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Design of a mini hydro-electric power plant

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Abstract
The core concept of hydropower centers on capturing the energy produced as water moves from a higher elevation to a lower one. This involves utilizing the resulting water pressure to generate electrical energy. This practical application of hydropower generation theory entails the design and installation of a mini hydropower plant.
To assess its performance, a storage tank was strategically positioned at the maximum height to optimize water pressure, and a plastic pipe was employed for transportation. The construction of a turbine and generator, along with the subsequent assembly of their respective components, constitutes the formation of the hydropower plant. The hydro turbine converts water pressure into mechanical shaft power, propelling the electric generator. The outcome is an alternating electromotive force (e.m.f) of 210 Volts at a frequency of 50 Hz, suitable for powering various household electrical appliances.

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1. Introduction

The quest for harnessing water's kinetic energy dates back centuries, but contemporary advancements have elevated the efficiency and viability of mini hydro-electric power plants. The background study delves into the historical evolution, technological breakthroughs, and the imperative driving factors that have propelled the development of small-scale hydropower systems. Tracing the roots of hydropower reveals its historical significance, from ancient water wheels to the sophisticated turbines of today. The evolution highlights the adaptability and enduring appeal of hydropower as a renewable energy source. One viable technological option involves producing electricity in close proximity to the consumption site using renewable energy sources, which are environmentally friendly. These sources include wind, solar, tidal, and hydro-electric power plants Adejumobi, & Adebisi (2011) [1]. Hydro-electric power, derived from flowing water, is a renewable energy resource. The generation of electricity requires the movement of water, where its potential energy, propelled by gravity, transforms into kinetic energy. The kinetic energy of the flowing water activates blades or vanes in hydraulic turbines, converting the energy into mechanical energy. The turbine then drives the generator rotor, transforming the mechanical energy into electrical energy, constituting a hydro-electric power station Okhueleigbe *et al*. (2016) [4].

The inception of hydro-electric power systems dates back to the 1880s. According to the International Energy Agency (IEA), large-scale hydro-electric plants currently contribute 16% of the world's electricity. However, these projects necessitate substantial land impoundment, dams, flood control measures, and often result in environmental impacts Igbinovia, & Orukpe, (2007) [5]. Micro-hydro-electric power plants offer an alternative for energy generation, representing the smallest type of hydro-electric energy systems. Installed across rivers and streams, they typically generate between 5 and 100 kilowatts of power.

Functioning akin to a battery, micro-hydro-electric power plants store power in the form of water. Notably, they present several advantages over similar-sized wind, wave, and solar power plants, including high efficiency (70-90%), exceptionally high capacity factors (>50%), gradual output power variations (as opposed to minute-to-minute fluctuations), and maximum output power during winter Dursun & Gokcol (2011) [6].

Comparing small-hydro-electric power plants (up to 10 MW capacity) with micro-hydro-electric power plants (up to 100 kW capacity) reveals that the former is more capital-intensive and involves significant political decisions, leading to challenges in various implementation phases. Conversely, micro-hydro-electric power plants are cost-effective, smaller in size, and can be implemented to serve small communities, aligning better with socio-political contexts. Many of these systems adopt a "run-of-river" approach, eliminating the need for impoundment. Instead, a fraction of the water stream is diverted through a pipe or channel to a small turbine positioned across the stream Adhau *et al*. (2012) [7]. This underscores the potential for harnessing micro-hydro-electric power plants by identifying suitable sites and designing appropriate power generation systems. A well-designed micro-hydro-electric power plant minimizes environmental disruption to the river or stream and can coexist harmoniously with the native ecology Mohibullah & Mohdiqbal (2004) [8]. Technological innovations have been instrumental in refining the design and efficiency of mini hydro-electric power plants. Advancements in turbine technology, materials science, and automation have contributed to optimizing energy conversion and enhancing overall system performance Molina & Pacas (2010) [10]. The background study explores the contemporary imperatives that drive the adoption of mini hydro-electric power plants. Factors such as the global emphasis on carbon neutrality, the need for decentralized energy solutions, and the quest for sustainable development play pivotal roles in shaping the landscape of small-scale hydropower. Examining successful case studies provides insights into the real-world applications of mini hydro-electric power plants. Projects from diverse geographical and environmental contexts showcase the adaptability of this technology and underscore its potential for positive socio-economic and environmental impacts.

Acknowledging the challenges faced by mini hydro-electric power plants, from regulatory hurdles to environmental concerns, sets the stage for innovative solutions. The background study delves into how the industry addresses challenges through technological innovation, best practices, and collaborative approaches.

The research work aims to contextualize the design of a Mini Hydro-Electric Power Plant by adopting the water storage tank as the source of water instead of using the conventional river flow.

2. Materials and Methodology

2.1. Materials

The materials used to accomplish the research includes a plastic bucket, pipes, elbow joints, alternator, constructed metallic stand, lamp holder, electric wires, plastic blades. In order to ensure that the storage tank is placed at a maximum height to the tap for rotating the turbine blade, a metallic support was constructed as shown in Figure 1 and 2, Figure 2 shows the complete set-up/arrangement of the respective components of used in the design of the research, Figure 3 depicts the designed blade which enabled easy rotation based on the low weight plastic materials used in its design.

Fig 1: Constructed metallic support for the alternator

Fig 2: Complete arrangement of the mini hydroelectric power plant

Fig 3: Designed blade for the mini Hydro-Electric power plant

2.2. Methodology

According to Torricelli's Theorem velocity of efflux i.e. the velocity with which the water flows out of the tap was calculated using the formula

$$V = \sqrt{2gh} \quad (1)$$

Where ***h*** is the depth of the hole below the liquid surface. Hence more the depth of the hole, more will be the velocity of the liquid coming out of the hole, and will be maximum if the hole is at bottom of the tank.

The attractiveness of hydro-power as an electrical energy source lies in its environmentally friendly nature and extensive global potential. Within the realm of hydro-electric power, there has been a notable surge in interest in small power plants in recent years. Various small hydropower schemes, encompassing radial, axial, and propeller-type turbines, have been proposed and effectively implemented.

2.2.1. Design of the turbine blade

The turbine's pivotal component is the blade, serving as its core. It is responsible for converting water power into the rotational force that propels the generator. Irrespective of the runner/blade type, its buckets or blades play a crucial role in capturing the maximum energy from the water. The curvature of each surface, both front and rear, dictates the path water will take as it maneuvers around until its eventual release. It's essential to note that each runner performs optimally under specific Head and Flow conditions, emphasizing the importance of closely aligning the runner with the site characteristics.

The efficiency and reliability of the turbine are significantly influenced by the quality of components and precision in machining. Plastic spoons with lower weight was used for the construction of blade, this encouraged easy rotation of the blade, thereby generating electricity.

Balancing is a critical aspect of runner design, aiming to minimize vibration—a factor that not only impacts efficiency but can also lead to long-term damage. Therefore, careful balancing of the blades was done.

2.2.2 Design procedures for the design of min hydro-electric power plant

Data preparation: This initial step involves performing calculations and measuring the net head of the hydro-power plant along with its water flow rate.

Calculation of Net Head (Hn):

$$H_n = (H_g - H_t)/im \quad (2)$$

H_g is the gross head, representing the vertical distance between the water surface level at the intake and at the turbine. This measurement can be accurately determined using modern electronic digital levels.

H_t is the head loss due to friction and other factors.

im is the overall hydraulic efficiency of the turbine.

These steps are fundamental in establishing the necessary site data for the subsequent phases of the turbine design.

Parameter Calculations: A hydro scheme requires both water flow and drop in height (head) to produce useful power. As the water falls through a certain height, its potential energy is converted into kinetic energy and this kinetic energy is converted to mechanical energy by allowing the water to flow through the hydraulic turbine runner.

Energy of the stored water= mgh (joules)

$$= \rho v g h \text{ (joules)} \quad (3)$$

At the point of striking the ground the potential of the water is converted to kinetic energy.

Kinetic energy of the moving water = $½mC^2$ joules (4)

Since the water enter the turbine at a certain volume rate of Q cubic metres each second, the energy released can be expressed in term of power.

Gross power= ρgQh joule seconds or watt (5)

Frictional and other losses in the penstock in the system make the output power to be much less than the gross power.

Net power= $\eta\rho gQh$ joules second or watt (6)

Where;

M is the mass of the water in kg

G is the acceleration due to gravity in m/s^2

h is the pressure head in m

ρ is the density of water in kg/m^3

v is the volume of water in m^3

C is the velocity in m/s^2

Q is the volume flow rate in m^3/s

If the power ratio in equation 6 is expressed instead as energy ratio by multiplying the time for which power is available or used, it is known as a capacity factor or plant factor as expressed in Equation 7 and 8.

$$\text{Power Ratio} = \frac{power\ used}{power\ installed} \quad (7)$$

Capacity factor or plant factor

$$= \frac{power\ used \times time\ power\ used}{power\ installed \times period\ considered} \quad (8)$$

$$\text{Capacity factor or plant factor} = \frac{energy\ used}{energy\ availabe} \quad (9)$$

The higher capacity factor indicates a better scheme and a low factor implies costly power. A high capacity factor can be achieved by careful seasonal and daily matching of water and power requirements, to water and power availability, and also good planning and financing of maintenance tasks. A careful survey will help achieve a high capacity factor.

3. Results and Discussions

The mini hydro-electric power plant was designed, constructed, and installed at the Federal Polytechnic, Ile-Oluji in Nigeria. Following the installation, the system underwent operation, and the output voltage was measured using a digital multimeter. The average obtained reading was recorded was 210V, the output was once more assessed using an oscilloscope, revealing a sine wave pattern. This output was then directed to a 5W bulb, this yielding a good performance.

During the testing, the storage tank which has a capacity of 40 liters was filled with water at different heights and the output voltage was monitored, Figure 1 shows the results obtained from the testing of the mini hydro-electric power plant, it was observed that the output voltage increase as the height of water in the storage tank increases.

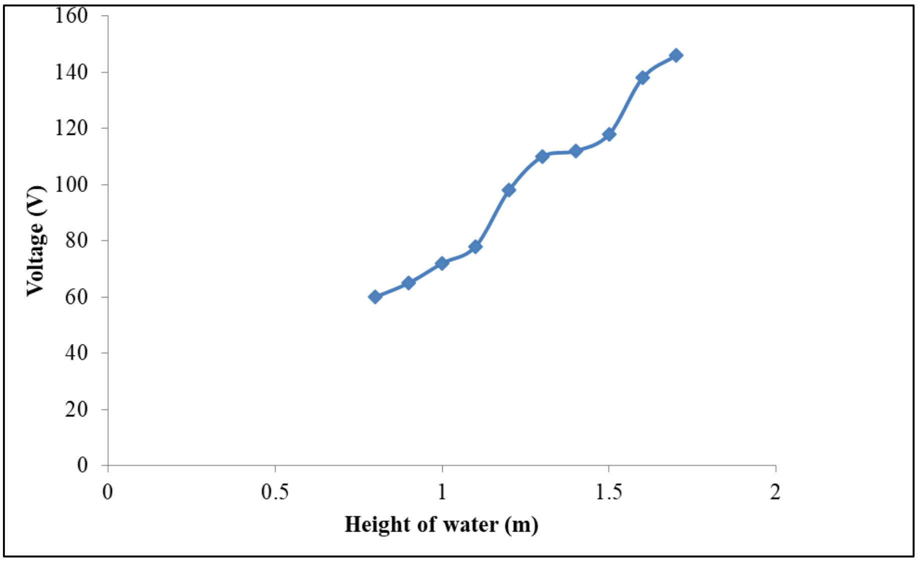

Fig 4

4. Conclusion

The research conducted on the mini hydro-electric power plant, utilizing cost-effective and environmentally friendly water, classifies the hydro turbine as an environmentally friendly source of renewable energy. This classification positions it as a catalyst for driving economic and industrial growth in regions where power generation remains notably low. The construction and widespread production of this mini hydro power plant offer an alternative for powering domestic and small industrial needs. This shift could alleviate the burden on the national grid, allowing the transmission company to redirect power to major load centers within the country. Consequently, this would enhance power quality, bolster power security, and improve the overall reliability of electricity for end-users.

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