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Renewable Energy Powered Water Supply System in Uganda: A Critical Review

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ABSTRACT

Renewable energy powered water supply system is very essential and important to be adopted in Uganda as a means of pumping water because of its harmless, free gift of nature, user-friendly and durability. Solar water pumping system is the most economic and user friendly pumping system that can effective and efficient used in pumping water. The battery-coupled solar water pump is the most suitable for pumping water because of its ability to supply water efficiently even when there is low power conversion efficiency. Battery-coupled solar water pump has the ability to work effectively during low irradiance because of the backup battery incorporated in the system to supply water to the reservoir when solar conversion energy is insufficient to supply the required amount of energy that can pump the water. The Battery-coupled solar water pump is highly recommended to be used in Uganda for supplying clean and safe water to their citizens as solar energy powered pump is durable, easy to maintain, user-friendly and harmless to the health.

Keywords: Renewable Energy, solar pump, water, solar Photovoltaics and Uganda

INTRODUCTION

Urbanization, migration and rapid increase in Ugandan population have drastically increased the demand for clean and safe water in Uganda according to the Ugandan Ministry of Water and Environment. A source of energy to pump water is also a notable problem in developing countries like Uganda. The cost of running diesel to meetup with the water demand of 48,582,334 population of Uganda as of 2023 will be so expensive and exorbitant to spend. The use of renewable energy sources as an alternative method of steady water supply at low cost in developing countries should be their utmost desire. This can also be encouraged because the cost of purchasing and installing of renewable energy systems such as photovoltaic (PV) pumps is cheaper, user friendly, easy to maintain than other conventional energy sources of water pump [1]. Solar Photovoltaic (PV) sources of renewable energy has been

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identified and adopted as one of the fastest renewable energy that will dominate in terms of energy generation in the future. This is because of its clean, free gift in nature, ease of maintenance and user friendly. These economic and health importance made PV energy sources attractive for many applications, especially in rural and remote areas of most of the developing countries like Uganda. Solar photovoltaic (PV) water pumping systems have been recommended as an alternative/suitable sources of energy supply for areas with inadequate electricity in poor countries with a high solar irradiance. Solar photovoltaic water pumping systems can provide water for domestic and farming purposes without the need for any kind of fuel or the extensive maintenance required by diesel pumps. They are easy to install and operate, highly reliable, durable and user friendly, produces clean and safe energy which can be installed at the site of use as standalone or building integrated rendering long pipelines unnecessary [2]. The output of solar power system varies throughout the day with respect to changes in weather conditions or partial shading of the panel. A properly and a well-designed solar pumping system will be efficient, simple and reliable and has the ability to work effectively for a very long time without maintenance. Solar powered pumping systems serves many purposes such as Town-city water supply, livestock watering, irrigation and so on. The Ugandan government is currently implementing a solar PV electrification of schools and other institutions in selected districts which are remote from the national grid as part of a national strategy to enhance the contribution of renewable sources of energy to the overall energy supply. In 2009 about 150 public institutions in Uganda were powered with 360 kW of PV electricity whereas the total capacity of the overall solar PV installations in rural areas of Uganda amounts to 6 MW. Despite this success, the percentage contribution of solar energy to the total energy mix is insignificant (less than 1%). Studies sponsored by Ministry of Energy have shown that Uganda holds tremendous potential in solar energy but only a small potion has been tapped.

Status of Solar Energy in Uganda

The level of solar energy utilization in Uganda is still very low. The use of solar PV began in the early 1980s mainly driven by donor funded programs for lighting and vaccine refrigeration in health centers. The Uganda Railway Cooperation, a government parastatal later installed 35kW solar supplied energy in 29 locations for signals and communication. The Uganda post and communications cooperation also installed 30kW at 35 remote telecommunication sites throughout the county. Recently, solar energy installations and technologies has been in used for providing electricity to remote homes and institutions from the national grid and for medium temperature water heaters for domestic and commercial usage. Solar electric systems are being imported and sold to end users in Uganda through a competitive and growing free market network that includes more than 10 importer and manufacturing companies.

Furthermore, a vibrant solar power market has been developed in Uganda for over 10 years now providing electricity to homes and institutions located in some remote areas where conventional sources of power were not available. The Average solar radiation in Uganda is approximately 5.1kW/m²/day. This data indicates an annual solar irradiance of about 4.5 to 5.5 W/m² (20%), which was possibly obtainable because of its nearness to equator [3].

Solar Radiation

The term **"solar radiation"** refers to the electromagnetic waves that the sun emits. It is commonly expressed in units of kilowatts per square meter (kW/m²). The earth receives a nearly constant 1.36 kW/m² of solar radiation at its outer atmosphere. However, by the time this energy reaches the earth's surface, the total amount of solar radiation is reduced to approximately 1 kW/m² [4]. The intensity of sunlight also varies based on the time of day. Solar intensity is greatest when the sun is perpendicular to the earth surface and light is passing through the least amount of atmosphere [5][6].

Solar Irradiance

The amount of solar energy per unit area arriving on a surface at a particular angle is called **irradiance** which is measured in watts per square metre (W/m²)[7].Solar irradiance can also be defined as is the amount of solar energy received from the sun in the form of electromagnetic radiation in the wavelength range of the measuring instrument

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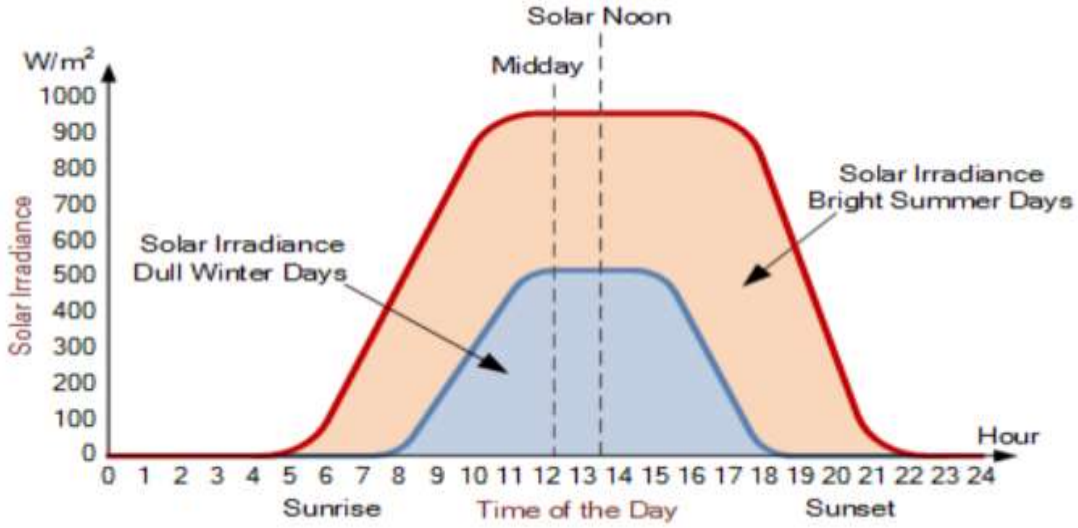
[8]. According to NASA, the average irradiance value measured on the edge of space and outside the Earth's atmosphere on a flat surface positioned perpendicular to the sun is about 1,370 watts per m^2 (1.37 kilowatts).

Figure 1: Solar Irradiance Performance Index [7]



Solar Insolation

Insolation is the amount of solar radiation received by a planet. Solar insolation is defined as the flux of solar radiation per unit of horizontal area for a given locality. It depends primarily on the solar zenith angle and to some extent on the variable distance of the earth from the sun [9].

Solar Power System

Solar power system is the complete connected solar components that generate energy through solar Photovoltaic phenomenon. Solar energy can be converted into electrical energy through concentrating solar power and solar photovoltaic techniques. In this paper solar photovoltaic components and process of energy generation will be discussed in detail due to its future prospects among other renewable energy. The major component of a solar photovoltaic (PV) system is the PV module which is made up of solar cells. A solar cell converts the energy in the photons of sunlight into electricity by the means of the PV phenomenon found in certain types of semiconductor materials such as selenium (Se) germanium (Ge) and silicon (Si). PV cells are connected in series to increase voltage output and connected in parallel to increase the current output [10][11]. Solar photovoltaic applications/technologies were mainly used for irrigation systems because of its durability, user friendly and ease of maintenance. Solar photovoltaic can be used as an alternative means of clean and steady energy supply for water pumping/irrigation. Solar powered irrigation system can be a suitable alternative for farmers in the present state of energy crisis in Uganda [12].

Components of Solar Power System

Solar power system are the components are the basic components required to produce effective and efficient electricity from the sun. The major required components are; solar panels, charge controller, power inverter and solar batteries for backup.

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Photovoltaic Operation Principles

The photons of the solar irradiance shines on top of the cell and some photon rays reflected, some penetrated into the substrate while the rest with lesser energy passes through the cell without any impact. A pair of electron-hole can only be created by photon rays with energy level above band gap of silicon and the pairs of electron-hole were generated on both sides of the p-n junction. The metal contacts situated at both sides of the solar cell is responsible for collection of generated current. The current was generated by using electric filed mechanism where the minority charges are diffused into the junction and were swept away in opposite direction in order to produce current [13]. Figure 2 showed the basic operating principles of solar cell. Photovoltaic cells generate electricity from the sun whereas Solar panel converts sun light into electrical energy for all electrical activities such as water pumping, household energy supply and so on [10], [11], [13]–[22].

Figure 2: Basic Working Principles of solar Photovoltaic Cells [13]

For a solar PV to give a reasonable amount of energy there must be a sequential order connection from cells to panel to array. A combined cells connected both in series and parallel forms panel/module and modules connected in series and parallels forms an array. Figure 3 is a typical samples of cells, panels/module and array.

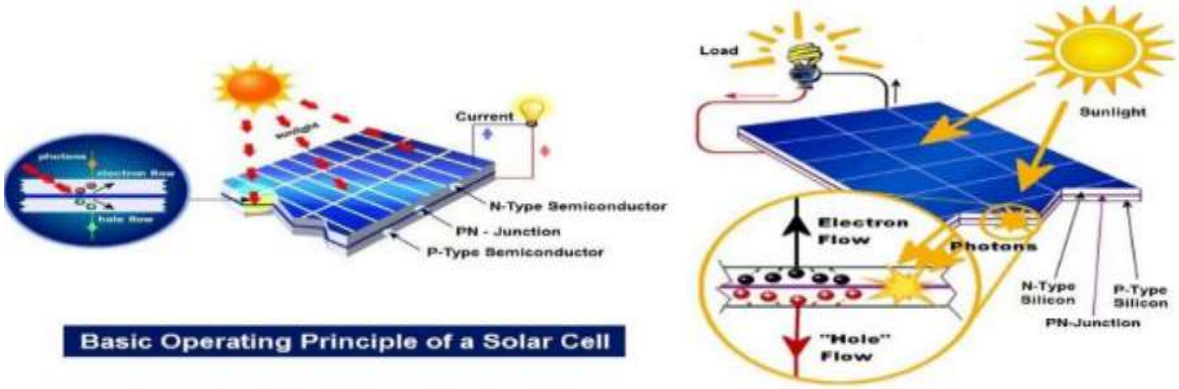

Figure 3: Solar cell, PV solar panel, and PV panel array [11]

Charging Units

Inverters convert low frequency main AC power to higher frequency for use in induction heating. The AC power is first rectified to provide DC power and inverter converts the DC power to high frequency AC power for storage. Solar energy stores power in a battery for backup during low efficiency [14], [15].

Water Pumping

Solar photovoltaic is one of the renewable sources of energy that is economically and efficiently used for pumping water for public consumption in Uganda. Solar Photovoltaic-powered pumping system can be used to pump water that will be sufficient for crop irrigation, livestock and domestic uses in Uganda. The use of reservoir for water storage should be an added advantage for users during low solar power conversion efficiency thereby eliminating the need for batteries and enhancing simplicity and reducing overall system costs. A solar-powered pumping system is generally in the same price range as a new windmill but tends to be more reliable and require less maintenance and more durable [23].

Solar Powered Water Pumps

A solar powered water pump is a mechanical or electromechanical devices that are designed to move water through pipes or hoses by creating a pressure differential using solar phenomenon. The two most common types of pumps used for pumping water are centrifugal pumps and positive displacement pumps. A solar powered pump can be more environmental friendly and economical in its operation compared to pumps powered by an internal combustion engine (ICE). A solar powered pump consists of two parts, namely;
(a) The actual pump, and (b) the energy source being powered by the sun. It can provide a reliable water supply and eliminate the installation of power lines in environmentally sensitive areas.

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Examples of Solar Water Pumps

DC water pumps in general use one-third to one-half the energy of conventional AC pumps. DC pumps are classified as either displacement or centrifugal, and can be either submersible or surface types.

- **Displacement pumps**

Use diaphragms, vanes or pistons to seal water in a chamber and force it through a discharge outlet.

- **Centrifugal pumps**

Use a spinning impeller that adds energy to the water and pushes into the system, similar to a water wheel.

- **Submersible pumps**

A submersible pump is an air-tight sealed motor close-coupled to the pump body. The main advantage of this type of pump is that it prevents pump cavitation, a problem associated with a high elevation difference between pump and fluid surface [24].

Working Principles of Solar-Powered Pumps

The submersible pump will be lowered deep into the water source and it is powered by a direct drive Solar photovoltaic arrays. The solar panels produce electricity, which is passed through a control unit and can be connected to batteries as well, and this drives the pump. Figure 4 is a typical solar PV powered submersible water pump.

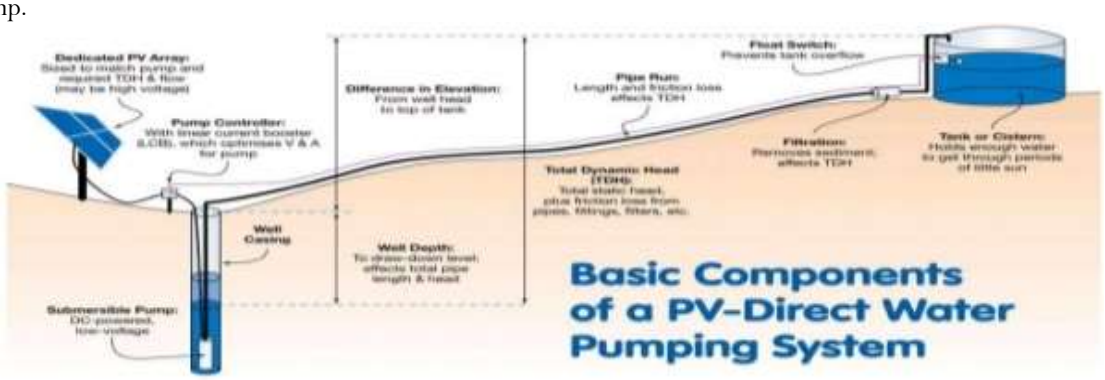

Figure 4: Schematic diagram of solar powered water pump system [23]

Advantages of solar powered water pumps

- High flow rate of approximately $10m^3/h$ to $15m^3/h$
- They have excellent efficiency
- Lifts up to 240 m
- Simple installation and less Maintenance
- Highly Durable
- Highly Reliable
- Cost-effective pumping
- User friendly

Disadvantages of solar powered water pumps

- An expert is required in terms of repair
- Costly at first installation

Solar-Powered Water Pumping System

There are two basic configurations of solar-powered water pumping systems which are; battery-coupled and direct-coupled. A variety of factors must be considered in determining the optimum system for a particular application. Each of the configuration techniques has its advantage and disadvantages which must be considered before choosing which configuration to be adopted. It is advisable to use battery coupled solar pumping system because of days of low irradiance and high temperature which is major factors that negatively affects the conversion efficiency of a solar PV system. Figure 5 is a battery-coupled solar water pumping system that was used to power the water reservoir

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system.

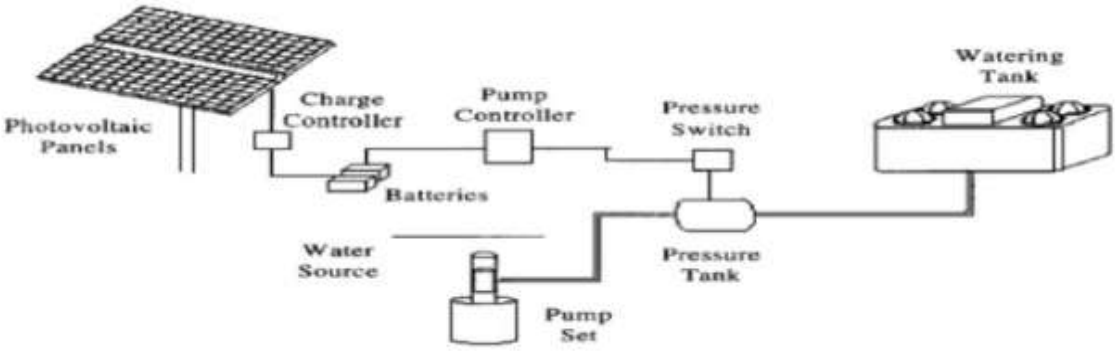

Figure 5: Battery-Coupled Solar Water Pumping System [23]

Advantages of Solar Energy in pumping water

- It is a clean and renewable sources of energy
- Its free gift in nature
- Harmless and pollution free.
- It is cheap to run
- It is user friendly

Disadvantages of solar energy

- It is expensive to install
- Intermittent in a cloudy weather
- Expert required for maintenance

Comparison with other Water Pumping Systems

The cost comparison of running the water pumping with wind, solar, diesel engines and electricity are compared in table 1. This showed that water pumping can be very cost effective when running it with none renewable sources of energy and some renewable sources of energy. Hence, after several cost effective analysis coupled with reliability and durability solar pumping system was considered to be the best because of its excellent futures and advantages over others as in table 1.Solar water pumping systems have many advantages over traditional windmill water pumps as it can operate effectively anywhere the sun shines which other water pumps cannot do effectively. Solar pumps are becoming a preferred alternative in remote area of Uganda to replace the increasingly expensive diesel pumps and hydroelectricity [4], [23].

Table 1: Comparison With Other Water Pumping System

	Advantage	Disadvantages
Hand Pumps	1. Easy to maintain 2. No fuel cost	1. Stressful and cannot be used commercially 2. Low/poor output
Wind pumps	1. Unattended operation 2. Easy to maintain 3. Long life 4. No fuel requirements	1. Water storage tank (reservoir) is required in low wind periods. 2. High system design and planning needs. 3. Not easy to install
Solar PV module	1. Unattended operation. 2. Low maintenance 3. Easy installation. 4. Long life. 5. Highly durable 6. User friendly 7. Harmless and pollution free	1. It is expensive to setup 2. Intermittent in a cloudy weather 3. Expert is required for maintenance
Diesel and gasoline pumps	1.Quick and easy to install 2. Inexpensive to setup	1. Fuel supply is erratic and expensive 2. High maintenance costs 3. Short life expectancy 4. Noise and harmful

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CONCLUSION

Renewable sources of Energy are the best energy sources to be used in water pumping and supply to reservoir. Solar water pumping system is the most economic and user friendly pumping system to be used for effective and efficient steady water supply. The battery-coupled solar water pump is the most suitable for pumping water because of its ability to supply water efficiently even when there is low solar irradiance which leads to low power conversion efficiency. Battery-coupled solar water pump has the ability to work effectively during low irradiance because when there is low irradiance the system will switch to battery. The Battery-coupled solar water pump is highly recommended to be used in Uganda for supplying clean and safe water to their citizens as solar energy powered pump is clean, user-friendly and harmless to the health.

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