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Design criteria for a domestic solar powered sub-surface water pumping system in Benin City metropolis

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Abstract

Renewable energy from the sun is an abundant and ubiquitous resource which has zero or low global warming potential. Only a small fraction of this available energy is sufficient for global energy demand. However, due to high cost in design, this energy has not been largely harnessed in different parts of the world. Perhaps reducing the components necessary to capture the sun's energy and convert it to electricity will go a long way in reducing the total system cost for a solar powered design. This paper provides simple procedures for the design of a domestic solar-powered sub-surface water pumping system. The design has been able to do away with components like batteries and inverters thus making the system design less expensive to fabricate. The design was suited for a typical home located in Benin City. However, the design criteria can be extended for other geographical areas of choice. This design shows that connecting an array of 250W and 120W Solar PV panels in series and with a total dynamic head of 49.34m (161.877ft), a flow rate of 0.397 liters/min can be maintained for a pump power rating of 290W..

Keywords: Renewable energy, solar power, pump, water, subsurface, pv panel, design, fabrication

Nomenclature

V_{Ws}	Volume of water stored in tank (liters)
V_{Wa}	Volume of water required or consumed by the family per day (liters)
N_d	Number of days for water storage in tank
V_p	Volume flow rate of the pump (liter/min)
t_s	Duration of solar insolation (hrs)
H_l	Vertical lift (m)
H_P	Pressure head (m)
H_f	Head loss due to friction (m)

1.0 Introduction

Solar energy is radiant energy in form of heat and light emitted by the sun. The potential of solar energy is almost limitless and this energy has been left largely untapped [1]. The International Energy Agency announced in 2011 that solar energy technologies have the potential to provide a third of the world's energy by 2060, if the world leaders commit themselves to limit climate change [2]. The total solar energy potential is much bigger and only a small fraction of totally available solar energy would be enough to satisfy global energy demand [3]. Solar energy is the most abundant form of renewable energy available in the world. Harnessing solar energy has enormous future potential, not only in electricity generation and heating but also for many other industrial processes [4, 5]. Photovoltaic (PV) panels are often used to capture the radiant energy from the sun. This has found wide application in agricultural and domestic operations, especially in remote areas or where the use of an alternative energy source is desired [6]. PV panels have been demonstrated to reliably produce sufficient electricity directly from solar radiation (sunlight) to power livestock and irrigation watering systems [7].

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Water is the primary source of life for mankind and one of the most basic necessities for rural development. The rural demand for water for crop irrigation and domestic water supplies is increasing. At the same time, rainfall is decreasing in many arid countries, so surface water is becoming scarce [8]. Groundwater or subsurface water seems to be the only alternative to this dilemma, but the groundwater table is also decreasing, which makes traditional hand pumping and bucketing difficult. As these trends continue, mechanized water pumping will become the only reliable alternative for lifting water from the ground [9]. Diesel, gasoline, and kerosene pumps (including windmills) have traditionally been used to pump water. However, reliable solar (photovoltaic [PV]) pumps are now emerging on the market and are rapidly becoming more attractive than the traditional power sources. This technology, powered by renewable energy source, is especially useful in remote locations where a steady fuel supply is problematic and skilled maintenance personnel are scarce.

2.0 Materials and Methods

In Benin City, the average water requirement for a typical single family home is about 262 liters (69.3 gallons) per day. The basic components needed for the system design includes:

i. The PV panel
ii. An electrical controller
iii. An electric-powered pump.
iv. Storage tank

Table1 shows pertinent information of a local well located in a residential home in Benin City which was used as a case study for the design.

Static water level as indicated in Table 1 is the undisturbed level of water in the well before pumping. The yield represents its dependable and continuous output during a long drought. Drawdown refers to the lowering of the water level relative to background condition like pumping.

Figure 1 shows the pump pipeline profile for the system design.

Following the basic procedure below, the fabrication of the subsurface solar water pumping system can be accomplished.

2.1 Water storage facility

First, the anticipated volume of water storage that the operation will need, which should be sufficient for a minimum of three days of water use, can be calculated using Equation (1).

$$V_{Ws} = V_{Wa} \text{ x } N_d = 262 \text{ x } 3 = 786 \text{ liters} \quad (1)$$

Where 262 liters is the volume of water required or the family consumes per day and 3 is the number of days required for the volume of water in tank to last.

Though, the value of the storage facility obtained is 786 liters, but the nearest standard size tank that is commercially available is 1000 liters and this was selected.

2.2 Flow rate of water pump

The design flow rate of the dc pump (V_p) can be calculated from Equation (2).

$$V_p = \frac{V_{wa}}{t_s} = \frac{262}{11 \text{ X } 60} = 0.397 \text{litres/min } (0.105 \text{gal/min}) \quad (2)$$

t_s = Duration of solar insolation = 11 hrs

2.3 Total dynamic head (TDH)

The total dynamic head (TDH) of the pump is given by Equation (3).

$$TDH = H_l + H_p + H_f \quad (3)$$

From the pertinent information given, the vertical lift (H_l) can be found by adding the static water level, drawdown and height of entry to the tank from the ground.

Since it is an open tank, the pressure of water in tank is atmospheric. Thus, Pressure Head (H_p) is 0 m.

Also, using a 40 PVC pipe and 0.0457metres pipe diameter, the friction head loss for a design flow rate of 0.397litres/min is 0.34 meters [10]. Therefore, the total dynamic head for the proposed pump can be given as summary in Table 2.

2.4 Pump Selection and Associated Power Requirement

Base on the flow rate and TDH value of the pump, the minimum power required for the pump can be found from Figure 2.

From Figure 2, at 0.105gal/min and 161.877ft, the minimum power required to drive the dc pump is 290 Watts.

2.5 PV panel selection

It is recommended that PV panels output should exceed the minimum peak power input to the pump by at least 25% to account for losses due to environmental factors [11]. Therefore, the PV panels will be sized to provide a minimum output of 363 Watts (1.25 X 290 = 363 W).

A single 250 Watts having a current and voltage rating of 8.37A and 29.99V and a 120Watts having a current and voltage rating of 10A and 12 V connected in series will be able to power the pump. These specifications are readily available in the market.

2.6 Water Flow Rates and Delivery Point Pressure

For proper operation of the system, the gravity tank is located at least 30 ft or 10 m above the highest outlet [7]. For the case of our design, we assumed a minimum height of 12 m.

$$P = \rho g h \qquad (4)$$

Since pressure varies directly with height as given in Equation (4), 1psi = 2.309 ft of water, it thus means that if the tank is raised to 12 m (39.37ft), the delivery pressure from the tank will be 17.05067 psi (1.1756bar), which is just sufficient for effective delivery into the house.

2.7 Summary of the system design

Table 3 shows the summary of components needed to fabricate the system design

3.0 Discussion

The utilization of solar energy to meet some of our energy requirements would reduce the depletion rate of fossil fuels and environmental pollution and slow down the impact of climate change. Solar energy is free to use, as nobody owns the sun. Improving economics of solar power technologies is the only thing that stands between us and clean energy future.

From the system design, direct current (DC) output from the PV panels can work directly with the pump, since the pump is a DC pump, thus ignoring the use of an inverter. Alternating current (AC) motors or pump can also be used, but they require more complex control systems. They also result in less total energy availability due to the electrical losses caused when an inverter is used to convert the DC to AC electricity. As DC motors do not require an inverter, the system utilizes a less complex control system, and result in more total energy availability.

A solar powered system may incorporate storage batteries that can be charged when incoming solar energy exceeds the pumping power requirement. The batteries can then be used to power the pump. However, the first goal of a solar-powered water pumping system is to store water, not electricity. The use of batteries should therefore be discouraged unless absolutely necessary since the added expense and complexity usually outweigh any advantages.

An important consideration when selecting the appropriate pump is the pump's minimum voltage. Pump manufacturers may provide pumps with similar operating characteristics but different voltages. A higher operating voltage tends to be more efficient since there is less energy loss from the reduced current required to deliver the same power.

Specifically, the flow rate of the water pumped is determined by both the intensity of the solar energy available and the size of the PV array used to convert that solar energy into direct current (DC) electricity. However from the design, it's important to note that the total dynamic head also has an effect on the flow pressure into the building.

The controller is a safety device that normally includes a main switch to provide an electrical disconnection of the PV array from all other system components. Since the amount of power produced by the array depends on the intensity of incoming solar radiation, the controller can cause the pump to be switched off until sufficient power is available to meet the pump's specified minimum operating power input range. Contrarily, when the PV panels produce too much power, the controller can limit the power output to the pump to prevent it from running faster than its maximum rated speed.

4.0 Conclusion

This paper has been able to address a less complex and cost effective design of a solar powered sub-surface water pumping system. This design system has shown that components like batteries and inverters can be neglected which can directly reduce the cost of fabrication unlike the conventional design which involves these components. Hence, it is necessary for a solar powered system designer to critically look at the output characteristics of a sink, so as to determine the simplicity of possible designs. This paper has shown that, connecting an array of 250W and 120W Solar PV panels in series and considering a total dynamic head of 49.35m (161.877ft) is just sufficient, for a pump power rating of 290W, to maintain a flow rate of 0.397litres/min.

Table 1: Pertinent information of a local well in Benin City

Pertinent parameters	**Value**
Static water level	34 m
Yield	151 liters/min
Draw down	3 m
Total well depth	56 m
Depth of pump below ground	54 m

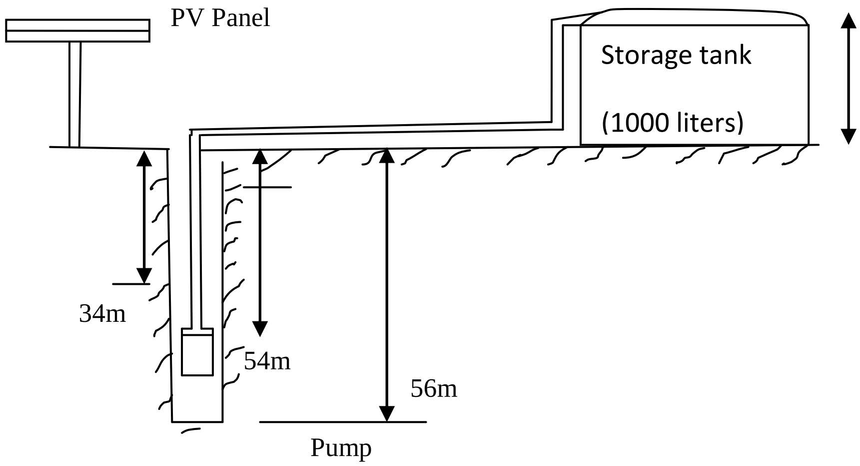

Figure 1: Typical well installation with pertinent parameters

Table 2: Total dynamic head of the dc pump

Dynamic head	**Value (m)**
Vertical lift (H_l)	49
Pressure head (H_p)	0
Head loss due to friction (H_f)	0.34
Total dynamic head	49.34 (161.877ft)

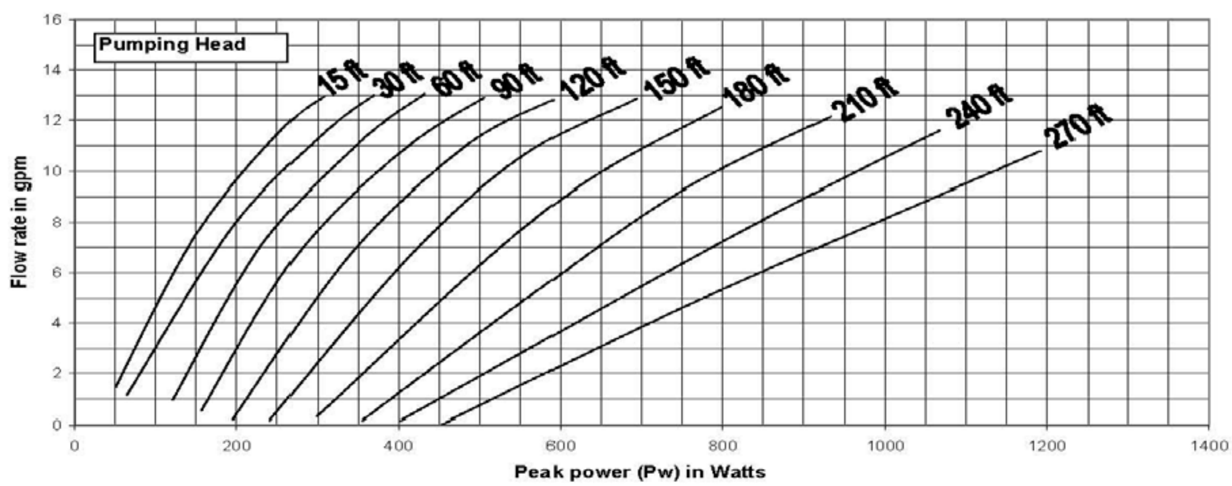

Figure2: Centrifugal Pump curves

Source: [10]

Table 3: Design specification of the sub-surface solar powered water pumping system

Design Parameters/ Components	Specification
Water storage facility (Tank)	1000litre
Flow rate of water pump	0.397litres/min (0.105gal/min)
Total dynamic head (TDH)	49.34m (161.877ft)
PV panel	250 Watts and 120 Watts

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