



Development and Performance Evaluation of a Solar-Powered Domestic Water Pump Using Locally Available Materials

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Abstract

Access to reliable domestic water supply remains a major challenge in many developing regions due to high energy costs, unreliable electricity supply, and environmental concerns associated with fossil-fuel-based pumping systems. Conventional electric and diesel-powered water pumps contribute significantly to operational expenses, greenhouse gas emissions, and system unreliability, particularly in rural and semi-urban areas. This study addresses these challenges by developing and evaluating the performance of a solar-powered domestic water pumping system using locally available materials. The aim of the study is to design a cost-effective, environmentally sustainable, and reliable alternative water pumping solution suitable for domestic applications. The methodology involved the conceptual design, component sizing, fabrication, and experimental testing of a photovoltaic-powered pumping system comprising a monocrystalline solar panel, charge controller, inverter, battery storage unit, and a centrifugal water pump. Design calculations were carried out for pump selection, hydraulic power, battery sizing, inverter capacity, and solar panel requirements. The system was fabricated using locally sourced materials to enhance affordability and ease of maintenance. Performance evaluation was conducted through field testing under actual operating conditions, with voltage, flow rate, and efficiency measurements recorded. Results indicate that the system successfully pumped water to an elevated storage tank at a flow rate of 0.35 L/s, achieving an overall pump efficiency of approximately 58.33%. The findings demonstrate that solar-powered pumping systems can provide a reliable and clean alternative to conventional systems while reducing energy costs and environmental impact. The study concludes that solar-powered water pumping systems using locally available materials are technically feasible, economically viable, and environmentally sustainable for domestic water supply applications, especially in off-grid and energy-constrained regions.

Keywords: Initial void ratio, natural moisture content, settlement, compression ratio, one-dimensional consolidation.

1.0 Introduction

A nation's water supply system, which supplies the populace with drinkable water, is an essential piece of infrastructure (Rising et al., 2022). A significant quantity of electrical energy is needed to operate the system while gravity is present (Mishra et al, 2023). Designing, building, running, and maintaining such a system is made much more difficult by Nigeria's difficult topography (Mishra et al, 2024). To supply water to Nigeria's urban and rural areas, the water accessible downstream in many places must be pumped uphill (Shrestha, 1996). Due mostly to power consumption, the pumping project has higher operating costs than a gravity-based water supply system (Mishra et al, 2024). The public must be willing and able to reimburse or offset the electricity costs incurred during the project's implementation and maintenance phase in order to guarantee the scheme's sustainability (Foster et al., 2017). Water supply is becoming increasingly important in emerging nations like Nigeria, particularly in the villages and interior regions of the nation. Sources of fresh water are becoming less available. Reliable alternative technologies are needed to fulfill the increased demand, especially in the upstream regions where population growth has increased demand. To extract water from the remaining downstream sources, researchers have concentrated on technology such as solar-powered pumps (Shrestha, 1996). Notably, a solar-powered water pumping system eliminates the need for finite fossil fuels to operate the pumps.

On the other hand, traditional electrically powered water pumping systems produce air and noise pollution. Because of the world's population growth and technological advancements, there is a greater need for power (Ahmed et al., 2023). According to Ahmed et al. (2023), one of the main causes of climate change is the burning of fossil fuels, which releases a large amount of CO₂ into the atmosphere. These factors have led many countries to adopt a sustainable, clean, and renewable energy source, namely solar power (Ahmed et al., 2023).

Fossil fuel use may decrease with the use of renewable energy. Solar energy is a good substitute for diesel-powered water pumps since it is generally accessible, even in isolated locations (Verma *et al.*, 2021; Mishra *et al.*, 2021). Compared to fossil fuel-based energy sources, solar energy is a renewable, environmentally benign energy source that has no negative effects on the environment. It can also be used in remote places where electricity is not readily available. One of the most significant renewable energy sources is this one, which may be utilized to create electrical energy that can power a household electrical water pump (Allouhi *et al.*, 2019; Bhosale, 2022). Thermal and electric energy are the main uses of solar radiation energy. To power pumps, engines, motors, and various industrial appliances like fans and refrigerators, it is an alternative method of producing electricity for a broader range of domestic uses as well as in some other fields like building applications, food storage products, and agricultural uses (Rajendran, 2021; Zhang *et al.*, 2020). Utilizing solar energy guarantees that the system will use green energy (Ahmed *et al.*, 2023). Being in the sun belt, Egypt receives a lot of direct solar radiation, with annual levels varying from 2000 to 3200 kWh/m² from north to south. There are a few overcast days throughout the year, and the sun shines for nine to eleven hours (Abdulhady & Metwally, 2020; Elboshy *et al.*, 2021).

In addition to providing water for household use, solar-powered pumping systems also meet water demands in the areas of irrigation, livestock watering, and community water supply (Waleed *et al.*, 2019; Sharma *et al.*, 2020). A solar-powered water pumping system consists of a pump, power converters, an electric motor, and a PV energy generator (Varshney *et al.*, 2019; Gevorkov *et al.*, 2023). Solar energy can be used photovoltaically, which uses solar cells built of semiconductor materials such as silicon to turn sunlight into electricity, or thermally, which uses solar thermal collectors for drying and heating. Solar cells are connected in series to create solar panels, sometimes referred to as photovoltaic panels. In agricultural settings, both varieties are widely used to improve productivity and make life easier. By pumping water into a high tank during the day and distributing it by gravity at night, the solar-generated electricity can subsequently be used to operate the water pump or saved. To store the energy produced during the day for use in electrical applications at night, a battery will be necessary (Sekmen *et al.*, 2022; Alagumalai *et al.*, 2022). There are two ways to use a photovoltaic system to pump water: The first method, called pumping in the sun, uses solar energy in real time. Water storage in a tank is required for this solution (for example, water pumped throughout the day is kept for later usage in the evening).

Using batteries to store energy is the second method. Later, water can be pumped using the energy that was stored during the day (Abdelkader & Mohammed, 2022). Solar radiation, PV surface temperature, shadow, tilt angle, and dust deposition are some of the variables that affect a photovoltaic system's output power. The design of a photovoltaic system should take into account various environmental conditions and elements, such as temperature, irradiance, and tilt angle. The output power of the PV is significantly influenced by these factors (Mustafa *et al.*, 2020; Elsaadawi *et al.*, 2022; Shi *et al.*, 2020). Efficiency drops by 0.48% in the summer and 0.42% in the winter when the surface temperature of the solar panel rises by 1 °C (Tayel *et al.*, 2019; Bayrak *et al.*, 2019). PV surface temperature, tilt angle, and system component efficiency are some of the variables that impact a photovoltaic system's output power. A PV system's design and operation should take these aspects into account. The PV cell's maximum output energy is achieved when the PV module's surface is exactly perpendicular to the sun's beams. Tracker orientation generates higher PV power than horizontal orientation since it is pointed toward maximum irradiance (Abdeen *et al.*, 2017; Kapou & Garg, 2021).

Many PV water pumping stations were found to have issues during operation, despite being well-designed from an engineering perspective. Additionally, the amount of water pumped from the station was found to be less than anticipated. This is because the technical and environmental elements that negatively affect the station's operation have not received enough attention. Thus, this work's objectives were to examine the PV-powered subterranean water pumping system's performance evaluation under real-world operating conditions using locally sourced materials, look into factors that could negatively affect the PV system, and show that this system could be relied upon as a secure and dependable substitute for conventional energy systems that are expensive and pollute the environment.

2.0 Materials and Method

The knowledge of the components and process stages involved in pumping the fluid are very important for the development and smooth operation of the solar-powered pumping system.

2.1 Conceptual Design of the Solar-Powered Pumping System

The conceptual design of the solar-powered pumping system consists of integrated electrical and mechanical components that work together to supply water for domestic use using renewable energy (Channe, 2025). The system primarily comprises a photovoltaic (PV) solar panel, a charge controller, a battery storage unit, an electric water pump, and a water storage tank. The solar panel captures solar energy and

converts it into electrical power, which is regulated by the charge controller to prevent overcharging and ensure system stability. The regulated power is either used directly to operate the pump or stored in the battery for use during low sunlight periods. The electric pump, selected based on required flow rate and head, draws water from a source such as a well or borehole and delivers it to an elevated storage tank. Gravity then enables water distribution to household outlets, minimizing continuous energy demand. Locally sourced materials are incorporated into the pump housing, mounting structures, piping, and support frames to reduce cost and promote sustainability. The system is designed for simplicity, reliability, and ease of maintenance, making it suitable for rural and semi-urban domestic applications. Overall, the conceptual design emphasizes energy efficiency, environmental friendliness, and affordability. The conceptual framework diagram is presented in the Figure 1. The material selection of the Solar-Powered pumping system is presented in Table 1

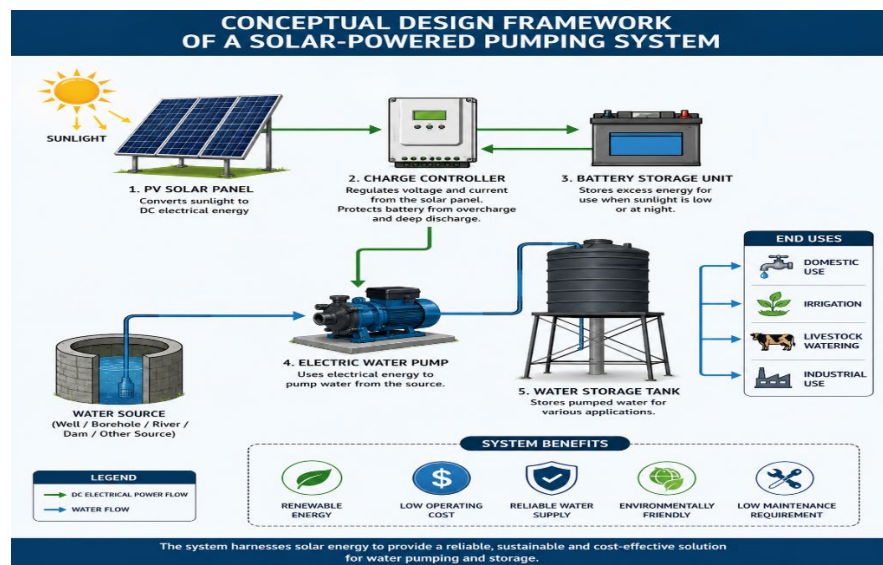


Figure 1: Conceptual Framework Design of a Solar-Powered Pumping System

Table 1: Materials and alternatives

S/N	Material/function	Type	Alternative
1	Solar Photovoltaic panel	Monocrystalline panel	Polycrystalline panel
2	Centrifugal pump	AC pump	DC pump
3	Battery	Lead acid battery	Lithium-ion battery
4	Steel Frame	Mild steel	High carbon steel, Stainless steel, Cast iron, Aluminium.
5	Charge controller	PWM Charge controller	MTTP charge controller
6	Solar inverter	Stand Alone (Off-Grid) inverter	Grid Tie (Synchronous) inverter.
7	Piping	1" PVC pipes and fittings.	1" Steel pipes and fittings.
8	Frame base	Plywood	Medium density fibre (MDF) board, particle board, solid wood, steel plate, plastic plate.
9	Panel support	Mild steel	

- i. Monocrystalline panel: A solar cell is a solid-state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. The monocrystalline panel is made out of single crystal silicon that allows electrons to move freely. The monocrystalline panels have higher efficiency than polycrystalline panels.
- ii. Centrifugal AC pump: The centrifugal pump was selected as shown in the pump selection chart in Figure 3.1. Alternating current (AC) was chosen over direct current (DC) for the pump's motor because, generally, AC pumps are more efficient than DC pumps, and the AC pumps have longer working life span.
- iii. Lead acid battery: Lead acid batteries are typically cheaper than lithium-ion batteries of the same rating and they have higher output power.
- iv. Mild steel frame: The frame was fabricated with 1¹/₂ inch mild steel angle bars. Mild steel was chosen to fabricate the frame because it is relatively cheap, weldable, easily machineable, and readily available.
- v. PWM charge controller: PWM charge controllers are cheaper than their MTTP counterparts, and they are designed to optimize battery life.
- vi. Stand-alone (Off-Grid) inverter: These are the inverters that work separately from the grid. Electronic devices are connected to the inverter output directly.
- vii. PVC pipes and fittings: PVC (polyvinyl chloride) pipes were chosen because they are readily available, they have very low cost in comparison with other pipe materials, they are also lightweight, very durable, have very good weather resistant properties and cannot corrode.
- viii. Plywood frame base: For the base of the frame, plywood was selected because it is cheap and readily available, it is attractive, has high strength, high durability and can withstand water to some extent.

2.2 Process Stages and Governing Equations for Solar-Powered System

The solar powered pump system is divided into the following sections:

Pump selection

Water is to be pumped at a design head of 20 metres with a flowrate of 1 litre/second (1l/s). Pump selection involves calculating the hydraulic power(p_h), shaft power(p_s), motor power (p_m), and the electrical generating capacity of the pump. The Figure 2 shows a pump selection chart.

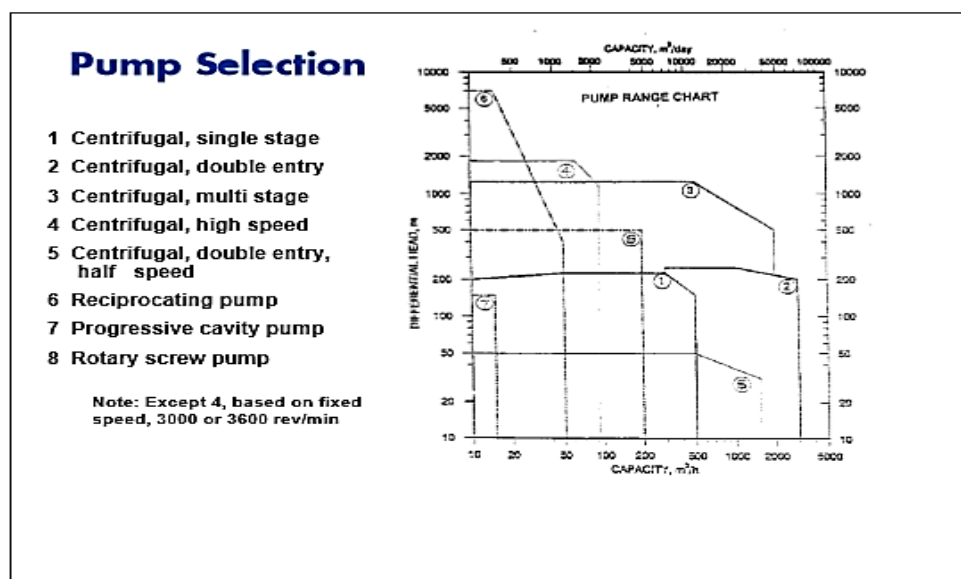


Figure 2: Pump selection chart

- i. Hydraulic power P_h

This is the energy conveyed on the fluid being pumped to increase pressure and velocity. The Equation (1) is the formula for hydraulic power p_h

$$p_h = qgh\rho \quad (1)$$

Where p_h = hydraulic power

q = flowrate

ρ = density of fluid

g = acceleration due to gravity

h = head

Given: $q = 1000 \text{ l/s} = 1 \text{ m}^3/\text{s}$

$1 \text{ l/s} = (\frac{1}{1000}) \text{ m}^3/\text{s}$

$\therefore q = 0.0006 \text{ m}^3/\text{s}$

From Figure 1, given that the flowrate / capacity is $0.0006 \text{ m}^3/\text{s}$ and the design head is 40m, we can select a single stage, centrifugal pump.

$g = 9.81 \text{ m/s}^2$

$h = 40 \text{ m}$

$\rho = 1000 \text{ kg/m}^3$

Hydraulic power $P_h = 0.0006 \times 9.81 \times 40 \times 1000$

$= 235.4 \text{ watts}$

ii. Shaft power P_s

This is power supplied by the motor to the pump shaft. It is dependent on the pump efficiency. Pump inefficiencies could arise from head loss, leakages or friction losses. The formula for shaft power is shown in the Equation (2).

$$P_s = \frac{P_h}{\eta_p} \tag{2}$$

Where η_p = pump efficiency

P_h = hydraulic power

P_s = shaft power

From the Table 2, the typical pump efficiency for a centrifugal pump $\eta_p = 85\%$,

Given Hydraulic power $P_h = 235.4 \text{ watts}$,

\therefore shaft power $P_s = \frac{235.4}{0.85} = 277 \text{ watts}$

Table 2. Typical pump efficiencies

Pump type/component	Typical Efficiency
Centrifugal pump	60-85%
Sliding vane pump	60-90%
Gearbox	70-98%
Belt drive	70-96%
Variable speed drive at full speed	80-98%
Variable speed drive at 75% full speed	70-96%
Variable speed drive at 50% full speed	44-91%
Variable speed drive at 25% full speed	9-61%

iii. Motor power

This is the power utilized by the pump motor in order to rotate the pump shaft. It is dependent on the efficiency of the motor and the shaft power. The formula for motor power is shown in the Equation (3).

$$P_m = \frac{P_s}{\eta_m} \tag{3}$$

Where η_m = motor efficiency

P_s = shaft power

P_m = motor power

Given Shaft power $P_s = 277 \text{ watts}$

Typical motor efficiency = 80%

\therefore motor power $P_m = \frac{277}{0.80} = 346.25 \text{ watts}$

iv. Motor generating capacity

Motor generating capacity is calculated from motor power with regard to potential overload during start up. It is a product of the motor power and power safety margin/factor (β).

Power safety factor can be selected from the Table 3.

Table 3. Power safety factor

P_m , KW	Under 1	From 1 to 5	From 5 to 50	Over 50
β	2 - 1.5	1.5 - 1.2	1.2 - 1.15	1.1

(Source: http://www.ence-pumps.ru/en/podbor_raschet_nasosov/#centrifugal_pumps)

Motor generation factor $M_{gf} = P_m \times \beta$ (4)

Given motor power $P_m = 346.25 \text{ watts}$,

Using table 3. as a guide, Safety factor $\beta = 1.3$,

$M_{gf} = 346.25 \times 1.3 = 449.8 \text{ watts} \cong 450 \text{ watts}$
 \therefore Motor generating factor $M_{gf} = \text{Total load} = 450 \text{ watts}$.

Battery sizing

Energy trapped by the solar panels is stored in the battery. To properly size a battery, the total energy required by the system has to be known.

a. Energy consumption

Given,

Motor generating capacity $M_{gf} = 450 \text{ watts}$.

Pump is to run for 2 hours in a day,

\therefore Max load in watt hours = $450 \text{ watts} \times 2 \text{ hours}$
 $= 900 \text{ WH (watthours)}$

b. Battery size in AH

$$\text{Battery size} = \frac{\text{power in WH}}{\text{Battery voltage}} \quad (5)$$

Given,

Power in WH = 900 WH

$$\text{Battery size} = \frac{900 \text{ wh}}{12\text{v}} = 75 \text{ AH}$$

Lead acid batteries perform only 50% of their given rated power, to cover up for the efficiency lost, the size should be multiplied by 2.

\therefore Safe battery size = $75 \text{ AH} \times 2 = 150 \text{ AH}$.

Inverter sizing

An inverter converts DC current into AC. Because the pump is AC, an inverter is required.

Given,

Additional further load expansion (AF) = 20%

Efficiency of inverter (I_e) = 80%

Total load = 450 watts

$$\text{Total load in VA} = \frac{450}{0.8} = 562.5 \text{ VA}$$

$$\begin{aligned} \text{Size of inverter} &= \text{Total load} + \frac{(1+AF)}{I_e} \\ &= \frac{562.5 + (1+0.2)}{0.8} \\ &= 704.625 \text{ VA say } 705 \text{ VA} \end{aligned} \quad (6)$$

The inverter to be selected should not be less than 705 VA.

Solar panel sizing

The Figure 3 is the "Lagos climate table" showing the average sunlight hours/day. According to the Figure 3.2, the minimum sunlight hours are 3hours which fall in July and August. Thus, designing for the least sunlight in the year,

Given,

Minimum sunlight hours = 3 hours

Max load = 450 watts

$$\begin{aligned} \text{panel size} &= \frac{\text{Max load}}{\text{sunlight hours}} \\ &= \frac{450}{3} = 150 \text{ watts} \end{aligned} \quad (7)$$

\therefore A 150 watts solar panel should be selected.

Lagos Climate Table													
Climate Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max Temperature °C (°F)	32 (90)	33 (92)	33 (91)	32 (90)	31 (88)	29 (85)	28 (83)	28 (83)	29 (84)	30 (87)	31 (89)	32 (89)	31 (87)
Average Temperature °C (°F)	27 (81)	28 (83)	29 (83)	28 (82)	27 (81)	26 (78)	25 (77)	25 (77)	26 (78)	26 (79)	27 (81)	27 (81)	27 (80)
Average Min Temperature °C (°F)	22 (72)	24 (75)	24 (75)	24 (75)	23 (74)	22 (71)	22 (72)	22 (71)	22 (72)	22 (72)	23 (73)	23 (73)	23 (73)
Average Precipitation mm (in)	13 (1)	41 (2)	84 (3)	146 (6)	202 (8)	316 (12)	243 (10)	122 (5)	160 (6)	125 (5)	40 (2)	15 (1)	1507 (59)
Number of Wet Days (probability of rain on a day %)	2 (6)	3 (11)	7 (23)	9 (30)	14 (45)	20 (67)	15 (48)	11 (35)	16 (53)	15 (48)	7 (23)	2 (6)	121 (33)
Average Sunlight Hours/ Day	5h 54'	6h 43'	6h 23'	6h 12'	5h 36'	4h 00'	3h 00'	3h 00'	3h 06'	4h 54'	6h 36'	6h 36'	5h 09'
Average Daylight Hours/ Day	11h 46'	11h 54'	12h 04'	12h 15'	12h 24'	12h 29'	12h 27'	12h 19'	12h 09'	11h 57'	11h 48'	11h 44'	12h 00'
Percentage of Sunny (Cloudy) Daylight Hours	51 (49)	57 (43)	53 (47)	51 (49)	46 (54)	32 (68)	24 (76)	25 (75)	26 (74)	41 (59)	56 (44)	57 (43)	43 (57)
Sun altitude at solar noon on the 21st day (°)	63.4	72.6	83.5	84.7	76.3	73.1	76.1	84.5	83.8	72.2	63.2	60	74.6

Figure 3. Lagos climate table (Source: <http://www.lagos.climateps.com/>)

Solar tilt angle

The latitude of the solar panel location is 7°36'21"N.

According to Landau (2017), for latitudes below 25°, use the latitude X 0.87.

$$\therefore 7^\circ \times 0.87 = 6.09^\circ$$

∴ The solar panel will be set at an angle of 6° from the horizontal axis.

Charge controller sizing

Solar charge controllers regulate the energy flowing from the PV array and transfer it directly to the batteries as a DC-coupled system, which is the most efficient and effective manner (Smalley, 2015). It prevents overcharging and may protect against overvoltage.

$$\text{controller size} = \frac{\text{power}}{\text{voltage}} + 25\% \left(\frac{\text{power}}{\text{voltage}} \right) \tag{8}$$

$$\text{controller size} = \frac{150}{12} + 25\% \left(\frac{150}{12} \right)$$

$$= 15.625 \text{ Amperes say } 16 \text{ Amps.}$$

∴ A charge controller of 16 amperes should be selected

2.3 Cad Design

CAD software Solidworks was used to design the solar powered pump system. The Figure 4 shows the 3D isometric view of the system, the Figure 5 shows the right-side view (or the control panel (the control panel is the part of the system where the inverter and charge controller can be accessed) and the Figure 5 shows the 3rd angle projection of the system respectively.

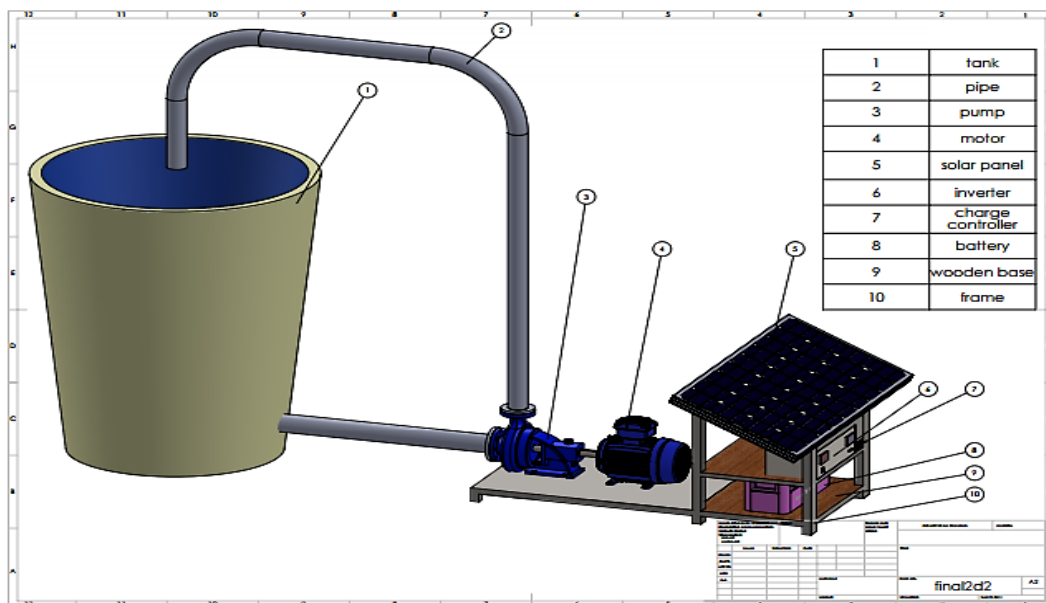


Figure 4. 3D isometric view of the system

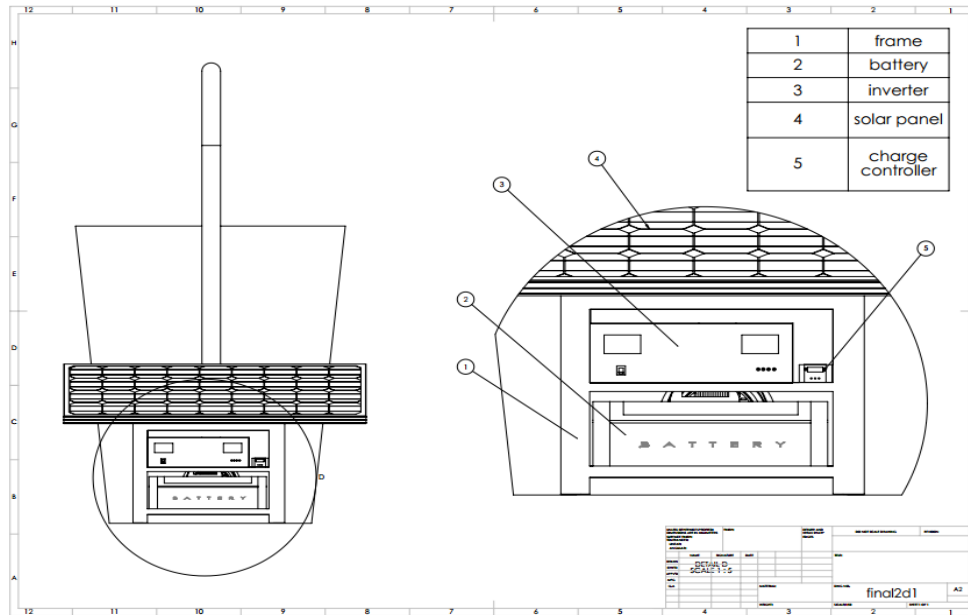


Figure 5. System control panel

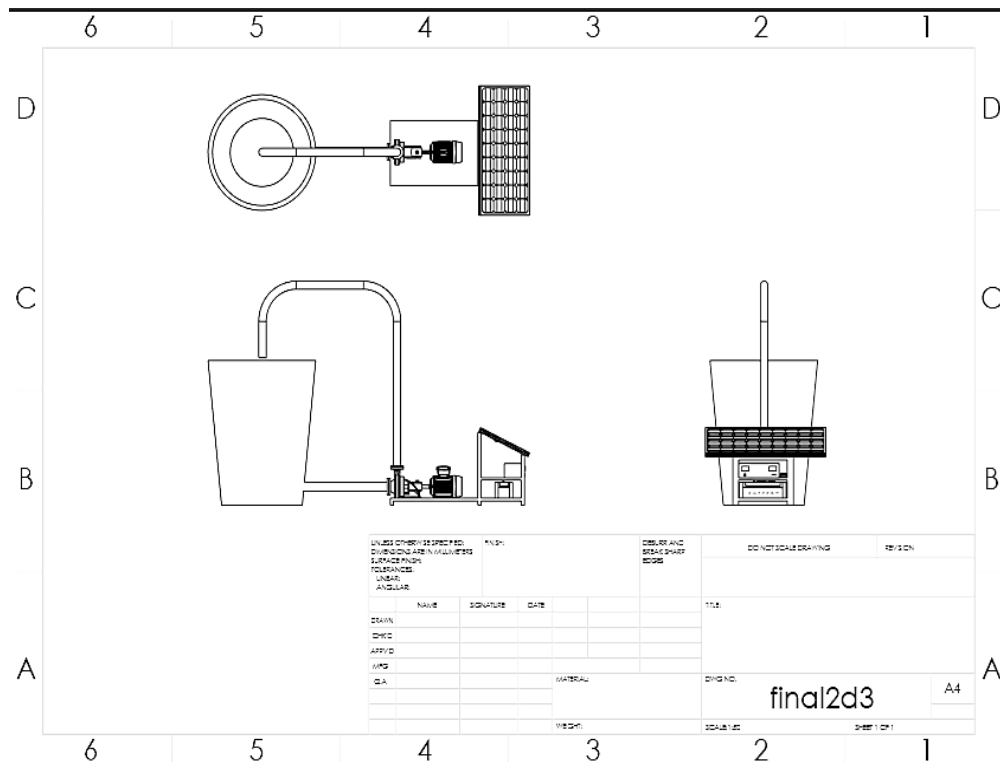


Figure 6. The 3rd angle projection

2.4 Construction

The solar-powered pump was fabricated and assembled at the workshop of the Mechanical Engineering Department of Afe Babalola University, Ado-Ekiti. The construction process included the purchase of materials, measurement of materials, cutting of selected materials, folding and joining of the materials, welding and painting of materials. After the various components were separately fabricated, they were assembled. The solar powered pump consists of several components, as illustrated in the working drawing. The various steps adopted for this work included the design theory, design calculations and fabrication.

2.4.1 Fabrication Process

The construction of the system involved fabrication of only 2 key components which were the system shelf and the roof panel support.

- i. The shelf;

This was fabricated using 1.5inch mild steel bars which were cut and welded according to specification as shown in the Figure 7. Plywood was used for the base layers to support the inverter and battery and a hole was drilled in the upper layer for wiring.

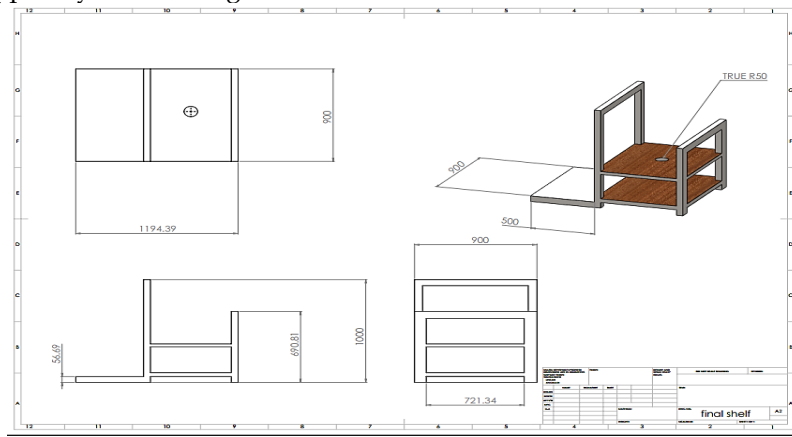


Figure 7. System shelf

ii. Roof panel support

The solar pump was adapted to provide water for the laboratories at the engineering college which warranted the need to install the panel on a roof rather than the initial setup on the shelf. A panel support shown in the Figure 8 was designed to hold the panel firm on the roof and to provide the accurate panel tilt angle.

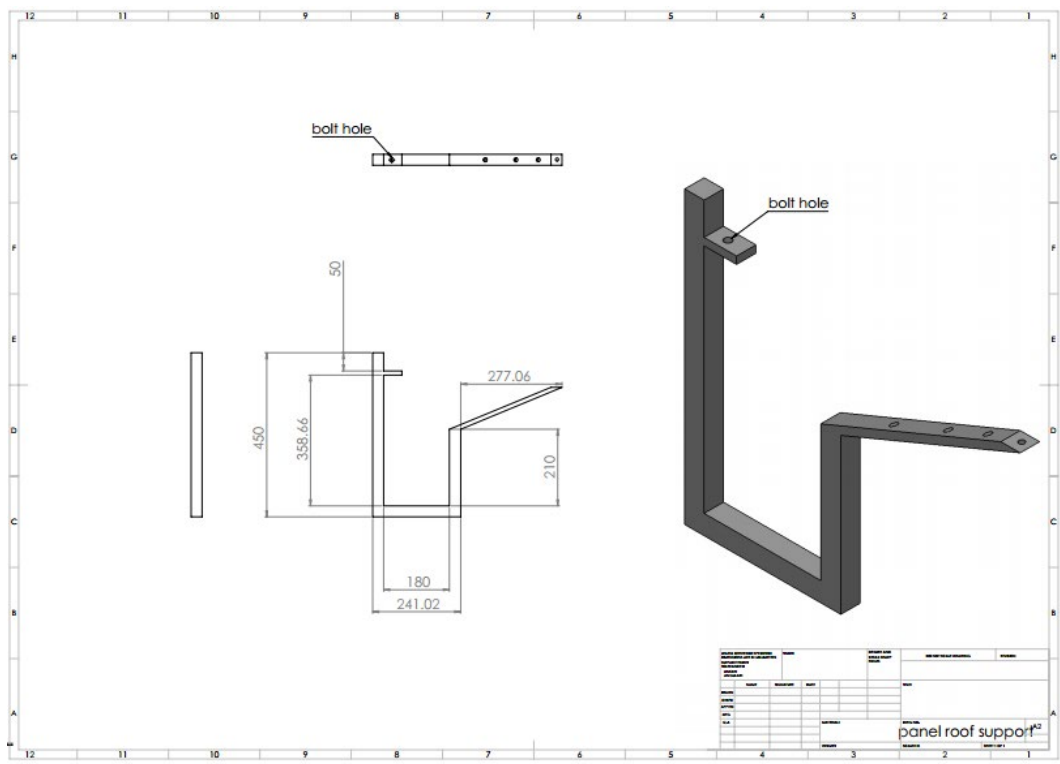


Figure 8. Roof panel support

2.4.2 Procurement and assembly

The various components of the system such as the battery, inverter, solar panel, charge controller, wires, and pipes were all procured after which they were assembled as depicted in the Figure 4.

2.5 Testing

After the fabrication and assembly of the system, the battery, inverter and solar panel output voltages were confirmed for safety using a multimeter. The solar panel to battery connection was monitored for 6 hours and various readings were taken using the multimeter. The pump was then connected directly to the inverter and run for 30 minutes. The results of the tests are shown and discussed in in the next section.

2.6. Solar pump selection/calculator software

A system selection/calculator software application was designed using C++ to enable users select the solar powered pump system and its components without doing rigorous calculations themselves. The software also includes battery sizing, inverter sizing, solar sizing, and charge controller sizing. The Figure 9 shows the “Pump selection” page, the Figure 10 shows the “Battery sizing” page, the Figure 11 shows the Inverter sizing page, the Figure 12 is the Solar panel sizing page and the Figure 13 is the Charge controller sizing page respectively.

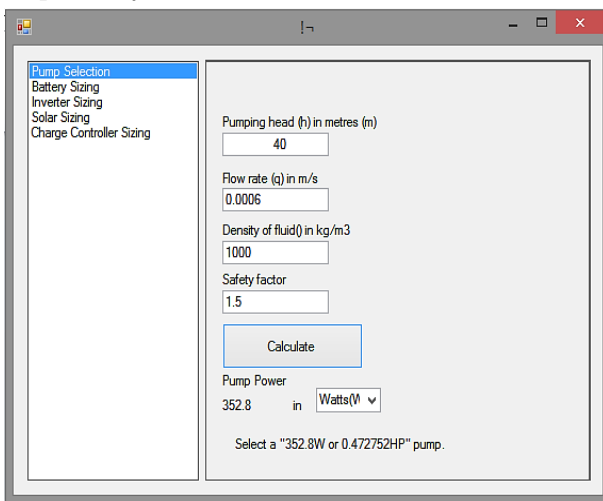


Figure 9. Pump selection page

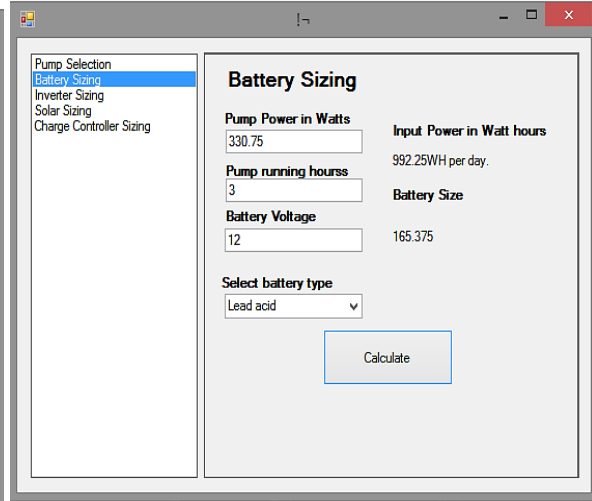


Figure 10. Battery sizing page

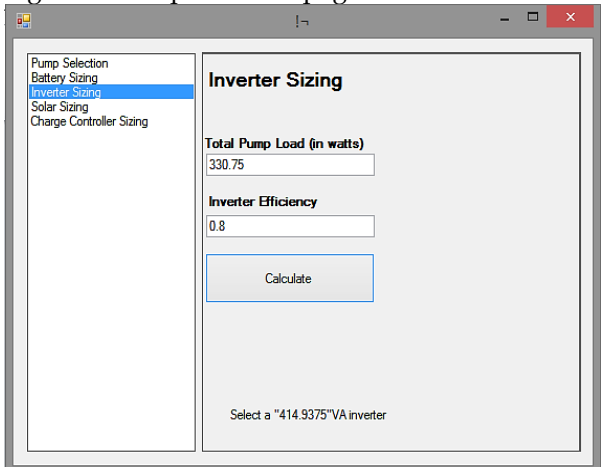


Figure 11. Inverter sizing page

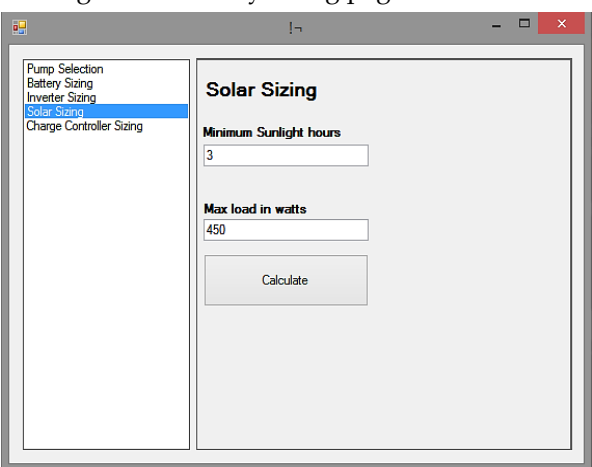


Figure 12. Solar panel sizing page

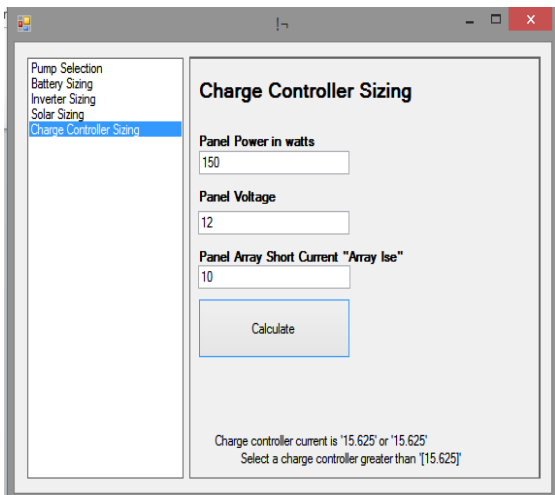


Figure 13. Charge controller sizing page

2.7. Bill of Engineering Materials and Evaluation

The Table 4 shows the materials used, their quantity and their respective costs in Naira.

Table 4 Bill of Engineering Materials and Evaluation

S/N	MATERIAL	QUANTITY	PRICE (NGN)
1	150 watts Solar panel	1	30,000
2	12v 150AH deep cycle battery	1	60,000
3	12v 1000w inverter	1	30,000
4	20A solar charge controller	1	15,000
5	0.5hp Centrifugal pump	1	12,000
6	Mild steel angle bars	2 lengths	7,000
7	PVC pipe	2 lengths	2,000
8	Plywood	2	1,000
9	Pipe fittings	5	3000
10	Pipe glue	1	1,000
11	Plastic water drum	1	3,500
12	Plug and electric wire	1	1,500
13	Solar wires	5 yards	2,500
14	Fabrication	-	8,000
15	Transportation	-	13,000
16	Workshop cost	-	20,000
17	Miscellaneous	10% of total cost	20,850
		TOTAL	230,350

3. Result and Discussion

After testing and monitoring the operation of the solar powered pump system on the 26th of April 2018 for about 6 hours, various readings of the system's voltages were taken using a multimeter as depicted in the Table 5.

Table 5 System Voltage Readings

TIME	SOLAR VOLTAGE	PANEL	BATTERY VOLTAGE	LOAD/NO LOAD
12:00	11.90		11.86	No load
12:30	12.10		12.05	No load
12:54	13.06		13.02	No load
13:00	13.12		13.08	No load
14:30	13.19		13.15	No load
15:20	13.20		13.16	No load
15:45	13.28		13.24	No load
15:46	13.30		13.25	No load
15:47	13.31		13.25	No load
15:48	13.32		13.27	No load
16:00	13.24		13.18	No load
16:01	13.21		13.15	No load
16:08	13.16		13.11	No load
16:20	13.13		13.08	No load
16:40	13.15		13.10	No load
16:43	13.19		13.14	No load
17:00	13.24		13.19	No load
17:35	12.31		12.27	No load
17:35	12.06		12.01	Load
18:05	12.24		12.20	Load
18:05	12.69		12.64	No load
18:08	12.64		12.60	No load
18:11	12.62		12.58	No load
18:35	9.38		12.14	No load
18:42	8.21		12.00	No load

The Figure 14 is a graph of voltage against time based on the Table 4.

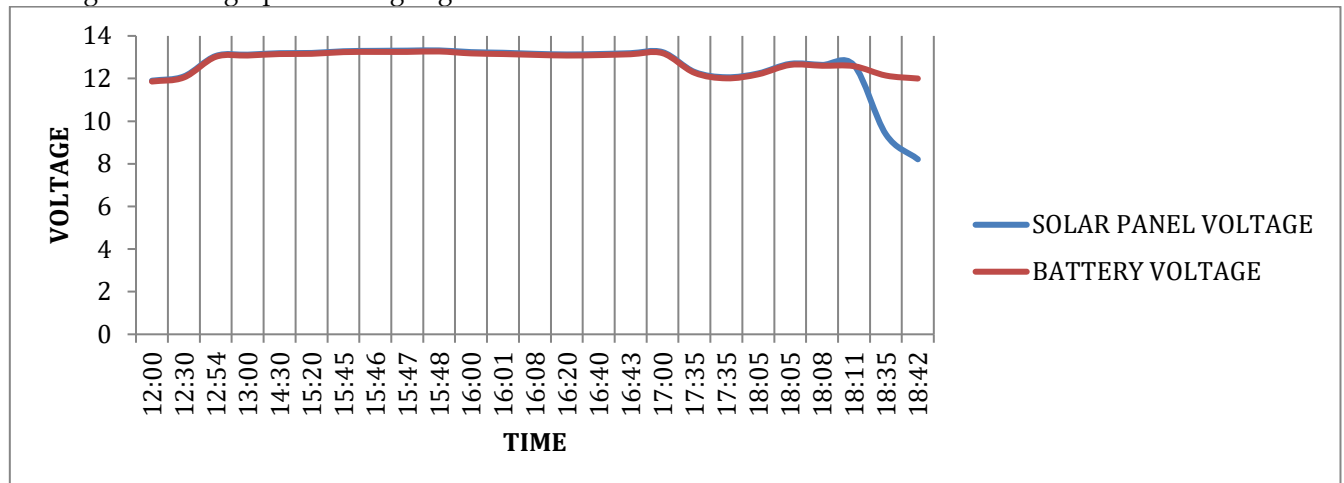


Figure 14. Graph of Voltage against Time

From the readings, it was observed that during the charging period, the battery voltage differed from the solar panel readings by about 4 volts due to energy losses in the system. It was also observed that cloud blockage of sunlight affected the radiation intensity and voltage generated by the solar panel. Finally, it was observed that as the sun set in the later hours of the day, the solar panel generated very little electricity as evident in the voltage readings from 18:09 in the Table 4. The 0.5hp centrifugal pump was used to pump water from 2 storage tanks at ground level to a 5metre high overhead tank with a capacity of 600litres($0.6m^3$). The tank was filled in 30 minutes at a flow rate of $0.35m^3/s$.

From the pump performance, the efficiency can be calculated by $\frac{\text{Actual flow rate}}{\text{design flow rate}} \times 100$

$$= \frac{0.35}{0.60} \times 100 = 58.33\%$$

4. Conclusions

- i. The study successfully achieved the design and development of a solar-powered domestic water pumping system using locally sourced materials, demonstrating that indigenous resources can be effectively utilized to produce functional and reliable renewable energy-based water supply systems.
- ii. Experimental testing confirmed that the developed system operates efficiently under real environmental conditions, delivering an adequate flow rate and acceptable pump efficiency suitable for domestic water supply applications, thereby validating the system's operational effectiveness.
- iii. The findings indicate that the solar-powered pumping system significantly reduces dependence on grid electricity and fossil fuels, leading to lower operating costs and improved energy efficiency when compared with conventional pumping systems.
- iv. The system's reliance on photovoltaic energy ensures zero direct carbon emissions during operation, thereby contributing to environmental sustainability and supporting global efforts toward clean energy adoption and climate change mitigation.
- v. The results demonstrate that the developed solar-powered pump is particularly suitable for deployment in off-grid and energy-constrained rural and semi-urban areas, offering a practical, scalable, and sustainable solution for improving domestic water access.

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