CHAPTER 2
THEORETICAL PRINCIPAL CONCERN

2.1 Introduction

Small/mini/micro-scale hydropower plant is one of the most cost effective and reliable energy technologies to be considered for providing clean electricity generation. In general, specifications of Hydro electric power system vary depending upon the installation location. The hydro turbine and generator employed therein are custom manufactured in accordance with site conditions.

In particular, the key advantages that small/mini/micro-scale hydropower has over wind and solar power are [14] :

- A high efficiency (70-90%), by far the best of all energy technologies.
- A high capacity factor (Plant factor) (typically>50%), compared with 10% for solar and 30% for wind
- It is a long-lasting and robust technology system can readily be engineered to last 50 years or more.

It is also environmentally friendly. Small/mini/micro-hydropower is in most case “run-of-river” in other words any dam or barrage is quite small, usually just weir, and little or no water is stored. The amount of an electricity production is directly a combination of two main factors: (i) Head (how far the water falls before it reaches the water turbine), (ii) Flow rate or Discharge (how much water volume is available).

2.2 Hydropower Plant Classification

In generally, the scale of the hydropower plant varies from less than hundreds kilowatt to several thousands kilowatt. Under the manual, the following classification is made in term of the installation capacity (Table 2.1).

Table 2.1 The hydropower plant classification.

Range	Descriptions
Large	All installation with an installed capacity of more than 5,000 kW,
Small	Installed capacity between (1,000 kW and 5,000 kW),
Mini	Installed capacity between (100 kW and 1,000 kW),
Micro	Installed capacity less than 100kW.

Source : [10].

2.3 Hydropower Plant System

In general, the system of hydropower plant captures the energy of falling water to generate electricity. A water turbine converts the energy of falling water in to mechanical energy. And then an alternator converts the mechanical energy from the water turbine to electricity energy. The amount of an electricity production is directly a combination of two main factors: (1) Head (how far the water falls before it reaches the water turbine), (2) Flow or Discharge (how much water volume is available). The basis diagram of the hydropower conversion scheme is illustrated in the figure 2.1.

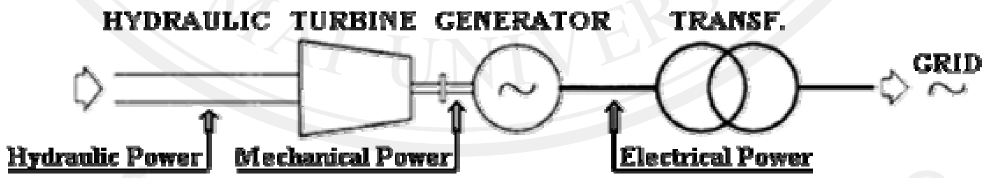

Figure 2.1 The basis diagram of the hydropower conversion scheme [7].

The electricity energy may be used directly with the local power system called isolated system or may be connected to the grid system which is a main power line system. The basic diagram of the hydropower system is illustrated in the figure2.2.

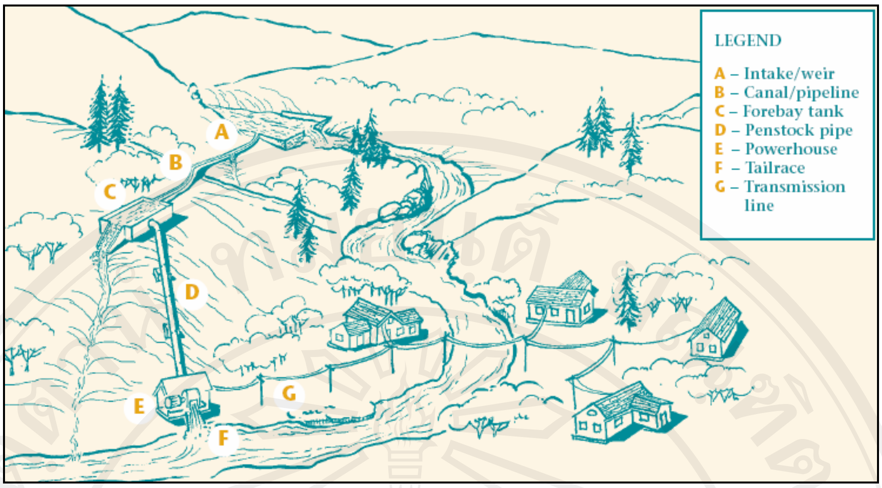

Figure 2.2 The general plan of a small/micro-scale hydroelectric system [14].

The operation process of hydropower system is shown in figure 2.3.

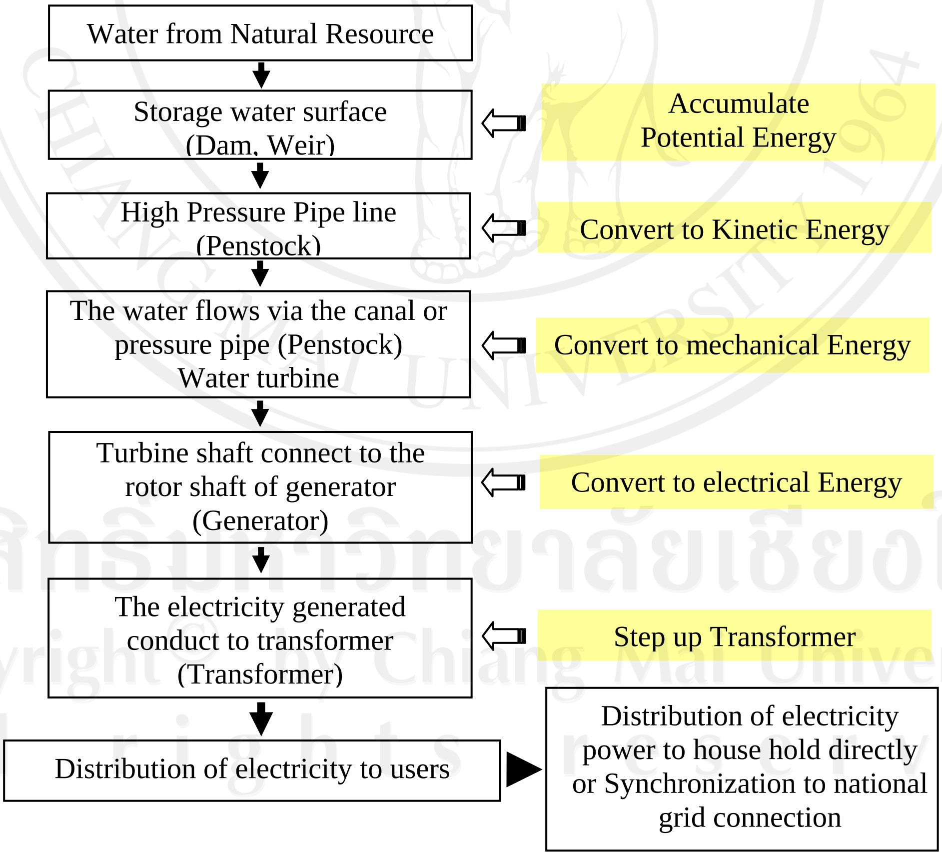

Figure 2.3 The basic diagram of the operation process for hydropower system [16].

2.3.1 Definition of Hydropower Plant Facilities

The hydropower plant structures are commonly shown as the figure 2.2. Their definitions is expressed in following :

a) Intake

The intake is a structure that diverts water into a conduit leading to the power plant. Its function is to prevent sediment from flowing in to the turbine. The top of the intake should be at least 0.5m below the top of the weir.

b) Head Tank or Forebay Tank

Surge tank is a hydraulic structure installed between the channel and penstock, and designed to control pressure and flow fluctuation in a penstock or tunnel. It functions as a reservoir that temporarily store or releases water pressure to the turbine.

c) Penstock or Pressure Pipeline

The penstock is the pipe which conveys water under pressure from the forebay tank to the turbine. Steel, cast iron, aluminum, polyethylene and PVC are material used for small hydro pipeline and penstock. Generally, for the high head site (above 20 m head) polyethylene or PVC is used. When the head is greater than about 60 meters, use of steel at lower end (higher head) of the pipeline is more economical.

d) Powerhouse

The powerhouse is the structure that houses the turbine, generators, and associated control equipment. The size of the power house is determined by the type and size of turbine installed. The substructure which consists of the pedestal of the turbine generator, the draft-tube or discharge cavity, and floor slap-, should be made of concrete. The superstructure which is above the floor and protect machine and electrical control from rain can be made of wood frame, metal frame, concrete block, log or self supporting metal panels.

e) Tailrace

The tailrace is a channel which leads the water from the turbine back into the stream. It can prevent the water from damaging any structure or the landscape. Selection of water outlet location should be selected to avoid damage to the structure or blockage due to the flow or deposited materials, so the safe discharge could be expected without excessive heaving during floods.

f) Transmission Line

The wire or cable system is used to conduct electric power to a convenience point, where it is subdivided for delivery to distribution system and also used as a generic term to indicate the conveyance of electricity energy over any or all of the paths from source to point of use.

2.3.2 The Principal Groups of Hydropower Plant Facilities

According to the function it is serves, the hydropower plant facilities may be divided into several principle groups; Power-generating equipment, auxiliary equipment, mechanical equipment and electrical equipment.

1) Power-generating equipment includes hydraulic turbine and the mechanical components of water-wheel generator.

2) Auxiliary equipment is to ensure the trouble-free operation of the power generating equipment. It includes process water-supply system, air handing facilities, oil supply system, dewatering (drainage) facilities.

3) Mechanical equipment refers to water wheel/water turbine, gates, trash racks, various mechanisms, and crane for servicing the hydraulic turbine and generator.

4) Electrical equipment includes the electrical components of generators, step-up transformers and switchgear apparatus such as: overhead, and cable transmission lines, relay protection system, automatic equipment, supervisory control system, and communication systems.

2.3.3 Work Parts of Hydropower Plant

In general, specifications of hydroelectric power system are varied depending upon the site location. The main purpose of hydropower plant is to generate the electricity energy. In general, the major works of hydropower plant consist of three main parts as the following :

1) Civil Work of the Hydropower Plant

The main components of civil facilities are parts including dam or weir, intake, de-silting basin, power canal, head tank, poundage, penstocks, power house and tailrace.

a) Intake Weir

The intake of a small/micro-hydro scheme is designed to divert a certain part of the river. It is as a gate on the dam or weir. The gravity pulls the water through the penstock or pressure pipeline and lead to the turbine.

Normally, a low weir is 1 m to 2 m height, and water flows over the weir most of the time. It should be built cross the stream. The example intake weir is shown in the figure 2.4.

Figure 2.4 Intake weir of Nam Mong MHP in Luang Prabang province of Lao PDR.

b) Head Tank Forebay Tank

The head tank is provided between the power canal and penstock pipe to adjust a turbine discharge corresponding to the load fluctuation. It functions as a reservoir that temporarily store or releases water pressure to the turbine. When the penstock pipe is connected directly to the de-silting basin, the de-silting basin may be designed and functions as a head tank.

The capacity of head tank is determined according to the responsive characteristic of the governors installed in the power plant.

(i) Mechanical governor and manual operation.

$$V > (Q_{\max} \times (120 - 180)) \quad (2.1)$$

Where, V : Capacity of tank (m^3),

A : Surface area of tank (m^2),

Q : maximum discharge (m^3/s).

(ii) Electric governor, compute governor and dummy load governor

$$V > ((Q_{\max} \times 20\sec) + (A \times 0.8)) \quad (2.2)$$

d) Powerhouse

The powerhouse is the structure that houses the turbine, generators, and associated control equipment. Selection of power station location should consider the condition as to prevent making the penstock excessively long, and lower tail water level as much as practicable, and care must be taken so that the power station is not to be located below the highest flood level. It is normally considered location near by the road.

The selection of the powerhouse location should be carefully considered to particular items such as: access condition, condition of foundations, flood water level, and installation conditions for the auxiliary facilities.

e) Tailrace

The tailrace is a channel which leads the water from the turbine back into the stream. Selection of water outlet location should be as to avoid damage to the structure or blockage due to the flow or deposited materials, and then the safe discharge could be expected without excessive heaving during floods.

2) Piping Work

a) Penstock or pressure pipeline

The penstock is the pipe which conveys water under pressure from the forebay tank to the turbine.

The conceptual design is to identify available pipe options, then to select a target head loss, 5 % of the gross head is a starting point [10]. The details of the pipes with losses due to the friction close to this target are then tabulated and compared for cost effectiveness. A smaller penstock may save on capital costs, but the extra head loss may account for lost revenue from generated electricity each year.

b) Support

In general, the pipe support for the small hydropower plant consists of two types, (i) Anchor block provided at the bend portion which should be settled on firm foundation to support penstock pipe against sliding. (The interval of each anchor block should be less than 100m in general) and (ii) Saddle pier are provide at (10 m) interval [10].

3) Mechanical Work

a) Hydraulic Turbine

A hydraulic turbine is a rotating machine, basically consisting of paddlewheel, to capture the kinetic and pressure energy of fluid and transform it into the directly usable mechanical energy of the rotating shaft. Furthermore, there are several types of turbine according to head, discharge, speed of rotation, structure, etc.

The water turbines are classified into two types according to their water energy utilities.

(i) Reactive turbine drives energy provided by the water partly in kinetic and partly in pressure form. The basic type of reactive turbine is i.e., Francis, Kaplan, Propeller, Bulb, Tube and Water wheel,

(ii) Impulse turbine drives energy provided by water in kinetic form, and the basic type of impulse is i.e., Pelton, Turgo and Michell-Banki is also known as Cross flow turbine.

The water turbine picture below has been seen in general uses for the hydropower plant are shown in figure 2.5.

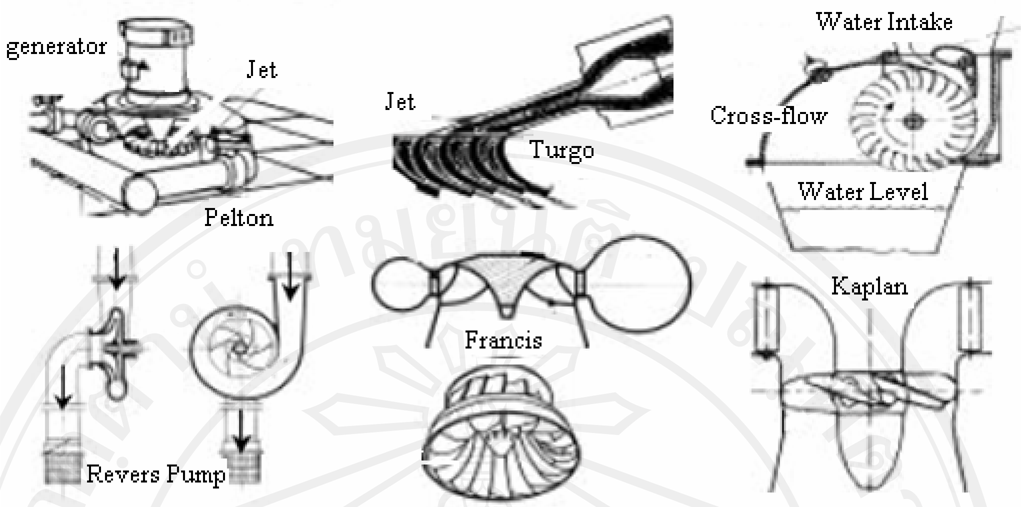

Figure 2.5 Type of hydraulic turbine [2].

In general, water turbines are classified as high head, medium head or low head machines. Their classification is illustrated in the table 2.2.

Table 2.2 The water turbine with typical range of heads.

Type	High head	Medium head	Low head
Impulse turbines	Pelton Turgo	Cross-flow multi-jet Pelton Turgo	Cross-flow
Reaction turbines		Francis	Propeller Kaplan

Source : [14].

Table 2.3 The water turbine typical range of net head, discharge and power capacity.

Head Range	Capacity classification	Turbine type	Net Head (m)	Discharge (m^3/s)	Capacity (kW)
High Head	Large-Medium Capacity	Vertical Shaft Pelton Turbine	200 or more	2 or more	3000 or more
	Medium-small Capacity	Horizontal Shaft Pelton Turbine	70 or more	0.2~3	100~500
Medium Head	Large Capacity	Vertical Shaft Francis Turbine	30~300	2 or more	2000 or more
	Medium-small Capacity	Horizontal Shaft Francis Turbine	15~200	0.4~20	2000~5000
	Small Capacity	Cross-Flow	5~100	0.1~7	30~1000
Low Head	Large Capacity	Vertical Shaft Kaplan Turbine	10~20	14 or more	2000 or more
	Medium-small Capacity	Tubular Turbine	3~20	4 or more	100~4000 or more

Source : [16].

b) Turbine Efficiency

Selecting the right turbine is one of the most important parts of designing a micro-hydropower system. The skills of an engineer are needed in order to choose the most effective turbine for a site, taking into consideration cost, variations in head, and variations in flow, the amount of sediment in the water and overall reliability of the turbine. Typical efficiency ranges of turbines and water wheels are given in table 2.4.

Table 2.4 Typical efficiency of water turbine and water wheel.

Type of turbine	Prime Mover	Efficiency Range [%]
Impulse turbine	Pelton	80-90
	Turgo	80-95
	Cross-Flow	65-85
Reaction Turbine	Francis	80-90
	Pump-as-turbine	60-90
	Propeller	80-95
	Kaplan	80-90

Source : [13].

4) Electrical Work

a) Generator

Generators convert the mechanical (rotational) energy produced by the turbine to electrical energy. It is the heart of any hydroelectric power system. The principle of generator operation is quite simple as when a coil of wire is moved past a magnetic field, a voltage is induced in the wire. There are two types of generators, i.e., synchronous and asynchronous. Synchronous generators are standard in electrical power generation and are used in most power plants. Asynchronous generators are more commonly known as induction generators.

The rotation speed of the generator is determined by the flowing equation based on the frequency rate of generated electricity and the number of poles.

$$N = \frac{120f}{p} \tag{2.3}$$

Where, N : Rated revolution voltage (rpm),

f : Rated frequency,

P : Number of poles.

(i) The synchronous generators are widely used to generate the three-phase alternating current with low-voltage terminal voltage for small capacity. This generator type induces the voltage in armature coil by rotating magnetic poles. There are several types of exciter system such as Separate Excitation type, Static Excitation type, and Alternate Current Excitation Brushless type. The Brushless type generators are often used in small hydropower plant because there are easy to maintain. Full-load efficiencies of synchronous generators vary from 75 to 90 percents, depending on the size of the generator.

(ii) Induction generators are generally appropriate for smaller systems. They have the advantage of being rugged and cheaper than synchronous generators. The induction generator is a standard three-phase induction motor, wired to operate as a generator. The efficiency of induction generators is approximately 75 percent at full load and decreases to as low as 65 percent at part load. Induction generator has a rotating structure compose of a primary and secondary winding, and electricity is generated through electromagnetic induction between the windings. Generally, this type of generator can not generate independently. Operation must be established by supply excitation current to primary winding from another power source. However, it tends to be applied to small/micro-hydropower plant because of its low cost, simple maintenance and easy operation and control.

b) Transmission/Distribution Network

The most common way of transporting electricity from the powerhouse to homes is via overhead lines. The size and type of electric conductor cables required depends on the amount of electrical power to be transmitted and the length of the power line to the home's user through a complex network of individual components, including transmission lines, transformers, and switching devices. For most micro-hydropower systems, power lines would be single-phase systems. For larger systems, the voltage may need to be stepped up using a transformer or a standard three-phase system in order to reduce transmission losses.

It is common practice to classify the transmission network in to the following sub systems :

- Transmission system,
- Sub transmission system,

- Distribution system.

Transmission system interconnects all major generating station main load center in the system. It operates at the high voltage levels (typically, 115 kV and above). The generator voltages are usually in the range of 11kV to 35kV. These are stepped up to the transmission voltage level, and power is transmitted to transmission substation where the voltage is stepped down to the sub transmission level.

5) Control System Hydropower Plant

a) Governor

The governor adjusts the water inflow mechanism such as guide vanes, needle valves and deflectors, turbine rotation speed and power output. As the part that adjusts the water inflow requires the large force, a hydraulic servomotor is used for medium-small scale hydroelectric power.

For small hydropower, an electric servomotor is applied due to its accuracy as well as its easy to maintenance and inspection. The CPU and electric circuit detect control parameters (such as a speed, water level, discharge, and power output), computer requirement range of control, and transmit the signal to the servomotor.

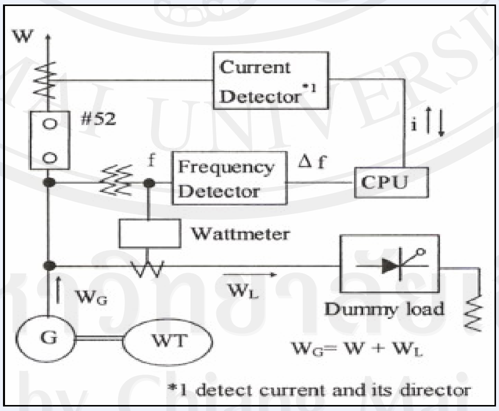

Figure 2.6 The Diagram of Control Power Generated System for Small /Micro-Hydropower Plant [10].

b) Automatic voltage regulator (AVR)

The AVR is used to control the power generation by adjusting the excitation current in the synchronous generator. It detects a voltage change in the generator bus and adjusts the excitation current. There are two types of AVR, the Brushless Excitation AVR which has a small excitation current and easy to control, and the Static Excitation AVR requires the large current and the time constant.

2.4 Consideration of the Interconnection to the Grid System

Interconnection to the grid utility usually lead to improve the system security and economy of operation, thus the interconnected to the grid may consider with the following cases :

1) The energy capacity can provide for the maximum load,

2) To improve the stability of the power system,

3) Requirement on the additional energy generation is based on the generator capacity,

4) The studying the economic viability at the peak demand (peak load).

The parameters can result in synchronizing system and the interconnecting to the grid which are more reliable, and to assist in the decision making on selecting the appropriated synchronizing system.

2.4.1 Synchronous Procedure

The process of interconnecting of two or more synchronous machines or the synchronous machine on to the power system (known as a grid) is known as synchronizing. In general, when a synchronous generator is connected to the grid, its rotor speed and terminal voltage are fixed by the grid and it is said operating on infinite bus bars.

Before a synchronous generator can be synchronized on to infinite bus bar the following condition must be satisfied :

1) The voltage of generator must be equal to that of bus bars,

2) The frequency of the generator must be equal to that of the bus bars,

3) The phase sequence of generator must be the same as that of the bus bars, and

4) At the instant of synchronizing, the voltage phases of the generator and the bus bars must coincide.

Synchronizing may achieve with the help of synchronizing lamps where the rotary lamp method being the most popular. Alternatively, a device known as the synchroscope may conveniently be used to facilitate synchronizing.

The basis process of synchronizing of the synchronous machine on to the power system (known as a grid) is show in the figure 2.7.

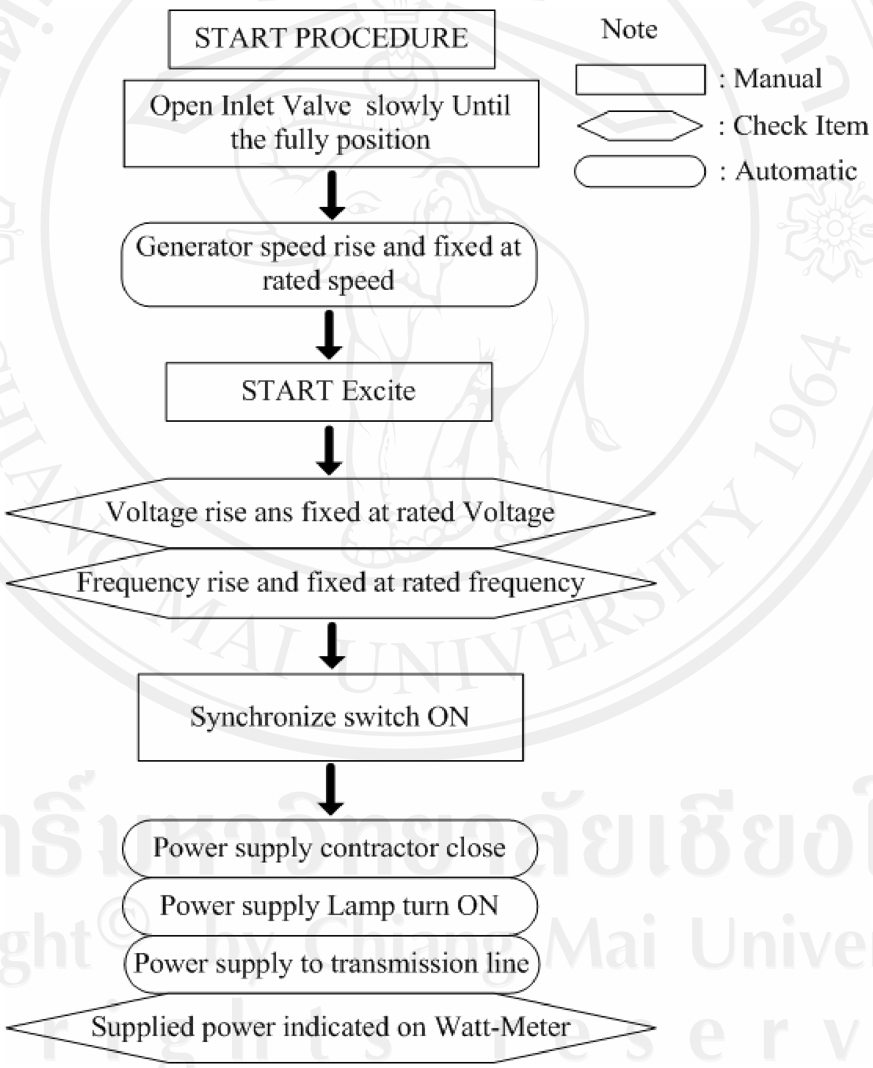

Figure 2.7 The basic process of synchronizing electrical power machine to the power grid [17].

2.5 Hydropower Basis

2.5.1 Measuring Water Flow Method

1) Flow Data of Water

Flow rate is the quantity of water available in a stream or river. It may vary widely over the course of a day, week, month and year. In order to adequately assess the minimum continuous power output expected from the micro-hydropower system, the minimum quantity of water available must be determined. The purpose of a hydrology study is to predict the variation in the flow during the year. It is important to know the mean stream flow and the extreme high- and low-flow rates.

2) Flow Rate Measurement Method

In general, the water discharge shall be measured daily or hourly .An essential discharge rating has to be investigated, especially in the dry season.

There are a variety of techniques for measuring stream flow rate. The most commonly used are briefly explained in this section. The river discharge can be derived using the following basic equation :

$$Q = V \times A \tag{2.4}$$

Where,

Q:	Discharge	(m^3/s)
V:	Mean Velocity	(m/s)
A:	Cross-Sectional Area	(m^2)

The determination the discharge of small/micro-hydropower plant is based on the following :

a) Determination of the minimum power discharge is based on the available minimum discharge for power generation (90% ~95 % dependable on discharge in general target).

b) Determination of the maximum power discharge depends on the peak load demand and the available discharge during the rainy season.

The relationship between the minimum and maximum power discharge is illustrated in the Figure 2.8.

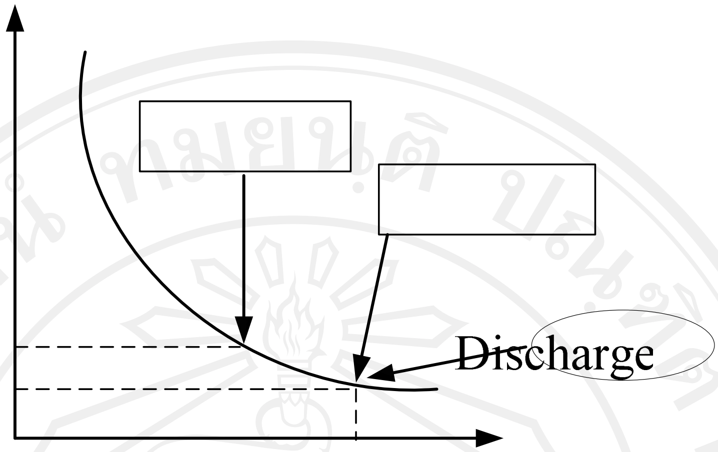

Figure 2.8 Relation between the maximum discharge and minimum discharge [10].

2.5.2 Determination Effective Head

The Head is the difference in elevation between two water surfaces. It is normally measured in meters :

1) Design head

Design head is the head at which the turbine will operate to give the best overall efficiency under various operating condition.

2) Gross head

Gross head is the difference of elevation between the water surfaces of the forebay and tailrace under specification condition.

3) Net head (effective head)

An effective head is to be used to estimate the power output. It can be obtained as the difference between full Supply water Level (FSWL) at the head tank or Intake Dam and Tail Water Level(TWL) at the powerhouse after deducting the head loss. The head loss between the head tank and the power house are expressed as follow :

Effective Head $H_e = H_g - H_{loss}$ (2.5)

Where, H_g: Grosses Head (m),

H_{loss}: Head Loss (m),

H_{loss} = *Major Head loss - Minor Head Loss*

The energy equation represents elevation, pressure, and velocity forms of energy. The energy equation for a fluid moving in a closed conduit is written between two locations at a distance (length) L apart. Energy losses (Head Loss) for flow through ducts and pipes consist of major losses and minor loss. Major losses are due to friction between the moving fluid and the inside walls of the duct. Minor losses are due to fittings such as valves and elbows. Major losses are computed using The Darcy-Weisbach friction loss equation (which utilizes the Moody friction factor) the Darcy-Weisbach method is generally considered more accurate method. Additionally, it is valid for any liquid or gas.

a) Major Head Loss

For determining the major head loss the Darcy- Weisbach Equation is used :

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \quad (2.6)$$

Where, f : Moody friction factor,

L : Total Pipe Length (m)

D : Inside pipe diameter (m)

V : Fluid velocity in the pipe (m/s)

g : Accelerated gravity (m/s^2)

The Reynolds Number and Related roughness are used to define the Moody friction factor (*f*) and the influential factors to fluid flows characteristics (Lamina flow or Turbulent flows) are velocity and viscosity of the fluid throughout the duct dimension. The Reynolds Number is shown of the fluid flow characteristic, and it is expressed with the formula :

$$N_R = \frac{\rho}{\mu} DV \qquad (2.7)$$

Where, N_R : Renold-Number (Unit-less),

$v = \frac{\mu}{\rho}$: Kinematics Viscosity (m^2/s),

ρ : Mass density (kg/m^3),

μ : Coefficient of Viscosity ($N.s/m^2$),

D : Inside pipe Diameter (m)

V : Fluid Velocity in the pipe (m/s).

$N_R < 2000$ If Lamina flows,

$2000 < NR < 4000$ Transition between Laminar and Turbulent flows,

$N_R > 4000$ Turbulent flows.

b) Minor Head Loss (h_m)

The minor head loss is head loss at trash rack, head loss at penstock inlet, head loss due to bend.

$$h_m = k\frac{v^2}{2g} \qquad (2.8)$$

Where, k: Minor Loss Coefficient (Unit-Less),

V: Velocity (m/s).

2.5.3 Determination Power Capacity and Annual Energy

The hydropower scheme requires both water flow and drop in height (called "head") to produce electric power. The rehabilitation on small and micro-scales hydropower plant depends on the available size of the river flow and head. For the preliminary estimation of potential power, the combined efficiency of small hydropower plant varies from 50% to 70%. The power output "Installed capacity" of the identified site is calculated by the following formula :

$$P = 9.8 \times E_f \times H_e \times Q \tag{2.9}$$

Where, P : Power output (kW),

Q : Power discharge (m^3/s),

9.8 : Acceleration of gravity value (m/s^2),

H_e : Efficiency head (m),

E_f: Combined efficiency of power plant.

The power output above is the magnitude of energy generated in one-second. When generated continuously, the work load is called the "energy generation" and is expressed in the Kilowatt-hour (KWh) or megawatt-hour (MWh).

The rehabilitation or improvement of hydropower plants are essential to consider the total energy generated in a year, called the "Annual Energy". It is defined by the formula :

$$Annual\ Energy\ (kWh/year) = P \times 24\ hours \times 365\ days. \tag{2.10}$$

2.5.4 Determination Plant Factor (PF)

The Plant Factor (PF) has a major influence on the cost of power and usually limited in variation of water supply. It is the ratio of the energy that the plant actually produces between a year period, called (Annual Energy Production), by the install capacity throughout the period. It is expressed with the formula :

$$Plant\ Factor\ (\%) = \frac{Annual\ Energy\ Production\ (kWh)}{Installed\ Capacity\ (kWh) \times 8760\ (hurs)} \times 100 \tag{2.11}$$

In general, the design for hydropower plant is considered by plant factor classification as shown in the table 2.5.

Table 2.5 The classification of plant factor of hydropower plant.

Type of Hydropower Plant	Plant Factor (%)	
	Available	In general
Reservoir	16~40	25
Poundage	30~60	40
Run-of-River	50~100	70
Pump Storage	7~20	10

Source : [18].

2.5.5 Assessment Power and Energy Requirements

To assess the feasibility of developing a micro-hydropower system, it should carefully examine power and energy requirements. The needed power is the instantaneous intensity of electricity required to power the appliances of user use. It is measured in kilowatts. The more appliances that are used at the same time, the more power required.

To estimate how much the energy requirement, consider with the following notes :

1) List all user's electrical appliances and lights and note when and how long they are used,

2) The power that each appliance consumes an appliance's power rating is usually written on the back of the appliance and is measured in watts or kilowatts,

3) The number of hours each appliance is used in a typical day,

4) For each appliance, multiply the power rating in watts by the number of hours used each day to obtain the number of watt hours (or kWh) that the appliance is used per day,

5 Energy-use patterns change with the seasons (e.g., lighting is generally used more in summer),

6) Add up the watt hours for all users' appliances.

Table 2.6 Estimation the range electricity energy consumption.

The Number of people	Energy Consumption [kWh]
500-1,000	30-60
1,000-2,000	60-120
2,000-4,000	120-240
4,000-6,000	240-360

Source : [13].

2.6 Economic Evaluation of the Project

In general, the evaluation efficiency for small and micro-scale hydropower plant project is based on the following :

1) Technical soundness,
2) Social and environmental acceptance,
3) Economical efficiency, and
4) Financial viability.

The latter two aspects (3) & (4) are evaluated on the basis of economic and financial analysis respectively. The decision for implement project depends on the profitability of a project comparing the revenue to investment cost. In addition, the financial and economic analysis are important for the study to yield decision that can/can not be the implementation of a project.

Economical evaluation for making decision before selection of the project for implementation is summarized as follows :

2.6.1 Key Comparative Indicator with Time Value

This is a complicated method, but it is used for economic analysis in general. These comparative indicators are given the best alternative solution for evaluating economic and financial viability of the project by using the interest rate of time value. They are shown as follows :

1) Discount Rate

Discount rate allows the present value of money to be completed with its value in the n year's time. This concept allows a relationship to be established between the present and the future worth 1.0 money unit year time corresponds to ($1/(1+r)^n$) today, where r is the discount rate.

2) Present Value (PV)

In the view of time value of money, the future value is considered to be equivalent to a smaller value at present. In other words a present value has increased future value.

The present value (PV) and future value (FV) are related to each other. They are expressed in the term of the following general formula for discounting :

$$PV = FV\frac{1}{(1+r)^n} \tag{2.12}$$

Where, r: Discount rate (%),
n: Year in the future.

Table 2.7 shows an example of present value of the micro-hydro project under the following of and example assumption :

Capital cost	10,000 US$,
Running cost/annual cost	2,000 US$/Year,
Revenue (benefit)	4,000 US$/year,
Project life (n)	10 years,
Discount rate (r)	10%,
Discount Factor	$\frac{1}{(1+r)^n}$

Table 2.7 An example calculation present value.

Year	Capital Cost	Running cost	Total Cost	Benefit	Net Cash flow (B+C)	Discount Factor	Present Value
0	(10,000)		(10,000)		(10,000)		(10,000)
1		(2,000)	(2,000)	4,000	2,000	0.909	1,818
2		(2,000)	(2,000)	4,000	2,000	0.826	1,653
3		(2,000)	(2,000)	4,000	2,000	0.751	1,503
4		(2,000)	(2,000)	4,000	2,000	0.683	1,366
5		(2,000)	(2,000)	4,000	2,000	0.621	1,242
6		(2,000)	(2,000)	4,000	2,000	0.564	1,129
7		(2,000)	(2,000)	4,000	2,000	0.513	1,026
8		(2,000)	(2,000)	4,000	2,000	0.467	933
9		(2,000)	(2,000)	4,000	2,000	0.424	848
10		(2,000)	(2,000)	4,000	2,000	0.386	771
Total	(10,000)	(20,000)	(30,000)	40,000	10,000		2,289

3) Net Present Value (*NPV*)

The project is expected to bring in revenue in the future years after its completion and also incur running cost. It is always expressed together with the discount rate as follows :

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^n} \qquad (2.13)$$

Where, B_t: Benefit in the t-th year,

C_t: Cost in the t-th year,

n: Number of years for evaluation (project life),

t: t-th year counted from the base year,

r: Discount rate (%).

4) Benefit-Cost ratio (B/C)

The Benefit-Cost ratio (*B/C*) is one of an indicator to show the efficiency of an investment for project. It is relied upon as a fundamental analysis method for the large or public sector project. All cost and benefit estimates must be convert to a common equivalent monetary unit at discount rate (interest rate). The equation is as shown in the following:

$$B/C = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^n}}{\sum_{t=1}^{n} \frac{C_t}{(1+r)^n}} \qquad (2.14)$$

This indicator shows the efficiency of the project

If B/$C \geq 1.0$, accept the project as economically acceptable for the estimate and discount rate applied.

If B/*C* ratio < 1.0 the project is not economically acceptable, it means earn less project cost.

If *B/C* ratio value is exactly or very near 1.0, none economic factors for helped make the decision for the "best" alternative.

The conventional *B/C* ratio, probably the most widely used is calculated as follows :

$$B/C = \frac{benefit - disbenefit}{\cos ts} \qquad (2.15)$$

5) Internal Rate of Return (IRR)

The internal rate of return (IRR) is the discount rate to equalize the NPV of benefit and cost as expressed below :

$$\sum_{t=1}^{n} \frac{C_t}{(1+r)^n} = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t} \qquad (2.16)$$

This indicator shows the percentage of interest rate IRR (%) by comparison of the minimum attracted rate of return (MARR).

If IRR $\geq$ MARR, the project will be accepted.

If IRR < MARR, the project will be rejected.

The internal rate of return is generally assumed for the micro-hydroelectric power that it should be greater than 15% [11].

6) Payback Period method

The payback period is the number of period (n_p) usually measured in the years. It will take for estimated revenue and others economic benefit to recover the initial investment and a sate rate of return. Payback analysis can take into two forms: one for discount rate (r> 0%) (also call *discount payback analysis*) and another for (r = 0%). The amount P is the initial investment or fist cost and NCF is the estimate net cash flow for each year (t). If the net cash flow are expected to be equal each year, the discount payback period at the state rate (r>0%), calculate the year n_p that make the following expression [4].

$$0 = -P + \sum_{t=1}^{t=n_p} NCF_t \left(P/F, r, t\right) \qquad (2.17)$$

Where, NCF_t : Net Cash Flow in the t-th year,

(NCF= Receipt-Disbursement),

P: Initial investment cost.

2.6.2 Determination Unit Energy Cost

Unit Energy Cost is an important for financial viability of the small/ micro-hydropower project. This indicator will provide a guide for determining selling price of energy. The Unit Energy Cost is calculated by the following equation :

$$Unit\ Energy\ Cost = \frac{(Ca + Cr)}{E} \tag{2.18}$$

Where, C*a*: Annualized Construction Cost (US$/year or other currency),
C*r*: Annual running cost (US$/year or other currency),
E: Annual energy Output (kWh/year).

It is noted that the annualized construction cost "Ca" shall be give in term of a constant annual sum throughout the life of the project. Therefore, the Unit kWh-Cost varies by the discount rate applied and the project life. The annuity equation provides a simple way of converting the initial construction cost in to annual cost.

$$Ca = C \times Cf \tag{2.19}$$

$$Cf = \frac{r(1+r)^n}{(1+r)^n - 1} \tag{2.20}$$

Where, C*f*: Capital recovery factor,
r: Discount rate,
n: Project life (Service life).

2.6.3 Sensitivity Analysis

Economic analysis uses to estimates of parameter's future value to assist decision making. Since future estimates are always incorrect to some degree, inaccuracy is present the economic projection. The effect of variation is determined by using sensitivity analysis. Sensitivity analysis determines how a measure of worth present worth (NPV), annual worth, rate of return (ROR), or benefit-cost ratio (B/C) and the selected alternative will be altered if parameter varies over a sated range of value.

1) Determination sensitivity of parameter variation

Sensitivity analysis usually concentrates on the variation expected in estimates of the capital cost, savage value, annual operating cost (AOC), estimate the project life (n), Unit Energy Cost, unit revenues, and similar parameters. These parameters are often the result of design question and their answers and discussed on their manner.

There is a general procedure to follow when conducting a through sensitivity analysis as follows :

a) Determine which parameter(s) of interest might vary from the most likely estimate value,

b) Select the probably range and increment of variation for each parameter,

c) Select the measure of worth,

d) Computer the result for each parameter, using the measure worth as a basic, and

e) The better interpret the sensitivity; graphically display the parameter versus the measure of worth.

The sensitivity analysis procedure should indicate the parameters that warrant closer study or required additional information. When there are two or more alternatives is better to use the NPV or annual worth in the step (c), if ROR is used is required the extra efforts of increment analysis between alternatives.

In general, for an investment of any project, the economic analysis viability is very important and the sensitivity analysis was used to determine the variation the parameters which are directly in negative effect to the benefit to the project.