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Design of Solar Powered System to Power a Submersible Pump for Domestic and Agricultural Use in both Urban and Rural Settlement in Northern Nigeria

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Abstract

A large number of urban and rural settlements in Northern Nigeria are without reliable access to a source of clean drinking water. In particular, hospitals and schools that serve a sizable population experience strain in obtaining clean drinking water. Furthermore, the national electric grid of Nigeria particularly the distribution agencies cannot always be relied on to provide consistent power, giving rise to the need for an alternate source of power. We provide a possible solution using a portable water system powered by a photovoltaic array. These solar-powered systems can supply institutions with clean water independent of the electric grid, providing reliable and economical access to drinking water.

Keywords: Solar panels, rechargeable batteries, Inverter, submersible pump.

Introduction

Due to health, hazards and scarcity of potable drinking water experienced in different parts of the country, especially in rural and some urban communities in Northern Nigeria; where the only supply of water is from a river source, free flowing stream or ponds which are not kept in good sanitary conditions, resulting in high epidemic rates such as cholera, typhoid guinea worm diseases etc. There is the need to reduce the nation's high health bills due to epidemics, and other water borne diseases. This is only achievable by improvement on the water supply system in these communities. Even with the availability of underground water within these region of the country, the national electric grid of Nigeria particularly the distribution agencies cannot always be relied on to provide consistent power, giving rise to the need for an alternate source of power.

Photovoltaic modules (PV) (i.e. solar electric panels) produce electricity from sunlight using silicon cells, with no moving parts [1]. The have been mass produced since 1979. They are so reliable that most manufacturers give a 25 years warranty and life expectancy well beyond 30 years [2], [3](Farooq, 2017). They work well in cold or hot weather.

Pump powered by solar energy are designed to utilize DC electric power from photovoltaic modules [1]. The pumps most work during low light conditions, when power is reduced, without stalling or overheating. Low volume pumps use positive displacement (volumetric) mechanisms which seal water in cavities and force it upward. Life capacity is maintained even while pumping slowly. A solar tracker may be used to tilt PV array as the sun moves across the sky during the day. Using a tracker can considerably increase the total solar energy absorbed by the PV, which means there is more energy and you can size pumps and panels smaller and cheaper [4]. Tracking works best in clear sunny weather. It is less effective in cloudy climates and on short winter days.

However, the last several years the cost of solar panels has come down so much that are usually more cost effective to add more solar panels than to add a tracker [5]. Additionally, since the tracker has moving parts they will tend to need repair after several years.

Storage is important, three to ten days storage may be required, depending on climate and water usage. Most systems use water storage tanks for simplicity and economy. On other cases, battery can be added to the system as well as inverters to invert the stored (DC) or direct current from the panel to (AC) in case of different pumps. Electrical energy from the solar modules is stored on the deep cycle batteries so that the pump can run at non sunny times or the power source.

Design and Performance Analysis of the Solar PV Water Pumping System

A solar water pumping system is designed with solar photovoltaic panels and a submersible pump of 0.37kw, 2850 r/min and 17 L/min – 33 L/min. The Solar Inverters is used to integrate with the solar water pumping system to operate it efficiently. Solar batteries store the energy produced by the sun and solar panels, allowing the energy to be stored as needed through an inverter. The charge controller monitors and regulates the voltage entering or requires charging the battery. The charge controller won't let any voltage flow in to the battery unless it is higher than the minimum voltage allowed for the specific controller. Submersible pump (or sub pump, electric submersible pump ESP) is a device which has a hermetically sealed motor close coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of the pump in that it prevents pump cavitation, a problem associated with a high elevation difference between pump and the fluid surface [6].

The solar powered pump system is used in areas where there is deficit in electricity and high diesel cost which affects the requirement of water. Therefore, using solar in powering pumps is a promising alternative to conventional electricity and diesel based powering systems.

There tens of thousands of solar powered pump in use around the world today. They are widely used on farms and out back situations in Australia to supply borehole and surface sourced water to livestock. In developing countries, they are used extensively to pump water from wells and rivers to villages for domestic consumption and irrigation of crops. PV powered pumping systems are a cost effective alternative to agricultural wind turbines for remote area water supply. This system has the added advantage of storing water for use when the sun is not shining, eliminating the need for batteries, simplicity, and reducing overall system costs. Since the need for water is greatest on hot sunny days, the technology is an obvious choice for the application. Pumping water using PV technology is simple, reliable and requires little or no maintenance.

Design Considerations.

i. **Short circuit of solar photovoltaic cell (I_{SC}):** The maximum current that a solar cell can deliver without harming its own construction, is measured by short circuiting the terminals of the cells at most optimized condition of the cell for producing maximum output. $J_{sc} = I_{SC}/A$ where A is the area of the solar cell.

ii. **Open circuit voltage of solar cell (Voc):** It is measured by measuring voltage across the terminal of cell when no load is connected to the cell. This voltage depends upon the techniques of manufacturing and temperature but not fairly on the intensity of light and area of exposed surface. Normally open circuit voltage of solar cell nearly equal to 0.5 to 0.6 volt. It is normally denoted by (Voc).

iii. **Maximum power point of solar cell**: The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the V_i characteristics of solar cell maximum power will occur at the bend point of the characteristics curve.

iv. **Current at maximum point (I_m):** The current at which maximum powers occurs current at maximum point is shown in the v-I characteristics of solar cell as (I_m).

v. **Voltage at maximum point:** The voltage at which maximum powers occur, Voltage at maximum point is shown in the V-I characteristics of solar cell as (V_m).

vi. **Peak Hour:** design of solar panel depends on the expected solar radiation power/h in the area it will be used in this case Kaduna state of Nigeria. Table shows the peak hour in some cities in Nigeria according to and as edited by [7] www.arnergy.com.

Cities	Peak hour/day
Enugu	6 hrs/day
Kaduna	6.5hrs/day
Anambra	6hrs/day
Kwara	7hrs/day
Kogi	6-8hrs/day

Choose 7 hours for Kaduna state and a clearance of 1.3 is also considered for designing a solar PV module for the required power consumption.

Components Used for the Designed System:

To make sure that the submersible pump operated effectively without failure, it is necessary to design for energy requirement of the pump or power consumption of the pump. The amounts of power require in the pump is equivalent to the energy need of the pump plus losses.

In addition, the relative time of operation of the pump in hours as compared to when the pump is powered by other source (generator) in a day to fill a 1000 litre overhead tank is also required. That is by World Bank Standard average water consumption of rural settlement of 20 litres/day/head [8] and that of the urban requirement of 285litres/day/Head [9].

Total power of submersible pump = 0.5hp, 220 – 240v

= 0.37kw = 370w

Total hours of operation = 3 hrs

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Solar Panel and Array (PV): For choosing a particular photovoltaic for specific project, it is essential to know the ratings of solar panel. These parameters enable us to know how efficiently a solar cell or photovoltaic cell can convert the light to electricity. Hence,

Power consumption = 05hp = 0.37kw = 370wh/day

Total hours of operation 3 hrs/day

370wX3hrs = 1,110wh/day, considering the clearance

1,110wh/day x 1.3 = $\frac{1443 wh/day}{7\ (peak\ hour)}$ = 206.14w/day

Thus, 250w is selected which is commercially available locally.

Battery Sizing: Factors or parameters to be considered when sizing battery are as follows:

i. Efficiency of battery: The percentage effectiveness of battery is normally within the range of 80% and 85%.

ii. Depth of discharge: is 60% (0.6)

Therefore capacity of battery =

$$\frac{Total \frac{wh}{day} x\ days\ of\ autonomy}{Battery\ efficiency\ x\ Depth\ of\ discharge\ x\ battery\ voltage} = \frac{1110x3}{0.85x0.6x12} = 544.12\ w/day$$

Since 100AH batteries are also commercially available locally, hence number of batteries required will be five (5).

Solar Change Controller Sizing (CC): For solar charge controller sizing, the CC to march voltage of the PV and batteries and identify as:

CC = I_{sc} of PV array x 1.3

Therefore CC = (2 strings x 7.5 A) X 1.3= 19.5A

The inverter should be rated 20A, 12V or greater.

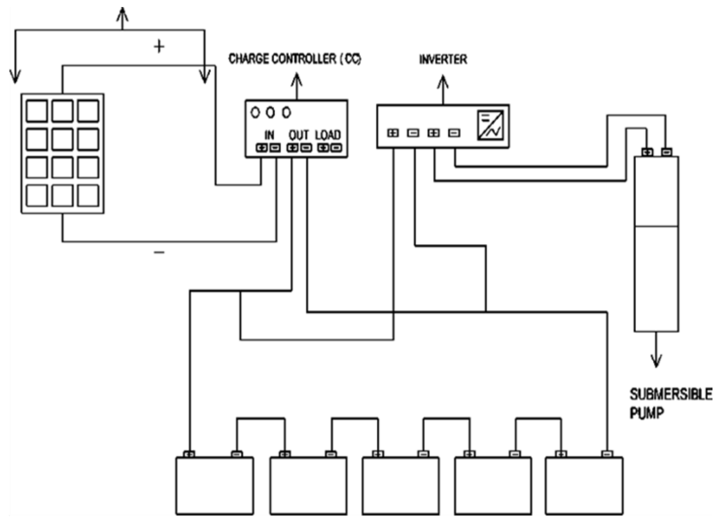
Inverter Sizing: The inverse size should be 25 to 30% bigger or greater than total watt of appliances. The input rating of the inverter should be same as PC array to allow for save and efficient connection.

For grade connection system

Total watt of the pump = 370w, 25% of 370w = 25/100 X 370 = 92.5

Therefore 370 + 92.5 = 462.5w = 470 w

The inverter should be 470w or greater.



Conclusion:

Proper design of solar pumping systems requires a lot of expertise. Design rules, optimal options, and best practices are disseminated in many specialist documents. In this paper, we designed a solar system which can be used for both residential, irrigation purposes of farmers in today's scenario particularly in area with little sustainable electricity supply.

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Figure 1: Solar Powered Submersible Pump Connection Diagram

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