Design of A Small Scale Solar Powered Water Pumping System

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***Abstract* - An intense irradiation by the sun on the earth causes excessive evapotranspiration (loss of water), a factor that is unpleasant to farmlands, livestock and remote areas where people reside. This unpleasant situation can be used as an opportunity to provide enormous supply of water to these areas.**

This work focuses on the design; fabrication and testing of water pump system powered by a solar photovoltaic (P.V) panel. Two 12V, 17AH battery was incorporated in the pump system to ensure storage and stability of power discharged. The system pumped water at an average of 30L/min within the hours of 1pm to 4pm at an hour interval. The pump was operated at different heads ranging from 3m to 10m. The pump performed with an efficiency of 3.94% to 13.14%. The power consumption was fixed at 0.373kWh. The design and testing of the solar pump are presented in this work. The design can be used in rural and semi-urban areas with a moderate population and farms for irrigation practices where grid electricity is unavailable.

Keywords:* P*hotovoltaic panel, solar pump.

1. INTRODUCTION

The need and demand for energy in different parts of the world is on the geometrical increase where different sources of energy are being harnessed to carry out work. Among all the energy sources, solar energy is gaining popularity in different parts of the world due to its daily availability and no pollution effects compared to fossil fuels. Solar energy is available in any part of the world, but the amount made available differs with respect to geographical locations, times and season [1]. The solar energy available at any particular geographical location is a measure of the solar irradiance falling on that location. Solar irradiance is the solar radiation intensity falling on a surface and is measured in kW/m^2 [2].

Solar energy is free, inexhaustible, yet harnessing it is a relatively new idea [1]. The sun is primary source of energy, and all form of energy on the earth is derived from it. Solar energy has the greatest potential of all the sources of renewable energy [7]. Many areas of design and inventions have found the use of solar energy very efficient and environmentally friendly compared to other energy sources. Solar energy, when converted into electrical energy, can be used to pump water from dug wells or streams to over-head tanks for storage or direct use on farmlands. Other methods used in pumping water include the electrical pump and fuel pumps. They all have their merits and demerits compared to the solar pump.

Solar pumping system is an integration of different components which generates power from the sun and operates on direct current to drive water from a particular source over a distance to another location. Solar pumping system requires the use of a solar photovoltaic panel to generate electricity from the sun to drive a pump which sucks up water from a particular source and discharges the water either to an over-head tank or piping within a long distance where water is needed. This is carried out in locations where electricity is unavailable. There are other methods to pump water for consumption and one of the best options is a photovoltaic (PV) pumping system. Solar water pumping provides a welcome alternative to fuel-burning generators for pumping water. Advantages of PV pumping systems include low operating cost, unattended operation, low maintenance, easy installation, and long life [3]. Solar pumping systems require no fuel. They are quiet, pollution free, efficient, simple, reliable and require little or no maintenance [4] [7]. Various facilities are available for automating the starting and stopping of water flow. Furthermore, solar pump can be available for small, medium and large-scale water requirements. The small system can cost little more than their fuel powered counterparts. Solar pumping is extremely efficient because maximum pumping power is available on intense sunny days when the water is needed most [5].

An intense irradiation by the sun on the earth causes excessive evapotranspiration (loss of water), a factor that is unpleasant to farmlands, livestock and remote areas where people reside. This intense irradiation being a menace can be used as an opportunity to provide large supply of water to the areas facing such crises. The use of a pump powered by a solar photovoltaic panel can be used to achieve this. This work focuses on the design, fabrication of a small- scale solar pump, testing and comparison with the electrical and fuel pumps.

2. METHODOLOGY

The design of a small-scale solar pump begins with the knowledge of daily water required, the solar irradiation of the location, the pumping time, the total head and power required to drive the water by the pump from the source to its destination [9].

2.1 The design processes

1. Calculating the water requirement..
2. Determining the solar irradiance.
3. Determining the flow rate for the pump.
4. Calculating the Total Dynamic Head (TDH) for the Pump.
5. Pump Selection and Associated Power Requirement.
6. Deciding pump power requirements.
7. Selecting the piping system to suit the design [8].

2.2 The design calculations

1. **The chosen daily water required by an average person:** 250L – 500L per day.

Table 1: The solar irradiance for Ibadan:

Month	Air temperature(^{0}C)	Relative Humidity (%)	Daily solar Radiation (KWh/m^2/day)	Atmospheric Pressure (KPa)	Earth Temperature(^{0}C)
January	26.1	56.9	5.50	99.0	28.2
February	26.4	65.2	5.70	98.9	28.6
March	26.0	79.5	5.64	98.8	27.6
April	25.9	83.8	5.35	98.9	27.0
May	25.7	84.5	5.09	99.0	26.7
June	24.9	85.6	4.57	99.2	25.7
July	24.0	85.6	4.00	99.3	24.5
August	23.9	84.8	3.79	99.3	24.5
September	24.3	85.7	4.11	99.2	25.1
October	24.6	85.0	4.70	99.1	25.5
November	24.9	81.0	5.11	99.0	25.8
December	25.4	67.7	5.35	99.0	26.8

Source:
http://eosweb.larc.nasa.gov/cgibin/sse/retscreen.cgi?email=rets%40nrcan.gc.ca&step=1&lat=7.23982&lon=3.59299&submit=submit [10]

2. DETERMINING THE FLOW RATE OF THE PUMP:

Water requirement in liters per second = $\frac{Q\,(\frac{ltrs}{day})}{T*3600}$

Q = A* V

Water requirement in liters per second = $\frac{Q\,(\frac{ltrs}{day})}{T*3600}$

$Q_1 = \frac{250}{4*3600} = 0.0174$Ltrs/s

$Q_2 = \frac{400}{4*3600} = 0.0278$Ltrs/s

$Q_3 = \frac{500}{4*3600} = 0.0374$Ltrs/s

3. TOTAL DYNAMIC HEAD (TDH) FOR THE PUMP:

The calculated TDH for the pump ranged from 10m to 14m. Using the $H_T = H_S + H_D$

Where: H_S is the static head = 10 -14m and 1m for Household usage and Irrigation respectively.

H_D is the dynamic head.

H_D from Darcy Weisbach equation:

$H_D = kV^2/2g$ [9]

Where:

K – loss coefficient

V – velocity of water in pipes

g- acceleration due to gravity [9].

4. PUMP SELECTION AND ASSOCIATED POWER REQUIREMENT:

Power required to pump the water for the flow rate and total head.

Power P (watts) = $\frac{Q\rho gH}{eff}$.

After the power required by the pump was determined, the input power from the motor was determined.

Power of the D.C motor.

P = Tω where T is the torque produced from the shaft of the motor. And $\omega(\frac{rad}{s})$ is the angular velocity of the shaft rotation.

$\omega = \frac{2\pi N}{60}$ where N is the shaft speed in rpm.

Static head chosen = max of 30m.

A power range of 15W – 80W to drive the water from the source to the destination for an average of 4-hours of solar irradiation.

Maximum output power = 80W * 4hours = 320Watt-hours.

2.3 DESIGN COMPONENTS

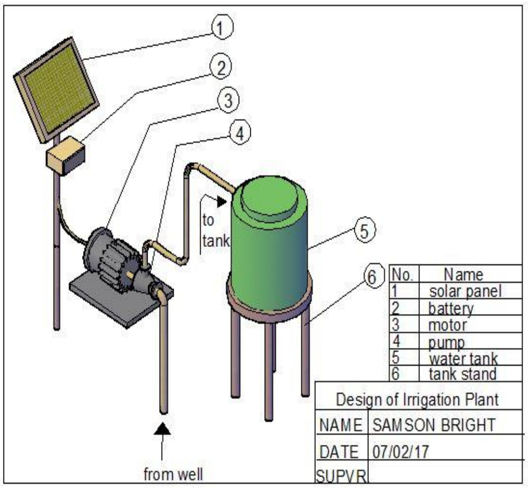

Fig 1: drawing of the solar pump system for domestic use.

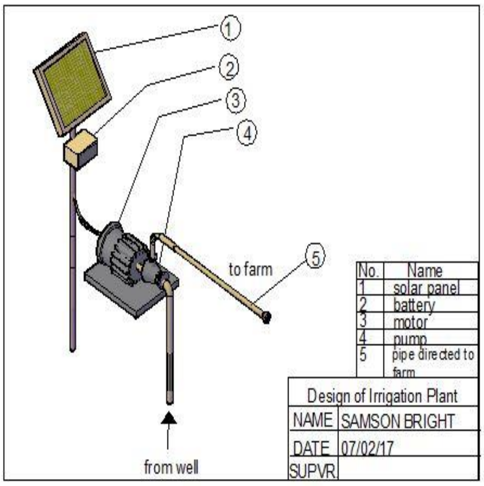

Fig 2: drawing of the solar pump system for irrigation

Table 2 : Components of the solar pump

S/NO	Irrigation	Domestic supply
1	Solar P.V panel	Solar P.V panel
2	Charge controller	Charge controller
3	Electric motor	Electric motor
4	Motor shaft	Motor shaft
5	Centrifugal pump	Centrifugal pump
6	Suction pipe (P.V.C)	Suction pipe (P.V.C)
7	Water source (a dam)	Water source (a well)
8	Delivery pipe (rubber pipe)	Delivery pipe (P.V.C)
9	Farmland	Overhead tank

Solar P.V panel → Charge controller → D.C Motor → Pump

PUMP SPECIFICATIONS

A pump is a machine for raising or transferring liquids or gases. A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. The basic purpose of the pump is to transfer fluid from a lower level to a higher level.The pump model chosen for this work is: Italian Gold water pump QB60,

Q = 30 – 35ltr/min

H = 5 – 30m, V_{input} = 220V, I_{input} = 2.5A, Frequency = 50Hz, Shaft speed on no load = 2850rpm. Input power P_{input} = IV = 220 * 2.5 = 550W, Output power = 0.5HP = 373W.

Hence pump efficiency = 70%.

$P = T\omega$, where $\omega = \frac{2\pi N}{60}$ where N is the shaft speed in rpm, T is the shaft torque.

P = 373W, N = 2850, $T = \frac{373*60}{2\pi*2850} = 1.3$. Shaft torque = 1.3.

With an output pump power of 320W and efficiency of 70%, input power for the pump = 457W.

Fig 3 : The water pump

A D.C motor with a minimum output power of 457W is required.

D C Motor

The direct current (DC) motor is one of the first machines devised to convert electrical energy to mechanical power. A **DC motor** is any of a class of rotary electrical machines that converts direct current electrical power into mechanical power. This DC or **direct current motor** works on the principle that a current carrying conductor, placed in a magnetic field, it experiences a torque and has a tendency to move.

A D C motor of model, voltage- 12v, speed – 2500 rpm, current – 14 Amp and output – 250 watt

Fig 4: The d.c motor

The Shaft Coupling

The shaft coupling is made up of steel discs of diameter 80mm and thickness 10mm which transmit rotary motion and torque from the D.C motor to the pump.

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Fig 5: The shaft coupling

The Battery

Electrical storage batteries are often used in PV systems, as the demand for energy does not always coincide with its production. The electric current produced by PV panels during daylight hours charges the batteries, and the batteries in turn supply power to the pump anytime water is needed. The use of batteries spreads the pumping over a longer period of time by providing a steady

operating voltage to the DC motor of the pump [6]. The primary functions of a storage battery in a PV system includes:

energy storage capacity and autonomy, Voltage and Current Stabilization and Supply Surge Current.

The battery used for this design based on availability is two 12V 17AHour Chitex deep cycle battery to be connected in parallel.

Fig 6: The deep cycle battery

The Charge controller

A solar charge controller or regulator is an essential component of every solar charging system. A charge controller may be used to power DC equipment with solar panels. The charge controller provides a regulated DC output and stores excess energy in a battery as well as monitoring the battery voltage to prevent under/overcharging. The main role of a controller is to protect and automate the charging of the battery.

The charge controller chosen for this work is a PWM controller.

Fig 7: The PWM charge controller.

The P.V Panel

Photovoltaic module: the power source for solar pumping, have no moving parts, requires no maintenance and can last for decades [7].

The panels used for this design are two monocrystalline panels rated at 12V, 30Watts. The panels connected in series receive irradiation from the sun and releases voltage to the system. The panels charge the batteries.


Fig 8: The Monocrystalline Solar P.V module.

The Casing

A steel casing with two handles made with dimension of 340mm x 340mm x 460mm, houses the motor, shaft, pump batteries and electrical systems.


Fig 9: The casing.

The Electrical system.

The electrical system of the design comprises the:

- The wirings
- The indicators

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- Circuit breakers and on/off switch


- The terminals

Fig 10: The electrical system

The total Assembly.



Fig 11: The total assembly

2.4 TESTING

The testing of the design was carried out at a well station at Fijabi Car-wash, along Ojoo/Iwo-road expressway in Ibadan with different heads ranging from 3m to 10m from the depth of the well at the water level between the hours of 1pm to 4pm at an hour interval.

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Fig 12: Testing of the design.

3.0 RESULT AND DISCUSSION

A fixed amount of 25litres to 30litres of water were obtained per minute at all the heads and time intervals totaling about 1500L to 1800L per hour. The output power of the system between 14Watts to 49Watts conformed to the power calculated during the design, a pump efficiency ranging from 4% to 13%. The solar pump consumed a constant power of 0.373kWh.

The results of the amount of water pumped in liters per minute at different heads are shown in the table 3 below:

Table 3: Flow rates, Output power, Efficiencies and Energy consumption of Solar pump

Head(m)	1-2Pm	2-3Pm	3-4Pm	Q(m^3/s)	Output Power(watts)	Eff(%)	Litres/H	Energy consumed (kWh)
3	30	30	30	0.00050	14.70	3.94	1800	0.373
4	30	30	25	0.00047	18.42	4.94	1700	0.373
5	25	25	25	0.00042	20.58	5.52	1500	0.373
10	30	30	30	0.00050	49.00	13.14	1800	0.373

Power consumption of the pump was determined without the use of a panel tested at heads 3, 4 and 5m.

Table 4**:** Output Power of pump without Panels.

Head (m)	Water pumped (Ltrs/min)	Average Discharge rate(m^3/s)	Output Power (Watts)
3	30	0.00050	14.72
4	25	0.00042	16.48
5	25	0.00042	20.60

The input power of the solar pump is 408W to drive a 373W powered by a 60W panel. Where:
Q(m^3/s) = amount of water pumped.
Output power P (watts) = $\frac{Q\rho gH}{eff}$
The power consumed by the solar pump is 408W and can successfully pump between 1500Ltrs to 1800Ltrs conveniently for an hour depending on the head and the irradiation from the sun.

The result of the work parameters of four different fuel pump stations and three different electrical pump houses are given below:

Table 5: Results of work parameters of Fuel engines.

Station	Head(m)	Capacity (litres)	Engine capacity (watts)	Pumping time (mins)	Average discharge (m^3/s)	Output power (Watts)	Eff (%)	Energy consumed (kWh)
M.M	8	10000	5500	40	0.0042	329.6	5.9	3.67
Fijabi	8	500	2238	6	0.0014	109.9	4.9	0.224
Orogun	8	8000	1492	40	0.0033	259.0	17.35	0.995
Texalon	8	7300	2984	20	0.0061	478.7	16.04	0.995

Table 6: Results of work parameters of electrical engines.

Station	Head(m)	Capacity (litres)	Engine capacity (watts)	Pumping time (mins)	Average discharge (m^3/s)	Output power (Watts)	Eff (%)	Energy consumed (kWh)
Niyi	15	1000	746	40	0.00042	61.8	8.3	0.497
Carol	20	3000	1865	120	0.00042	82.4	4.4	0.435
Aaron	16	3000	1119	60	0.00083	130.3	11.6	1.119

A fixed amount of 25litres to 30litres of water were obtained per minute at all the heads and time intervals totaling to about 1500L to 1800L per hour for the solar pump. The output power of the system between 14Watts to 49Watts conformed to the power calculated during the design, a pump efficiency ranging from 4% to 13%. Comparing the test results of the solar pump with the electric and the diesel pump from different houses and pump stations respectively, the diesel pump gave the greatest efficiency ranging from 6% to 17% while that of electric has an efficiency ranging from 8% to 11%. The diesel pump has the greatest energy consumption ranging from 0.222kWh to 3.67kWh, the electric pump consumed 0.435kWh to 1.12kWh, the solar pump consumed a constant power of 0.373kWh.

Table 7: COMPARATIVE ANALYSIS OF THE SOLAR, ELECTRICAL AND FUEL PUMPS.

	SOLAR	ELECTRICAL	FUEL
Power source	The all available sun	Grid electricity where available	Liquid fuel (diesel or petrol
Maintenance	Little or no maintenance	High cost of maintenance due to burnt coil from irregularities in power supply.	Constant purchase of fuel and high servicing cost.
Durability	Highly durable in years	Moderately durable in months	Highly durable in months
Efficiency	Moderately efficient between 4 – 13%	Efficient only with a good power supply between 8 – 11%	Highly efficient between 6 – 17%
Performance	Good	Good	Very good
Availability	Not easily available	Readily available	Not easily available
Installation and cost	Not easily installed, high initial installation cost but mobile and immobile	Easily installed, low purchase cost but immobile.	Not easily installed, high initial installation cost but mobile and immobile.
Effect on the environment	No side defect on environment nor farmland and livestock.	No side defect.	Causes pollution both noise and air pollution. Unpleasant for farmlands and livestock.
Renewability	The all available sun, highly renewable and inexhaustible	Non renewable	Non renewable
Power consumption	Very low consumption: as low as 0.373kWh	High power consumption ranging between 0.435 – 1.12kWh	highest power consumption ranging between 0.222 – 3.67kWh

4.0 CONCLUSION

It can be concluded that the amount of water pumped at different time hours is not a function of the time nor the head since at all heads, there is equal amount of 30L water pumped except the 5m head with close amount of 25L.

After a careful analysis of the results obtained from the tests of the solar pump, with close visual observation of the performances of the diesel and electric pumps:

- the solar requires little or no maintenance when compared with the fuel and electrical pumps.
- The fuel pumps have the highest efficiency and best performance compared with the electrical and solar pumps.
- as its own advantage, the solar pump is the cleanest, environmentally friendly, has the least energy consumption and has the cheapest source of energy (the all - available sun).

A solar pump of equal power consumption with the diesel and electric pump will give a better output. Therefore, the solar pump should be harnessed in farms and rural areas having no access to national grid.

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