SIMULATION ANALYSIS ON THE EFFECT OF INLET CHANNEL BED SLOPE AND DIAMETER OF BASIN FOR WATER VORTEX TURBINE SYSTEM

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DECLARATION

I hereby declare that this thesis, which was submitted to Universiti Malaysia Sabah as part of the requirements for a Bachelor of Mechanical Engineering degree, has not been submitted for a degree to any other university. I further attest that the work described here is all my own, apart from excepts and summaries of sources that have been properly credited.

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ABSTRACT

Hydropower is one of the renewable energies that generate electricity. One of the micro hydropower systems is the Gravitational Water Vortex Power Plant (GWVPP) which is a cost-effective and environmentally friendly energy system that uses a gravity vortex pool to convert low-head potential energy into kinetic energy that drives turbines. Some researchers have made different analyses on different configurations of the water vortex turbine system. However, there is still little research related to the inlet channel bed slope and the size of the diameter of the basin. Thus, this project will focus on the study of the effects of these two different configurations. Nevertheless, this study will study more on hydraulic energy which studies the effects on the stability and uniformity of the vortex profile formation with a diffuser and without a turbine. In this study, the use of Computer-Aided Design (CAD) by using SolidWorks 2018 software and Computational Fluid Dynamics (CFD) by using the ANSYS CFX R21 software was utilized. The reliability of this software was validated by experimental work which the percentage of difference is 9.09%. The inlet channel bed slope was investigated from without a slope and up to six degrees of slope, while the diameter of the basin was investigated from 0.30m to as large as 0.60m diameter of basin. The simulation results show different effects for both configurations. It was found that the inlet channel bed slope does not affect the water vortex system, but the change of size for the diameter of the basin shows different effects and the preferable result will be based on a different type of data obtained.

ABSTRAK

ANALISIS SIMULASI TERHADAP KESAN CERUN DASAR SALURAN MASUK DAN DIAMETER BESEN UNTUK SISTEM TURBIN VORTEKS AIR

Tenaga hidro adalah merupakan salah satu tenaga boleh diperbaharui yang boleh menjana tenaga elektrik. Salah satu sistem kuasa hidro mikro ialah Gravitational Water Vortex Power Plant (GWVPP) yang merupakan sistem tenaga yang menjimatkan kos dan mesra alam yang menggunakan kolam pusaran graviti untuk menukarkan tenaga potensi paras air rendah kepada tenaga kinetik yang memacu turbin. Sesetengah penyelidik telah membuat analisis yang berbeza pada konfigurasi berbeza sistem turbin vortex air. Walaubagaimanapun, masih terdapat sedikit kajian berkaitan cerun dasar saluran masuk dan saiz diameter besen. Oleh itu, projek ini akan memberi tumpuan kepada kajian kesan dua konfigurasi yang berbeza ini. Namun begitu, kajian ini akan mengkaji lebih lanjut mengenai tenaga hidraulik yang mengkaji kesan ke atas kestabilan dan keseragaman pembentukan profil vortex dengan bilah pemfokus aliran air dan tanpa turbin. Dalam kajian ini, penggunaan Computer-Aided Design (CAD) dengan menggunakan perisian Solidworks 2018 dan Computational Fluid Dynamics (CFD) dengan menggunakan perisian ANSYS CFX R21 telah digunakan. Kebolehpercayaan perisian ini telah disahkan melalui kerja eksperimen yang peratusan perbezaanya ialah 9.09%. Cerun dasar saluran masuk disiasat dari tanpa cerun dan sehingga enam darjah cerun, manakala diameter lembangan disiasat dari 0.30m hingga sebesar 0.60m diameter besen. Keputusan simulasi menunjukkan kesan yang berbeza untuk kedua-dua konfigurasi. Didapati bahawa cerun dasar saluran masuk tidak menjejaskan sistem pusaran air, tetapi perubahan saiz untuk diameter besen menunjukkan kesan yang berbeza dan keputusan lebih baik adalah berdasarkan jenis data yang berbeza diperolehi.

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LIST OF NOMENCLATURE

ρ	-	Fluid Density
v	-	Kinematic Viscosity
g	-	Gravitational Acceleration
V_θ	-	Tangential Velocity
V_r	-	Radial Velocity
V_z	-	Axial Velocity
θ	-	Bed Slope Angle
S_F	-	Friction Slope = Slope of Energy Line
S_o	-	Longitudinal Bed Slope of a channel
V	-	Velocity
Q_{in}	-	Input Volume Flow Rate
Q_{out}	-	Output Volume Flow Rate
r	-	Radius
y	-	Water Depth
y_o	-	Normal depth
D	-	Depth
D_N	-	Normal Depth Line
D_C	-	Critical Depth Line
Z	-	Elevation Water Surface in Reservoir Above Datum Level

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The vortex turbine combines kinetic (run-of-river) and static potential energy (head) principles to create a power-generating device that has little impact on the river and aquatic life. Mini hydropower plants offer a lot of promise for supplying electricity to rural areas. The gravitational water vortex power plant (GWVPP) is a cost-effective and environmentally friendly energy system that uses a gravity vortex pool to convert low-head potential energy into kinetic energy that drives turbines. To extract energy and generate electricity, small hydro systems can employ either run-of-river (RoR) or a drop in elevation. To make use of the water flow, RoR systems must be installed in the river, while static head-based systems require either a weir or dam or a substantial natural drop such as waterfalls or rapids. The vortex system generates power by turning a turbine using both river flow and a gravitational vortex. The turbine is driven by the dynamic force of the vortex, not by pressure differential. Because the hydraulic head requirement is as low as 1 m, this type of power plant may be constructed along rivers or streams. Water can be supplied into the vortex turbine via an open channel or, in certain circumstances, a closed conduit or pipe, which is better for smaller installations (Rycroft, 2018).

With a low head and low flow rate, the gravitational water vortex power plant (GWVPP) generates energy. A runner and a tank are the key components of this gravitational vortex water turbine. When water is introduced into the tank, the turbine creates energy from the gravitational vortex that forms when the water is drained from the bottom. This water turbine is also considered to have an aeration function, which involves rolling up the air above the free surface surrounding the runner to enhance the dissolved oxygen concentration of the downstream water. Even though the structure of this water turbine is very basic, the flow field is exceedingly complex due to the free surface (Nishi & Inagaki, 2017). The dynamic force of vortex flow is used by water vortex turbines. Water flows tangentially into a circular basin from a big intake. The water then forms a strong vortex that is directed out of a hole in the basin's center. The vortex forces the turbine to spin, generating mechanical energy that is transferred to electrical energy in the generator (Rizwan Ghani, 2019).

Another alleged benefit of the GWVPP is its capacity to facilitate fish passage through the turbine without the need for an additional fish ladder. This gain would exceed the advantages of a higher efficiency turbine owing to cheaper construction costs due to the need for a separate fish ladder, lower head loss due to the lack of a fish screen, and the ability to draw more water from the river and hence generate greater power capacity. Some turbine manufacturers claim that two-way or one-way fish passage is feasible (Timilsina, Mulligan, & Bajracharya, 2018).

According to the research made, there are still low number of articles and journals that relate to the designation of the GWVPP system that specifies every part of the GWVPP system. This issue contains a variety of branches that have not been researched and studied to give benefits in the production of renewable energy for long-term usage. Hence, in this project, one of the goals is to further research the inlet channel and diameter configuration effects on the GWVPP system.

1.2 Problem Statement

The electrical power demand is rising even faster than the global energy demand, which is increasing at a rate of 1% per year on average. There are 1.2 billion people without access to electricity in the globe, with 85 percent of them living in rural regions. Rural electrification by utilizing hydropower technology is the greatest method for supplying people with electricity. Generally, this is one of the methods to get power to those remote regions that don't have access to the grid or it would take a lot of money to connect to it (Sedai et al., 2020). One of the hydropower technologies is the Gravitational Water Vortex Power Plant, GWVPP system that was made to convert hydraulic energy to mechanical energy through the turbine runner located in the center of the water vortex that will generate electricity.

There were several past research that has been done related to GWVPP to improve the system to find the optimum configuration of the system. Generally, most of the study is more focusing on the designation of the runner and the basin configuration, and usually least research is done related to the GWVPP inlet channel. There is research that studied the effects on the length of the inlet channel and the gap of the neck of the inlet channel. From this research, an idea was generated to further study the inlet channel with the bed slope effects on the water vortex flow in the GWVPP system. Nevertheless, the diameter of the basin will be one of the studies in this project. This is to determine the effects of the inlet channel bed slope and diameter of the basin effects on the velocity, uniformity of the water vortex profile formation, and water vortex height without a runner.

1.3 Research Objectives

The main objective of this project is to study CFD modeling of vortex flow for GWVPP systems as well as to study the effects of the bed slope for the inlet channel and diameter of the basin for water vortex flow performance. The objective is further categorized into three sub-objectives as listed below.

i. To develop computational fluid dynamics modeling for water vortex systems and compare the vortex flow simulation with experimental work for validation.
ii. To study the effects of the vortex flow stability on the inlet channel bed slope with a diffuser.
iii. To investigate the effects of the vortex flow uniformity on the diameter of the basin with a diffuser.

1.4 Scope of Works

In this project, the knowledge of CFD modeling of vortex flow for hydropower systems will be improved by simulation analysis using ANSYS CFX R21 software and experimental works in the laboratory. This project strengthens research for renewable energy for gravitational water vortex power plants with various parameter trials.

a) Articles and journals literature review regarding the respective project related to the GWVPP system.
b) Simulate the inlet channel of the model with a diffuser until able to achieve less than ten percent of percentage difference by using ANSYS CFX software to validate the model in the simulation.
c) The data from the simulation and experiment will be optimized based on ANSYS software validation and experimental work.
d) Study the parameters that include in the GWVPP system such as the water vortex height and velocity.
e) Simulation analysis using ANSYS CFX R21 software to design and analyze the optimum slope of the inlet channel base slope that able to give the optimum performance of the water vortex flow velocity and vortex height with uniform vortex profile formation.

1.5 Research flow chart (general methodology)

The methodology of this project is based on three phases.

Phase 1 (Literature review research)

i. Problem statement

- Investigate the problems and limitations of the project model and aim for one of the parameters to improve the efficiency and performance as well as to obtain the optimum result.

ii. Background research

- Obtain and gather the information that relates to Gravitational Water Vortex Power Plant from journals, articles, and books on the internet.

Phase 2 (Analysis)

i. ANSYS CFX simulation

- Design the vortex turbine model system.

ii. Experimental work

- Conduct the experimental work in the laboratory to validate the results of the simulation analysis.

iii. ANSYS CFX simulation

- Adjust the model parameter once validate from experimental work by analyzing different parameters of the inlet channel base slope for the research.

Phase 3 (Testing)

i. Validate

- The results obtained from the analyzed data from the simulation will be used for analyzing the simulation model prediction accuracy towards reality.

ii. Optimization

- Analyze the performance of the simulation analysis and experimental work of GWVPP to achieve the most optimum performance and efficiency.

iii. Documentation

- Obtain all the information from the literature review and analysis to do a full report and submit it.

Research methodology flow chart

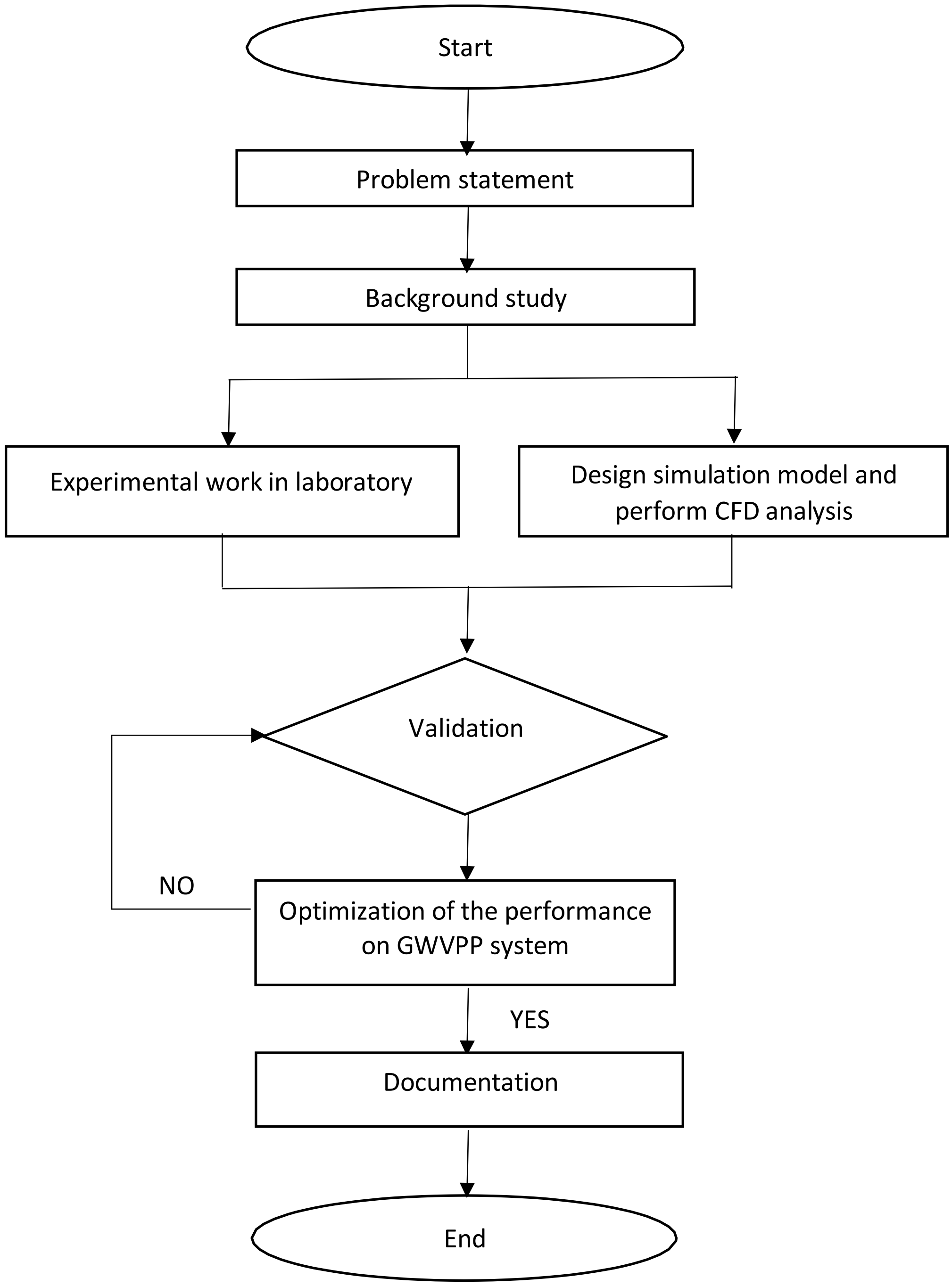

Figure 1.1 : Flow Chart of The Project

1.6 Research expected outcomes

The expected outcome of this project is to study the effect of the inlet channel bed slope on the water vortex flow by increasing the bed slope to a certain value. Commonly, the inlet channel without the bed slope was used in the industry and experimentally. This research will study more the effect of the inlet channel bed slope on the water vortex flow performance in terms of the speed of the turbine generate, the turbulence that may occur through the inlet channel to the vortex turbine, and the effectiveness of the slope to increase the flow rate of the water flow. This research will also study the effects of different diameters of basins.

1.7 Research Contributions

This research will contribute to the isolated rural areas communities as this system is renewable energy that only uses the run-of-river system to work on the system. This project of GWVPP is one of the beneficial renewable energy systems that can convert potential energy from the run-of-river system to kinetic energy that generates electricity. It is one of the favorable methods to get power to those remote regions that don't have access to the grid or demand a lot of money to connect to it. Moreover, this system is fish-friendly as the system will not harm aquatic life. The research will improvise and study the optimum designation to contribute to the best model of the GWVPP system for the users.

1.8 Research Commercialization

This GWVPP is suitable and in high demand in rural areas since it can be used naturally from the natural environment water flow from the river since there are still a lot of rural areas that do not have access to electricity. Hence, the chances for commercialization potential are high. This GWVPP is affordable and environmentally friendly which is suitable to commercialize widely for community uses. This will not only benefit in terms of cost but also save the earth by its renewable energy characteristic.