AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Cost Analysis of Pico hydro Turbine for Power Production

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ARTICLE INFO

Article history:
Received 25 June 2014
Received in revised form
8 July 2014
Accepted 14 September 2014
Available online 27 September 2014

Keywords:
Cost, low flow, low head, pico hydro, turbine.

ABSTRACT

Background: Turbine played a significant role in the hydro system and a determinant of the quality and quantity production of electric power in each power system. **Objective:** In this paper, several types of pico hydro water turbines are reviewed and compared. The water head, water flow rate and the current market price are the basic aspects considered in discussing the turbines selection. **Results:** Most of the small hydro turbines currently available are mostly suitable for low head high flow or high head low flow condition. By the assumption that the percentage of turbine efficiency is consistent for all conditions of water resources, the ability of water turbine to produce high output during low head low flow condition is low. **Conclusion:** The effectiveness of a turbine does not only depends on the productivity of the turbine to generate output power, but must also be seen in terms of cost and economical investment.

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To Cite This Article: Mohd Farriz Basar, Razali Sapiee, Syukri Rahman, Shuhada Borhan, Zulfiqah Hamdan, Kamaruzzaman Sopian., Cost Analysis of Pico hydro Turbine for Power Production. ***Adv. Environ. Biol., 8(14),*** *147-151, 2014*

INTRODUCTION

The stability of the environment should not be affected by the power generation system. For example, the massive constructions of large dams have changed the earth landscape, destroying the wildlife habitat and contributing to the global warming [1]. From this aspect, the large hydro power is not categorized as renewable energy [2]. In contrary, small-hydro (i.e. micro & pico) which is insulated with the negative effects is declared as clean technologies. Pico hydro can also be seen as an alternative to generate power and is more beneficial than the other small-scale renewable or conventional energy. Based on a few aspects that the system may offer, people start to explore the system to get the benefit from it. As a result, it boosts the technology development which is currently not fully explored by some of the researchers [3]. Besides, the demand for pico hydro in the market shows that it is a favorable solution in the generation of electricity. Lahimer *et al* [4] reported that the electricity demand is increasing rapidly over the years and one of the ways to secure access to electricity for a low income community is by choosing the right technology by considering a few important factors. The concept has met the electricity basic needs for the small community even though the capability to generate power is less than 5kW [5]. However, as for the cost per kilowatt output of the commercial turbine is considerably high, more research need to be done to overcome this problem [6-7]. For extremely low head water condition, pico hydro is the most cost-effective renewable energy system. [8]. This paper analyzes the market prices of water turbine which is basically used in the existing pico hydro power generation. It is evaluated based on the turbine costs in reference to the water head and water flow rate of water resources.

Turbine Ability:

Turbine converts the gravitational potential energy which is under the force of gravity to become kinetic energy when the water turbines are spanned by water rushing down and at the same time it simultaneously drives the electric generators. General output power of the turbine can be calculated by mathematical calculation as expressed below:

$$P_T = \eta \rho g H Q \quad (1)$$

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where: P_T= Turbine power output (W) g = Gravitational acceleration (m/s^2)
η = Efficiency percentage of energy transferred H = Water head (m)
ρ = Density of water (kg/m^3 or kg/l) Q = Flow discharge (l/s)

Based on equation (1), water head (H) and water flow rate (Q) are the key parameters in determining the reliability of a turbine to produce power output. Generally, the parameter is either high, low or both parameters are low. The water turbines available in the market today are mostly suitable only for the high head low flow application or vice versa [1, 3, 5-6]. Anyhow, up to now, there are still a few numbers of turbines that are capable to operate efficiently in low head low flow rate condition [4, 7]. Referring to equation (1) again, by assuming that the percentage of turbine efficiency is the same for all conditions of the water resources, the ability of the water turbine to produce high output during low head low flow condition is unfavorable. Regardless of how it operates, the effectiveness of the turbine does not only depend on the productivity in generating power output but also must be practical in terms of cost and economical investment.

In the early stages of a project, a Pugh Matrix can be applied for evaluation and selection of a turbine [9]. In any case, this approach is relatively subjective with less emphasize on the turbine design analysis. Williamson *et al* [10] reported that the most appropriate assessment and selection of pico hydro turbine can be acquired by using quantitative and qualitative analysis. The selection criteria are based on the requirement set by the end user. However, multi-criteria analysis presented does not discuss in detail about the importance of taking into account the financial implications in the selecting process of the turbine.

Turbine Cost:

The cost to make a turbine plays an important role in the effective cost of a pico hydro system. The turbine designs are classified into two types according to design which are the simple and complex designs. The complex design usually requires high expertise to make a turbine as it involves attentive care in terms of the fineness of blade profile, size, blade angle and etc. [2, 7, 10]. However, the complex design does not determine the ability of the turbine. Low-cost turbine units are usually made in China and other Asians countries [11]. The prices are reasonable compared to the one from the Western countries. The higher the output power required by the consumer, the higher the cost of the turbine. Medium and low head unit are much cheaper than high head unit for the same power output [11]. This is due to high demand as well as the manufacturers producing it in bulk, thus reducing the per unit price.

Table 1 : Comparison of head, flow and cost for fifteen types of pico hydro turbine.

Category	Turbine	Head (m)		Flow (l/s)		Cost (USD/kW)	
		MAX	MIN	MAX	MIN	MAX	MIN
Impulse turbine	Peltric set	50	20	20	10	2,160	933
	Pico power pack	100	25	15	3	3,000	2,000
	Low Cost DC	60	20	10	5	2,150	1,800
	MDFH	30	20	2	1	3,000	2,000
	Stream engine	100	2	1.5	0.04	2,150	1,800
	Turgo	20	5	8	2	3,400	3,200
	Cross-flow	20	5	50	5	3,000	2,000
Reaction turbine	Power pal	5	1	130	35	2,000	1,500
	Open flume	6	3	100	10	4,000	2,500
	Split reaction	5	2	16	8	1,200	1,000
Wheel	Overshot	10	2.5	4	2	5,000	4,500
	Undershot	2.5	0.5	10	7	4,000	3,300
	Pump as turbine	20	5	50	5	3,000	2,000
	Submersible Pico hydro	In stream		4		2,000	1,500
	Archimedes screw	5	2	8	0.5	2,000	1,000

Table 1 displays a list of pico hydro turbines available in the market capable of producing power up to 5kW. It compares fifteen types of pico hydro turbines with maximum and minimum range of the water head (H), flow rate of water (Q) and the cost per kW. The data collected is based on the current market price which has been identified after conducting surveys [12-20]. Each turbine has different prices depending on two important parameters; water head and flow rate.

According to Table 1 above, most pico hydro turbines used are of the impulse type followed by the reaction turbine type. Less pico hydro turbine used from wheel type due to its highest cost compared to other types. The most economic turbine is split reaction turbine where the cost is around USD1,200/kW. The most expensive turbine is overshot wheel turbine where the cost can go up to USD5,000/kW. On average, the cost per kW of the pico hydro turbines is between USD2,000 - USD3,000. In term of flow rate, MDFH turbine has the smallest range which is between 1 to 2 liter per second while Power pal turbine has the widest range between 35 to 130 liter per second.

The fifteen pico hydro turbines listed in Table 1 are then compared according to their cost range to produce 1 kW power against the range of flow rate. Fig. 1 shows the comparison of cost per kW range against the water flow rate range. It is plotted based on the data range; cost per kW range and flow rate range shown in Table 1 for each pico hydro turbine types which form a rectangular shape for each type. From the cost aspects, split reaction has the lowest cost range from USD1,000 to USD1,200 per kW power and the highest market price is open flume which ranges between USD2,500 to USD4,500 per kW power. Based on the graph, the average flow rate falls in the range from 0.04 to 20 liter per second and the cost average lies between the ranges of USD1,800 to USD3,000. Referring to Fig. 1, by taking into consideration the cost per kW average and flow rate average which falls into more than one rectangular areas, it can be summarized that power pal is the best choice to be used as pico hydro turbine as the market price is quite low and the range of the flow rate is wider compared to the other turbines.

Fig. 2: Cost per kW range versus flow rate range for fifteen pico hydro turbine types.

Apart from the comparison shown in Fig. 1, Fig. 2 shows a graph comparing cost per kW range against the flow rate range which also forms a rectangular shape for each pico hydro turbine type. The lowest range for head is undershot that lies between 0.5 to 2.5 meter and the widest range is stream engine which ranges from 2 to 100 meter. As for the cost, overshot has the highest market price with the range from USD4,500 to USD5,000. The peltric set however, has the lowest price range between USD933 to USD2,160. The average for head falls between the range of 1 to 60 meter and the cost per kW average are from USD1800 to USD3000. From this graph, the best choice for the turbine types selection in terms of cost are split reaction, peltric set and Archimedes screw pico hydro turbine types.

Fig. 2: Cost per kW range versus water head range for fifteen pico hydro turbine types.

Based on Fig. 2 before, the turbine with low head and low flow rate requirements has low market price. Besides, most of the reaction type turbines have low market prices compared to the other type of turbines. Non complex turbine design and the type of materials used in fabrication are the contributing factors why the type of turbines has low market prices. The turbine size factor also plays a role in determining the cost of turbine. The graph shown in Fig. 2 also shows that the wider the head range, the low the flow rate of the turbine design and vice versa. The highest cost for the turbine design is the open flume turbine and the lowest cost would be the split reaction, power pal and peltric set. Theoretically, split reaction and power pal falls under the reaction turbine types, so as a conclusion, the reaction turbine types has the lowest cost.

Conclusion:

The selection of proper turbine can be based on the suitability of water resources. In addition, the financial resources are very important. Most turbines available are from the impulse type, followed by reaction turbines. As a whole, the cost per kW is between USD2,000 to USD3,000. At this cost, the range of water head is from 5 meters to 50 meters and the water flow rate is between 2 l/s to 50 l/s. Interestingly, split reaction, overshot, undershot, submersible and Archimedes screw are the turbines that are capable to operate at low head low flow water condition. In addition, these turbines offer low cost per kW except for overshot and undershot waterwheel turbine. With the capability of pico hydro system in generating output power up to 5 kW, the cost per kW can be said to be the same for all types of turbines. Not being similar with the water head and flow rate, the ranges for both are too large and notable among the fifteen types of pico turbines available in the market.

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