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Fabrication of Solar-Powered Pumped-Storage Hydroelectric Power Station

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ABSTRACT

Renewable energy is now accepted as the preferred alternative for electricity generation and as the replacement for fossil fuels. Worldwide demand for energy derived from renewable resources, especially hydro energy, is rising in tandem with rising fuel prices and environmental concerns. Our power station aims to harness the renewable energy potential of solar and hydroelectric power, combining them in an innovative and efficient manner. The prototype power station incorporates two main components: solar photovoltaic (PV) arrays and a pumped storage hydroelectric system. The solar PV arrays consist of a network of solar panels that capture sunlight and convert it into electricity. The generated solar power is used for both immediate consumption and for pumping water to a higher elevation. Efficiency and efficacy differ substantially between the values obtained from upstream and downstream. Significantly surpassing downstream, upstream generates 30W of electricity at 20V of voltage and 1.5A of current. By comparison, downstream has to work with a voltage of 42mV, a current of 0.04A, and a power production of just 0.00168W. These differences amply show that the upstream arrangement makes better use of solar energy. As such, upstream proves to be the superior choice for using solar energy because of its increased productivity and performance.

1. INTRODUCTION

The investigation of effective energy storage options has been motivated by the rising need for environmentally friendly energy sources as well as the temporary nature of energy from renewable sources result. The needs for unlimited power supply for our demand many research and projects are developed (Afif et al., 2016, 2019; Azad et al., 2021). The creation of a prototype for a solar-powered pumped-storage hydroelectric power plant has a lot of potentials to solve the problems of irregularity and storage of energy that arise with the production of renewable energy(Kandari et al., 2023; Koohi-Fayegh & Rosen, 2020).

This prototype attempts to deliver a dependable and renewable source of electricity by utilizing the concepts of pumped-storage hydroelectric systems with the power of the sun. This research will improve renewable energy technology by examining the technological viability, financial viability, and environmental advantages of such a prototype.

It is evident that throughout human history, people have attempted to use water for labor. Humans eventually discovered how to use water to create energy. The mid-1700s saw the start of the modern hydro-power turbine's development. However, the notion of pumped-storage hydro-power first surfaced in the late 1800s. Built in Switzerland, the first pumped storage hydro plant began operations in 1909 (M. Michael et al., 2014). Operating since 1929, the Rocky River Plant was the United States' first significant pumped storage hydroelectric facility(Dames & Moore, 1981). A number of pump storage facilities were constructed from the 1960s to the late 1980s. The early 1970s oil crisis was a major contributing factor(N. Dorji, 2004). The earliest plants were relatively simple, with a motor, pump, and turbine on one shaft and a turbine on another. The Tennessee Valley Authority put the first reversible pump (Hiwassee Unit 2) into service in 1956. Subsequently, there has been a significant advancement in technology and materials, which has improved overall efficiency and made it possible to build an increasing number of units to meet increased demand(Upton et al., 2015).

Pumped-storage hydroelectric power plants depend on the idea of energy storage to operate (Machado et al., 2017;

Yang et al., 2023; Zaini et al., 2017). The technical and financial potential of pumped-storage hydroelectric systems are examined an integrated, which can improve grid stability and offer backup power during times of high demand or periodic green energy supply (Lu & Wang, 2017; Ramos et al., 2014).

A conceptual design was proposed for a solar-driven pumped-storage hydroelectric power station and examined the possible benefits of this integrated system. The design was presented for increasing the potential conversion efficiency of a micro hydro power plant to 95% from around 50% by using solar electricity to heat the water (Md Shahed Iqubal et al., 2014).

Despite these developments, there remain inconsistencies and disagreements in the literature that call for additional research(Jurasz et al., 2018; Nzotcha et al., 2019; Punys et al., 2013). There hasn't been much research done on integrating solar energy with pumped-storage hydroelectric systems, especially in terms of cost-effectiveness and system performance optimization (Awad et al., 2020; Javed et al., 2020). Further investigation is necessary into how such hybrid systems affect the environment, taking into account things like water use, land use, and other ecological effects (Chowdhury, 2021).

By conducting a thorough examination of the suggested solar-powered pumped-storage hydroelectric power plant prototype, we hope to fill these gaps in the literature in this thesis. By analyzing previous research critically and incorporating our results, we hope to increase our knowledge of sustainable power production systems and make significant contributions to the field of energy from renewable sources.

2. MATERIALS AND METHODS

The system design of the solar-powered pumped-storage hydroelectric power station prototype incorporates several key components illustrated in Figure 1. The experimental set-up of the solar-powered pumped-storage hydroelectric power station prototype is shown in Figure 2. The pump transfers water from the lower reservoir to the upper reservoir during periods of excess solar power, while the hydroelectric generator utilizes the stored water to generate electricity during peak demand.

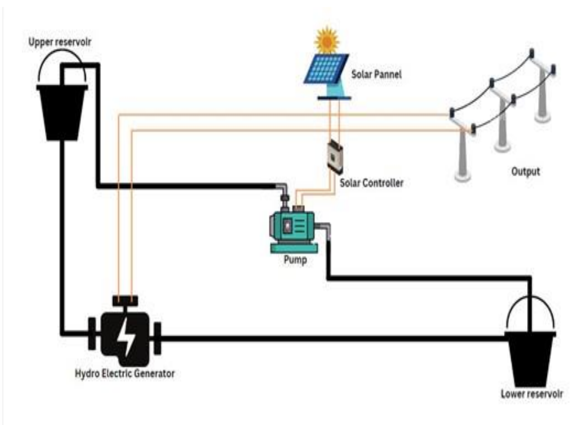

Figure 1: Schematic diagram of the solar-powered pumped-storage hydroelectric power station prototype.

Solar panels are integrated to capture solar energy and supplement the electricity generation. The reservoirs serve as storage for water and are designed to accommodate the required capacity and elevation difference.

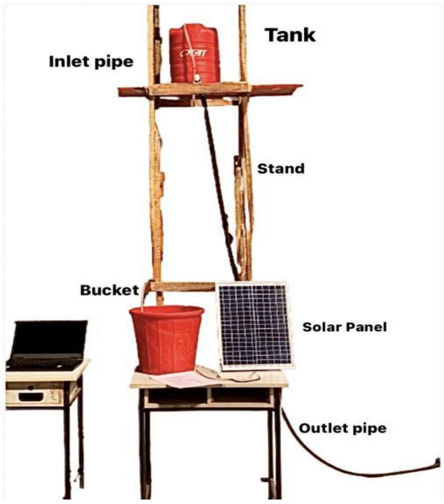

Figure 2: Experimental set-up of the solar-powered pumped-storage hydroelectric power station prototype.

The operation of the solar-powered pumped-storage hydroelectric power station involves a cyclic process of charging and discharging to optimize energy storage and generation. This section outlines the key steps and processes involved in the operation of the prototype.

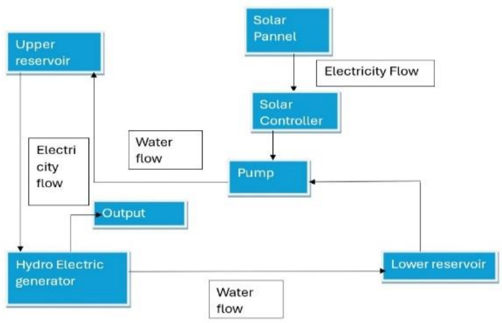

Figure 3: Schematic flow process of the solar power system

During periods of excess solar power generation and low electricity demand, the pump is activated, transferring water from the lower reservoir to the upper reservoir. The pump utilizes the surplus electricity to drive the water upward against the gravitational potential energy. This process stores the potential energy in the form of the elevated water in the upper reservoir, ready for subsequent electricity generation. The prototype power system runs through an advanced technological process, which is shown in Figure 3.

During periods of peak demand or when the solar power supply is insufficient, the stored water in the upper reservoir is released to drive the hydroelectric generator. The controlled release of water from the upper reservoir flows through turbines, generating electricity through the conversion of the potential energy of the falling water.

In the context of Bangladesh, photovoltaic (PV) performance is influenced by various factors such as the duration of sunlight, average irradiation levels, and geographical location. Bangladesh, located in South Asia, experiences ample sunlight throughout the year due to its geographical positioning near the equator. With an average of about 5 to 6 hours of sunlight per day, the country possesses significant potential for solar energy harnessing. The average solar irradiation levels in Bangladesh range from 4.5 to 6 kWh/m²/day, making it conducive for PV system installations and operations. Moreover, Bangladesh's geographic location provides an advantageous position for solar energy utilization, contributing to the country's efforts towards sustainable energy development and reducing dependence on fossil fuels (Lipu et al., 2013).

When the national grid system is experiencing periods of excessive demand, pump storage generation provides an essential backup resource. The pumping and generation hour is depicted in Figure 3 above the daily load curve (Whiteman et al., 2016). In addition, PSH offers power system control features like frequency stability, voltage balancing, and black starts (Engie, 2024; Dorji, 2004).

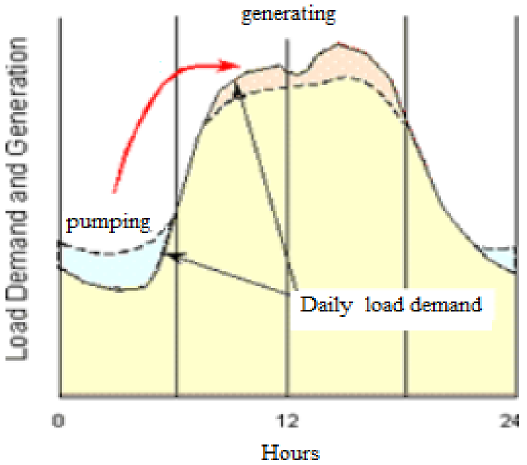

Figure 3: Load demand (pumping) with power generation.

The SPC analysis is used in this research to predict the current values. "SPC" typically refers to Statistical Process Control, which is a methodology used to monitor and control processes in order to ensure they are operating within specified limits. This SPC involves statistical analysis techniques to identify and address variations or abnormalities in data.

The study goal was to ascertain how much energy the PHES system is capable of storing. To calculate the amount of electrical energy that can be transformed into potential energy in high-elevation storage, the following methods can be employed to estimate the pump power of water needed(Kabo-Bah et al., 2022):

Firstly, calculating the pumping head rating. Secondly, when a pump with a 1 MW rated power is used to raise the water level to the rated head, find the rated pump power of the water in the upper reservoir.

QP is the rated volume flow rate (m^3/s), and

$$PP = QP \times \eta P\ g \times \rho \times h \quad (1)$$

where, PP is pump power rating (W), ηP is pump efficiency, g is gravity's acceleration (9.8 m/s^2), ρ is water density (1000 kg/m^3) and h is water head (m).

Thirdly, determining how many hours a pump may operate nonstop at a specific rated power for each session. Fourthly, calculating the required volume of the higher reservoir.

$$VR = QP \times T \quad (2)$$

where, VR is the volume of the upper reservoir (m^3) and T is time of pumping (s).

The top storage, which was so far limited to storing energy for 1 MW rated pumping power, can now be used to increase the system capacity by increasing the required rated pumping power by its volume.

3. RESULTS AND DISCUSSION

Table 1. Average values of upstream and downstream phase

Upstream		Downstream	
Solar Volt	20V	Volt generation	42mV
Solar Current	1.5A	Current generation	0.04A
Power	30W	Power generation	0.00168W
Solar Intensity	115 W/m2	-	-
Total Time	8 Minutes	Total Time of Discharge	7 Minutes
Flow Rate	0.03125 l/s	Flow Rate	0.0357 l/s

Table 1 shows the values of upstream and downstream phase. In downstream the current and voltage are less than the upstream due to not attach the solar power. Figure 4 shows the relationship between flow rate and input power. Flow rate is the rate where fluid flows through a system and input power is the energy amount that is supplied to the system to drive the flow. The power was calculated by using equation (1). Here, as the input power increases, the flow rate also increases which indicates a direct relationship between the amount of energy supplied and the flow rate. So, it might be governed by the principles of fluid dynamics where higher energy input can lead to greater fluid movement.

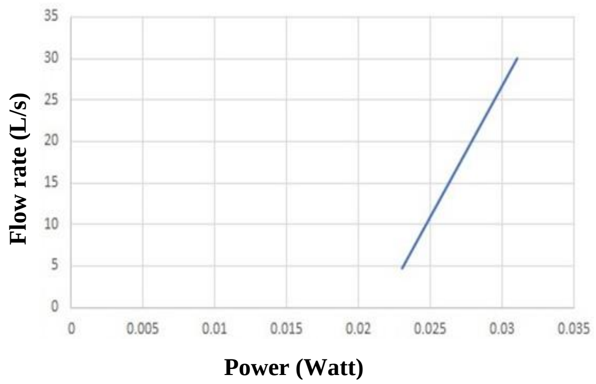

Figure 4: Flowrate patterns with input power.

Figure 5 shows the relationship between discharge flow rate and output power. Discharge flow rate is the rate at which fluid exits the system and output power is the amount of energy delivered by the system. Here, the discharge flow rate and output power maintain a direct relationship like the previous graph was calculated by using equation (2). The result could be fluctuated by some factors such as the design of the system, components' efficiency, and fluid properties.

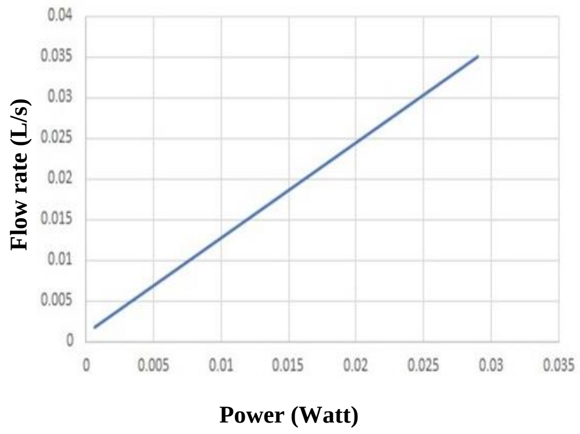

Figure 5: Discharge flowrate patterns with output power.

The experimental results of the solar-powered pumped-storage hydroelectric power station prototype revealed lower-than-expected efficiency in energy conversion and storage. The pump and hydroelectric generator exhibited reduced performance during the charging and discharging cycles, primarily due to mechanical inefficiencies and hydraulic losses. Suboptimal positioning of the solar panels also led to lower solar energy capture. In both cases, the result gives a positive correlation between power and flow rate.

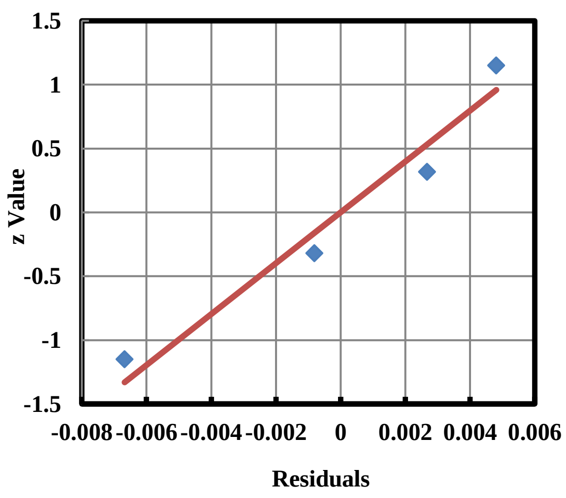

Figure 6: Normal Probability Plot of Residuals.

The potential outcome of the experiment suggests areas for improvement in the system design and operation. By closely examining the graphs, it is possible to find areas where the power plant's performance can be optimized. For instance, non-linear behavior or saturation effects in the relationship between input power and flow rate may require adjusting system components or settings in order to enhance energy conversion efficiency. Similarly, there can be chances to improve the generator's efficiency or lower energy losses in the system if the output power does not proportionately reflect the input power. Optimizing pump efficiency, refining the solar panel configuration and orientation, and enhancing the hydroelectric generator's performance can enhance energy conversion and storage. Additionally, improving control systems and algorithms can optimize the overall operation of the system.

The regression analysis of intensity vs current and its relationship with light angel are investigated through the SPC. The standardized residual has been done.

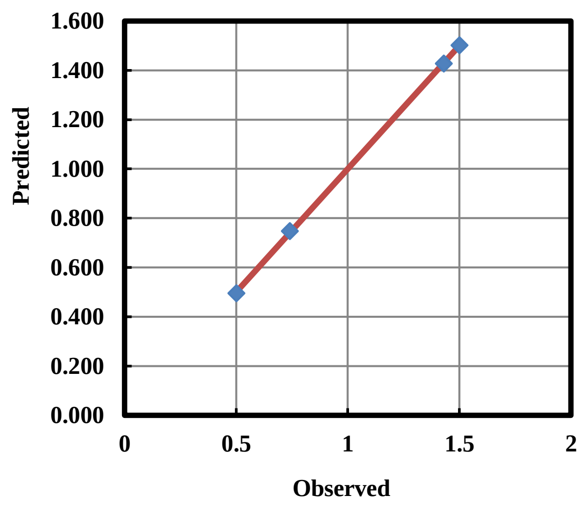

Figure 7: Predicted Values with respect to Observed Values.

The regression Statistics values are R-sq 99.99%, Adjusted R-sq 99.97%, Mean 1.043, Standard Error 0.00869, Coefficient of Variation 0.834, 4 Observations, Durbin-Watson Statistic 2.364, PRESS 0.00996, and R-sq Prediction 98.66%.

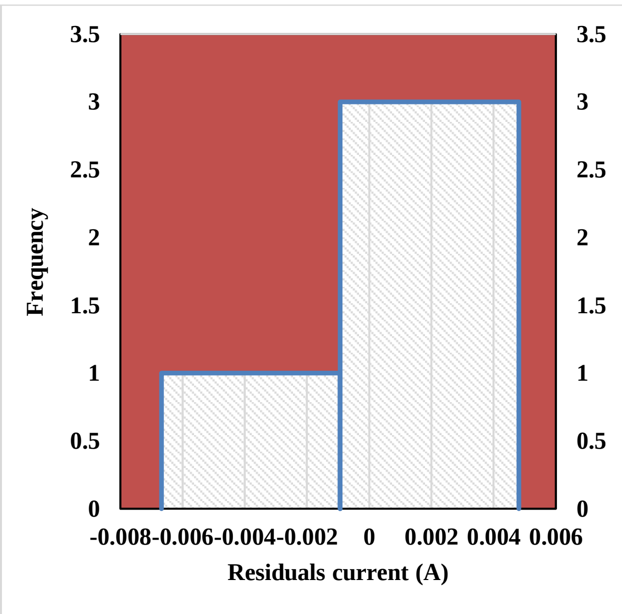

Figure 8: The histogram of frequency with current.

Anything in red was a potential outlier. Also with the regression, two regression charts have been found automatically. A normal probability plot of the residual's values is shown in Figure 6 and the predicted values vs the observed values plot is shown in Figure 7. Straight line means it's a good, normal probability plot. The histogram of frequency was also analyzed with respect to current. Figure 8 presents the histogram of the residual current.

9. CONCLUSIONS

The prototype of a solar-powered pumped storage hydroelectric power station presents an innovative approach to harnessing renewable energy sources. The design incorporates solar PV arrays and a pumped storage hydroelectric system to maximize energy efficiency and storage capacity. The efficiency and effectiveness differences between the values of upstream and downstream are really large. At 30W, upstream generates a strong output at 20V and 1.5A, indicating better use of solar energy. Conversely, downstream generates just 0.00168W of power, at 42mV of voltage, and 0.04A of current. These differences clearly show how well the upstream arrangement captures solar energy, resulting in increased output and performance. The study highlights the potential of this concept, paving the way for further research and development in the field of renewable energy systems.

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