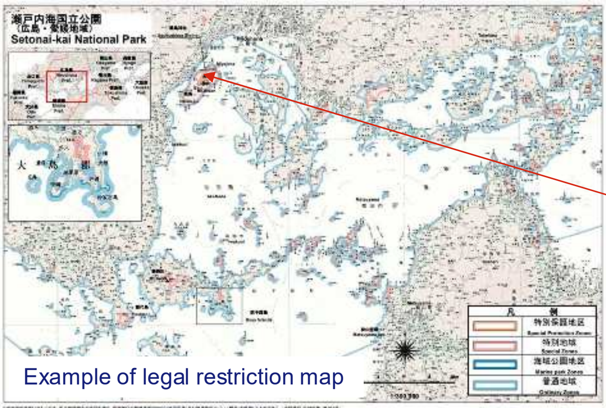
In most cases, the tower will need to be modified or rebuilt to interconnect to the existing transmission line.

Transmission line (2)

Route

- ✓ In the case of underground transmission lines, there shall be a reason(e.g. No land for a steel tower exists in the city) for using underground lines.
- ✓ The transmission line shall avoid areas with legal restrictions.

Construction cost of underground line is expensive.
(about 3 or more times higher than the overhead line in Japan)
Therefore, a reason must be given for using underground lines such as below.
･No land for a steel tower exists in the city.
･The route is crossing a railroad and can't outage that electricity.
･Tall structures cannot be built because they would interfere with flights near the airport.



Example of legal restriction map

http://www.env.go.jp/park/setonaikai/intro/files/area_3.pdf

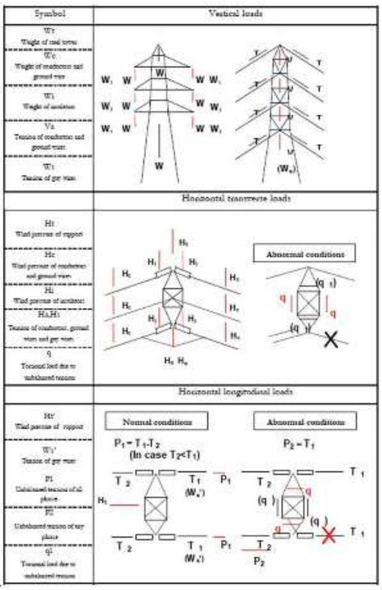
In Japan, in order to protect outstanding natural scenery, zones have been established to regulate various activities such as development.

https://www.pref.hiroshima.lg.jp/site/bunkazai/bunkazai-data-102010030.html

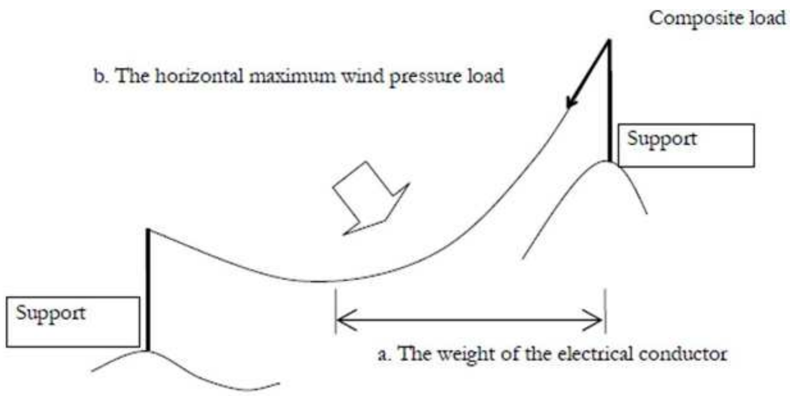
Transmission line (3)

Structures, Wire type

- ✓ Supporting structures of overhead lines shall be designed appropriate loads specified in GREPTS and SREPTS.
- ✓ Conductors shall have properties specified in GREPTS and SREPTS such as the tensile strength.



Loads of steel tower



Loads of conductors

Transmission line (3)

Structures, Wire type

(Reference) SREPTS Article 27, 31

2. Loads on Conductors for Overhead Transmission Lines

2.1 Assumed Load and Safety Factor

Overhead transmission conductors and overhead ground wires (excluding cables, the same applies hereafter in this clause) shall be installed with the tension to allow a safety factor specified in the following Item 2.1.2 when they are subject to the assumed load specified in the following Item 2.1.1 below at the average temperature in the area.

2.1.1 Assumed Load

The assumed load for the calculation of tension of overhead transmission conductors and overhead ground wires shall be the composite load of the vertical loads specified in the following item a and the horizontal loads specified in the following item b.

a. The vertical load shall be the weight of the electrical conductor.
b. The horizontal load shall be the horizontal maximum wind pressure load of the electrical conductor's vertical projected area.

2.1.2 Safety Factor

A safety factor of 2.5 or more shall be applied to the tensile strength (ultimate tensile strength; breaking strength) of overhead transmission conductors and overhead ground wires.

2.1.3 Reference Wind Velocity

Reference wind velocity to design overhead lines shall be as given in Table 13.

Table 13: Reference Wind Velocity

Yearly maximum of 10-minute average wind velocity (50 year return period)	32 m/sec

In the following circumstances, the above reference wind velocity can be changed.

a. When sufficient observed data have been accumulated.
b. When greater reliability is especially needed.
c. When the design is needed to cooperate with the designs of neighboring countries.

1. Basic Conditions

a. Supporting structures of overhead lines shall be designed, taking into account the following loads.

Table 16A: Type of Loads

Type of Load	Components of Load
Vertical loads	Weight of the supporting structure
	Weight of the conductors and the ground wires and the accessories supported by the supporting structure
	Weight of the insulator strings and the fittings supported by the supporting structure
	A vertical component of the maximum tension of the guy wires supporting the supporting structure, if any
Horizontal transverse loads	Wind pressure on the supporting structure under the maximum wind velocity
	Wind pressure on the conductors and the ground wires supported by the supporting structure under the maximum wind velocity
	Wind pressure on the insulator strings and the fittings supported by the supporting structure
	A horizontal transverse component of the maximum tension of the conductors and the ground wires supported by the supporting structure and the guy wires supporting the supporting structure, if any
Horizontal longitudinal loads	Wind pressure on the supporting structure under the maximum wind velocity
	A horizontal longitudinal component of the unbalanced maximum tension of the conductors and the ground wires supported by the supporting structure and the maximum tension of the guy wires supporting the supporting structure, if any

b. Supporting structures and foundations of overhead high-voltage lines shall be designed, taking the value of wide pressure based on the reference wind velocity prescribed in Article 27 of these SREPTS into consideration.

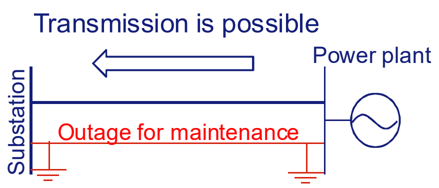
c. Supporting structures and foundations of overhead high-voltage lines shall be designed to withstand the maximum loads, taking appropriate safety factors into consideration.

d. In case overhead high-voltage lines are installed at places with the worst conditions, such as inside river areas, windy areas, and so on, the supporting structures and the foundations shall be designed to withstand such severe conditions.

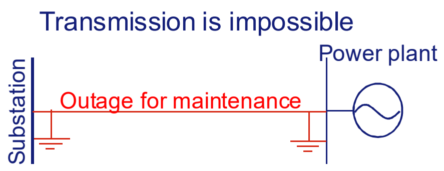
Transmission line (4)

Number of circuits

✓ In the case of a single line, generation curtailment during transmission line maintenance work shall be taken into account.



Case of 2 circuits



Case of 1 circuit

https://www.chuden-kogyo.co.jp/works/painting.html

Rust-proof painting of steel tower

Maintenance such as painting of tower arms, replacement of dampers, inspection of substation facilities, etc. requires power outages, and a single line cannot transmit power during such maintenance. For example, In Japan, steel towers are repainted every 15 years or so, depending on conditions and types of paint, and inspection of substation facilities such as transformer is conducted every 6 years.

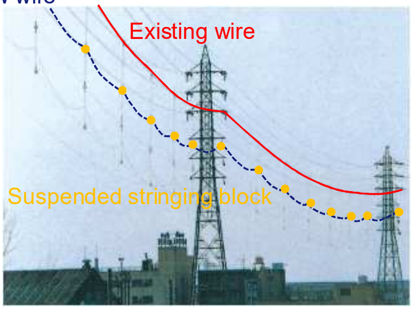
Transmission line (5)

Things crossing transmission lines route

- ✓ In the case of crossing large rivers, railroads, existing power lines, etc., the method of crossing shall be considered.

https://www.fepc.or.jp/enelog/archive/field/vol5.html

Transmission lines across the sea in Japan



https://www.kawakita.co.jp/business/safety/

Stringing conductors using stringing block

When crossing wide rivers or oceans, it is necessary to construct tall and strong towers or towers over water.
Special construction equipment is required for long span because of the high wire tension required.

When constructing new transmission lines over railroads, highways or existing transmission lines, etc., a method is needed to ensure that the wires do not come into contact with them during the construction.

Transmission line (6)

Matching of power generator and transmission line capacity

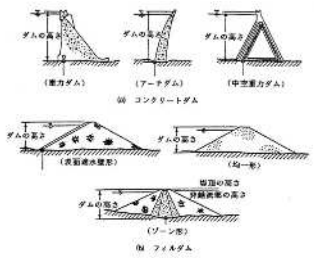
- ✓ Transmission line capacity shall be greater than power plant generation capacity.
- ✓ The type of wire shall be inexpensive, taking into account construction and O&M costs, transmission losses, and service life.

The capacity of the transmission line must be sufficient to transmit the power generated by the power plant.

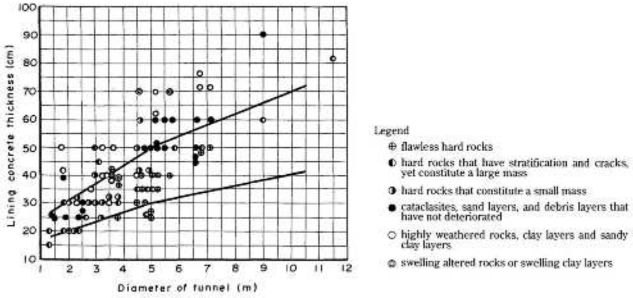
The use of larger capacity wire type generally increases the cost and the strength of the supporting structures due to the higher tension (This is because a larger cross-sectional area has larger capacity. The use of thicker wires increases weight and requires higher tension to reduce dip.).
On the other hand, transmission lines with high load factors may have higher transmission losses due to wire resistance, and therefore, a wire with low resistance may be cost effective.

No.	Evaluation Item	Check point for FS review	Remarks
〔Common〕		・Hydroelectric power generation facilities shall not cause harm or damage to residents in the vicinity or to items outside the power plant. ・Hydroelectric power generation facilities shall not adversely affect other electrical facilities electrically or magnetically. ・No significant impact on the power supply in the event of damage to the hydropower facilities. ・Hydroelectric power generation facilities shall not adversely affect the surrounding environment. ・Hydroelectric power generation facilities must be capable of stably generating the prescribed amount of electricity during the project period.	
1.	Survey Plan for Hydroelectric Power Plant		
1.1	Selection of the Type	・N/A	
1.2	Location Survey	・N/A	
1.3	Traffic	・A survey of the general transportation conditions (transportation method, transportation routes and transportation capacity) in the vicinity of the construction area and a survey of the power supply for the construction (capacity of existing transmission lines) shall have been conducted. ・Existing transportation facilities/method shall be checked, and expansion plan of existing transportation facilities or new construction of transportation facilities shall be considered if necessary.	
1.4	Topographic,　Geological Survey		
1.4.1	Topographic Survey	・In addition to the main civil engineering structures such as dams, waterways, power plants, etc., and reservoir areas, a topographic map should be prepared with a certain amount of leeway to cover construction roads, material extraction sites, and sites for temporary facilities. ・A cross-sectional survey of the river at the point of the outlet should be conducted and a discharge rating curve (H-Q curve) should be prepared.	・Generally, a scale of 1/5,000~1/10,000 is required for hydropower plan with small reservoirs, and a scale of 1/10,000~1/25,000 for hydropower plan with large reservoirs. ・Discharge rating curve (H-Q curve) are used to set the water level of outlet for electric power calculations. ・Gross head between the intake and outlet is an important factor in determining the power generation capacity and must be accurately determined. Measurement accuracy can be ensured by using level surveying and GPS based on existing benchmark.
1.4.2	Geological Survey	(Common) ・Appropriate geological investigations, permeability tests, and strength tests shall be conducted for the ground at the proposed location and around the reservoir, depending on the size of the dam and reservoir capacity. ・The possibility of landslides around the reservoir must be considered. In particular, narrow ridges and potential landslide areas should be investigated in detail. ・No geological serious problems that may affect the feasibility of the project should be identified. ・In the case of collecting aggregate for concrete or filling materials for fill dams, the distribution of materials in the area where the materials are to be collected, the amount of material that can be collected, and the physical and mechanical properties of the collected materials should be investigated. (For Concrete dam) ・The required performance of the foundation of the concrete dam shall be determined by in-situ testing.	・ Geological investigations during the FS phase include geological reconnaissance, aerial photo interpretation, geophysical surveys, and exploratory borings, and if necessary, exploratory pits may be excavated. ・The shear strength, internal friction angle, and deformation coefficient of concrete dams shall be determined by in-situ tests. ・Regarding conducting the in-situ tests, the geology of the dam foundation should be fully considered, and a representative point suitable for determining the foundation characteristics of the dam should be selected.
1.4.3	Earthquake	・Seismic studies have been conducted and the seismic loads assumed at the proposed site have been appropriately set.	・The main items to be investigated and studied regarding seismic study are as follows (1) Understanding of seismic tectonics around Cambodia (2) Understanding the active fault/active tectonics around the proposed site (3) Survey of historical earthquakes and earthquake damage (4) Seismic hazard assessment (5) Establishment of design seismic intensity (OBE/MCE)

1.5	Hydrology Survey	(For the study of power generation plans) ・Accuracy and duration of river flow data, which will serve as the basis for the study of the power generation plan, shall be sufficient. If sufficient flow data is not available, the river flow shall be calculated by an appropriate method. ・The flow data used in the power generation planning shall be daily flow data in the study a run-of-river type, and monthly flow data in the study of a reservoir type. ・In the case of a reservoir type, studies and analyses related to evaporation shall have been conducted. (For the study of the design flood) ・Design flood shall be established in a manner appropriate to the size of the dam or reservoir. ・Design flood are appropriately set based on adequate and appropriate hydro-meteorological investigations and analyses. (For the study of sediment volume) ・Analysis of sediment volume has been conducted, and the estimated sediment volume and its impact on power generation has been properly calculated and evaluated.	(For the study of power generation plans) ・River water discharge is estimated as the product of the cross-sectional area of flowing water and the average velocity, both of which need to be measured in the discharge measurement. There are several methods for measuring river velocity, such as flow current meter, float measurement, and weir type flow meter. ・The flow data that forms the basis for power generation planning should be at least 10 years, and preferably 30 years. ・The following methods are available for converting and calculating river discharge, and should be selected according to the type and duration of the existing (available) hydrologic data used for flow calculation. - Method based on the catchment area ratio conversion - Method based on catchment area ratio conversion taking into account of rainfall - Methods using runoff models (e.g. tank model) - Method based on correlation between flow and rainfall (For the study of the design flood) ・Design flood can be a probable maximum flood (PMF) or a probability flood, depending on the size of the dam or reservoir. ・The design flood discharge is set based on the dam classification described in SREPTS_Article-21.
1.6	Energy Generation Calculation		
1.6.1	Energy Generation of Run-of-river type	・The calculation method of maximum output and electric energy shall be appropriate.	・Review the validity of the gross head, the calculation method of the head loss, the efficiency curves of the turbine/generator, and the outage rate. ・On estimating the head loss, one method is to add 2~3% of the total head as other losses to the losses due to the waterway. A simpler method is to estimate 7~9% of the gross head as the total head loss. ・Usually, the run-of-river type is used as the base power supply.
1.6.2	Energy Generation of Reservoir type	・The calculation method of maximum output and electric energy shall be appropriate. ・In the case of a reservoir type, the reservoir operation (rule curve) shall be efficient, taking into account the changes in flow during the wet and dry seasons. ・The power generation operation must meet the power demand of the grid.	・Review the validity of the calculation method of gross head, head loss, efficiency curves of the turbines/generators, annual reservoir operation, and outage rate. ・In Cambodia, river flow changes significantly between wet and dry seasons, and if appropriate reservoir operation is not carried out, power generation may not be possible during the dry season. ・In general, the reservoir type is mainly used for peak power supply. However, it should be noted that in hydropower-dominated systems, even reservoir systems may be used as a base power supply.
2.	Basic Design of Each Structures		
2.1	Intake facilities		
2.1.1	Weir/Dam	(Common) ・Necessary freeboard (margin height) shall be secured according to the type of dam, presence or absence of flood discharge facilities, and wave height in the reservoir. ・The reservoir should not adversely affect the surrounding ground. ・There is no risk of flooding of houses, etc. in the upstream area due to the rise in water level caused by the construction of the dam and sand deposition. If there is a risk of flooding, appropriate measures shall be taken. ・The dam water level (such as N.H.W.L., F.W.L., and L.W.L.) and the height of the non-overflow portion of the dam body shall be set appropriately. ・The anticipated loads (including earthquake inertia forces) to be considered in the design of the dam shall be appropriately calculated. ・The dam foundation shall have the necessary shear strength and shall not cause	(Common) ・In the FS phase, the stability of the dam should be evaluated by static analysis using the seismic intensity method. ・The concept of N.H.W.L., F.W.L., and L.W.L. settings is described in SREPTS_Article-22. ・The concept of the height of the non-overflow section of the dam body is as described in SREPTS_Article-23. ・The loads to be considered in the design of the dam body are as described in SREPTS_Article-24. (Concrete gravity dam) ・The concept of structural stability of concrete gravity dams is described in

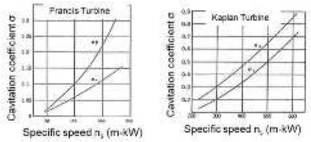
		significant settlement, cracking, slip failure, erosion, etc. ・Appropriate measures (grouting, drainage systems, etc.) shall be implemented in the dam foundation to prevent increased uplift pressure and significant leakage and seepage failures. ・The reservoir does not cause harmful leaks or landslides that could damage settled are, farms, roads, etc. Water leakage prevention and/or landslide prevention measures shall be taken as necessary. ・The reservoir is not expected to cause deterioration of water quality in or downstream of the reservoir, such as cold water and turbid water problems. If deterioration of water quality in or downstream of the reservoir is expected, appropriate measures such as removal and purification of pollutants around the reservoir and/or mitigation measure must be planned in accordance with the EIA report. ・When installing a facility that discharges the amount of water necessary for water utilization or environmental preservation into a reduced water flow area, the facility must be capable of discharging the necessary amount of water and must be stable against vibration during partial discharge. (For concrete gravity dam) ・The structural stability of the concrete gravity dam shall be ensured. ・The dam and its foundation (including the dam foundation rock and the contact surface between the dam and the bedrock) must be watertight and strong enough to support the anticipated loads. (For fill dam) ・The main body of the fill dam shall be designed to be safe against failure due to slips and seepage. ・The fill material (impervious material, semi-permeable material, permeable material) shall have the specified mechanical properties. ・The dam foundation (including the dam foundation bedrock and the contact surface between the dam body and the bedrock) must have the specified performance and be safe against failure caused by sliding, slipping, or seepage flow. ・The technical requirements applicable to each dam type (uniform type, zoned type, and surface impervious type) must be satisfied.	SREPTS_Article-30. The outline is as follows (1) Vertical tensile stresses shall not occur on the upstream face of the embankment. (2) Safe against shear-induced sliding at and near the joint between the embankment and the foundation rock. (3) Stresses in the embankment should not exceed the allowable stress. ・As for the treatment method of the foundation, replacement concrete is planned when the objective is to improve the strength and deformation characteristics of the weak areas. Foundation grouting is generally used to improve the deformability and imperviousness near the contact area between the embankment and the foundation soil. ・The concept of allowable stresses in concrete is described in SREPTS_Article-29. (Weir) ・When fish, etc. that need to be protected are identified, a fish-path, such as stairway type, slope type, elevator type, or other may be installed. (Fill dam) ・As with slope stability, stability against slip is generally analyzed using the simple circular-slip surface method. ・The slope, crest width, and thickness of each zone of a zoned type dam are determined in consideration of safety against slip and seepage flow. In general, the slope of a uniform type dam is less steep than that of a zoned type dam. ・The treatment method of the foundation sis the same as that for concrete dams. ・The mechanical properties required for each fill material are described in SREPTS_Article-34. ・Mechanical characteristic requirements for fill dam foundations are described in SREPTS_Article-35. ・The concept of stability of fill dams is as described in SREPTS_Article-36. ・Technical requirements applicable to each dam type (uniform type, zoned type, and surface sealed wall fil dam type) are given in SREPTS_Article-38.  Source: 水力開発ガイドマニュアル（第 1 分冊 一般水力・揚水式水力発電）（独立行政法人　国際協力機構（JICA)、電源開発株式会社、株式会社開発設計コンサルタント　2011.3）, p11-3
2.1.2	Discharge equipment	(Common) ・Flood discharges facilities capable of safely and reliably discharging design flood and lower flows shall be installed. ・The flood discharge does not affect the stability of the dam. ・The discharge water from the dam must be adequately reduced so that it does not adversely affect the dam itself or the downstream areas. ・Appropriate measures are taken to ensure that water is discharged as necessary for water use and conservation of the river environment in the downstream areas of the dam or water intake.	・Sediment control measures (sediment bypass facilities, sand storage dams, flushing facilities, etc.) may be installed or excavation and dredging may be performed in order to reduce sediment capacity, lower dam height, and semi-permanent use of the dam. ・The structure must be designed to prevent scour and erosion downstream of the dam and damage to adjacent structures caused by high-speed water flowing down the flood discharge. ・The flood discharge of a dam is classified into 3 types according to its relationship with the embankment: - Attached type: Discharge facilities are installed on the embankment of a concrete

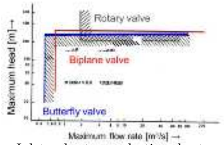
		・Discharge facilities for water utilization, flood control, and water management must be constructed so that they will not be rendered unusable by sedimentation or other causes. (For fill dam) ・The dam body must not be planned to have a flood discharge or a channel that would cause cracks in the interior of the dam. ・No spillway is planned to be installed in the dam body.	dam - Adjacent type: Discharge facilities are installed adjacent to the embankment of a fill dam - Separated type: Discharge facilities are installed away from the embankment. ・In the case of the adjacent type and the separated type flood discharge, the flow velocity in the channel should be kept below 3~4 m/s to prevent sediment inflow and sediment transport in the channel. ・It is recommended that a discharge system be installed to lower the water level in the reservoir during inspections, repairs, and emergencies. If a discharge facility for other purposes already has this function, it is not necessary to install a discharge facility.
2.1.3	Intake	・The Intake shall be safe against collapse of the surrounding mountain slope, soil and rocks. ・The channel must be able to properly take water from rivers, reservoir, regulating reservoir. ・The structure and location shall be such that sediment, debris, dust, etc. cannot flow in. ・The structure must be safe against anticipated loads. ・Sluice gates or watertight panels are to be installed to allow for inspection and repair of the waterway. ・If the water intake is connected to a pressure conduit, conduit, or hydraulic steel pipe, it must be located and structured to prevent air from entering the waterway, and must be capable of taking water at any water level within the range of the water depth to be used.	(Common) ・The intake shall be designed to satisfy the following conditions - The intake should always be capable of taking in the planned amount of water (the amount of inflow water can be adjusted as necessary). - No vortex generation or air entrainment during water intake. - No inflow of sediment, driftwood, branches, or leaves during water intake. - No damage due to floods, landslides, etc. - Not be affected by sedimentation caused by the dam ・Generally, the velocity of inflow at the intake is designed approximately 0.3~1.0 m/s. (For non-pressure type (open channel type)) ・Generally, the sill level of the intake is about 1 m higher than the top of the sediment discharge of the intake dam to prevent sediment from flowing into the channel. In some cases, a submerged weir is installed in front of the intake to prevent sediment from flowing into the channel. ・A screen with a bar of 5cm to 15 cm spacing is installed in front of the intake. (For pressure type (conduit type)) ・The water depth at the pressure channel inlet should be 1.5~2 times the diameter of the conduit to prevent air entrainment. ・A screen should be provided in front of the intake, and the shape of the inlet should be bell-mouthed to reduce the head loss. ・The height of the intake sill should be determined in consideration of the expected sediment surface.
2.1.4	Settling basin	・The structure shall be capable of settling suspended sand that may cause damage to downstream channels and turbines, and shall allow for easy flow of settled and deposited sediment. ・The structure must be safe against collapse of surrounding mountain slope, soil and rocks. ・Stable against anticipated loads.	・The sedimentation basin should be long enough for fine sand to reach the bottom at the end of the sedimentation basin while settling from the water surface. In many cases, the length of the sedimentation basin is at least twice the calculated value, taking into account the effects of vortex, sub currents, etc. ・The depth of the sedimentation basin is designed to be somewhat deeper than the conduit, and the width of the channel is often set so that the average velocity is around 0.3 m/s. ・The bottom of the sedimentation basin is sloped and a sediment discharge gate is installed at the end of the basin so that sediment can be easily flushed by water energy.
2.2	Headrace facilities		
2.2.1	Headrace (water way)	(Common) ・The waterway shall not be damaged by flooding or landslides. ・Construction of the waterway shall not cause leakage, landslides, or other adverse effects. In the event of water leakage from within the channel, it must not affect the surrounding ground or structures.	(For open channel and culvert channel) ・Generally, the flow velocity is about 2~3m/s and the channel slope is 1/1,000~2,000 for open channel and 1/500~1,500 for culverts. ・In the case of culverts, the thickness of concrete is approximately 20~30cm.

		・Necessary countermeasures shall be taken when passing through areas with weak geological conditions. ・The waterway shall be safe against anticipated loads. ・In case of possible settlement of the surrounding area (due to water leakage from the channel), lining or other measures shall be provided. ・The channel must be able to safely and reliably control the designed flow rate and be stable against expected hydraulic phenomena. ・Sediment deposited in the channel shall not cause damage to downstream channels or turbines. (For open channel) ・There should be no danger of landslides near the waterway route. (For culvert channel) ・The structure must be safe against external pressure (groundwater pressure, earth pressure, grouting pressure, etc.). (For pressure type (conduit type)) ・The structure shall be safe against external pressure (ground pressure, earth pressure, grouting pressure, etc.) and internal pressure (hydrostatic pressure, water hammer pressure, surging pressure, etc.). ・The headrace shall be installed below the hydraulic gradient line of the lowest water level in the intake system and the surge tank.	(For pressure type (conduit type)) ・In the case of general hydro power, it is often around 2~4m/s. ・The following figure shows the actual inner cross-section width and roll thickness in pressure channels.  Source: 水力開発ガイドマニュアル（第 **1** 分冊 一般水力・揚水式水力発電）（独立行政法人　国際協力機構（JICA)、電源開発株式会社、株式会社開発設計コンサルタント　2011.3）, p11-32
2.2.2	Head tank/Surge tank	(Common) ・Be safe for the anticipated loads. (For head tank) ・The capacity must be sufficient to prevent air from entering the hydraulic iron pipe during normal operation and load surges. ・It must have a spillway that can safely discharge the maximum amount of water used in the event of a full load shutdown. However, this does not apply if the facilities are capable of safely discharging water by a method other than a spillway. ・The water level rise at the time of overflow from the head tank must not adversely affect the upstream channel/culvert. ・The discharge of excess water shall not adversely affect the surrounding facilities or rivers. ・It must be designed to prevent dust and floating sand from flowing into the penstock, and must be capable of easily discharging accumulated sand. ・It must have the necessary surface area to mitigate the effects of water surface fluctuations and wave action during normal operation. (For surge tank) ・The structure shall be such that water level fluctuations in the surge tank do not increase and equilibrium is achieved in a short period of time (damping condition). ・The water level in the surge tank (up-surge) shall not overflow at the time of full load shutdown. However, this does not apply if facilities are installed to safely divert surplus water (full-load shutdown condition). ・The water level in the surge tank (down-surge) shall not fall below the top of the waterway and hydraulic iron pipe during a half-load surge (half-load surge condition).	(For head tank) ・In general, the capacity of the head tank should be such that it can operate for 1~2 minutes at maximum output without refilling from the headrace. ・The head tank should be designed with the following points in mind - Avoid sudden cross-sectional changes in order to prevent vortexes in the intake water flowing into the head tank. - The water depth at the mouth of penstock should be at least twice the inner diameter of the hydraulic pipe to prevent air from being conducted into the pipe due to vortex generation. ・Generally, the flow velocity in the head tank should be designed to be about 0.4 to 0.6 m/s. (For surge tank) ・In the case of AFC (Automatic Frequency Control)/ALC (Automatic load Control) operation in hydro power plants, resonance conditions may occur in the water surface vibration, and this should be taken into consideration during the detail design process.
2.2.3	Head tank Spillway (Excess water spillway)	・It shall be stable under the anticipated loads. ・The structure shall be designed to prevent slides and to prevent water tightness. ・An energy dissipater shall be installed at the end of the channel to ensure safe discharge	・The topography, geology, and surrounding environmental conditions from the head tank to the river should be thoroughly investigated when selecting the route and deciding on the type of structure for the spillway.

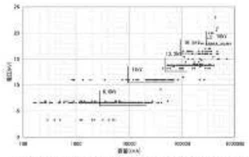
		of water. ・When excess water is discharged directly into a river, the structure must prevent excessive scouring of the river bed. ・In the case of a pipeline, ventilation holes shall be installed at bends.	・In the case of Pelton type turbines, it may be possible to omit the excess water spillway by slowly closing the intake gate and discharging the deflector.
2.2.4	Penstock	(Common) ・The penstock shall be safe under the anticipated loads for each type of penstocks (exposed type, bedrock embedded type, and soil embedded types). The thickness of the penstock shall be set in consideration of the required load. ・The top of the penstock shall be set lower than the hydraulic gradient line when the water level in the head tank or surge tank is at its lowest. ・The penstock must be safe and stable against vibration, buckling, and corrosion. ・The hydraulic pipes must not cause serious leakage. (For exposed type) ・The route shall be planned to be unaffected by natural disasters such as landslides. ・In the case of an exposed pipe, anchor blocks and concrete saddles shall be installed to support the penstock. Anchor blocks and concrete saddles shall be stable under the anticipated loads. ・Concrete saddles shall be able to move smoothly according to the expansion and contraction of the water hydraulic pipe. (For embedded type) ・It shall be planned on a route with sufficient soil cover and good geological quality.	(Common) ・In many cases, the flow velocity in the pipe is about 2~4 m/s. (For exposed type) ・When steel pipes are used in penstock, anchor blocks are installed at 50~100 m intervals. ・The straight sections between anchor blocks are supported by ring girders or concrete saddles, with ring girders at 18m intervals and concrete saddles at 6m intervals. (For embedded type) ・There are two types of shafts, inclined shafts and vertical shafts. In general, inclined shafts have a slope of 45° or more to facilitate the fall of excavation soil/rocks during construction.
2.3	Powerhouse		
2.3.1	Types of Powerhouse	・N/A	
2.3.2	Location of Powerhouse	・No damage from flooding or landslides.	・The following are the considerations on determining the location of the power plant - The foundation ground must be favorable - Not be damaged during floods and not be impinged by water currents - No risk of landslides - Convenient location of outdoor switchyards and power lines - Easy transportation of construction materials and equipment, and future maintenance
2.3.3	Design of Powerhouse	・The power plant building shall be stable against expected loads. ・Structures around the turbine shall be stable against vibration. ・Space for overhaul and repair of water turbines, generators, etc. shall be provided in the powerhouse.	・The support structure for generators with large loads is often a barrel type with a vertical thick-walled cylindrical structure for large power plants, or a two-floor type with a beam structure for small power plants.
2.4	Tailrace	・Layout and structure shall be such that it will not be damaged by river water or drifted riverbed. ・Be safe under the anticipated loads. ・Leakage from tailrace shall not affect the surrounding ground and structures. ・If collapse of tailrace occur, it will not have a significant adverse effect on the downstream area. ・If settlement of the surrounding area (due to leakage from tailrace) is anticipated, lining or other measures shall be provided.	・Items to be considered when determining the location of the water discharge outlet are as follows - There is no risk of obstruction of the outlet due to sediment accumulation in the stream - Location where there is no direct conflict with the flood flow or its tributaries - No risk of damage from flooding - The riverbed does not fluctuate due to flooding and the water surface does not rise significantly during flooding. - No narrowing of the river width near the downstream of the outlet
3.	Basic design of hydroelectric equipment		
3.1	Water turbine-related facilities		

<table>
<tr><td>3.1.1</td><td>Design of water turbine</td><td>・The items necessary for water turbine design shall be selected.
・The materials such as river flow conditions shall be calculated appropriately.
・The number and type of turbines shall be selected according to the effective head and the amount of water used.
・The turbine output shall be calculated in consideration of the turbine efficiency.
・The optimum water turbine suction height shall be set.</td><td>(Turbine type)
・Select applicable water turbines in the water turbine type selection chart.
・If multiple turbine types can be selected, the annual amount of electricity generated by each type of turbine shall be calculated, and the economic efficiency, maintainability, and other factors shall be comprehensively considered before selection.

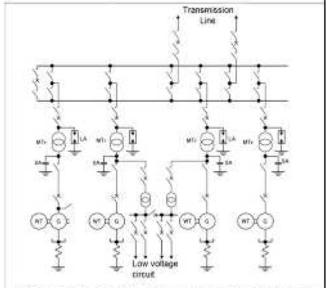
Water turbine type selection
Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.14
(Turbine output, Turbine efficiency)
・Turbine output
$Pt = 9.8 \times Qmax \times He \times \eta t$
Pt :Maximum output of turbine at effective head [kW]
Qmax :Maximum water consumption at effective head [m^3/sec]
He :Effective head [m]
η_t :Turbine efficiency
<table>
<tr><td>(Initial value of turbine efficiency)</td><td></td></tr>
<tr><td>Pelton Turbine</td><td>:0.88～0.92</td></tr>
<tr><td>Francis Turbine</td><td>:0.88～0.92</td></tr>
<tr><td>Diagonal Flow Turbine</td><td>:0.88～0.92</td></tr>
<tr><td>Propeller Turbine</td><td>:0.80～0.85</td></tr>
</table>
(Rotation speed and specific speed)
・Specific speed
$n_s = n \times \frac{P_t^{1/2}}{H_e^{5/4}}$
n_s :Specific Speed [m-kW]
n :Rotational Speed [min^{-1}]
H_e :Head [m]
P_t :Maximum output of turbine at effective head [kW]
<table>
<tr><th>Type of Turbine</th><th colspan="2">Upper limit and applicable range of specific speed</th></tr>
<tr><td>Pelton Turbine</td><td>$n_s \leqq \frac{4,300}{H_e+200}+14$</td><td>8～25</td></tr>
<tr><td>Cross Flow Turbine</td><td>$n_s \leqq \frac{4,000}{H_e+20}+10$</td><td>90～110</td></tr>
<tr><td>Francis Turbine</td><td>$n_s \leqq \frac{21,000}{H_e+30}+40$</td><td>100～350</td></tr>
<tr><td>Diagonal Flow Turbine</td><td>$n_s \leqq \frac{21,000}{H_e+20}+40$</td><td>100～350</td></tr>
<tr><td>Propeller Turbine Kaplan Turbine</td><td>$n_s \leqq \frac{21,000}{H_e+16}+50$</td><td>200～900</td></tr>
</table>
(Water turbine suction height)
・Water turbine suction height
$Hs = Ha - Hv - \sigma H$
Hs :Water turbine suction height [m]
Ha :Atmospheric pressure [mH_2O]
Hv :Saturated vapor pressure [mH_2O]
σ :Cavitation coefficient
H :Effective head [m]


Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.26</td></tr>
<tr><td>3.1.2</td><td>Selection of inlet valve</td><td>・The inlet valve shall be selected according to the capacity of the power plant.
・An inlet valve or other device shall be installed to shut off incoming water.</td><td>(Inlet valve type)
・Select applicable inlet valves in the inlet valve type selection chart.


Inlet valve type selection chart
(Function of inlet valve)
・Check for the ability to shut off incoming water.
・If inlet valve doesn't have the ability to shut off incoming water, ensure that one of the following is satisfied.
1. Water turbine with guide vanes of water pressure self-closing, spring closing, or counter weight closing type, or with emergency pressure oil tanks or emergency servomotors.
2. Gate valve with emergency closing device of water intake, head tank or surge tank.
3. The rotating parts are structurally safe until the runaway speed rotating turbine can be stopped, and the discharge water to downstream during this period does not any danger to person or facilities.</td></tr>
<tr><td>3.1.3</td><td>Design of turbine accessories</td><td>・The appurtenant equipment shall be designed in consideration of the size and operation of the power plant.</td><td>(Turbine accessories)
・Type of turbine accessories
Governor, Pressure oil device, Lubricating equipment for bearings, Water supply device, Drainage device, Air compressor, etc.
・Considerations for selection
Confirm that the design takes into account the risk to the surrounding environment and economic efficiency. (water less, oil less, omission of equipment, prevention of oil spillage to the outdoors, etc.)</td></tr>
<tr><td>3.2</td><td colspan="3">Generator-related facilities</td></tr>
</table>

<table>
<tr><td>3.2.1</td><td>Design of generator</td><td>・The type of generator and installation method shall be selected according to the scale of the power plant.
・The generator output, rated power factor, and generator capacity shall be appropriate.
・The generator voltage shall be selected to match the generator capacity.</td><td>(Type of generator, Installation method)
・Type of generator
Synchronous generator：Mainly used
Induction generator：Adopted in consideration of economy when not operating independently with a small capacity
・Installation method
Although installation methods are selected by generator capacity based on past experience, selection should be made based on a comprehensive evaluation of economic efficiency, maintainability and other factors.
Horizontal shaft: under 10MW
Vertical shaft　：over 10MW (type: Single floor barrel type, Two-floor type)
(Generator output, efficiency, rated power factor and capacity)
・Generator output
$Pg = Pt \times \eta t$
Pg :Generation Output [kW]
Pt :Maximum output of turbine[kW]
ηg : Generator efficiency
・Generator capacity
$Pg' = Pg / Pf$
Pg' :Generation Capacity [kVA]
Pg :Generation Output [kW]
Pf :Generator rated power factor
Normally, the rated power factor is between 98 and 85%.
(Generator voltage, Generator current)
・The generator voltage is generally selected as follows for the capacity of the generator.
<table><tr><th>Generation Capacity [MVA]</th><th>Generator voltage [V]</th></tr><tr><td>Less than 3</td><td>400</td></tr><tr><td>3 – 10</td><td>6,600</td></tr><tr><td>10 – 50</td><td>11,000</td></tr><tr><td>50 – 100</td><td>13,200</td></tr><tr><td>100 – 300</td><td>16,500</td></tr><tr><td>More than 300</td><td>18,000</td></tr></table>

Relationship between generator rated capacity and rated voltage
Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.36
・Generator current
$Is = Pg' / \sqrt{3} / E$
Is :Generator current [A]
Pg' :Generator rated capacity [kVA]
E :Generator rated voltage [kV]</td></tr>
<tr><td>3.2.2</td><td>Design of exciter</td><td>・The exciter shall be selected according to the power plant operation method and generator capacity.
・The exciter shall equip necessary functions.</td><td>(Type of exciter)
・DC excitation type(this has not been adopted in recent years)
・Thyristor excitation type(this is used in power plants that require responsiveness such as system frequency adjustment)
・Brushless excitation type(this is used for small and medium-sized machines)
(Function of exciter)
・The following functions can be added to exciter depending on the equipment type and operation method, and should be selected.
Automatic Voltage Regulator (AVR)
Automatic power factor regulator (APFR)
Automatic reactive power regulator(AQR)
Load current compensation(LCC)
Over excitation limiter (OEL)
Under excitation limiter(UEL)
V/f limiter(V/f)
Power system stabilizer(PSS)</td></tr>
<tr><td>3.3</td><td colspan="3">Main circuit-related facilities</td></tr>
<tr><td>3.3.1</td><td>Main circuit connection system</td><td>・The main circuit configuration and power plant layout shall be according to the importance of the power plant.</td><td>(Main circuit configuration)
The main circuit connection of a hydro power plant shall be determined by comprehensively judging from the reliability, economic efficiency and technical aspects of the power plant in consideration of the following.
- Capacity and number of generators</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>- Number of transmission line lines and withdrawal method
- Constraints such as power plant space
- How to receive power from the facility
- Presence or absence of distribution lines
- Transport conditions
- Power outage range in the event of an accident
- Safety and ease of failure repair and operation maintenance, etc.

・One transmission line or Two transmission lines not double bus-bar
These are common configurations. Depending on the number of turbine generators and the importance of the power plant, two transmission lines will be adopted.
・Two transmission Lines with double bus bar
This will be adopted to a large capacity power plant such as a pumped storage power plant, which is an important power plant because multiple turbine generators are connected.


4 Generators, 2 Transmission Lines, Double bus bar
Source: Hydroelectric Development Guide Manual, JICA(2011), Chapter 12 p.41
(Power plant layout)
Check the equipment layout from the plan view and cross-sectional view of the power plant.</td></tr>
<tr><td>3.3.2</td><td>Composition of electric equipment</td><td>・The capacity of the transformer shall be consistent with the rated capacity of the generator.
・Does the house transformer capacity match the capacity of the power consumption in the power plant.
・An appropriate circuit breaker shall be selected.
・Water turbines, generators and other protective devices shall be properly selected.</td><td>(Main transformer/ house transformer)
Check that the rated voltage, rated current, capacity, etc. are consistent with other equipment.

(Circuit breaker)
Choose a circuit breaker type by rated Voltage. Check its capacity that can Cut off a short circuit and ground Fault current.

Circuit breaker type by rated voltage (Japanese case)<table><tr><th rowspan="2">Insulation Type</th><th colspan="8">Rated Voltage [kV]</th></tr><tr><th>7.2</th><th>12</th><th>24</th><th>36</th><th>84</th><th>168</th><th>300</th><th>500</th></tr><tr><td>Oil</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td></td><td></td><td></td></tr><tr><td>Gas</td><td></td><td></td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td></tr><tr><td>Vacuum</td><td>○</td><td>○</td><td>○</td><td>○</td><td>○</td><td></td><td></td><td></td></tr></table>
(Disconnection switch, instrument transformer, lightning arrester)
Check that it is installed where it is necessary. The layout shall be referred to the main circuit configuration.

(Switch gear selection)
Check that the required number of switch gears is secured.
Check that space is available for placement and maintenance.</td></tr>
<tr><td>3.3.3</td><td>operation・control・protective device</td><td>・The operation control method shall be selected according to the type of the power plant.</td><td>(Operation control method)
・The operation control method is selected from the following
- One-person control type
- Remote supervisory control system
- Fully automatic control type
(Protective device)
・Check that the power plant protection devices are installed in each of the following categories.
- Generation protection
- Transformer protection
- Bus bar protection</td></tr>
</table>

			- Transmission line protection
3.3.4	DC power supply system	・The capacity of the DC power supply system required for control shall be available.	(DC power supply) ・Check that the capacity of the charging device (rectifier) takes into account the maximum load current and the battery charging current. ・Select the capacity of the storage battery in consideration of the discharge time and discharge current.
3.4	Other equipment		
3.4.1	Design of crane	・The rated load, lifting height, and movable range of the crane shall be appropriate.	(Crane) ・Rated load Main crane: Determine from the maximum weight (generally the generator rotor weight) to be lifted by the main crane. Supplementary crane or hoist: This is for vertical work of equipment and hanging of small items. The rated load of this should be determined from the weight of the lifted parts, frequency, workability, and economy. ・Lifting height Main crane: Check that the turbine casing can be hung and the hook can reach the bottom floor. Supplementary crane or hoist: Check that the hook can reach the bottom floor. ・Movable range of the crane Check that the running direction is the longitudinal direction of the building and that the movable range is taken into consideration.
3.4.2	Design of ground wire	・The design value of grounding resistance shall be less than or equal to the target value.	(Earthing) ・The target value of grounding resistance is decided by the electrical safety standard of the country, but it is roughly the following value. - Power system of direct grounding: less than 1 ohm - Others (resistance grounding etc.): 10 ohm
3.4.3	Design of emergency power supply system	・An emergency power generation facility with an installed capacity according to the operation shall be installed.	(Emergency electric supply unit) ・Select from below - Diesel generator - Gas turbine generator ・Capacity - Emergency power generator is installed to start the water turbine generator even during a power outage. - An emergency generator will be installed so that the power plant will not be submerged or the hydraulic pressure, air pressure, DC voltage for control, etc. will not drop due to a long-term power outage.
5.	Determination of Optimum Scale	・N/A	
6.	Other	・The project shall comply with the laws and regulations governing the protection and preservation of the environment in Cambodia. ・Facilities related to hydropower generation (including maintenance facilities and temporary facilities for construction) shall be stable against expected loads and protected from damage caused by landslides and floods. ・Fluctuations in river levels caused by the discharge of power generation should not cause damage to downstream areas. If there is a risk of damage to downstream areas due to sudden fluctuations in water levels caused by the discharge of power generation, appropriate measures must be taken.	

(Glossary)

- SREPTS：SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)

(Remarks)

- Article No. is as stated in the SREPTS.

(Reference)

- SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)
- EXPLANATION SHEET FOR SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)
- 水力開発ガイドマニュアル（第 1 分冊 一般水力・揚水式水力発電）(独立行政法人　国際協力機構（JICA)、電源開発株式会社、株式会社開発設計コンサルタント　2011.3)

IPP_Feasibility Study Check List (PV)

＊ In the report presented by the IPP, it is necessary to check the following items are appropriate or not.

＊ Main guidelines in Japan: 2019 solar power generation business guide, 2019 ground-based solar power generation system design guidelines, Interpretation of technical standards for electrical equipment

Evaluation item	Specific elements	Remarks
1. Site Assessment		
1.1 Site Location	Is the site location appropriate for PV installation? (Compared to the case of flat and plane land, it is necessary to consider the influence when it is on slope in the mountains, or sea breeze close to the sea, etc.)	・In Japan, based on the guidelines*, we do preliminary surveys (material surveys / field surveys) for the terrain condition of installing PV equipment, such as soft ground, reclaimed land, embankment, mountains, hills, cliffs, steep slopes etc. ・In addition, we are confirming whether or not the site has been specified as a landslide warning area by using goverment publishing. ・If site locasion is the landslide warning area, it is necessary to confirm that the foundation design has reasonable consideration.
1.2 Site Boundary	Are not there any private houses and/or factories around the site location? (It should be avoid the influence of shade from the building. Also, if it is close to a residential area, it is necessary to check whether there is a complaint due to the reflection of the panel. And if it is close to the factory, it is necessary to check whether the contaminated dusts comes in.)	・At the Fukuyama Solar Power Plant, the experience of cleaning the panel surface by chemical cleaning occurred because the power generation efficiency decreased due to the adhesion of flying objects (mainly iron and calcium) from neighboring factories to the panel surface. ・If the PV installation point is close to a factory, etc., it is necessary to confirm that special consideration has been given.
1.3 Site Connectivity	Is easy road access to the site location? (It is necessary to confirm the access conditions to carry in and out of sand soil to the site, and such as transportation of equipment under the construction, also operation and maintenance is ease or not.)	・A road is required for transport vehicles such as panels, PCS, transformers, and heavy construction equipment at the construction stage.
1.4 Geography	Is the ground condition suitable for PV installation? (Because the basic design changes depending on whether the ground condition is hard or soft, it is necessary to check the ground conditions before construction.)	・In Japan, ground surveys and soil tests are conducted, but it depend on the results of the 1.1 preliminary survey. ・There are some method such as standard penetration test, simple dynamic cone penetration test, Swedish sounding test (SWS test), etc. If the test result is soft ground, it is necessary to consider the basic design such as improvement of soil condition and/or increase pile driving amount.
1.5 Natural disaster risks		
1.5.1 Seismic	Is a low probability of an earthquake? (It is necessary to confirm whether the risk of equipment damage due to the occurrence of an earthquake in the area is evaluated as based on the data of the Cambodia Meteorological Agency and various documents. Or are there any appropriate countermeasures taken?)	・In Japan, when landslides and storms caused by rare disasters such as heavy rains and earthquakes has occured, the surrounding social infrastructure and houses must not be affected by the collapse of solar power generation facilities. ・It is necessary to confirm whether an appropriate evaluation has been made by IPP using past literature. ・ If there is a risk of sediment discharge from site or ground collapse, it must be taken pre countermasures to prevent it.
1.5.2 Flood hazard	Is a low probability of flood disasters and landslides such as in the mountains? (It is necessary to confirm whether the risk of equipment damage due to heavy rain disasters or landslides in the area is evaluated as based on Cambodia Meteorological Agency data and various documents. Or are there any appropriate countermeasures taken?)	・Ditto
1.5.3 Cyclone	Is a low probability that the cyclone will adverse affect the equipment? (It is necessary to confirm whether the risk of equipment damage due to cyclone storms, etc. in the area is evaluated as based on Cambodia Meteorological Agency data and various documents. Or are there any appropriate countermeasures taken?)	・Ditto
1.5.4 Lightning	Is low probability that the equipment will be affected by a lightning strike? (It is necessary to confirm whether the risk of equipment damage due to lightning strikes in the area is evaluated as based on Cambodia Meteorological Agency data and various documents. Or are there any appropriate countermeasures taken?)	・In Japan, if a lightning surge is expected to electrical facilities, it is necessary to confirm whether installing an appropriate arrester (lightning protection element). ・In addition, for high voltage, it is necessary to secure a certain distance between the arrester and a wooden wall (1 m or more), and the arrester should be grounded (grounding resistance value is 10 Ω or less).
2. PV System		
2.1 Facility Structure	Is the equipment design appropriate such as single diagram? (It is necessary to confirm that the single diagram, device configuration, and various device specifications are properly designed or not.)	・It is necessary to confirm that the equipment configuration is appropriate, such as voltage, capacity, and number of lines.
2.2 Foundation	Is the foundation design appropriate depending on the ground conditions? (It is necessary to confirm whether the foundation is properly designed according to the ground conditions, and how the ground soil improvement if necessary.)	・It is necessary to confirm whether the load design is appropriate based on the 1.4 results of the ground survey. It is necessary to consider the static load, wind pressure load, seismic load, etc.
2.3 Frame structure	Is the mount frame design appropriate depending on the weather conditions? (It is necessary to confirm that the mount frame is properly designed, such as the panel will not fly away when a cyclone storm coming.)	・In Japan, the standard wind speed is 34 m/s or less for design. (40m/s or less for strong wind specifications).
2.4 Solar PV module	Is appropriate the module manufacturer that has much delivered record in other projects, and appropriate the proposed equipment performance and warranty period? (It is necessary to confirm whether the module manufacturer has a lot of experience, and whether the proposed equipment performance and warranty period are appropriate or not.)	・It is necessary to confirm whether the module manufacturer has much past supply records (generally 10 years or more) and whether the module warranty period is appropriate (generally 20 years or more).
2.5 PCS	Is appropriate PCS manufacturer that has much delivered record in other projects, and the proposed device performance? (It is necessary to confirm whether the module manufacturer has a lot of experience, and whether the proposed equipment performance is appropriate or not.)	・It is necessary to confirm whether the PCS manufacturer has much past supply records (generally 10 years or more).
2.6 Tilt angle optimisation	Is appropriate panel angle depending on the illuminance conditions? (It is necessary to confirm whether an panel angle is appropriate according to the illuminance conditions or not.)	・In Japan, the solar panel is designed facing south which aim to power generation amount is large, and the array tilt angle which is designed for maximizes the amount of annual power generation. ・The array tilt angle of Fukuyama and Ube solar power plant was set to 20°. (the optimum array tilt angle from the amount of solar radiation was 30°, but we considered a matter of against strong winds of tyephoon and reduction of foundation costs).
2.7 DC / AC ratio for optimal plant configuration	If it is PV panel overloaded, the whole design is appropriate? (It is necessary to confirm whether the proposed overload design is appropriate or not.)	・It is expected that the annual power generation will be increased by installing a larger DC capacity (panel capacity) than the AC capacity. But there is a possibility of curtailment problem of the power output, so it is necessary to check the design is correct or not.
2.8 DC Cabling	Are appropriate cable laying design for each string to the CB hub and PCS specification? (It is necessary to confirm whether the cable laying design from the PV panel to each CB and PCS are appropriate or not.)	・It is necessary to design the PCS input such as the PV maximum voltage, current and the number of connections to the string circuit. ・In Japan, it is necessary to use the insulating material should be cross-linked polyethylene when using a high-voltage DC cable in a mega solar, and voltage should be 1.5 kV or less.
2.9 AC Cabling, Voltage transformer ,Grid interconnection	Are appropriate design for the AC equipment, transformer, and circuit breaker? (It is necessary to confirm whether AC equipment, transformer, and circuit breaker design are appropriate or not.)	・It is necessary to have thermal strength of equipments under normal operating conditions. ・It is necessary to appropriately select such as the regular voltage and current, transformer ratio, regular breaking current for the connection circuit.
2.10 Facility protection device	Are appropriate design and specifications for the protective system in the event of a ground fault, short circuit, or lightning strike? (It is necessary to confirm whether protection system is appropriate or not, when ground faults, short circuits, lightning surges during lightning strikes, etc. are occurred.)	・It is necessary to install a lightning arrester (lightning protection element at an appropriate position in the electrical facilities and circuits for protect from abnormal voltage and current. ・ In Japan, in the event of a short-circuit/ground fault, independent operation, etc., a protection relays have to detect abnormalities (overvoltage, undervoltage, frequency, independent operation detection, etc.) and have to disconnect the equipment automatically.
2.11 Monitoring and Control Equipment	Are appropriate design for the specifications of remote monitoring / control system such as SCADA? (It is necessary to confirm whether the remote monitoring / control device design is appropriate or not.)	・In Japan, when using the remote monitoring and control system, it is necessary to monitor the operating status ceaselessly and it have to operate the circuit breaker when start and stop of the power plant. ・In addition, it is necessary to have a function to alert in the event of an abnormality condition such as a fire and lower gas pressure of gas insulation equipment etc,.
2.12 Boundary wall and fencing	Are appropriate desigin for the equipment boundaries? (It is necessary to confirm whether the design has been made and proposed to prevent electric shock due to the invasion of humans and/or animals, and also equipment damage, etc.)	・In Japan, power plant must be surrounded by gates, fences, etc. to prevent intrusion and for the purpose of ensuring public safety. ・For example, the sum of the height of the fence and the distance to the charging point must be 5m or more in case of special high voltage equipment 35kV. ・In addition, it is necessary to indicate a signboard at the entrance and exit that entry is prohibited.
2.13 O&M	Are appropriate design for the operation and maintenance plan such as checking the power generation, PV panels and mounts, peripheral facility, and weed treatment? (It is necessary to confirm whether the operation / maintenance plan is appropriate or not.)	・In Japan, it should periodically check whether the amount of power generation is as expected or not, and if it is not, it should analyze factors such as equipment trouble or unseasonable weather condition. ・In Japan, we periodically check the bolts looseness of the fundation and peripheral equipment (fences, etc.) and we use a matching mark on the bolts and nuts. At the same time, we mow weeds to avoid power generation reductions due to the shade of weeds.
3. Energy Assessment		
3.1 Evaluation of site	Are appropriate illuminance conditions at the PV installation site? (It is necessary to confirm whether the appropriate illuminance conditions and whether it is not shaded by trees or building.)	・In Fukuyama and Ube power plant, the array tilt angle was designed from between the tilt angle and the amount of solar radiation for site using a publishment by the New Energy and Industrial Technology Development Organization (NEDO). Cambodia is closer to the equator and it might be shallower tilt angle.
3.2 Calculation of solar PV system energy yield	Is appropriate power generation forecast according to the equipment conditions such as illuminance conditions and panel / PCS performance? (It is necessary to confirm whether the appropriate power generation in consideration of illuminance conditions, and including panel / PCS degradation, transmission / transformation loss, etc.)	・It is necessary to check a power generation simulation based on the panel module efficiency, PCS performance and transmission / transformation. ・The general capacity factor in Japan is about 17%.
3.3 Evaluation of results of Curtailment	Is appropriate power output evaluation according to the energy demand, capacity of the transmission, power tidal current, etc.? (If curtailment occurs, it is necessary to confirm whether the power output evaluation is appropriate or not.)	・In Japan, the solar power generation ratio into whole electrical demands is relatively high during the light load season in spring and autumn, and there is a problem that is curtailment of power output due to congestion in the power grid system. ・It depends on the congestion condition of the power system, it should considered when excessive the curtailment amount is exceeds 5% during the year.

Training for Capacity Building on
IPP Project Evaluation (JICA)

Asiam

WG3 Demand Forecast
Material 1

Simple-E: An Excel® Add-in Software for Econometric Model Analysis

20~24 December 2021
Asiam Research Institute, Inc.
CHEW CHONG SIANG

1.1 Simple-E is a Software for Econometric Analysis

You can use Simple-E like you command Microsoft Excel®, because;

1. Simple-E is fully compatible with Excel.
2. Simple-E is used as an "add-in tool" to Excel.
3. By Simple-E, econometric models can be written on spreadsheets in the same manner as by Excel.

→ You can use Excel tools within Simple-E sheets, as well as in separate spreadsheets attached to the model for simultaneous generation of tables, graphs and other analysis.

1.2 Models & Tools as Software for Econometric Analysis

1. Models and Tools are different
   a. **Model** is a set of equations that consistently express conceptual, theoretical and mathematical relationships of the elements to form a system.
   b. **Tool** is a computer software, which can numerically represent and treat theories and models.
2. In practice, capability and efficiency of numeric models are deeply dependent on modeling tools since;
   a. A model must be numerically formulated by modeling tools.
   b. A model can represent only simplified relationships because of physical and operational constraints.
   c. Hence, efficiency of a modeling tool is important.

→ Simple-E is a modeling tool easy to use while offering most of methods for econometric analysis.

1.3 Models and Tools: Integration or Disintegration?

1. Integration:

   In most of the famous models, tools are internalized.
   - **Customized optimization models: WASP**(IAEA) ,**MARKAL**(IEA)**, EFON**
   - **Customized econometric (simulation) models: ENPEP**(USDOE)**, IIASA model**
   - **Integrated models: AIM** (Asian-Pacific Integrated Model , NIES)
   - **Accounting models: LEAP** (Long-range Energy Alternatives Planning model)

   → These are "ready made" models for specific purposes but are difficult to re-customize for different objectives.

2. Disintegration:

   Tools are evolving over time to be as versatile as possible.
   - Excel spreadsheet for wide-range of simulation, E-Views for econometric simulation, GAMS for optimization

   → These tools have increased versatility but require substantial additional work to create a specific model.

1.4. Feature of Simple-E

1. Transparency

   Simple-E **shows inside of a model clearly**; such as data, variables, equations, logics and methodologies, structure, output, etc.

2. Transferability

   It is **easy to import or export** the data, variables, equations, logic (methodology), structure, output, etc., pending the compatibility between Excel and other models.

3. Simplicity

   For simplicity of use, Simple-E is designed to require
   - almost **no programming,**
   - only a small number of processing/manipulation,

   so that user can concentrate on modeling once data is ready.

1.4.2 Feature of Simple-E (…continued)

4. Integration of methodologies/tools

   Simple-E **can accommodate various methodologies** and tools in a integrated manner; such as Functional Options, Database, Table Operation, Iterative Calculation, Optimization, Econometric analysis (SEEx), Monte Carlo simulation, etc.

5. Easy Operation and Maintenance

   a. Simple-E is easy to
      - Update data, model, and output
      - Easy to share models with others

   b. Simple-E has popular and familiar interfaces; in particular, it is compatible with other office-use interfaces.

   c. Simple-E is designed as automatic as possible for operation.
      - Its operation is seamless from data input to simulation output
      - All the components are always checked for consistency.

1.4.3 Feature of Simple-E (…continued)

6. Expansion and Reduction

   Simple-E is easy to expand, reduce or modify;

   - Size of the data,
   - Model types
   - Components of methods.

7. Non intrusive approach

   a. Simple-E is designed to minimize the impact on the workflow making it easy to use;

   - available data at hand
   - familiar methods at use

   b. However, user can create completely new model with new method using Simple-E if it is necessary.

1.5 Spreadsheet for Transparency and Model Sharing

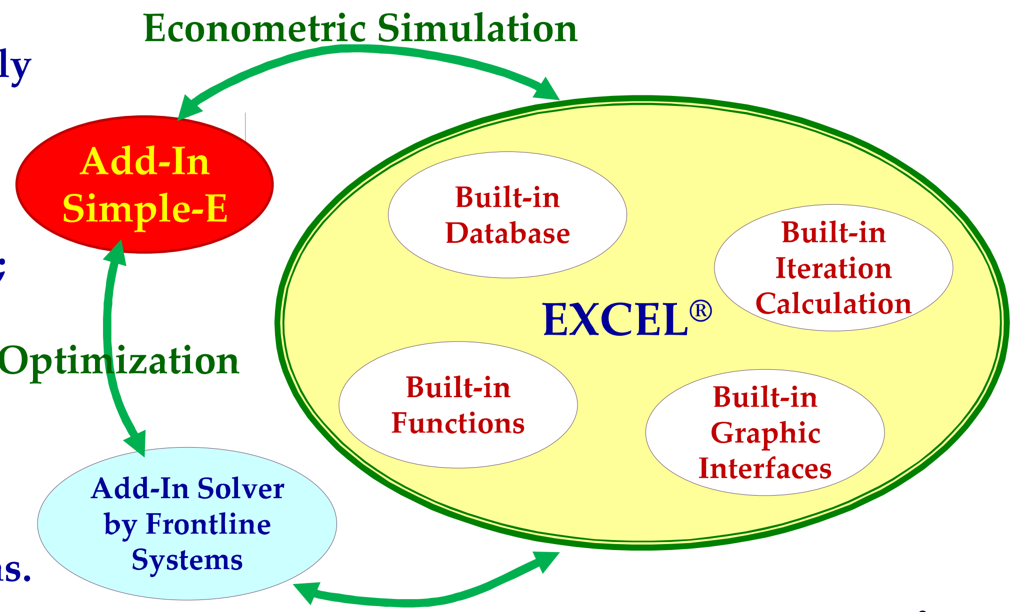
Concept of Simple-E as a modeling tool:

1. to use Excel as the modeling platform, without bothered by packaged models or other specific methods.
2. to build user's own original model.

- Advantages
  - Users can concentrate on the key objectives/ideas free from the existing models.
  - Users can structure model framework flexibly in consideration of availability and quality of data.
  - Users have a freehand to attach sub-models.
- Disadvantages
  - Need to build a model from scratch (with some examples)
  - Constrained by the capacity of Excel and its Add-ins.

2.1 Model Building Environment of Simple-E

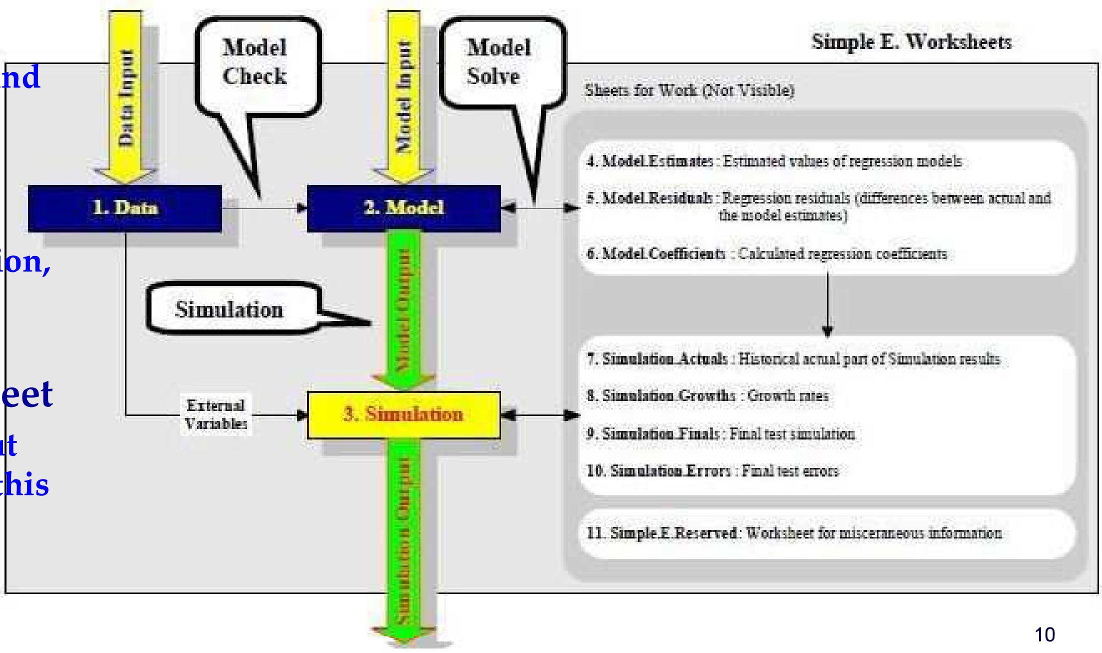
1. By Simple-E, models will be developed fully utilizing functions of Excel®.
2. By Simple-E, models will be developed for;
   a. Econometric simulation and projection,
   b. Optimization for planning or selection of options.



2.2 Conceptual Diagram of Simple-E

(SEEx. means Simple-E Extended)

1. Data Sheet
   To prepare data and preconditions.
2. Model Sheet
   To prepare the model by definition, condition or regression.
3. Simulation Sheet
   Simulation output will come out in this sheet.

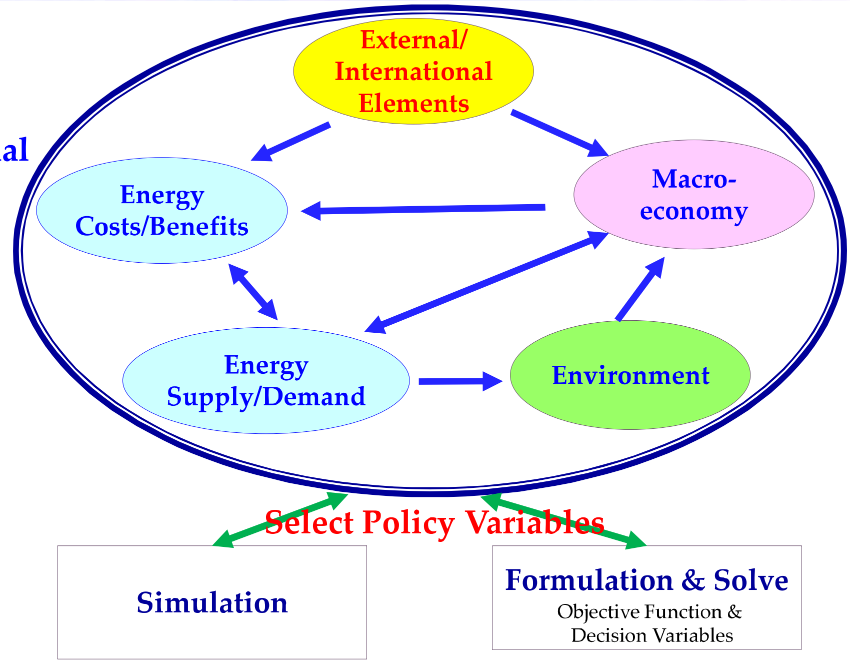


3.1 Typical Integral Model on Energy/Economy/Environment

1. **Data**
   Give past data, assumptions and external conditions.

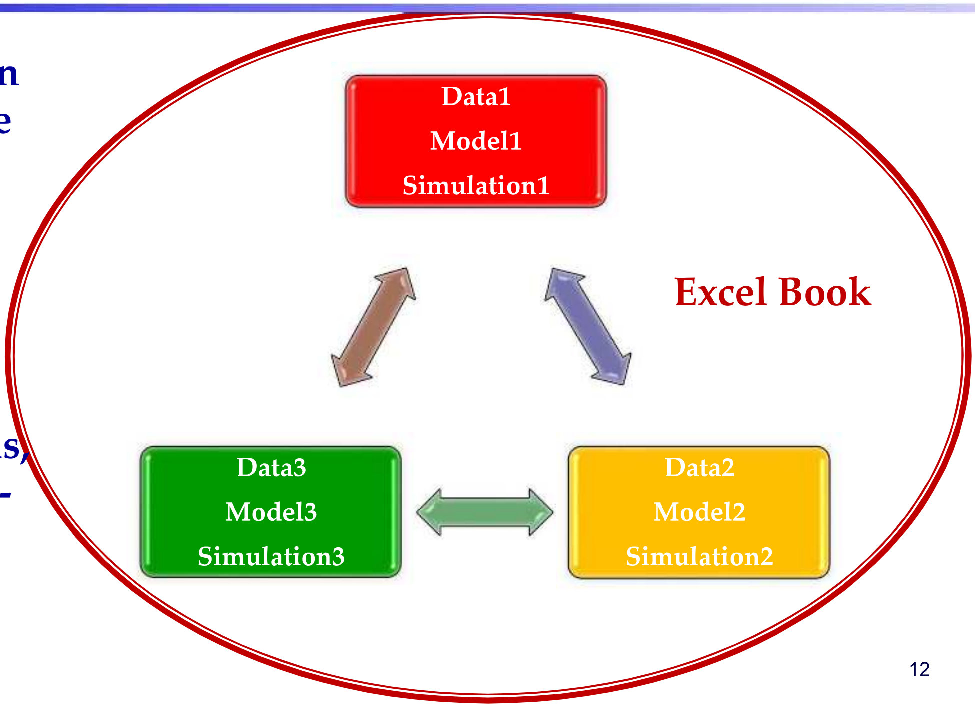
2. **Model**
   Define the objective system by formulating the relationship of or logic on elements.

3. **Simulation**
   Model run.

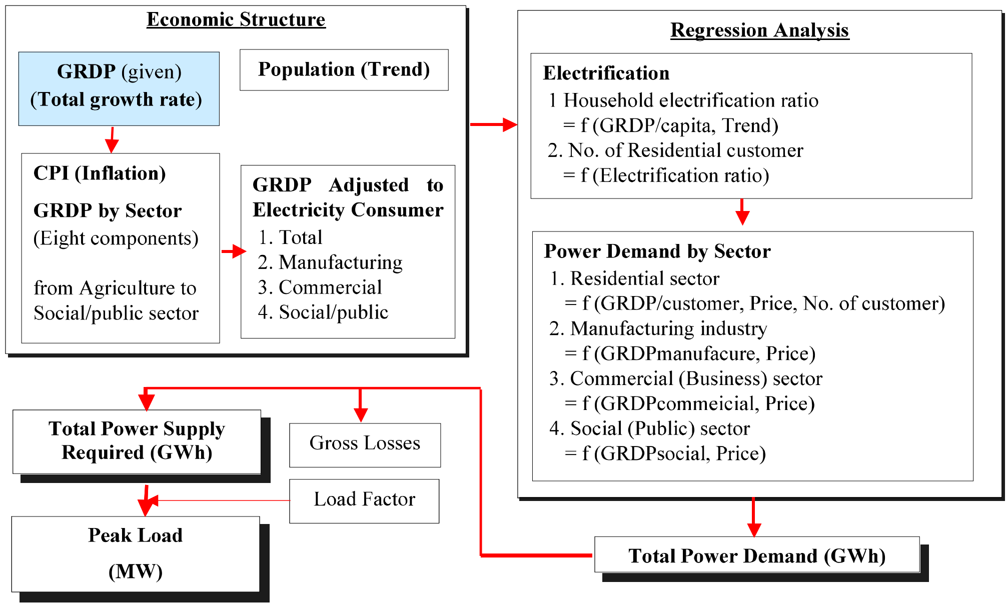


3.2 Application for Multiple Systems

1. Multiple models can be developed in one Excel book.
2. Each model can be developed and run separately.
3. Output of models can be linked; that is, models can be inter-connected as a cascade system.



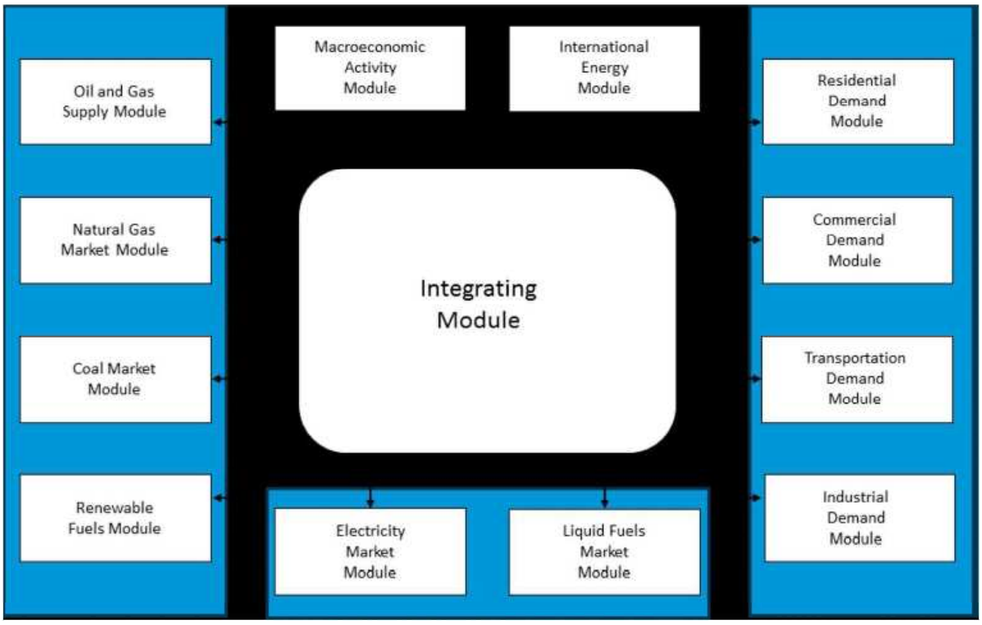
3.3 Example-1;
Regional Power Demand Model (Japan)



3.4.1 Example-2.1; US EIA
US National Energy Modeling System (NEMS)

NEMS

1. Represents the behavior of energy markets and their interactions with the U.S. economy.
2. Reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior.
3. Consists of 13 modules: integrating module provides the mechanism to achieve a general market equilibrium among all the other modules.

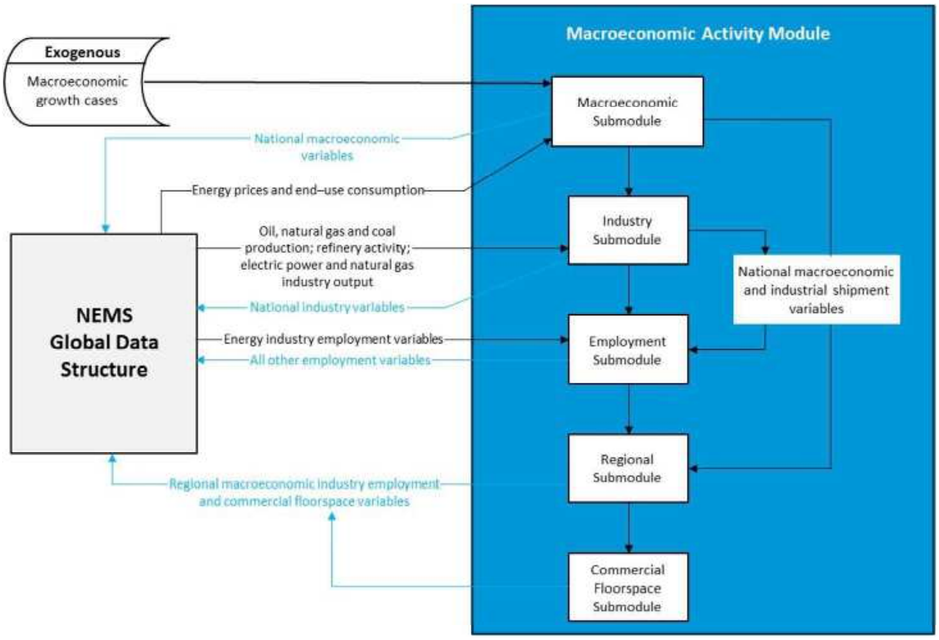


Source; US EIA NEMS Overview 2018, https://www.eia.gov/outlooks/aeo/nems/documentation/

3.4.2 Example-2-2; US EIA
NEMS-Macroeconomic Activity Module

MAM Structure

1. MAM links NEMS to the rest of the economy by providing projections of economic driver variables for use by the supply, demand, and conversion modules of NEMS.
2. NEMS employs the IHS Markit Ltd. model of the U.S. economy in the EViews environment.
3. All of the MAM models are linked to provide a fully integrated approach to estimating economic activity at the national, industrial and regional levels.

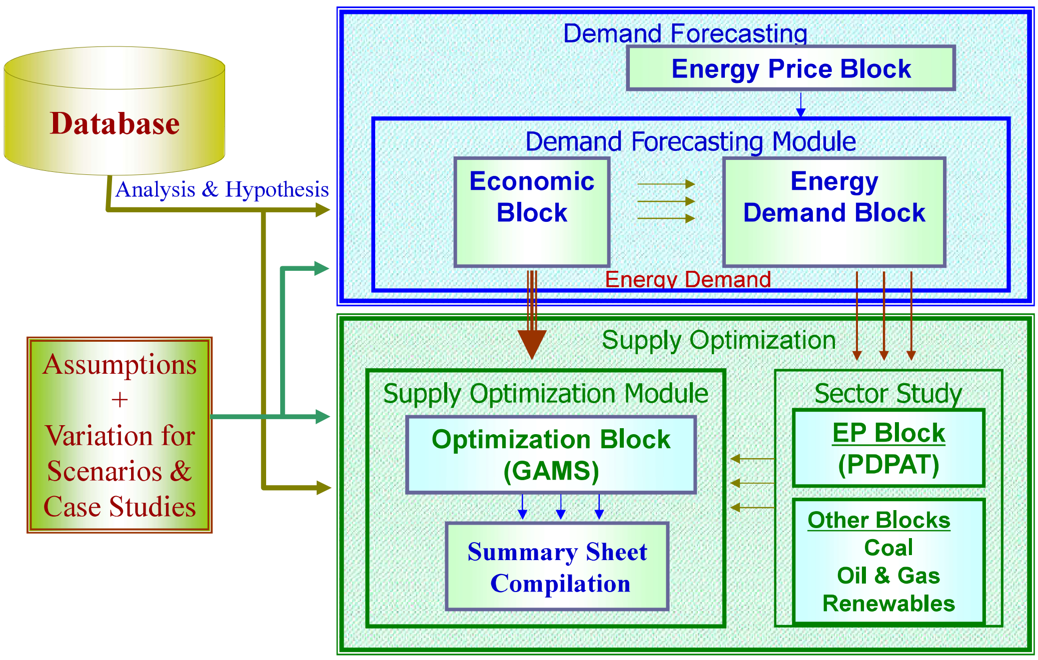


Source; US EIA NEMS Overview 2018, https://www.eia.gov/outlooks/aeo/nems/documentation/

3.5.1 Example-3; IEEJ Model
for the Philippine Energy Plan (PEP)

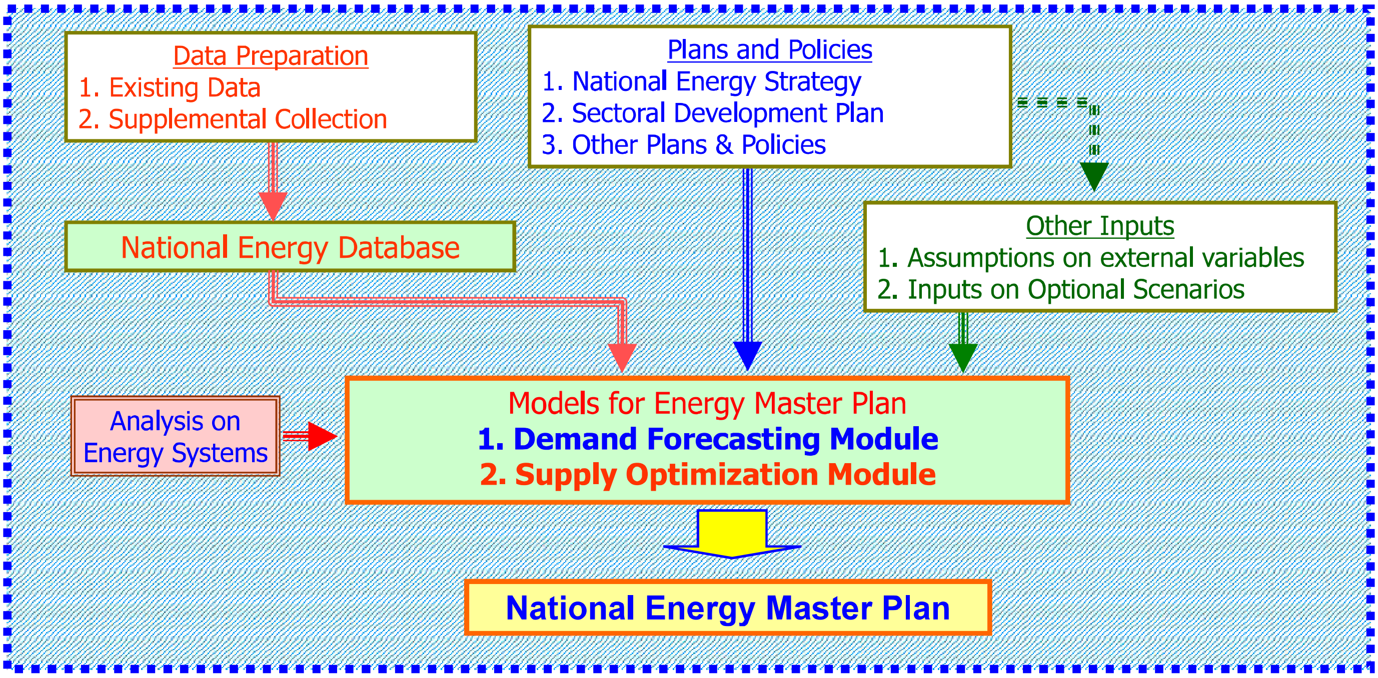
IEEJ Model for PEP

1. Model comprises demand module developed on Simple-E and supply module applying GAMS.
2. Energy demand is forecast first by the demand module.
3. Against the projected demand outlook, energy supply is optimized by the supply module.

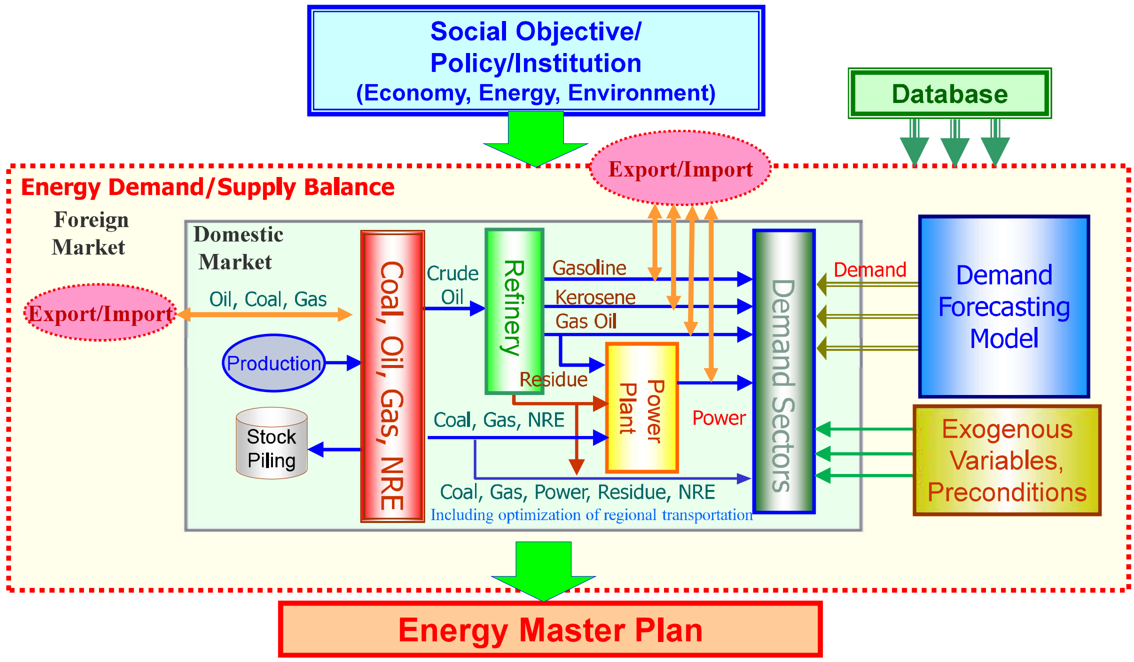


Source; IEEJ/TEPCO "JICA Study on Philippine Energy Plan Formulation", 2008

3.5.2 Example-4; IEEJ Model
Data Flow



3.5.3 Example-4; IEEJ Model
Structure of Supply Optimization Module



4.1 Introduction to Simple-E Ex; Basic Exercises

Simple-E operates on 3 spreadsheets - Data, Model and Simulation

1. **Data sheet; Preparation of historical data and external assumptions**
2. **Model sheet; Construction of a model = preparation of equations and definitions**
   1) Equations; parameters to be estimated by regression analysis, where following statistics are calculated;
      a. Interpretation of Parameters:
         R-Square, Adjusted-R-Square, DW-statistics, t-Value, F-Value, RSS, correlation between Xs
      b. Dynamic Variables: lagged dependent variables
   2) Manual definition including conditional equations
   3) Direct data transfer

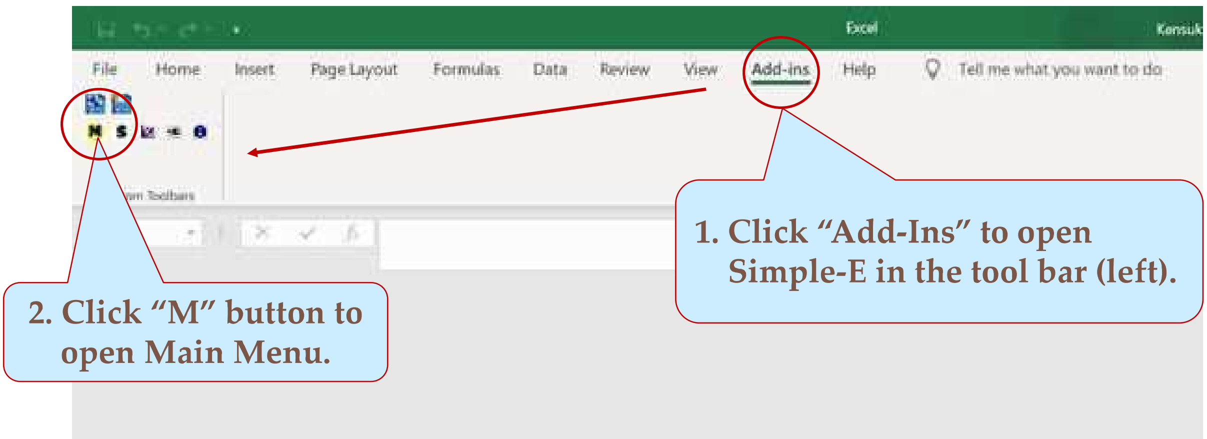
   → **Model Options**

   Equation, Ordinary Least Square, Double-Log Transformation, Semi-Log Transformation, Auto-regression and GS(grid Search Option), CA(Constant adjustment)
3. **Simulation sheet; Output are shown in this sheet automatically after simulation**

4.2 Start Simple-E Software

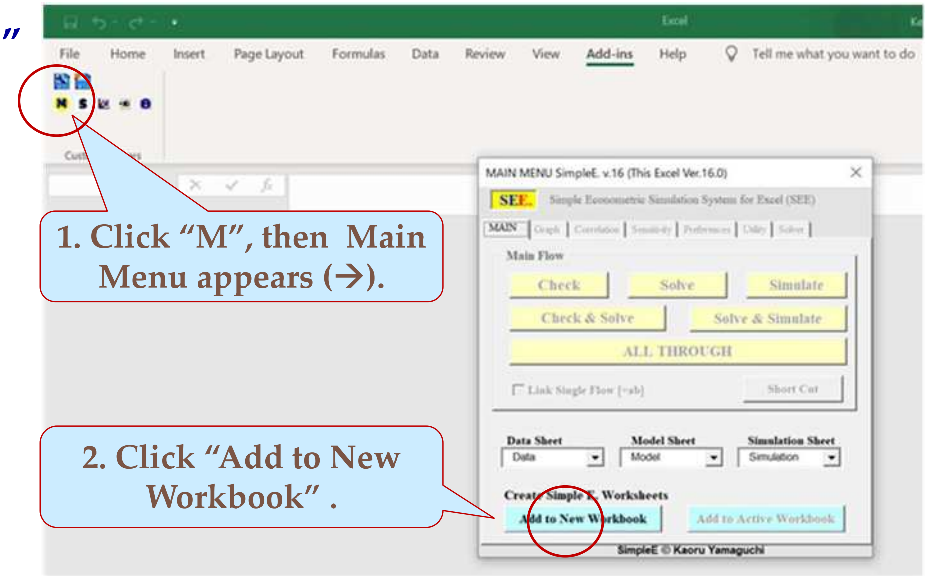
1. **Copy and paste Simple-E(SEEx.) File to your computer.**
2. **Open Simple-E file by clicking the icon.**
3. **Click "Add-ins" and click "M" button in the tool bar**

SimpleE



4.3 Create Simple-E Workbook

1. Click Main Menu Bottom "M"
2. Click "Add to New Workbook"
3. Workbook will be created as shown in the next sheet.
4. Click "OK" in the next sheet.
5. Start modeling on the book.

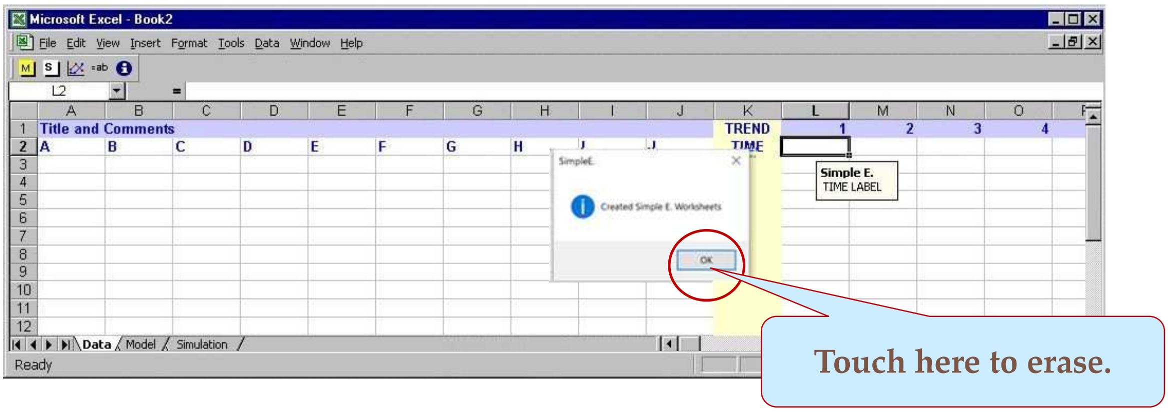


To open an existing model, open "Simple-E" first and then open the model file. Simple-E is automatically put in "Add-Ins". Then, minimize or close Simple-E.

4.4.1 Start Modeling with Simple-E: Data Input

Start formulating a model on the "Data" sheet.

1. Create a list of variables to be used in the model and code name tables.
2. Set Time Label in Column "L2" and onwards (see slide 4.5.1).
3. Input Code Name (data name) in column K.
4. Input Comments in Column A – J.
5. Copy and Paste, or Input data on the Data sheet.



4.4.2 Systematic Code-Name Table

For efficiency of modeling, it is important to create Code Names systematically, though modeler can freely define them.

For example, code names of transport sector variables for fuel consumption may be created using "CONCATENATE" function as below.

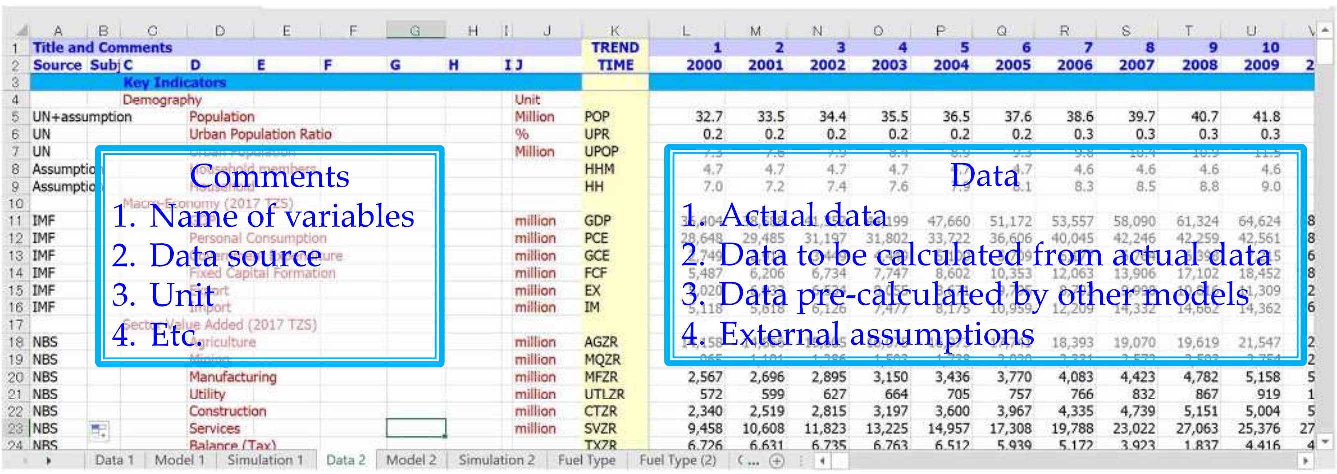
1. **Vertical columns from Coal through Total shows different type of fuels consumed in the transport sector.**
2. **Horizontal columns from Total through Others shows sub-sectors.**
3. **Combined codes may be used for variables in this sector.**

		Total	Road	Rail	Air	Other
		TP	RD	RL	AR	SP
Coal	CL	TPCL	RDCL	RLCL	ARCL	SPCL
Natural Gas	NG	TPNG	RDNG	RLNG	ARNG	SPNG
LPG	LPG	TPLPG	RDLPG	RLLPG	ARLPG	SPLPG
Oil	PT	TPPT	RDPT	RLPT	ARPT	SPPT
Combustible Fuel Total	CF	TPCF	RDCF	RLCF	ARCF	SPCF
Electricity	EL	TPEL	RDEL	RLEL	AREL	SPEL
Total	TL	TPTL	RDTL	RLTL	ARTL	SPTL

4.5.1 Building Econometric Models ; Code Name and Data Input

To begin with, "Model" may be developed on the "Data" sheet as follows.

1. **Set Time Label in Column L2 and onwards** (as an axis for time series analysis)**.**
2. **In put Code Name of variables in column K. Formulate them systematically!!**
3. **Input Valuable Names and Comments in Column A – J.**
4. **Copy and Paste, or Input, Data on the Data sheet in columns L and onward.**



4.5.2 Function Forms
Typical functional forms written in the model sheet

G H I J	Internal Y	Option Type	X1	X2	X3	X4	X5
Typical Functional Form							
Y = a + b*X	FNEL		GDP				
Y = a + b*X + c*Y(-1)	FNEL		GDP	lag1.FNEL			
LN(Y) = a + b*LN(X)	FNEL	$DL	GDP				
LN(Y) = a + b*X	FNEL	$SL	GDP				
Y = a + b*LN(X)	FNEL		LN(GDP)				
LN(Y) = a + b*LN(X) + c*LN(Y(-1))	FNEL	$DL	GDP	lag1.FNEL			
LN(Y) = a + b*LN(X1) + c*LN(Y(-1)) + d*X2	FNEL	$DL	GDP	lag1.FNEL	exp(TREND)		
	Ln(FNEL)		LN(GDP)	LN(PRICE)			
Definition	FNEL	=	EXP(Ln_FNEL)				
Y = a + b*X1 + c*X2	FNEL		GDP	PRICE			
Y = a + b*X1 + c*X2 + d*Y(-1)	FNEL		GDP	PRICE	lag1.FNEL		
LN(Y) = a + b*LN(X1) + c*LN(X2)	FNEL	$DL	GDP	PRICE			
LN(Y) = a + b*X1 + c*X2	FNEL	$SL	GDP	PRICE			
Y = a + b*LN(X1) + c*LN(X2)	FNEL		LN(GDP)	LN(PRICE)			
Y = a + b*LN(X1) + c*X2	FNEL		LN(GDP)	PRICE			
LN(Y) = a + b*LN(X1) + c*LN(X2) + d*LN(Y(-1))	FNEL	$DL	GDP	PRICE	lag1.FNEL		
LN(Y) = a + b*LN(X1) + c*LN(X2) + d*LN(Y(-1)) + e*X3	FNEL	$DL	GDP	PRICE	lag1.FNEL	exp(TREND)	

4.5.3 Fitness of Equation
by Regression Analysis

1) R	R-Square, 0 ≤ Explained variance / Total variance ≤ 1, (The larger the better)
2) AR	Adjusted R-Square, AR ≤ 1, (The larger the better)
3) SD	Standard Deviation: SD = $(\sum e^2 /(n-k))^{1/2}$,
	e = Residual, n = Sample size,
	k = Number of independent variables
4) DW	Durbin Watson Statistics, 1 < DW < 3
	DW = 2 : No serial correlation
	DW → 0 : Positive correlation
	DW → 4 : Negative correlation
5) Dh	Durbin h Statistics with lag, | Dh | < 2
6) t-value	| t | ≥ 2 : Significant
	2 > | t | ≥ 1 : Admissible to use
	| t | < 1 : Insignificant
7) Rho	Coefficient of serial correlation, | Rho | < 1
8) DF	Degree of Freedom, DF > 1 (The lager the better)
9) F	F-value, F-Statistic: F > 0 (The larger the better)
10) RSS	Residual Sum of Square, RSS > 0, (The smaller the better)
11) YX	Correlation Coefficient between Y and Xs, | YX | < 1
12) XX	Correlation Coefficient between Xs, | XX | < 0.95

4.6 Main Flow of Simple-E; Check, Solve and Simulate

1. Model Check
1) Check adjustment of code names and report inconsistent names.
2) Check and set a sample range for each variable.
3) Distinguish internal and external variables.

2. Model Solve
1) Values of each internal variable are searched and calculated, and the results are stored in the "Simulation" sheet.
2) For a regression model of a variable, the model equation will be solved and determined with statistics for check of admissibility. Regression results are also calculated.

3. Simulate
1) Solve models for each variable under the given future assumptions of external variables.
2) Integrating definition or regression equations for each variable, the whole model will be solved and simulated (simultaneously).

5.1. Scenario Setting for Model Analysis

1. Scenarios may be set corresponding to the future socio-economic outlook, social targets and policy options, which are considered difficult or inappropriate for forecasting by the model.
2. In general energy/environment analysis, scenarios are set on future development of socio-economic elements; such as population growth rate, economic growth rate, crude oil prices, currency exchange rate, monetary/fiscal policies, industrial structure change, energy structure target (energy conversion, energy import/export), energy tariff options, energy efficiency target, GHG emissions target, new/renewable energy introduction policy, environmental policies, etc.
3. A scenario for model analysis comprises a set of assumptions and projections numerically expressed on these elements.

5.2 Scenario Setting by Data Sheet; Projection of Variables

1. Scenarios should be prepared in numerical values and given to the model as **a set of projected external variables** in the "Data" sheet.
2. For **case studies**, different scenarios may be examined changing the projection for variables and running the model for each such set.

14 1998	15 1999	16 2000	17 2001	18 2002	19 2003	20 2004	21 2005	22 2006	23 2007	24 2008	25 2009	26 2010
167	180	188	196	208	218.4	229.32	240.786	252.8253	265.4666	278.7399	292.6769	307.3107
239.7	258	281.7	288.2	313.6								
51014291	57998089	65341135	66035016	73560041								
380	380	380	420	420								
1.59	1.47	1.35	1.46	1.34								
		Actual values			Scenario							

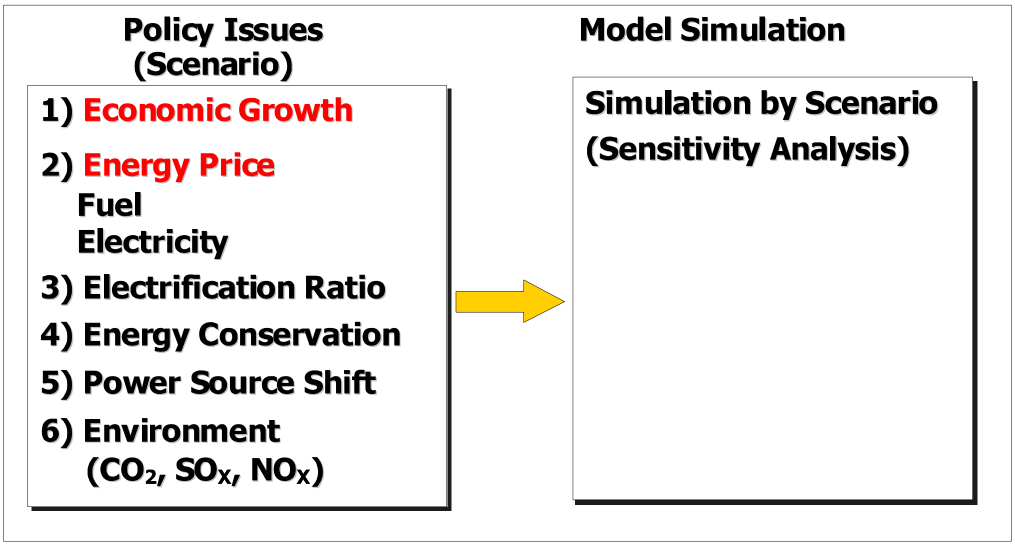
5.3 Scenario Setting by Model Sheet; Defining Equations

Scenarios are also set by defining the relationship of variables shown by **equations and values of parameters.**

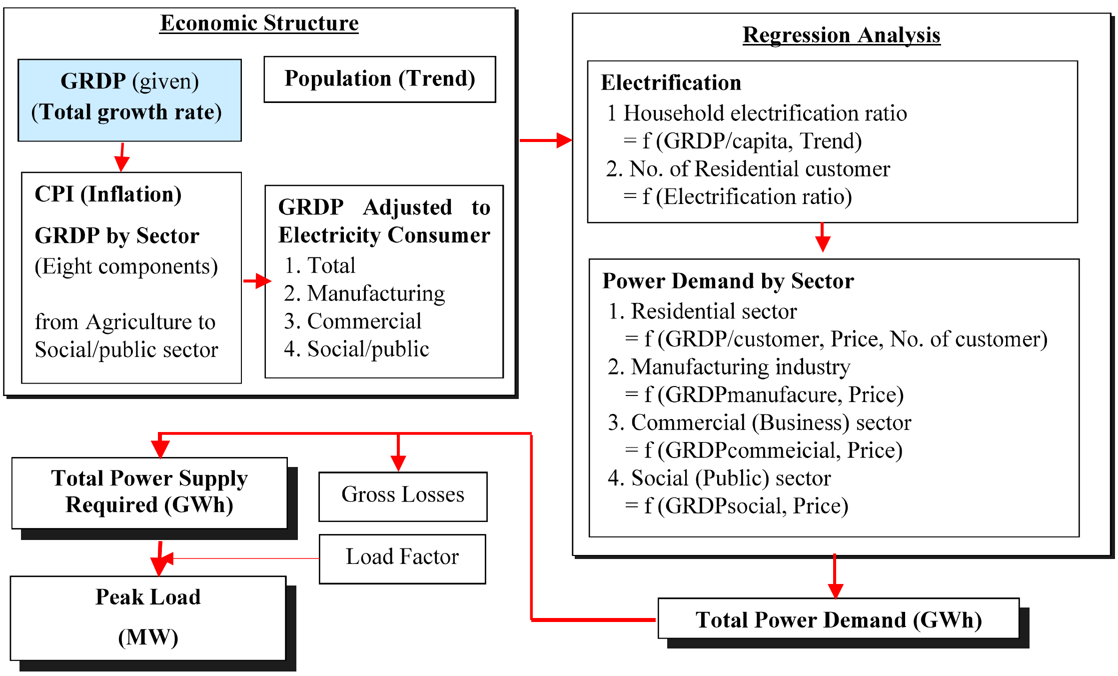
GDP Share							
	Industry		%		SHIN	$CA	LN(TREND)
	Commercial		%		SHCM	$CA	LN(TREND)
	Public		%		SHPU	$CA	LN(TREND)
	Others		%		SHOT	$CA	LN(TREND)
	for ajustment to total 100 %				SHTL	=	SHIN+SHCM+SHPU+SHOT
GDP	GDP Growth rate		%	(External)	GR	=	**4.5**
	Total (Scenario)			(External)	GDP	=	lag1.GDP*(1+GR/100)
	Industry			(External)	GDPIN	=	GDP*(SHIN/SHTL)
	Commercial			(External)	GDPCM	=	GDP*(SHCM/SHTL)
	Public			(External)	GDPPU	=	GDP*(SHPU/SHTL)
	Others			(External)	GDPOT	=	GDP*(SHOT/SHTL)
CPI			1995=100		CPI	=	lag1.CPI*(1+INFL/100)
Inflation			%	(External)	INFL	=	**GR*1.2**
Price Scenario (Real Value Constant)							
	Industry		/kWh		PINEL	=	lag1.PINEL*(1+INFL/100)
	Residential		/kWh		PREEL	=	lag1.PREEL*(1+INFL/100)
	Commercial (Business)		/kWh		PCMEL	=	lag1.PCMEL*(1+INFL/100)
	Public		/kWh		PPUEL	=	lag1.PPUEL*(1+INFL/100)

6.1 Example of Electricity Model; Function of an electricity model

On key policy issues, impacts of different policy options may be examined by giving different scenarios and iterating simulations.



6.2 Schematic Diagram for Power Demand Forecasting



6.3 Energy Flow and Model Solving

Energy Flow

For some energy, final demand may be constrained by supply capacity or availability.

For other energies, their supply to satisfy the final demand will be decided through optimization taking account of the market price, key conditions and supply mechanism.

<Primary Energy Requirement>
- Domestic Production
- Import
- Export
- Stock Change
- Total Primary Energy Supply

<Primary Energy Supply>
- Coal
- Crude Oil & Petroleum Products
- Natural Gas
- Nuclear
- Hydro, Geothermal
- Biomass, New Energy, etc.

<Energy Conversion & Own Use>
- Electric Utilities
- Auto Generation
- City Gas Production
- Coke and Gas
- Oil Refining
- Own Use & Losses

<Secondary Energy Supply>
- Electricity
- City Gas
- Coke, Charcoal
- Gas Products (LNG, GTL)
- Oil Products (LPG, Gasoline, Naphtha, Jet Fuel, Kerosene, Diesel, Fuel Oils, etc.)

<Final Energy Consumption>
- Industry
- Agriculture, Forestry & Fishery
- Mining
- Construction
- Manufacturing
  - Foods
  - Textile
  - Pulp & Paper
  - Chemicals
  - Ceramics & Cement
  - Iron & Steel
  - Non-ferrous Metals
  - Metal Products & Mechanic
  - Others
- Transport
- Residential & Commercial

<Final Energy Demand>
- Industrial Sector
  - Electricity
  - Fuels
  - (Coal, Coke, Gas, Natural Gas LPG, Oil Products, Biomass, RE)
- Transportation Sector
  - Electricity
  - Fuels (Coal, Natural Gas, LPG, Gasoline, Jet Fuel, Diesel, HFO, Biofuel)
- Residential & Commercial Sector
  - Electricity
  - Fuels (Firewood, Charcoal, Coal, Natural Gas, LPG, Gasoline, Kerosene, Diesel, HFO)
- Non-energy Sector
  - Coal, Natural Gas, LPG, Naphtha, Solvents, Lubricants, Asphalt, etc.

Model Solving

6.4 Final Energy Demand Block

Main Indicators (External Variables)
- Population, Urbanization Ratio
- Economic Indicators (Real GDP)
- Energy Prices (Electricity and Fuels)
- Consumer Price Index
- Household Electrification Ratio

Sector GDP

Agriculture, Mining, Manufacturing, Transport, Commerce, Public Services, Others,

Final Energy Demand Block

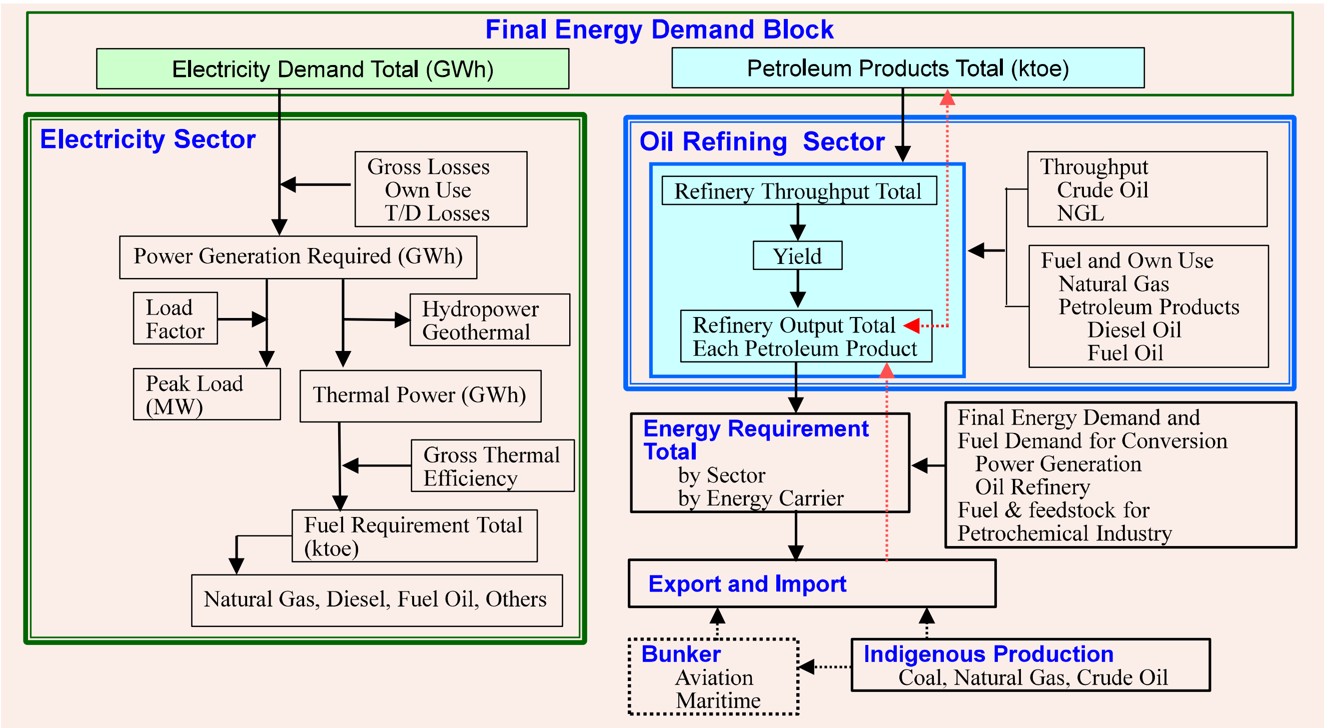
Electricity Demand By Sector
- Industry (manufacturing)
- Residential
- Commercial
- Public
- Other

Fuel Demand by Sector and Energy Carrier

Industry	Coal
Transportation	Natural Gas
Residential & Commercial	Petroleum Products
Agriculture	Electricity
Non-Energy Use	NRE

Energy Conversion and Supply Block

6.5 Energy Conversion and Supply Block



Information

1. Simple-E is distributed by the Asiam Research Institute, Inc. For any inquiry, please contact http://www.asiam.co.jp/ .
   a. Latest version is compatible with Excel 19®.
   b. Simple-E can be modified and customized upon user's request.
2. Simple-E is a computer software for constructing econometric models on demand forecast and optimization analysis.
3. Simple-E is widely used for energy sector analysis and national energy planning for countries in Asia, Middle East, Eurasia, Africa and Latin America under programmes of IEEJ, APEC, ERIA, JICA, etc. Capacity development programs on Simple-E are also provided.

Thank you

Training for Capacity Building on
IPP Project Evaluation (JICA)

WG3 Demand Forecast
Material 2

~Fundamental for Energy Demand Modeling Building~

20~24 December 2021
Asiam Research Institute, Inc.
CHEW CHONG SIANG

Our Target

1. Training of trainer (1st training)
2. Training by trainer (2nd training)
3. On-Job (3rd training)
   Review the Power demand projection for the previous "Power Master Plan" prepared on 2019.
4. Create a "Manual for Power Demand Forecast" for Cambodia. (paper work)

Training Contents

1. Demand forecast method (analysis flow, energy balance table, predictive model, data collection and analysis method etc.)
2. Demand forecast accuracy verification method (GDP correlation, sensitivity analysis, predicted value / actual value / similar country comparison, etc.)
3. Sectoral analysis method (industry / consumer, energy conservation effect, etc.)
4. Demand forecast examples among ASEAN countries
5. How to use Simple-E

What we have done in the past?

(1) Power Master Plan 2019

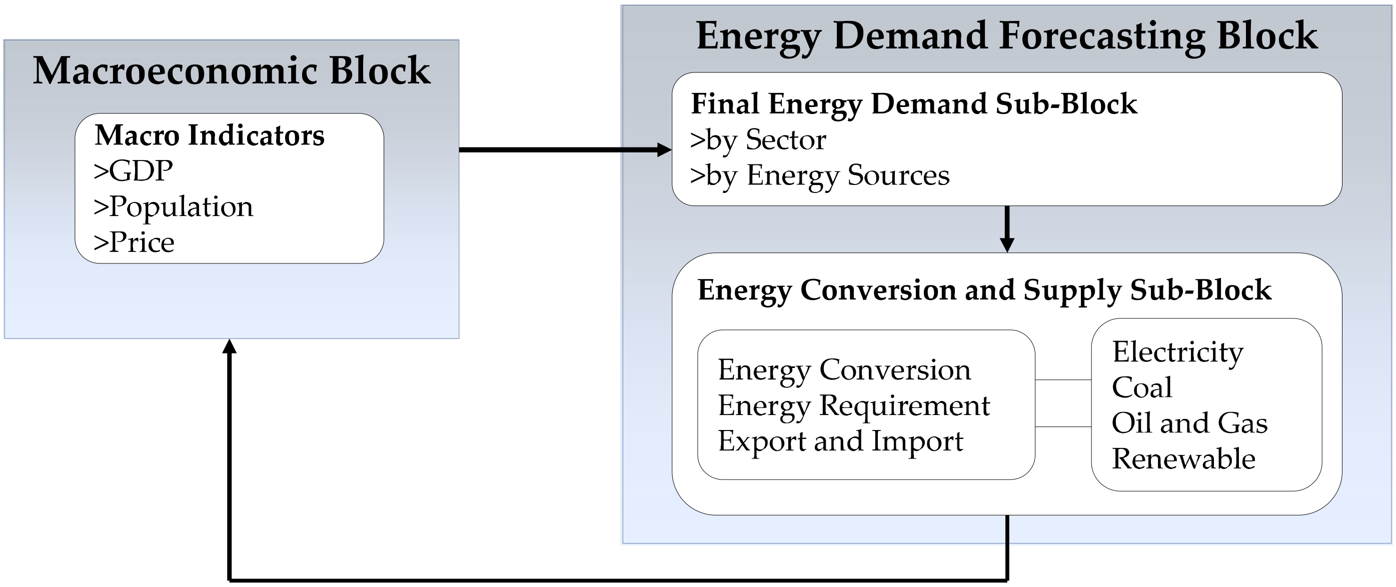
reference_1_power master plan 2019

(2) Power demand forecast

reference_2_power modeling

How to start?

1. Concept of Energy Demand Forecasting Model

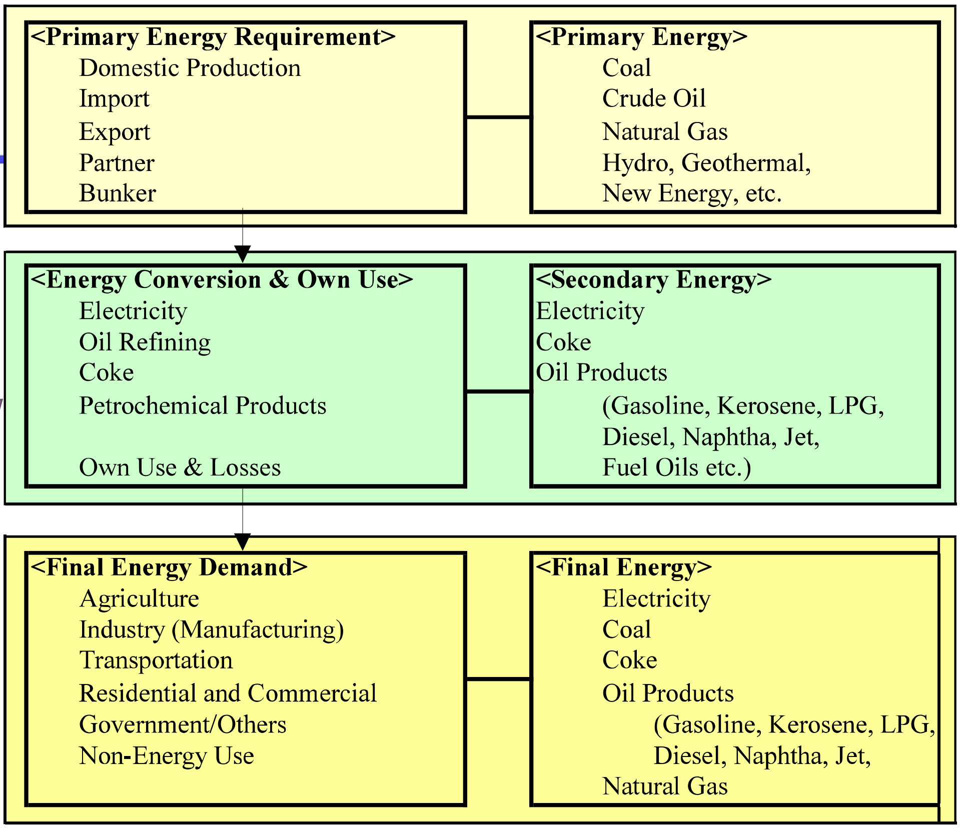


2. Calculation Steps

- Modeling platform: Energy Balance Table
- Analyzing procedure: From bottom to upper

Optimization Model

Our focus: Energy demand Forecast Model



Macro Indicator
1. GDP – External Variable

1) Key driver for energy demand forecast

2) Have a strong correlation to energy demand

3) Data performs by same structure with energy balance sheet. (By sectoral)

4) Data source: easy to collect (UN, ADB, Cambodia Central Bank etc.)

Please open the excel file "practice_1_GDP"!

Attentions: GDP current price? GDP real price?

Macro Indicator
2. Population – External Variable

1) Key driver for demand forecast
2) Especially household
3) Data source: United Nation Statistic Division
Statistic department in Cambodia?

Please open the excel file "practice_2_population"!

Macro Indicator

3. Price – key assumption

1) Deflator
2) Consumer Price Index (CPI)
3) Electricity tariff

GDP Deflator (%) = GDP current price / GDP real price

Thank you