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Design and Construction of a Mobile Solar-Powered Water Pumping System Suitable for Niger Delta Rural Dwellers

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Abstract- To ameliorate the low availability of electrical power and poor water supply conditions experienced by rural dwellers in the Niger Delta region. A mobile standalone, solar-powered water pumping system was designed, fabricated, and tested to make use of the freely available sun power in this study. Using the solar generation factor for Nigeria, detailed calculations were carried out to obtain the design parameters necessary for sufficiently sizing the various mobile standalone solar powered water pumping system components. Also, the machine was tested for performance by determining its volume flow rate. The results of two separate experiments obtained show that at a total height of 19.27m, using a 0.37kW pump, a tank of 1200liters was filled in less than an hour with flow rates of 21.43l/min and 20.69l/min. Hence, the results obtained demonstrated the functionality and feasibility of the pilot system operation in the region. Consequently, the system produced is reliable, safe, and can be operated with low maintenance cost as a mobile standalone system to supply water to homes and public institutions in the Niger Delta area. Similar studies should be encouraged in other regions of the country to help solve the problem of portable water supply in Nigeria.

Indexed Terms- Design, Flow rate, Mobile, Rural dwellers, Solar, water pumping system

I. INTRODUCTION

Water is essential for the development and maintenance of the dynamics of every ramification of society (Murphy, 2006). The availability of a safe and reliable source of water is an essential prerequisite for sustained development (Asonye et al, 2007). The Niger Delta region of Nigeria is naturally endowed with abundant water resources. Even with this potential, problems related to the availability of potable drinking water are being faced in several rural parts of the Niger Delta of Nigeria with the people having to drink from polluted streams and rivers (Horizon Concept, 2000; Babatunde, 2020). As reported in Owamahet al. (2021), majority of the rural communities and public institutions in the Niger Delta have no access to a good drinking water source with the greater number of their water sources not meeting the World Health Organization (WHO) water quality guidelines (WHO, 1993) and Federal Environmental Protection Agency standards and guidelines in Nigeria (FEPA, 1991). To combat the water shortage experienced, various governments within the region set up water corporations to manage this important resource (kong et al, 2012). But most of these water corporations are not functioning and their facilities had been vandalized or stolen. Another problem is that the activities of oil pipeline vandals had caused oil pollution of water which constitutes a potential health risk to humans who use water for domestic and drinking purposes and consume fish found therein (Helmer and Hilhorst, 2006; Atubi, 2009). Thus, this has led the populace to consume the available contaminated water that can cause various diseases such as typhoid fever, dysentery, cholera, and other intestinal diseases (Adeyemi and Aro, 2004).

Again, Nigeria faces the triple challenges of providing a reliable power supply, reducing greenhouse gas emissions, and keeping energy affordable to consumers. The low availability of electricity in Nigeria has worsened over the years, which also affected the Niger Delta rural dwellers. Its commercial and industrial sectors have become heavily reliant on self-generated power, using petrol and diesel generators. As a result of this problem, domestic water supply to homes and public institutions in the region relied largely on self-generated power using petrol and diesel generators, contributing to environmental pollution of the region (Oyedepo et al.,2018).Furthermore, the problem of bad terrain in the major part of the riverine areas had made it difficult and expensive to transport portable water to the people in the region. Consequently, the unavailability and inadequate electric power supply and other problem mentioned in this region had brought about the poor provision of water in Niger Delta rural areas.This challenge of poor supply had contributed negatively to the quality of health, economic activities, and agricultural productivity of the people. There need to look at renewable resources such as solar energy to ameliorate the poor availability and pollution caused by the utilization of fossil fuels. The Niger Delta region possesses an annual average solar irradiation 5.5kWh/m2/day and experiences an average sunshine of 6 hours daily(Fasina, 2019).Therefore, solar water pumping system application has great prospect of utilization in this country specifically in the Niger Delta region.

Solar water pumping is one of the most widely used solar energy applications all over the world today, with thousands of solar-powered water pumping systems installed both in developed and developing countries (Abu-Aligah, 2011; Abdourraziq et al, 2013; and Kavitha et al, 2014). Solar water pumping applications include domestic water, livestock watering, rural water supplies, and irrigation. Solar water pumping is a technology that uses photovoltaic energy to convert sunlight into electrical energy that powers water pumps for water supply. In solar water pumping applications, water may be stored in a storage tank; however, a period of overcast may exist for some days making the use of backup batteries often necessary (Ozoegwu& Akpan, 2021). Solar water pumping systems are relatively simple, require little maintenance, and provide independent water pumping schemes(Gualteros &Rousse, 2021). A typical solar water pumping system consists of an array of solar panels, a direct current (DC) controller, a pump, and a water tank (Hamidat and Benyoucef, 2008; Boxwell, 2017).

Many researchers have carried out studies in solar water pumping applications because of its importance as mentioned. Bolaji and Adu (2007) successfully carried out the design of a Photovoltaic pumping machine to supply water to rural dwellers in Nigeria. The paper reported that this system is reliable. Also, Abu – Aligah (2011) design a photovoltaic water pumping system and compared it with a Diesel-powered Pump. The study revealed that there are differences between the two powered sources in terms of cost and reliability. It further stated that Diesel Pumps are typically characterized by a lower first cost but very high operation and maintenance costs. While solar pumps have high initial costs but low maintenance and operation costs, which made them more economical than diesel engine-powered pumping machines. Likewise, Raghav et al. (2013) conducted a study on a solar water pumping system of 1.5 kW capacity and concluded that the reliable life of the system is about 15–20 years. Furthermore, Yorkor and Leton (2018) designed a solar-powered water pumping system that can supply water to rural dwellers in River State. The study stated that a solar water pumping system is feasible and can provide a solution to the problem of the unavailability of drinking water in rural communities in the state. In other studies, Mohammadu (2014) and Okakwu et al. (2022) stated that the application of solar water pumping systems for drinking and irrigation in Nigeria is in a steady state. Also, Ezenugu and Ezeh, (2019) carried out a study of a standalone solar-powered water pumping system at Imo State University Faculty of Engineering. Ayodele et al. (2019) also studied a standalone solar water pumping system in various abattoirs in Ibadan, Nigeria, and Gbaarabe and Sadiki, (2022) carried out a reengineering of a hybrid solar and diesel water supply system in the Niger Delta. These research works concluded that the utilization of solar energy for pumping water should be encouraged in Nigeria and suggested that case studies should be encouraged to harness the availability of solar potential in Nigeria.

The findings from the previous studies review indicated that solar-powered water pumping and mobile internal combustion engines (ICE) powered water pumping machines are available and well-studied. From the available literature look at during this study, a mobile standalone solar-powered water pumping machine application in the Niger Delta region has not been previously undertaken. Thus, the problem of vandalization and theft common with Niger Delta rural dwellers for panel and pump for fixed installation have not been addressed. Therefore, this study intends to bridge this gap of knowledge by designing and constructing a mobile solar-powered water pumping system that can be utilized by Niger Delta rural dwellers.Hence, the goal of this study is to develop a mobile standalone solar water pumping system that can be used in the Niger Delta area of Nigeria. The proposed system intends to be used to pump water from boreholes, in public institutions, market places, rural settlements, and isolated areas in Niger Delta as mentioned. Also, after pumping water, it can be removed and stored in a safe place until it is needed again to prevent vandalization.

II. MATERIALS AND METHOD

2.1 Design Consideration and Materials Selection

In carrying out the design of the mobile standalone solar water pumping system factors such as Cost of the materials, functionality, reliability, portability, and space, usability, maintenance, cost, and safety were consideredto achieve a feasible and functional system. The materials selected for the design of the system were based on their mechanical properties, physical properties, fabrication requirement, and economical requirement. The majority of the components selected are manufactured in Nigeria which makes them easy to access. The selected components and the purpose for choosing them are presented in Table 1.

Table 1: The Materials Needed for the Project Work

S/N	Materials	Purpose
1	Pump	To pump water
2	Mild Steel Angle bar	To construct the solar panel stand
3	Mild steel sheet	To construct the system's box
4	Electrical cables	For wiring DC and AC circuit
5	Switches	To operate and control the pumping system
6	Fan	To remove heat from the system's chamber
7	25.4mm pipe and coupling	To convey water in and out of the system
8	Lamp indicator	To indicate the system has been switched on
9	Socket	For 13A and 15A AC outlets for non- pumping application.
10	Timer	To control the time of operation
11	Battery	To store energy and also make the system more reliable.
12	Solar panel	To convert solar energy into electrical energy.
13	Inverter	To convert DC to AC
14	Tank	To store water
15	Tires	To move the system from one location to another.

2.2 The Mobile Solar Powered Water Pumping System Concept

The major components are solar panel array, solar charge controller, battery, inverter, and AC pump as shown in Figure 1. In this Concept, the solar PV will absorb sunlight intensity or solar irradiation, which will be converted to DC electricity. Then, the solar charge controller will regulate the voltage and current coming from the PV panel going to the battery and prevents battery overcharging, also prolonging the battery life. Furthermore, the battery stores the electrical power need especially for the no sun period. Next, the inverter converts the DC output produced by PV modules into a clean AC for appliances such as the AC pump and AC Switches and Sockets. Furtherly, the AC pump pumps the water from the borehole to the storage tank for water supply output. Apart from the solar PV panel, the other components are encased in a box for ease of mobility. Advantages of this concept are its ease of mobility, portability to overcome the challenge of poor terrain, its ability to pump water from similar wells in various locations,and it is not exposed to vandalization because it will be kept in a safe place after being used. The only disadvantage is the cost of mobility which safety of the system carter for it.

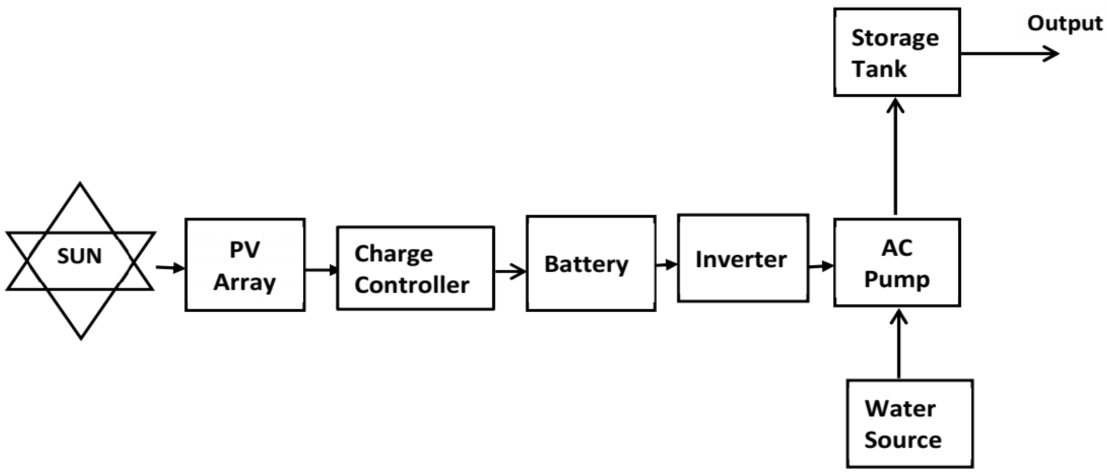

Figure 1: The Block diagram of theMobile Standalone Solar water pumping system

2.3 Detail Design of the Mobile Standalone Solar Powered Water Pumping System

Typical borehole information in Warri, Delta State, Nigeria was considered for the design as follows:
Depth from water level to pump = 9.14m

Height from the pump to the top of the tank = 9.75m

The total dynamic height (TDH) can be computed using Equation (1) as stated in Yorkor and Leton (2018). Using the data of the borehole aforementioned.

$TDH = TVH + h_f$ (1)

where TVH is the total vertical, which is the sum of depth from water level to pump and height of tank of the pump to the top of the tank, h_f is pipe friction loss, which was assumed to be 2% of TVH (Yorkor and Leton, 2018), using the data of the borehole aforementioned.

Equation (2) was used to calculate the hydraulic energy (E_h) required to pump water from the well to the TDH as stated in Frenjo et al. (2017).

Hydraulic energy, $E_h = \rho \times g \times v \times TDH$ (2)

where, ρ = density of water, 1000kg/m^3, g = acceleration due to gravity, 9.8kg/m^3, v = required volume of water tank, 1.2m^3/day. This volume of the water tank was chosen as provided by Enuneku et al. (2021) for homes and public institutions' water daily consumption in rural areas. The value of hydraulic energy obtained was 63.01Wh.

2.3.1Solar Power System Sizing

A pump capacity (P_p) that can pump water above the total dynamic head was computed using Equation (3) as stated in Frenjo et al. (2017). It was assumed that the fan heat expeller power (P_e) will be 10W also, 2 hours assumed for the time taken (t) to fill the water storage tank.

Total energy (E_t) = (Pp +Pe) x t(3)

The Total PV panels' energy needed per day (E_d) is the total appliances in watt-hours per day (Tamrakar et al., 2022), which was computed using Equation (.4).

$E_d = 1.3E_t$ (4)

2.3.2 Size the PV Panel

The peak watt, W_P produced depends on the size of the PV panel and the climate of the site location (Nigeria). For Niger Delta, Nigeria, the panel generation factor (PGF) is 3.596 (Yorkor and Leton, 2018) was considered. The total watt–peak (Wp) of PV panel capacity was determined using Equation (5)

The Total Watt -Peak of PV Capacity, $W_p = \frac{E_d}{PGF}$

(5)

The available panel of 200watts was selected using Equation (6).

Number of PV panels,

$$N_{PV} = \frac{W_p}{\text{Available panel power}} \quad (6)$$

2.3.3 Inverter Sizing

For safety, the inverter should be approximately 3 times the capacity of the motor and must be added to the inverter capacity to handle surge current during starting (Keller and Kroposki, 2010). This was considered for this study.

2.3.4 Battery Sizing

The sizing of the battery was based on the desired number of days of autonomy. The usable battery capacity (B_c) was determined using Equation (7) as stated in RET Screen (2004). The battery loss(η_b) and depth of discharge factors (η_d) were taken as 0.85 and 0.6 respectively.

Battery capacity $B_c = \frac{E_t \times D}{\eta_b \times \eta_d \times V}$ (7)

WhereE is the total watt-hours per day used by the appliance, D is the days of autonomy at½ day, and V is the nominal battery voltage at 12V.

2.3.5Solar Charge Controller Sizing

The PV module specification considered for the design are as follows: Pm =200Wp, Vm=37.8V, Voc =44.64V, Isc = 6.05A. The solar charge controller rating was calculated using Equation (8) as stated in Bhoye and Sharma (2014).

Solar charge controller rating = N_{pv} xI_{sc} x1.3 (8)

2.4MANUFACTURING SPECIFICATIONS

Based on the values obtained from the design specification, the manufacturing specifications were selected and presented in Table 2.

Table 2: Material Specifications

S/N	Components	Material	Dimension	Qty
1	Solar Panel	PV Cell	200W	2
2	Battery	Lead Acid and Plastic	100AH	1
3	Inverter	Plastic and Metal	1000W	1
4	Pump	Plastic and Metal	0.75kW	1
5	Charge controller	Plastic and metal	30AM	1
6	Heat Expeller	Metal	10W	1
7	Timer	Plastic		1
8	Switch	Plastic		4
9	Angle bar	Mild steel (ASTM A36)	5m Length	6
10	Flat plate	Galvanized metal	1.5mm Thickness	1
11	Bolt & Nut	Mild steel (ASTM A36)	10mm, 8mm	8, 4
14	Pipe	Plastic	25.4mm	1
15	Pipe	Galvanized	2m	1
16	Union connector	Plastic	25.4mm	4
17	Tyres	Rubber	ϕ75mm	4
18	DC & AC Cables	Copper wire	9m	1
19	Socket	Plastic	13A/15A	2

2.5Manufacturing Process and Operation

Some of the mobile standalone solar-powered water pumping system components were constructed locally such as the solar panel stand, metal box, boxer cover, and metal handle while other components such as AC pump, battery, inverter, solar charge controller, fan, sockets, and switch were purchased from the shelf in Nigeria. The arrangement was assembled locally based on the manufacturing specifications provided in Table2. The solar panel stand was welded using mild steel (ASTM36) angle bar with the aid of an arc welding machine. The stand was constructed in such a way that it can be folded after being used for ease of storage. Also, a 1.5mm thick mild steel sheet was used to form the metal box and cover it with the aid of an arc welding machine. DC cables were used to connect the solar panel and solar charge controller and battery while the AC wires were to connect the inverter and AC pump, switch, and sockets.

The mobile solar water pumping system is set up as shown in Figures2 and 3. The pump suction is connected to the borehole fittedoutlet to take water from the well, while the pump discharge is connected to the water storage tank. When the system is switched on after the battery is wellcharged by the solar panel, the system pumps water from the borehole through the suction pipe and discharges it to the water storage tank through the discharge pipe. There is an AC socket attached to the metal box for low electricity demand. The system is switched off when the tank is filled. The operation of the switch on and off can also be controlled by a contactor attached to the metal box when necessary. Furthermore, there is a timer to control the use of the electrical power supply to the pump. After the operation, the solar panel, the solar panel stand, and the metal box are detached and kept in a safe placeuntil the need arises.

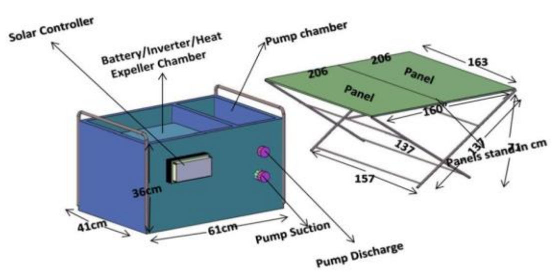

Figure 2: Isometric View of the Mobile Standalone Solar Powered Water Pumping System

Figure (3): Pictorial View of the Mobile standalone Solar Powered Water Pumping System

2.6Test and Evaluation

After the construction of the mobile standalone solar powered water pumping system, it was tested by connecting it to an existing borehole in Warri, Delta State. When the machine was not on load, the battery voltage and current, and ambient temperature of the environment were measured and recorded every 30 minutes for 2 hours per day between the hours of 9am to 3pm for 30 days. Also, the solar pumping machine was used to pump from the existing well into a 1.2m^3 (1200 litres) water storage tank at TDH of 19.27m as stated in during the design stage. The test was canaried out twice and on different days. The first day was between the hours of 3.58pm to 1.56pm and the second day was between the hours of 10.58am to 11.58am to fill the water storage tank. During this process, the time taken to fill the water storage tank, voltage, current and ambient temperature were measured and recorded accordingly.

In evaluating the performance of the mobile solar powered water pumping machine, the principle of conservation of energy and mass was considered. Equations (9) and (10) were used to determine the actual hydraulic energy and volume flow rate of the machine respectively.

$$E = IVt \quad (9)$$

where I, V, and t represent current, voltage, and time respectively

$$\dot{V} = \frac{v}{t} \quad (10)$$

where v is the volume of water in the tank

III. RESULTS AND DISCUSSION

3.1 Available Energy to Power the System

The results of the test carried out on no load on the system are presented in Table 3. Also, the outcomes of hydraulic energy computed from Equation (9) are presented in this table.

Table3: Voltage, Current, and Ambient temperature readings

DAY	VOLTAGE(V)	CURRENT (A)	TEMP. (^{0}C)	DURATION (h)	ENERGY (Wh)
1	12.9	2.8	37	2	72.24
2	13.0	3.1	37	2	80.6
3	13.2	3.2	38	2	84.48
4	13.1	3.1	37	2	81.22
5	13.0	2.6	37	2	67.60
6	13.4	3.9	38	2	104.52
7	13.3	3.6	39	2	95.76
8	13.2	3.4	38	2	89.76
9	12.8	2.6	37	2	66.56
10	13.2	3.5	38	2	92.40
11	13.0	3.4	38	2	88.40
12	13.2	3.1	39	2	81.84
13	13.4	4.0	39	2	107.2
14	13.4	4.1	39	2	109.88
15	13.4	4.2	39	2	112.56
16	13.4	4.1	39	2	109.88
17	13.2	3.9	38	2	102.98
18	13.1	3.7	38	2	96.94
19	13.5	4.6	39	2	124.2
20	13.2	3.7	38	2	97.68
21	13.4	3.9	38	2	104.52
22	13.1	3.7	37	2	96.94
23	13.3	4.2	38	2	111.72
24	13.2	4.1	38	2	108.24
25	13.4	4.5	39	2	120.60
26	13.2	2.9	38	2	76.56
27	13.4	4.6	39	2	123.20
28	13.3	4.2	38	2	111.75
29	13.4	4.7	39	2	125.96
30	13.2	3.9	38	2	102.96
TOTAL	396.8	111.3	1144	60	2949.15
AVG	13.2V	3.71A	38.1^{0}C	2	98.305Wh

It was observed from Table 4 that the voltage, current, and temperature values of the system obtained range from 12.9 to 13.2V, 2.8 to 4.7A, and 37 to 38 ^{0}C respectively. The values obtained have shown that these parameters were stable during the system operation. Also, the available energy obtained ranges from 72.24 to 125.96Wh. in addition, the value of the average available energy calculated is 98.305Wh, which is greater than the required energy of 63.01Wh obtained to operate the mobile standalone solar-powered water pumping machine. Again, this indicates that there is adequate available solar energy to charge the battery in Warri that can be used for the system.

3.2 Flow Rate Evaluation

The results of the tests carried out when the system was in operation (pumping water) are presented in Figures 4 and 5. The outcomes volume flow rates computed from Equation (10) are presented in Figure 6.

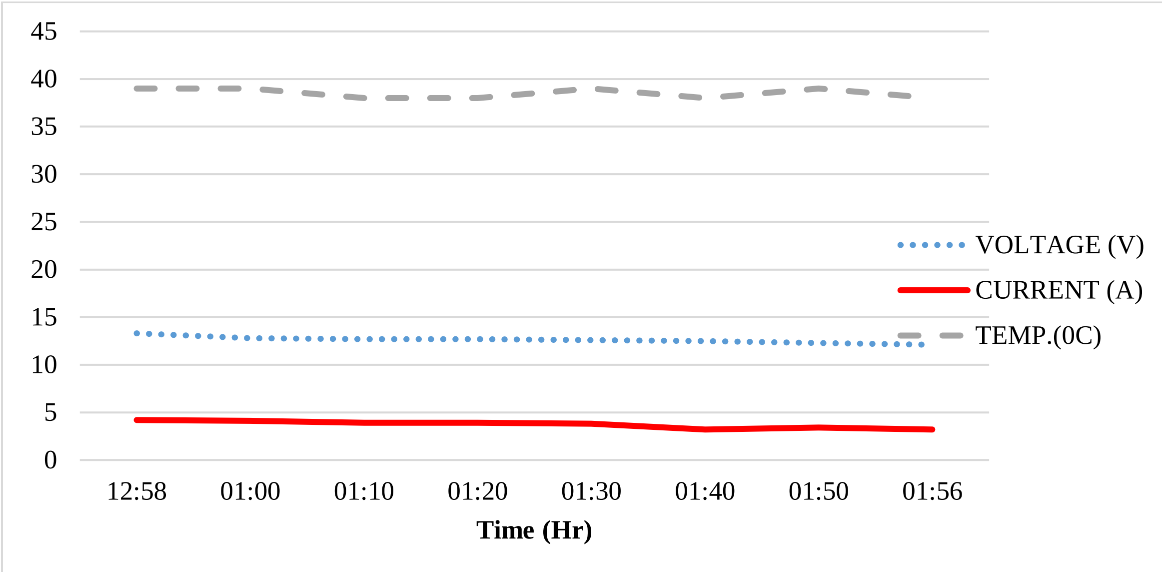

Figure 4: The variation of current, voltage and temperature with time for first test

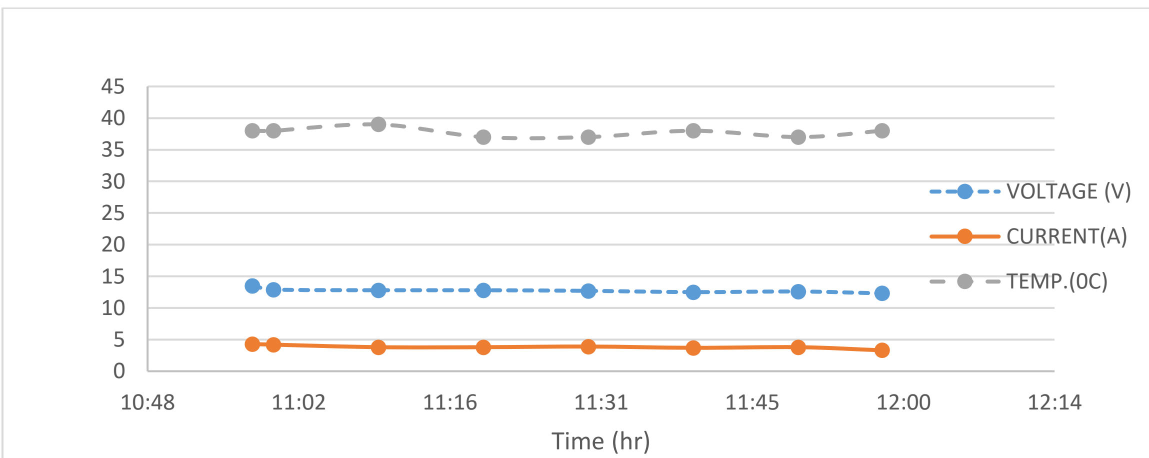

Figure 5: The variation of current, voltage, and temperature with time for the second test

As shown in Figures 4 and 5, there was a slight variation in voltage and current with time during the water operation test. This indicates that the operation of the mobile solar-powered water pump was stable during the system operation and it can be recommended for water pumping in small-scale utilization in rural communities of the Niger Delta region.

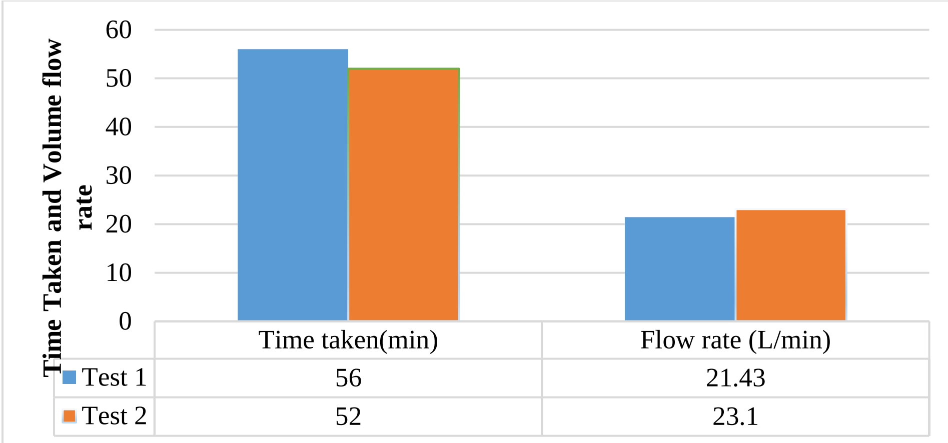

Figure 6 (4.1): The value of tine and flow rate for the two tests

As shown in Figure 6, the time taken for the mobile standalone solar water pumping system to fill the 1200 litres capacity water storage tank is 56minutes and 52minutes for the first and second tests respectively. Also, the volume flow rates for the two tests carried out are 21.43 and 23.1 litre/minute to fill the tank at TDH of 19.27m using a 0.37kW pump. Again, this has demonstrated that the mobile standalone solar-powered pumping system designed and constructed was found to be functional and feasible. The pilot system provided the basic design requirement for a mobile standalone solar water pumping system, which can be scaled up for higher demand. Therefore, the system can be utilized for pumping water in the Niger Delta region.

The construction of the stand so that the stand can be folded was not easy at the beginning of the fabrication. Also, the mounting of the pump in the Pump chamber was challenging. These challenges were overcome after many attempts and accurate measurements taken from working drawings.

CONCLUSION AND RECOMMENDATION

The design, fabrication, and performance evaluation of a mobile standalone solar-powered water pumping machine has been successfully carried out. The analysis carried out revealed that the available solar energy in Warri was enough to power the system. Test results have shown that at a total dynamic height of 19.27m using a 0.37kW pump, overhead tanks of 1200 liters were filled between 52 and 55 minutes. Majority of the materials used were sourced locally, it is reliable, safe, and can be operated at low-cost maintenance. Furthermore, the system was found to be functional and feasible to pump and supply good water to Niger Delta rural dwellers. Also, similar studies should be encouraged for other regions in Nigeria that have similar situations.

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