UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PROJECT COMPLETION REPORT
FOR
SHORT TERM RESEARCH GRANT

OPTIMIZATION OF CROSS-FLOW TURBINE
FOR
PICO-HYDRO SYSTEM

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ABSTRACT

One of the main obstacles of rural electrification programs in most of the develop countries nowadays is to replace the traditional usage of power sources such as generator and firewood. The ever increasing of fuel price recently created more burdens to the villagers to maintain the application of generator. On the other hand, the usage of firewood to light up houses and for cooking purposes resulted unhealthy condition to the communities such as respiratory and eyesight problems. Therefore, it is necessary to find out suitable and reliable alternative renewable energy to provide cheap and clean power source. Since most of the rural settlements are located near to the rivers, hydro based is suggested to replace these traditional methods of producing the power supply. In this particular case, the application of Pico-hydro turbine is preferred due to its cost effectiveness. Pico-hydro turbine can produce power output of maximum 5 kW and can be operated under low head with low flow rate of water. In this research, cross-flow turbine, a type of pico-hydro turbine which capable to operate under low head has been chose. This type of turbine does not required expensive construction and huge reservoir for water storage. In this short-term project, the cross-flow turbine will be fabricated in-house. At the end of the research, the fabricated cross-flow turbine should be able to run under low head with low flow rate condition. From the CFD analysis results, the maximum velocity of the streamline for flow rate 50 l/s was 9.742 m/s. On the other hand, the factor of safety of the main structure for the cross-flow turbine was 255.819 and the factor safety of the runner blades was 15.7204.

ABSTRAK

Salah satu halangan utama program bekalan elektrik luar bandar di kebanyakan negara-negara membangun ialah untuk menggantikan penggunaan sumber kuasa tradisional seperti penjana elektrik dan kayu api. Peningkatan harga bahan api baru-baru ini mengakibatkan bebanan yang lebih tinggi kepada penduduk kampung untuk menggunakan penjana elektrik. Sebaliknya, penggunaan kayu api untuk pencahayaan di rumah-rumah dan untuk tujuan memasak mengakibatkan kesan yang tidak sihat kepada masyarakat seperti masalah pernafasan dan penglihatan. Oleh itu adalah perlu untuk mencari tenaga alternatif sesuai yang boleh diperbaharui untuk menyediakan sumber kuasa yang murah, bersih dan boleh dipercayai. Oleh kerana kebanyakan penempatan di luar bandar terletak berhampiran sungai-sungai, sumber kuasa berasaskan air dicadangkan untuk menggantikan kaedah tradisional dalam penghasilan bekalan kuasa. Dalam kes ini, penggunaan Pico-hidro turbin atau lebih dikenali sebagai turbin aliran silang menjadi pilihan kerana kos yang murah. Pico-hidro turbin boleh menghasilkan output kuasa maksimum 5 kW dan boleh dikendalikan pada ketinggian yang rendah dengan kadar aliran air yang rendah. Turbin jenis ini juga tidak memerlukan pembinaan yang mahal dan takungan besar bagi simpanan air. Dalam projek penyelidikan ini, objektif utama ialah untuk mereka bentuk keseluruhan sistem turbin aliran silang. Di penghujung projek penyelidikan ini, turbin aliran silang yang direka haruslah dapat berfungsi pada situasi ketinggian yang rendah dengan keadaan kadar aliran juga adalah rendah. Halaju maksimum garis aliran untuk kadar aliran air 50 l/s adalah 9.742 m/s. Faktor keselamatan untuk struktur utama adalah 255.819 manakala faktor keselamatan untuk bilah turbin pula adalah 15.7204.

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LIST OF SYMBOL

m	=	Mass of water (kg).
g	=	Acceleration due to gravity (9.81 m/s^2),
H	=	Effective pressure head of water across the turbine (m).
c	=	Jet velocity of water at the intake of the turbine blade (m/s).
P	=	Mechanical power produced at the turbine shaft (Watts),
η	=	Hydraulic efficiency of the turbine, ρ is the density of water (1000 kg/m^3),
Q	=	Volume flow rate passing through the turbine (m^3/s),

CHAPTER 1

INTRODUCTION

1.1 PICO HYDRO SCHEME

Pico hydro is a type of hydropower which capable to produce electrical output up to 5 kilowatts. Pico-hydro systems benefit in terms of cost, its simplicity from different approaches in the design, planning and installation compared to those which are applied to larger hydropower scheme. The pico-hydro scheme is more preferred due to its effectiveness in producing power output, cost-effective, clean, user friendly and do not involve with huge construction works. Recent innovations in Pico-hydro technology have made it an economic source of power even in some of the poorest and most inaccessible places around the world gained the benefits from this green technology application. It is also a versatile power source. Alternating Current (AC) electricity can be produced enabling standard electrical appliances to be used and this electricity can be distributed to the whole village.

Common examples of devices which can be powered by Pico-hydro are light bulbs, radios, televisions, refrigerators and food processors. On the other hand, mechanical power can be utilised with some designs. This is useful for direct drive of machinery such as workshop tools, grain mills and other agro-processing equipment.

On a global scale, a very substantial market exists in developing countries for pico-hydro systems (up to 5 kW). There are several reasons for the existence of this market.

a) Often, small communities are without electricity even in countries with extensive grid electrification. Despite the high demand for electricity, grid connection of small communities remains unattractive to utilities due to the relatively low power consumption.

b) Only small water flows are required for Pico-hydro so there are numerous suitable sites. A small stream or spring often provides enough water.

c) Pico hydro equipment is small and compact. The component parts can be easily transported into remote and inaccessible regions.

d) Local manufacture is possible. The design principles and fabrication processes can be easily learned. This keeps some equipment costs in proportion with local wages.

e) The number of houses connected to each scheme is small, typically under 100 households. Therefore it is easier to raise the required capital and to manage maintenance and revenue collection.

f) Careful designed on the Pico-hydro schemes produces lower cost per kilowatt than solar or wind power. Diesel generator systems, although initially cheaper, have a higher cost per kilowatt over their lifetime because of the associated fuel costs.

The principle reasons why the market for Pico-hydro remains untapped due to the Pico-hydro turbine generator units are not available in many countries. Another reason is because only few people know how to design and install completely this particular scheme according to its specification and needs.

1.2 PROBLEM STATEMENT

Currently, power generation at off-grid settlements are provided using diesel or petrol generator, which operating hours are limited with high cost of fuel. In some cases, the villagers are still using firewood as their main source to light up their houses, for cooking and for other daily activities. However the usage of the firewood can harmful to people's health such as respiratory problem and eye sight problem (Alex Zahnd et. al 2009). Therefore to overcome this situation, alternative renewable energy especially hydro based has been introduced in order to replace the usage of the existing generator as well as firewood. In this project, a cross-flow turbine will be designed and fabricated for the application of pico-hydro scheme under low head with low flow rate condition.

1.3 OBJECTIVE

The main objective of this project is to design and fabricate a cross-flow turbine for Pico-hydro scheme under condition of low head with low flow rate of water.

1.4 SCOPE

- To develop technical drawings for a cross-flow turbine which suitable for low flow and low head application.
- To fabricate a complete system of cross-flow turbine.
- To do buy-off test to ensure the cross-flow turbine can be functioned in good condition according to its specifications.
- To do experimental study on the cross-flow turbine for a certain range of flow rates.

CHAPTER 2

LITERATURE REVIEW

2.1 HYDROPOWER

Hydropower is one of the energy sources that come from the force of moving water. The fall and movement of water is a part of continuous natural cycle which called the water cycle. Energy from the sun evaporates water in the earth's oceans and rivers and draws it upward as water vapour. When the water vapour reaches the cooler air in the atmosphere, it condenses and forms clouds. The moisture eventually falls to the earth as rain or snow, replenishing the water in the oceans and rivers. Gravity drives the water, moving it from high ground to low ground. The force of moving water can be extremely powerful.

Hydropower is called a renewable energy source because the water on the earth is continuously replenished by precipitation. As long as the water cycle continues, this particular energy source will not run out (Baumann et al. 2010).

2.1.1 History of Hydropower

Hydropower has been used for centuries. The Greeks used water wheels to grind wheat into flour more than 2,000 years ago. In the early 1800s, American and European factories used the water wheel to power machines. The water wheel is a simple machine. The water wheel is located below a source of flowing water. It captures the water in buckets attached to the wheel and the weight of the water causes the wheel to turn. Water wheels convert the potential energy (gravitational energy) of the water into motion. That energy can then be used to grind grain, drive sawmills or pumps water (Baumann et al. 2010).

In the late 19th century, the force of falling water was used to generate electricity. The first hydroelectric power plant was built at Niagara Falls in 1879. In the following decades, many more hydroelectric plants were built. Inexpensive fossil fuel plants also entered the picture. At that time, plants burning coal or oil could make electricity more cheaply than hydro plants. Soon they began to under-price the smaller hydroelectric plants. It was not until the oil shocks of the 1970s that people showed a renewed interest in hydropower (Baumann et al. 2010).

In 2008, 20% of world total power consumption provided by hydropower. China has become the leader in the hydropower sector in Asia Pacific with a capacity of 146 GW at that time. This has been highlighted by the operation of Three Gorges Dam in China which is currently producing 300 TW of electricity. Most hydropower available around the world can be categorized as large hydro (Baumann et al. 2010).

2.1.2 Classification of Hydropower

Hydropower plant can be classified according to the size of electrical power produce as shown in table 2.1.

Table 2.1: Classification of Hydropower (Adewoyo, 2009)

CLASS	POWER
Large Hydropower	More than 50 MW
Small Hydropower	30 MW to 50 MW
Mini Hydropower	100 kW to 30 MW
Micro Hydropower	5 kW to 100 kW
Pico Hydropower	Less than 5 kW

However most experts agree that hydropower of more than 1 MW cannot be considered as renewable (K. Sopian et al. 2009). This is due to factors which reducing its capacity after a number of years. Water reservoir or dam also leads to environmental damages and remove people from their roots. While the micro and Pico-hydro may be small compared to hydropower classes of mini to large, they have made significant contribution to remote and off-grid settlements. This small-scaled hydropower provides enough power to light-up the community at night. The system does not require dam, instead it uses run-of-river application through penstock to provide the head and flow rate to the turbine.

A pico-hydro is categorized based on its capability of producing the electricity up to 5 kW. Most of the time there will be a trade-off between head and the flow rate. When the stream is small, meaning the flow rate is low, high head will ensure the turbine to provide enough power as required, and vice-versa.

2.2 STATUS AND APPLICATIONS

Developing countries provide at least 70 percent economically feasible sites for hydropower plant (Bartle, 2002). This is referring to large-scale (mini to large classes) hydropower plant. In Malaysia, there is 2400 MW Bakun project with several other mini hydro worth about 40 MW while technically seen to have another 29000 MW potential of hydropower (Lidula, 2007). However the capability of small-scale hydropower scheme is not included despite the availability of potential sites which could benefit the rural community tremendously.

Malaysia has many rivers, big and small, which are capable of producing electricity especially to off-grid settlements living nearby. Even sites with low head (less than 10 m) are worth looking at for their potential (Sadrul Islam, 2002). Due to seasonal variation of depth of these small rivers it is important to choose appropriate turbine for specific locations. Therefore selection criteria of the turbine need to be clarified to suit the head and the flow rate. Several renewable energy hybrid systems using small scale hydro were being tried at various locations. Among them is a project at Taratak Indonesia, which has been successfully in operation using a head of 5.5 m and discharge rate of 240 l/s (Muhida, 2001). Another in Cameroon, a water turbine of 5 kW capacity with available head of 10 m and flow rate of 92.6 l/s is used to provide 24 V DC system (Nfah, 2009).

Some comparisons between pico hydro and solar powered systems have been made to evaluate the feasibility of the renewable energy resources by Maher et al. (2003) in the off-grid electrification options in rural Kenya. Similar assessment was made by Nunes and Genta (1996) at bigger micro hydro turbine (up to 100 kW) for off-grid electrification program in Uruguay. Both hydro systems are cost effective compared to using the solar panels when the settlements are located near river. Therefore smallscale hydro system should be considered, whenever available, due to cost and environmental concerns (Paish, 2002).

Small hydropower schemes combine the advantages of large hydro on the one hand and a decentralized power supply on the other hand. They do not have many disadvantages, such as environmental issues, and high cost of investment in case of large hydro power plant. Small hydro power plants can be connected to electricity grid. Most of them are run-of-river type; they do not have any sizeable reservoir and produce electricity when water provided by the river flow is available, when river dries up generation cesses. The efficiency of small hydro units are ranging from 60% to 90% while modern coal burning units around 43% to 63% (Wazed and Ahmed, 2008).

2.3 PICO HYDRO POWER SYSTEM

A pico-hydro system makes use of the power in falling water. Figure 2.1 shows the layout of a pico-hydro system. Each of the components has been described in more detail below.

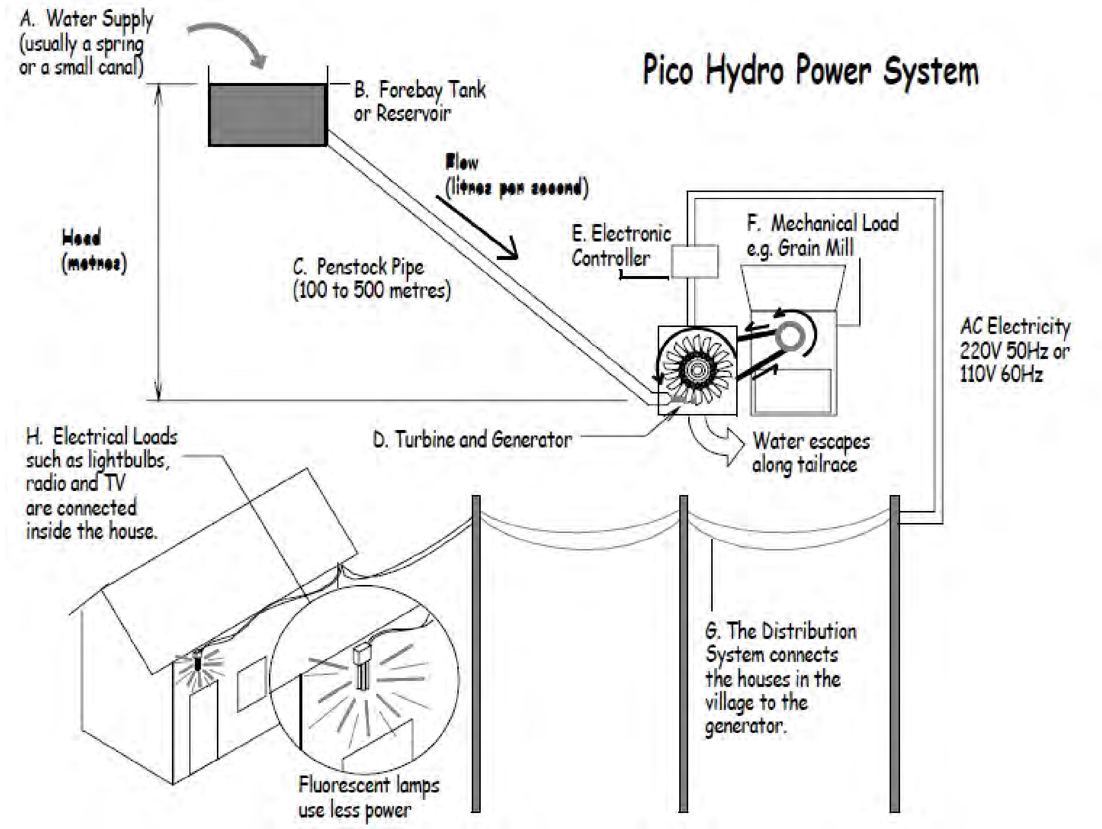

Figure 2.1: Component of Pico Hydro System (Maher and Smith, 2001)

As shown in Figure 2.1, the concept of pico hydropower system can be explained in detail. Firstly from water supply, water will enters the turbine's system and allow the rotor which includes runner blades to rotate. During rotation, the turbine produces kinetic energy which then converted to electric energy by the generator which attached together with its shaft. Next, once when the generator produces electric energy it is then will be distributed to the houses by the distributer system. Detailed explanation about the pico hydropower system can be referred from A to H.

A- The main source of water is a river stream or sometimes an irrigation canal. Small amounts of water can also be diverted from larger flows such as big rivers. Springs make excellent sources as they can often be depended on even in dry weather and are usually clean. This means that the intake is less likely to become silted up and require regular cleaning.

B- The water is fed into a fore bay tank. This is sometimes enlarged to form a small reservoir. A reservoir can be a useful energy store if the water available is insufficient in the dry season.

C- The water flows from the fore bay tank or reservoir down a long pipe called the penstock. At the end of the penstock it comes out of a nozzle as a high-pressure jet.

D- The power in the jet, called hydraulic power or hydro power is transmitted to a turbine runner which changes it into mechanical power. The turbine runner has blades or buckets which cause it to rotate when they are struck by water. The turbine is a general name that usually refers to the runner, the nozzle and the surrounding case. The runner typically spins 1500 times each minute. The turbine is attached to a generator. The purpose of the generator is to convert rotating power into electrical power. This is how the water flowing in a small stream can produce electricity.

E- An electronic controller is connected to the generator. This matches the electrical power that is produced, to the electrical loads that are connected. This is necessary to stop the voltage from going up and down. Without a load controller, the voltage changes as lights and other devices are switched on and off.

F- The Mechanical Load is a machine which is connected to the turbine shaft often using a pulley system so that power can be drawn from the turbine. The rotating force of the turbine runner can be used to directly turn equipment such as grain mills, or woodwork machinery. Although approximately 10% of the mechanical power is lost in the pulley system, this is still a very efficient way of using the power. More power is available because none is lost in the generator or in an electric motor.

G- The Distribution System connects the electricity supply from the generator to the houses. This is often one of the most expensive parts of the system.