



Design and Construction of a Mini Self-Contained Hydroelectric Power Generation Plant.

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ABSTRACT

Energy is a critical factor in developing countries for economic growth as well as for social development and human welfare. Hydropower is a renewable source of energy, which is economical, non-polluting and environmentally friendly. In this paper, a prototype mini hydroelectric power generation system was developed. Locally available materials were utilized for the design and development. Some of the materials includes: Primary and secondary reservoirs, Dynamo, Rotor, developed peltier wheel turbine, pump etc. The results of the mechanical power of the system were found to be 30.65MW and 10.14MW at total flow rates of 88.67m³/s and 35.68m³/s respectively. The turbine efficiencies were found to be 79.52% and 58.34% at 10.06m and 4.10m water inlet velocities. The generator efficiencies were found to be 88.45% and 69.85% at 10.06m and 410m inlet water velocities respectively. The generator efficiencies were found to be 88.45% and 69.85% at net head of 337.1 m and 364.29m respectively. The turbine efficiencies were found to be 79.52% and 58.34% at net head of 337.61 and 364.29m. The project was evaluated and concluded that the designed mini hydropower plant was found to be economical. The hydroelectric power plant was able light three (3) bulbs of 10Watts each

1.0 INTRODUCTION

Thousands of years ago, people started using hydro-power to produce mechanical work for mainly agriculture purposes. In 1882 first hydro-power plant was built to produce electric energy which consider the hydro-power

as the first technology used to produce electricity from renewable source (Nasr *et al.*, 2018).

Hydro-power is considered as one of the most desirable sources of electrical energy due to its environmentally friendly nature and extensive potential availability throughout the world. Within the scope of

hydro-electric power, small power plants have gained much attention in recent years. Small Hydro power Plants being a mature technology may be optimally employed for sustainable power generation in rural communities. Hydropower plants convert potential energy of water at a height to mechanical energy which is used to turn a turbine at a lower level for generation of electricity (Anyaka, 2013). In rural areas, small run-of-river hydro turbine is suitable for electrification because it is green, inexpensive not fuel dependent and is simpler to implement than other green energy technologies. A small hydropower scheme requires both water flow and a drop in height called a head to produce useful power. Water in nature is considered a source of power when it is able to perform useful work particularly turning water wheels to generate electricity at a rate such that the development of power can be accomplished in a most efficient and economical way (Adejumobi, 2011). About two-third of Nigeria lies in the watershed of the Niger River which empties into the Atlantic at the Niger Delta with its major tributaries; The Benue in the Northeast, the Kaduna in the North Central, the Sokoto in the Northwest, and the Anambra in the Southeast. The Niger is African's third longest river and fifth largest in terms of discharge. Several rivers of the watershed flow directly into the Atlantic notably the Cross river in Southeastern Nigeria and the Ogun, Osun and Oyan in the Southwest. (Muhammadu 2020).

Nigeria has a gross exploitable large hydro potential of 14,750MW which 14% of the power is amounting to 1930MW is harnessed contributing approximately 30% of the total installed grid connected electricity generation (Karki et al, 2010).

Several rivers of Northeastern Nigeria including the Komadugu Gana and its tributaries flow into Lake Chad. The lake rests in the centre of a major drainage basin at the point where Nigeria, Niger, Chad and Cameroon meet. Kainji Lake created in the late 1960s by the construction of the Kainji Dam on the Niger River in Nigeria. The country's topography ranges from lowlands along the coast and in the lower Niger valley to high plateau in the North and mountain along the eastern border, most part of the country is linked with productive rivers which are scattered virtually all over the country (Gerald, 2018). In Nigeria, electricity is seen as an essential infrastructure in the same category as roads, telecommunication and water. In fact, it is the life-blood of our national development and industrial growth. Although electricity is treated as an essential social service. After slightly over 100 years ago the industries are still characterized by erratic supply of inadequate coverage in term of geographical spread covering less than 40% of the population and a record of low per capita consumption. (Gerald, 2018). Energy is a critical factor in developing countries for economic growth as well as for social development and human welfare (Gerald, 2018).

About two-third of Nigeria lies in the watershed of the Niger River which empties into the Atlantic at the Niger Delta with its major tributaries. The Benue in the North central, the Kaduna in the North Central, the

Sokoto in the Northwest, and the Anambra in the Southeast. The Niger is African's third longest river and fifth largest in term of discharge. Several rivers of the watershed flow directly into the Atlantic notably the Cross river in Southeastern Nigeria and the Ogun, Osun and Oyan in the Southwest. (Gerald, 2018)

The first generating plant was built in Lagos in 1898 by the colonial government and was managed by the Public Works Department (PWD). Native and Municipal Authorities thereafter set up understating by 1950, the federal government established electricity corporation of Nigeria (ECN) through the instrument of ordinance No. 15 of 1950, which was vested with the responsibility of running the generating stations subsequently in 1962 the Niger Dam Authority (NDA) was established to build dam. However, the first large scale hydro power station in Nigeria was built in Kainji on the river Niger with an installed capacity of 760MW and with expansion to 1,150MW in 1968 then followed by Jebba in 1984 and Shiroro in 1990 with installed capacity of 570MW and 600MW respectively. (Zarma 2017)

Small and micro-hydro power plants have a long tradition in Africa, but never reached a massive dissemination. Although, the geographical conditions in some regions are favorable. In most of the countries the existing MHP plants were funded by international donors or NGOs and remained isolated projects, which are rarely well documented and were never scaled up (Gaul, et al., 2010).

The aim of this work is to develop a mini self-contained hydroelectric power plant that can generate electricity to homes.

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for the fabrication of the self-contained hydroelectric power generation mini plant are: $3\frac{1}{4}$ Pipe, Generator fan coil, Abro PVC gum, 1inch mild steel stanchion, KCDT 6A control switch, 100 and 50 litre reservoirs, P.T.F.E Teflon tray tape, $\frac{1}{2}$ inch and $1\frac{3}{4}$ inch reducer, coil, Dynamo, rotor, $\frac{1}{2}$ inch ball gate, $3\frac{1}{4}$ PVC adaptor pipe socket, 12V DC pump, 12V DC Battery, 1 inch Ash back knot.

3.2 Method of Assembling

Water which was stored in the primary reservoir (downstream) was made to fall onto a Pelton wheel turbine. The turbine was connected to a permanent magnetic motor through a primary shaft. The motor was connected to the rotor. The rotor was connected to dynamo. The rotor was connected to a stator. The stator was connected to 12V bulb. The dynamo was connected to the 12V battery. The battery was connected to the pump. The secondary reservoir (downstream) collects

the fallen water. The pump was connected to the upstream and downstream reservoirs.

3.3 Stages of the self-contained hydroelectric power generation

3.3.1 Energy Supply

The up-stream reservoir of 30 litres holds water (potential energy) and mounted on a stanchion of head height 338.59m. This head height directly influences the pressure exerted by the water fall on the turbine (kinetic energy) and consequently affecting the electricity output.

3.3.2 Energy Conversion

The water stored in the reservoir has potential energy. When the water flows from higher altitude, the potential energy is converted to kinetic energy. The force of the fallen water drives the turbine and creates torque hence kinetic energy is converted to mechanical energy. The generator converts mechanical energy into electrical energy. The electrical output generated is used to power three (3) 10W bulb and to charge 12V battery.

3.3.3 Return

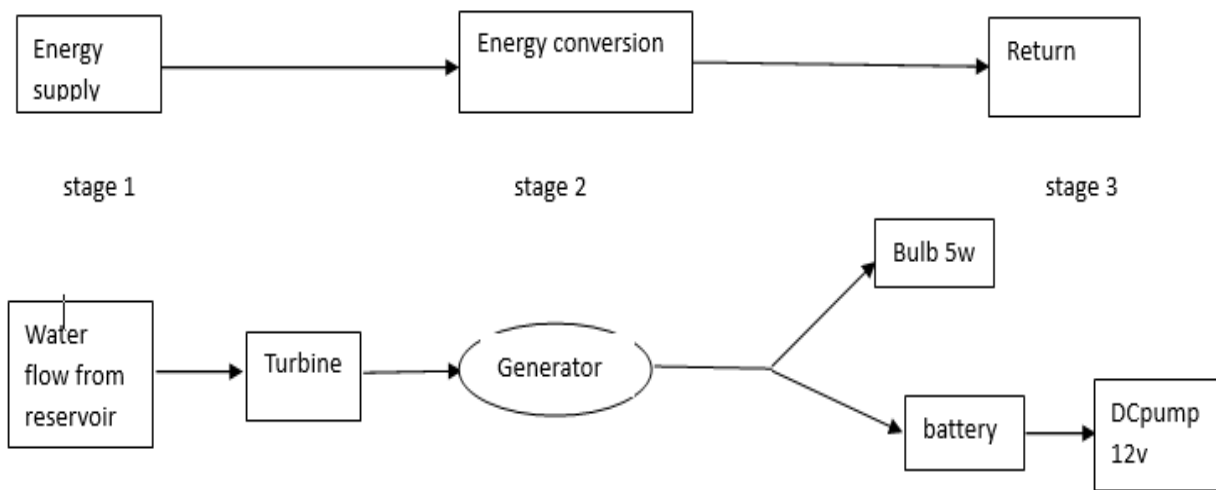


Fig 3.1 Stages of the Self-contained Hydroelectric Power Generation

In this final stage, the battery was used to power a 12V d.c pump which is used to recirculate water collected at the down-stream back to the up-stream making it a closed system and reducing water wastage

3.4 Fabrication of the Pelton Wheel

The mini pelton wheel is made up of a paint bucket cover with eight 45-degree pipes (2 inches in diameter), evenly divided into two vertical sections. From the center of the cover, eight lines, each 45 degrees apart, are drawn. Along these lines, marks are placed 6.5 centimeters from the tip of the cover, indicating the points for drilling and attaching turbine blades. Using a hacksaw, holes are cut at these marked points, forming eight openings on the cover. The turbine cups are created from the 2-inch diameter pipes, each with holes bored 6.5 centimeter from a specific chosen end.



Fig. 3.2 Fabricated Pelton Turbine

3.5 Fabrication of the Vane



Fig. 3.3 The Vane

2 Inch pipe was used to develop the turbine vane. The pipe was cut 5cm into eight (8) different sizes. The vane was cut using a hacksaw and the edges were polished and grinded to give a curved edge.

3.6 Determining the Head

Head can be defined as the vertical distance that water falls from the upstream level to the downstream level. Head produces a pressure and the greater the head, the greater the pressure to drive the turbines. To determine head, we need to consider the gross head and the net head. Gross head is the maximum available vertical fall in the water. It is the vertical distance between the top of the penstock that conveys the water under pressure and the point where the water discharges from the turbine. Head is typically measured rather than calculated (Olumide *et al.*, 2012)

3.7 Determining the flow rate

Area and speed method is used in streams with a higher flow. Water flow can be measured by constructing a weir of known dimensions and measuring the time necessary for the pooled water to rise to a known height. An object can be placed and timed to float from the upstream to the downstream line. Flow rate is the product of water

volume and cross sectional area as given in equation 3.1 (Yulianus and Adelhard, 2014).

$$Q = V \times A \text{ ----- } 3.1$$

3.8 Power Generation

The power potential was determined by measuring the flow rate and the head. The power generation is given by:

$$P = (Q) \times H \times g \text{ ----- } 3.2$$

3.9 Mechanical Efficiency

The Mechanical efficiency is the ratio of the mechanical output power to the mechanical input power and given by equation 3

$$\eta_m = \frac{(\text{Mechanical Output Power})}{(\text{Mechanical Input Power})} \text{ ----- } 3.3$$

3.10 Water outlet velocity is given by

$$V = \sqrt{(2gh)} \text{ ----- } 3.4$$

3.11 Electrical generator efficiency

$$\eta = \frac{E \times I \times PF}{\text{Mech In}} \text{ ----- } 3.5$$

3.12 Efficiency of the self-contained hydroelectric power generation plant

$$\eta = \frac{W_{out}}{W_{in}} \times 100\% \text{ ----- } 3.6$$



Fig. 3.4 Pump Assembly



Figure 3.5: The Mini Hydro Power Plant

4.0 RESULTS AND DISCUSSIONS

4.1 Results: The results of the experiment conducted on the mini hydroelectric power plant are shown in table 4.1 and 4.2.

Table 4.1: Result from the Measurements by Flow Rate

Test number	Opening of the tap gate Y [%]	Mechanical power P_{mech} [MW]	Flow rate Q_{rate} [m ³ /s]	Leakage flow Q_k [m ³ /s]	Cooling flow Q_{cooling} [m ³ /s]	Total flow Q_{turbine} [m ³ /s]	Net head H_n	Efficiency [%]
1	78.8	30.65	87.78	0.6	0.0	88.67	42.40	85.10
2	80.7	30.71	81.02	0.6	0.0	81.67	42.75	87.80
3	78.4	28.03	74.43	0.6	0.0	75.14	43.09	91.16
4	68.5	25.04	67.03	0.6	0.0	68.74	43.18	89.91
5	60.4	21.56	59.29	0.6	0.0	60.99	43.27	87.84
6	50.9	18.02	50.10	0.6	0.0	52.90	43.52	84.92
7	45.5	14.72	43.41	0.6	0.0	46.11	43.64	80.08
8	36.7	10.14	34.98	0.6	0.0	35.68	45.00	65.89

Table 4.2: Calculated variables

Water inlet velocity [m/s]	Water outlet velocity [m/s]	Net head [m]	Generator Efficiency [%]	Mechanical power [W]	Turbine efficiency [%]
10.06	1.56	337.61	88.45	9.57	79.52
9.64	1.50	338.76	86.44	8.42	87.43
9.28	1.44	339.86	85.43	7.20	86.59
8.93	1.39	340.81	82.41	6.07	85.03
8.37	1.30	342.23	80.40	5.41	81.31
7.70	1.20	345.59	79.35	4.31	69.94
7.13	1.11	350.19	77.26	3.49	65.47
6.17	0.96	358.80	75.97	3.58	63.13
5.09	0.79	360.64	72.50	2.28	60.34
4.10	0.64	364.29	69.85	2.12	58.34

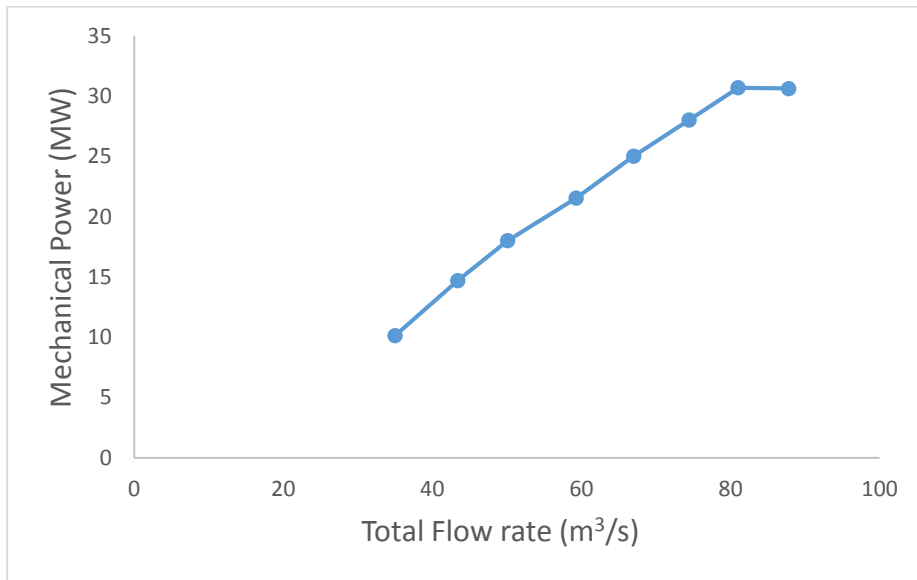


Fig. 4.1 Graph of Mechanical Power against Flow Rate

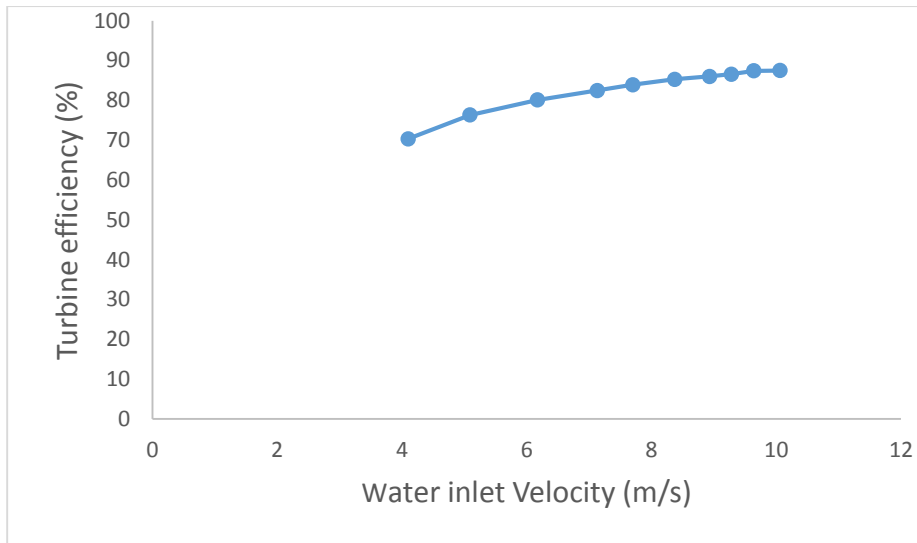


Fig. 4.2 Graph of Turbine efficiency against Water inlet velocity

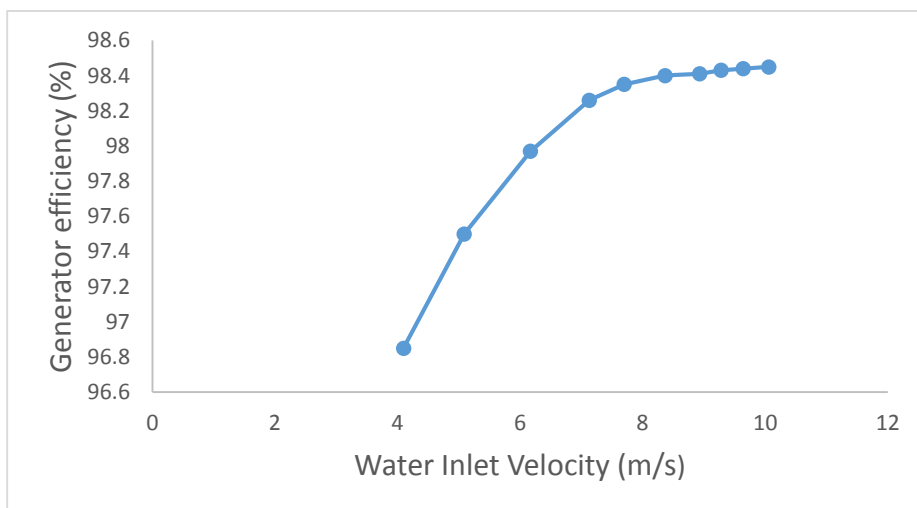


Fig. 4.3 Graph of Generator Efficiency Against inlet Velocity

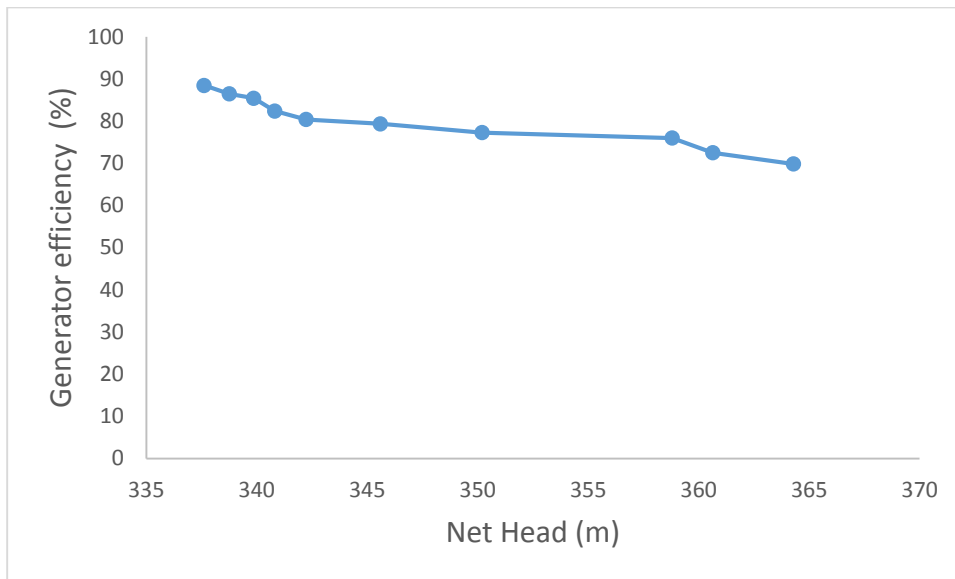


Fig. 4.4 Graph of Generator Efficiency against Net Head

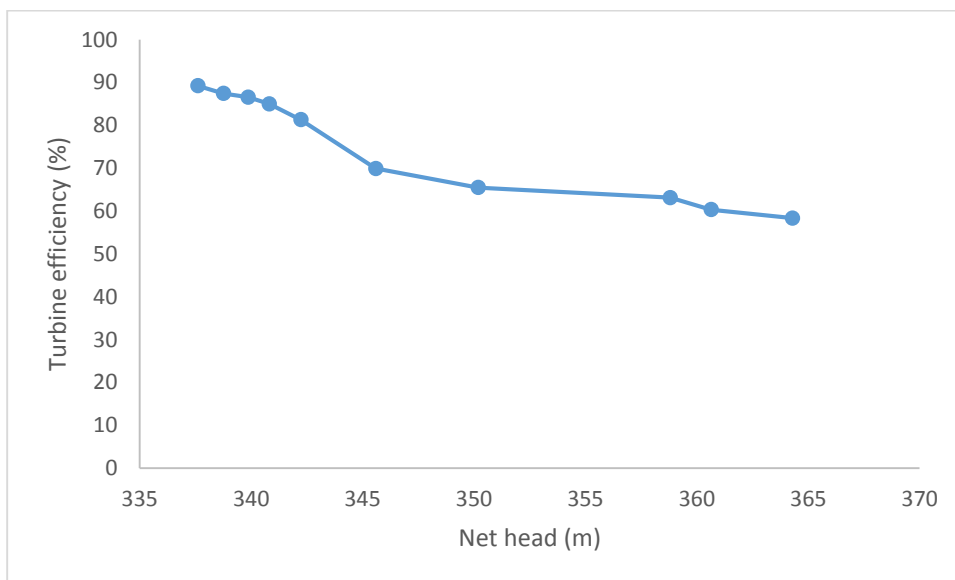


Figure 4.5 Graph of Turbine Efficiency against Net Head

4.2 DISCUSSIONS

Figure 4.1 shows the graph of Mechanical power against flow rate, it can be seen from the graph that the highest mechanical power was recorded to be 30.65 MW and the lowest was recorded to be 10.14 at total flow rates of 88.67% and 35.68% respectively. The graph shows that as the total flow rate increases the mechanical power also increases.

Figure 4.2 shows the graph of Turbine efficiency against water inlet velocity. The highest turbine efficiency was recorded to be 79.52% and the lowest was recorded to be 58.34 % at water inlet velocity of 10.06m/s and 4.10m/s respectively. It can be seen from the graph that

as the water velocity increases the turbine efficiency also increases.

Figure 4.3 shows the graph of Generator efficiency against the water inlet velocity. The highest generator efficiency was recorded to be 88.45 and the lowest was recorded to be 69.85 at 10.06% and 4.10% water inlet velocity. It can be seen that as the inlet water increases the generator efficiency also increases.

Figure 4.4 shows the graph of Generator efficiency against Net Head. The highest Generator efficiency was recorded to be 88.45% and lowest was recorded to be 69.85% at net heads of 337.61m and 364.29m respectively. It can be seen from the graph that decrease in net head increases the generator efficiency

because the water is closer to the turbine and produces more energy.

Figure 4.5 shows the graph of Turbine efficiency against the net head. The highest turbine efficiency was recorded to be 79.52 and the lowest turbine efficiency was recorded to be 58.34 at net heads of 337.61m and 364.29 m respectively. It can be seen from the graph that as the net head decreases the turbine efficiency increases because the water height is closer to the turbine

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