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Modelling and Simulation of 100 kW Pumped Storage Hydro Power System

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Abstract:- Renewable energy sources are an attractive alternative option for augmenting the supply that comes from the utility Grid. This is because they are environmentally friendly. However Photovoltaic power generation is intermittent in nature. Hence, it is usually combined with energy storage systems such as batteries. In this study, pumped hydroelectric energy storage is used for supplementing the power produced from the Solar Photovoltaic system especially during peak demands and when the solar irradiance is low especially at night. Thus, the objective of this study is to model and simulate a pumped energy storage hydro system that can provide power supply of up to approximately 100 kW for a 10 hour period to service the night time. The proposed system is modeled using MATLAB Simulink. A total volume of 91836.7 m^3 of storage water was calculated to achieve this purpose. Maximum torque of about 90 N/m was attainable when the angular speed of the water turbine was between 1100 and 1200 rpm. Recommendation for further works can be considered to maintain the angular speed of the turbine within this range.

Keywords:- *Solar Photovoltaic System; Pump Hydroelectric Storage, Induction Generator, Matlab /Simulink.*

I. INTRODUCTION

Renewable energy such as solar and wind power, are an attractive alternative option for augmenting the supply that comes from the utility Grid. However, both wind power generation and photovoltaic power generation are intermittent and random [1]. The use of a pumped hydro system as well as a regulated power supply has the ability to effectively reduce fluctuations generated from wind and solar power. The integration of a hydro system with solar power are mutual beneficial to each other as regarding weather conditions [2]. Solar PVs are favourable during the day time when there is sunshine, while the pumped hydro system can be used at night when there is no irradiation. Pumped hydro system can also be used when the irradiation is low or at peak load demands. Various literatures have considered the optimal configuration of Photovoltaic – pumped generation [3], conversion efficiency improvement of photovoltaic power generation [4], and reliable operation strategies by designing appropriate controllers [5], Moreover, an optimization sizing model of a stand-alone PVPG to support the energy supply of load distributions have been proposed in the literature [6]. The main objective of this paper is to model and simulate the dynamic performance of pumped storage hydropower and the possibility of providing continuous power supply to service the load demands for a period of 10 hours during the night time, for any given rural communities.

II. CONFIGURATION OF PUMP HYDROELECTRIC GENERATION

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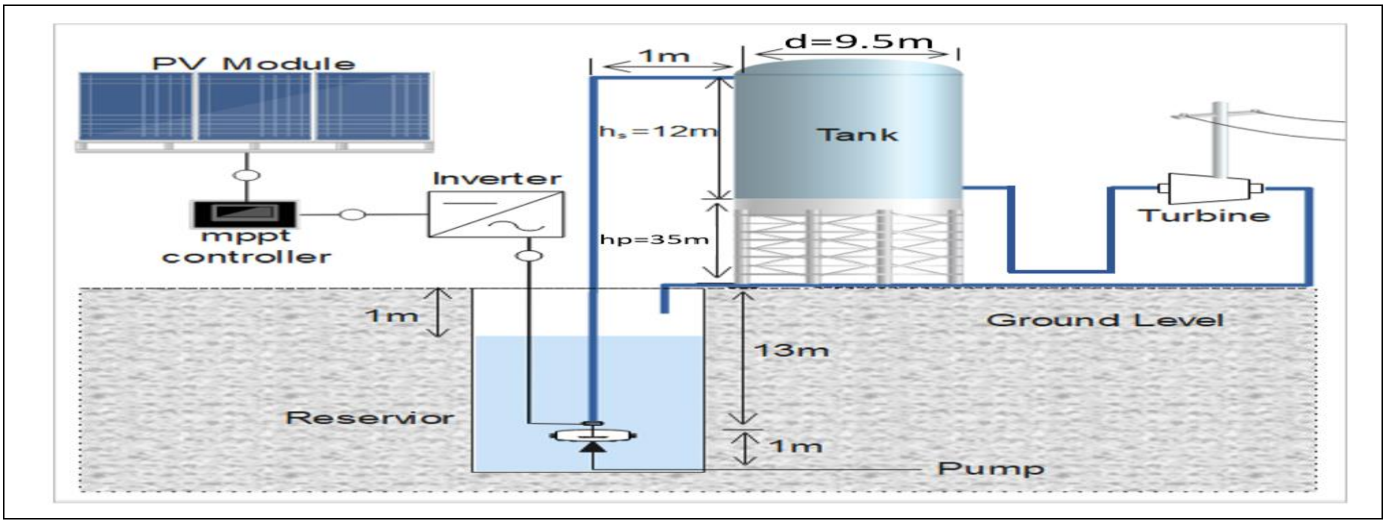

Fig 1: Schematic Diagram of a Pump Storage Hydro System

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As seen in figure 1, power supply from the Solar PV system is fed to the electrical motor to pump water from the underground water reservoir to the overhead tank. The output of tank is connected to the turbine to rotate the shaft of the turbine, thereby producing electricity that can be fed to the dynamic loads. Recent works on pumped storage hydro system are considered in the literatures [7-10].

Thus there are two stages involved: the solar water pumping stage [10 – 12] and the generating stage. However in this study only the generating stage is considered, which involves the aspect of Pump-storage hydro generation.

III. MODELLING OF THE PUMP STORAGE HYDRO SYSTEM

Let the discharge volume of water from the jet be Q. Therefore, the hydraulic energy is given as:

$$E_h = \rho Q g H \quad (1)$$

The hydraulic power;

$$P_h = \rho \dot{Q} g H \quad (2)$$

Consider the turbine having the jet of the penstock impinging on it. Thus it is converting the kinetic energy to mechanical energy. Assuming there are no losses, the hydraulic power, P_h will be converted to Mechanical energy, P_m

$$P_h = P_m$$

$$\tau = \frac{P_m}{\omega_m} \quad (3)$$

Where τ is the torque

A. Calculation of Stored Energy and Water Volume

In this study, about 10 hrs of power supply is (i.e 8pm – 5 am) is required to service the night time. Therefore, in order to generate 100 kW of power for the 10 hr period, 1000 kWh of energy should be stored. Based on the equation (1) for Energy, E, the volume of water to be discharged can be calculated

$$1\ kwh \approx 3.6e^6 J$$

Therefore,

$$1000\ kwh \approx 3.6e^9 J \quad (4)$$

By equating equations (1) and (4), the discharge volume Q, required can be estimated

Therefore:

$$\rho Q g H = 3.6e^9 J$$

A typical storage tank is raised at a height of between 35 – 40 metres above ground level,

$$1000 * Q * 9.81 * 40 = 3.6e^9 J$$

Making Q subject of the formular,

$$Q = \frac{3.6e^9 J}{1000 * 9.81 * 40} = 91836.7\ m^3 \quad (5)$$

A typical big – sized GP tank has a capacity of 5000 litres or 5 m^3 of volume. Therefore, about 1,836 GP tanks will be required to store 91836.7 m^3 of water, for the generation of 1000 kWh of electricity.

B. Calculation of Pressure [Pa]

The water pressure formula on the tank at a height of 40m is given by,

$$P = \rho g h = 1000 \times 9.8 \times 40 = 3.9 \times 10^5\ pascal. \quad (6)$$

Therefore the total estimated pressure for 1,836 GP tanks is $7.16 \times 10^8\ pascal$

IV. RESULTS AND DISCUSSION

A. Matlab/Simulink Implementation

The first step is to determine the speed at which the turbine rotates after being subjected to continuous pressure from 0 to as high as $7.15 \times 10^8\ pascal$, as shown by the ramp input signal in figure 2. The hydraulic resistive tube is used to represent a typical tank height of 40 m. The Simulink diagram that is used to simulate this is presented in Figure 2

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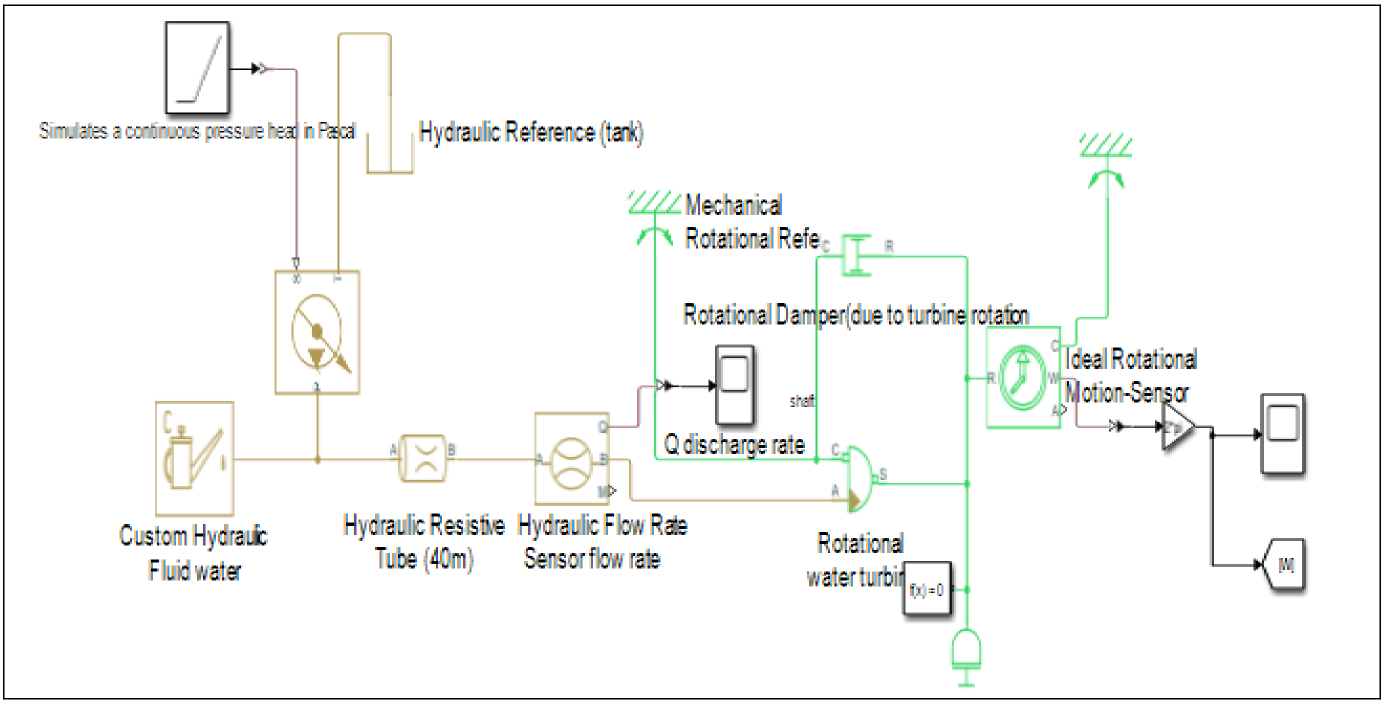

Fig 2: Determination of the Discharge Rate Q and Angular Speed ω_m at which the Turbine Rotates

The induction machine or asynchronous machine has a rating of 5.4 (4 kW), 400 V, 50 Hz, at a rated speed of 1430 RPM and a synchronous speed of 1500 RPM. The mechanical input is the derived angular speed, ω_m from figure 2 that is used to provide power to the induction generator. The shaft of the turbine is attached to the induction generation (figure 3) such that as the shaft rotates at the given angular speed ω_m, the induction generator generates three phase electrical power that can be supplied to the rural community.

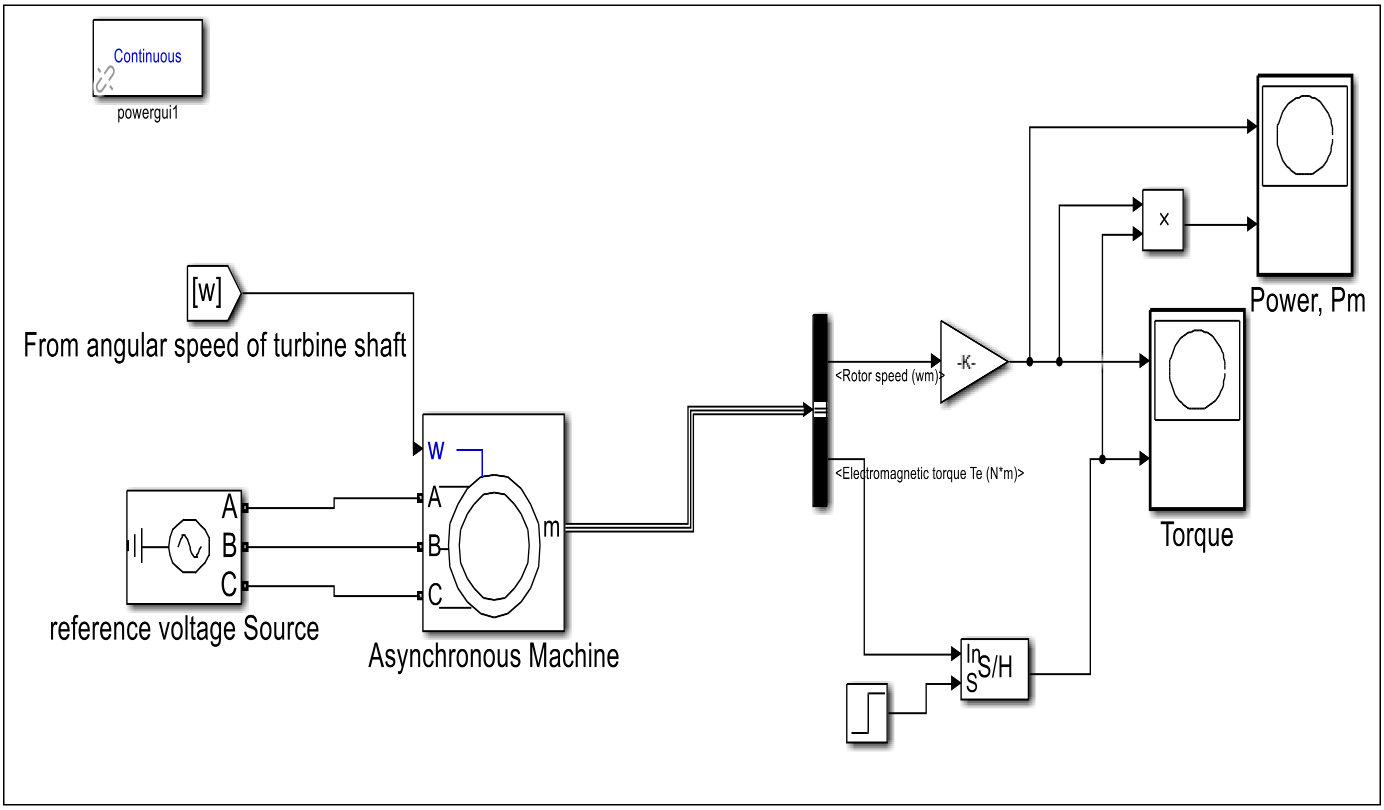

Fig 3: Determination of the power torque, τ_m and mechanical power, Pm generated

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The plot in Figure 4 presents the discharge rate of water through the hydraulic resistive tube of 40 m, also known as the penstock.

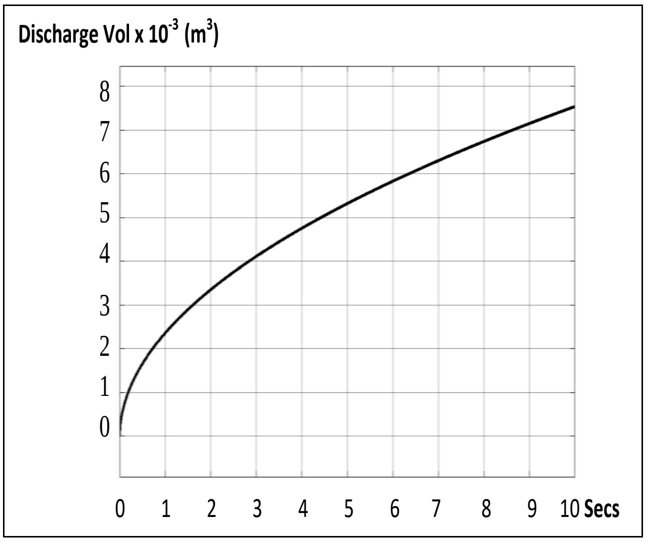

Fig 4: Discharge, Q with Respect to Time

From the plot it can be seen that approximately 0.0075 m^3 of water is discharged in 10secs.

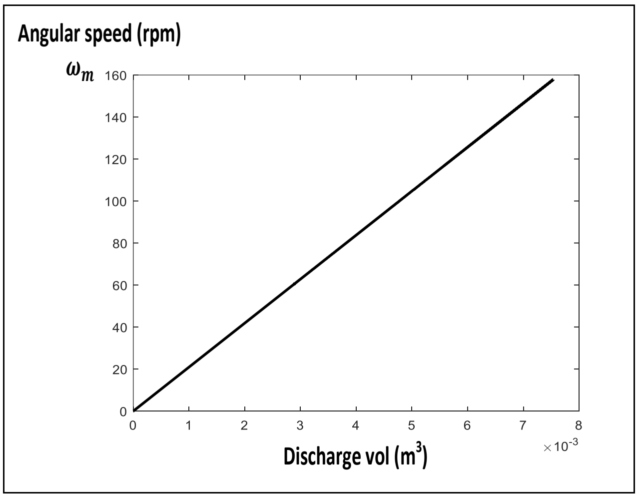

Fig 5: Rotation of Water Turbine with Respect to the Discharge Rate

From the plot it can be seen that approximately 0.0075 m3 of water is discharged in 10secs (as shown in figure 4) to rotate the water turbine at an angular speed of approximate 150 RPM. It can be seen that by increasing the discharge rate, the magnitude of rotation of the turbine will also increase. Therefore an optimum angular speed of 1100 – 1200 RPM is desired in order to produce maximum torque and power as depicted in Figures 6 and 7.

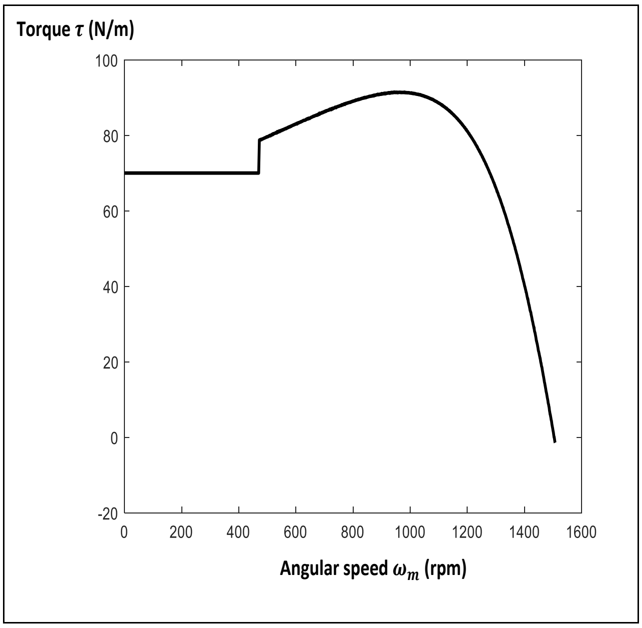

Fig 6: Generated Torque with Respect to Angular Speed

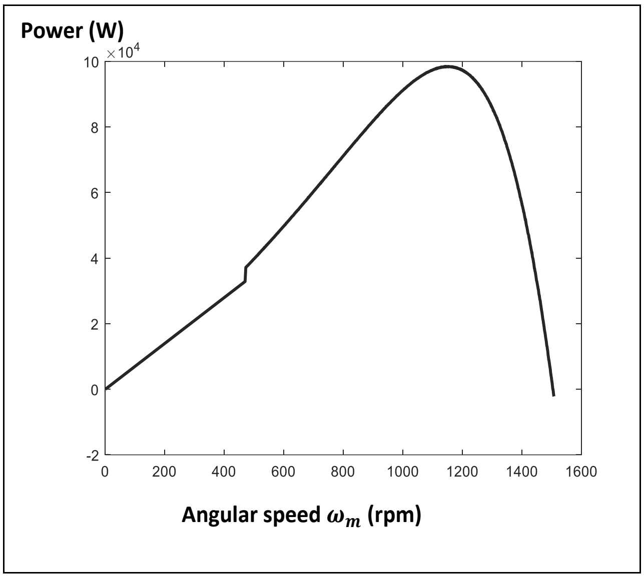

Fig 7: Generated Power with Respect to Angular Speed

From Figures 6 and 7, it can be seen that the maximum torque of 90 N/m and power of approx. 100 kW can be generated when the turbine shaft rotates at an angular speed within the range of 1100 – 1200 rpm.

Table 1: Summary of Results Obtained for Pump Hydro Power

Parameter	Estimated values
Discharge Volume	91836.7 m3
GP tanks (5 m3)	1836
Volumetric Flow rate	0.00075 m3/s
Tank Height	40 m
Induction generator Size	$5.4\ kVA$
Storage Capacity	$1000\ kwh$
Angular speed	1100 and 1200 rpm

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V. CONCLUSION

This study modelled and simulated a pumped energy storage hydro system that can provide power supply of up to approximately 100 kW. Assuming power generation for a 10 hour period to service the night time, the required volume of water storage was calculated to be 91836.7 m^3. This will require about 1836 GP tanks each having a capacity of 5 m^3 and at a pressure head of 40 meters. Maximum torque of about 90 N/m was attainable when the rotor speed of the induction machine was between 1100 and 1200 rpm. The simulated induction machine or asynchronous machine has a rating of 5.4 (4 kW), 400 V, 50 Hz, at a rated speed of 1430 RPM and a synchronous speed of 1500 rpm.

The system can be designed to operate at generating mode when the rotor speed, n_r is greater than n_s = 1500 rpm. Simulating a Pump Hydro system using MATLAB and Simulink can offer several benefits. Some of these benefits include designing and analyzing complex systems, so as to evaluate its performance before implementation. Thus the system design can be optimized and different configurations can be explored. Moreover, the performance of the Pump Hydro system can be assessed under various operating conditions. Factors such as power output, energy efficiency, response time, and transient behavior can be studied and possible ways to improve the system's performance and operation can be identified. By modeling and simulating different system configurations, the impact on capital costs, operational costs, and overall economic feasibility can be evaluated.

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