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Potential Evaluation of Vertical Axis Hydrokinetic Turbine Implementation in Equatorial River

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Abstract. In rural areas, small villages are often disconnected from the electrical grid because of lack of economic resources. Long extensions of the grid, only contributing small rural areas with electricity, are not economically beneficial. The temporary solution for the disconnection is to contribute with diesel-generators. These have become common for remote electricity distribution because of their quick installation and mobility. However, the high expenses of the fuel for the diesel generators, along with the challenging fuel transportation because of the scarce to non-existing infrastructure, are not a sustainable solution for electricity distribution in the rural areas. Hydrokinetic turbine is an attractive option for harnessing energy from natural flow of rivers where no static head exists. However, equatorial river system is subjected to high amount of sediment and flowing objects due to the large quantity of vegetation in the area. This leaves the turbine exposed to a higher degree of erosion on the blades and a higher risk of getting clogged. A field study was conducted to attain the velocity and characteristics of sediment in the Niah River located in Miri of Sarawak state, Malaysia. The collected data was analyzed and used as input values during simulations of a turbine model by the Computational Fluid Dynamics. Areas on the turbine exposed to the water with a high velocity and containing a high concentration of sediment were examined. The investigation states that areas on the blade's outer sides are most exposed to erosion and will be in need of protection in form of a harder surface. Adaptation of hydrokinetic turbine for the conditions prevailing in the equatorial river is essential to improve the efficiency and lifetime of the turbine.

Keywords: hydrokinetic turbine, equatorial river, sediment, erosion

1. Introduction

Electrification is generally seen as one of the key indicators that can reduce poverty. Thus, rural electrification is an essential element in bringing about the social and economic development of the underprivileged rural populations. Nevertheless, considering the high cost of distribution and associated transmission loss, grid power supply in rural areas is not economically viable. For most of rural community in Malaysia, the source of power comes from a diesel generator, which operates for about 2 to 3 hours a day. However, the cost of running the generator is relatively expensive as the price of diesel as well as the cost of bringing the fuel to the longhouse can be very high. The off-grid electricity, which can be generated by solar, wind or hydro technology, provides the opportunity to expand the capacity of rural electrification and has distinct advantages for the community as a cost-effective strategy and reliable source of energy.

Photovoltaic solar energy conversion systems have been used to supply electricity for isolated locations in equatorial region. However, the system installed in this area is found to be seriously hampered by tropical weather-related problem. The intense heat and humidity in this region corrode and crack electrical connections and electronic components and encourage mold growth on panels. Tropical

climates characterised by fast-changing irradiance conditions due to high variations in cloud coverage influenced the battery charging operation of small solar energy systems [1]. Frequent rains and lightning strikes are also a common cause of system failures in which faulty systems are usually abandoned due to scarcity of spare parts as well as expert know-how among the local community to exert simple maintenance [2].

Wind energy conversion systems have had little applications in remote locations of Malaysia due to poor wind resources. However, a few small turbines, such as those in Sabah and Sarawak are being used in hybrid systems, integrated with solar panels or diesel generators. Similar with the solar energy, strikes by lightning is also one of the major barriers to using wind turbines in equatorial region.

Hydrokinetic turbine is a low pressure run-of-the-river ultra-low-head turbine that will operate on the equivalent of less than 0.2 m of head [3]. The turbines are used to take advantage of the energy in rivers, tidal and ocean currents. For implementations in rivers, hydrokinetic turbines are an attractive alternative for small scale hydropower where the environmental effects from dams can be avoided. The turbines are also a cheaper alternative as investment costs are low and less maintenance work is necessary.

Though, smaller particles in the water such as soil sediments will expose the turbine to erosion. The sediment causes damage to exploited segments of the turbine and will result in alteration of blade profile, increased vibration, fatigue damage, inefficient operation and system failure. The effect of erosion is dependent on the characteristics of the particles, flow of the water and concentration of the sediment as well as the operating conditions of the turbine.

Assessing the sediment properties of a stream where a hydrokinetic turbine is planned is an essential prerequisite to evaluate potential hazards for the turbine and thereby contribute to a higher accessibility to electricity in remote areas. The objective of the current study is to investigate the areas on the turbine most exposed to erosion as of the high amount of sediment in the water and to improve knowledge of turbine wear with regards to relevant suspended sediment parameters.

2. Methodology

Data were collected during the field study in Niah River located in Miri of Sarawak state, Malaysia. Niah River is an equatorial stream located about 3 km from the small town of Batu Niah, 110 km southwest of Miri on the island of Borneo. The 105 km river originates from the Niah basin with total area of 1,343 km². The area has a tropical rainforest climate with two monsoon seasons: the southwest monsoon, which is the dry season from April to September, and the northeast monsoon, which is the wet season from October to March. The annual rainfall is around 250 to 380 cm with the air temperature between 23 °C to 32 °C the whole year round. The morphological cross-section of River Niah is shown in Fig. 1.



Fig. 1. Morphological cross-section of River Niah

2.1. Velocity of flowing water

Sediment erosion is caused by the stroke of sediment in the flowing water making an impact on the solid surface. The amount of sediments in the water is highly connected to the current amount of discharge and the current water velocity. Measurements were carried out during the field study to establish the

velocity of the water in the Niah River. The velocity of the flowing water in the river was measured by using a Swoffer propeller type current meter consisting of moving blades that rotates with the water velocity. The device had the possibility to be used at different depths and was in this case used to measure the velocity at depth level of 0.4 m, 1.5 m and 3.0 m. The velocity of the water varies considerable depending on where in the river the measurements are taking place. The water velocities measured at the several subsections as shown in Figure 6. For each measuring point, 3 to 5 readings were taken and averaged to give a mean point velocity to reduce the error due to variation in water flow.

2.2. Sediment profiling

To collect information about the sediment, water was sampled from specific depths and afterwards analysed using a Laser In-Situ Scattering and Transmissometry (LISST) instrument shown in Fig. 2. The water was sampled in vertical line at three different depths using a US P-61-A1 point integrating sampler on a moving boat along the whole section of the river. Due to the streamlined designed and the sampling method it can provide undisturbed water samples. This device provides the input samples for the LISST instrument in which laser refractometry is used to measure volumetric concentrations for particles based on 44 logarithmically spaced size classes between 0.34 to 500 μm . In-situ measurements of particle size and concentration is provided by a laser beam directed into the sample volume where particles in suspension scatter, absorb, and reflect the beam. The scattered laser light is received by a series of ring shaped detectors of progressive diameters that allow measurement of the scattering angle of beam. Particle size can be calculated from knowledge of this angle either by using the Fraunhofer approximation or the exact Lorenz-Mie solution. Particle size dependency is eliminated by basing concentration measurements on these measured particle sizes, thus allowing both particle size and volume concentration to be simultaneously measured [8].



Fig. 2. Laser In-Situ Scattering and Transmissometry (LISST) instrument

2.3. Sediment erosion

Sediment erosion is caused by the stroke of sediment in the flowing water making an impact on the solid surface. The effect of erosion is dependent on the characteristics of the particles and also the operating conditions of the turbine, such as the flow of the water [4]. The rate of increased effect from erosion from sediment is also increasing with the concentration of the sediment. The actual effect of erosion is very complex because of the many different factors affecting the result [5]. The phenomenon is almost impossible to simulate with the accuracy of the actual flow of the river. However, experimental trials have been conducted to determine the erosive wear on a Pelton turbine buckets [6]. From the trials, a simple equation, determining the amount of erosion per unit of water discharge W as a function of current conditions, could be established using Equation (1) in which s represents the silt size, c the sediment concentration, v the water velocity and t the operation time.

$$W = 4.02 \cdot 10^{-12} (s)^{0.0567} (c)^{1.2267} (v_w)^{3.79} (t) \quad (1)$$

2.4. Computational fluid dynamics simulation

Simulations of the vertical axis hydrokinetic turbine were conducted using computational fluid

dynamics (CFD) software tool ANSYS Fluent. The turbine to be implemented was constructed based on 3 rotor blades design with size of 0.85 m wide and 0.70 m height as shown in Fig. 3.

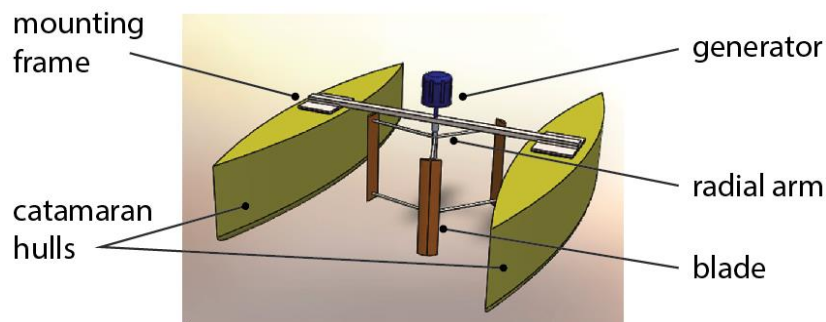


Fig. 3. Vertical axis hydrokinetic turbine

The turbine model was simplified to 2D and the planar surface is set to be symmetric across the direction normal to the plane (z-axis). In the analysis the pressure from water hits the turbine blades and subsequently yields certain magnitude of resultant force that initiate the rotation. The turbine rotation is driven by the moment produced from the net force acting on the blade in radial direction and the arm length. The CFD analysis was used to identify the areas on the turbines which achieve the highest velocity. The geometry for the analysis was prepared in ANSYS Spaceclaim Direct Modeler™ with number of blade of 3 and the NACA profile of 0018. The 2D plane was generated considering the traced profile and the pattern tool was used to create the 3 blades configuration as shown in Fig. 4. The element size of the mesh used during the simulations of the turbine was set to 1mm, containing 104,832 elements and 105,605 nodes. In order to obtain fine results across the blade profile, inflation was introduced and bounded along the profile edge.

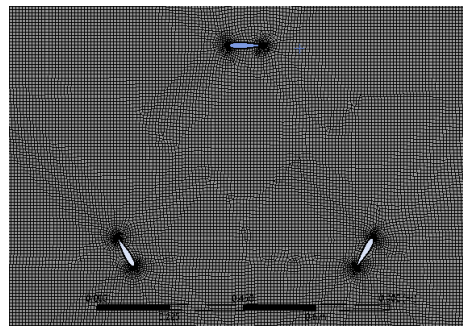


Fig. 4. Vertical axis hydrokinetic turbine

The particles were assumed to have the same velocity as the water, the higher the velocity of the water hitting the turbine, the higher the impact on the turbine from particles. The areas on the blades which achieve the highest velocity were determined as the most vulnerable areas as the majority of the erosive effect will occur at these areas.

The information of the collected extent of sediment in the water was used as inlet data of moving particles in fluid flow during simulations of the turbine. The mean concentration of the sediment from the different depths were used to give an applicable result as the depth of implementation was not yet determined. The amount of sediment at the different depths could indicate whether the erosion on the turbine might differ depending on the depth, or not, which should be considered when determine the depth of implementation.

3. Results and Discussion

The velocity of the water varies considerable depending on where in the river the measurements are taking place [7]. This was confirmed during the field study. The water velocities measured at the several subsections with different depth of the river show that the flow velocity occurs in the central of main

channel region, which decreases towards the side banks as summarized in Table 1. The water level also varies widely in the Niah River depending on seasons. Because of the portability of the turbine it is however easy to move to an area with higher level and velocity during dryer periods. The mean velocity of measurements of the central region of the river was calculated to be 1.02 m/s, and it was used during CFD simulations of the turbine.

Table 1. Velocity of river flowing water at different subsection

| | Subsection 1 | Subsection 2 | Subsection 3 | Subsection 4 | Subsection 5 |
|-------------|--------------|--------------|--------------|--------------|--------------|
| Depth 0.4 m | 0.19 m/s | 0.63 m/s | 1.33 m/s | 0.52 m/s | 0.31 m/s |
| Depth 1.5 m | 0.29 m/s | 0.77 m/s | 0.97 m/s | 0.66 m/s | 0.42 m/s |
| Depth 3.0 m | 0.26 m/s | 0.64 m/s | 0.78 m/s | 0.58 m/s | 0.29 m/s |

The measured suspended sediment data consist of 30 observations from ten locations of the river indicates that all samples are dominated by silt and fine sand particle with the mean size range of < 50 μm . A detailed box-plot representation of the mean size and concentration distribution of suspended sediment particle for depth level is shown in Fig. 5.

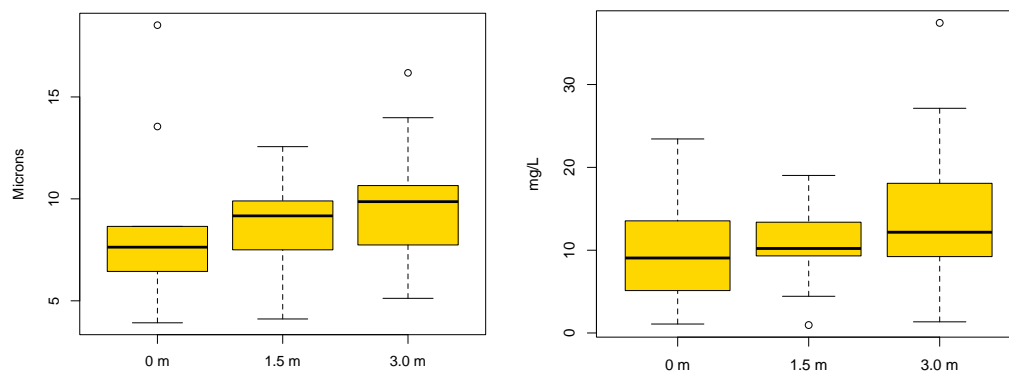


Fig. 5. Mean size and concentration distribution of suspended sediment particle at different depth levels

The erosive wear that may occur at different depth level was established by equation (1) as shown in Table 2.

Table 2. Erosive wear estimation at different depth levels

| Depth Level | Mean Sediment Size (μm) | Mean Sediment Concentration (mg/l) | Erosive Wear (mg erosion / l) |
|-------------|--------------------------------------|------------------------------------|-------------------------------|
| 0 m | 8.698 | 10.019 | 9.074×10^{-10} |
| 1.5 m | 8.866 | 10.670 | 9.813×10^{-10} |
| 3.0 m | 10.025 | 14.667 | 14.601×10^{-10} |

The sediment in the water makes the areas that are exposed to the high velocities even more exposed to a higher degree of erosion than other areas of the turbine. Thereby, the velocity is an important factor to detect the most vulnerable areas of the turbine. As erosion is a complex phenomenon and almost impossible to simulate, the focus of CFD analysis has been to determine the vulnerable areas of the turbine, where most sediment will hit. A visual indication as shown in Fig. 6 was used to establish more exactly where the highest water velocity interacts with the turbine blades and the force on each blade in the radial direction.

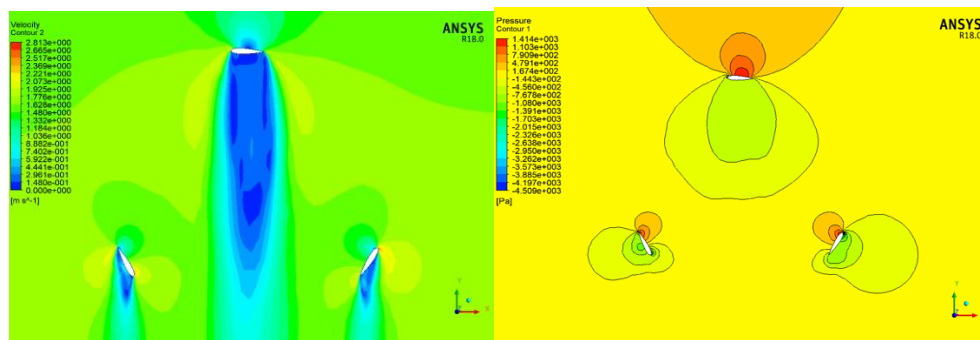


Fig. 6. Areas where highest water velocity interacts with the turbine blades and the force on each blade

The results confirm that outer surface of the blades is exposed to higher velocities, and they are thereby more exposed to the effect of erosion. The increased pressure forcing the blades to move results in a higher velocity exerted on the part of the blade than compared to the connected radial arm. According to simulations, it would be recommended to add a coating on the outside of the blades as these are the areas most exposed to a high velocity and thereby a high concentration of silt.

4. Conclusion

Hydrokinetic turbine is an attractive option for harnessing energy from slow flowing water where no static head exists. However, equatorial river system is subjected to high amount of sediment that will exposed the turbine to erosion. Therefore, ways to protect the turbines were investigated. Measurements were carried out during a field study in Niah River located in Miri of Sarawak state, Malaysia where water velocity as well as size and concentration of suspended sediment were analyzed. A model of the turbine to be implemented was simulated using ANSYS Fluent in which the collected information from the river was used as the input data. Areas of the turbine where sediment-full water hits with a high velocity were detected and considered as the most vulnerable areas for erosive effect. The method is particularly applicable in predicting the silt erosion on solid surface of turbine components due to dynamic action of suspended sediment. In view that the efficiency of the turbine will decreases with the increase in the erosive wear, it is therefore necessary to improve on the hydraulic and protective design of the component.

5. References

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