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Design And Evaluation Of Hydro-Kinetic Turbine For Energy Generation From Streams And Open Channel Apparatus

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Abstract **In the work, design and evaluation of hydro-kinetic turbine for energy generation from streams and open channel apparatus is presented. The turbine considered in the study is the Gravity Water Wheel (GWW) and the case study river was Ibagwa River located in Ibagwa Akwa Ibom State. SolidWorks CAD package was used to model the Gravity Water Wheel and the open channel apparatus. The open channel water flow apparatus setup was used to test the water wheel. In the experiments that were conducted using the open channel flow apparatus, the water wheel was able to achieve 20 revolutions in 9.34 seconds, which is equivalent to over 128 rpm. The results from the no load test, was 8 V at no-load condition but when a load was applied the voltage dropped to 5V and to stabilize the voltage, a battery management system circuit (BMS) was used to avoid excessive voltage increase. In addition, by reducing the discharge by varying the nozzle diameter of the pipe, the rpm increased rapidly and the water wheel was able to record above 10V. The output power from the water wheel turbine was able to charge some mobile phones. In all, the results show that the Water wheels is capable of addressing rural electrification problems as it has been used before the discovery of fossil fuels.**

Keywords— Hydro-Kinetic, Open Channel Apparatus, Gravity Water Wheel, Turbine, Normalized Rotational Speed

1. Introduction

Renewable energy is defined as "energy derived from natural processes that are replenished at a faster rate than they are consumed" [1,2]. The most widely used renewable energy source in developed countries is gotten from hydropower [3,4,5]. In developing countries, the rising demand for electricity in combination with large distances means that decentralized electricity generation has a high priority [6,7]. In addressing this energy need hydropower energy is the solution as it offers numerous benefits.

Notably, Nigeria has a very long coastline covering over 853km [8]. As such, the use of hydropower will be of immense benefit as the coastlines is an untapped resource in this country. The use of hydropower in highly industrialized countries of the world as an alternative to fossil fuel is at an increase [9,10]. An internal water network of space of about 900 Km^2 [11] provides a better opportunity to harness this hydropower in rivers located in rural settlements in Nigeria, where electrical power supply is usually unavailable. Addressing this need, water wheels have been used as a source of energy for driving mechanically powered pumps, machines, textiles, grinding and many other machineries in the ancient times [12,13]. Therefore, this study focuses on the design and evaluation of a gravity water wheel for harnessing energy from Nigerian rivers using Ibagwa River as our case study. In addition, the gravity water wheel solution presented in this study is a portable, inexpensive hydro-kinetic turbine capable of producing a usable amount of power from streams or rivers as well as from open channel apparatus for laboratory studies.

2. Methodology

2.1 Evaluation of the fluid characteristics of the case study Ibagwa River

1) The case study Ibagwa River was examined for its fluid characteristics with focus on the flow velocity, depth of the river and width of the river.

2.1.1 Flow velocity

The flow velocity of Ibagwa River was determined using a Styrofoam floater and a stop watch. As the Styrofoam floater was dropped on the water, the distance was measured from the start point to the end point of the travel of the Styrofoam floater and the time for the travel was recorded using a stop watch. The flow velocity was calculated thus;

$$\text{Velocity} = \frac{displacement}{\text{time}} \quad (1)$$

2.1.2 Depth of the river

The depth of the river was determined using a rope, stone and bottle mechanism. The bottle was acted as a pulley for the lift and drop of the rope to the river and out and also as a point marker for the diver to make point of the depth of the river on the rope.

2.1.3 Width of the river

The width of the river was calculated by taking an approximate distance at the bank of the river to the other bank of the river and the distance was measured using a measuring tape.

Figure 1 The main view of the case study Ibagwa River under a bridge

Figure 2: Diver measuring the river depth at Ibagwa River

2.2 The description and design of the Gravity Water Wheel

Water wheel potential energy converter is made up of radially aligned bucket located tangentially to the center of the wheel. It operates primarily by transferring momentum from the moving fluid to the paddles of the wheel, harnessing the potential energy of water under atmospheric pressure.

The water wheel turbine is a 3D printed wheel made from PLA filament. It is designed to be fused with the driving transmission spur gear, the increase the rotational torque. The water wheel has twelve (12) blades or paddle. A structure is printed to suspend the wheel on air when placed on the open channel apparatus. Two small shafts with bearings located at the center of the wheel helps in rotating the wheel easily. The design parameters include; the bucket angle, the annulus width, the outer radius and the inner radius. The outside radius, 61.5mm; The wheel width, 85mm; Annulus width, 40mm; Bucket angle, 30°. The permanent magnet generator is 15v and variable torque.

Some key parameters of the water wheel are determined using analytical expressions while some of the parameters are provided as design input values. First, the power input (P_{in}) to the wheel is determined using the following expression;

$$P_{in} = \rho\,(g)(Q)(H) \quad (1)$$

Where density of water, (ρ), total flow rate (Q) and head difference (H). The power output (P_{ou}) from the wheel was determined with respect to voltage (V) and current (I) using the following expression;

$$P_{out} = (I)(V) \quad (2)$$

The efficiency of the turbine is calculated using this relation;

$$\eta = \frac{\text{Pout}}{\text{Pin}} \quad (3)$$

The area of the wheel is determined using the following expression;

$$\text{Area of wheel} = \text{width of paddle} \times \text{height of paddle} \times \text{number of paddles} \quad (4)$$

$$\text{The area of the pipe} = \frac{\pi d^2}{4} \quad (5)$$

The velocity of flow is computed with respect to the flow rate, Q which varies from Q_{min} = 0.3m^3/h to Q_{max} =3m^3/h as follows:

$$V_{min} = \frac{Q_{min}}{A} \quad (6)$$

$$V_{max} = \frac{Q_{max}}{A} \quad (7)$$

The torque is computed with respect to the angular velocity (ω) and pump power rating as follows;

$$P = \tau \times \omega \quad (8)$$

$$\omega = \frac{2\pi N}{60}\ \text{(rad/s)} \quad (9)$$

The normalized rotational speed (N*) is computed as follows;

$$N^* = \frac{\text{Pout}\,.\,\text{r}}{\sqrt{2\,gH}} \quad (10)$$

Where r is the radius of the wheel, while $\sqrt{2\,gH}$ is the Torricelli .

3 Results and discussion

The summary of the Water wheel design input parameters is presented in Table 1 while the diagram of the designed Water wheel mechanism is presented in Figure 3. The detailed bill of materials of the designed water wheel assembly with open channel water flow apparatus is presented in Figure 4. The isometric view of the gearing system for the water wheel is presented in Figure 5 while the isometric view of the water wheel with the gear incorporated to it is presented in Figure 6.

Table 1 The summary of the Water wheel design input parameters

SN	Description of Parameter	Parameter Value and Unit
1	Height of wheel	0.085m
2	Diameter of wheel	0.12m
3	Flow rate	0.3-3m^3/h
4	Frontal area of wheel	0.0058344m^2
5	Bucket angle	30°
6	Thickness of the paddle	5.75mm
7	Number of paddles	12
8	Efficiency of the wheel	64.1%
9	Velocity of flow	0.167-1.667m/s

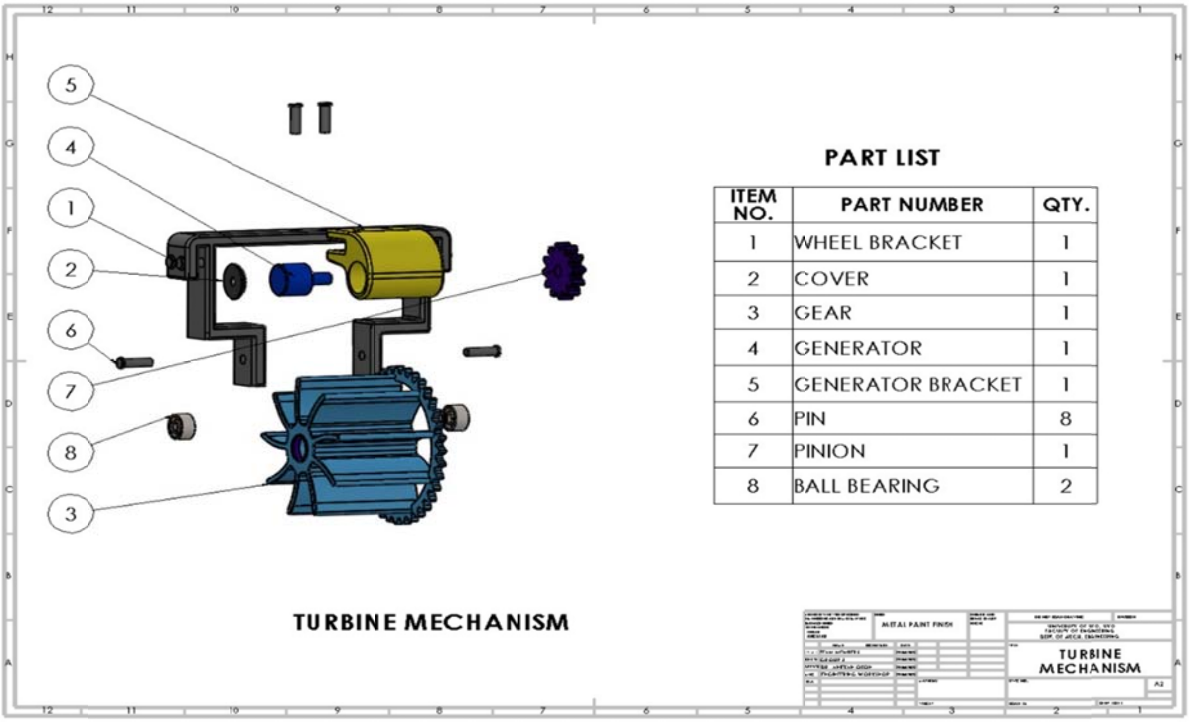

Figure 3 The designed Water wheel Mechanism

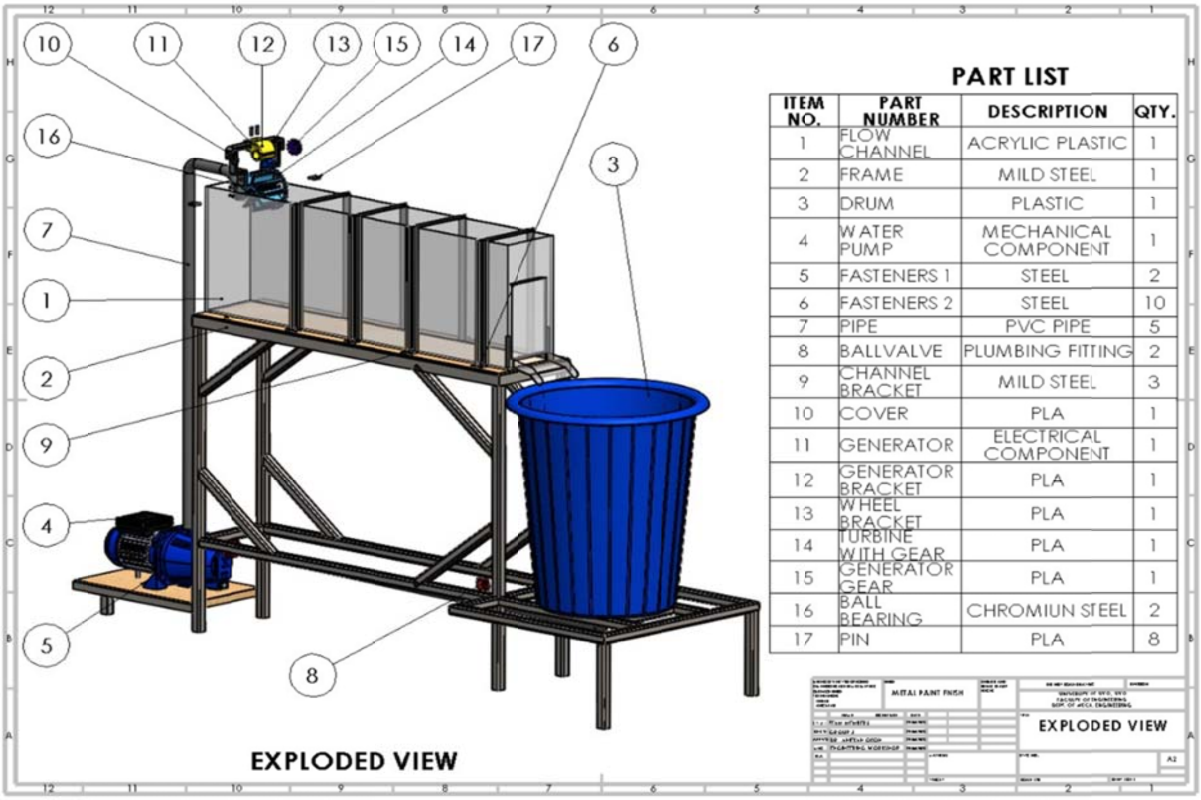

Figure 4 The bill of materials of the designed water wheel assembly with open channel water flow apparatus

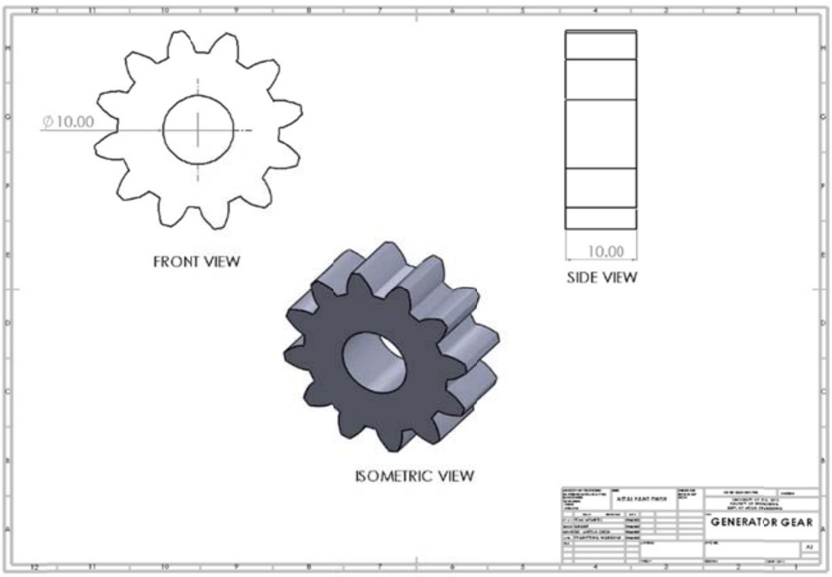

Figure 5 The isometric view of the gearing system for the water wheel

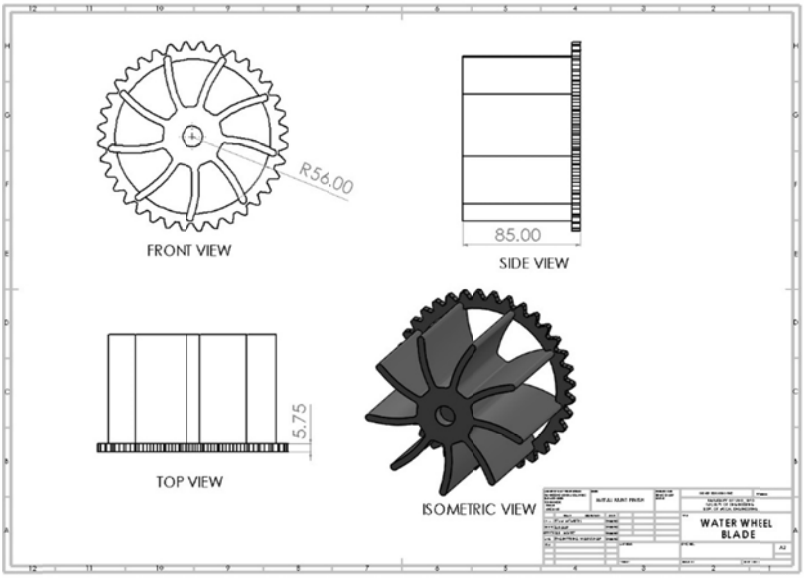

Figure 6 The isometric view of the water wheel with the gear incorporated to it

The open channel water flow apparatus setup was used to test water wheel. The results of the test for the normalized rotational speed versus head difference obtained from the experiment conducted with the water wheel is presented in Table 2. Also, the graph of the normalized rotational speed versus head difference for the water wheel is presented in Figure 7. The graph shows the characteristics of the water wheel in an open channel pipe flow. The power output is as a function of the potential energy developed by the wheel paddles on rotation. Specifically, the results in the graph show that the rotational efficiency of the water wheel which is depicted by the normalized rotational speed decreases with decrease in the head difference, H.

Table 2: The results for the normalized rotational speed versus head difference obtained from the experiment conducted with the water wheel

SN	The normalized rotational speed , **N***	The water head difference, H
1	0	0
2	0.1591	0.2
3	0.1517	0.22
4	0.1452	0.24
5	0.1395	0.26
6	0.1345	0.28
7	0.13	0.3
8	0.1258	0.32

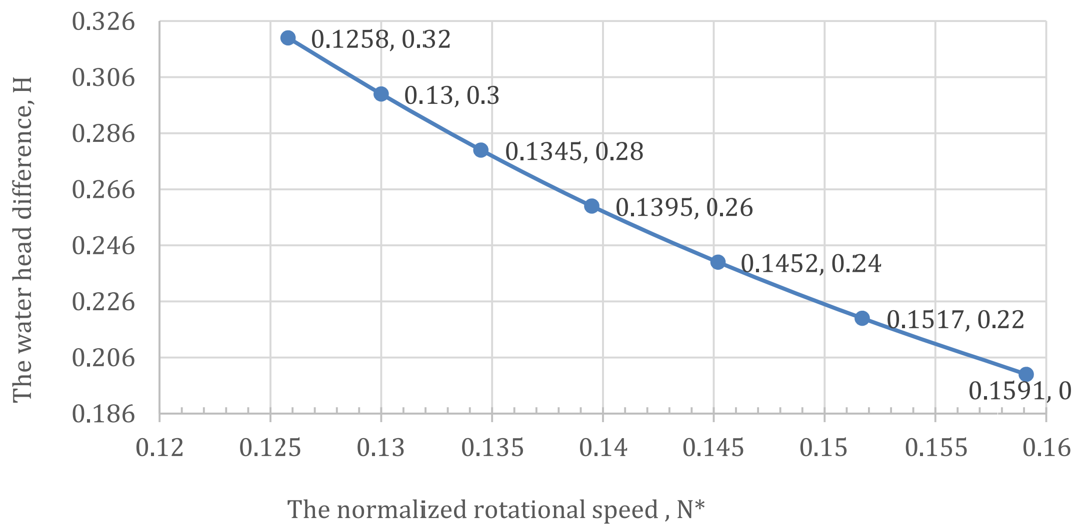

Figure 7 The graph of the normalized rotational speed versus head difference for the water wheel

Further results on the Computational fluid dynamics (CFD) of the water wheel are presented in Figure 8 and Figure 9. The CFD visualization of the water wheel velocity assisted with gears is presented in Figure 8 while the CFD visualization of the water wheel pressure assisted with gears is presented in Figure 9.

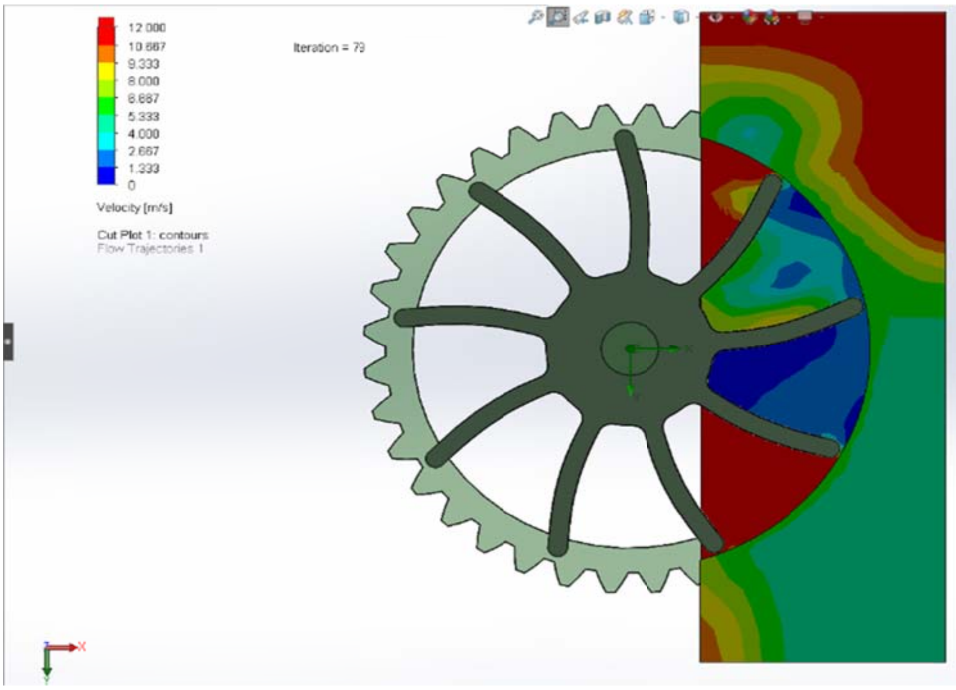

Figure 8 The Computational fluid dynamics (CFD) visualization of the water wheel velocity assisted with gears.

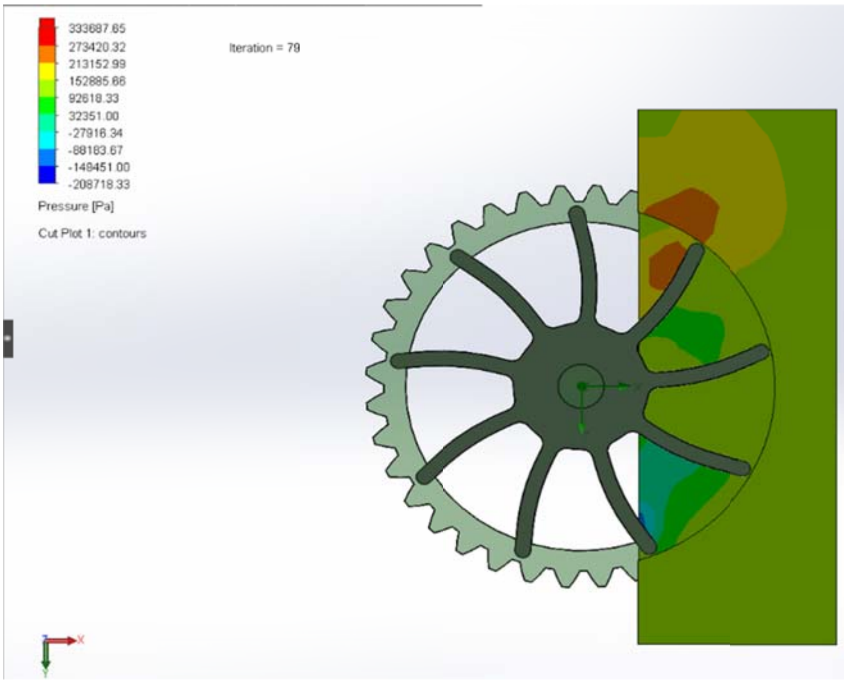

Figure 9 Computational fluid dynamics (CFD) visualization of the water wheel pressure assisted with gears.

In the experiments that were conducted using the open channel flow apparatus, the water wheel was able to achieve 20 revolutions in 9.34 secs, which is results to over 128 rpm. The results from the no load test, was 8 V at no-load condition but when a load was applied the voltage dropped to 5V and to stabilize the voltage, a battery management system circuit (BMS) was used to avoid excessive voltage increase. In addition, by reducing the discharge by varying the nozzle diameter of the pipe, the rpm increased rapidly and the water wheel was able to record above 10V. The output power from the water wheel turbine was able to charge some mobile phones. In all, the results show that the Water wheels is capable of addressing rural electrification problems as it has been used before the discovery of fossil fuels.

4. Conclusion

The design and evaluation of hydro-kinetic turbine is presented. The turbine considered is the Gravity Water Wheel which is designed for operation in streams and open channel apparatus. While the stream is used to model the operation in real life application, the open channel apparatus considered in this study is meant for laboratory demonstration of the hydro energy harvesting using rotating engine. The design calculation analytical models are presented along with different views of the designed water wheel generated using SolidWorks CAD package. The results of the rotational efficiency of the water wheel was also examined.

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