# PICO HYDRO: CLEAN POWER FROM SMALL STREAMS

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*Abstract:* - Running the generator and use of battery to light up the house are common to rural folks. The difficulty of getting the fuel and the cost of fuel are the main problems. Use of other alternative renewable energy such as solar photovoltaic modules, which is available for a number of hours per day, is very costly. It is required to find suitable option to provide cheap and reliable option. While large hydropower provides electrical power for industry and domestic use, small-scale hydro is making some contributions toward providing this basic need to remote and off-grid areas especially in developing countries. This paper is focusing on pico hydro, a run-of-river application which does not require dam or reservoir for water storage. It is cost effective, environmentally friendly and the turbine can be manufactured locally. Several applications in developing countries are highlighted. Small-scale hydro turbines are reviewed and their applications at power production environment. Finally, the paper also discusses the efforts made by Universiti Kebangsaan Malaysia (UKM) to promote this technology for rural electrification program.

*Key-Words:* - Pico hydro, small-scale hydropower, turbine, rural electrification, run-of-river

## 1 Introduction

Hydropower provides about 20% of world total power consumption. In Asia Pacific China has become the leader in the hydropower sector with a capacity of 146 GW at the end of 2008. This has been highlighted by the operation of Three Gorges dam in China which is currently producing 300 TWh of electricity.

Most hydropower available around the world can be categorized as large hydro. The hydropower plant can be classified according to the size of electrical power it produces as shown in table 1.

Table 1 Classification of Hydropower

| Power | Class |
|---|---|
| > 10 MW | Large |
| < 10 MW | Small |
| < 1 MW | Mini |
| < 100 kW | Micro |
| < 5 kW | Pico |

However most experts agree that hydropower of more than 1 MW cannot be considered as renewable. 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 tradeoff 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.

This paper will focus on the pico hydro turbine, its status, application and the turbine technology. Several examples of the application in developing countries will be discussed. Efforts by Universiti Kebangsaan Malaysia (UKM) to promote this technology for rural electrification program will be highlighted.

## 2 Status and Applications

Bartle [1] highlighted the status of hydropower potential, its development and activities. At least there are 70 percent economically feasible sites which can be developed, located mostly in developing countries. This number is just assuming large development hydropower project as such 2400

MW Bakun project is considered as Malaysia only current hydropower activities. Malaysia is technically seen to have another 29000 MW potential of hydropower, yet with only the utilization of Bakun project and several mini hidro worth about 40 MW [2]. The small-scale hydropower scheme is not included despite the availability of potential sites which could benefit the rural community tremendously.

Sadrul Islam et al. [3] looked at the potential sites for small-scale hydro which has low head (less than 10 m). It is important to choose appropriate turbine for these locations due to seasonal variation. Selection criteria of the turbine were highlighted.

Muhida et al. [4] discussed the application of small-scale hydropower in the hybrid system of PV and hydro at Taratak, Indonesia. The system has been in operation successfully at a head of 5.5 m and discharge rate of 240 l/s. In Cameroon, Nfah and Ngundam [5] is also looking at the same thing, the feasibility of hybrid power system. 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.

Maher et al. [6] discussed the off-grid electrification options in rural Kenya. Comparisons between pico hydro and solar powered systems were made to evaluate the feasibility of the renewable energy resources. Nunes and Genta [7] had earlier made the same assessment using slightly bigger micro hydro turbine (up to 100 kW) for off-grid electrification program in Uruguay. Paish [8] reviewed small-scaled hydro which is operating on the basis of run-of-river should be considered due to cost and environmental concerns.

## 3 Turbine Technology

Since each potential site for small-scale hydropower scheme is unique turbine selection is based mostly on the water head and the available flow rate. As the scheme head reduces, the flow rate should be higher. The penstock and turbine should increase proportionally to support the increment [9]. It is important that steps are taken to find successful approaches to provide standardized equipment, engineering designs and implementation methods specifically for a particular location [10].

The power produced by hydropower turbine can calculated using the following equations:

$$P = \eta \rho g H Q \tag{1}$$

$$H = h - h_f \tag{2}$$

$$h_f = f \frac{LV^2}{D2g} \tag{3}$$

$$\eta = \eta_{turbine} x \eta_{generator} \tag{4}$$

Or approximately:

$$P = 7.8HQ \tag{5}$$

P = power output
$\eta$ = total efficiency
$\rho$ = density
$g$ = gravitational constant
$H$ = net head
$Q$ = flow rate
$h_f$ = head friction loss
$f$ = Darcy friction factor
$L$ = pipe length
$V$ = jet velocity
$D$ = pipe diameter

In most cases impulse turbines are used for high head sites, and reaction turbines are used for low head sites. Impulse turbine is embedded in the fluid and powered from the pressure drop across the device. Pelton and Turgo turbines are suitable high head, larger than 50 m, and medium head ranging between 10 and 50 m. Crossflow turbine suitable for medium and low head, which is less than 10 m.

Reaction turbines operate with the flow hits the turbine as a jet in an open environment, with the power deriving from the kinetic energy. Francis turbine in medium head scheme and propeller and Kaplan turbines are suitable for low head applications.

Alexander and Giddens [11] and Alexander et al. [12] discussed the use of Pelton Wheels and propeller turbines for low head hydro systems, which is capable of producing power between 0.2 – 20 kW at head range of 2 – 40 m. Montanari [13] highlighted problem of designing hydro system with small head and modest flow rate if traditional turbines such Kaplan or Francis turbines are used, which has high initial capital cost. He suggested propeller turbines or Michell-Banki turbines due to their costs and potential power produced.

Fig. 1 shows the range of suitability of various types of turbines based on the flow rate and net head. Propeller, Kaplan and crossflow turbines are suitable for low head low flow applications.

Fig. 2 shows the efficiency of typical small scale hydro turbines relative to turbine flow relative to their design flow. Crossflow turbine has significant advantages over other turbines if the flow rate varies a lot during seasonal variations.

Nunes and Genta [7] calculated the cost of using axial flow and cross-flow turbines. They found out the cross-flow turbine costing per unit kW produced is less in all three categories involved, namely for power less 200 kW, for power more than 200 kW and grid connected applications. Williams [15] suggested the use of small centrifugal pump together with induction motor as turbines for low cost small-scaled hydro power application.

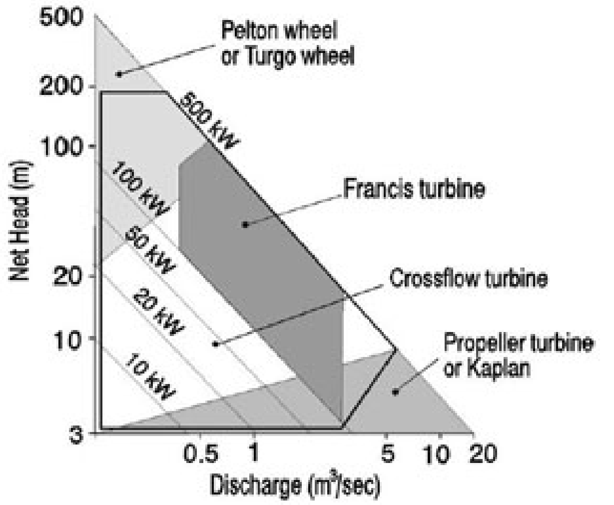


Fig.1 Head-flow ranges of small hydro turbines [8]

Another selection criterion for turbine selection is the specific speed of the turbine. The specific speed is important in determining the turbine speed, which will determine the correct ration needed to provide the required generator speed. The correlation between specific speed and net head are given for the following turbines [16]:

Crossflow $$\eta_s = \frac{513.25}{H^{0.505}}. \quad (6)$$

Propeller $$\eta_s = \frac{2702}{H^{0.5}}. \quad (7)$$

Kaplan $$\eta_s = \frac{2283}{H^{0.486}}. \quad (8)$$

Costa Pereira and Borges [17] investigated the nozzle flow in a crossflow turbine, which shows no effect of changing the runner from 25 to 10. The diameter of the runner, D, for crossflow turbine can be calculated based on the turbine shaft speed, n, and net head, *H*, while the length of the runner, *L*, based on flow rate, *Q*, net head and jet thickness, $t_j$, which is usually between one tenth and one fifth of runner diameter [18].

$$D = 40\frac{\sqrt{H}}{n} \quad (9)$$

$$L = \frac{0.23Q}{t_j\sqrt{H}} \quad (10)$$

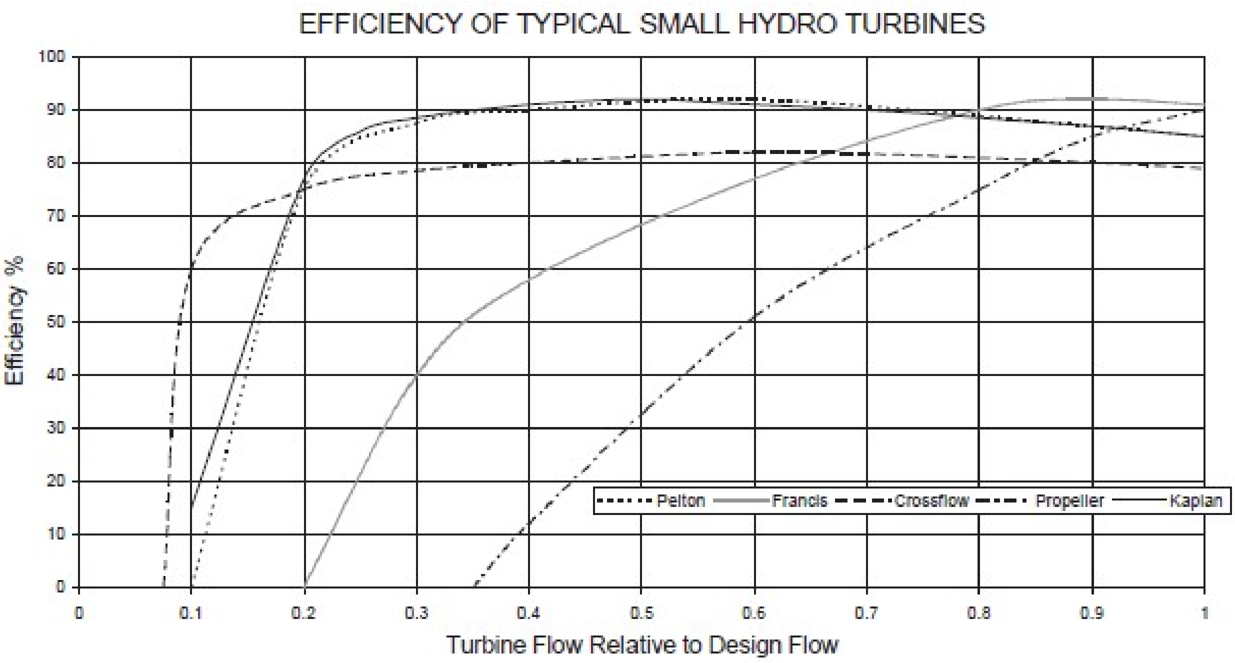


Fig. 2 Efficiency of small hydro turbines [14]

## 4 UKM Efforts

Currently, all small-scaled hydro applications in Malaysia consist of micro-hydro implementations, which have high head, and mostly are schemes at Sabah and Sarawak. Among the successful implementations are at Long Lawen in Sarawak, and at Terian and Bantul Sabah. Long Lawen project won runner up spot in the ASEAN Energy Prize for Renewable Energy, Off-the-Grid category, in 2006.

UKM is actively involves in similar application but at a smaller scheme. Pico hydro is selected to provide electrification program for remote off-grid community. The first project is the first pico hydro is installed at Kampung Tuil in Kelantan. The second project is the research on the low head low flow turbine, done at the university. The upcoming project include water fountain project at Tasik Cempaka, Bangi.

### 4.1 Case 1: High Head Pico Hydro

This project at Kampung Tuil is intended to provide up to 5 kW power to the factory for processing agriculture product. The village is sandwich between two small streams, one with a width of about 3 m and another at 5m. It is located at the valley surrounded by small hills. Initially the village is provided with solar panels and battery sets to light their home at night.

In collaboration with Global Peace Mission, UKM managed to secure fund from Ministry of Science Technology and Innovation Malaysia to install pico hydro facility at this Orang Asli village.

The location of the village provides about 40 m head. It takes about 47 polypipes, each of 6 m long from the water intake to the turbine. The outside diameter of the pipe is 200 mm with a thickness of 3 mm. The pico hydro turbine produces 220 V AC voltage and 22 A current. When in operation the pressure is about 350 kPa.

### 4.2 Case 2: Low head Low Head Pico Hydro

In this research project pico hydro system is to be tried at a location which has low head and low flow to produce alternative energy option. A natural flowing pond within the university is selected as case study as shown in Fig. 3

In this case two turbines are selected for testing, namely propeller and crossflow turbines. The propeller turbine (Fig. 4) is out-sourced, while the crossflow turbine (Fig. 5) is fabricated in-house.

Propeller turbine providing AC however produce too small current to be considered further, based on the basic requirements of low head and low flow. Crossflow turbine managed to pass the first stage test, charging the battery. It managed to produce about 60 W on a head of about 1 m and 10 l/s flow rate.

Fig. 3 Pico hydro system in the university lake

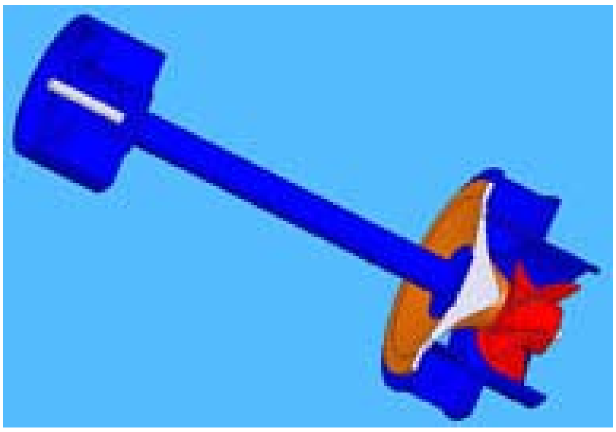

Fig.4 Propeller Turbine

The pico hydro system consists of crossflow turbine, gear system and alternator with charge controller and a set of battery as storage. The crossflow runner diameter is 450 mm and the length of the blade is 300 mm. Several ratios of gear system were tested, 12:50, 12:70 and 12:108. The ratio of 12:108 provides the best output with enough power to charge the battery. The alternator as a generator produces a maximum of 15.25 V in 12 V DC system

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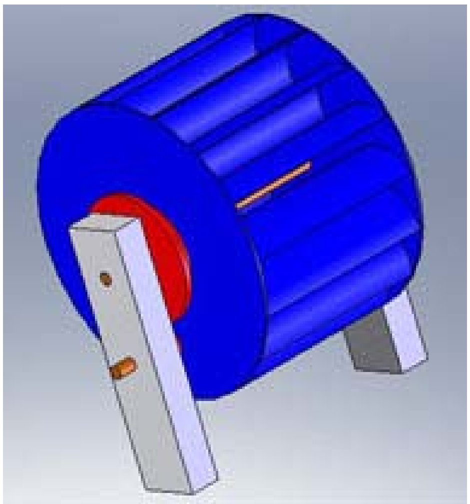

Fig.5 Michelle-Banki Turbine

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Fig. 5 shows the simulated power output based on 1 m head with varying flow rate. The power output could reach up to 360 W for flow rate of 30 l/s. This is based on the gear ration of 12:108. Increasing the head would definitely change the curve upward, resulting higher power produced at a particular flow rate.

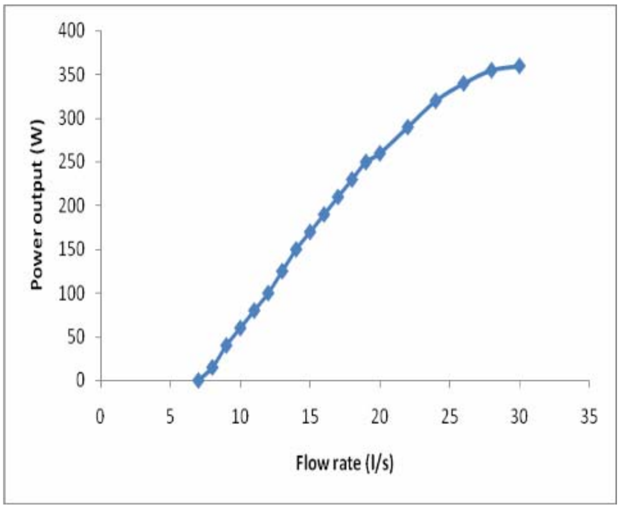


Fig. 3 Power output at 1 m head

The next step of the research project is to hybrid the pico hydro with photovoltaic modules, wind charger, with battery set as storage and generator set as back-up. The system will be a 12 V DC system. Both pico turbine and solar panels provide DC system while wind charger is producing AC thus the requirement for converter. All three renewable components are connected to charge controller, which is the connected to battery set. The battery will be the main power provider in this case.

### 4.3 Case 3: Water Fountain Project

This upcoming project is in collaboration with the state government to educate people about renewable energy. A hybrid system of pico turbine, solar panels and battery set as storage and power provider, will be installed at this Taman Tasik Cempaka, a recreational area for people in Bangi. The system is intended to power up to 1.5 kW water fountain there.

## 5 Conclusions

Since each site for small-scale hydro implementation is unique depending on the availability of the head and flow rate, care needs to be taken to select the correct turbine for implementation.

Crossflow turbine proves to be a suitable turbine for low flow and low head implementation and when significant variation of flow rate occurs seasonally. Given enough head and flow rate this low cost turbine can provide as little as three times enough power compared to the one provided by solar panels at lower rate.

Small stream with small drop of elevation would be big enough to provide green sustainable energy using pico hydro technology.

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