SOLAR-POWERED WATER PUMPING FOR RURAL COMMUNITY WATER SUPPLY

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Abstract

Many people in the rural communities lack access to clean and safe water for drinking and personal hygiene. Cases of waterborne diseases such as cholera, dysentery, typhoid, etc. are common in rural communities due to the poor quality of water they drink from streams, lakes, ponds, etc. Underground water from deep wells is safer to use. This paper discusses solar water pumping as an alternative to electric water pumping in rural areas not connected to the national grid. The system considered 100 litres as the minimum daily water requirement per person to design a DC-powered solar water pumping for 1,500 persons in a rural community with a daily sun hour of 5.5h/day. The system consist of the solar panels, DC motor, pump, and water storage tank and the method of solar water pump design and sizing is presented. The solar-powered water pumping can significantly improve water access and quality in rural areas, contributing to the overall well-being and health of the community. Governments and organizations should consider the implementation of solar-based water pump in order to provide clean and safe water for people in the rural areas.

Keywords: Solar-powered, Water, Rural Communities, Solar Water pumping

Introduction

Access to clean and safe water for drinking and sanitation has been considered one of the basic human rights essentials according to the United Nations resolution on 28 July 2010. Therefore, it has become the responsibility of the government to provide access to clean and safe water to rural communities (Machado et al., 2023).The World Health Organization recommends between 50-100 litres of water per person per day for personal and domestic uses.

In rural areas, surface water from lakes, streams, rivers, ponds, etc. is used for drinking, cooking, and personal hygiene. Untreated water from these sources is not safe for human consumption as such outbreak of diseases such as typhoid, dysentery, and cholera is frequent in rural communities (Adu &Bolaji, 2004). The lack of access to adequate safe water supply contributes to death and illness, especially in children (Ishaku et al., 2011) and according to Nawaz et al., (2023) about 2.2 million lives are lost annually due to poor sanitation and the use of contaminated water. Underground water from deep wells is clean and safer to use but the greatest problem is lack of electricity which is required to pump the water for the people (Yorkor & Leton, 2017). Many rural communities are not connected to the national grid (Muhammadu, 2014) and even the few that are connected continue to experience epileptic power supply(Yorkor & Leton, 2017).

Traditionally, the human physical power used in fetching water from a deep well is not convenient for small children, aged and physically challenged (Usman & Mbajiorgu, 2019). The Hand-operated water pumps can reduce the effort applied in fetching water and make life a bit easier but this pumps often fail due to excessive force applied in pumping the water and require frequent maintenance which makes it costly for rural communities as most of the parts are not readily available(Ramos & Ramos, 2009). Also, the discharge capacity is too low for large communities (Bruni &Spuhler, 2020) thus making the petrol and diesel-powered pumps better alternatives.

But the recent increase in the price of petrol as a result of petrol subsidy removal in Nigeria and the air pollution as a result of the release of harmful gases into the atmosphere from the burning of fuels in petrol and diesel engines and the increase in the level of greenhouse gases leading to global warming causing floods leading to loss of lives and properties (Prasad, 2019)(Verma et al., 2020) have necessitated finding and using a cheaper and environment-friendly alternative to provide access to clean and safe water to the rural communities across the country.

Nigeria is located in the solar belt, thereby receiving maximum sunlight exposure. This available and free renewable energy can be harnessed for purposes such as solar water pumping(Abdullahi et al., 2017). The use of a PV direct solar pumping system will ensure a smooth and regular water supply in rural areas at reduced costs as batteries and inverters are not involved (Dankoff et al., 2022). Therefore, lack of access to clean water in many rural communities in Nigeria can be addressed with a direct PV solar pumping system.

Methodology

The main purpose of this work is to use the available and abundant solar energy for solar water pumping in rural communities not connected to the national grid. The block diagram of the solar water pumping system as shown below in Figure 1 consists of the solar PV panels, DC motor and Pump and the water storage tank. The sizing of the system components are performed in the following subsections.

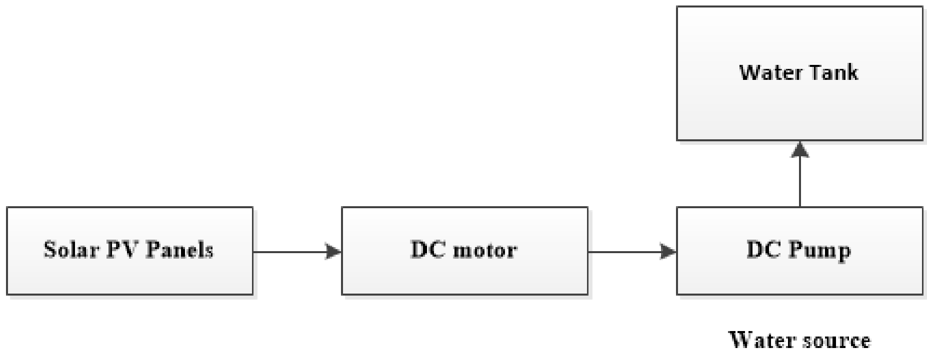

Figure 1: Typical block Diagram of Solar Pump System

Determination of the Daily water Requirement of households in m^3/Day

The water requirement of a rural community is the most important parameter in the design of a solar water pumping system. It determines the sizes of the remaining system components for the effectiveness of the system in fulfilling its intended mission. Water is use for drinking, cooking, bathing, laundry and many other domestic activities. As earlier mentioned under the introduction a minimum daily water requirement of 100 litres/person/day according to the world health organisation. A population size of 1,500 people is considered in this design. The daily water requirement is calculated and presented below using equation 1(Electrical Technology, 2020).

$$\text{the daily water requirement of a household}$$
$$= \text{number of persons} \times \text{minimum water requirement} \dots\dots\dots\dots (1)$$
$$= 1{,}500 \times 100 = 150{,}000 \text{ liters}$$

$$1\, m^3 = 100\ litres$$

To accommodate visitors' water requirement in the community a unit storage tank of 22, 000 litres capacity was considered in this work

Determination of the Total Dynamic Head (TDH)

The pressure and flow rate of the water are the parameters that determine the force and energy required for effective water delivery to various points and positions in the building. When these are not properly chosen, the water may not reach the intended destinations in the building. The pressure and the flow rate are directly proportional to the total dynamic head (equation 3) of the pump. The total dynamic head is made up of the total frictional losses and the total vertical lift (equation 2).

$$\text{Total vertical lift} = \text{Elevation} + \text{Standing Water Level} + \text{Drawdown} \dots . (2)$$

The elevation is the height of the tank above the ground level. The standing water level is the depth of the well from the ground level to the water surface and the drawdown is the height from the standing water level to the submersible pump. The height of the standing water level depends on location

$$Total\ vertical\ lift\ =\ 10.2\,m\ +\ 10\,m\ +\ 4.2\,m\ =\ 24.4\,m$$
$$The\ Frictional\ loss\ =\ 5\ \%\ of\ the\ total\ vertical\ lift\ =\ 24.4\ \times\ 0.05\ =\ 1.22\,m$$
$$Total\ Dynamic\ Head\ (TDH)\ =\ Total\ vertical\ lift\ +\ Frictional\ loss\ \ldots.(3)$$
$$Total\ Dynamic\ Head\ (TDH)\ =\ 24.4\,m\ +\ 1.22\,m\ =\ 25.62\,m$$

Determination of the Total Hydraulic Energy Required Per Day (Watt-Hour/Day) For Pumping the Water

The hydraulic energy according equation 4 is a function of the total dynamic head and the daily water requirement (volume) calculated above.

$$Hydraulic\ energy\ required\,(HER)\ =\ mass\ \times g\ \times \text{total dynamic head}\ \ldots.(4)$$

Since $density\ =\ volume\ \times\ mass$ equation 4 can be written as

$$Hydraulic\ energy\ =\ density\ \times\ volume\ \times g \times\ TDH \ldots\ldots\ldots.(5)$$

Where $\text{g}\ =\ \text{acceleration due to gravity} = 9.8 \times ms^{-2}$

$\text{Density of water}\ = 1000\ kgm^{-3}$

Determination of the Solar Radiation Available At the Location

Since the system is solar powered, the daily sun hours at a particular location must be considered in the design. The daily sun hours defines the period the sun is available at peak capacity at the location. The daily sun hour at this location is 5.5 h/day (Abam et al., 2014)

Determination of the Size and Number of PV Modules Required

At this point, the power required to drive the solar water pumping system which is harnessed from the sun using solar panels is calculated using equation 6

$$Total\ wattage\ of\ pv\ panel\ = \frac{total\ hydarulic\ energy}{no\ of\ hours\ of\ peak\ sunshine\ per\ day} \qquad (6)$$

$$= \frac{1534.35\ wh/day}{5.5h} = 278.97\ watt$$

Considering the system losses,

$$total\ wattage\ of\ pv\ panel\ = \frac{total\ wattage\ ofpv\ panel}{pump\ efficiency \times mismatch\ factor} \qquad (7)$$

$$= \frac{278.97}{0.40 \times 0.85} = 820.45\ watt$$

Considering the PV module operating factor,

$$the\ total\ wattage\ of\ pv\ panel\ = \frac{Total\ wattage\ of\ pv\ panel\ considering\ system\ losses}{operating\ factor} \qquad (8)$$

$$= \frac{820.45}{0.75} = 1094\ watt$$

$number\ of\ \ of\ 250\ Wp\ PV\ modules\ required$

$$= \frac{The\ Total\ wattage\ of\ PV\ panel\ considering\ the\ operating\ factor}{250\ Wp} \quad (9)$$

$$= \frac{1094}{250} \cong 4\ modules$$

A 250 W solar panel manufactured by Pannello with specifications given in Table 1 is considered for this work

Table 1 Solar panel specifications

S/N	PARAMETERS	VALUES
1	Peak power (wp) (Pmax)	250 W
2	Power output tolerance	0/3
3	peak voltage at (Vmp)	36 V
4	peak current (Imp)	6.94A
5	Open circuit voltage (Voc)	43.2V
6	Short circuit current (Isc)	7.64A
7	Module efficiency	15.3

Determination of the motor rating, its efficiency, and losses

The motor rating considering efficiency and system losses is calculated using equation 10

$$Power\ rating\ of\ the\ DC\ motor\ = \frac{Total\ wattage\ of\ pv\ panel\ considering\ the\ operating\ factor\ of\ the\ PV\ module}{746w\ (1\ hp)}$$

(10)

$$= \frac{1094}{746w} = 1.47\ hp \cong 1.5\ hp$$

Based on the calculated parameters, a 1.5 hp, 4-inch submersible-filled motor solar pump manufactured by DIFFUL is selected. The specifications of the pump are given in Table 2

Table 2 Specifications of the solar pump

Model	Dc voltage range	Power	Max flow	Max's head
4DFS5.9-107-1100	60-380Vmp (60-440Voc)	1100 W	5.9 m^3/h	107 m

Source: diffulpump.com

Table 3 input power, flow rate, and pump head

model		Input power									
4DFS5.9-107-1100		300	400	500	600	700	800	900	1000	1100	1200
		Q (m3/h)									
H(m)	10	2.8	3.4	3.8	4.2	4.6	4.9	5.2	5.4	5.6	5.8
	20	1.6	2.5	3	3.6	3.9	4.3	4.6	4.8	4.8	5.4
	30	0.7	1.4	2	2.6	3.1	3.6	3.9	4.2	4.5	4.8
	40		0.7	1.3	1.8	2.3	2.7	3.1	3.5	3.8	4.2
	50			0.6	1.1	1.5	2	2.3	2.7	3.1	3.5
	60				0.6	1	1.4	1.7	2.1	2.4	2.8
	70					0.5	1	1.3	1.6	1.9	2.1
	80						0.6	0.9	1.2	1.5	1.7
	90							0.4	0.9	1.1	1.3

Source: diffulpump.com

PV generator

PV generator is the number of PV modules connected in series and parallel to generate the voltage and current required to drive the pump.

$$Number\ of\ modules\ connected\ \ in\ series, Ns\ =\ \frac{Vmpp}{vm} \qquad (11)$$

$$Ns = \frac{72\ vmp}{36} = 2$$

Number of modules connected in parallel

$$N_p = \frac{I_{mpp}}{I_m}$$

$$N_p = \frac{15.27}{6.94} \cong 2$$

Vm and Im are the voltage and current of a module at mpp

Number of PV panels required of 100 wp = total wattage of PV panel considering the operating factor of 100.

Results

To meet the water pumping requirements of the 1,500-persons in the community, the results obtained show that a 1.5 hp (horsepower) 4-inch submersible pump having the TDH of 25.62 meters (considering both the total frictional losses and the total vertical lift) is required to provide the total hydraulic energy of 1534.35 Watt-Hour/Day needed. Considering the 5.5 hours of peak sunshine per day at the location, four 250 Wp (Watt-peak) PV panels connected both in series and parallel are used to provide a total of 1094 watts required

Discussion

This research work shows that problem of clean and safe water faced by people living in rural communities can be solved by using a solar power pump. The result enables us to know the actual values of all the components required which will enable the volume of water required to be pumped daily. This system does not require a backup since the solar radiation available at the location is high, but it cannot work effectively if the weather is not favourable, thus reducing the volume of water produce per day.

Conclusion

Solar-powered water pump is a sustainable and environmentally friendly alternative to conventional fuel-powered pumps, offering clean and safe water to rural communities without access to the national grid. Appropriate PV modules and DC motor were used in the system designed to ensure consistent water supply. This system will reduce waterborne diseases caused by contaminated water sources which would help to improve the health and well-being of rural dwellers. Governments and organizations should consider implementing solar-based solutions to fulfill the basic human right of access to clean and safe water. However, successful implementation requires proper planning, and consideration of factors like sunlight availability, seasonal variations, and initial investment. By addressing these challenges, solar-powered water pumping can significantly improve water access and quality in rural areas, contributing to the overall well-being and health of the community

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