Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 6 (2024)

Design and Performance Analysis of a Solar-Hydro Hybrid Power System

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Abstract:-The dependence on the national grid, unreliable power outages in Nigeria, and technological advancement in the world have led researchers to look at other renewable energy sources, such as solar power and hydropower. In this research, the design and construction of a solar-hydro hybrid power system were carried out using the following materials: 50 Watts solar photovoltaic (solar panel), 12V battery, 12V charge controller, water pump, inverter, acrylic plastic step-up gear that is 3D printed and alternator. The power generated by the two systems has been tested, yielding a power output of 1.57 Watts for the solar system and 0.114 Watts for the hydro system. This research work presents a novel operation of the two systems. The photovoltaic energy was used to charge the battery during the day, and the stored energy in the battery was used to power the water turbine, which generates electricity at night. Comparing the power output generated by both systems, it was shown that the solar system is more dependable.

Keywords: *hybrid, alternator, technology, photovoltaic energy, electricity*.

1. Introduction

Solar energy is generated from the sun or derived through solar radiation. It is the most common source of renewable energy along with hydropower. Renewable energy emanates from natural resources and replenishes as they get used. They do not get depleted over time and are environmentally friendly as they do not emit any greenhouse gases (Green power). The word hydro means water. Hydro energy is the energy generated from fast-moving water. It is the power derived from kinetic energy (KE) of fast-moving water. It is referred to as hydroelectricity or hydroelectric power. A hybrid solar system is a combination of two or more sources of energy. It is typically a combination of solar power and another renewable energy source. It also has a battery which stores the generated power for later use when solar energy is in limited supply or unavailable. The essence of the battery for energy storage is that solar energy is a weather/climate-dependent energy source. During rainy or cloudy weather, the energy supply from the sun is low. In a hybrid solar system, sunlight is captured and converted into electric power (electricity) through solar photovoltaic (SPV) cells. This energy can be used directly or stored with the help of the battery for later use. Apart from storing the energy for use when solar energy is in low supply, the battery also stores excess energy generated when the availability of sunlight is very high. Therefore, the battery can be referred to as the backup source of the hybrid solar system. Energy is essential, like food and water. Everything around us requires energy.

The Earth's population has grown over time, which is proportional to the amount of energy consumed. Energy is required for the operation of all conceivable devices, machinery, and equipment. Finding sustainable sources of renewable energy that can lessen reliance on fossil fuels is becoming more important as fossil fuel reserves are depleting. Solar energy is the most abundant form of energy available to us. It is estimated that 1000 W/m2 of solar energy is incident on Earth's surface each day (Ezekiel, Alcariona, &Manzon, 2022). There has been a minimal increase in energy consumption every year, with approximately 1–1.5 percent growth per year. By 2040, there will be a 56% increase in global energy consumption (Koussa et al., 2012).

Solar photovoltaic (SPV) cells, commonly called solar panels, are devices designed to convert sunlight into electrical energy directly. SPV cells became popular in the 1970s as an alternative power source in areas where grid electricity was expensive or inaccessible, such as remote regions, rural areas and islands. Recently, countries like Nigeria have seen more individuals utilizing electricity from SPV cells instead of depending on the epileptic main power grid. This is due to the increased efficiency and reduced costs of SPV technology in generating electricity from sunlight. Electricity is generated in the SPV cells when sunlight strikes them, causing the photons to dislodge electrons from the atoms within the cell. These free electrons then move through the cell, creating electrical energy.

SPV cells are commonly constructed by layering two semiconducting materials on each other. The top layer, referred to as the N-type semiconductor, is negatively charged, while the bottom layer, referred to as the P-type semiconductor, is positively charged. This arrangement creates a P-N junction. When exposed to sunlight, these solar cells (semiconductor devices) convert solar energy into electricity or electrical energy. It is through these solar cells that the actual electrical power is generated (Zeman, 2003).

Depending on the final application, the technology of SPV systems can be evaluated. There are two primary types of SPV systems that are currently in use: off-grid or stand-alone systems and grid-connected or grid-tied systems. These systems are operated using different configuration structures.

Grid-connected SPV systems, known as GcPVs, generate solar power interconnected with the electrical loads and the utility grid. These systems have gained increasing popularity, particularly in building integrated applications. GcPVs are directly connected to the grid through an inverter, eliminating the need for batteries. The electricity generated by the SPV system is primarily consumed locally, and any surplus energy is fed back into the grid unless it is stored on-site (Ashiq, 2021).

Having a grid-connected SPV system is similar to receiving electricity from a traditional power station, with the key distinction being that a portion or all of the electricity used is derived from solar energy. When there is insufficient sunlight to generate electricity through SPV cells, the energy demand is supplied by the power from the utility grid. GcPVs can also function as miniature power stations (Zeman, 2003). Off-grid SPV systems are suitable for various remote applications, offering reliable and independent operation without relying on the grid. They can be deployed in diverse locations. Off-grid SPV systems are capable of utilizing rechargeable batteries to store electricity, which is particularly beneficial in situations where the SPV cells generate minimal power output. These systems often incorporate a charge controller for optimal performance, which safeguards the battery against overcharging or deep discharge. Also, an inverter is included to convert the direct current (DC) power generated by the SPV arrays into alternating current (AC). When arranged to obtain a specific power output, two or more SPV modules are called solar photovoltaic arrays. The array unit is the group of solar photovoltaic modules already encapsulated as a group of solar cells. The cell temperature, solar radiation, and output voltage of the array itself influence the output characteristic of an SPV array. Several SPV arrays are tied together in series or parallel assembly, with a centralized inverter which converts the DC electricity generated to AC electricity (Van Helden et al., 2004).

The energy generated from an SPV module depends on the power attained from sunlight and the orientation angle between the sun and the PV module. Therefore, it is essential to consider the seasonal, weather or climate changes when designing any system that relies on solar radiation for energy production. Furthermore, it is advantageous to consider the amount of solar radiation incident on the SPV tilt angle, which is perpendicular to the module surface.

The amount of solar radiation received by the SPV panel is largely determined by its tilt angle. Its defined angle separates the plane of the solar device from the horizontal plane. The maximum power output for a fixed tilt angle can be obtained when the tilt angle is in line with the location's latitude. The tilt angle of an SPV panel can vary depending on factors such as geographic latitude, climate conditions, and the desired period of utilization. These factors have a considerable impact on the performance of the SPV module (Chang, 2008). Moreover, many investigations have been done by researchers like Agarwal et al. (2012) and King et al. (2004) to ascertain the solar system's ideal slope angle. "Plus (+)" for winter and "minus (-)" for summer are the two values they proposed for the tilt angle: $\Phi \pm 20$, $\Phi \pm 8$. These represent the location latitude angle, Φ

Hydropower and solar power are the two most abundantly renewable energy sources. Solar radiation drives the hydrological cycle's swiftly flowing water, which produces hydropower. In areas of the land or sea where water is present, incoming solar radiation is absorbed by the surface and causes heating and evaporation. Nearly half of the solar radiation reaching the Earth's surface is used to evaporate water and drive the hydrological cycle (Nawar, 2016).

The solar-hydro hybrid power system combines SPV cells with hydroelectric power generation to create a hybrid renewable energy system. The system uses solar and hydro energy resources to generate power, providing a reliable and sustainable power supply. Excess electricity generated can be used to pump water into the higher reservoir (bucket/tank) for storage during high sunshine when solar energy production is very high. The stored water can then be used to generate hydroelectric power during periods of low sunlight where solar energy production is low, allowing for efficient use of resources and maximizing energy capture. Also, the energy obtained from solar photovoltaic (SPV) during sunny weather can be stored in batteries and the batteries will then be used to power the water pump to produce a high-velocity fluid jet to strike the turbine blades. The two systems that make up the hybrid system can run concurrently to maximize power generation, or each system can work as a stand-alone system where the resources (sunlight or water) are largely available.

Hybrid renewable energy systems are becoming the new normal for maintaining operational reliability. Research on a grid-connected solar hydropower system to complement inadequate power supply in Ado-Ekiti, Ekiti State, Nigeria shows that a small hydropower system generated 2.21 MW and a solar PV power system produced 6.69 MW. The system was able to inject 8.90 MW into the 11 kV distribution networks (grid distribution), thereby increasing and improving power supply quantity and quality in the city (Saka et al., 2022).

The power generated from the hybrid system can be integrated or transmitted to the grid distribution network and sold as electrical energy to conventional energy providers. The goal is to complement the deficiencies of the conventional power supply system. As a stand-alone system, the hybrid system can be used in residences at night when power consumption is at its peak, thereby reducing the cost of electricity during this period.

For the stability of the hybrid system, energy storage is required to supplement the generator when the SPV and hydropower system cannot generate sufficient electricity, especially at night. Therefore, the significant concerns of the battery storage system are the performance, longevity (i.e. lifetime) and durability of the hybrid system. The paramount importance of the solar-hydro hybrid power system is the ability of each constituent power system to complement the deficiencies of each other, thereby ensuring regular and reliable power supply.

This study was carried out due to erratic or irregular power supply, which is frequently experienced in Nigeria, high energy cost, especially in areas where grid electricity is unavailable or unreliable and environmental concerns, which are familiar with fossil fuel power generation as they emit greenhouse gases and cause climate change. This study aims to design and construct a solar-hydro hybrid power system for power generation which addresses the challenges of over-dependence on national grid power by integrating two sources of renewable energy, of which the solar energy source is the primary source, thereby overcoming the limitations of over-dependence on the national power grid. Furthermore, this study harnesses renewable energy and reduces the environmental impact of conventional energy sources, including the reduction in emission of greenhouse gases, energy diversification and reduction in the cost of energy (power) generation using conventional energy sources.

2. Research Methodology

Materials and Equipment used

The materials used for the solar-hydro hybrid power system are determined based on the design parameters and the power requirement or energy output of the system. These materials are: Inverter, Battery, Alternator, Turbine, Pump, Bearings, Penstock (pipe), Charge controller, Solar panel and other materials.

Fig. 1(a): Inverter

Fig. 1(b): 12V Battery (6.5 Ah)

Fig. 1(c): Alternator

Fig. 1(d): Turbine disc and cups

Fig. 1(e): Pump

Fig. 1(f): Charge controller

Fig. 1(g): Step-up gear train

Fig. 1(h): Solar Panel

Fig. 1 (a-h): Materials and equipment used for the solar-hydro hybrid power system

The inverter, also called the solar inverter, is an essential component of a solar power system, as shown in Fig. 1(a). It is the component responsible for converting direct current (DC) electricity generated by the SPV cells into alternating current electricity needed by homes and appliances. In addition to its ability to convert DC to AC electricity, the solar inverter also ensures optimal power output by tracking the maximum power point (MPP) of the SPV cells. Different solar inverters can be employed in the solar power system, such as string inverters, micro inverters and power optimizers, each with advantages and can be employed based on the energy requirement or installation scenario.

Fig. 1(b) shows the solar battery or energy storage system of the solar power system. It is used to store excess energy generated by the SPV cells during periods of high sunlight, such as daytime, for later use during periods when sunlight is low such as night time or cloudy days. The battery works by storing the excess energy generated by the SPV cells in chemical form. It is essential to know that not all solar power systems need batteries to function. Grid-connected SPV systems (GcPVs) can still deliver optimal performance without the battery.

Excess energy generated by the SPV cells in this system is fed back into the grid. Incorporating a battery into a solar power system gives the system greater energy independence because it does not rely on the grid and will not be affected by the constant power outages that have bedevilled the national grid. The decision to incorporate a battery into the solar power system depends on specific energy requirements or demands, budget and the goals of the system owner. The battery used in this current study is a 12V battery with 6.5Ah (Amp-hour).

An alternator, also known as a generator, is a component of the hydropower system that converts mechanical energy into electrical energy in the form of alternating current (AC), as shown in Fig. 1(c). It consists of a rotor and a stator. The rotor is connected to the turbine, which rotates as water flows over the turbine buckets. Most alternators are designed to use a rotating magnetic field with a stationary armature. The rotation of the turbine induces a magnetic field in the stator, which contains wire coils. The interaction between the magnetic field and the coil, which is stationary (armature), generates alternating current. The alternator can also be called an AC dynamo but must be distinct from the dynamo that generates DC electricity.

Fig. 1(d) shows the turbine used in the current study. It is an essential component of the hydropower system responsible for converting kinetic energy in flowing, fast-moving or falling water into mechanical energy. The converted energy drives an alternator or generator to produce electricity. The turbine is a rotary device with blades or buckets (sometimes called cups) that capture the kinetic energy of water and turn it into rotational energy. Selection of a type of turbine for a hydropower system project depends on a few factors, such as the head (i.e. vertical distance at which the water falls), flow rate and some specific conditions that are determined during the design or construction phase.

The pump in Fig. 1(e) transfers water from a lower reservoir to a higher reservoir. During periods of low energy demand, when surplus energy is generated by the solar power unit of the solar-hydro hybrid power system, the excess energy is used to run the pump. As the pump transfers water from the lower reservoir to the upper reservoir, energy is stored as gravitational potential energy. When energy is in high demand or during peak periods, the water from the upper reservoir is released back to the lower reservoir. As the water flows downwards, it drives the turbine, which is connected to the generator and thereby converts the stored gravitational potential energy back into electrical energy. A pump with a rating of 9 litres/min ($1.5 * 10^{-4}\ \mathrm{m}^3/_\mathrm{s}$) is used in this current study to increase the pressure of the water that runs the turbine buckets.

In a hydropower system, the primary means of conveying water from the upper reservoir to the lower reservoir is usually the penstock. Penstocks are large pipes that control the flow of water from high-level source. They are designed according to the pressure and flow requirements of the hydropower plant to be constructed. In this current study, a hose is improvised for the large pipe (penstock).

The charge controller or regulator in Fig. 1(f) is an essential component of the solar power system. The purpose of the charge controller is to regulate and manage the flow of energy between the SPV cell and the battery. It is the intermediary between the solar panel and the battery, ensuring proper charging, protection and optimization of the battery storage in the solar power system. Different types of charge controllers can be employed in solar power systems. These include Pulse Width Modulation (PWM) controllers and Maximum Power Point Tracking (MPPT) controllers. The MPPT charge controllers are more efficient and can extract more power from the solar panels under different weather conditions. MPPT charge controller with a rating of 20A is used in this current research and can handle both 12-volt and 24-volt batteries.

Other materials used in this current study include a 3D printed step-up gear made of plastic (PLA) in Fig. 1(g), SPV cell (solar panel) in Fig. 1(h), which captures the sunlight and converts it to DC electricity, a hose for transferring water, acrylic plastic used for making the water barrel that houses the turbine and the gear train seat, 608 ball bearings, 1 inch angle iron (mild steel) for constructing the frame that supports the system and 3D printed couplings (PLA).

Design Analysis

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
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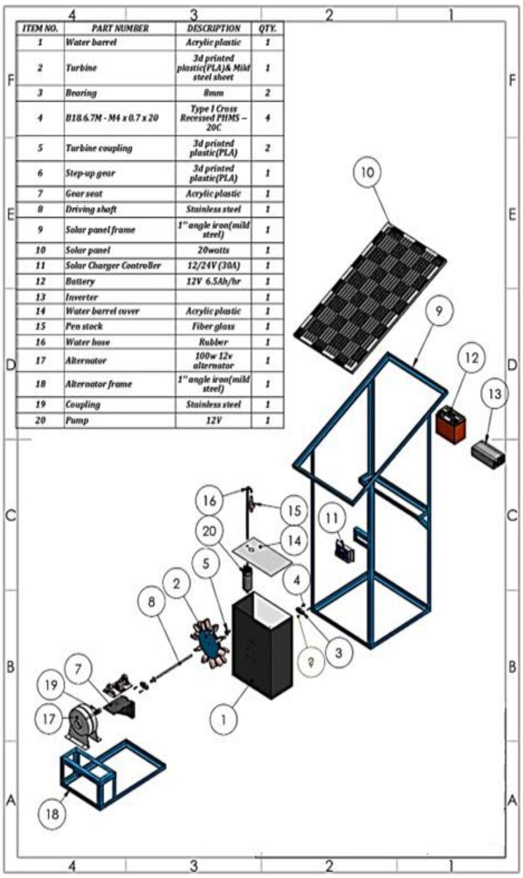
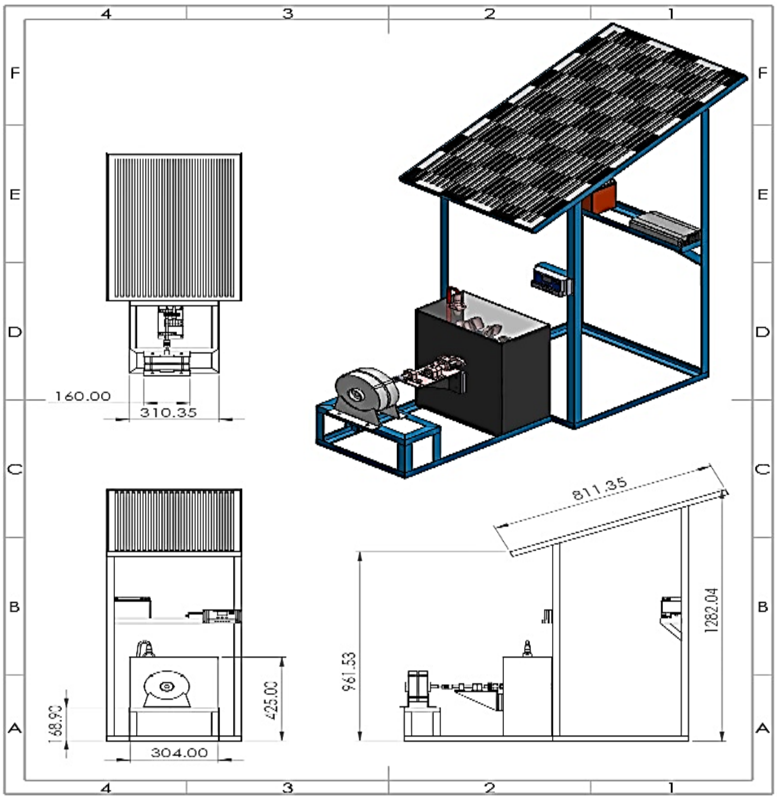
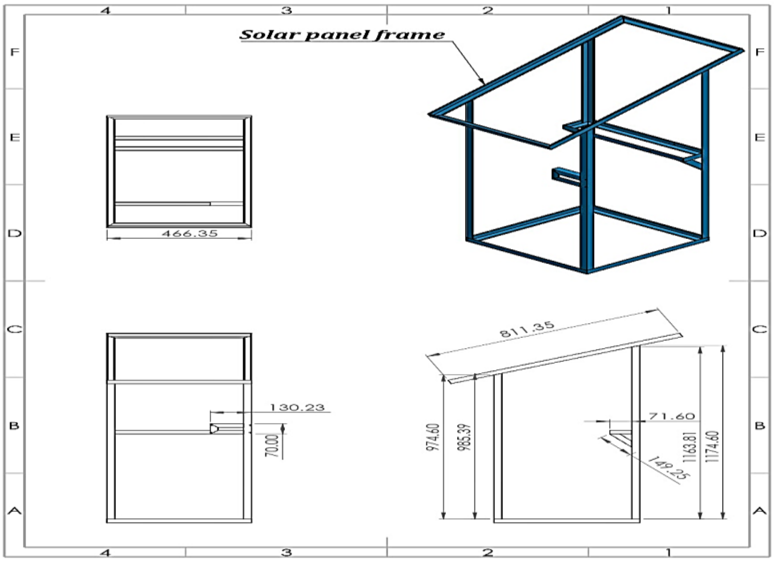
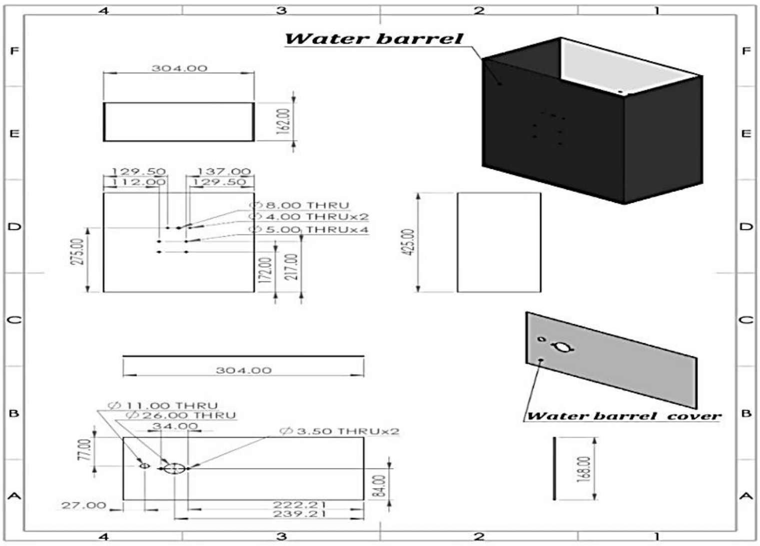


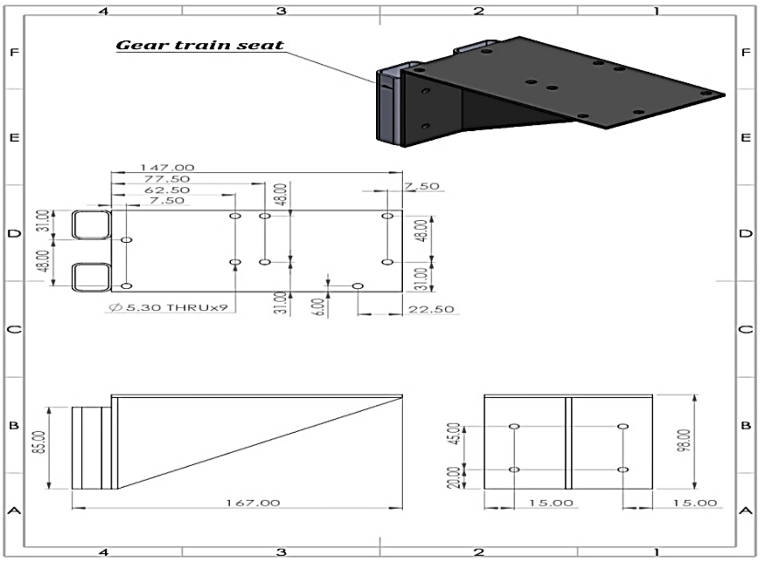
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Water barrel	Acrylic plastic	1
2	Turbine	3d printed plastic(PLA)& Mild steel sheet	1
3	Bearing	8mm	2
4	B18.6.7M - M4 x 0.7 x 20	Type I Cross Recessed PHMS – 20C	4
5	Turbine coupling	3d printed plastic(PLA)	2
6	Step-up gear	3d printed plastic(PLA)	1
7	Gear seat	Acrylic plastic	1
8	Driving shaft	Stainless steel	1
9	Solar panel frame	1" angle iron(mild steel)	1
10	Solar panel	20watts	1
11	Solar Charger Controller	12/24V (30A)	1
12	Battery	12V 6.5Ah/hr	1
13	Inverter		1
14	Water barrel cover	Acrylic plastic	1
15	Pen stock	Fiber glass	1
16	Water hose	Rubber	1
17	Alternator	100w 12v alternator	1
18	Alternator frame	1" angle iron(mild steel)	1
19	Coupling	Stainless steel	1
20	Pump	12V	1

Plate 1: Assembly Drawing




Solar panel frame
466.35
130.23
70.00
811.35
974.60
985.39
71.60
1163.81
1174.60


Water barrel
304.00
162.00
129.50
112.00
137.00
129.50
∅8.00 THRU
∅4.00 THRUx2
∅5.00 THRUx4
275.00
172.00
217.00
425.00
304.00
Water barrel cover
∅11.00 THRU
∅26.00 THRU
34.00
∅3.50 THRUx2
77.00
84.00
27.00
222.21
239.21
168.00


Gear train seat
147.00
77.50
62.50
7.50
48.00
7.50
31.00
48.00
48.00
31.00
∅5.30 THRUx9
31.00
6.00
22.50
65.00
167.00
45.00
20.00
98.00
15.00
15.00

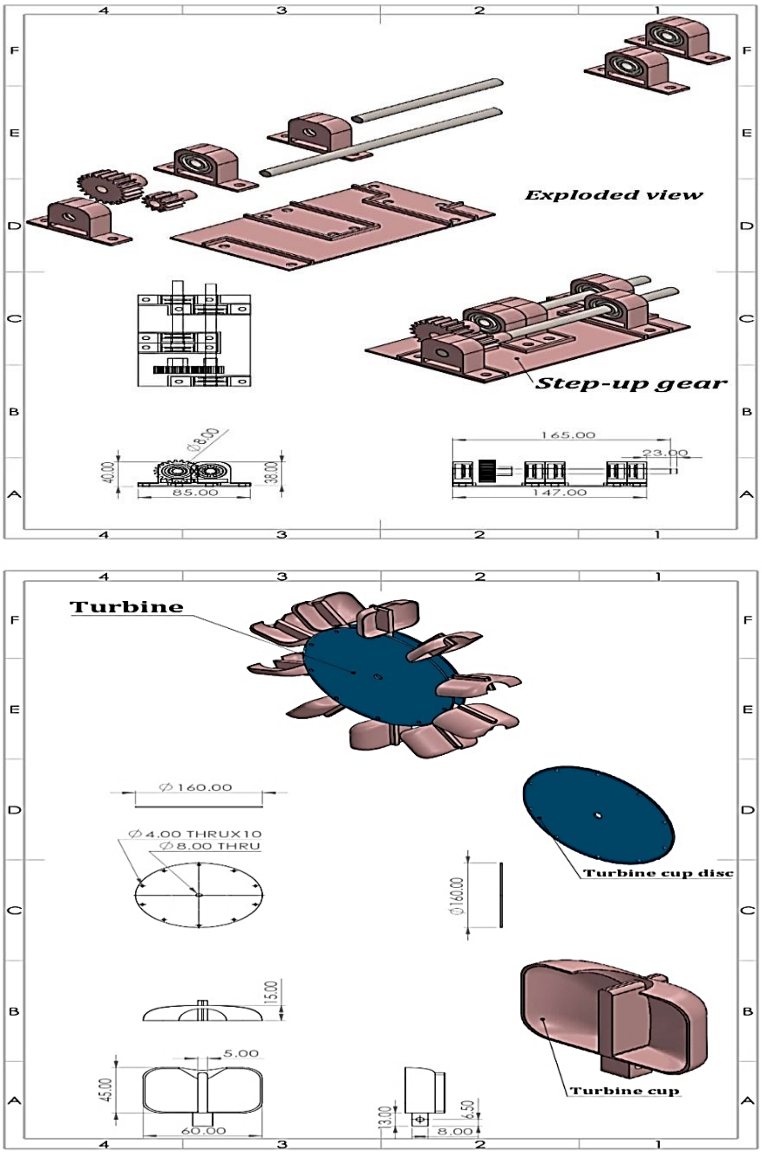


Plate 2: Detailed Design Drawing

Calculations on the Solar Power Unit

- Total energy requirement or total load (Watt)

  =Number of SPV units * equipment rating

  =1 * 50

  =50W

- Actual power output of the SPV cell (Watt)

  =Peak power rating * operating factor

where;

Peak power =50W (1KW) and,

Operating factor =α

NB: 0.6≤∝≤0.9 depending on operating conditions such as temperature, dust on panel, etc.

- Inverter and battery size or capacity

Battery capacity $= V * Ah = V * It$

Where V =Voltage (Volt)=12V and,

$Ah = I * t =$ Charge capacity =6.5Ah (Amp-hour)

- SPV efficiency (η)

$(\eta) = \frac{Pmax}{Pin} * 100\% = \frac{Pmax}{E*Ac} * 100\%$

where; P_{max}=Maximum power output (W) =50W

P_{in} =Power input (W) =E * A_c

E =Incident radiation flux (Irradiance) =1000W/m^2 and,

A_c=Area of collector =0.725m * 0.425m =0.306m^2

P_{in}=1000 * 0.306 =306W

Therefore; $\eta = \frac{50}{306} * 100\% = 16.339\%$

Power Requirement of the hydropower unit is determined with the following parameters:

- Power input into the turbine= $P_{in}= \frac{1}{2}\rho Q V_1{}^2$(Watts)

where;

Density of water = ρ =1000 $^{Kg}/_{m^3}$

Volumetric flow rate =Q = $^{9litres}/_{min}$ (obtained from the pump)

I.e. Q = $^{0.54\ m^3}/_{hr} = 1.5 * 10^{-4}\ ^{m^3}/_{s}$ [where 1 $^{litre}/_{min} = {}^{0.06\ m^3}/_{hr}$]

Diameter of the jet = d =5mm = 0.005m

It is known that; Q=A_j * V

where;A_j=Area of the water jet = $\frac{\pi}{4}d^2 = \frac{\pi}{4} * 0.005^{\wedge 2} = 1.9635 * 10^{-5}m^2$ and

V = Velocity of jet = $V_1 = V_{w1} = \frac{Q}{A_j} = \frac{1.5*10^{-4}}{1.9635*10^{-5}} = 7.6394\ ^{m}/_{s}$

Therefore;

$$P_{in} = \frac{1}{2} * 1000 * 1.5 * 10^{-4} * 7.6394^{\wedge 2} = 4.377W$$

- Velocity of the turbine wheel= U = $\frac{\pi DN}{60}$ $(^{m}/_{s})$

Speed of turbine runner = N = 160 rpm (measured using a tachometer)

Diameter of the turbine wheel= D=160 mm = 0.16 m

$$U = \frac{\pi * 0.16 * 160}{60} = 1.34\ (^{m}/_{s})$$

- Power developed by the runner= P_{runner}= $\rho * Q * (V_{W1} + V_{W2})U$ (Watts)
- Work done= W = $\frac{(V_{W1}+V_{W2})*U}{g}$ (Nm)

Acceleration due to gravity = g =9.81 $^{m}/_{s}2$

- Hydraulic efficiency= $\eta_h = \frac{2*(V_{W1}+V_{W2})*U}{V_1{}^2}$
- Overall efficiency = $\eta_h = \frac{P_o}{P_{in}}$

where;

P_o = Output electrical power = $I_o * V_o$ (measured from ammeter)

$P_o = 7.85V * 0.2A = 1.57$ W

$V_{w1} = V_1$=Velocity of jet before striking bucket and,

V_{w2} =Velocity of jet after striking bucket

$V_{r1} = V_1 - U = 7.6394 - 1.34 = 6.3\ ^{m}/_{s}$

Bucket friction $K = \frac{V_{r2}}{V_{r1}} = 1$ (for smooth surface)

Therefore; $V_{r2} = V_{r1} = 6.3\ ^{m}/_{s}$

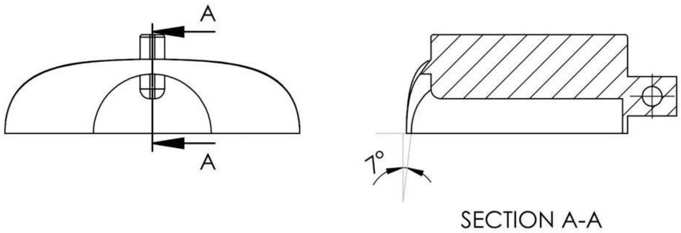


Plate 2: cut-out section of the design drawing of the turbine cup

From fig. 3, $\beta_2 = 7°$

$$\cos\beta_2 = \cos 7° = \frac{U + V_{w2}}{V_{r2}} = \frac{1.34 + V_{w2}}{6.3}$$

$1.34 + V_{w2} = 6.3 * \cos 7 = 6.253$

$V_{w2} = 6.253 - 1.34 = 4.913\ ^{m}/_{s}$

$P_{runner} = 1000 * 1.5 * 10^{-4}(7.6394 + 4.913) * 1.34 = 2.523W$

$$W = \frac{(7.6394 + 4.913) * 1.34}{9.81} = 1.746Nm$$

$$\eta_h = \frac{2(7.6394 + 4.913)1.34}{7.6394^2} = 0.5764 = 57.64\%$$

$$\eta_o = \frac{1.57}{4.377} = 0.3587 = 35.87\%$$

Miscellaneous design Calculations

- Gear ratio or velocity ratio: $Gr = \frac{\text{Number of teeth of driven gear}}{\text{Number of teeth of driving gear}} = \frac{11}{22} = \frac{1}{2} = 1:2$
- Gear module: $m = \frac{\text{Pitch circle diameter}}{\text{Number of teeth}} = 1.5$ (standard module)
- Speed ratio of turbine wheel to output gear:
- $Nr = \frac{\text{RPM of turbine wheel}}{\text{RPM of output gear}} = \frac{160}{320} = \frac{1}{2} = \quad 1:2$

- Volume of water barrel:

$$v = length * breath * depth = 0.304 * 0.162 * 0.425 = 0.0209304m^2$$

- Power loss in shaft bearing:

$P_{loss} = 1.05 * 10^{-4}MN$,

where;

M is total frictional moment and N is the rotational speed.

$M = 0.5\mu * Pd_B$,

Where;

μ is the coefficient of friction = 0.0010 (for deep groove ball bearings),

P is bearing load = 305 lbs = 1370.05N (for 608 bearing), and

d_B is the bearing bore diameter= 8mm = 0.008m.

Therefore;

$M = 0.5 * 0.0010 * 1370.05 * 0.008 = 5.4802 * 10^{-3}Nm$,

$P_{loss} = 1.05 * 10^{-4} * 5.4802 * 10^{-3} * 160 = 9.206 * 10^{-5}W$

$$P_{shaft} = P_{runner} - P_{loss} = 2.523 - 9.206 * 10^{-5} = 2.5W$$

Now;

Mechanical efficiency $\eta_m = \frac{P_{shaft}}{P_{runner}} = \frac{2.5}{2.523} = 0.991 \rightarrow 99.1\%$

Generator efficiency $\eta_g = \frac{P_o}{P_{runner}} = \frac{1.57}{2.523} = 0.6222 \rightarrow 62.22\%$

Volumetric efficiency η_v is always between 0.97 – 0.99 (for Pelton turbine)

3. Results and Discussion

Behaviour of the solar-hydro hybrid power system with different loads

The behaviour of the solar-hydro hybrid power system under different conditions is studied and displayed in Figures 2 to 6.

Fig. 2 showsthevoltage difference when the system is connected to the solar panel. It was observed that the voltage increases and decreases at different times. This is due to the fluctuations in the intensity of sunlight at different times, which makes the output voltage unstable. This is one of the major limitations of solar systems when used for power generation. This is often referred to as intermittency.

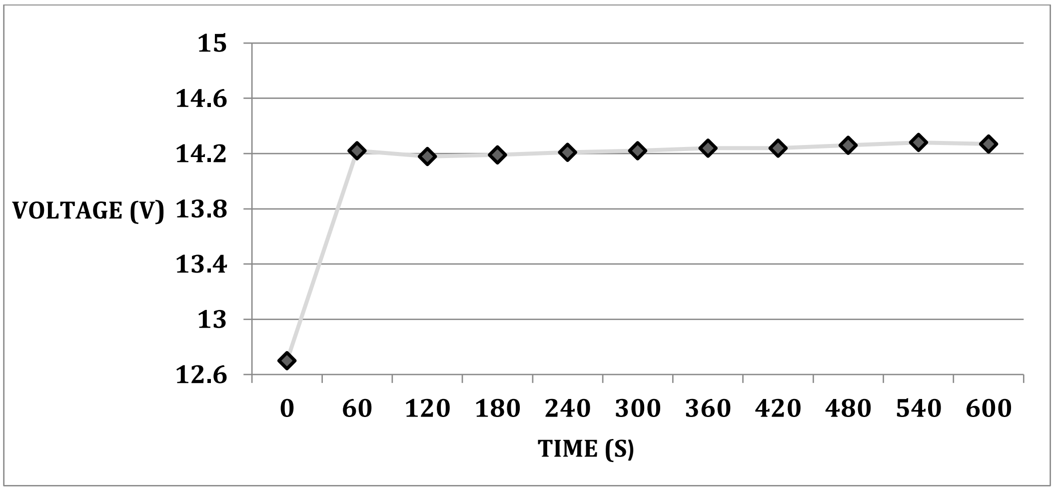


Fig. 2: Voltage difference when system is connected to solar panel

The voltage difference when the system is connected to the hydro turbine (with the pump connected to an external power supply) is shown in Fig 3. Before connecting the output voltage to the battery (i.e., to charge the battery or store up energy), the output voltage of the alternator was 52.24V and the speed of the turbine wheel was extremely fast. During this period, the battery voltage increases and maintains constant, increases again and maintains constant and finally increases and remains constant, as shown in Fig. 3. However, immediately after the output voltage of the alternator is connected to the battery, the speed of the turbine wheel reduced significantly. From the specification of the hydropower system alternator, the higher the speed of the alternator, the higher the voltage and current output. The speed reduction caused the voltage and current charging the battery to be reduced, consequently making the charging rate very slow.

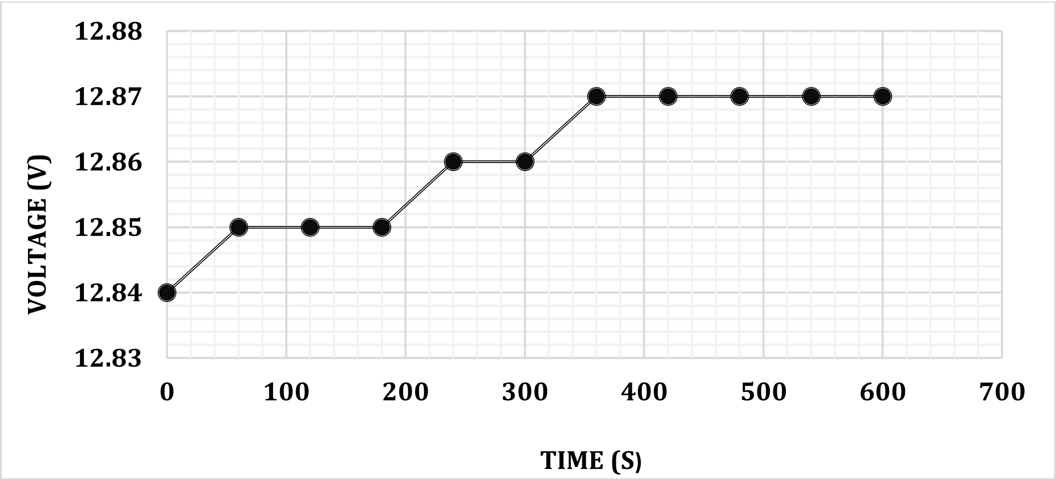


Fig. 3: Voltage difference when the system is connected to the hydro turbine (with the pump connected to an external power supply)

Fig. 4 shows the voltage difference when the system is connected to the hydro turbine (with the pump connected to the main battery) when charging the battery. Moreover, when the pump is connected to the main battery, the voltage increases slightly because the pump needs to draw more current from the battery to keep the turbine wheel running (rotating). The higher the current drawn from the hydro alternator, the higher the torque required to keep the alternator running and to deliver more current. Afterwards, the voltage decreases as the pump operates the turbine wheel, as shown in Fig. 4.

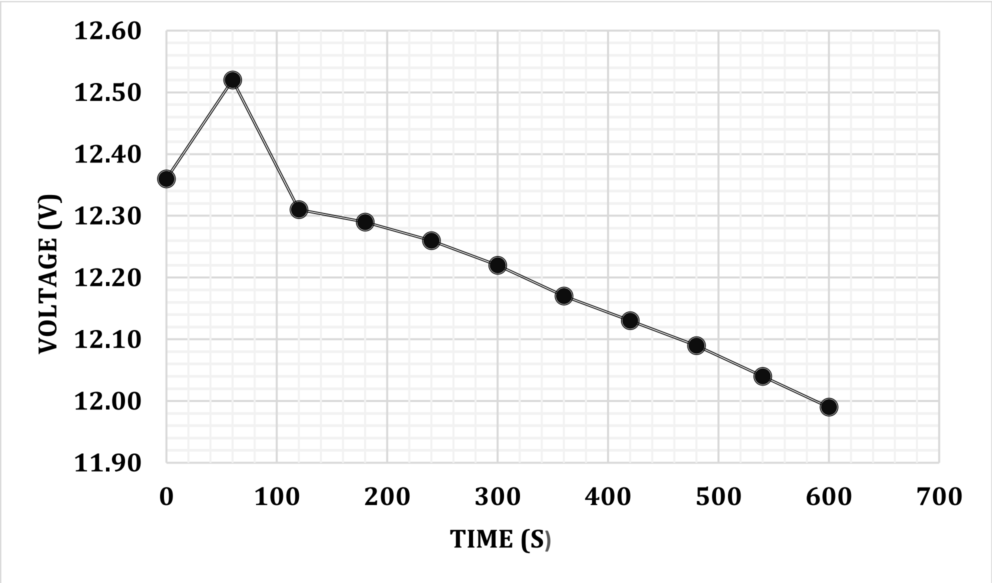


Fig. 4: Voltage difference when the system is connected to the hydro turbine (with pump connected to the main battery) when charging the battery

The voltage difference when the system is connected to the hydro turbine (with the pump connected to the main battery) without charging is shown in Fig. 5. Instead of having an increment in the battery voltage level, the voltage drops gradually. This is because the main battery is powering the pump. The power drawn from the battery caused the battery voltage level to decrease.

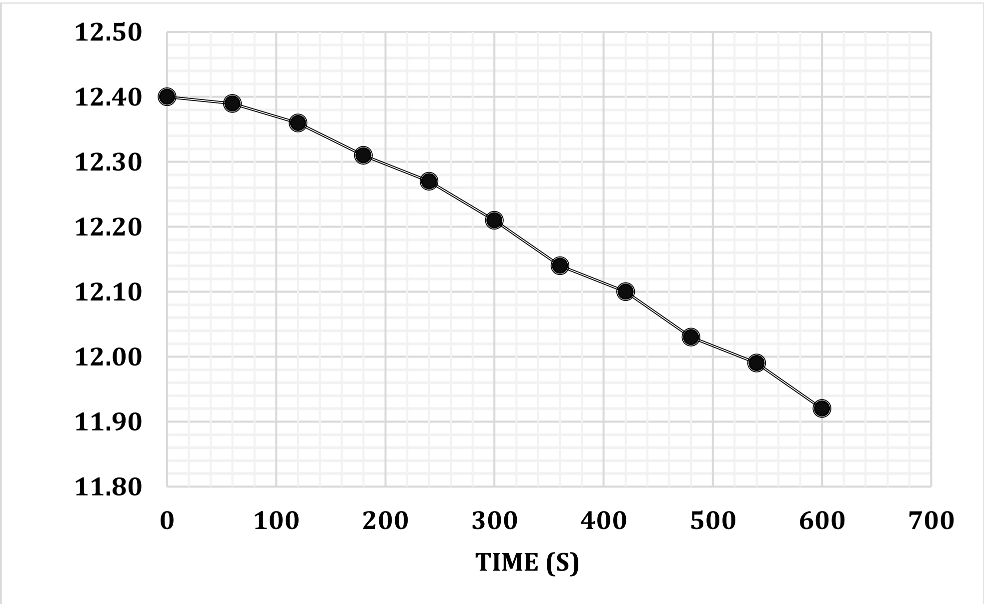


Fig. 5: Voltage difference when the system is connected to the hydro turbine (with pump connected to the main battery) without charging

Fig. 6 shows the voltage drop in the battery when the inverter is connected to the battery on a 50 W load. It is observed that the battery was 12.85V before switching on the inverter and later dropped to 12.04V in 10 minutes (600 seconds), which is the total time it can use. Therefore, the inverter is estimated to shut down on 11.92 V of the battery voltage on a constant load of 50 W.

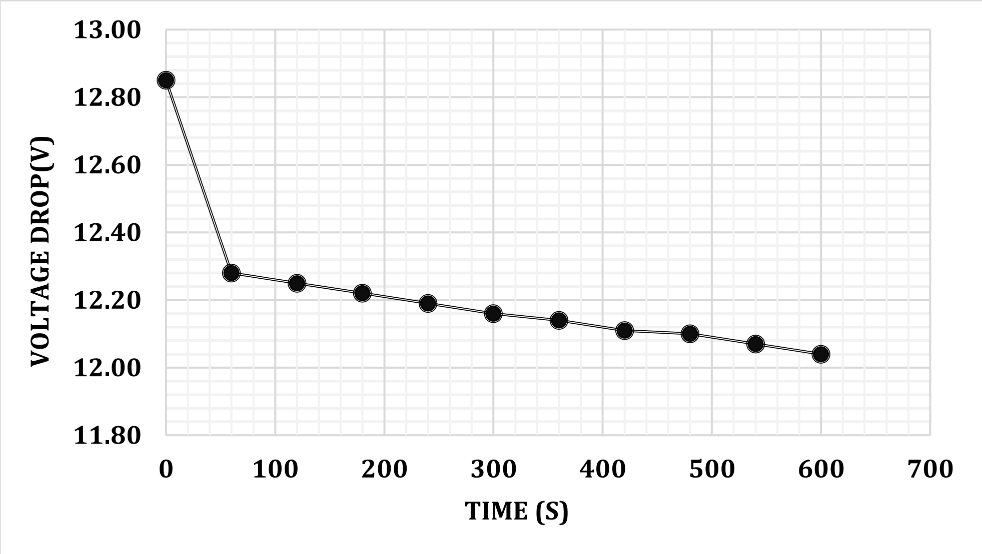


Fig. 6: Voltage drop in battery (on 50W load)

Efficiency comparison of the Hydro Turbine in the Solar-Hydro Hybrid Power System.

Comparing the solar-hydro hybrid power system with a prototype hydropower plant for power generation in a rural setting developed in Ekiti State University, Ado Ekiti which is working as a stand-alone system.

Table 1: Efficiency obtained from prototype hydropower plant

S/N	Efficiency	% Efficiency
1	Hydraulic	57.64
2	Volumetric	98
3	Mechanical	99.1
4	Generator	62.22
5	Overall	37.87

Table 2: Comparison of solar-hydro hybrid with hydropower plant

Parameter compared	Solar-hydro hybrid	Hydropower plant
Power input into the turbine	4.377W	54.528W
Power generated (on load)	50W (for solar) and 1.57W (for hydro)	0.114W
Hydraulic efficiency	57.64%	38%
Overall efficiency	35.87%	0.209%

From Table 2, it is observed that the power input into the turbine of the small hydropower plant is higher. This is because the prototype hydropower plant has a head (1.45m) which contributes to the increase in its gravitational potential energy. The gravitational potential energy is converted into the kinetic energy of water that spins the turbine buckets. However, there is no head involved in the solar-hydro hybrid power system.

The hydraulic efficiency of the solar-hydro hybrid power system is higher. This is because of the pressure of the water pump (powered by the battery), which increases the velocity of the water jet. Also, the friction loss between the water jet and the internal surface of the hose used in the solar-hydro hybrid power system is minimal compared to the prototype hydropower plant.

The overall efficiency of the solar-hydro hybrid power system is higher. This is because the solar unit of the solar-hydro hybrid system is used to power the battery (for charging the battery or pumping water) and more power is delivered to the alternator. Moreover, the step-up gear increases the speed delivered to the alternator. Subsequently higher power output results from the alternator because higher speed of the shaft results in higher power output by the alternator.

4. Conclusion

In contrast to a pumped storage power system, which uses the battery's energy to power the pump, which in turn powers the turbine during times of high demand, like night or cloudy weather, the solar-hydro hybrid power system with a switch incorporated, allows both of the system's units to operate simultaneously or as stand-alone system. Also, this revolutionary power system has an edge over the conventional hydropower system in the area of conservation of water because, unlike in hydropower systems where the water is discharged off from the tail race, which consequently reduces the impact of the water jet on the turbine as the water level reduces, the water in this hybrid power system is conserved and hence maintains the impact of the water jet against the turbine bucket.

The power generated by the two systems has been tested, yielding a power output of 1.57 Watts for the solar-hydro hybrid system and 0.114 Watts for the hydropower system. The data shows that the solar-hydro hybrid system is more dependable as compared to a hydropower system.

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