RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 7 No. 1 (2026) 88-101
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Turbine Design and Optimization for Energy Harvesting from Underground Water Pipe Sources: A Renewable Energy Approach

Muhamad Arif Haziq Rosdi[1], Zuliazura Mohd Salleh[1*]

[1] *Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia*

*Corresponding Author: zulia@uthm.edu.my
DOI: https://doi.org/10.30880/rpmme.2026.07.01.011

Article Info

Received: 1 December 2025
Accepted: 1 February 2026
Available online: 28 February 2026

Keywords

Design turbine, Angle of blade, Underground water pipe, Ansys CFD, RPM, Pressure, Power

Abstract

This study investigates the hydro turbine design optimization for energy extraction from underground water pipes in Malaysian industry. The overuse of fossil fuels has led to economic, environmental, and sustainability concerns, necessitating the development of alternative energy resources. This study investigates the optimization of the hydro turbine blade angle for optimum energy efficiency at realistic underground pipe flow conditions. Three blade angles of 40°, 50°, and 60° were created in SolidWorks and investigated using Computational Fluid Dynamics (CFD) simulation in ANSYS Fluent. The study measured pressure distribution, velocity, RPM, and efficiency for optimal performance. The findings indicate that the 50° blade angle design provides an optimal balance between RPM and energy efficiency, minimizing turbulence and maximizing energy conversion. This optimum design has the potential for the installation of small-scale hydro turbines in existing industrial infrastructure, offering a renewable and inexpensive option to fossil fuels. The findings of this study are in line with Malaysia’s energy transition plans by incorporating renewable technology into industrial systems.

1. Introduction

In Malaysia, fossil fuels like coal, oil, and gas provide the majority of the country's energy. Although these sources have aided in the nation's progress, they also pose significant challenges. In addition to being costly and fossil fuels harm the environment and are not sustainable in the long term [1-3]. These behaviors have consequences on public health and the environment, which also contribute to climate change. In response to those challenges, Malaysia is swiftly looking towards more effective and clean alternatives to generate energy, particularly for the industrial sector, which is responsible for a significant portion of the country's energy consumption.

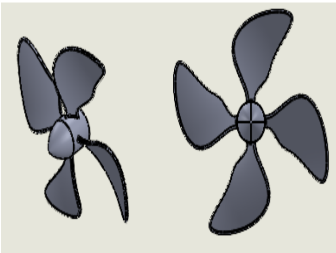
Using hydro turbines, which use water that travels through underwater water pipes to generate electricity, is one suitable alternative. These underground pipes are a practical choice for renewable energy due to their presence are already present in many industrial countries [4]. The energy of moving water is transformed into mechanical energy, which is subsequently transformed into electrical energy by hydro turbines. This approach has cheaper long-term operational expenses and eliminates any risky pollutants like fossil fuels.

The main objective of this study is to determine how different blade angles impact the energy output, rotation speed, and pressure distribution of hydro turbines in an underground water pipe. Additionally, the goal is to identify the best blade design that can encourage the use of renewable energy sources, decrease pollution, and reduce the amount of electricity used in industries. The hydro turbine blade designs that are currently on the market are the only ones covered by this study. The turbine's other components remain unchanged, only the blade angle is changed to different blade angles, 40°, 50° and 60°. SolidWorks is used for design creation, while ANSYS Fluent simulations are used to evaluate each design's performance [5]. The study examines significant findings including pressure, torque and rotation per minute, with a particular focus on turbines established inside underground water pipes [6].

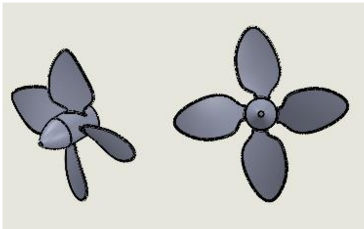
2. Methodology

The methodology integrates advanced design tools, computational simulation and calculations to validate an optimized turbine design capable of converting the kinetic energy of flowing water into electrical energy [7].

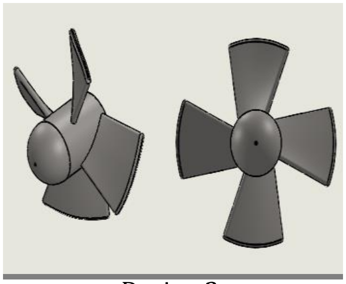
2.1 Model Geometry



Design 1



Design 3



Design 2

Fig. 1 *Propeller design*

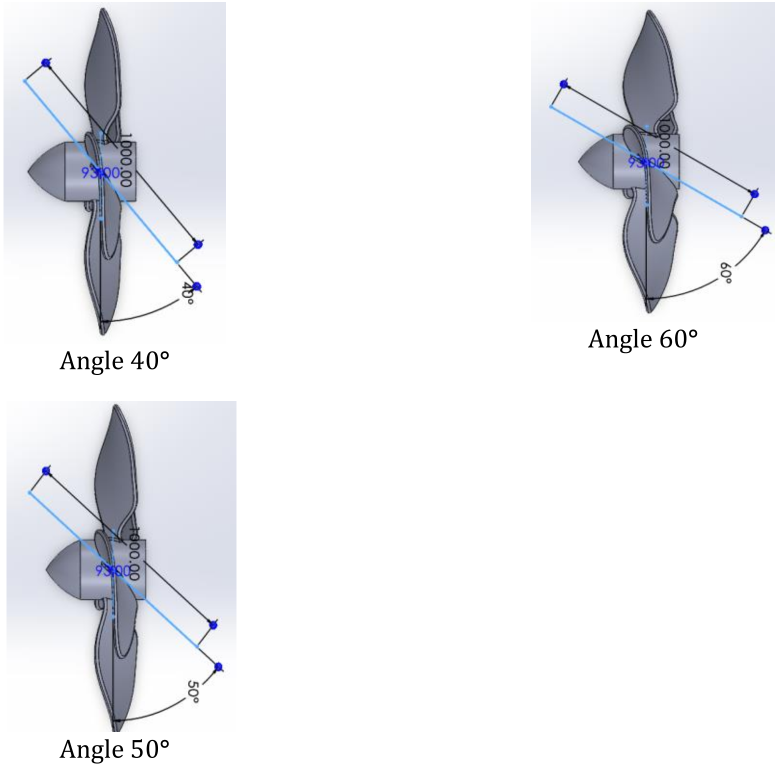


Fig. 2: *Design 1 hydro turbine with angle (measurement in mm)*

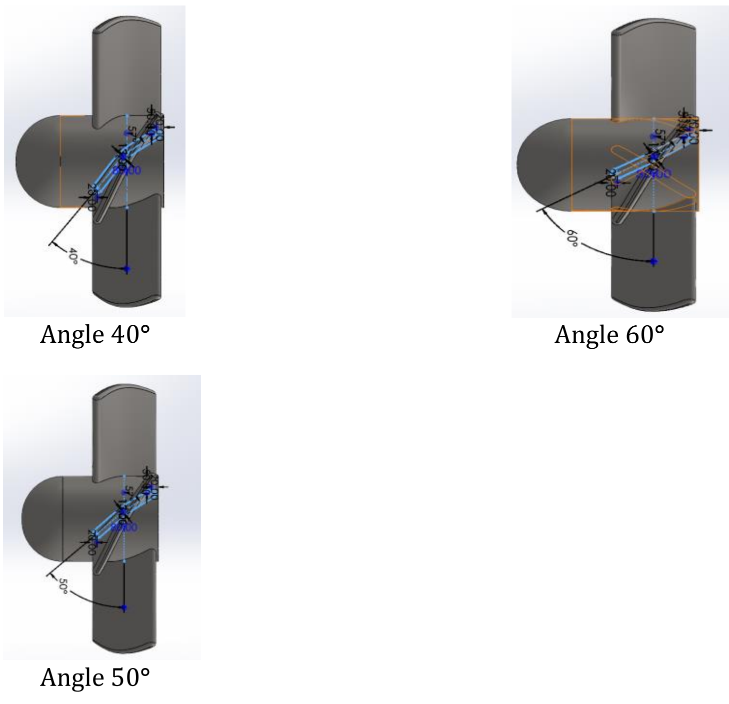
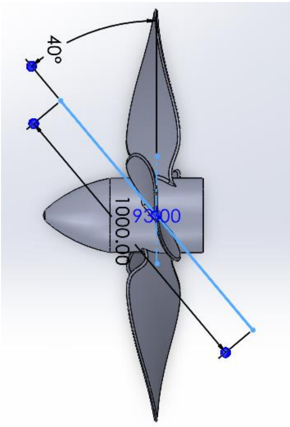
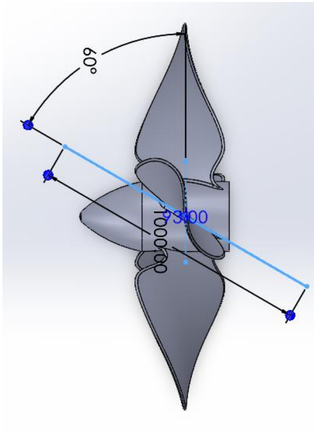


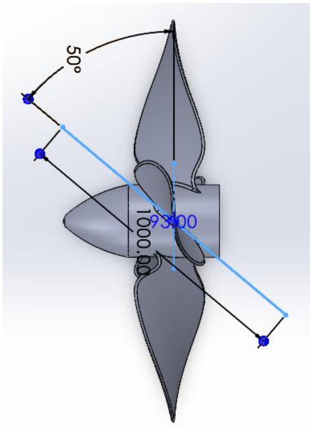
Fig. 3: *Design 2 hydro turbine with angle (measurement in mm)*



Angle 40°



Angle 60°



Angle 50°

Fig. 4: *Design 3 hydro turbine with angle (measurement in mm)*

2.2 Boundary condition

Boundary conditions are essential in computational fluid dynamics (CFD) simulations as they define the physical conditions at the boundaries of a computational domain [8]. In this simulation, the following parameters are involved:

Table 1: Parameters of research

Parameters	**Specification**
Material of the pipe	copper
Length of pipe	10m
Thickness of pipe	2cm
Pipe diameter	31cm
Water flow rate	2.1m/s
Blade angle	40°,50°,60°

Diameter propeller design 1	21cm
Diameter propeller design 2	28cm
Diameter propeller design 3	24cm
Number of blades	4
Material of the propeller	Stainless steel
Density of water	997kg/m^3
Acceleration due to gravity	9.8 m/s

2.3 Simulation analysis

For this study combination of analytical calculations and computational simulation was involved to evaluate the performance of the hydro turbine with different angles. The process was structured into three key steps, which are determining the total pressure inside the pipe, rotating the turbine and calculating the performance turbine.

Before conducting a simulation, the water flow velocity at the turbine was assumed by the standard water flow rate inside an underground pipe in an industrial area in Malaysia (Department of Standards Malaysia, 2017, *MS 1910:2017)*. By using a similar pipe with the same diameter, length and flow rate. In this study, the pipe length is 10 meters and the diameter is 0.3 meters. To calculate the power output and efficiency of a hydro turbine in an underground pipe, we need to look at a few important factors. These include the height of the water, how fast the water flows, the density of water, gravity, and how efficient the turbine is [9]. The turbine uses the energy from moving water to generate electricity. We can calculate the power using a basic formula based on water flow and the parameters of the pipe [10].

The cross-sectional area of the pipe was calculated using the formula:

$$A = \frac{\pi D^2}{4}$$
$$A = \frac{\pi(0.3)^2}{4} = 0.07069m^2$$

The water velocity of the inlet pipe was calculated using the volumetric flow rate:

$$Q = A \times V$$
$$0.07069m^2 \times 2.1m/s = 0.1484m^3/s$$

The simulation was conducted using ANSYS, focusing design of the propeller on angle configurations to obtain pressure and velocity data. The data provided insights into fluid behaviour and turbine performance. From the simulation result, additional performance metrics, such as force, torque, power and RPM using the following calculations.

Force;

$$F = P \times A$$

P represents the pressure obtained from simulations
A is cross cross-sectional area

Torque;

$$\tau = F \times r$$

F represents the force obtained from the calculation
r is the turbine radius
power;

$$P = \tau \times \omega$$

τ is represents the torque obtained from the calculation

ω is represents angular velocity

Head;

$$H = \frac{power}{\rho \times g}$$

Power is obtained from the calculation

ρ is the density of water taken as 998 kg/m^3

g is the acceleration of gravity, equal to 9.81 m/s^2

RPM;

$$Ns = \frac{N \cdot \sqrt{P}}{H^{\frac{5}{4}}}$$

$$N = \frac{Ns \times H^{\wedge}(5/4)}{\sqrt{P}}$$

Ns is the specific speed Kaplan tubular water turbine is equal to 200

Power is obtained from the calculation

H is obtained from the calculation

2.3.1 Calculation result

Table 2 displays the entire set of turbine performance of the power form turbine. Pressure, flow rate and other operational characteristics are used to gather data for the efficiency calculation. A thorough reference for examining the variations in efficiency between various turbine designs and propeller angles is provided by this data.

Table 2: calculations data

Design	Power			Torque			RPM		
	40°	50°	60°	40°	50°	60°	40°	50°	60°
Design 1	9610W	9600W	9601W	3845.98Nm	3840.51Nm	3840.73Nm	63	63	62
Design 2	19680W	19800W	20010W	7872.63Nm	7919.11Nm	8002.77Nm	107	108	109
Design 3	14470W	14610W	14690W	5786.41Nm	5843.81Nm	5876.58Nm	85	86	87

3. Results and discussion

The analysis examines three designs with three angles, which are 40°,50° and 60°. There are 2 types of pipes horizontal pipe and vertical pipe design 1 and 2 are horizontal pipes, while design 3 is a vertical pipe. These variations aim to identify trends and correlations between the parameters, determine the optimal blade angle and configuration for maximum efficiency, and provide insights into turbine design considerations. These findings are integral to achieving the objectives of the study and contribute to advancements in turbine design for enhanced energy conversion. The results are systematically organized and discussed to ensure clarity and relevance.

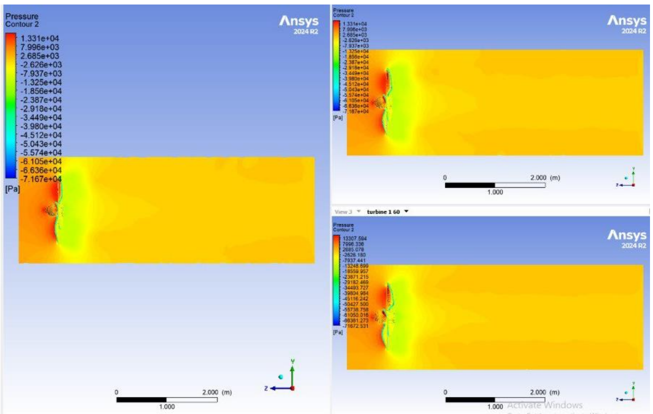
The pressure data from the simulations, presented in table 2, highlights several important trends across the angles 40°, 60° and 50°. This study contrasts three turbine designs 1, 2 and 3, having different blade angles of 40°, 50°, and 60° to determine the effect of pressure within a pipe on performance and safety. Pressure is among the critical factors in a turbine system because higher pressure usually greater energy output adds more stress to the pipe. Lower pressure is safer for the system may result in less energy. Design 1, with a horizontal pipe had the minimum pressure and hence is the safest design with the least amount of pipe stress. Design 2 with a horizontal pipe resulted in the maximum pressure, meaning that it will carry more energy but with the greatest possibility of pipe damage. Design 3, with its vertical pipe registered a medium pressure.

Table 3: Pressure from CFD simulation

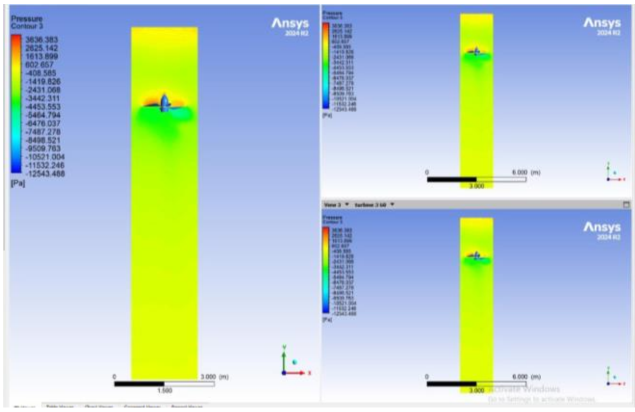
Pressure			
Design	Angle		
	40°	50°	60°
Design 1	362709 Pa	362193 Pa	362213 Pa
Design 2	742456 Pa	746839 Pa	754729 Pa
Design 3	545708 Pa	551121 Pa	554211Pa

Comparing blade configurations, design 2 with 40° consistently exhibits the highest pressure values across all angles. For example, at 50° and 60°, the average pressure for the design 2 pressure is around 7500 Pa, which is higher than the design 1 and 2 configurations, which are around 5000 Pa at the 40°, 50° and 60° configurations. In contrast, the design 1 turbine records the lowest pressure values, highlighting its limited ability to utilize water flow effectively. The effect of increasing blade angles is evident as pressure values significantly drop. The largest declines occur between 50° and 60° at designs 2 and 3, reflecting reduced energy capture and interaction between the water flow and turbine blades at steeper angles. These trends suggest that higher blade angles are less effective in maintaining efficient energy transfer, while design 1 is better at higher angles.

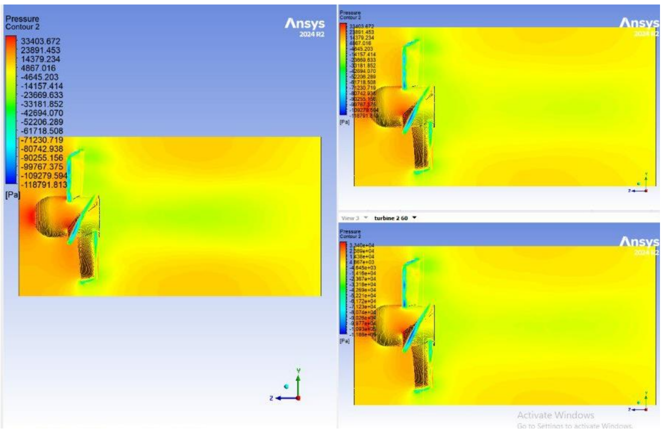
Research Progress in Mechanical and Manufacturing Engineering Vol. 7 No. 1 (2026) p. 88-101



Design 1



Design 3



Design 2

Fig 5. Pressure inside the pipe

The contour for Figure 5 demonstrates a highly uniform and widespread pressure distribution across the blade surfaces. This uniformity ensures optimal interaction between the water flow and the turbine blades, maximizing energy capture and conversion. The high-pressure zones are concentrated along the leading edges of the blades, indicating effective utilization of the water flow's kinetic energy.

3.1 Effect of design and blade angle on torque

The relationship between blade angle and torque is important in determining turbine performance because it directly influences the efficiency of energy transfer from fluid flow to rotational motion. Understanding how different blade angles affect torque generation provides useful information for optimising turbine design for maximum performance. The analysis, which is supported by existing research, shows that torque behaviour varies significantly with blade angle changes. For example, one study found that as the angle of attack increased, turbine torque decreased, with the best performance achieved at a blade angle of design 2 at 60°. This trend is consistent with the idea that lower blade angles are better at capturing rotational force from fluid flow.

A hydro turbine's capacity to transform water flow into mechanical energy is directly impacted by the torque it produces, and blade angle is a critical factor in this relationship. Figure 6, which contrasts the three designs, demonstrates that Design 2 continuously produces the most torque at all blade angles, 40°, 50°, and 60°. Its bigger propeller diameter, 28 cm and horizontal position, which maximise the flow impact area and boosts rotational force, are responsible for this.

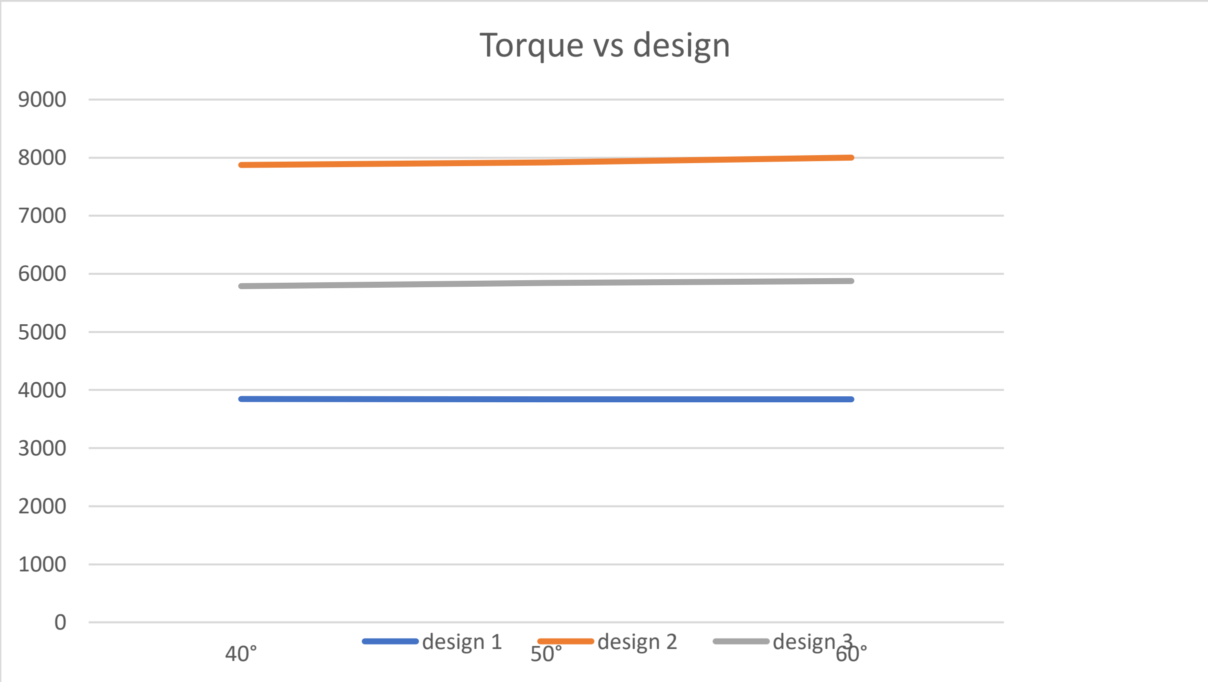


Fig 6. Torque vs design

The design 2 configuration consistently generates the highest torque across all designs, as shown in Figure 6, followed by the 2 design and design 1, the lowest, indicating that increasing the size of the propeller improves the transfer of force to the turbine. Torque is highest at blade angles is at 60°, as shown in figure 6, regardless of the blade configuration, making this range optimal for maximizing rotational force. However, for design 1, torque decreases significantly beyond design 3 due to the design 1 dimension being smaller, indicating diminishing returns at lower blade angles. A similar trend is observed for design 3, although with slightly lower torque values compared to design 2, but design 3 is average in terms of performance and safety. In contrast, the design 1 configuration consistently records the lowest torque across all angles, emphasizing the influence of the dimension of propeller count on performance.

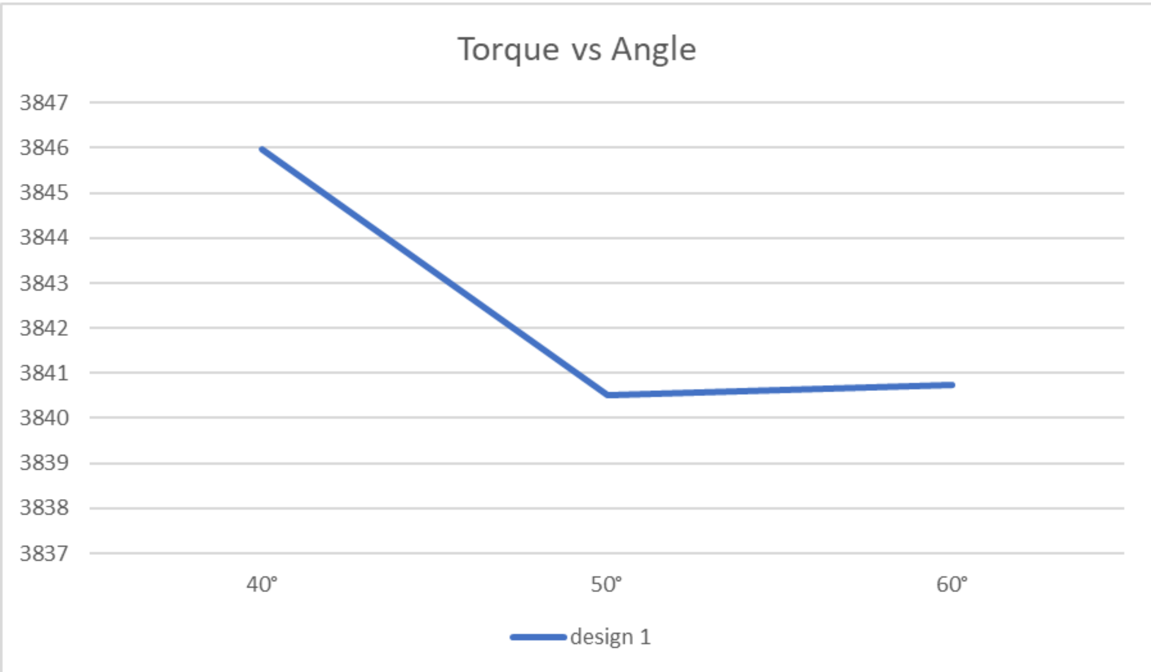


Fig 7. Design 1 torque vs angle

Design 1 highest torque at 40 degrees, and the lowest is at 60 This proves that design 1 is suitable for small angles. In Figure 7, design 1 shows a decreasing torque trend as the blade angle increases. The highest torque is observed at 40°, 3845.98 Nm, and it slightly decreases to 3840.73 Nm at 60°. This suggests that design 1 performs better at smaller angles, likely due to its smaller blade diameter of 21 cm and less water interaction at steeper angles.

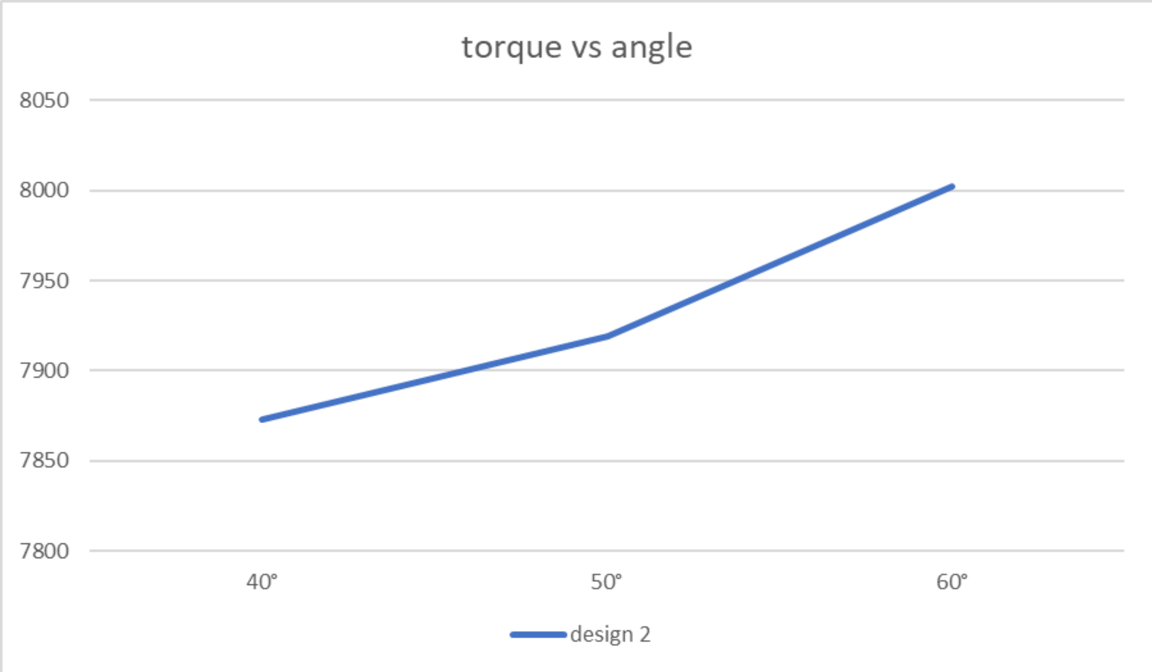


Fig 8. Design 2 torque vs angle

Figure 8 further emphasizes that design 2 reaches peak torque at 60°, which is 8002.77 Nm, which aligns to maximize force transfer from fluid to rotation. The steady increase from 7872.63 Nm 40° to 8002.77 Nm 60° supports the idea that higher blade angles enhance torque for this specific design.

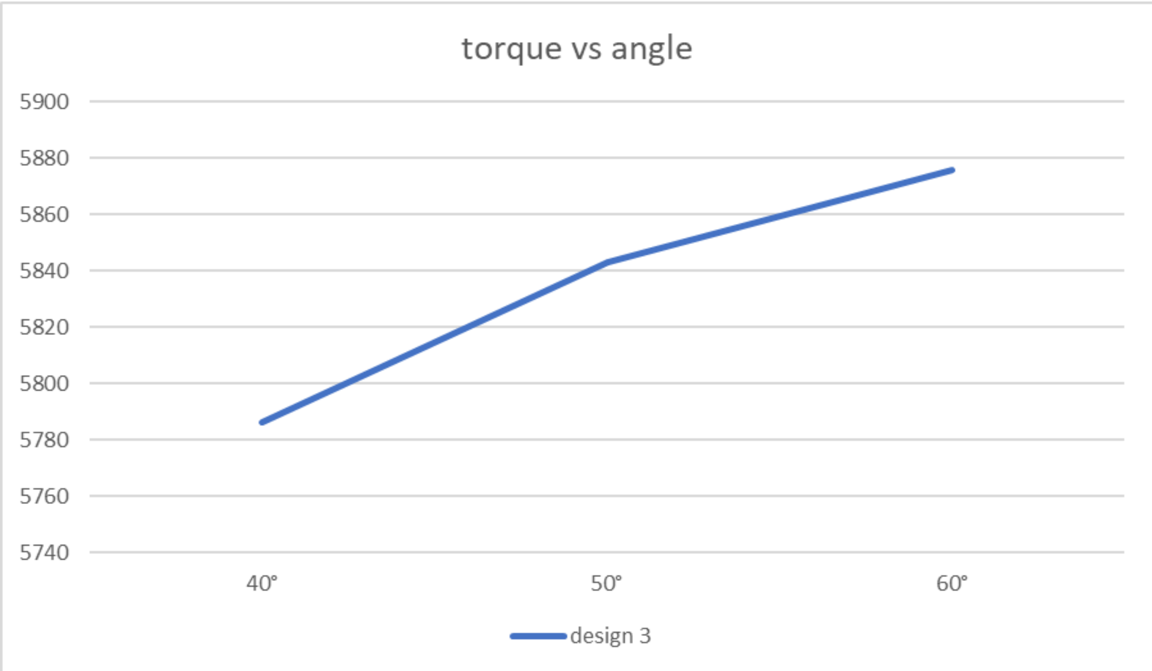


Fig 9. Design 3 torque vs angle

In figure 9, design 3 also shows increased torque with angle, from 5786.41 Nm at 40° to 5876.58 Nm at 60°. While it doesn't reach the same performance as design 2, design 3 offers a balanced result, being a vertical configuration that combines moderate torque with lower pressure risk.

3.2 Effect of design and blade angle on power

Considering that it directly affects the efficiency of energy conversion from fluid flow to usable mechanical output, the link between blade angle and power is crucial in evaluating turbine performance. Optimizing turbine design to attain optimal performance requires an understanding of how various blade angles impact power generation. The data demonstrate that power production fluctuates dramatically with changes in blade angle, which is corroborated by previous research. Turbine power, for instance, is often improved with increasing angle of attack, with the highest performance. The power output of the hydro turbine is a critical measure of how effectively the turbine converts the kinetic energy of water into mechanical energy. According to the simulation results in Table 2 and Figure 10, Design 2 consistently generates the highest power across all blade angles 40°, 50°, and 60°, ranging from 19680 W to 20010 W. This high output is largely due to the larger propeller diameter 28 cm and horizontal orientation, which allow better interaction with the water flow, increasing energy capture.

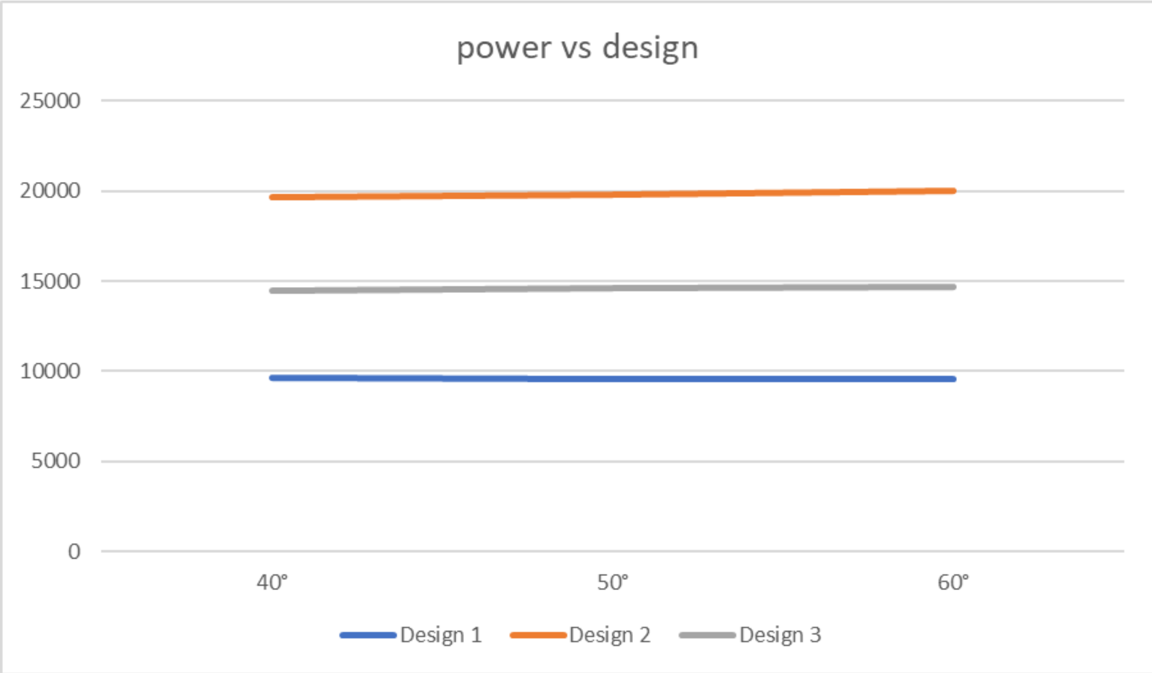


Fig 10. Power vs design

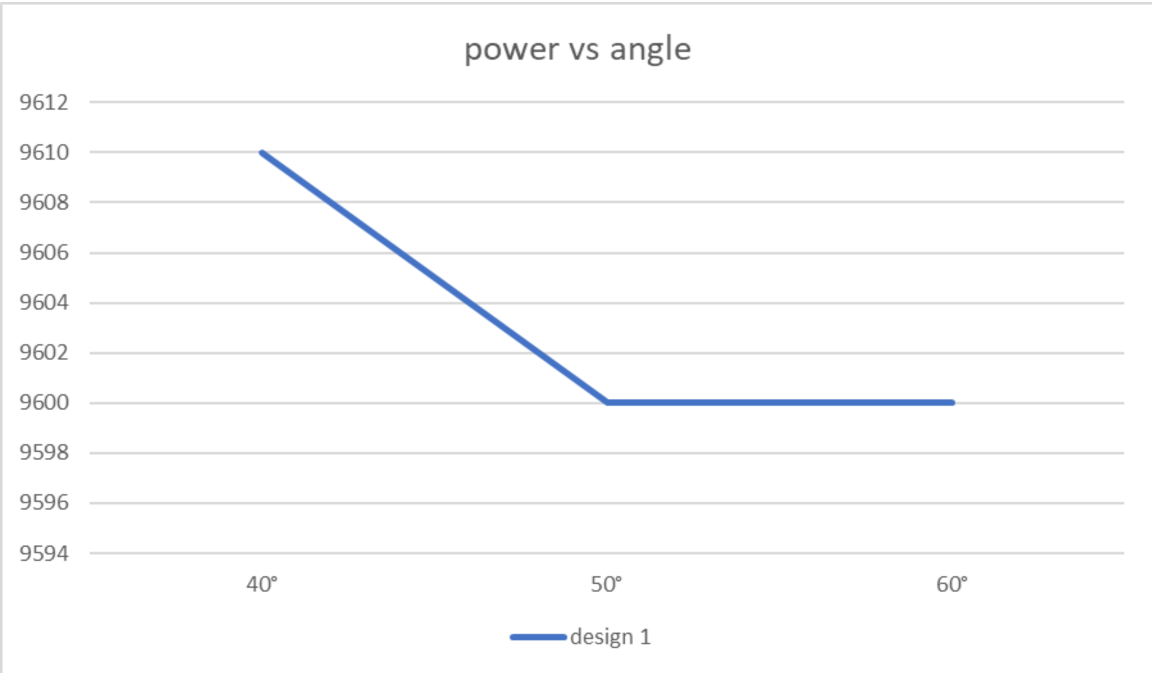


Fig 11. Design 1 power vs angle

On the other hand, design 1 generates the lowest power, with values around 9600 W, regardless of blade angle. This is due to its smaller blade diameter of 21 cm and limited surface area for flow interaction, resulting in reduced energy conversion.

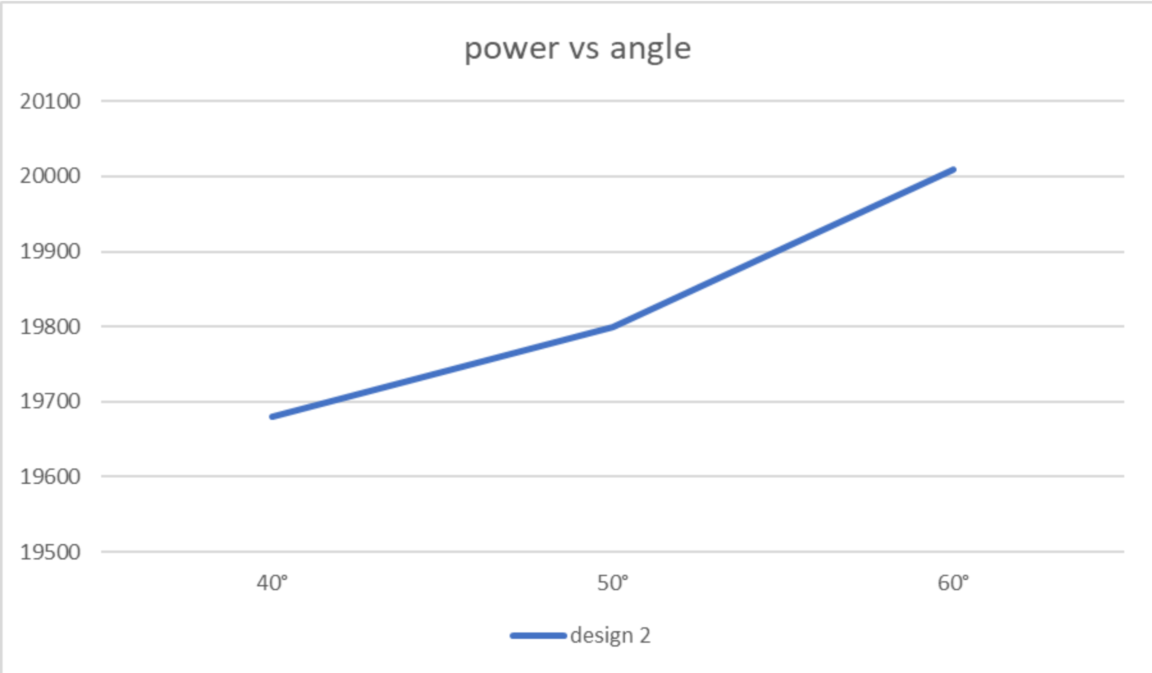


Fig 12. Design 2 power vs angle

Blade angle also plays a role in power performance. While all designs show relatively stable power values across angles, design 2 at 60° produces the highest power, 20010 W, indicating that a higher blade angle can enhance power generation for designs optimized for flow coverage.

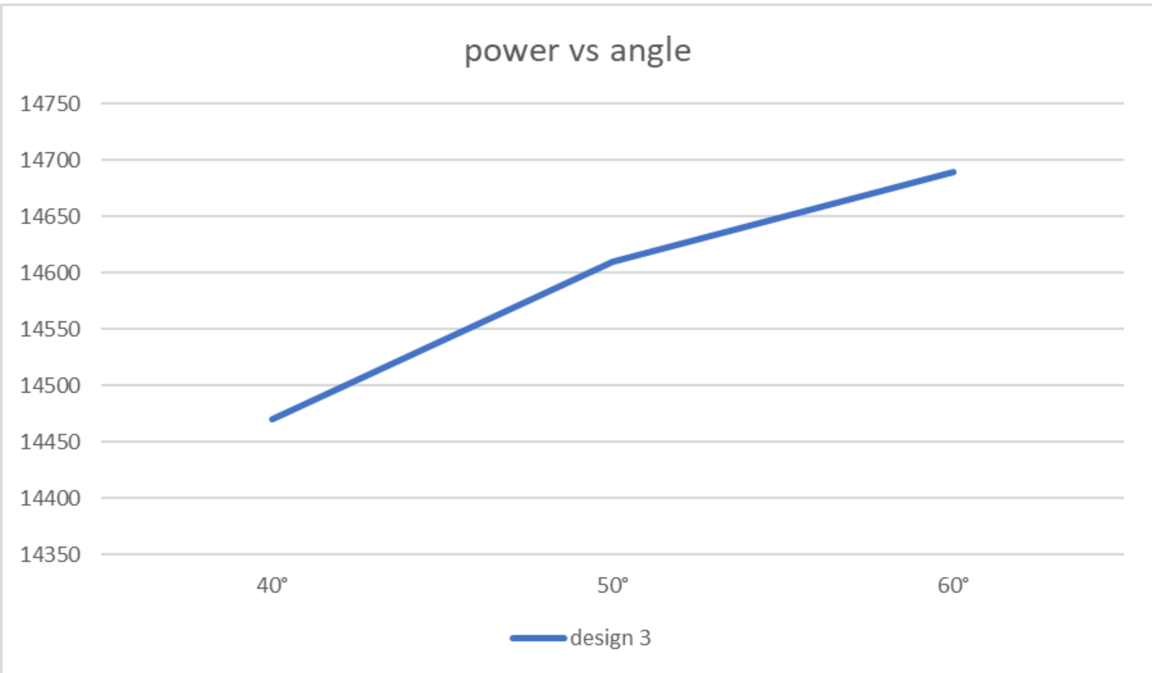


Fig 13. Design 2 power vs angle

Design 3, a vertical turbine configuration, also performs well with power outputs between 14470W and 14690W. Its design appears to support steady and moderate power generation, making it suitable for installations where a balance between performance and structural simplicity is desired.

3.3 RPM

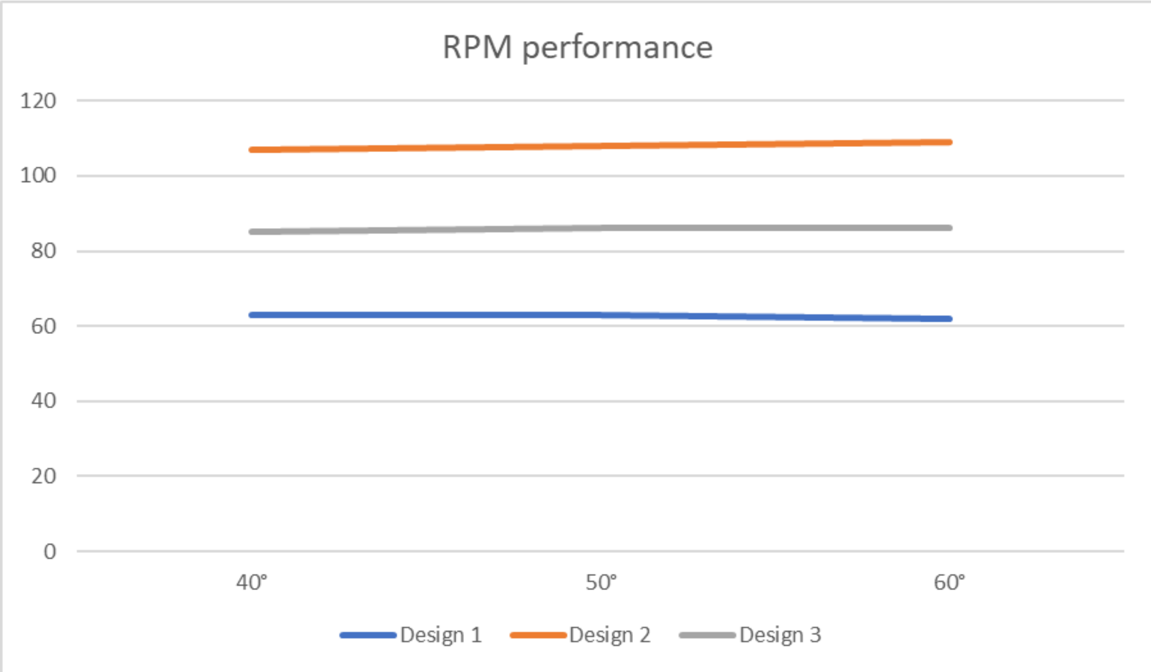


Fig 14. RPM performance

Figure 14 demonstrates the RPM performance of the three turbine designs. Design 2 proves again to be better than the rest, with RPM between 107 and 109 for the tested angles. Not only does it show high power output, but it also shows efficient rotational speed, which is required for mechanical-to-electrical energy conversion efficiency. Design 3 mid-range RPM of 85 to 87, a compromise between stability of operation and speed, is especially essential in vertical units, where even pressure and flow distribution reduce the stress in the turbine. Design 1, on the other hand, operates at a low RPM of 62 to 63.

4. Conclusion

Comparison has been made in the present study between the performance of three hydro turbine designs with varying blade angles in terms of major parameters such as pressure, torque, power, and RPM. From the simulation output and calculations, it is evident that the design and angle of the turbine blades are of critical importance to overall efficiency and operational safety [11]. Of the three designs, Design 2, a horizontal pipe design with the larger blade diameter, performed highest in efficiency, particularly at a blade angle of 60°. It produced the highest power, 20010 W, and the highest RPM of 109 and performed well in torque. Design 2 also recorded the highest internal pressure, 754729 Pa, however, which could impose extra mechanical stress on the pipe walls and the turbine housing. In its current state, therefore, Design 2 possesses tremendous energy conversion potential but needs extra heavy-duty structural material and occasional monitoring to ensure system integrity in the long term. Conversely, Design 3, also known as the vertical pipe turbine, had moderate power and RPM output while maintaining pressures comparatively lower at the 550000Pa range. Its structure facilitates smoother, more consistent fluid distribution that reduces mechanical load and vibration. Design 3 is therefore a balanced option, appropriate for installations where both system performance and long-term durability are of primary concern. Design 1, the safest with the lowest pressure levels, 362000Pa, performed the worst at all tested blade angles. Its lower blade diameter and reduced flow interaction make it most suited for low-demand applications where mechanical simplicity and longevity are valued more than power output [12].

In summary, the choice of turbine design and blade angle has to be as per the system requirements. For high performance and maximum energy generation, Design 2 at 60° is best, keeping in mind that the system will be made strong enough to support higher internal pressures. For stable and secure operation with acceptable power generation, Design 3 at 50° and 60° is best. These findings support previous literature that describes the utmost significance of blade geometry and flow configuration to hydro turbine efficiency and structural integrity [13].

Acknowledgement

This author expresses their gratitude to the Faculty of Mechanical Manufacturing Engineering at Universiti Tun Hussein Onn Malaysia for their valuable support and opportunity to conduct this study.

References

[1] Tam, S. W., et al. (1979). "Underground pumped hydro storage—An overview." *Energy Sources*.
[2] Morabito, A., et al. (2020). "Underground pumped storage hydropower case studies in Belgium: Perspectives and challenges." *Energies.*
[3] Pujades, E., et al. (2017). "Underground pumped storage hydropower plants using open pit mines: How do groundwater exchanges influence the efficiency?." *Applied Energy.*
[4] Rosli, N., et al. (2018). "Home underground pipeline leakage alert system based on water pressure." In *2018 IEEE conference on wireless sensors (ICWiSe)*.
[5] Menéndez, J., et al. (2019). "Stability analysis of the underground infrastructure for pumped storage hydropower plants in closed coal mines." *Tunnelling and Underground Space Technology*.
[6] Alkasseh, J. M., et al. (2013). "Applying minimum night flow to estimate water loss using statistical modeling: a case study in Kinta Valley, Malaysia." *Water resources management.*
[7] FOOK, L. (2016). "*Effect of design peak flow factor to the capital cost of sewerage reticulation in Malaysia."* (Doctoral dissertation, Universiti Teknologi Malaysia).
[8] Junoh, M. M., et al. (2022). "Estimation diameter of buried pipe using principle of ground penetrating radar and electromagnetic locator." *International Journal of Geoinformatics*.
[9] Orazem, M. (Ed.). (2014). "*Underground pipeline corrosion."*. Elsevier.
[10] Choi, H. W., et al. (2017). "A Study on the Safety Management of High Pressure Underground Pipeline in Industrial estate." *Journal of the Korean Institute of Gas.*
[11] Ahmran, M. S. A., et al. (2024, February). "A Case Study of Ground Settlement and Volume Loss from Pipe Jacking and Microtunelling Activities for Sewerage Pipe Installation in Ipoh, Perak." In *IOP Conference Series: Earth and Environmental Science*.
[12] Amran, T. S. T., et al. (2017, January). "Detection of underground water distribution piping system and leakages using ground penetrating radar (GPR)." In *AIP conference proceedings.*
[13] Z. Lillahulhaq, (2022). "Experimental study of small hydro turbine propeller performance with a variety of blade angles of attack," SINERGI.