DESIGN OF PICO-HYDRO TURBINE BY USING A PUMP AS A GENERATOR

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ABSTRACT

Nowadays, hydropower is one of the significant renewable energy that most developed. This source of energy is hugely known as an environmental friendly operation put it as a main choice among other salvage source of energy. The objective of this project is to design a pico hydro turbine that can generate a sufficient amount of energy by modifying an aquarium pump and turn it into a generator. Besides that, the purpose of this project also to build a useful, effective, convenience, reliable, environment friendly and safe to use turbine. The project scopes were to design, modified, analyze and implement it as a renewable source of energy. Different kinds of blade design were used to aid in gathering information on the efficiency of the turbine. This turbine design is efficient, portable and able to operate in many different kind of flow to generate electricity such as using a wind or in the river. The testing for the turbine was carried out to meet the objective of this project. Result from this study can contribute to the future Research and Development (R&D) particularly in the field of small scale hydropower generation.

ABSTRAK

Dewasa ini, kuasa hidro adalah salah satu contoh jenis tenaga yang boleh diperbaharui. Sumber tenaga ini sangat dikenali sebagai salah satu sumber tenaga yang beroperasi secara mesra alam yang meletakkannya sebagai pilihan utama di kalangan sumber pilihan tenaga yang lain. Objektif projek ini adalah untuk membina sebuah hidro pico turbin yang boleh menjana jumlah tenaga yang cukup dengan mengubahsuai pam akuarium dengan mengubahnya menjadi penjana. Selain itu, tujuan projek ini juga untuk membina turbin yang berguna, berkesan, mudah, boleh dipercayai, mesra alam dan selamat untuk digunakan. Skop projek ini adalah merekabentuk, mengubah suai, menganalisis dan melaksanakan turbin sebagai sumber tenaga. Pelbagai jenis reka bentuk bilah telah digunakan untuk membantu dalam mengumpul maklumat mengenai kecekapan turbin. Reka bentuk turbin ini adalah cekap, mudah alih dan mampu beroperasi dalam pelbagai jenis bentuk keadaan seperti menggunakan angin atau di dalam sungai untuk menjana tenaga elektrik .Ujikaji keatas turbin ini telah dijalankn untuk memenuhi objektif projek ini. Keputusan daripada kajian ini boleh menyumbang kepada Penyelidikan dan Pembangunan (R &D) di masa hadapan teruatama dalam penjanaaan kuasa hidro yang kecil.

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LIST OF SYMBOLS

ω	Angular velocity
c	Outer radius of the shaft
ρ	Density
P	Power
r	Radius
A	Area
v	Velocity
T	Torque
J	Polar Moment of inertia
τ_{allow}	Allowable Torque
V	Voltage
I	Current

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Pico hydro refers to the smallest scale in a hydropower plant with a capacity of less than 5kW. Hydro power of this size benefit in term of cost and simplicity from different approaches in the design, planning and installation than those with are applied to larger hydro power. In the energy crisis era, innovations in Pico-hydro technology have made it an economic source of power even in some of the world's poorest and most inaccessible place. Solution such as Pico-hydro turbine is becoming an attractive prospect in satisfying the basic electricity needs of remote communities. It is also a versatile power source.

AC electricity can be produced enabling standard electrical appliances to be used and the electricity can be distributed to a whole village. Common examples of devices which can be powered by Pico-hydro are light bulbs, radio, televisions, refrigerators and food processors. Mechanical power can be utilized with some designs. This is useful for direct drive of machinery such as workshop tools, grain mills and other agro-processing equipment. This thesis explains how to select and install Pico-hydro systems for hilly and mountainous locations.

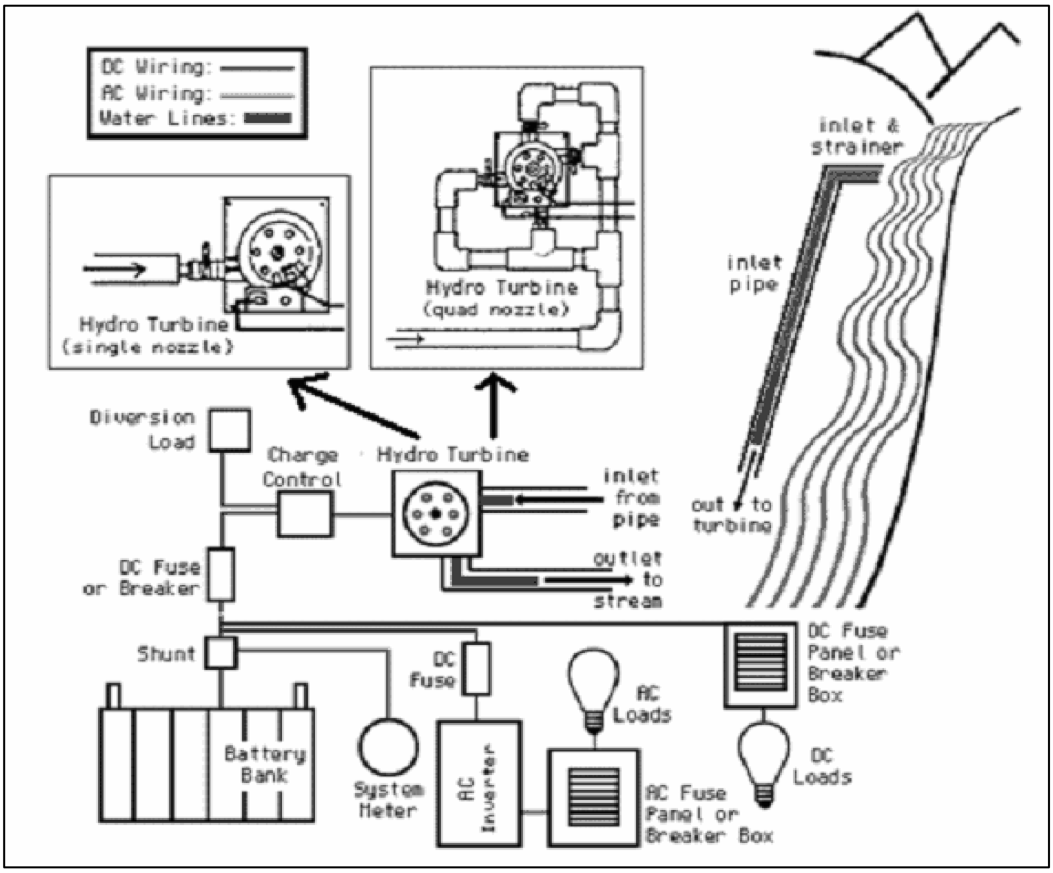

Figure 1.1: Example of Pico-hydro power system.
(Source: Zainuddin, 2009)

Figure 1.1 shows an example of Pico-hydro power system with necessary protection devices, battery storage, inverter and etc. The most important parts to create the electricity are power source (water), turbine, nozzle, pulley system and alterator.

In general, this system will operate using upper water reservoir which is few meter high from ground. From the reservior, water flow downhill through the piping system. This downhill distance is called "head" and it allows the water to accelerate for prime moving system.Thus, the turbine will rotate the alternator to produce electricity. In cold climates, the inlet pipe should be well insulated and even buried underground if possible, to minimize the chance of freezing. A small, one-nozzle turbine can well operate with a 2'' diameter pipe, while a larger 4 nozzle turbine require a 4'' pipe to allow sufficient water flow to reach the generator whell. Smaller diameter penstock would cause excessive friction and energy loss as the water flowed through the pipe.

1.2 PROBLEM STATEMENT

Based on the scenario in Malaysia, the recent price increment of fuel has major impact on the usage of generator. To overcome this burden, other alternative solution must be considered in order to replace the usage of the existing generator. Since the rural settlements are located near to the water supply for the daily needs and activities, therefore, the implementation of Pico-hydro turbine as one of the alternative way to replace the generator is the compatible choice. Furthermore, Pico-hydro turbine has less installation set-up with no involvement of dam or reservoir. It also has the advantage of less maintenance and replacement cost as well as environmental friendly for long-term application.

1.3 RESEARCH OBJECTIVES

Based on the problem statement described in the previous section, therefore the objective of this research are:

i. To modify the existing water pump into a generator
ii. To design a turbine that work efficiently with the generator

1.4 SCOPES OF RESEARCH

In order to achieve the above objectives, the following scopes have been drawn:

i. Modification of water pump motor into a generator
ii. Design a Pico-hydro turbine using pump as a permanent direct current motor.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the basic knowledge which is related to Pico-hydro turbine will be described. The first method is to make a utility study on the fundamental of Pico-hydro system which includes the application and generation system. In addition, make a detail study on the possible of Pico-hydro system focuses on the turbine, motor and etc.

2.2 PICO HYDROPOWER

Pico hydro is a hydro power with a maximum electrical output of five kilowatts (Thake, 2000). Hydro power systems of this size have benefits in the terms of cost and approaches in design, planning and installation than those which are applied to larger hydro power. Pico hydro technology in recent innovation has made it an economic source of power even in some of the world's poorest and most inaccessible places. It is also a versatile power source.

2.3 TURBINES

Water turbine can be classified by the type of generator used or the water resources in the installed place. A water-head turbine is the most generally used system. The turbine rotates by converting the potential energy of water into kinetic energy. Hydro systems have two terms that will be used in designing the turbine namely are head and flow.

The head pressure is determined by the vertical distance the water falls. Meanwhile flow is the quantity of water flowing in a given period of time. This water turbine has the advantage of high efficiency, but the construction cost for a dam or waterway is high and can cause significant environmental problems.

Water turbines used for Pico-hydro are typically two types : reaction and impulse turbine. Reaction turbines rely on a pressure drop in the water across the turbine to transfer energy to the shaft while impulse turbines transfer the moment of a high velocity water jet to the turbine (Thake, 2000).

Both types are commonly used for small scale hydropower with the selection depending on the head and flow rate conditions of the site. Head is often broken down into several classifications, low, medium, and high, define as less than 10m, 10-50m, and greater than 50m respectively (Paish, 2002).

Table 2.1: Impulse and Reaction Turbine.

Turbine Type	**Head Classification**		
	High (>50m)	Medium (10-50m)	Low (<10m)
Impulse	Pelton	Crossflow	Crossflow
	Turgo	Turgo	
	Multi-jet pelton	Pelton	
Reaction		Francis	Propeller
		Pump-as-turbine	Kaplan

(Source: Paish, 2002)

2.3.1 Reaction Turbines

Reaction turbines operate under pressure in an internal flow regime. Water passes through the stator, which takes the form of spiral casings or guide vanes, to introduce swirl into the flow. The flow is then redirected by the runner blades. The angular momentum of the water forces rotation in the runner. In contrast to impulse turbines, the water pressure drops at the stator and the runner (Fraenkel et al.,1991). Examples of reaction turbines include propeller, Kaplan, and Francis Turbines. Reaction turbines often have complex blade geometries and housings, which make them more difficult to manufacture at smaller scales in a developing country setting. However as seen in Table 2.1, reaction turbines can perform well even in the low head range (less than 10 m), making them more desirable since low head water sources are more accessible and closer to end-use location (Paish, 2002). Pictures of various reaction turbines are shown in Figure 2.1 and Figure 2.2.

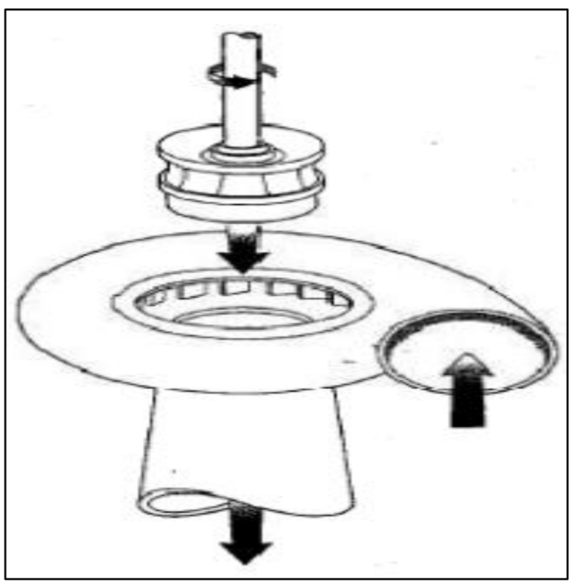

Figure 2.1: Example of a Francis turbine

(Source: Thake, 2000)

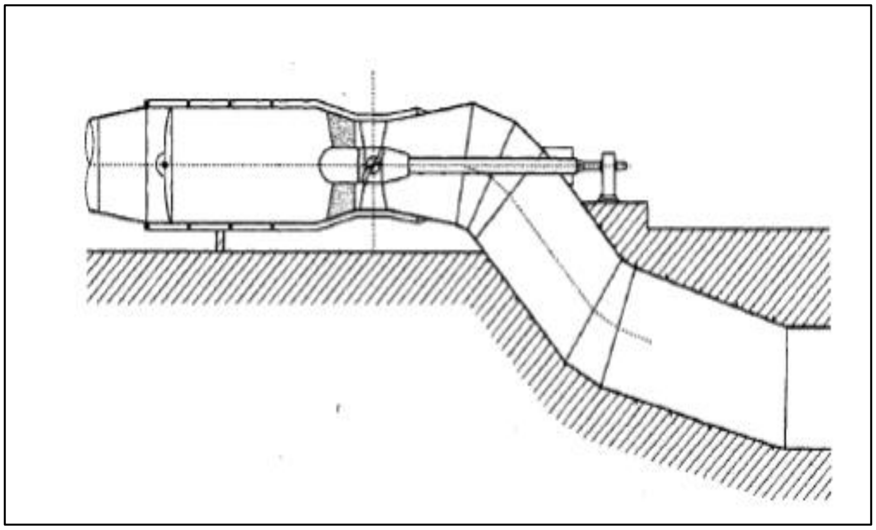

Figure 2.2: Propeller of Kaplan turbine
(Source: Thake, 2000)

2.3.2 Impulse Turbines

Pressurized water from the penstock is converted to high-speed water jets that transfer the kinetic energy of the jet by impacting the turbine blades or cups causing rotation.The pressure drop in the water flow occurs at the nozzle and the runner operates at atmospheric pressure (Fraenkel et al., 1991).

Examples of impulse turbines include the Pelton wheel, Turgo wheel, and cross-flow (Banki-Michell) turbines. Impulse turbines generally operate best with medium or high head (above 10 m).

A Pelton turbine, shown in Figure 2.3, is usually used for high head and low flow rate conditions (Williams, Simpson, 2009). Pelton turbines offer high operating efficiency over a wide range of flow conditions, are widely available, and are fairly inexpensive to manufacture making them a common choice for high head applications.

Due to the cup design however, higher flow rates tend to lead to interference between water entering and with the water exiting the bucket resulting in poor efficiency at high flow rates. Empirical data suggests that turbine efficiency begins to drop when nozzle diameter exceeds approximately 11% of PCD (Thake, 2000). Above this limit, flow interactions inside the turbine cups become more significant and reduce turbine efficiency.

Though turbine efficiency drops when nozzle diameter exceeds 11% of PCD, it may still be advantageous to use a larger nozzle, provided the power increase resulting from the higher flow rate offsets the power lost to the reduction in efficiency (Williams, Simpson, 2009). Larger flow rates can also be achieved by adding additional jets. For pico-hydro, up to 4 jets are commonly used on vertical axis and up to 2 jets on horizontal axis installations (Thake, 2000) .Turbines ranging in pitch-circle-diameter (PCD) from 100 to 400 mm can cover most applications up to 100 kW with heads up to 200 m, where PCD is the diameter of the turbine measured to where the jet strikes the turbine.

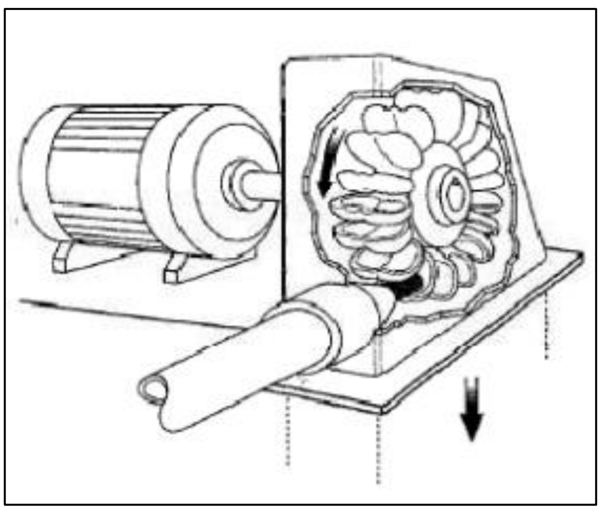

Figure 2.3: Example of a Pelton Turbine
(Source: Thake, 2000)

A Turgo turbine, as shown in Figure 2.4, like the Pelton turbine, is also useful for high head and low flow rate conditions. Additionally, since water passes through the Turgo turbine (i.e. in one side and out the other) higher flow rates can be handled. With higher flow rates, Turgo turbines can operate effectively at lower head conditions than the Pelton turbines but are still classified as medium to high head turbines.

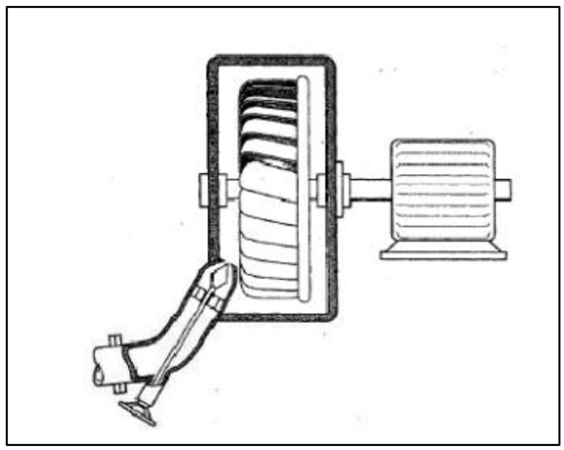

Figure 2.4: Example of a Turgo Turbine
(Source: Thake, 2000)

A cross-flow turbine, pictured in Fig. 2.5, is used for low head and high flow rate conditions. A rectangular nozzle directs the water flow across the width of the turbine. Most of the water's kinetic energy is transferred to the runner as it enters with a little more imparted upon exiting the turbine. They typically have lower peak operating efficiencies compared to other turbines but can operate near peak efficiency for a wide range of flow conditions, unlike other low head turbines such as propeller and Francis turbines. Figure 2.6 shows turbine efficiency as a function of the proportion of design flow for different turbine types. A well designed (fully engineered) cross-flow turbine can achieve an efficiency as high as 85%; whereas, locally-made versions tend to fall in the 60-75% efficiency range (Harvey, Brown, 1993).

Cross-flow turbines also tend to be easier to manufacture than other low head turbines because:

i. They do not require complicated turbine cases.
ii. The turbine geometry is simpler.

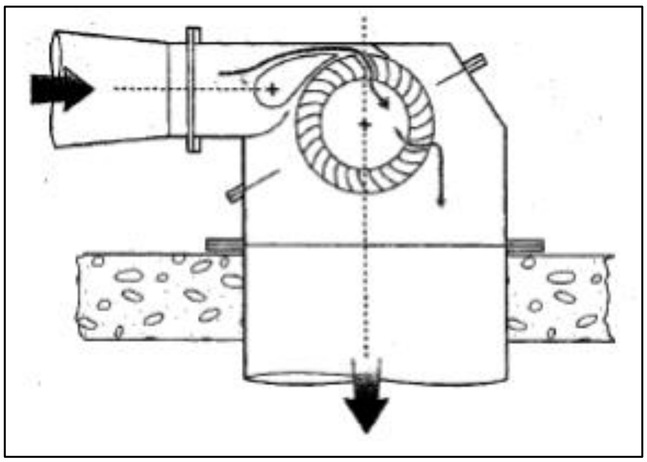

Figure 2.5: Example of a Cross Flow Turbine
(Source: Thake, 2002)

Difference types of turbines can be selected to best suit given head and flow conditions. Figure 2.6 shows the typical application range of various turbines.

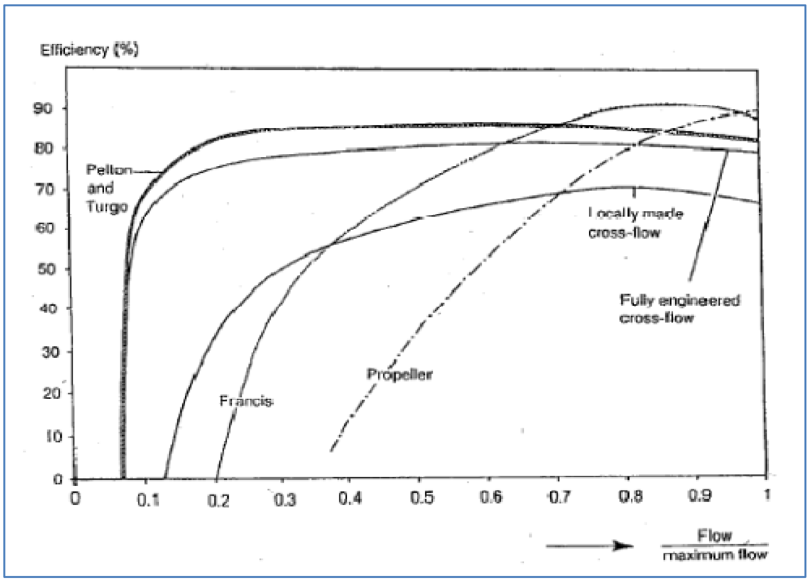

Figure 2.6: Turbine efficiency vs. proportion of design flow for various turbine types (Source: Harvey, Brown,1993)

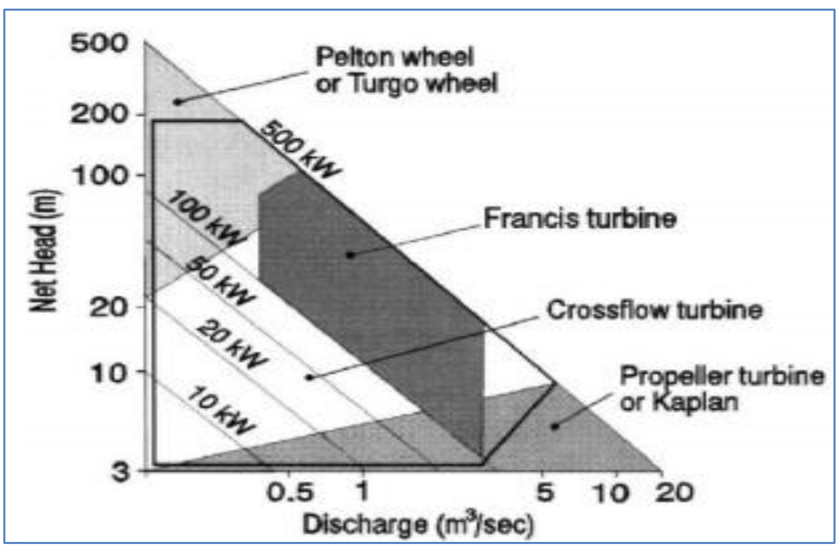

Figure 2.7: Turbine selection chart based on head and flow rate (Source: Fraenkel et al., 1991)

2.4 PICO-HYDRO POWER GENERATION CASE STUDY

2.4.1 Peltric Set

The 'Peltric Set' was developed at Kathmandu Metal Industry in Nepal and is shown in Figure 2.8. A vertically mounted induction generator is directly couple to a Pelton turbine. The turbine casing also forms the base for the generator which makes the design simple and economical with material. AC electricity is generated which means that the power can be distributed economically over hundreds of meters. There are approximately 500 unit types electrifying villages in Nepal at present time.

Figure 2.8: The Peltric Set developed at Kathmandu Metal Industry in Nepal.
(Source: Lahimer, 2011)

2.4.2 Columbian Alternator System

Columbian Alternator system has been designed at FDTA (Fundacion Desarollo de Technologias Appropiades) in Colombia, South America.The turbine runner is also a small Pelton wheel but a 12V DC car or truck alternator is used as a generator.

The turbine is coupled to the alternator using a pulley belt and mounted on a simple steel-angle frame that is easy to manufacture. The installation of this design is shown in Figure 2.9

Figure 2.9: A Colombian manufacturer installing a DC Pico-Hydro Generation system (Source: Lahimer, 2011)

The turbine shaft of the system is horizontal; it is possible to run other machines with hydro-power in addition to the generator. It has been highlighted that this design has been used to provide the energy source for a mechanical refrigerator. No extra control system is required other than voltage regular which is already included with the alternator. Since Direct Current (DC) is generated, no frequency regulation is required but the electricity must be used close to or at the powerhouse. Pico Power Pack combines the low-cost steel angle base and horizontal shaft of the Columbian alternator unit with the simple design of a Pelton turbine directly driving an induction motor used with the Peltric Set.

2.4.3 Pico Power Pack

The 'Pico Power Pack' components are shown in Figure 2.10. The generator is mounted horizontally on a steel angle (Phil Maher & Nigel Smith, 1999). Since AC (Alternating current) is generated, the system is suitable for electrifying houses that are up to one kilometer away from the powerhouse, same as the 'Peltric Set'. The removable case makes it easy to inspect the turbine and the nozzle and to clean them when necessary. The generator shaft is extended at the opposite end from where turbine is attached.

This allows a pulley to be fitted. Small machines such as mills, grinding wheels or saws can be driven with a pulley. In this way, the hydro-power can be used for a wider range of productive purposes. The extra money made through running a small business using Pico-Hydro power, makes it easier to repay the cost of the scheme.

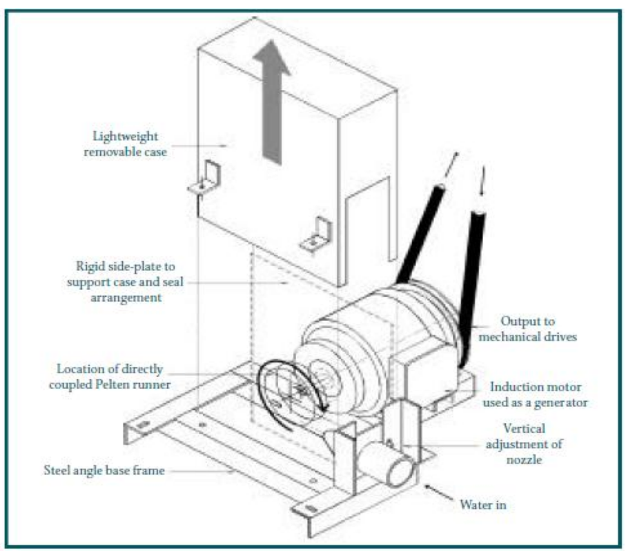

Figure 2.10: Diagram of 'Pico Power Pack' system

(Source: Mayer, Smith, 1999)