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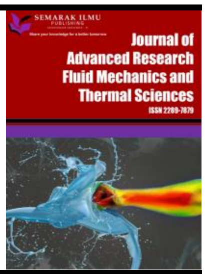

Performance Analysis of a Crossflow Vortex Turbine for a Gravitational Water Vortex Power Plant

Abel Alfeuz[1], Fadzlita Tamiri[1], Farm Yan Yan[1], Wan Khairul Muzammil[1], Melvin Gan Jet Hong[1], Dayang Salyani Abang Mahmod[2], Nuramalina Bohari[3], Mohd Azlan Ismail[1,*]

1 Faculty of Engineering, Universiti Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia
2 Department of Chemical Engineering and Energy Sustainability, Universiti Malaysia Sarawak, Kuching, Sarawak, Malaysia
3 School of Engineering & Technology, University of Technology Sarawak, Sibu, Sarawak, Malaysia

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ABSTRACT

The micro hydro system is the most favorable renewable energy source to supply electricity for rural areas. The Gravitational Water Vortex Power Plant (GWVPP) is one of the micro hydro systems that is suitable for very low-head hydropower sites. GWVPP consists of three major parts: electromechanical components, civil structures, and electric distribution. The micro hydro turbine in GWVPP is called a vortex hydro turbine and is used to convert induced vortex flow to mechanical energy coupled with a generator to produce electricity. This paper investigates crossflow vortex turbine performance using Computational Fluid Dynamics (CFD) software and experimental work. The CFD results provide qualitative and quantitative comprising velocity distribution, water vortex profile, and water vortex height. The optimum hydraulic performance in the water vortex was observed and determined for different turbine positions. The vortex crossflow turbine was placed 0.05 m from the bottom surface of the basin at the highest vortex tangential velocity. A 0.05 m turbine position was chosen for the turbine installations as it creates a high-velocity profile. The comparative performance was conducted on the vortex crossflow blade with different inlet blade angle designs at a range of 40^0 – 70^0. The experimental analysis was conducted at rotational speeds of 30 rpm – 70 rpm to determine its efficiency performance. The optimum design for the crossflow blade was at 50^0 with an operational speed of 50 rpm, which exhibited torque and power output at 0.27±0.02 m and 1.49±0.08 m respectively with an efficiency recorded at 18.98%.

1. Introduction

Hydropower contributes the highest world's renewable energy resources, accounting for more than 16% of net electricity output [1]. Despite the rise in the popularity of wind and solar energy in recent years, hydropower leads as a power generation with 55% of the total power generation capacity from renewable resources [2].

* *Corresponding author.*
E-mail address: lanz_mr@ums.edu.my

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Hydropower produces energy by harnessing the kinetic energy of the flowing water. The movement of the turbines converts the kinetic energy of water into mechanical energy, which is then transformed into electrical energy using the electric generator. This process allows hydropower to generate clean energy from the natural energy of flowing water. According to Ullah *et al.,* [3], hydropower can be the primary source of future energy production as it can offer clean and renewable electricity.

The Gravitational Water Vortex Power Plant (GWVPP) is one of the prominent types of hydropower that has attracted attention in recent years [1,2]. GWVPP has recently become an alternative option for electricity generation and can operate at very low head sites ranging from 0.7 m to 2.0m [4]. GWVVP operates by using induced vortex flow producing tangential inlet velocity that creates a rotating flow due to the conservation of momentum. The water exits at the basin opening producing an air core in the middle of the vortex flow [3].

Other than that, GWVPP is a considerably low investment cost due to its versatility; suitable for retrofit to existing infrastructure [5]. In 2006, the investment cost for 10 kW of GWVPP was reported at 60,000€, relatively lower compared to conventional types of hydro turbines [6]. One of the main reasons for the lower cost of GWVPP is does not require a big reservoir or installation footprint [2]. In addition, GWVPP is designed for very low-head rivers, located at relatively flat hydropower sites, thus further reducing the overall installation cost.

The GWVPP consists of two parts: 1) the civil structure consists of a water inlet, open channel, and basin 2) the electromechanical components consist of a turbine, shaft, and electric generator [3]. The civil structure of the GWVPP collects and diverts water from the river and channels the water to the GWVVP basin. Induced vortex flow intensity and performance are subject to the geometric size and shape of the civil structure. Potential energy from height difference between inlet water and outlet opening of the basin induced vortex flow, conversion to kinetic energy. Electromechanical components consist of hydro turbines that convert kinetic energy to mechanical energy. The turbine performance is strongly dependent on the vortex strength with a stable vortex profile. In this regard, it is significant to determine the pattern of a stable vortex profile for turbine optimization. By coupling the turbine blade with an electric generator, the mechanical energy is then converted into electrical energy.

There is intensive research interest in improving turbine blade efficiency through blade geometry modification by considering its rotational effect on the swirling flow of the vortex. This is especially important for high-efficiency operations at optimum runner shape that relies on the appropriate design of the turbine blade profiles [4]. Dhakal *et al.,* [5] performed a comparative investigation on the three different blade profiles using CFD. The comparative data are based on the turbine efficiency performance, and it was found that the curved blade profiles yield significance high efficiency at 82% followed by twisted and straight blade profiles which are 63% and 46% respectively.

Then, Kayastha *et al.,* [6] obtained a 35.59% enhancement in turbine efficiency using curved blade profiles with optimum turbine position and Kueh *et al.,* [7] found that the turbine efficiency could be increased by about 22.24% using curved blade profiles based on the constant operating speed. Other than that, Nishi *et al.,* [8] achieved improvement in turbine performance using crossflow blade profiles as they found the hydraulic losses from the interactions between the water and the turbine blade can be minimized, and the power efficiency output could be about 55%. In addition, Aziz *et al.,* [9] conducted an experimental study using a flat turbine in the enclosed gravitational water vortex system and found a maximum mechanical efficiency of 16.06% with the best efficient point at 6.3 L/s of water flow rate. Whilst Del Rio *et al.,* [10] numerically study the torque produced at different rotational speeds and in this case, the H-Darrieus type of turbine was used as the rotor in the water vortex turbine, and they found that the maximum torque was at 50 RPM. Moreover, Aziz *et al.,* [11]