The effect of support structure on RANS actuator disc for shallow water application

A Rahman, N B Yahaya, M T A Rahman

School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Main Campus, 02600 Arau, Perlis, Malaysia.

Abstract. The effect of support structure on the wake formation of the tidal turbine needs to be considered when investing in a tidal energy farm. The wake resulted from the support structure may vary with the array of turbine. There is various type of support structure that are under development and each type of the support structure exhibit a different behaviour of the wakes. Four types of geometry of the support structure such as cylinder, ellipse, square and diamond were analyzed using Computational Fluid Dynamic (CFD). The k-epsilon turbulence model was used to analyze the effects of the support structure. From this study, the flow of turbulence on each support structure exhibits different behaviour. For a single turbine, it was found that ellipse geometry of the support structure indicates the shortest turbulence form. However, in terms of velocity deficit the diamond geometry illustrates the highest value followed by the square, cylinder and ellipse geometry. For the array configuration, it proves that the 1.5D for distances between two turbines is acceptable since turbulence occurrence is separated from each of the turbine. In addition, for three turbines arrangement, the separation between the first and second rows is agreeable on 3D because the wakes are well merged and almost return to ambient condition at 1D downstream. Based on the results of this research it can be concluded that ellipse support structure shows promising results due to the wake formation recovers back to the inlet velocity the fastest among the other support structure when passing through the tidal turbine.

1. Introduction
The growth of the population is proportional to the demanding of electricity usage. Electricity can generate by a various source of energy. Nowadays, natural energy such as water, solar, wind, wave, and tide are widely used to gain electricity. The usage of natural energy is increasing from time to time. Before this, fossil fuel such as coal, oil and natural gas are used to generate electricity [1]. The changes of the technologies happen because the negatives impact on the environment. This study will be focusing on the support structure. The support structure is important in order to make the turbine stand stiffly. In order to choose the suitable support structure, there are several characteristics need to be considered. The support structure is choosing based on the size of the turbine, the depth of the water and the suitability of the soil condition. Thus, the type of the support structure for shallow water needs to be considered based on these characteristics.

2. Software used
In this project, there are two types of software have been used. In order to model the 3D modelling, this project used Computer-Aided Design (CAD) software which is SOLIDWORKS. Then, to make a meshing and run the simulation for the model, this project used ANSYS software.
2.1. SOLIDWORKS
SOLIDWORKS is one of the CAD software that is widely used in industry. It is easy to use for parametric design and to edit the design. Since this software has been teaching in class session, it makes easier to use this software.

2.2. ANSYS
ANSYS software is recognized as the most powerful engineering design and analysis software. It also used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. This project will use the FLUENT fluid flow model to simulate the effect of the support structure.

3. Results and Discussion
This chapter discusses the results that obtained throughout the whole process. The results were compared with the published data. The results are contained of single turbine, two turbines and three turbines. Then, the results are compared with the M.E. Harrison et al technical paper[2] and Muchala et al technical paper[3]. Based on the results, the discussion was carried out.

3.1. Single turbine
The results of this study were compared with the previous study in terms of velocity magnitude. The comparison was made with M.E. Harrison et al technical paper. The comparisons are between the actuator disc without support structure from previous study and actuator disc with support structure from this study. Based on the M.E. Harrison et al technical paper, the study is about the far wake prediction between the experimental and the CFD simulation on actuator disc.

![Figure 1: The results of velocity magnitude against the published data](image)

**Figure 1:** The results of velocity magnitude against the published data

*Figure 1* displays the velocity magnitude of two different downstream which are 4D downstream and 20D downstream. At 4D downstream, it shows the actuator disc with support structure have higher wake than the actuator disc without support structure. Among all the support structure geometry, ellipse support structure shows the highest velocity followed by cylinder, square and diamond geometry. However, the wakes decreasing gradually in the absence of the support structure while increasing in the presence of the support structure as shown in Figure 1(b). This is due to the higher
blockage in the domain with the presence of the support structure. The geometry of the support structure, the different model use and the inlet velocity used also contributes to the different results of the wake formation.

3.2. Two turbines

![Figure 2](image-url)

**Figure 2:** The velocity magnitude at different height from seabed taken at 0.125D downstream.

*Figure 2* shows the velocity magnitude at 0.125D downstream with three differences distance on support structure which is 5 meters, 8 meters and 12.5 meters from the seabed. The purpose of taken three difference place on support structure is because to investigate the behaviour of the wake formation based on the sea depth. As can be seen, at 5 meters and 8 meters, the wake recovery on support structure is faster than at 12.5 meters. The center line of wake velocity is increasing with the distance of the of the support structure from the seabed. This is because the presence of the free surface on the top of the disc. The presence of free surfaces allows the depth to change and require gravity considerations. At 5 meters and 8 meters, the wake of each support structure merges at between 20 to 35 meters lateral width. However, at the 12.5 meters it merges at 25 to 30 meters of the lateral width. Along the downstream, the wake formation start to recovery and almost returned to ambient condition at 2D downstream as shown in *Figure 3*. However, at 12.5 meters the wake formed is still in recovery state. This is because at this location the surface of the support structure and the disk is in contact. Thus, the surface roughness between two objects is affecting the turbulence occurrence.
Figure 3: The velocity magnitude at different height from seabed taken at 2D downstream.

3.3. Three turbines

Figure 4 shows the behaviour of the wake formation from first rows. The first row of the turbine shows the similar behaviour as the analysis on the two turbines. The wakes start to merge after passing through the support structure. The wake formation start to recover at 1D downstream and almost returned to ambient condition. However, at 3D downstream, the wake formation starts to meet the second row of the disk as shown in Figure 5. Thus, the wake formed start to spilt up by the support structure in between. The blockage effect from the second rows of the support structure affects the acceleration of the flow of the turbulence.
4. Conclusion
This paper found that the best design of the support structure for shallow water is mono-pile support structure. This is because the suitable water depth to plant the mono-pile support structure is 30 meter and above which is suitable with the Malaysia’s open water depth. Next, this paper also analysed the influence of support structures on the actuator disc wake formation and examined the impact of the support structure on flow interactions between devices in the array. It was found that the flow of the turbulence on each support structure showed different behaviour. For a single turbine, it is clearly shown that ellipse support structure has the shortest turbulence form and it is the fastest among the support structure that recover back into inlet velocity after passing through the tidal turbine.

For the array of support structure, the 1.5D for the distance between two turbines was proven to be acceptable due to the turbulence occurrence being separated from each of the turbine. Next, for three turbines the separation between the first and second rows is agreeable to be 3D on a basis that after passing through the support structure the wakes are well merged and almost return to ambient condition at the 1D downstream. Among all the support structure, the first geometry to recover to the inlet velocity is ellipse geometry in array condition. To summarize, in comparison with previous research it is can be concluded that the results of this research approximately follow similar pattern of published data for a deeper site depth.

Acknowledgement
The first author would like to acknowledge the School of Mechatronic Engineering, UniMAP for the financial support. This project would never be possible without the help of my student, Nuur Baizura, who is tireless in the pursuit of knowledge.

References
[1] Khan N, Kalair A, Abas N and Haider A 2017 Review of ocean tidal, wave and thermal energy technologies Renew. Sustain. Energy Rev. 72 590–604.
[2] Harrison M E, Batten W M J, Myers L E and Bahaj A S 2010 Comparison between CFD simulations and experiments for predicting the far wake of horizontal axis tidal turbines IET Renew. Power Gener. 4 (6) 613–627.
[3] Muchala S and Willden R H J 2017 Influence of support structures on tidal turbine power output Renew. Energy 114 588–599.