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SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEM APPROACH FOR ELECTRICITY GENERATION AND IRRIGATION: REVIEW

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Abstract

Solar energy for water pumping is a possible alternative to conventional electricity and diesel-based pumping systems, particularly given the current electricity shortage and the high cost of diesel. The literature survey includes a comparison between previous studies of pumping systems using photovoltaic cells, and the extent of the influence of external factors such as radiation intensity and temperature on the efficiency of the system. Additionally, the use of water storage to generate electrical energy through potential energy by means of hydraulic generators and the effect of the amount of flow and height on the amount of energy generated, as well as the types of hydraulic generators are discussed in this paper.

Nowadays, solar power is a major contributor to the world's electrical energy supply, either by generating electrical energy directly from solar cells or through water storage, which will be covered in this review. When compared to electricity or diesel-powered systems, solar water pumping is more cost-effective for irrigation and water supply in rural, urban, and remote areas. This paper also highlights the challenges that must be overcome to develop high-quality, long-lasting solar power technology for future use.

Keywords: solar energy, renewable energy, photovoltaic water pump, hydraulic generator

List of Symbols/Acronyms

PV: Photovoltaic
SPV: Solar photovoltaic
PVWPS: Photovoltaic water pumping system
WPS: Water pumping systems
SIPs: Small isolated power systems
PVsyst: Photovoltaic system software
PHT: Pico-hydro turbine
PHES: Pumped-hydro energy storage
LPSP: Loss of power supply probability
SWP: Solar water pump
SDrOP: The Solar Powered Drip Irrigation Optimal Performance model
LCC: Life cycle cost
AM: Air mass
SynRm: Synchronous Reluctance Motors
IM: induction motor

1. INTRODUCTION

Today's rapidly depleting traditional energy sources, coupled with the constant rise in energy demand and environmental concerns, have sparked intense research for new, more efficient technologies. The sun provides the majority of global power usage needs, making solar power a clean and sustainable source of power. Utilizing solar power through photovoltaic (PV) generation is a cost-effective option. Street lights, solar panels (an array of photovoltaic cells), and water heaters are being powered by solar energy. This technology has a variety of uses, including in agricultural irrigation systems [1]. Relying on renewable energy sources to power our homes and businesses is a crucial step in mitigating the effects of climate change and global warming. In addition, renewable energy sources are important resources for countries with large populations that lack access to the standard energy grid [2].

Perhaps the most prevalent application of solar power nowadays, especially in dry and semiarid areas and even certain metropolitan areas, is powering water pumping systems (WPS) for irrigation with solar PV energy [3]. To ensure optimal solutions, however, before installing a PV system for irrigation, it's vital to evaluate the available solar and water resources in the area [4].

Therefore, PVWPS have a number of significant benefits over traditional water delivery systems, making heir widespread use attractive, particularly in remote locations and places with abundant sunlight. Hydraulic pumps powered by the sun are extremely low-maintenance and energy-efficient, as they use no fossil fuels. When compared to traditional water pumps, properly constructed and sized PVWPS can deliver crucial long-term savings. Given this, it's important to look back at the stages of development of PVWPS research and improvement to see if there were any consistent improvements made to components, if the PV component of the systems interacted better with the consumption machinery, and if consumption was accounted for and optimized [5].

Hydro resources have a greater potential for widespread use than either fossil fuels or nuclear fuels [6]. Hydropower is currently an important source of electrical energy all over the world, responsible for producing the equivalent of 20% of all electricity generated worldwide. In many nations, it is the sole source of power. Hydropower projects come in a wide variety of scales and types, with designs customized to meet the requirements and constraints of a specific location [7]. Many countries' rural areas would be unable to access electricity without the help of small, mini, and micro hydro plants, which have the potential to immediately displace fossil fuels due to their greater ability compared to any other energy source [6, 8].

The surveyed studies showed the importance of utilizing solar power for crop irrigation and electricity generation. The aim of the current review is to reveal the advantages of PVWPS, which consists of solar panels, a pump, an upper and lower tank or water well, and a hydraulic generator to generate electricity by taking advantage of the potential energy in the upper tank as in figure 1 [9].

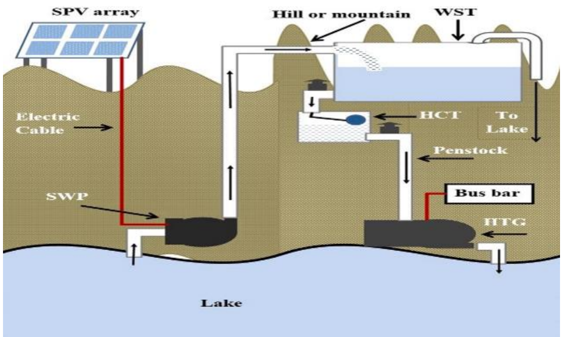

Fig. 1. Solar-PHES power system [9]

2. PHOTOVOLTAIC SYSTEM

Photovoltaic energy and other renewable energy sources are suitable for areas located far from the national grid with moderate energy needs due to their low cost and the possibility of developing them as needed [10, 11]. PV systems use solar energy to produce energy directly without harming the environment. PV generating systems have a promising future due to their decreasing cost and increasing efficiency [12, 13]. However, photovoltaic (PV) power system technology is still developing, driving up the cost of producing one unit of energy. The energy conversion efficiency of power-generating PV panels determines the effectiveness of these systems. Practical systems are often inefficient. The PV array, controllers, battery, wiring, and inverter work together to convert solar energy into an AC system.

When studying photovoltaic energy systems, some important conclusions have been reached. The reliability of small, isolated power systems (SIPS) using PV is highly dependent on location [13, 14]. The operating temperature of PV modules is significantly affected by the local climate, which, in turn, affects the amount of electricity produced [15, 16]. The robustness of solar renewable credit terms is determined by the magnitude of incentives, the price of residential solar PV, the price of electric energy, and the amount of solar insolation [15, 16]. Therefore, modeling the solar PV system is crucial for four reasons: maximizing system efficiency, boosting confidence in future output estimates, securing adequate funding for the project, and streamlining installation [17, 18, 19].

3. SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEM

3.1. Principle of a solar water pump

PV technology is the foundation of solar water pumping; this technology transforms sunlight into energy in order to pump water. The photovoltaic arrays are linked to a engine that can run on direct current or alternating current [20]. This motor is responsible for transforming the electrical power provided by the PV panels into mechanical energy. The pump then transforms from mechanical to hydraulic power. The ability of a PV pumping apparatus for moving water is mostly dependent on three key factors: the pressure of the water being pumped, the flow rate, and powers available being providing the pump. When it comes to design, pressure may be thought of as the amount of work that is put in by a pump in order to transport a specific quantity of water to a vessel. The amount of work that a pump needs to undertake is based on the difference in elevation the water supply and the storage tank [21]. Replacement of older PV modules with new modules can increase power output from PV panel and boost solar system efficiency. To keep working for many years to come. From July 2013 through May 2014, Fig. 2 displays the experimental results of the PV Systems pump on regular bright days during the summer, winter, and rainfalls [22]. When the pumping system is equipped with Synchronous Reluctance Motors (SynRM), it is better than the induction motor (IM) type and obtains an efficiency increase of 2-25%, especially for these pumps operating with a photovoltaic system [23]. the simulation approach in modeling the real photovoltaic pump system with the help of Matlab/Simulink environment can help to calculate efficiency for different insolation and temperature ranges by tuning the input parameters, Further improvement of the model will include experimental validation and integration of the efficiency characteristics of solar tracker and maximum power point tracking device [24]. Equation is used to calculate the total efficiency of the solar water pump [3]:

$$\eta_{total} = \eta_{PV} \times \eta_{MP} \quad (1)$$

where:

η_{PV} PV system efficiency, $\times\eta_{MP}$ The pumping system's efficiency .

$$\eta_{PV} = \frac{PPV}{GGLOB * Aarray} * 100\% \quad (2)$$

where:

P_{PV} is the PV array's maximum power under Standard Testing Conditions (STC: radiance = 1000 W/m2, AM 1.5 (Air mass by how much 1.5), cell temperature = 25˚C) [Wp].

G_{GLOB}: is the global sunlight radiance on a level surface [W/m2].

A_{array}: area of the Solar array [m2].

A simplified method proposes a simple arithmetic formula that can be used to determine the approximate value of the rated power of the Photovoltaic panel according to Equation (3):

$$P_{PV} = I_{array} * V_{array} \quad (3)$$

The current and voltage coming out of the solar panel at greatest load are practically calculated using a digital clamp meter.

Where:

I_{array}: The current from the solar panel [Amp]

V_{array}: The output voltages of the solar panel [volt].

The pumping system's efficiency It can be calculated by dividing the hydraulic output power by the input electrical power resulting from the power of the solar panels.

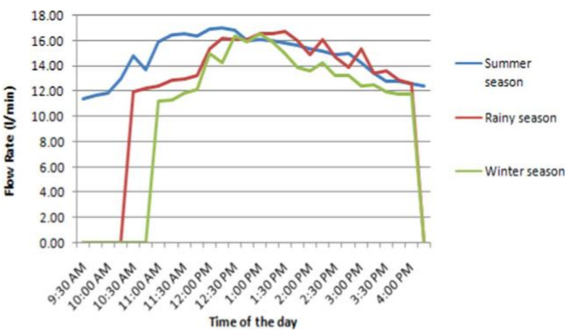

Fig. 2. Water flow rate during seasons [22]

3.2. Performance indicators for a solar pump

The performance of a photovoltaic pump is mostly influenced by the fluid flow, which in turn is impacted by the weather conditions at the location, particularly the solar irradiation and temperature fluctuations in the air [26]. The effectiveness of a PV pump is determined by the demand for water, the size of the water tank, the head (m) by which the water needs to be lifted, the volume of water that needs to be pumped (m3), the simulated energy from the solar array (kWh), the energy at the pump (kWh), the unused PV energy (kWh), the pump efficiency (%), and the system efficiency (%) [27]. The efficiency of the solar panel used in the PV generator also has a significant impact on performance [28].

3.3. Performance improvement of pv water pumping systems

Researchers Abdolzadeh et al. [29], and Kordzadeh [30] examined how a solar water pumping system could work if water was sprayed over solar panels under various operating situations. Spraying water in parallel allows for the investigation of the efficiency of photovoltaic (PV) water pumps that have two or three photovoltaic modules that are each 225 watts. It has been discovered that when the module temperature is elevated, not only does the module's performance suffer, but also the system's performance. When water is sprayed over photovoltaic modules, the temperature of the modules drops, which in turn boosts the modules' effectiveness. Additionally, the pump's output flow rate increases significantly when the components are cooled. Researchers Abdolzadeh & Ameri [31] examined the possibility of enhancing a solar pumping system's efficiency by spraying water on the solar panels. According to the findings, using water in a mist form can produce a mean PV efficiency of 12.5%. On the day of the test, the average flow at 16 meters of head for a system that did not spray water over the PV modules was around 479 l/h, but the flow rate for a system that did spray water over the PV panels reached 644 l/h. The cooling of the photovoltaic modules, which is achieved by spraying water over the modules, increases the system's effectiveness and its subsystems. Direct-connect systems are most effective as soon as an elevated water tank is filled with water. In this configuration, the electric power from the panels is transformed into the increased water's stored energy, which can subsequently be used as needed, usually by gravity [32]. The removal of the intermediate stage or the storage battery, for the purpose of energy storage, is a significant contributor to the success of the pumping system. Because there is a direct connection between the pump and the solar panel, it is possible to pump water while the sun is out. From the sunlight to the flow of the water, the overall performance has been measured to be greater than 3% [33]. The submersible pump's flow power characteristic curve matches the simulated relation's requirements and shape when designing and implementing a solar-powered borehole water pumping system using PVsyst software, indicating a satisfactory performance ratio (68.1%) for linking the photovoltaic cells array and pumping system [34]. To determine the best layout for an Iraqi solar water pumping system using direct-coupled modules, annual results reveal a 42.6% gain in pumping efficiency, a 10950 m^3 decrease in wasted water, and a 48.8% drop in unused energy [35].

4. THE EFFECT OF RADIATION INTENSITY AND INSOLATION ON SYSTEM EFFICIENCY

In analyzing the performance of a photovoltaic (PV) system, it is important to take into account the environmental factors of irradiance, ambient temperature, and air velocity [36]. In a study by researchers Pali and Vadhera [37], an isolated PV system was investigated, which produced a constant power at a consistent voltage by utilizing locally recommended renewable resources such as Pumped Hydro Energy Storage (PHES), open well, Solar Water Pump (SWP), and Photovoltaic Heat and Power (PHT) systems.

In particular, the study focused on photovoltaic water pumping systems that replace the energy used by diesel engines with solar energy for pumping operations. To evaluate system performance, the researchers employed MATLAB to simulate real sun irradiation, and the suggested model was run for 72 hours. The results obtained from the study were found to match the simulations.

It was found that changing the inclination of the solar panels resulted in a decrease in the amount of sun energy falling on the solar arrays during the day, leading to a decrease in the hydraulic capacity of the pump per day, and ultimately, a decrease in the amount of water flowing during the day [38]. In addition, the summertime solar radiation input is sufficient to activate the system in the early morning, resulting in higher water flow rates compared to the rainy and winter seasons. Specifically, during the summer season, the system starts up at 9:00 a.m., while in the rainy season, it begins at 10:30 a.m., and in the winter, the pump is engaged at 11:00 a.m. [22], as shown in Figure 3.

Overall, these findings highlight the importance of considering the effect of radiation intensity and insolation on the efficiency of PV systems, and the need to optimize the tilt and orientation of solar panels to maximize the amount of solar energy captured and utilized by the system.

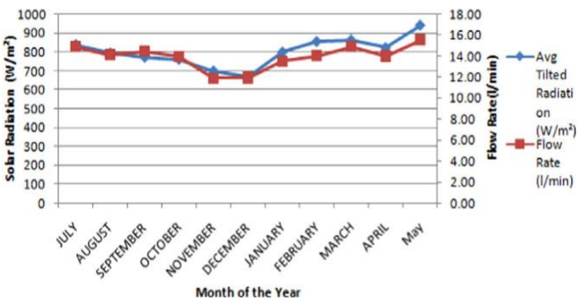

Fig. 3. Monthly flow rate water on inclined PV panels [22]

5. THE COST

Given the fact that the cost of photovoltaic (PV) cells has been gradually decreasing in accordance with More's Law, while the cost of diesel has been steadily increasing, photovoltaic pumping has become a economically feasible option [1]. It is important to consider the cost of installing any system, and in this regard, we will review the study of a group of researchers who assessed the cost of a PVWPS system. Due to the high price of PV modules, solar pumping systems for irrigation are more expensive than diesel motors [39]. However, if adequate space is available for photovoltaic panels, PV irrigation could be a viable option. One of the challenges associated with the use of photovoltaic arrays for generating electricity is the number of panels required and the space they would cover [40]. A researcher developed a photovoltaic water and irrigation system for places without mains electricity, which showed that solar pumps can pump from a 200 m head and 250 m3/day. Photovoltaic pumps outperform 1 kWp of irrigation power, and up to 3 kWp of diesel pumps are available. Solar photovoltaic (SPV) irrigation pump systems are low-maintenance, economical, and environmentally friendly. In winter, the operation and water flow efficiency decreases by 20-30%, which increases the cost of building a solar energy unit for small and medium-sized space owners by 54.1% [41]. However, the results demonstrate opportunities for system cost reduction, and the SDrOP approach was able to lower system LCC by up to 56% compared to commercial software [42].

6. ELECTRICITY GENERATION FROM WATER STORAGE

The most significant benefit of water storage for PV energy is the generation of electrical power through the water's energy stored in the upper reservoir by means of a hydraulic generator that depends on the flow and the height of the reservoir. In terms of environmental impact, hydroelectricity ranks among the best of all renewable energy options [43]. One of the more cost-effective power generation options that could be explored in less developed nations is micro-hydropower [44]. The term "micro hydropower" describes the use of electricity produced by the force of flowing water to provide power to individual homes or small communities [45]. The lack of water storage and the presumed lack of environmental impact make micro-hydro systems a feasible renewable energy option [46]. The turbine shaft spins due to the force of the water, and this rotational energy is then transferred by the generator into electrical power [47]. Table 1 illustrates how hydropower systems can be

Table 1. Classification of hydropower by size [45, 48]

NO.	Type (hydro)	The Power	Site of use
1.	Large	>100 MW	normally connected to a major power network
2.	Medium	15 - 100 MW	often used to supply an electrical network
3.	Small	1 - 15 MW	typically connected to a network
4.	Mini	100 kW - 1MW	both independent systems and those that connect to the network
5.	Micro	5kW - 100 kW	off-grid power sources that supply electricity to a small town or rural factory
6.	Pico	< 5kW	Off-grid energy sources supply electricity to a group of homes with specific uses

categorized in terms of the amount of power they produce. Pumping water from a lower tank to a higher tank stores energy as potential energy. Low-cost electric pumps can move water from the lower tank to the upper one using off-peak electricity. Hydro turbines discharge stored water to generate power during peak demand. Reversible turbine/generators can pump or generate power. Figure 4 demonstrates how water can be moved from lower to upper storage using standard proposed pumped-hydroelectric-storage (PHES) systems with PV solar alternatives [49].

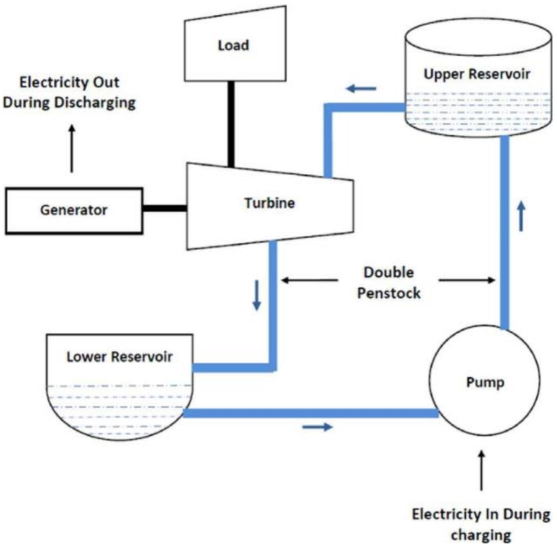

Fig. 4. Pumped hydroelectric storage system (PHES) [49]

7. CONCLUSION

Solar energy is set to become increasingly vital in the years to come as a means of lowering our reliance on fossil fuels and addressing environmental concerns. PV is a perfect example of the shift away from huge, integrated supply systems that take advantage of scale economies that is occurring in the energy technology sector. The current review is dedicated to the study of the water storage system using the pumping system with photovoltaic cells and its utilization in irrigation and electricity generation through photovoltaic generators. Several important points were concluded:

Solar energy is a clean and sustainable source through the use of photovoltaic panels. Studies have shown that the use of pumping systems is ideal in areas with high solar potential. It is considered a low-maintenance system because it does not use fossil fuels. Modeling is recommended in the design of photovoltaic pumping systems. The inclination of the panels towards the sun affects a large percentage on the efficiency of the system in general. Therefore, from the conclusions of previous studies, we can develop and increase the efficiency of pumping systems with photovoltaic energy for irrigation and electric power generation by using direct current pumps and not using batteries and inverters to reduce costs. One of the difficulties that we face when installing photovoltaic water pumping systems is the cost of batteries and inverters, so we recommend using a direct current water pumping pump.

Overall, the use of solar energy in pumping systems with photovoltaic cells is a promising approach to address the issues of high costs, environmental concerns, and low efficiency that are often associated with traditional fossil fuel-based systems. The research in this field is ongoing, and we expect to see further innovations and improvements in the coming years.

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