Wake analysis between nested design and cylindrical representation of a low current speed vertical tidal turbine

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Abstract. Over the past years, electrical energy demand has increased dramatically worldwide. Malaysia being a developing country, the need for electrical energy is expected to rise yearly. Therefore, to prevent the energy crisis and global warming, the Malaysian Government has started to switch focus to renewable energy technologies. This paper will analyse the wake characteristics produced by the vertical axis tidal turbine design. Malaysian waters have shallow depth and low water current speed, contributing to an ideal solution to implement a nested turbine. The numerical analysis compares the wake generated from the actual turbine design and a hypothetical ‘actuator’ cylinder which represents vertical axis tidal turbine. The simulation result has been validated with other studies which brings about the understanding of the wake generated from nested turbine and ‘actuator’ cylinder.

1.0 Introduction
Malaysia is rich in natural resources and minerals. Sadly, these resources are not renewable. About 80% of Malaysian electricity is generated from power stations, mostly fuelled by coal [1]. On the other hand, coal is not a sustainable source of fuel and is harmful to the environment. The Malaysian Government has started to invest in renewable energy sector in which about 2% of renewable energy sources explored by the government is available in Malaysia. This paper focuses on tidal energy and its application towards shallow water and low current speed condition. Tidal energy is a renewable energy source that is predictable and highly reliable, due to the gravitational pull from the sun and the moon. To harness the kinetic energy from the ocean tide, few technologies can be implemented, such as tidal barrage, lagoon, and stream. The similarity of tidal stream to wind turbines makes it more relatable to use the existing turbines’ design for extracting tidal energy. There are two types of turbines that are prominently used, namely, horizontal axis tidal turbine (HATT) and vertical axis tidal turbine (VATT). For Malaysian water conditions, it is more suitable to use VATT design such as Savonius, H-Darrieus and Nested Turbine as it can generate power from low-speed current.

1.1 Savonius Turbine
Savonius is a drag-based turbine that uses drag force to rotate the turbine. A Savonius turbine design has several factors that can influence the performance. One of the factors is the overlap ratio of the turbine. A study conducted by Yaakob Omar showed that the best turbine performance is found to have an overlap ratio of 0.21 as it gives a high torque value [2]. Another simple modification can be done by adding an endplate to the two ends for the turbine to maintain the pressure of the turbine and prevent the flow from moving away from the turbine blade, as demonstrated by Patel [3]. The result of this improvement has increased the performance of the turbine significantly.
1.2 H-Darrieus Turbine
H-Darrieus is a lift-based turbine that uses the lift force to turn the turbine. The performance of the H-Darrieus turbine is influenced by the NACA blade design. Three designs can be commonly used for the blade, which are NACA0015, NACA0018, and NACA0021. All these blade designs are in a symmetrical shape. The only difference between the three designs is the thickness of the blade. The thickness of the blade has major influence on the turbine such as the starting capability, aerodynamic efficiency and the impact flow on the blade [4]. Figures 1 and 4 illustrate the different thicknesses of the three NACA blades and the Computer Aided Design (CAD) model of H-Darrieus turbine employed in this study.

![Figure 1. NACA blade design for low current speed](image)

1.3 Nested Turbine
A nested turbine or a hybrid turbine is designed to overcome the limitation of a standalone turbine. Some of the limitations of the standalone turbine are low starting torque (H-Darrieus) and low efficiency (Savonius). A nested turbine combines the advantages of the standalone turbines i.e. low starting speed and produces power at a very low velocity. The rationale behind it is that the nested turbine will utilize two forces; the drag force and lift force. Combination of the two standalone turbines in a nested turbine gives an outcome where the drag force will be absorbed by the Savonius turbine to give a high starting capability [4] and the H-Darrieus will use the lift force to provide good efficiency and increase the power output of the nested turbine.

2.0 Methodology
For the nested turbine geometry, CAD models were created using SolidWorks[5] software for two different designs - the Savonius and H-Darrieus. The two turbines are then assembled by mounting the Savonius turbine at the middle of the H-Darrieus turbine as illustrated in Figure 5. The CAD file was then imported into Ansys Fluent[5] to run the Computational Fluid Dynamics (CFD) simulation using the k-epsilon model. The model’s domain was created in Ansys design modular window as shown in Figure 2 with a clearances gap of 15m top and bottom of turbine. The boundary condition setting was obtained by previous studies done by Hoe [6], A.Bakri [7] and Yaakob Omar [2]. Table 1 shows the boundary condition used for this numerical study.

| Parameters                  | Values                  |
|-----------------------------|-------------------------|
| Speed of water current      | 0.6 m/s and 1.0 m/s     |
| Viscosity                   | 0.00092 Ns/m²           |
| Density of sea water        | 1023 kg/m³              |
There are three nested turbine models with different NACA blades designs (NACA0015, NACA0018 and NACA0021) and cylindrical objects (i.e. hypothetical ‘actuator’ cylinder) as a representation of the standalone VATT turbine. The simulation was conducted to compare and validate the generated wake and velocity deficits from the cylinder and nested turbine. As for the different NACA blade design used, the purpose is to investigate the performance and velocity deficits produced by each NACA blade design that are used in the nested turbine design. All nested turbines and the ‘actuator’ cylinder have the same diameter and height for validation purposes, which is to analyse the characteristics of the wake generated by the nested turbines and cylindrical object. Notably, this validation will also provide an insight into the velocity deficit experienced by the devices under shallow water condition with low current speed.

2.1 Design of turbine and parameters

Details regarding model’s design and dimension are illustrated in Figures 3 and 4. Figures 5 and 6 meanwhile represent the CAD model of a nested turbine design and the hypothetical ‘actuator’ cylinder.
3.0 Results and discussion

3.1 Comparison of 5D 0.6m/s and 1.0m/s velocity deficits

Note that ‘previous study (x)’ used in the plot’s legend refers to the study conducted by A. Bakri [7], while D refers to diameter of the turbine, which is 5 meter. The results in Figure 7 are for flow velocity of 0.6m/s for nested turbine with NACA0018 and NACA0015 blades, which show the highest velocity deficit. However, for Figure 8 with the current velocity set at 1.0m/s, the ‘actuator’ cylinder shows the highest velocity deficits. In terms of low current speed, a nested turbine will have the highest acceleration at the downstream region. If the velocity of the current is set to be higher (i.e. from 0.6 m/s to 1.0 m/s), then the downstream flow of the nested turbine will not accelerate at its full potential. This may be due to the influence of drag force from the Savonius affecting the Darrieus performance [8].

On the other hand, for the velocity recovery, nested turbine with NACA0015 and NACA0018 demonstrate faster recovery at the speed of 0.6m/s. Figure 9 and 10 display the velocity counter plot for the nested turbine using NACA0018 and ‘actuator’ cylinder, respectively. From the figures, it can...
be seen that the deceleration of nested turbine is bigger compared to ‘actuator’ cylinder. In contrast, for freestream velocity of 1.0 m/s, the deceleration of ‘actuator’ cylinder is actually larger when compared to the nested turbine using NACA0018, as illustrated in Figure 11 and 12.
4.0 Conclusion

Based on the presented results, it can be concluded that nested turbine with NACA blade designs NACA0018 and NACA0015 have a higher acceleration at the downstream region in comparison to the cylindrical object at 0.6 m/s. At 1.0 m/s, however, the results demonstrate opposing trend where the ‘actuator’ cylinder displays higher acceleration than the nested design. This could be due to the fact that the three tested NACA blades are specifically designed to operate in a slow-moving fluid environment between 0.6 – 0.8 m/s. Additionally, the drag force generated from Savonius turbine does not only affect the performance of the nested turbine, but it can also impede the velocity recovery of the device. The results presented in this paper have provided insights into the behaviour of nested turbine design blades under different slow-moving flow environment and can be used to further analyse another nested turbine parameter.

Acknowledgments

The authors gratefully acknowledge the financial support received from the Ministry of Higher Education Malaysia through the Fundamental Research Grant Scheme for Research Acculturation of Early Career Researchers (FRGS-RACER) - RACER/1/2019/TK07/UNIMAP/1.

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