8/10

RESEARCH METHODOLOGY
(MPSW 5013)

ASSIGNMENT 3

RESEARCH PROPOSAL

TITLE

DESIGN OPTIMIZATION OF AXIAL FLOW TURBINE
FOR
COST-EFFECTIVE PICO-HYDRO TURBINE

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1. INTRODUCTION

One of the main obstacles of rural electrification programme is to find an alternative energy to replace power generated by generator. The ever increasing fuel price and its cost of transportation to the remote location limited the availability of electricity to certain of the day. Since the rural settlement usually is located near water source, renewable energy based on hydro is suggested. This paper will discuss about the development of model system for cost-effective pico-hydro turbine. The sizing of the turbine will be based on low flow and low head application. Two types of turbine, propeller and cross-flow, are evaluated under these conditions. Techno-economics evaluation are done so that the model of the system will be able to select the optimum sizing of the turbine based on the flow rate for a cheap efficient and cost-effective hydro turbine.

A cross-flow turbine has been designed, and fabricated. Together with the existing propeller turbine, both of them will be installed in one model system equipped with complete storage tanks as well as piping system. Centrifugal pump will be used to ensure the circulation of the water from main bottom storage tank into top storage tank where the propeller turbine is located. With fixed head, and variable parameter of water flow rate which will be controlled by using controller valve and flow meter, the data collection of power output for each turbine will be done. Besides experimental, the performance of both turbines will also evaluated by using CFD's simulation software.

1.1 PROBLEM STATEMENT

Pico-hydro turbine is categorized and suitable for low head turbine (below 10 meters) with high flow rate, and can produce power output up to 5 kilowatt. However, most of the rivers of off-grid in our country available with low flow rate of water which below 50 litres/second. Due to this scenario, the pico-hydro turbine can only produce power output about 360 watt[1], which is much lower compare to its ability whereby it can produce power output up to 5 kilowatt. This is because the rotation speeds of the turbine's blades were not fast enough to produce more power output since the flow rate of water is very low.

Therefore, in this particular case, which is for low head and low flow rate of water, two types of turbines which are propeller and cross flow turbine are choosed for evaluation. The blades of propeller turbine will redesign and optimize in order to improve the speed rotation of the blades as well as the shaft which is connected to the generator. As a result these will improve the power output of the turbine.

1.2 OBJECTIVES/PURPOSE OF STUDY

i. To redesign the existing propeller turbine's blades in order to improve the performance of speed rotation of the blades.

ii. To improve the power output performance of the propeller turbine under low head with low flow rate of water condition by redesigning the existing blades.

1.3 SCOPE OF THE RESEARCH

i. To develop a complete model system (test-rig) of pico-hydro turbine that consists of propeller and cross flow type for the experimental purposes. Data of power output for both turbines will be collected and at the end of experiments, comparison will be made upon these two types of turbines.

ii. To develop and optimize the propeller turbine blades design by using SolidWorks and CFD simulation software.

iii. To fabricate a prototype of redesign blades and install in the model system.

iv. To run experiments and collect the power output data for the existing blade and redesign blade of propeller turbine. Comparison will be made for both of the blades to find out the performance of the speed rotation of the blades.

1.4 SIGNIFICANT OF STUDY

i. It is important to do research study on the pico-hydro turbine as an alternative energy in order to produce electricity since most of the rural settlement usually is located near to the water source which is river.

ii. The pico-hydro turbine is suggested to replace the conventional generator as power supply source due to it cost, which is much cost-effective and environmental friendly. The cost of the generator usage is tremendously increased lately due to the price increased of petrol and diesel.

iii. The implementation of pico-hydro turbine for off-grid will support the government programme such as National Electrification Programme in order to increase and improve the standard of living for rural areas.

1.5 RESEARCH HYPOTHESIS

The power output of the existing propeller turbine for low head with low flow rate of water was very low. This has been proven by experimental results done by a group of researchers under Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia (UKM) [1]. In order to improve the performance of power output of the propeller turbine, redesigning the blades are necessary, since it is the main component in the turbine whereby the spinning of the shaft which are connected to the generator, are totally depend on the rotation speeds of the blades. The low power output was because the rotation of the existing blades was not fast enough to produce the power output needed by the turbine. Moreover this situation needs to compensate with low head and low flow rate of water.

Redesigning the existing blades such as its profile, hub to tip ratio, blade angles as well as number of blades might influence the speed rotation of the blades. As a result, the rotation speeds of the blades will increase and this might improve the power output performance as well.

2. BACKGROUND/ LITERATURE REVIEW

Generally, turbine can be classified according to the head and quantity of water available such as high head turbine with low flow rate of water, medium head turbine with medium flow rate of water, and low head turbine with high flow rate of water. Impulse turbine such as cross-flow type and on the other hand for reaction turbine such as propeller type (which is also known as axial-flow turbine) are the most well known turbines used for low head condition. The ideal head is about 10 meters in height which can produce up to 5 kilowatt of power output. In order to compensate with low head situation, therefore the flow rate of water should be high enough to operate these types of turbines. However, most of the off-grid's rivers in our country available with low flow rate of water and due to this, it affect the speed rotation of the blades. As a result the power outputs produced by the turbines are also less than expected. A group of researchers from SERI, UKM has proven this phenomenon. An experimental has been done for propeller turbine and power output data has been collected. The head involved was about 1 meter with water flow rate about 25 litres/second. At the end of the experiment, the data showed that the current produced by the propeller turbine was too small to be considered further [1].

Since the nature of the river is very difficult to be changed, therefore the propeller turbine itself needs to do something in order to overcome this situation. Figure 1, shows about the propeller turbine that is going to implement on the research study. Based from Figure 1, propeller turbine can be divided into few modules which are the moving runner or blade section (or also known as rotor), the fixed guide vanes (also known as stator), shaft, and generator with copper wire. Another main module which is not include in the figure is known as draft tube.

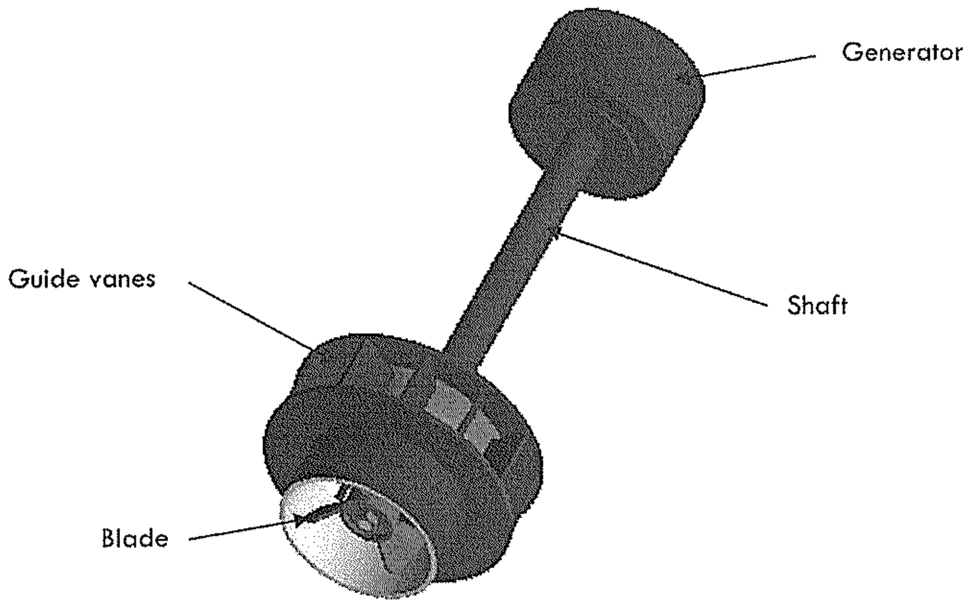

Figure 1 Propeller turbine

As we can see from Figure 1, shaft is a component which connects the blades and the generator. Therefore, clearly shows that the speed rotation of the blade play very important roles in order to produce more current from the turbine. Figure 2, shows the existing blade of propeller turbine which was similar to the experiments that has been done by a group of researchers in SERI, UKM, Bangi, Selangor.

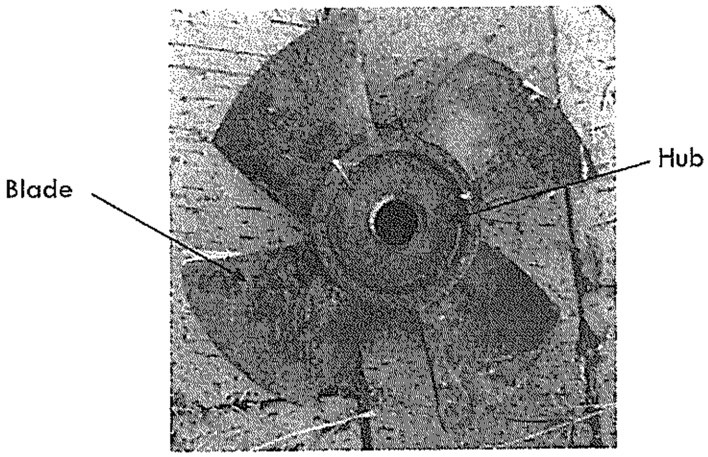

Figure 2 Propeller turbine's blade

In this research study, the turbine's blade will become as a main focus. Some of the parameters such as blade profile, hub to tip ratio, blade angles, and number of blades will be evaluated in order to improve the performance of blade's speeds rotation and increase the power output produce by the propeller turbine.

2.1 HUB TO TIP RATIO

Figure 3 shows the schematic diagram of hub to tip ratio of a blade and number of blades. Hub to tip ratio is defined as the ratio of the hub radius to the blade tip radius. On the other hand number of blades means the quantity of blades on the propeller which attached to the hub. The research will focus on the influence of this hub to tip ratio and the number of blades as the main variable parameters while other such as blade angle and blade profile will still remain as fixed parameters.

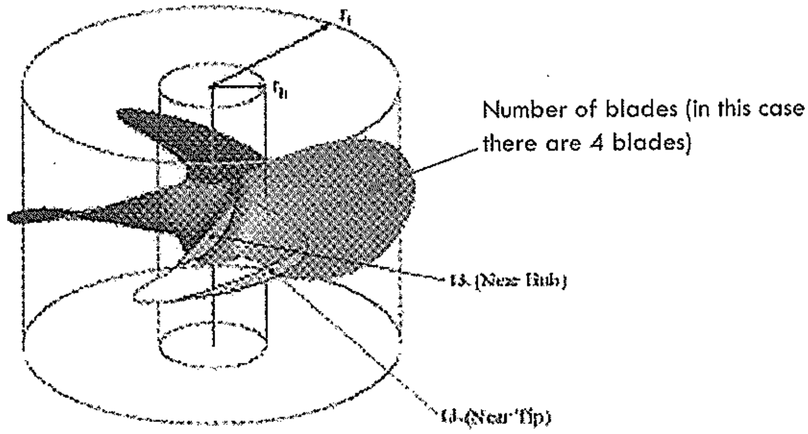

Figure 3 Schematic diagram of hub to tip ratio and number of blades

2.2 THEORY OF BLADE

2.2.1 VELOCITY TRIANGLE DIAGRAM OF THE AXIAL TURBINE STAGE (AT FIXED GUIDE VANES AND MOVING BLADES SECTIONS)

The velocity triangle diagram is the most basic concept of blade's design that need to consider before can proceed with the modification of the turbine blades. Velocity triangle diagram is about the relative and absolute velocities of the blade rows together with the fluid[4]. Figure 4, shows the example of velocity triangle diagram.

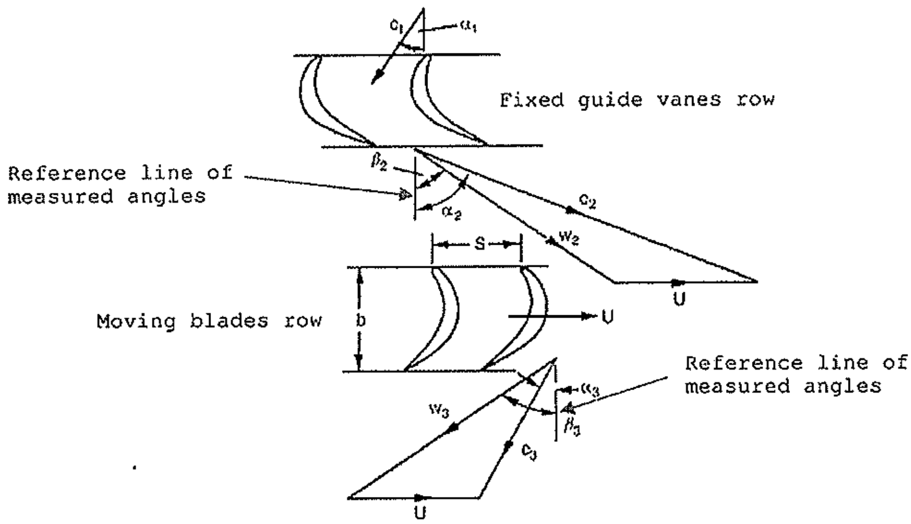

Figure 4 Flow velocity diagram of the axial turbine

Nomenclature for Figure 3:

b = height of blades.
S = pitch of blades.
U = blades speed.
c_1 = absolute flow velocity at inlet of fixed guide vanes.
α_1 = absolute angle for inlet of fixed guide vanes.
c_2 = absolute flow velocity at outlet of fixed guide vanes.
α_2 = absolute angle for outlet of fixed guide vanes.
w_2 = relative flow velocity at inlet of moving blades.
β_2 = relative angle at inlet of moving blades.
w_3 = relative flow velocity at outlet of moving blades.
β_3 = relative angle at outlet of moving blades.
c_3 = absolute flow velocity at outlet of moving blades.
α_3 = absolute angle at outlet of moving blades.

Notes: All angles are measured from the axial direction.

From the velocity diagram in Figure 3, the fluid or water enters the fixed guide vanes with absolute velocity, c_1, and with absolute angle, α_1. Then, it will accelerate to the fixed guide vanes outlet at an absolute velocity, c_2, with angle α_2.

Next the fluid will enter the inlet of the moving runner section with relative velocity, w_2, at angle β_2. This can be found by subtracting vectorially, the blade speed, U, from the absolute velocity, c_2. The relative flow within the blades accelerates to velocity w_3, at an angle β_3 at moving blades outlet. The absolute flow which represented with c_3 at an angle α_3 is obtained by adding vectorially the blade speed, U, to the relative velocity, w_3.

Based from continuity equation for uniform, steady flow is:

$$\rho_1 A_1 c_{x1} = \rho_2 A_2 c_{x2} = \rho_3 A_3 c_{x3} \qquad \text{———— (1)}$$

(Where: ρ:water density; A:cross-section area of the blade; c:absolute velocity)

In the turbo machines, for two-dimensional theory, it is usually assumed that the axial velocity remains constant, therefore:

$$c_{x1} = c_{x2} = c_{x3}$$

We can conclude that, equation (1) can be simplified as:

$$\rho_1 A_1 = \rho_2 A_2 = \rho_3 A_3 = constant \qquad \text{———— (2)}$$

2.2.2 VELOCITY TRIANGLE DIAGRAM OF AXIAL TURBINE AT THE BLADE HUB AND TIP

Punit Singh and Franz Nestman [2], and K.V. Alexander [3], has been investigated about the performance of the propeller turbine blades for low head application. They found that, by decreasing and adding the angles of blade hub and tip, has great influenced to the performance of the blade itself.

Arthur William [4], who is also focus on hydro-turbine with low head application, had involved with investigation about the Francis turbine blade. From his research, he found that, by decreasing the angle of the existing blades, and on the same time maintained the radius as well as the number of blades had improved the performance of the power output of the turbine.

2.2.3 FREE (IRROTATIONAL) VORTEX FLOW THEORY

When fluid is drawn down a plug-hole, one can observe the phenomenon of a free vortex. The tangential velocity, v, varies inversely as the distance, r, from the center of rotation, so the angular momentum, rv, is constant. The vorticity is zero everywhere (except for a singularity at the center line) and the circulation about a contour containing $r = 0$ has the same value everywhere. The free surface (if present) dips sharply (as r^{-2}) as the center line is approached [5].

The tangential velocity is given by:

$$v_O = \frac{\Gamma}{2\pi r}$$

Where: Γ is the circulation while r is the radial distance from the centre of the vortex.

In non-technical terms, the fluid near the centre of the vortex circulates faster than the fluid far from the centre. The speed along the circular path of flow is held constant or decreases as move out from the centre.

3. METHODOLOGY

i. The SolidWorks software will be used at the early stage to develop and design the overall of the model system (test-rig) as well as to redesign the propeller turbine's blades. 3 dimension (3D) drawings as well as 2 dimension (2D) technical drawings which consists of all related fabrication and standard part components, together with assembly drawings will be formed. All drawings are developed into one to one scale, in order to get a very clear picture of how the overall model system look like. This is because in 3D drawings, the detection of any kind of errors are much easier to do and can save a lot of time, especially for those which involved with assembly tasks. On the other hand, the bill of materials will be prepared once the overall model system has finalized.

ii. The performance of the redesign blades will be analyzed and optimized by the implementation of Computer Fluid Dynamics (CFD) simulation before proceed to the prototype stage. As discussed before there are few parameters on blade itself which can improve the performance of the turbine power output. However it is quite impossible to involve all of the parameters at one time. This is because of too many variables parameters need to be considered with. Therefore, hub to tip ratio and number of blades are the variables parameters that need to focus on in this research study, while the rest of the parameters such as blade profile and blade angle are fixed values. At the end of this stage, comparison will be made by using CFD and experiments for both of the existing and redesign blades.

iii. The model system (test-rig) of the pico-hydro turbine will be established in order to run the experiments. This test-rig will be built besides the Research Room compound which is located at Phase B, Faculty of Mechanical Engineering, UTeM. The redesign blade's prototype will also fabricate during this stage for the experiment purposes. In this case, the cross flow turbine will be fabricated locally in-house, while the propeller turbine will be purchased from out sources.

iv. Few experiments will be conducted for the power output data collections. In this experiment, fixed head with variable parameter of water flow rate will be used. The water flow rate is controlled by using controller valve and flow meter. Firstly, the experiment will involve with the propeller type of turbine with the existing blades, before proceed with the redesign blades. The next experiment will be conducted by running the cross flow turbine.

v. At the end of the experiments, comparison of all data collections for both propeller and cross flow turbine will be made to find out the most optimum power output produced.

4. EXPECTED RESULTS

i. At the end of experiments, the new/redesign blades of propeller turbines will become more efficient and able to produce more power output (about 30% higher) compare to the previous blade's design.

ii. From the data collection and analysis, it also shows that by increasing the hub to tip ratios influenced the performance of the blades. However by increasing the number of blades between three to six pieces has no significant at all to the blade performance.

5. CONCLUSION

Redesigning the turbine's blades need a very careful consideration. Parameters such as blade profile, hub to tip ratio, blade angles, and number of blades play very important role in order to increase the speed rotation of the blades. The increment of the speed rotation will improve and increase the power output of the turbine. The implementation of simulation software such as CFD is very useful to gain early information about the performance of the blades before it undergoes the fabrication process. It also can reduce human error and save time. Expected the final results will indicate that by increasing the value of hub to tip ratio of the blades can contribute about 30% increment of the power output of the axial flow turbine under low head with low flow rate conditions.

6. REFERENCES

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GUNT CHART FOR 3 YEARS PLANNING

	YEAR 2011												YEAR 2012											
ACTIVITIES	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	oct	Nov	Dis
Literature review Collect journals, proceeding papers & related resources.																								
Conceptual design of 'test-rig'.																								
Conceptual design of blades.																								
Searching for fabrication & standard parts for prototype.																								
Purchase the raw materials & standard parts.																								
Receive the raw materials & standard parts for installation.																								
Finalized the conceptual design of 'test-rig' & blade's design.																								
Detail design of the 'test-rig'.																								
Detail design of the blade's design.																								
Assembly design of the 'test-rig' & blade's design.																								
Fabricate the prototype of 'test-rig'.																								
Fabricate the cross-flow turbine's prototype.																								
Installation of axial & cross flow turbine on the 'test-rig'.																								

	YEAR 2011												YEAR 2012											
ACTIVITIES	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dis	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	oct	Nov	Dis
Test by-off of the 'test-rig'											→	→												
Modification on the existing prototype (fabricate & reinstall).													→	→	→									
Run experiments & collect data (for axial-flow turbine with new design blades)																→	→	→						
Run experiments & collect data (for axial-flow turbine with new design blades)																			→	→	→			
Run experiments & collect data (for cross-flow turbine)																						→	→	→

	YEAR 2013											
ACTIVITIES	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dis
Compilation of all the data to evaluate & comparison.	→	→	→									
Report writing.		→	→	→	→	→	→	→				
Correction of report after discuss with supervisor.								→	→	→		
Final report writing & compilation before submission.										→	→	→