Solar Powered Water Pump Application in Rural Villages. A case study of Mahango village –Mbarali District Tanzania

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Abstract - *Application of solar energy for drinking water supply pumping is a practicable answer mainly for remote villages and homes where electricity may be inaccessible. The problem of delivering water to this area more effectively is further complicated by a lack of grid power. Most communities started to use diesel pumps or generators but the cost of operation (fuel and maintenance) were unaffordable, even as a short term solution. Advantages of PV pumping systems include low operating cost, unattended operation, low maintenance, easy installation, and long life. Using Photovoltaic (PV) pumps has major advantages where grid connection is not available, good solar conditions exist, and distances from transport facilities are long. In solar powered pumps, pumping and transporting water from the source to end user requires a lot of energy. The energy required for pumping and transporting water can be obtained from solar powered pumps. The overall objective of this paper is to study the capability of solar powered pump/solar photovoltaic pump for drinking water supply in rural areas of Tanzania*

Keywords - *Solar Pump, Solar Energy, Drinking Water, Solar water pumping, PV Sizing*

I. INTRODUCTION

In locations where electricity is unavailable, other means are necessary to pump water for consumption. One option is a Photovoltaic Pumping System (PVPS). Advantages of PVPS include low operating cost, unattended operation, easy installation, low maintenance cost, and long life. These are all important in remote locations where electricity may be unavailable. The development of this research was focused on estimation of the available radiation at a particular location on the earth's surface and then analyzes the characteristics of a photovoltaic generator and a photovoltaic network. The purpose of this research paper is to examine all the necessary steps and key components needed to design and build a solar powered water pump system. Most of the PVPS installations are intended to supply drinking water to the population living in the remote regions. For the great part of these regions, the photovoltaic (PV) energy is very suitable to use because of the solar radiation availability and the non CO_2 emission and low maintenance costs [1]. Generally, PVPS consists of a PV array and a pumping subsystem. The principal component of the PV module is the PV solar cells which convert instantaneously the solar radiation received on the surface of the PV cells into electric energy. The pumping subsystem is composed of a motor-pump set and a power conditioning equipment. The storage of water in tanks is the solution most implemented in the majority of the PV pumping applications. Nevertheless, in some cases, there are storage batteries for some PV pumping applications for diurnal uses and during cloudy days.

The main objective of this paper is study the possibility of solar photovoltaic pump for drinking water supply in rural areas of Tanzania. In order to achieve the main objective the following are the specific objectives:

- To analyze the system components such as solar PV sizing, solar battery sizing, inverter sizing and charger controller sizing, cable sizing, and solar pump selection;
- PV Modules mounting for solar driven water pump system.

II. LITERATURE REVIEW

Water is the world's most precious commodity. Every living thing on earth needs water in order to survive. For developing countries, this resource is difficult to obtain on a regular basis and some people must walk for kilometers every day in order to get a regular supply. The lack of safe drinking water is still an issue to be solved in many developing countries, especially in rural areas [2].The trend of increasing fossil fuel price and its high contribution to environmental problems makes fossil energy sources doubtful. Different researches have been carried out and their results show that, renewable energies are the best alternative energy sources to replace the fossil energy.

A. Solar Photovoltaic Power

Solar or Photovoltaic (PV) cells are made of semiconducting materials that can convert sunlight directly into electricity. When sunlight strikes the cells, it dislodges and liberates electrons within the material which then move to produce a direct electrical current (DC). This is done without any moving parts. Individual cells make up a module. An array consists of sets of modules as shown in Figure 1 [3].

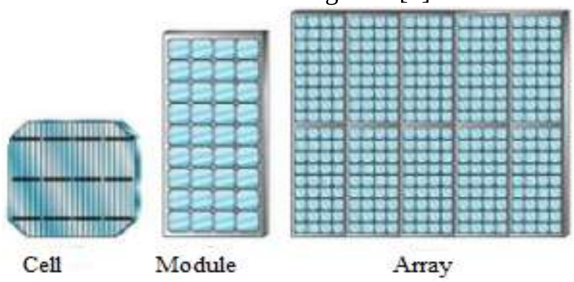
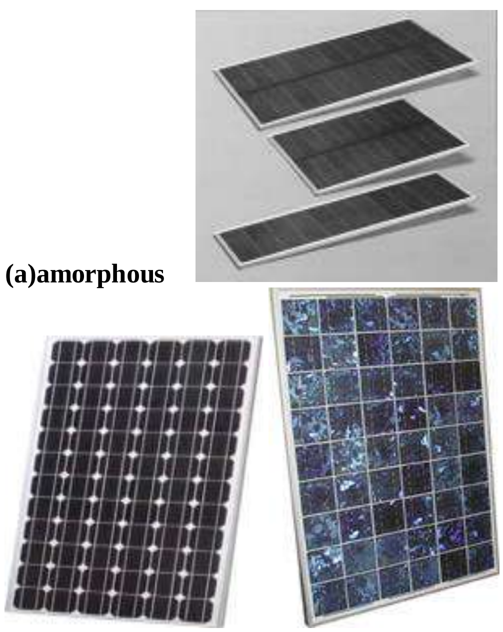


Figure 1: Individual cell, module and array

Most commercial PV cells are made from silicon, and come in three general types. Figure 2 presents examples of the types of PV modules: a) amorphous; b) monocrystalline; and c) polycrystalline [3].



(a)amorphous

(b) Monocrystalline **(c) Polycrystalline**

Figure 2: Examples of the types of PV modules

The amount of power available from a photovoltaic (PV) device is determined by: The type and area of the material; the intensity of the sunlight, and the wavelength of the sunlight. According to [4], a typical single crystal silicon PV cell of 100cm^2 will produce about 1.5 Watts of power at 0.5Volts DC and 3Amps under full summer sunlight (1000Wm^{-2}). The power output of the cell is almost directly proportional to the intensity of the sunlight. (For example, if the intensity of the sunlight is halved the power will also be halved) [4]

B. Photovoltaic Pumping System (PVPS)

Photovoltaic pumping system (PVPS) remains one of the most popular solar energy applications in developing countries. The most of the PVPS installations are intended to supply drinking water to the population living in the arid and remote regions. For the great part of these regions, the photovoltaic (PV) energy is very suitable to use because of the solar radiation availability and the non CO_2 emission [5] and low maintenance costs.

Generally, PVPS consists of a PV array, a pumping subsystem. The principal component of the PV module is the PV solar cells which convert instantaneously the solar radiation received on the surface of the PV cells into electric energy. The pumping subsystem is composed with a motor-pump set and a power conditioning equipment. The storage of water in tanks is the solution most adopted in the majority of the PV pumping applications. Nevertheless, in some cases, there are storage batteries for some PV pumping applications for daytime uses and during cloudy days as shown in figure 3

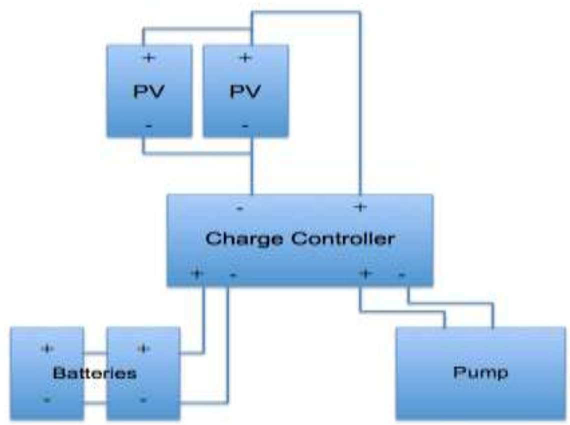


Figure 3 Photovoltaic pumping systems

C. Charge Controller

A charge controller is necessary to maintain the proper charging voltage on the battery bank, and direct the necessary amount of power to operate the pump. The charge controller will be a Pulse Width Modulation (PWM) solar controller and must be rated to handle the currents in the system and the open circuit voltage of the solar panel.

D. Battery

Batteries are often used in Photovoltaic (PV) systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (During the night and periods of cloudy weather). Battery capacity is the maximum amount of energy that can be extracted from a battery without the battery falling below the prescribed value; it is given in kWh or Ah at constant discharge rate [6]

E. Inverter

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery. It is not very commune that users of the system smaller than 100wp require inverters [6]

F. Sizing of Photovoltaic Pump

Sizing of photovoltaic pump involves determining the volume of water required to be supplied per day in m3/day, head of water against which the pump works, and yield of water from the source of water supply. PV systems are usually sized based on the average value of energy required, availability of solar energy, and components efficiencies [7].

Storage tank sizing for drinking water considers the number of days, usually two to three days, for which water has to be stored [8].

G. Cable Sizing

To avoid unnecessary losses the of use appropriate cables and proper installation to the devices is recommended. Cables should always be as short as possible. To ensure that the voltage loss does not exceed 3%, the cable between the PV panel and the battery should have a cross-sectional area of at least $0.35mm^2$ (12V-system) or $0.17mm^2$(24V-system) per metre and module. Thus a 10m cable for 2 modules would require at least $10 \times 2 \times 0.35mm^2 = 7mm^2$.If a part of this cable is exposed to the open air, it should be designed so that will withstand all weather conditions. Tolerance to ultraviolet rays may be an important feature [9]

H. A Cost and Reliability Comparisons Between Solar and Diesel Powered Pumps

There are differences between the two power sources in terms of cost and reliability. Diesel pumps are typically characterized by a lower initial cost but a very high operation and maintenance cost. Solar is the opposite, with a higher initial cost but very low ongoing operation and maintenance costs. In terms of reliability, it is much easier (and cheaper) to keep a solar-powered System going than it is a diesel engine. This is evident in field where diesel engines lie rusting and unused by the thousands and solar pumps sometimes run for years without anyone touching them.

III. Methodology

Following methodologies has been adapted to present feasibility study and comparative analysis of the solar powered pumps.

- Water supply demand analysis based on population data and national standard water provision of the country;
- To determine the energy required from the source and the size of photovoltaic module;
- Economic analysis of the system in general and cost comparison between Solar and fossil energy sources.

Basic steps involved in system sizing are [10]:

- Determine the daily water needs of the population to know the rate flow required;
- Use design-month insolation (hours each 1-sun) as the hours of pumping to find the pumping rate;
- determining of the inclination of the photovoltaic generator which can be placed;
- Find the total dynamic head H Vs Flow Q;
- Find a pump capable of delivering the desired head H and flow Q, Pump efficiency ηP

A. Data Collection

The study was conducted at Mahango village, Mbarali district in Mbeya region. This area was selected because the village is facing the problem of drinking water. During data collection, the researchers were involved in performing the following activities:

- Depth of the well in meters and Average Daily solar radiation.
- Monthly mean Peak sun Hours of Mbeya region.
- Population density of humans, animals and their consumption per day.

B. Sizing a photovoltaic water pumping system

Photovoltaic water pump sizing is the determination of the power of the solar generator that will provide the desired amount of water

The photovoltaic water pump sizing consists of:

- Assessment of daily water needs of the population to know the rate flow required;
- Determining of the available solar energy;
- Determining of the inclination of the photovoltaic generator which can be placed;
- Sizing of the PV generator (determination of the required electrical energy).

C. Data Analysis

During the study, the essential data were collected. Thereafter editing, classifying according to the requirement of each specific objective, tabulating and computing was done to facilitate interpretation and analysis. The analysis intended to accomplish the objectives.

IV. Data Presentation, Analysis and Discussions of the Results

This part gives the data compilation, analysis and interpretation of results and viability of solar photovoltaic (PV) system.

A. Sizing a Photovoltaic water Pumping System

Computation of size of the array requires data of mean daily insolation at the place of installation. The monthly solar insolation is averaged for a day to obtain solar insolation in kWh/m^{2}day.The monthly mean peak sun hours and average monthly mean sunshine hours of Mbeya region in kWh/m^2 for three years is as shown in table 1 and table 2 respectively.

Table 1 Monthly Mean Peak Sun Hours of Mbeya Region in (kWh/m^2) for the period of four Years (2015-2018)

	Years			
Months	2015	2016	2017	2018
Jan.	5	3.8	3.9	4
Feb.	4.5	4.5	4.3	4.4
March	4.6	4.9	4.5	4.6
April	4.1	5	4.3	4.5
May	4.7	4.9	5.1	5.3
June	5.3	5.3	5.2	5.4
July	5.4	5.2	5.2	5.4
Aug.	5.6	5.3	4.9	5
Sept.	5.5	5.7	5.3	5.4
Oct.	5.5	5.5	5	5.2
Nov.	4.3	5.3	4.3	4.5
Dec.	3.7	4	4.1	4.3
Aver.	4.9	5	4.6	4.8

Source: TMA, 2018

Table 2 Average **Monthly Mean Peak Sun Hours of Mbeya Region in kWh for the period of four years (2015-2018)**

Months	kWh
January	4.1
February	4.4
March	4.6
April	4.4
May	5
June	5.3
July	5.3
August	5.2
September	5.4
October	5.2
November	4.6
December	5.2
Average	4.9

Source: TMA, 2018

Table 3 The Estimated Maximum Daily Water Demand for Mahango village 2018.

consumers	Requirement Litres/Consumer	Total consumer	Demand Litres/day
Man	25	6555	163875
Dairy cows	80	305	24400
Beef cows	50	50	2500
Pigs	20	135	2700
Sheep & goats	10	497	4970
Chickens	0.1	7000	700
Horses	50	42	2100
Total demand			**201,245**
Estimated maximum demand is			**201,545**

Source: Mahango Village, 2018

B. Determination of the Ratings of the Pump

At Mahango village, Mbarali district the head of the well is 80metres, and the maximum volume of water required as from table 3 is 201,545litres/day or 201.5m^3/day (since 1m^3= $1000litres$**).** Water is pumped for 6 hour a day at the village**.**

When water is pumped from the well to the overhead tank, potential energy (PE) is involved.

$$PE = mgh \text{ And } m = \rho v \quad \therefore PE = \rho vgh = \frac{1000\,kg}{m^3} \times 201.5m^3 \times 10\frac{m^2}{s} \times 80m = 161236000J$$

$$P(W) = Energy/time \;.\therefore P = \frac{161236000}{6\times60\times60} = 7464.6W = 7.4646kW$$

The suitable motor as per data sheet is 8kW. For lightings which operate for 10hours at the pump house and tank let the total power be 500W or 0.5kW the total power is 8.5kW per day.

Method for calculating PV module size is given by:

$system\ output =$

$$\frac{Daily\ load\ in\ watt\ hours + 20\%\ system\ loss}{peak\ sunshine\ hours\ (PSH)} \quad (1)$$

Calculation of PV module size is also given by:

$$Array\ system(kW) = system\ output \times Adjustment\ factor \quad (2)$$

A load adjustment factor for system losses (rainy periods and others) is given by: $Adjustment\ factor = (\eta_{BC} \times \eta_{SD} \times \eta_V)^{-1}$ (3)

Where: η_{BC} =Battery charging efficiency;
η_{SD} =Battery self- discharge level
η_V =Variability factor.

For system with $\eta_{BC} = \eta_{SD} = \eta_V = 0.9$ (RAI, 2000)

$\therefore Adjustment\ factor = (0.9 \times 0.9 \times 0.9)^{-1} = 1.37$

Insolation of Mbeya region is 4.9 PSH from table 2

$$Array\ size(W) = \frac{(8000W \times 6HRS) + (500W \times 10HRS) + (20\% \times 49000)}{\frac{4.9PSH}{day}} 1.37 = 16440W$$

Consider a module of 200W; number of module required to supply a load of 16440W is $\frac{16440\,W}{200\,W} = 83$ modules.The rating of the system was calculated corresponding to the pump specifications referring to paper [11]

C. Solar Battery Sizing

Battery capacity is given in kWh or Ah at constant discharge rate.

$$Battery\ capacity = \frac{Demand\ (Wh) \times Days\ of\ autonomy}{system\ voltage\ (V) \times Depth\ of\ discharge\ (\%) \times \eta_{IV}}$$

Where: Inverter efficiency (η_{IV}) for sine wave inverters is 80% to 95%;

Depth of discharge for deep cycle batteries mostly used is 80%;

System voltages in general when load is exceeding 6000Wh the system voltage of 48V is chosen. Choose depth of discharge = 80%; $\eta_{IV} = 90\%$ and $Days\ of\ autonomy = 2$

$\therefore$Battery capacity (Ah)= $\frac{49000 \times 2}{48 \times 0.8 \times 0.9} = 2836Ah$

Choosing a solar battery of 300Ah, number of batteries required $\frac{2836\,Ah}{300\,Ah} = 9.5 \approx 10\ batteries$

D. Charge Controller Sizing

Size of charger controller is estimated as follows:

$Charge\ controller(kA) = \frac{1.3 \times array\ size\ (kW)}{System\ voltage}$; Where 1.3 is the factor of safety

$Charge\ controller(kA) = \frac{1.3 \times 16.44kW}{48V} = 0.44525kA \approx 445A$. The suitable charge controller is that of 500A as per data sheet.

E. Inverter Sizing

In sizing the inverters the safety factor in operating the system is taken into consideration. Size of inverter is determined as follows;

$Inverter\ Size(kW) = 1.3 \times system\ size(kW)$

$Inverter\ Size = 1.3 \times 8.5 = 11.05kW = 11050W$

F. PV Modules Mounting

Solar panels produce the most power when they are pointed directly at the sun. The tilt angle is the angle between the plane of the solar panel surface and the ground. The PV panels should be mounted facing in a location where they receive maximum sunlight throughout the year. For maximum energy collection, the panel surface should be perpendicular to the sun. Solar incident angle (θ) is the angle being measured between the beam of rays and normal to the plane. This angle is found by adding the latitude angle of the site to10^0.For Mbeya region latitude angle is $8^0\ 54'\ 53''S$.$Solar\ Incident\ angle = 8^0\ 54'\ 53'' + 10^0 = 18^0\ 54'\ 53'' = 18.9^0$

Since the site is south of the Equator the module are directed at $18.9^0\ North$.The PV mounting at Mahango village is as shown in figure 4.

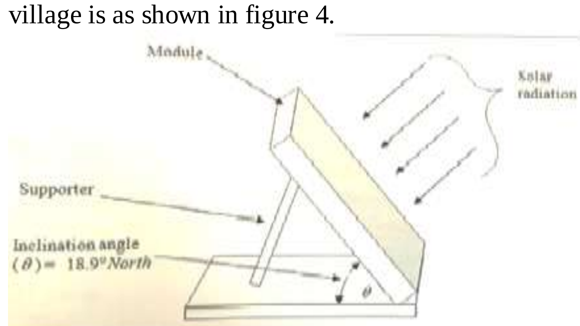


Figure 4 Mounting of the PV Module

Locating the PV modules close to the water source is important to keep voltage loss in the system wiring to a minimum. A fence around the PV modules is required to protect the PV panels from damage due to animals. After installation, the area inside the fence must be maintained. Shading from weeds or a single tree branch can limit power output.

G. Area of Mounting PV Modules.

From section 4.1.1on d**etermination of the Ratings of the Pump and the** number of module needed to supply a load of 16440W it was found that 83 modules were required.

$$Area\ require = Number\ of\ modules \times Area\ of\ one\ module = 83modules \times 2.5m^2 = 207.5 \approx 208m^2$$

Area available is 752 m^2; this area is enough for mounting of the modules required.

CONCLUSION

In this paper, the viability of solar photovoltaic water pumping system has been investigated for Mahango village in Tanzania. The designed system is capable of providing a daily demand of 201.5 m3/day for the village as indicated in table 3. The main advantage of solar system is, when the prices of fossil fuels rise and the economic advantages of mass production reduce the peak watt cost of the photovoltaic cell

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LIST OF ABBRIVIATIONS AND ACRONYMS

PE	Potential Energy
PV	Photovoltaic
PVPS	Photovoltaic Pumping System
PWM	Pulse Width Modulation
TMA	Tanzania Metrological Agency
PSH	Peak Sun Hours

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