# An Overview of the Key Components in the Pico Hydro Power Generation System

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*Abstract:* - Pico hydro is a green energy that using small river to generate electricity without relying on any sources of non-renewable energy. This alternative energy offers a green scheme that is reliable, efficient and cost-effective. No more concern about the cost of capital, pollution, fuel sources, and life expectancy. On the other hand, many people still lack of knowledge about the working mechanism of the pico hydro generation system. This paper discussed about the key components and overview of the main parts involve in the typical pico hydro system; from the water source until the electrical output. The heart of a pico hydro system is water turbine and based on the literature studies, the selection of turbines is depends on the condition of available water resources. Besides that, employing inaccurate generator, penstock and intake system also affected the efficiency rate of system and simultaneously wastes the water power available. Pico hydro is the best option to improve the living standard of rural people in condition; the system itself needs to be designed properly in line with the available water supply.

*Key-Words:* - generator, green energy, intake system, penstock, pico hydro, water turbine

## 1 Introduction

Pico hydro is a hydro-electric that capable of producing a maximum output power up to five kilowatts. Electricity generated by Pico-hydro is very useful especially to a rural community village that has approximately 30 houses which have small electricity consumption, for example, fluorescent lights and TV or radio [1]-[2]. Pico-hydro is also able to upgrade the living standards of people in poor countries and in rural areas where it is difficult for the government to set up the transmission grid line [3]-[4].

Nowadays, the research works and innovation in developing this green technology is very encouraging. This effort provides many benefits in terms of capacity, cost-effective, the size of the design, and installation compared to other larger hydro. Currently, many developing countries rapidly have implementing the pico-hydro generation system due to anxiety of the fossil fuels shortage and the volatile of oil prices. Furthermore, pico hydro system has become one of the most people's choices because 70% of the earth's surface is covered by water. However, without a good generating system, it will not be efficient and due to that, it is important to have a good turbine system that can utilize all the available water power [5].

This paper will focus mainly on the key components that interconnected in the typical pico hydro power generation system. It has an overview of main components that involve in the development of a typical pico hydro power system.

## 2 Head and Flow

Pico hydro power system is based on simple concepts of hydropower. The moving water will spin the turbine which will cause the drives of the generator and hence, the electricity will be produced. This is the main component in the simple mechanism of hydropower and it is better to begins with the basic concept of the water power, head and flow.

Figure 1 presents two main items that involve in pico hydro generation system as reported by M.F. Basar *et al.* [1]. It should be noted that the water power consists of two important components; namely the head and the flow. Newton's equation state that there will be no electrical power produced by the hydropower generation system if these two components are omitted.

ISBN: 978-1-61804-175-3

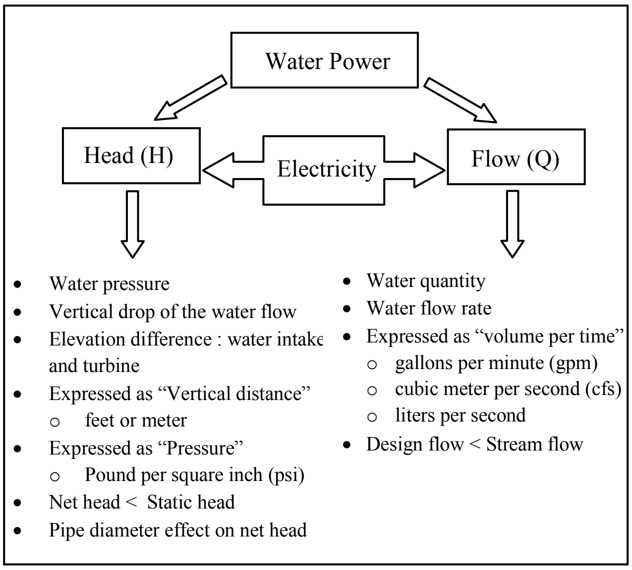


Fig. 1 Head and flow in water power

Head refer to the water pressure where it can easily define as vertical fall of water. Head is developing by the elevation difference of the water intake and the turbine. Head can be expressed as vertical distance (feet, meter) or pressure pound per square inch.

On the other hand, pressure ($P$) can be expressed as a head and it is measured in Newtons per square meter ($N/m^2$) or Pascals (Pa). Pressure is defined as force ($F$) applied per unit area ($A$). According to Newton's equation, force is the product of mass, $m$ (in kg) and acceleration, $a$ (in $m/s^2$). Equation (1) to (7) list all the formulas that can be used to calculate the force, pressure and height or head.

The force can be calculated by using Newton's law;

$$F = ma \quad (1)$$

or

$$F = \rho V a \quad (2)$$

Normally the acceleration of the water is equal to the gravity constant when the water moves freely. Thus the equation to calculate the force is also equal to;

$$F = \rho V g \quad (3)$$

The equations to calculate the pressure are given by;

$$P = F / A \quad (4)$$

or

$$P = \rho V g / A \quad (5)$$

Since volume is equal to height multiplied by area, thus pressure can also be calculated by using these formula;

$$P = \rho h g \quad (6)$$

Manipulate this equation will give;

$$h = P / \rho g \quad (7)$$

In order to produce a given amount of power at high head scheme plant, it is rule of thumb to use small and low cost equipment as compared to the equipment required at low head sites [1]. Moreover, a low head site regularly is not effective in cost. There exist an argument state that; in order to an adequate force for effective power production, it is better to use more head is than more flow. Compared to high head micro hydro, the low head water wheel requires more water to run. Yet, nowadays, there is a research in finding in low flow that proved the system designed capable to produce electricity with high efficiency [5].

Basically, the gross head is the maximum energy produce by the vertical fall of the water, starting from the upstream level to the downstream level. The net head or effective head is the actual head that turbine faces. The net head is slightly less than the gross head due to losses (i.e friction, trash rack, entrance losses, penstock's bending) that occurred during the transformation of the water to the system. Meanwhile, static head is the pressure available when the water is turned off. Normally, the net head is less than static head due to the occurrence of the friction losses between water and pipe. Referring to

The other component that plays an important role in harnessing the water power is the flow. Flow refers to the water quantity and it is also known as water flow rate. It is the volume of water passing per second and it can be expressed as volume per time, with the unit of cubic per meter second. Usually, the maximum flow for the hydro system is designed to be less than maximum stream flow

## 3 Intake

Water from the variable stream flow is taken by the intake at a weir before divert it into the pipelines. Typically, the intake or water diversion is located at the highest point in the pico hydro system. Other advantages of the intake system instead of diverting the stream are to remove dirt and debris and to supply deep enough water in order to set air-free inlet condition to the pipeline. Actually, the existing of air in the system itself can reduce the horsepower that can affect the performance of the turbine [6].

Before entering the pipelines or penstock, the water have to go through filtration process starting from larger debris likes leaves and twigs, dirt and other sediment especially in slow flow water. The entire thing that is not required can be suspended by employing the trash racks and rough screen. Besides that, self-cleaning screen using fine also capable to

ISBN: 978-1-61804-175-3

filters the large debris and small particles. Filtering the water is important in order to maintain the lifetime period and the performance of the turbine.

## 4 Penstock and Power House

Penstock is a pipeline that responsible to moves the water to the turbine located inside the powerhouse. The pipeline actually has a huge effect to the head pressure. The more vertical drop, the more water power will focus at the bottom of the pipeline, where the turbine is situated. On the other side, an open stream does not need any penstock because the energy from the water is obtained as the water flows downhill.

Besides that, the efficiency of the penstock is highly depending on material, length and diameter of pipe. The larger pipelines diameter, the less friction occurred and the more power can be delivered to the turbine but the cost will be more expensive. Table 1 show the head loss in feet per 10 feet of pipeline for polyvinyl chloride (PVC) pipe [6]. It can be seen that as the pipe size increase, the head loss tend to decrease.

Table 1 Head loss in PVC pipe

| Pipe Size (inches) | Head loss (Cubic feet per second) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.05 | 0.10 | 0.20 | 0.33 | 0.45 | 0.66 | 0.89 |
| 2 | 0.128 | 0.465 | 1.680 | 3.570 | 6.060 | 9.920 | - |
| 3 | 0.018 | 0.065 | 0.233 | 0.493 | 0.836 | 1.790 | 3.060 |
| 4 | 0.004 | 0.016 | 0.057 | 0.123 | 0.202 | 0.437 | 0.752 |
| 6 | - | 0.002 | 0.008 | 0.017 | 0.029 | 0.062 | 0.103 |
| 8 | - | - | - | 0.004 | 0.007 | 0.015 | 0.025 |

Instead of piping size, another factor need to be considered is the material of the pipe. The most common piping material used in pico hydro system are polyvinyl chloride (PVC), mild steel, high-density polyethylene (HDPE) and medium-density polyethylene (MDPE). Table 2 shows the relative merits for four type material mentioned above that usually used in penstock of pico hydro [7].

In pico hydro schemes, many people decide to use PVC pipe because it is very elastic, less friction loss and hard to corrosion. PVC pipe also easy to be install and the cost for the installation is cheap and yet easy to carry everywhere. Instead of the price of PVC is cheaper than others, PVC pipe also has various in sizes ranging from 25mm to 500mm. The user will experience a different pressure rating when varying the wall thickness even though generally the outside remain constant. However, PVC is relatively fragile and its surface is easily cracking when continuously exposed to the direct sunlight. Thus, the percentage of losses occurred is high which will also affect the pressure rating of the pipe.

Table 2 Relative merit for material use in penstock

| | Material | | | |
|---|---|---|---|---|
| | PVC | Mild Steel | HDPE | MDPE |
| Friction loss | * * * * * | * * * | * * * * * | * * * * * |
| Weight | * * * * * | * * * | * * * * * | * * * * * |
| Corrosion | * * * * | * * * | * * * * * | * * * * * |
| Cost | * * * * | * * * * | * * * | * * * |
| Jointing | * * * * | * * * * | * * | * * |
| Pressure | * * * * | * * * * * | * * * * | * * * * * |

* = Poor * * * * * = Excellent

An alternative for PVC pipe are MDPE and HDPE even though both are more expensive than PVC. On the other hand, MDPE and HDPE are easy for installation and recommended to be used in pico hydro scheme. These pipes does not need to go through the process of burying, wrapping, painting or covering with foliage as both are not deteriorate when subjected to sunlight. Having the same criteria with PVC, these pipes have excellent friction loss and corrosion characteristics. The disadvantage of these pipes is in the process of joining the pipes as the user needs special equipment for heating the ends and fuses the pipe.

Another type of pipe that most widely used is the mild steel pipe due to its robustness to fight mechanical damage. Yet, it has medium friction loss and relatively heavy. Generally, it is well protected by surface coating, so the life time longer, which is up to twenty years.

The powerhouse is a building which protects the main components in pico hydro generation system that consists of the turbine, generator and system controller. Usually in pico hydro scheme, power house can be picture as a small house, with regard to maintain the efficiency for the system. If the small house is not accurately designed, for example the turbine and generator does not mounted properly, then it can create a head loss, friction loss in joining the pipes and power loss at turbine's moving parts. Thus, it will reduce the efficiency of the pico hydro system.

## 5 Turbine

Turbine is the main parts in the pico hydro system, where the task is to convert water power to rotational force in order to drive the generator. It is important to select the right turbine as most of the losses are due to this component. Besides that, the ratio of the generator speed to turbine should not be more than 3:1 [7]. As for example, if the generator used in the system has 3,000 rpm, thus the selected turbine must able to spin by at least 1,000 rpm. The type of turbines used and generators are varying depending on the head, water flow, local condition, financial plan and equipment availability.

In general, water turbine can be classified into two types; namely impulse turbine and reaction turbine. Table 3 below shows various types of water turbines for small, mini, micro and pico power plants with refer to the head pressure [8]. Most of the impulse turbines are suitable for high head and medium head with low flow site. In contrast, a reaction turbine is used for low head and ultra low head sites with high flow water, without taking into consideration whether it is horizontal or vertical arrangement.

## 5.1 Impulse Turbine

This turbine is axial flow and it is declared as impulse turbine because the occurrence of a direct drive or impulse on the blades which creates by the water. It is operates in open environment with driven by one or more high-velocity jets of water which produce by the nozzle and impinge on the buckets. In the nozzle, pressure head was converted into kinetic energy where the pressure change occurred. The momentum of water that hitting the turbine runners will entirely produced a power of impulse turbine for drive the generator's shaft.

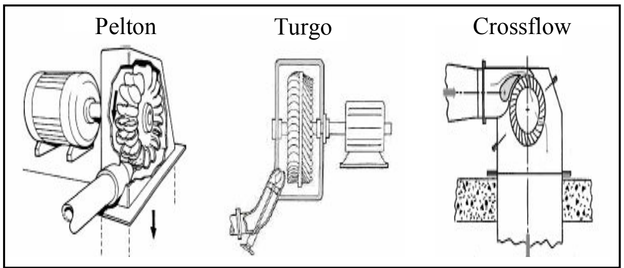


Fig. 2 Various type of impulse turbine for pico hydro

In term of cost, impulse turbines are cheaper than reaction turbines as there is no faultless pressure casing and no carefully engineered clearance are needed. Having the same concept as Pelton and Turgo, it works using the runners which operate without being immersed. Figure 2 shows an example of impulse turbine used for pico hydro power generation. In addition, pelton turbine is commonly employed due to its suitability for a small scale hydro power system and more frequently in pico-hydro system [9]-[10].

Table 3 Various type of water turbine with refer to the head

| Water turbine | | Head pressure | | | |
|---|---|---|---|---|---|
| | | **High Head** | **Medium Head** | **Low Head** | **Ultra Low Head** |
| **Impulse** | Pelton | √ | | | |
| | Turgo | √ | √ | | |
| | Multi-jet Pelton | √ | √ | | |
| | Cross flow | √ | √ | √ | √ |
| **Reaction (Mixed flow)** | Francis horizontal | √ | √ | √ | |
| | Francis vertical | √ | √ | √ | |
| | Francis open flume | | | √ | √ |
| **Reaction (Axial flow)** | Vertical fixed blade Propeller | | | √ | √ |
| | Bulb (Horizontal propeller) | | | √ | √ |
| | Rim (Horizontal propeller) | | | √ | √ |
| | Tubular fixed blade with wicket gates (Horizontal propeller) | | | √ | √ |
| | Vertical adjustable propeller (Kaplan) | | √ | √ | |
| | Tubular with adjustable blades and fixed gates (Horizontal Kaplan) | | | √ | √ |
| | Pump as turbine | | √ | | |
| | Split | | | √ | √ |

A pelton turbine is the best option for the places which have a high head and low flow rates water [11]. It consists of a wheel surrounded with a series of split bucket. The jets water hits each split bucket (split into two halves), so that each halves is turned and deflected back almost through 180 degrees. The bucket will propel when all the energy of the water goes to the bucket and finally the deflected water falls into a discharge channel. As mentioned by Alexander and Giddens [12], the pelton and propeller turbine have been applied in ultra low head and low head (2-40 meters) hydro schemes and it is able to produce power up to twenty kilowatts.

Turgo turbine actually is akin to the pelton turbine but the jet strikes the plane cup of the runner at certain direction or angle. The water enters the runner on one side and exits on the other side. In pelton turbine, it is effective when the jet impinges only on single bucket per jet at any instant, whereas in Turgo wheel, the jet impinges on several buckets continuously. In addition, for an equivalent power, Turgo turbine commonly has a smaller width runner compared to the Pelton.

However, cross flow turbine or also known as Mitchell-Banki turbine is operating with the partial air admission and the runner partly immersed in water even though it is declared in the family of impulse turbine. It work using the water which passes through a large opening with rectangular shape, and hit the runner called squirrel cage. R. Montanari [13] recommended that, to employ a Mitchell-Banki turbine for small head and modest flow rate with respect to the cost benefit and potential power produced. It is because the Francis and Kaplan turbines have high initial cost for the same condition.

## 5.2 Reaction Turbine

According to the Newton's Third Law; for every action, there is an equal and opposite reaction. Reaction turbine is radial flow where it use runner that is fully immersed in water and is enclosed in a pressure casing or volute. It is a machine that suitable for low head and high flow rate water [7]. This turbine is rotate by reactive force rather than direct push. The turbine blades turn in reaction to the pressure of the water falling on them. Figure 3 shows the most popular reaction turbine hydro power systems are Francis, Kaplan and Propeller.

In larger hydro schemes, the most popular turbines is a Francis turbines, although it is generally more complex and expensive machine. This turbine has an outer ring and inner ring. Outer ring is a stationary guide blades fixed to the turbine covering. Inner ring has a rotating blade structuring the runner. The guide blades will be in charge to organize water enters to the turbine in a radial direction and discharged in an axial direction. As the water passes over the rotating blades of the runner, it will cause a reaction force which drives the turbine.


Kaplan

Fig. 3 Most popular reaction turbine

The propeller turbine consists of propeller and it is similar to a ship's propeller. It has three to six blades, however for low head, three blades is adequate. The wicket gates or swiveling gates is responsible to regulate water flow. The propeller turbine has a runner with blades which water passes through the runner in an axial direction with respect to the shaft. The pitch of the blades may be fixed or moveable. One more type of Propeller turbine is recognized as the Kaplan turbine. Kaplan turbine is more sophisticated version of propeller turbine and suitable to be used at large scale hydro sites. The wicket gate can be adjusted to maintain the high efficiency under part flow condition. In addition, the wicket gate is designed to induce tangential velocity or whirl in the water. The dissimilarity of the both turbines is the pitch of the blades can be altered in the Kaplan in order to get a better the results of the power generation process, but this operation is not suitable for the Propeller turbine.

Furthermore, there is a project which employed the pump as turbine (PAT) concept in pico hydro project for isolated communities. One of the projects is 2kW PAT scheme in Lao Peoples Democratic Republic as reported by Mariano Arriaga [8]; the PAT concept is suitable to be used at low head and low flow. Generally, the application of PAT in small hydro systems has advantages in term of cost effective, maintenance and efficiency. The concept is to use a normal water pump, reverse engineer the pump curve for running the pump backwards efficiently, and run the penstock into the normal discharge outlet.

In addition, Abhijit Date presents the first published work regarding on split reaction water turbine (SRT) [14]-[15]. The SRT as shown in Figure 4 is almost similar to the lawn sprinkler and the author also mentioned that this pipe is inspired by the savonius wind rotor. It can be develop with simple method by splitting a plastic pipe into halves and then off-setting their centers between top and bottom plates to create the exit nozzles. The turbine is work when the water enters the bottom cover of turbine and leaves the turbine tangentially with high velocity from the exit nozzles. The water will enter the rotor axially under high pressure or high head and leaves the rotor tangentially. The SRT turbine is small in size, lightweight and able to be used for low head and low flow condition. This turbine is not expensive, as the material used is PVC pipe, thus no corrosion can occur.

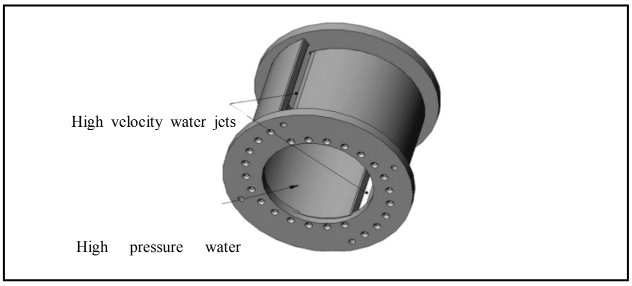


Fig. 4 Split reaction turbine concept drawing

Refer to the theoretically result, this turbine has high efficiency. According to the SRT experimental results, if the water head is fixed, then the rotational speed is increased when the optimum diameter of turbine is reduced. However, the efficiency is less than expected due to jointing or seal frictional losses encountered. But as a whole, this turbine is reliable for the low head and low flow condition.

## 5.3 Turbine Selection

Selection of turbine is very important in the design and development of a hydro power system. R.K Sharma and T.K Sharma [16] explained that there are a few factor need to be considered in selecting a turbine which are based on the specific head, maximum head, head variation, load variation, efficiency of turbines for various load, discharge availability and power house. Chart in Figure 5 can be used as a guide to select the most suitable turbine based on the available head pressure.

The selection of turbine also can be done with refer to the nomogram in Figure 6. This figure illustrate the various type of turbine based on flow rate and net head. Furthermore, the turbine is selected based on the speed range and power capacity of alternator to be used.

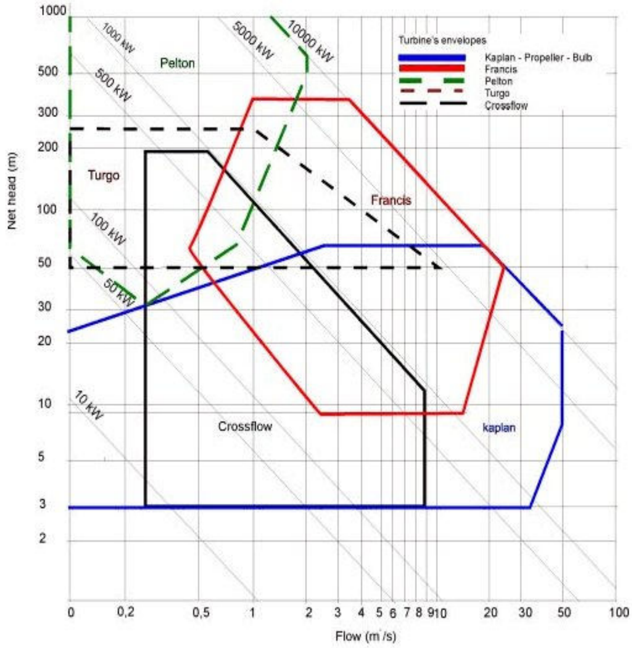


Fig. 5 Turbine selection chart

Besides that, a significant factor in selecting a turbine is their relative efficiencies. Figure 7 shows the typical efficiency curves where the efficiency percentage versus turbine flows relative to design flow. Referring to the curves, Pelton and Kaplan turbines hold very high efficiencies, however, the efficiency of the Crossflow and Francis turbine falls away drastically when operate below half their normal flow.

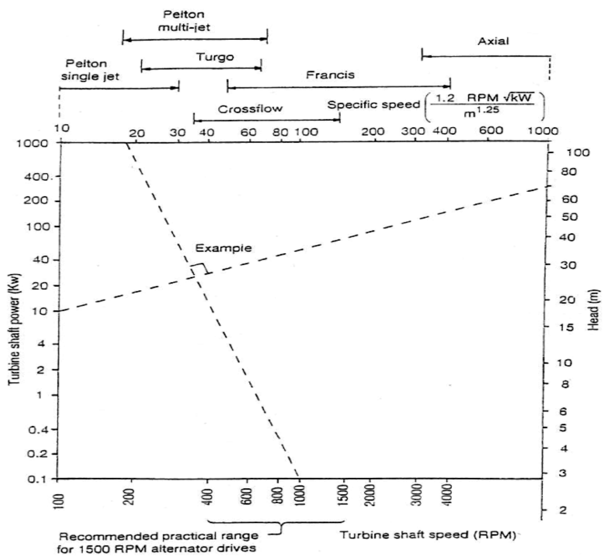


Fig. 6 Nomogram for selection of a turbine

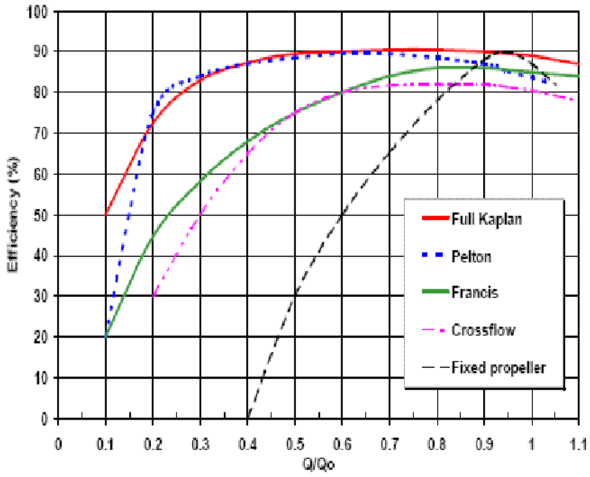


Fig. 7 Typical efficiency curves

## 6 Generator

Generator is a machine used to converts the rotational energy from water turbine into electricity and at this stage; there will be a reduction in efficiency. However, with facilitating the modern technology, well built generators deliver good efficiency. Generating system for a hydro power scheme is selected based on the estimated power of a hydro power system, type of supply system and electrical load, available generating capacity in the market and generator with cost effective

Alternators or DC generators is typically used for small household system. It usually connected with rectifiers, batteries and inverters. In contrast, AC generators whether it is single-phase or three-phase, are typically used with system producing about 3kW or more. Usually, this generator is installed with the voltage regulator and transformer, thus it is able to connect to the transmission lines. An important point to note that, AC has a frequency which determined from the rotational speed of generator shaft. In order to obtain the 50 Hertz or 60 Hertz frequencies, the turbine controller need to be used for regulates the frequency.

Normally, pico-hydro systems use AC generator either induction or synchronous machine type because electrical power produced can be used to supply AC electrical appliances, with controlled by set of modified light dimmers cum dummy load circuits [17].

However, a brush permanent magnet DC generator is preferred in pico-hydro system as proposed by the H. Zainuddin [2]. This generator has a significant advantage compared to AC generator because it is designed to provide high currents at minimum voltage requirement for the charging of battery and operation of direct current loads. This is related with the load type to be supplied. Moreover, permanent magnet generator is selected as it is much cheaper and has smaller overall size rather than of wound field. Other than that, this type of generator is more efficient because no power is wasted to generate the magnetic field [18].

## 7 Conclusion

It should be noted that, there are many components involved in the pico hydro generation system. The heart of this system is a water turbine and turbine selection is based on the availability of the head and flow of water resources. Besides, most people choose to use dc generator to facilitate the charging process but there are also advantages of using the AC generator. Employing inaccurate water turbine, generator, and penstock and intake system also affected the efficiency rate of system and simultaneously wastes the water power available. As a conclusion, the understanding about working mechanisms of the pico hydro is essential for selecting the key component in order to obtain a high efficient pico hydro system.

## 8 Acknowledgment

The authors would like to thank Universiti Teknikal Malaysia Melaka UTeM for the financial support of this project and the permission to publish the work.

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