CFD STUDY OF FLOW FIELD AROUND TURBINE

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This report is submitted
in fulfilment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "CFD Study of Flow Field Around Turbine" is the result of my own work except as cited in the references

Signature :…………………….

Name :…………………….

Date :…………………….

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature :…………………….

Name of Supervisor :…………………….

Date :…………………….

DEDICATION

To my beloved father and mother

ABSTRACT

Depletion of fossil fuel caused mankind to look for sustainable and green energy resources. The characteristic of hydrokinetic turbine with ability to operate at low head stream and at low cost made it a good choice for use to harness hydro source of energy. As hydrokinetic turbine gain attention by the industry player, many experimental and Computational Fluid Dynamics (CFD) studies related to hydrokinetic turbine have been carried out. Yet the relationship of flow depth variation and wake recovery behind the turbine is still not fully understood. There is limited study about the effects of flow depth variations on the wake recovery behind the turbine. In this paper, a CFD model investigation was done based on published experimental work by Aghsaee and Markfort (2018). A hydrokinetic water turbine was drawn using the MHKF1-180 and NACA4418 foils dimensions. The transient CFD study is conduct using SST k-ω turbulence model and dynamic mesh method. As sensitivity result proved that SST k-ω turbulence model and dynamic mesh method give more accurate result compare to k-ε turbulence model and sliding mesh method. The results obtained in this study show that in near wake region, the wake at deeper depth will recover faster as deeper depth has larger surrounding flow field which is able to transfer momentum at a faster rate. At first investigation was planned for three different depths (110 mm, 125 mm and 140 mm) but due to limitation of time only two depths (110 mm and 125 mm) managed to be done in this study. The obtained result agrees well with the finding of Aghsaee and Markfort (2018) and a near wake observation was reported from the verified CFD models.

ABSTRAK

Kekurangan sumber bahan api fosil mendesak manusia untuk mencari sumber tenaga yang mesra alam dan boleh diperbaharui. Ciri-ciri turbin hidrokinetik yang boleh beroperasi dalam turus air yang rendah serta kos yang rendah telah menjadikan turbin hidrokinetik satu pilihan utama untuk ekstrak tenaga dari sumber hidro. Setelah turbin hidrokinetik mendapat perhatian daripada industri, banyak eksperimen dan kajian Perkomputeran Dinamik Bendalir (CFD) berkaitan dengan turbin hidrokinetik telah dijalankan. Tetapi hubungan antara kelainan kedalaman arus dan pemulihan keracak belakang turbin masih kabur. Kajian berkaitan kesan kelainan kedalaman arus kepada pemulihan keracak belakang turbin adalah terhad. Dalam kertas kerja ini, satu kajian model CFD telah dijalankan berdasarkan satu kerja eksperimen (yang telah diterbit) oleh Aghsaee dan Markfort (2018). Satu turbin hidrokinetik air telah dilukis menggunakan dimensi kerajang udara MHKF1-180 and NACA4418. Analisis fana CFD telah dijalankan dengan menggunakan model turbulensi SST k-ω dan kaedah jejaring dinamik. Hal ini kerana keputusan kajian sensitif telah membuktikan model turbulensi SST k-ω dan kaedah jejaring dinamik dapat memberi keputusan yang lebih tepat berbanding dengan model turbulensi k-ε dan kaedah jejaring gelangsar. Keputusan kajian ini telah membukti bahawa dalam kawasan keracak dekat, keracak di kedalaman yang lebih mendalam dapat pulih dengan lebih pantas. Hal ini kerana, dalam kedalaman lebih mendalam medan aliran keliling adalah lebih besar dan momentum dapat dipinda dengan lebih cepat. Rancangan asal kajian ini adalah untuk mengkaji dalam tiga kedalaman iaitu pada 110mm, 125mm serta 140mm. Tetapi disebabkan kekangan masa, hanya dua kedalaman yang dapat dikaji dalam kajian ini. Keputusan kajian ini seakan dengan hasil kajian Aghsaee dan Markfort (2018) serta pemerhatian keracak dekat telah dilapor berdasarkan CFD model yang telah disah.

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LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
IHA	International Hydropower Association
BEM	Blade Element Momentum
TSR	Tip Speed Ratio
2D	Two Dimensional
3D	Three Dimensional
DNS	Direct Numerical Simulation
LES	Large Eddy Simulation
RANS	Reynolds-Averaged Navier-Stokes
DHAHT	Darrius Horizontal Axis Water Turbine
MHKF	Marine and Hydrokinetic Foil
NACA	National Advisory Committee for Aeronautics
SST	Shear Stress Transport

RMS	Root Mean Square
UDF	User Define Function

LIST OF SYMBOLS

P	=	Power
ρ	=	Density of fluid
A	=	Cross-sectional area swept by the rotor
U	=	Velocity of the water stream
C_p	=	Power coefficient of hydrokinetic turbine
η	=	Efficiency
E	=	Kinetic energy
V	=	Volume
m	=	Mass
L	=	Length
τ	=	Torque
T	=	Thrust
C_τ	=	Coefficient of torque
C_t	=	Coefficient of thrust
S	=	Solidity

R	=	Radius swept by rotor
ω	=	Speed of the blade's rotation
c	=	Blade chord length
B	=	Number of blades
σ	=	Cavitation number
C_{pmin}	=	Local pressure minimum coefficient
p_{atm}	=	Atmospheric pressure
h	=	Distance between free surface and radial position on hydrokinetic rotor
p_v	=	Vapor pressure
W	=	Relative velocity on blade section
V_{CAV}	=	Cavitation velocity
φ_{up}	=	Value at upwind node
$\vec{r}$	=	Cector from upwind node to ip
U_{hub}	=	Mean stream-wise velocity at hub height level
I_{hub}	=	Turbulence intensity of the incoming flow at hub height level
I	=	Turbulence intensity
u'	=	Root mean square of turbulence velocity fluctuations
k	=	Turbulence energy

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Energy can appear in many forms including in the forms of heat and work. Energy cannot be created nor can it be destroyed but it can change into several forms. For an example, man require energy from food to survive and machine requires electric energy to operate. Energy exists in many forms such as solar energy, hydropower energy, wind energy and many more. Energy can be put to good use with the help of tools or technology. The inappropriate use of energy will bring bad impact to human daily life. According to Coyle and Simmons (2014), history show that each time an energy crisis occur, economy will slow down. To avoid energy from being wasted, men increase the process of exploiting of energy sources especially from fossil fuel. This is because fossil fuel is cheaper compared to other source of energy and the technology or method to harvest the energy is more stable compared to other sources like solar energy, wind energy, hydro energy and nuclear energy.

The drastic needs for the use of fossil fuel from 19 century until today has led to depletion of the source. In addition to that, the imperfect processes of energy change in the technology used to convert fossil fuel into useful energy leads to many environmental issues like air pollution and global warming. This is because burning of fossil fuel will produce pollutant like carbon dioxide, nitrogen oxides, sulfur dioxide, volatile organic compounds and particulate matter (Pisupati, 2018). Particulate matter and volatile organic compounds will cause air pollution. On the other sides, carbon dioxide produce is responsible for global warming due to its characteristics which will trap the heat from release to the atmosphere.

The present of global warming is then lead to extreme weather events and melting of glaciers (NUNEZ, 2019). The occurrence of such incident causes destruction and loosing of costal area which bring negative impact on economy and human quality of living. To avoid these negative impacts, mankind need to find renewable energy sources or green energy technology as an alternative to the use of the depleting fossil fuel (Newell et al., 2019).

Renewable energy is defined as sources of energy that can be renewed all the time. The renewable energy source will not diminish but if it is used in a wrong way it could lead towards bad impact to the environment ("What Is Green Power?," 2019). On the other hand, green energy or green power is a subset of renewable energy that categorize the source of energy that do not bring harm to the environment. Figure 1.1 shows the general category of powers and example of sources that can be categorized as conventional power, renewable energy and green power.

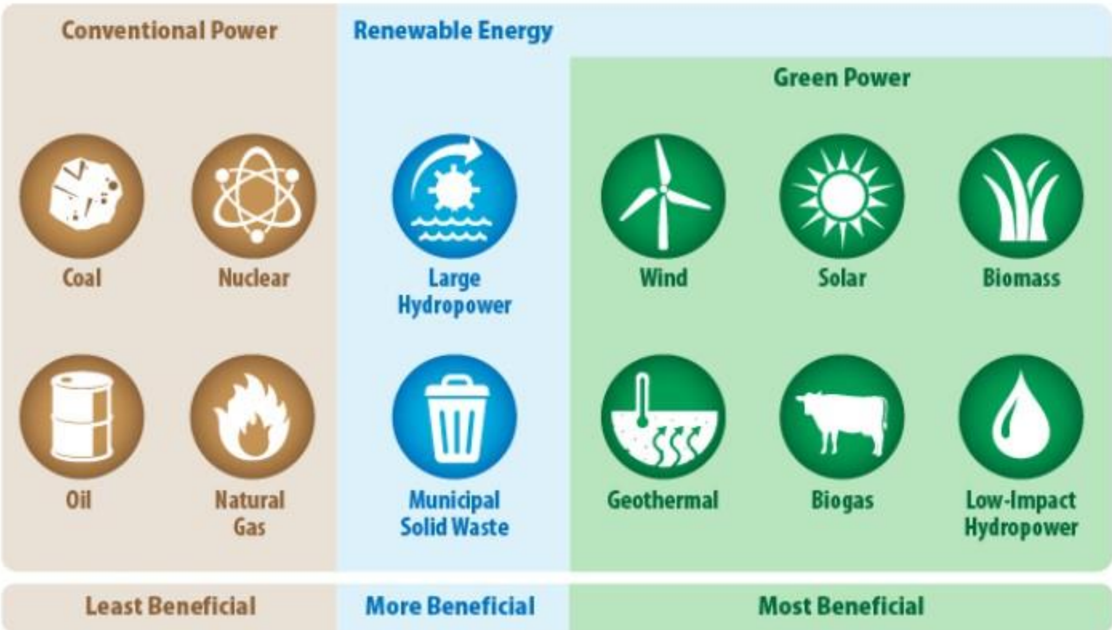

Figure 1.1 Relationship and Example of Conventional Power, Renewable Energy and Green Power ("What Is Green Power?," 2019)

Data and statistics of International Energy Agency website *Data and statistics* (2020) show that, hydropower generation is the global most crucial source of clean energy. Hydropower generation is cheaper and more efficient compared to other sources like solar energy, wind energy and geothermal energy (Ehrlich and Geller, 2017). Such advantages make it becomes one of the most important sources of green energy. Hydropower generation use turbine to extract energy from the source with high potential and kinetic energy sources like water flow from a dam, tidal wave or river stream. Figure 1.2 shows the working principles of a hydropower plant. This kind of hydropower plant requires high water pressure or potential energy to generate electricity.

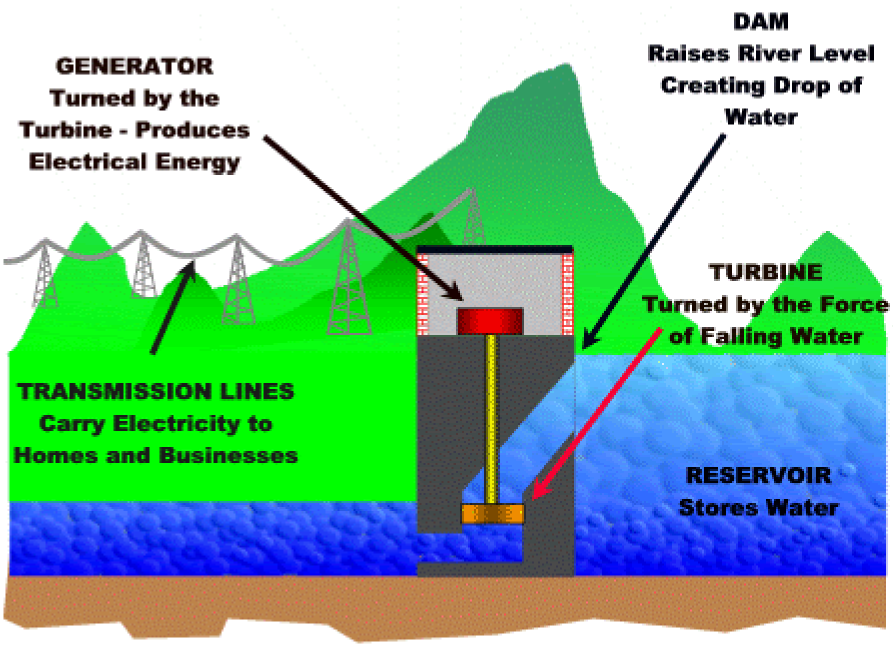

Figure 1.2 Working of Hydropower Plant ("How Hydropower Works," 2020)

According to Musa et.al (2019) there are some disadvantages of hydropower generation using dam. As construction of dam will limit the production of energy due to geolocation. Besides that, building of dam also cause other environmental issue where large area of land will be submerged in water after the dam is built. Laws and Epps (2016) suggested the use of hydrokinetic turbine or also known as reaction turbine where the turbine is able to function with low water pressure or potential energy. This enable the hydropower generation to be made available at almost any location with water stream, as long as the water is flowing.

Laws and Epps (2016) also stated that the hydrokinetic turbine needs to be deployed in array form so that bigger power can be generated to fulfil the economy demand. Array form means multiple turbines are arranged at specific sequence, usually two or three turbines being placed after the first turbine at particular distance. This is because the power generation of a single hydrokinetic turbine is usually low and insufficient. By deploying hydrokinetic turbine in array arrangement, more energy able to be produced and hence increasing the ability to fulfil the economy demand and it speeds up the return of investment. Understanding performance of turbine is crucial so that more energy sources can be transformed effectively and efficiently into useful electricity. So, there is a need to carry out a study on how to improve the performance of hydrokinetic turbine as the turbine technology is attractive because they have lower requirement on geolocation yet able to produce sufficient amount of energy. Investigations related to the wake behaviour of flow near the turbine is also important as it will give impact on the performance of the turbine either in single operation or in array arrangement.

1.2 PROBLEM STATEMENT

Wake recovery is a term that represents the recovery of flow velocity due to momentum drawn into the wake by lateral or horizontal mixing of the fluid external to the wake region (McKay et al., 2012). Wake recovery is an important aspect that needs to be understood in many applications involving turbine as it affects the performance of the turbine array and flow of the surrounding. The experimental study of Aghsaee and Markfort (2018) found that the rate of wake recovery will increase with the increase of flow depth. Their finding helps to better understand the relationship between flow depth and wake recovery which is crucial in increasing the performance of turbine array. Unfortunately, there are very limited study related to the effect of flow depth to the wake recovery of the turbine. So, there is a need to study the effects of flow depth variations on the wake recovery behind a turbine. With the result of this study, future decision can be made to increase the performance of turbine array through the manipulation of depth of water flow.

1.3 OBJECTIVES

The objectives of this project are as follows:

1. To model the flow across hydrokinetic turbine by using CFD
2. To investigate the effects of flow depth variations on the wake recovery behind the turbine