A NOVEL DESIGN WORK IN ENERGY EXTRACTION FROM IN-STREAM WATER BY VARIOUS TYPES OF MICRO HYDRO TURBINES

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ABSTRACT: *Purpose- Micro-hydroelectricity power projects are becoming popular because it is a proven low cost electricity-generating source. This research designed to evaluate energy extraction efficiency of single stage and multistage blade of micro Hydro turbine. Experiments have been conducted with two-laboratory scale turbine at instream water velocity ranges from 0.5m/s to 1 m/s. The finding shows that energy extraction and transfer efficiency of multistage MHT is about 5.5 percent higher compare to single stage MHT. This study concludes that multistage MHT is cost effective as energy extraction efficiency is higher and it could be an energy solution for rural societies. Indeed, the multistage MHT could be a useful electricity generating equipment for supporting rural economy.*

Keywords: Micro Hydro Turbin,; Multi-Stage MHT, energy Efficiency, Energy Performance

1. RESEARCH BACKGROUND

This research aims to assess the most efficient way to generate green energy from instream water by using micro-hydro turbine. This study carried out to support clean and renewable energy application to ensure the environment sustainability. Besides, this study performed to support communities living in the coastal areas by providing information to harvest energy from Instream water by using Micro Hydro Turbine (MHT). Thus, the research on MHT is an approach to contribute to achieve economic and environmental sustainability.

In coastal areas, have the difficulties of getting constant electricity supply due to its remote surrounding where normal power grid is not available. Currently, fossil fuel based generator use to carry out this function for supplying electricity. The problems of using commercial generator are not environmental friendly due greenhouse gas emission and the maintenance cost of engine operations. In this context, renewable energy is the best option. Micro hydropower plant is one of the favoured options among other alternatives such as wind power and solar system.

Hydropower is the most favourable because this source is available constantly. Application of MHT shall be environmental friendly compared to the conventional hydro power plant and mini hydro power plant. The method of energy harvesting of MHT is the same as the conventional hydropower do. The operating procedure of MHT is the water velocity turns the turbine blades and produce mechanical energy; and this energy is transfereg to generator for producing electrical energy.

The known fact is that energy harvesting optimization from instream water would contribute to reduce electricity production cost; and in order to achieve this goal, it is essential to know MHT configuration and installation criteria. Abundance of information on MHT operations and energy extraction procedure are available in the published literature; even the authors of this paper have published a few research papers on MHT operations and energy harvesting. However, in the aspect of energy extraction efficiency difference between multistage MHT and single stage MHT is not available in published literature. In order to fil-up this gap, authors have undertaken this research project.

1.2 Problem Statement

In coastal area, the society living there having difficulty in getting constantly supply of electricity. In absence of supplying electricity from national grid, communities living in these areas, fossil fuel base generators use to produce electricity. In this aspect, micro hydropower plant has the potential to solve the energy issue faced by the coastal area. Thus, micro hydropower plant appears electrical energy supply source for coastal areas. In this aspect, needs to pay attention on for fully utilizing production capacity of MH for increase energy harvesting efficiency.

Therefore, operating properties of MHT is essential to evaluate optimum electric energy production condition. To ensure expected energy harvesting from MHT, this research designed to get answer of the questions about, “**which turbine is energy efficient between single and multistage blade?**

1.3 Objective Of The Study

The objective of this research is to investigate energy extraction performance of MHT by using multi stage blades and single stage blade turbine at lower water velocity ($V \leq 1.0$ m/s). In order to achieve the goal, the broad objectives divide into three specific objectives:

a) Measuring energy extraction performance by using multistage blade micro hydro turbine in In-stream water.
b) Measuring energy extraction performance by using single stage blade micro hydro turbine in In-stream water.
c) To evaluate impact of multistage and single stage blade on turbine performance at low water velocity ($V \leq 1.0$ m/s).

1.4 Scope Of Work

For achieving the research goals, theoretical framework relevant to this research gathered from the published research papers. Laboratory scale of one-multi stage blades and one single stage blade MHT used separately for conducting experiment. The last stage of this research is data analysing for achieving targeted research goals.

1.5 Novelty Of Research Study

This paper focused on the evaluation of energy extraction performance of multistage and single MHT at water velocity ranging of 0.5 m/s to 1 m/see. This type of work is not available in the published literature. In this aspect, the current work is original and novel.

2. LITERATURE REVIEW

Micro-hydro projects are becoming popular due to society's need for generating electricity from green energy sources like in-stream water. To operate a MHT, dam is not required; the capital cost equipment of this type of turbine lower than compare to the large-scale hydro systems [1]. The latest studies on micro hydro turbine system suggest that this technology is reliable and friendly to environment compare to fossil fuel energy. It also provides a solution to energy supply for remote and hilly areas where the extension of national grid system is not economically and technically feasible [2,3]. Hydro power plant is a technology that utilizes the energy contains in in-stream water. Conventionally, a turbine use for harvesting instream water energy by installing MHT in the direction of a water stream. The velocity of the water stream turns turbine blades and transmits mechanical energy to generator for producing electricity. **Micro hydro** is a type of **hydroelectric** power that typically produces from 5 kW to 100 kW of electricity by using the natural flow of **water**. The efficiency of most MHT found to be ranging from 30 percent to 40 percent [4].

In regards to Cross flow MHT, Verdant Power had made a test report on operations and which indicates that energy extraction of MHT depends on water velocity and effective area of turbine blades [5,6]. New energy corporation manufactured a turbine, their test report had indicated that it produced 13.0 kW at water velocity 2.5 m/s. Thropton Energy Service had made a similar report; they found that their manufactured turbine had produced 2.0 kW at water velocity 1.5 m/s. These results proved that the power extraction efficiency depends on water velocity. Alternative Hydro Solutions LTD and GCK Technology Inc. had produced a few turbines with blade area 3.0 m^2 and 1.0 m^2 respectively. The output power of these turbines was 2.6 kW and 0.70 kW respectively, though the water velocity for both cases was 1.4 m/s and 1.3 m/s respectively. These findings have proved that turbine blade area can play a significant role in extracting energy from water [7].

2.1 Theoretical Framework For Energy Extraction Performance By Using Multistage Blade System

Optimizing energy extraction is the key objective of this research project. To achieve this goal, a mechanical device is essential to maximize velocity drop across the turbine blades for maximizing energy harvesting from in-stream water [8]. In order to increase energy extraction efficiency, the outlet water velocity (V_o) at the turbine exit must be minimized; and to achieve this condition, the water velocity drop across the blades must be maximized. Therefore, the challenge of this research project is to increase velocity drop by reducing outlet water velocity (V_o) across the blade surface.

2.1.1 Energy Flow Modelling Of Instream Water

The conceptual model of energy extraction and conversion to mechanical energy of MHT presents in Fig.1.

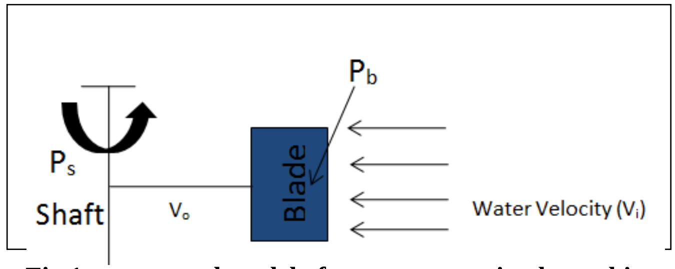


Fig.1: conceptual model of energy extraction by turbine blades

Fig.1 demonstrates that the inlet water velocity (V_i) is passed over the blades surfaces. At the exit of blade surface, water velocity V_i is reduced to V_o. The difference between V_i and V_o is known as velocity drop(▲V) across turbine blades. The velocity drop considered as indicator of energy extraction by turbine blades. Therefore, the interaction maximization between water flow and blade surfaces is the determinant of energy extraction of MHT [9].

2.1.2 Model Development Of Energy Extraction By Using Multistage Blade System

The energy available in instream water presents by Eq.1:

$$E = \frac{C\rho A V^3}{2} \qquad \text{Eq. (1)}$$

Here, E is kinetic energy carrying by in-stream water. 'A' is the blade area contact with flowing water. 'C' is power coefficient; 'V' is water velocity in m/s at inlet point. And 'ρ' water density (kg/m^3) at normal atmosphere conditions [10]. This equation indicates that blade area is a dominant factor for energy extraction. Another important factor of energy extraction is water velocity drop across blades of a turbine [11].

2.1.3 Model Development For Water Velocity Drop

In a study on MHT, Arena (2011) had found that the velocity drop in a single stage turbine is about 33 percent with respect to inlet water velocity [11, 12]. It indicates that in the single stage turbine, water velocity at MHT exit point is quite high (about 67 percent). This concept mathematically represents by Eq.2:

$$\Delta V = \sum_{i=1}^{n} \Delta V \qquad \text{Eq.(2)}$$

Where, V_i is inlet velocity of water at Turbine blade. V_o is outlet velocity of water at turbine exit point. 'n' is the stage of turbine blades, i =1,2,3------n and ▲V [▲V = Vi-Vo] is the velocity drop across the turbine blades.

2.1.4. Mode Development For Blade Area For Energy Extraction Performance

2.1.4 (a) Model Development For Multi-Stage Blade Area

The basic model of energy extraction that stated by Eq.1 which shows that energy extraction performance depends on blade surface and water flux. The total blade area of a multistage turbine presents in Fig. 2 and by Eq.3 [11].

$$A_t = \sum_{i=1}^{n} A_i \quad \text{Eq.(3)}$$

Here, 'A_t' is total blade area of turbine; 'A_i' is area of individual blade; 'n' is the number of blades of a turbine.

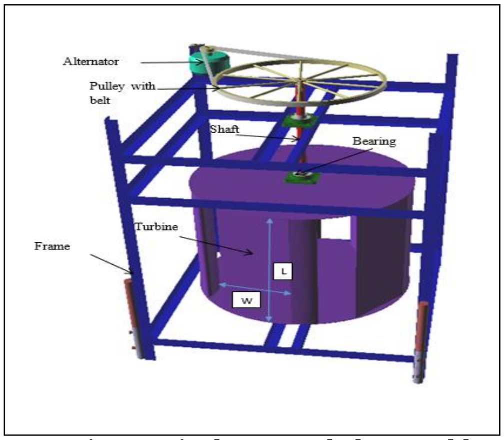
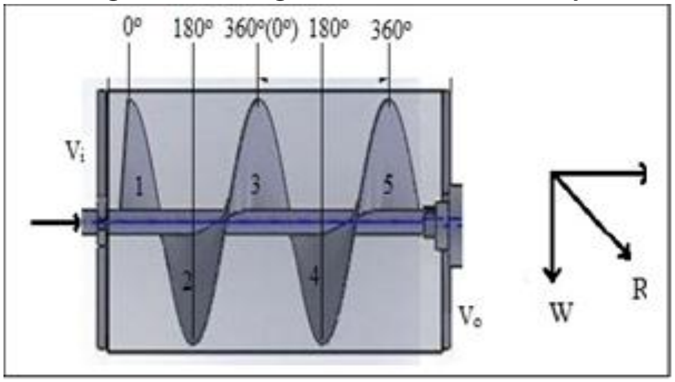


Fig. 2a: Single Stage Blade assembly

Fig. 2b: Multistage Turbine Blade Assembly



The energy vector shown in Fig. 2b indicates that 'R' is the reactive force, which generates during water flow over the blades. The magnitude of 'R' depends on the amount of water velocity drop over the blade surface and this force contributes to rotating turbine shaft.

2.1.4 (a) Model Development For Single Stage Blade Area

In the single stage MHT, the blades installed parallel to each other and in-stream water only hits blades n^{th} time during the flow over blade. This scenario has depicted in Fig.3. The area of the blades presents by Eq.4 [11].

$$A_t = LxW \quad \text{Eq(4)}$$

Here, 'A_t' is total blade area of turbine; 'A_t' is area of individual blade which can be measured by using blade length(L) and width (W).

Model Development For Energy Extraction And Transfer Efficiency

The hydro energy flow from water to blades and transfer to turbine shaft sated in 2.1.1 and by Figure 1. This energy transfer model indicates that a part of kinetic energy of water stream absorbs by turbine blades (Pb) when water moves over the blade surface; and a part of Pb transfer to turbine shaft (Ps). The difference between Pb and Ps consider as energy loss due to friction within the turbine system. Finally, the shaft energy Ps convert to electricity through a generator. Based on this statement, the Energy Extraction and Transfer Efficiency' model develop presents by Eq.5.

$$\eta = \frac{Ps}{Pb} \quad \text{(Eq.5)}$$

Here,. 'η' is energy extraction and transfer efficiency ($\eta > 0$).

2.1.5 Mode Development Of Energy Loss In Turbine System

The energy loss in turbine system is the difference between the amounts of energy absorbs by the turbine blades (Pb) and energy transfer by turbine shaft (Ps). The energy loss model presents by Eq.6

$$\Delta E = P_b - Ps \quad \text{(Eq.6)}$$

The energy loss in percentage form is:

$$\Delta E\% = \frac{Pb - Ps}{Pb} 100 \quad \text{(Eq.7)}$$

3. RESEARCH METHODOLOGY AND EXPERIMENT SETUP

The study on evaluating energy extraction performance by MHT conducted at operations research laboratory of Universiti Malaysia Sarawak. At the first state, a significant number of relevant published papers reviewed for collecting latest research information on MHT research. At the second stage of research, a few number of conceptual models and mathematical models have developed relating to energy extraction and energy transfer performance. The authors did experiment with multistage MHT and single stage MHT at the third stage. At fourth stage, data collection, quality control of data and model estimate performed. The authors did reporting writing at the last stage of this research.

3.3 Research Design

Two-laboratory scale MHT have used for conducting this research. One multistage MHT with five blades (five blades are installed in series format in a common shaft); and another single stage blade MHT (blades are installed in a shaft in parallel format) have used. The water velocity ranges of this research were from 0.5m/s to 1.0 m/s. To achieve research objectives, Inlet (V_i) and outlet (V_o) water velocity were measured, and energy extraction efficiency model estimated as present by Eq 5 [13,14].

3.2 Experiment Setup And Data Collection Procedure

The layout and machinery setup of this experiment presents in Fig.3a and In Figure 3b.. The main equipment associated with the experiment were water channel, variable speed water pump, water flow piping system, five stage MHT, single stage MHT and alternator for converting mechanical energy to electrical energy.

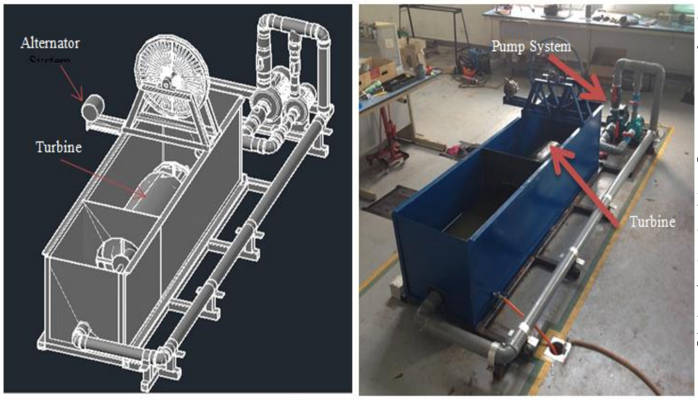


Fig.3 (a) layout of experiment setup;(b) machinery setup

Fig3a. layout of Experiment Setup (b) machinery

Fig 3b. Experiment Setup

Two centrifugal pumps used to maintain water flow. Water flow rate and water velocity regulated by using frequency inverter. Two velocity meters used to measure inlet and outlet water velocity. One manual-drive tachometer used to measure turbine speed (RPM). The total operating time of machinery was 240 hours in different working days. Four sets of data (0.5m/s, 0.7m/s, 0.9m/s and 1.0 m/s) gathered from experiments. In order to reduce estimated error and achieving higher data quality, statistical technique, and SPSS software used. The data within 3.0 standard deviations (3σ) used for model estimation.

4. DATA ANALYSIS AND FINDINGS

This study conducted to evaluate the energy extraction performance of multistage blade and single stage blade micro hydro turbine at water velocity ranging from 0.5m/s to 1.0m/s. Energy extraction performance measured in terms of energy extraction efficiency, velocity drop at blade surface and energy transferred by turbine shaft. The findings of this research relating to three objectives listed in Table 1. The analysis of three research objectives presents in sections 4(a), 4(b) and 4(c).

4(a). Measuring Energy Extraction Performance By Using Multi Stage Blade Micro Hydro Turbine In In-Stream Water

The energy extraction performance of multistage MHT listed in column 3 of Table 1, which relates to objective number one of this research. The estimated results indicate that energy extraction performance increased with velocity. At water velocity 1.0 m /s energy, extraction appeared 75.2 percent which highest value recorded during the experiment. The velocity drop found 24.8 percent with energy transfers 54.3 percent, which appeared the highest value at 1 m/s of water velocity. On the other hands, energy lost in the turbine system found 24.5 percent, which appeared highest value compared to energy lost at water velocity 0.5m/s. Thus, this study achieved research objective as stated in 1.3(a).

4(b). Measuring Energy Extraction Performance By Using Single Stage Blade Micro Hydro Turbine In In-Stream Wate

The energy extraction performance of single stage MHT listed in column 4 of Table 1. The estimated results indicate that energy extraction performance increased with velocity. At water velocity 1.0 m/s, energy extraction found 68.1 percent, which appeared the highest recorded value during the experiment. The velocity drop found 23.5 percent with energy transfers 43.2 percent at 1.0 m/s water velocity. On the other hands, energy lost in the turbine system found 31.7 percent, which appeared highest value compare to energy lost at water velocity 0.5m/s. Thus, this study estimated energy extraction performance of single stage MHT that state in 1.3(b).

4(c). To Evaluate Impact Of Multistage And Single Stage Blade On Turbine Performance At Low Water Velocity (V≤ 1.0 M/S)

The research findings indicate that te energy extraction efficiency of multistage MHT is about 10.5 percent higher compared to single stage MHT. The water velocity drop across the multistage MHT blades found about 5.5 percent higher compare to single stage MHT. However, the energy loss at single stage MHT found about 3.9 percent higher. In this aspect, multistage turbine appeared energy efficient compare to single stage MHT. The energy transfer of multistage MHT found about 18 percent higher compare to single stage MHT. Based on these experimental findings, the study concludes that the performance of multistage MHT is higher than single stage MHT at water velocity ranging of 0.5 m/s to 1.0 m/s. Thus, this study achieved the research objective that stated in 1.3(c) [15].

Table 1: Micro Hydro Turbine Performance Matrix

Water Velocity (m/s)*	Performance Indicator**	Efficiency of Multistage blade MHT	Efficiency of Single Stage Blade MHT
0.5	Ƞ-Turbine Efficiency in percent (%)	59.5	51.1
0.65		65.3	59.3
0.80		69.5	62.8
1.0		75.2	68.1
	▲ Ƞ= (ȠM - ȠS).The multistage MHT on average is 10.5 percent more efficient compared to single stage turbine		
0.5	▲V- velocity drop in percent (%)	16	15
0.65		17.5	16.5
0.80		21.0	20
1.0		24.8	23.5
	▲ V= (VM - VS), The velocity drop of multistage MHT is at an of average 5.5 percent more efficient compared to single stage turbine		
0.5	▲E- energy loss at turbine in percent (	39.2	48.8
0.65		34.2	40.6
0.80		20.3	37.1
1.0		24.5	31.7
	▲E- EM-ES. The energy loss at multistage MHT is 3.8 percent less than single stage turbine.		
	Ps-Energy transfer by turbine shaft		
0.5		24.1W (40W/m2)	19.2W(32W/m2)
0.65		33.2W(55W/m2)	27.0W(45W/m2)
0.80		45.0W(75W/m2)	37.8W(63W/m2)
1.0		54.3W(90W/m2)	43.2W(72W/m2)
	▲Ps- PM-PS. The energy transfer efficiency of multistage MHT is about 18 percent higher compared to single stage MHT		

- *Water velocity –meter/see. ** Defined in section 2.1.1 to 2.1.*

5. CONCLUSION AND RECOMMENDATIO

This study evaluated energy extraction performance of multistage and single stage MHT. Based on findings, authors conclude that the performance of multistage MHT is higher than single stage MHT at water velocity ranging of 0.5 m/s to 1.0 m/s. This finding is very similar and comparable with other studies of the authors. Shahidul et al. (2015) reported that multiage MHT significantly efficient compared to single stage MHT. Shahidul et al (2011) also reported that velocity drop across turbine blade and the energy extraction are significantly higher at water velocity ranges from 1.0 m/s to 2.5m/s [3]. Based on all research findings, the authors conclude that multistage MHT at low water velocity could give energy solution [11, 15].

5.1 Implication Of Research Findings

The outcomes of this research have a few implications in the rural economy. The established fact is that multistage MHT is an energy solution for remote area; indeed, the higher efficiency of MHT will contribute to reduce energy production cost. In this aspect, multistage MHT is a cost effective energy solution for rural economies. The multistage MHT is an energy solution for coastal area in generating electricity for household activities, agriculture farming and to operate water desalination process. These findings would insist policy makers for commercializing this turbine.

5.2 RECOMMENDATION FOR FUTURE RESEARCH

The current study focused on evaluating energy extraction performance of multistage and single MHT at water velocity ranging from 0.5m/s to 1m/s. The operating properties of this turbine at higher water velocity is unknown. The recommendation from the authors for future study is to test multistage MHT with velocity ranging of 1.5 m/s to 2.5 m/s. Another direction for future study is to model energy extraction with more than five stages of blades.

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