

**CFD ANALYSIS ON COST-EFFECTIVE PICO-HYDRO TURBINE: A CASE  
STUDY FOR LOW HEAD AND LOW FLOW RATE CONDITION**

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## CFD Analysis on Cost-effective Pico-hydro Turbine: A Case Study for Low Head and Low Flow Rate Condition

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### Abstract

Pico-hydro turbine has been widely used for off-grid settlement especially for stand-alone domestic application. In most cases there is a trade-off between the flow rate and the available head. The fluctuation of water flow rate between wet and dry seasons obviously affected the performance of the turbine. The problem is compounded when a specific turbine is used in low head and low flow application. This paper discusses the performance of an axial-flow (propeller) turbine in this particular condition. Evaluation is made based on the blade parameters in order to improve its existing performance. Comparisons are made between the current blade and a modified version of it, in term of hub to tip ratio and the number of blades used. The values of hub to tip ratio ranging between 0.4 to 0.7. The numbers of blades used are 3, 4, 5, and 6. Simulation analysis was done using Computational Fluid Dynamics (CFD) software. Analyses were done on each of the turbine blade to find the optimum stream velocity and power output which can be derived for each combination of turbine parameters. The analysis results show that with lowest value of hub to tip ratio which is 0.4 and the lowest number of blades which is 3, contributed the best performance of the axial-flow turbine.

**Keywords:** CFD analysis, Pico-hydro turbine, Low head, Low flow rate.

### 1. Introduction

Pico hydro-turbine is one of the alternative renewable energy which has been developed significantly for off-grid areas. Pico-hydro turbine is chose because of its environmental friendly, cheap installation during first time set-up due to it does not require the involvement of big reservoir or dam as water storage, less maintenance and even the cost of the turbine itself is very cheap. Some parts in Nepal, Vietnam, Thailand, India, and even in Peru has been used this kind of technology as their daily needs to light up their houses or doing other related tasks which energized by electricity. Committee such as in Humla, a part of rural area in India, has been implemented the pico-hydro to replace the usage of fire wood as their main energy. As a result, their life style has been improved and health conditions such as respiratory and eye sight problems because of fire wood smoke have been totally avoided (Alex Zahnd, 2009).

Pico-hydro turbine can be operated under condition of low head with high flow rate of water stream or vice versa which is high head with low flow rate of water. However, the fluctuations between seasons are the main concern especially during dry season. This is because during dry season, the flow of the river water is very low and this influenced obviously to the performance of hydro turbine (Sadrul Islam, 2002). Based from investigation which has been made by a group of researcher from Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia (UKM), found that the low performance of the axial-flow turbine might probably due to rotation of turbine's blades and further investigation about this phenomena need to be done (Kamaruzzaman Sopian, 2007). Alexander and Giddens (Alexander K.V., 2008) and Alexander et al. (Alexander K.V, 2008) has been discussed about pelton wheel and axial-flow turbine for the usage under low head application which capable to produce power output up to 20kW. Besides that, Montanari (Montanari R., 2003) has suggested to implement axial-flow turbine or Michell-Benki turbines for rural areas application due to lower costs and power produced.

This paper will discuss about the performance of the pico-hydro turbine under condition of low head with low flow rate of water. Axial-flow turbine or also known as propeller turbine is one of the pico-hydro families which will be used as a subject matter. In this case study, it will involve with original and redesign blades of axial-flow turbine. Two parameters which have been selected to redesign the blades are hub to tip ratio and number of blades. Each blade will be analyzed by using Computational Fluid Dynamics (CFD) software to find out the flow velocity in order to estimate the power output produced. In addition, by implementing the CFD software, it can also indicate how the flow pattern looks like between blades from inlet to outlet of the runner section as in the real situation. It also can check the efficacy of the shape of the blades designs (Guoyi, 2005) for the optimization purposes before selection of the best blades designs can be made (Wu J., 2007).

## 2. Methodology

As mentioned earlier, original blades of axial-flow turbine will be used as a case study. Figure 1 and Figure 2 shows about the original blades of the related hydro-turbine in different views of angle.

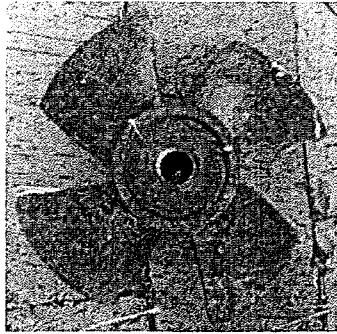


Figure 1. Front view of blade

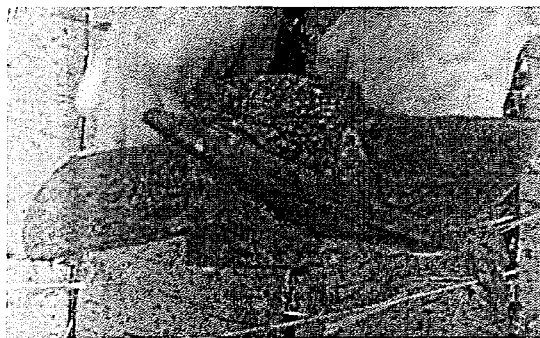


Figure 2. Side view of blade

The axial-flow turbine consists with 4 blades where the size of the blades measured from tip to tip is 162mm in diameter while the thickness is 4mm. On the other hand, the diameter of the hub is 66mm with 70mm in height. Since comparison will be made between the original blades and redesign blades by using CFD software, therefore at the beginning stage the original together with redesign blades should be drawn in a form of 3D modeling by using any Computer Aided Design (CAD) software before imported to CFD ANSYS and meshed. In this particular case, SolidWorks will be used as design software to transform the original and redesign shapes of the blades into 3D CAD data. Hub to tip ratio and number of blades are two parameters that will be emphasized in the redesign blades. The value of hub to tip ratio is ranging from 0.4 to 0.7. The total numbers of blades to be analyzed are 3, 4, 5 and 6. In some cases, the value of hub to tip ratio was restricted to 0.3 due to it might increase the flow area and reduces the flow velocity. As a result hydraulic losses might be occurred (P. Singh, 2009). According to P. Singh, the numbers of blades are totally depends on the length and pitch of the blade. Therefore, it is preferable to have larger number of short blades rather than smaller number of long blades.

Once all the 3D data are ready, each combination of the parameters will be analyzed by using CFD (CFX) ANSYS simulation software. The analysis should considered low head which is 2m and low flow rate of water and therefore it has been set to 50kgs-1, 40kgs-1, 30kgs-1, 20kgs-1 and 10kgs-1. The analyses were done to find out the flow velocities for combination of each parameter under low flow rate condition. All data which has been collected will then be converted into graphical form to facilitate the understanding of the end results.

In some cases such as Hydro-Quebec has been implemented CFD to determine the performance of the existing turbines by analyzed only on a single runner blade (J Nicolle, 2010). Reverse engineering techniques has been implemented and two different methods were used. The first method involved with a laser FARO ScanArm and the second method was using Atos1 photogrammetric scanner from GOM. Both of the methods could obtained a close surface triangulation which containing around 450K elements while NURBS which represented the measured surface can be defined and this make it easily integrate with the CAD data and then analyze it under CFD software.

### 3. Results and Discussion

All data which has been collected after run the analysis are saved under spreadsheets and then converted into graphs. There were 80 data which needs to evaluate. Figure 3 to Figure 6 shows some of the examples of analyses which have been conducted by using CFD (CFX) ANSYS analysis software. Table 1 to Table 4 shows about the data analysis for the flow velocity with the number of blades involved. Figure 7 to Figure 10 are the graphs which have been converted from these data analysis.

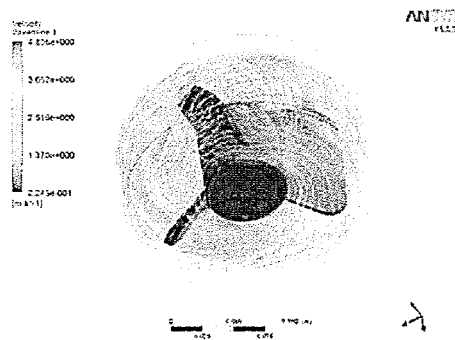


Figure 3. CFD data analysis for hub to tip ratio 0.4, 3 blades with mass flow rate 10kgs<sup>-1</sup>

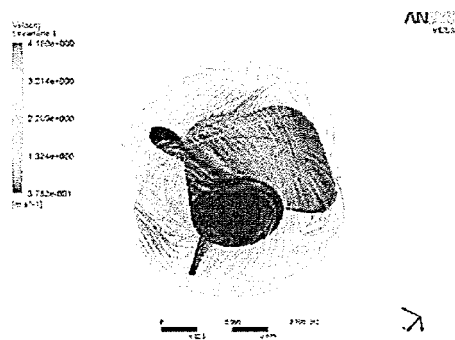


Figure 4. CFD data analysis for hub to tip ratio 0.5, 3 blades with mass flow rate 10kgs<sup>-1</sup>

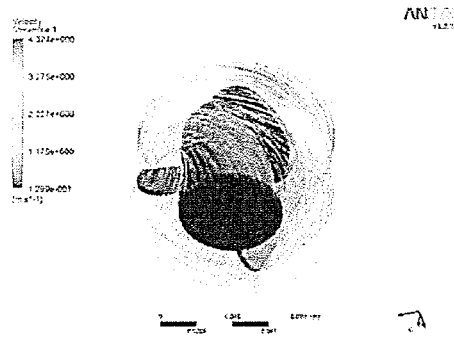


Figure 5. CFD data analysis for hub to tip ratio 0.6,

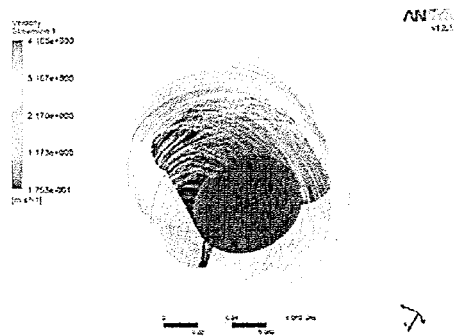


Figure 6. CFD data analysis for hub to tip ratio 0.7, 3 blades with mass flow rate 10kg/s<sup>-1</sup>

Table 1. Flow velocity with 3 blades

MFR	Hub to Tip Ratio			
	0.4	0.5	0.6	0.7
10	4.808	4.160	4.324	4.165
20	5.719	5.214	4.910	5.726
30	6.563	5.678	7.463	8.068
40	6.885	7.053	8.371	10.690
50	6.891	8.462	10.380	13.780

Table 2. Flow velocity with 4 blades

MFR	Hub to Tip Ratio			
	0.4	0.5	0.6	0.7
10	4.349	4.123	4.287	4.005
20	5.637	5.036	4.902	5.825
30	6.516	5.390	6.721	7.907
40	6.678	6.742	8.671	10.510
50	6.709	8.242	10.930	10.930

Table 3. Flow velocity with 5 blades

MFR	Hub to Tip Ratio			
	0.4	0.5	0.6	0.7
10	4.319	4.136	4.219	3.917
20	4.447	5.013	4.949	5.633
30	6.482	5.401	6.791	8.053
40	6.645	6.747	8.844	10.480
50	6.635	8.254	10.810	13.000

Table 4. Flow velocity with 6 blades

MFR	Hub to Tip Ratio			
	0.4	0.5	0.6	0.7
10	4.177	4.101	4.224	3.881
20	5.496	4.951	4.975	5.742
30	6.442	5.555	7.006	8.302
40	6.715	7.319	9.230	10.920
50	6.679	9.106	11.550	12.290

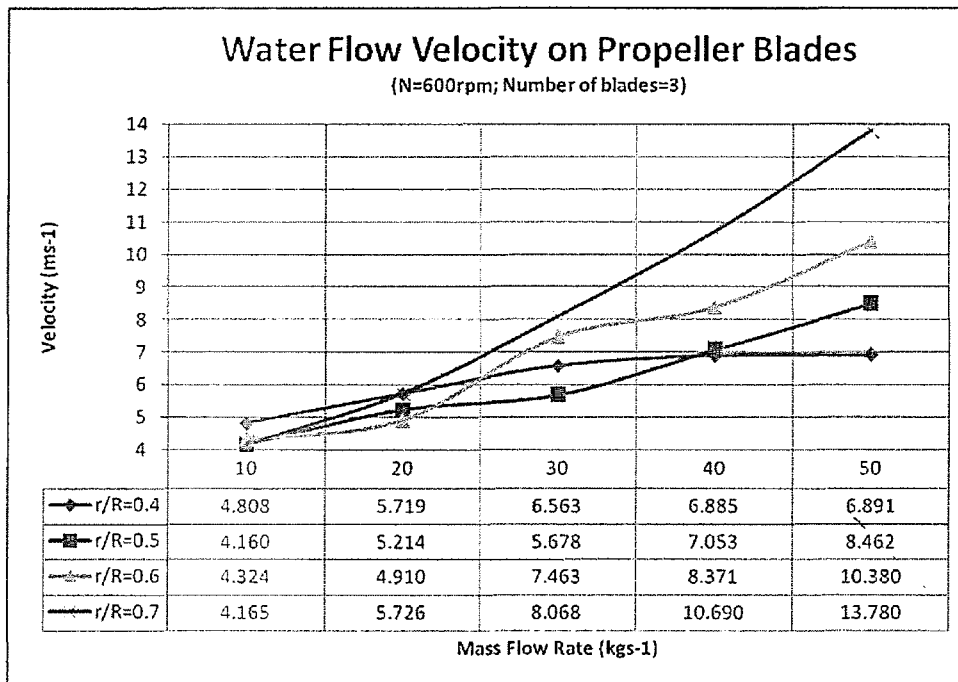


Figure 7. Schematic graph of flow velocity with 3 blades

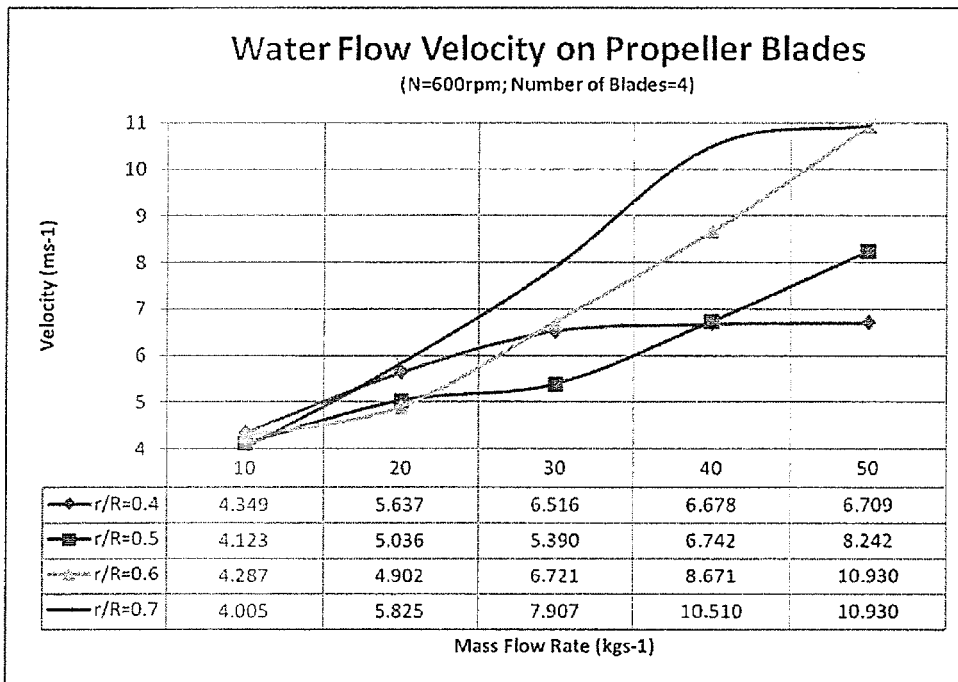


Figure 8. Schematic graph of flow velocity with 4 blades

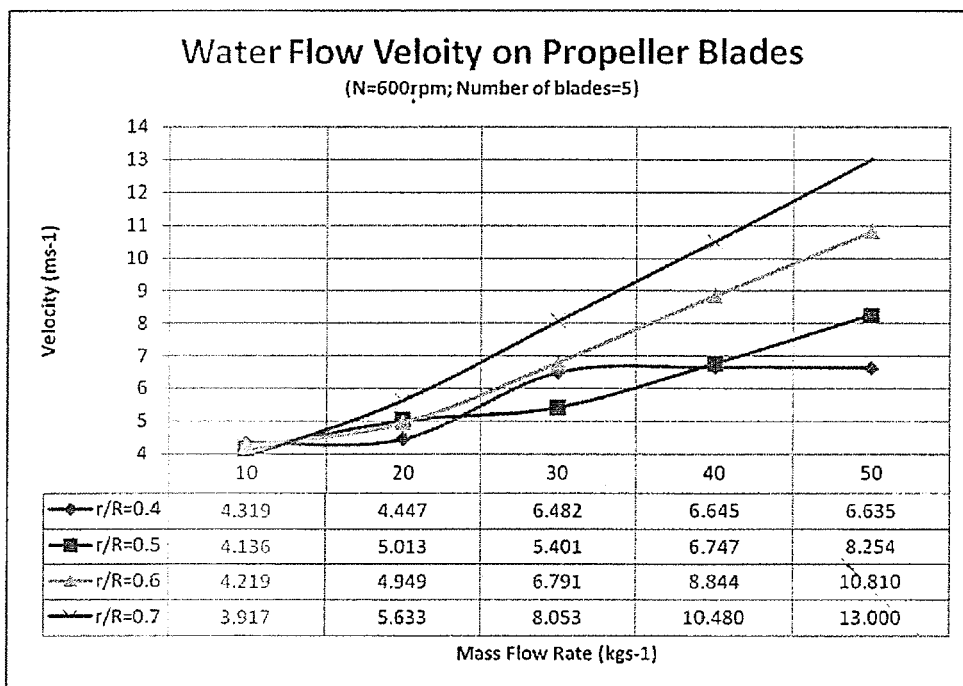


Figure 9. Schematic graph of flow velocity with 5 blades

Table 7. Summarize of maximum flow velocity for 5 blades

r/R	Hub to tip ratio (kgs <sup>-1</sup> )				
	10	20	30	40	50
0.4	4.319	-	-	-	-
0.7	-	5.633	8.053	10.480	13.000

Table 8. Summarize of maximum flow velocity for 6 blades

r/R	Hub to tip ratio (kgs <sup>-1</sup> )				
	10	20	30	40	50
0.6	4.224	-	-	-	-
0.7	-	5.742	8.302	10.920	12.290

**Power output calculation generated by the turbine**

In order to derive the power output produced by the turbines, a general calculation can be used. The equation that can be used to calculate the power output as stated below.

$$P = \eta \rho g HQ \tag{1}$$

Where:

P = Power output produced by turbine

$$\eta = \text{Efficiency} = \eta_{\text{turbine}} * \eta_{\text{generator}} = 75.65\%$$

$$\eta_{\text{turbine}} = 85\%$$

$$\eta_{\text{generator}} = 89\%$$

$\rho$  = Density of water

g = Gravitational constant

H = Head

Q = Flow rate

In this particular case, water flow rate can be determined by using equation as stated below:

$$Q = AV \tag{2}$$

Where:

$$A = (\pi/4)(D)^2$$

D = pipe diameter

All summarized results for the flow velocity can be substituted into both of these equations to determine the power output produce by each turbine involved. Information in Table 9 stated the best selected final results which including power output produced by the axial-flow turbine according to the selected parameters.

Table 9. Overall final results of the analysis together with the power output

- |   |  |
|---|--|
| <ul style="list-style-type: none"> <li>For mass flow rate of 10kgs<sup>-1</sup>:<br/>Number of blades = 3<br/>Hub to tip ratio = 0.4<br/>Maximum value of flow rate = 4.808ms<sup>-1</sup><br/>Power output = 67 Watts</li> </ul> | <ul style="list-style-type: none"> <li>For mass flow rate of 20kgs<sup>-1</sup>:<br/>Number of blades = 4<br/>Hub to tip ratio = 0.7<br/>Maximum value of flow rate = 5.825ms<sup>-1</sup><br/>Power output = 394 Watts</li> </ul> |
| <ul style="list-style-type: none"> <li>For mass flow rate of 30kgs<sup>-1</sup>:<br/>Number of blades = 6<br/>Hub to tip ratio = 0.7<br/>Maximum value of flow rate = 8.302ms<sup>-1</sup></li> </ul>                             | <ul style="list-style-type: none"> <li>For mass flow rate of 40kgs<sup>-1</sup>:<br/>Number of blades = 6<br/>Hub to tip ratio = 0.7<br/>Maximum value of flow rate = 10.920ms<sup>-1</sup></li> </ul>                             |



Power output = 562 Watts

Power output = 739 Watts

- For mass flow rate of  $50\text{kg s}^{-1}$ :  
Number of blades = 3  
Hub to tip ratio = 0.7  
Maximum value of flow rate =  $13.780\text{ms}^{-1}$   
Power output = 932 Watts
- 

#### 4. Conclusions

In this case study, the implementation of simulation analysis software such as CFD plays very important role in order to obtain results at an early stage before proceed to the next levels such as fabrication and the actual experiments. The data collections from the CFD analysis results, also allows inference can be done more easily. Furthermore, the most crucial factors which are the manufacturing costs and overall time consuming can be minimized significantly. CFD software can also shows in simulation way how the water flows between each blades of the axial-flow turbine from the inlet to the outlet of the runner. Therefore, in other words, the implementation of CFD simulation is very helpful as a validation and optimization tools in this case study.

From the analysis results, conclusion can be made that there is influence between hub to tip ratio and number of blades on the performance of the runner. As stated in Table 9, the minimum power output which produced by the turbine was 67 Watts and the maximum value was 932 Watts. However, these values of power output are just as guidelines. In order to validate these values, experiments are needed so that the comparison between the experiments results and analysis results can be done and with this the most optimum results can be achieved.

#### 5. Acknowledgement

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