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A Review on Solar Photovoltaic Powered Water Pumping System for off-Grid Rural Areas for Domestic use and Irrigation Purpose

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***Abstract*:- Utilization of solar photovoltaic powered (PV) as a power source in water pumping systems has emerged as one of the valuable solar applications. Solar PV water pumping system (SPVWPS) is used to fulfill the demand of water in the field of irrigation and domestic use. This technology is recognized as a sustainable and environmentally friendly solution to provide water for domestic use and irrigation purpose.The tendency to use renewable energy resources has grown continuously over the past few decades, due to fear over warnings of global warming or because of the depletion and short life of fossil fuels or even as a result of the interest which has developed among researchers doing scientific research into it. This work can be considered as joining any of these groups with an objective of supplying drinking water and irrigation purposes to the society living in rural areas of the country as reported in the literature to serve as a quick reference to researchers and engineers who are interested in the subject. For further research perspective in the field of SPVWPS a few suggestions are recommended.**

Keywords: Solar water pumping,* photovoltaic, *Irrigation, off-grid

1. INTRODUCTION

Water is the primary source of life for mankind and one of the most basic necessities for rural development. The Likelihood, it is possible to conclude that, there is no moment without this significant factor and (because of this) the rapidly increasing world population growth gives rise to a greatly increased demand for water and energy.Most people in the world still lack access to basic water and energy services.In developing countries, generally composed of several villages sparsely located and with different topography, it is very difficult to extend the electric grid to every location where it is required. In some areas of the countries the traditional water pumping systems powered by diesel or gasoline engines have been used for a long time, but fuel cost escalation, transportation problem, lack of skilled personnel make the conventional water pumping system unreliable and expensive for rural communities. Although a large amount of high-quality water is present in the world, often it is not available at locations where it can be readily used. This raises the need to pump high-quality water from its source to the locations where it is in demand. For this purpose, water pumps have been in use for decades. Nowdays, different researches have been carried out all over the world and their results showthat, renewable energies are the best alternative energy sources to replace fossil energy.Solar water pumping system is now emerging on the market and rapidly becoming more attractive than the traditional power sources. It is considered a promising solution to solve those challenged issues. It presents a clean source of supplying water for irrigation with low maintenance required and with a reliable system that matches the generated energy with water needs for irrigation. Using solar water pumping in the remote area is environmental friendly; it has low running cost, long lifetime when compared to a diesel generator.Several renewable sources of energy can be used for water pumping. However, solar photovoltaic (PV) turned out to be the suitable one. While being clean and naturally available, solar energy has been proved to have a direct relationship between its availability and water demand. The solar intensity is high in many locations where the electric grid does not reach and there is a high need for water(Aliyu et al., 2018).Solar water pumping systems are an attractive application of renewable energy technology. The results suggest that photovoltaic water pumping systems are technically and economically feasible. Technical feasibility is determined from the maximum power required for pumping water and economic feasibility is determined by comparing present value cost of the photovoltaic and diesel pumping systems. Also, the results of this study suggest that the price of the diesel fuel has increased within the last 10years to make the photovoltaic water pumping systems economically feasible, despite the initial costs of photovoltaic systems. As the price of the solar panels decreases, the capital costs will decrease, making photovoltaic systems even more economically attractive. The use of renewable energy is attractive for water pumping applications in remote areas of many developing countries(Shinde & Wandre, 2015). PV system is based on semiconductor technology that converts sunlight into electricity. This is a proven technology but costs more than other electricity generation methods such as power plant based on coal, oil, natural gas and conventional hydro(Ã et al., 2008).In present paper, a review of research literature relevant to solar pumping is given. It aims to discuss the updated status and different aspects of SPVWPS and it would act as a guide for the system installation. The major objectives of present review work can be expressed as;

i. Introduction of the SPVWPS, its components and advantages,
ii. Summarization of the factors affecting the performance of SPVWPS, and

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iii. Summarization of performance assessment and optimization methods of SPVWPS.

2. STUDIES ON SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEMS

The photovoltaic power generation systems have invariable nature. They did not produce any harmful by-product. They are not extracted from the earth layers and do not return any harmful pollutant to the surroundings(Chandel et al.,2015)(Sharma et al., 2019).SPVWPSs consist of solar photovoltaic panels, a motor and a pump, which is depicted in figure 1.

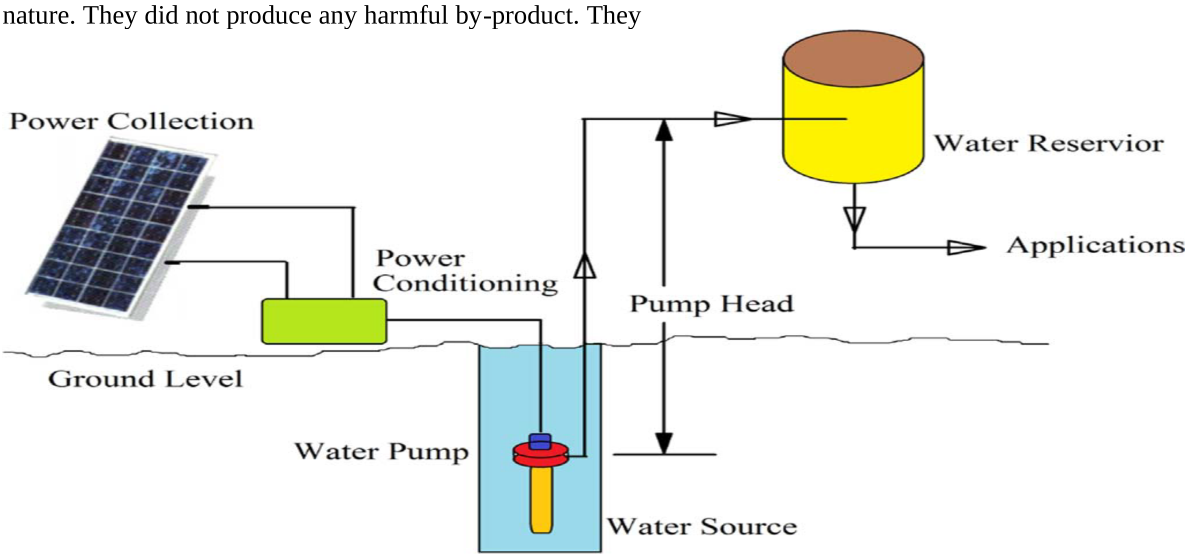

Figure1. Schematic diagram of a generalized solar powered water pumping system(Aliyu et al., 2018).

Depending on the system design, it requires storage batteries and a charge regulator, the current output of the system. If the motor uses AC, it is necessary to install a DC to AC converter. Battery-less SPVWPS are low-cost, which requires less maintenance compared to battery powered systems. However, the storage batteries have the advantage of providing consistent performance during lean and off sunshine hours. The addition of a water storage tank in SPVWPS is more economical than battery storage backup. The use of solar photovoltaic energy is considered to be a primary resource for the countries located in tropical regions, where direct solar radiation may reach upto1000W/m^2(Gopal et al., 2013).

Table 1 summary of some investigation on SPVWPS

References	Applications	Outcomes
(Shinde & Wandre, 2015)	Irrigation applications	Payback period of 6years was reported
(Ebaid et al., 2013)	Drip irrigation	Solar photovoltaic water pumps are operating more effective than other traditional water pumping systems
(López-luque et al., 2015)	Irrigation applications	Solar photovoltaic pumping systems are suitable for medium head domestic water pumping applications
(Sharma et al., 2019)	Domestic water pumping	The performance of the systems is highly affected by ambient parameters such solar intensity, ambient temperature, wind velocity
(Siecker et al., 2017)	Irrigation applications	Solar photovoltaic pumping systems are suitable for medium head domestic water pumping applications
(Ã et al., 2008)	Domestic water pumping	The SPVWPSs could reduce the CO_2 emissions considerably over 25 year life time
(Chand & Kalamkar, 2016)	Domestic water pumping	It was concluded that overall efficiency of the photovoltaic water pumping system was improved by better System design and load matching
(Chandel et al., 2017)	Irrigation applications	Directly coupled photovoltaic water pumping systems are suitable for low head irrigation applications
(Al-smairan, 2012)	Domestic water pumping	The presence of storage tank will improve the performance of the photovoltaic water pumping systems
(Nisha & K, 2020)	Domestic water pumping	It was concluded that overall efficiency of the photovoltaic water pumping system was improved by better system design and load matching using BLDC Motor

A brief discussion no the studies reported with the performance, the types of motors and pumps, the optimal sizing of the photovoltaic panels, the cooling of the solar photovoltaic panels, the control of SPWPS, economic and environmental considerations are discussed in this subsection. The components used in SPVWPS should conform to the national/international specifications, whichever is applicable in a country.

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Table 2. Major Components of SPVWPS and their description

Component	Application	Types	Description
PV array	Source of electrical energy	Amorphous, Mono-crystalline Polycrystalline. (Mono-crystalline has highest efficiency but amorphous has the lowest efficiency).	PV array is analyzed based on the I-V curve and each array has its own disposition.Consequently many factors such astemperature, the load and radiation can affect the MPPT
Motor	Pump and draw water from well	AC/DC,brushed/brushless, permanent magnet, synchronous/asynchronous,variable reluctance	If the system works with DC, the PV array could be directlyconnected to the motor, otherwise an inverter/controllerlocated between the motor and PV array
Pump	Draws water from reservoirs, deep/shallow wells	Floating pump, submersible, surface pumps	The selection of pump depends on; water requirement, the height of water(well), and the quality of water
Controller	Mandatory part if the motor is AC	Intelligent algorithm, Proportional-integral, fuzzy logic speed controller	Although it is one of the defenseless part of the system, but it can provides the optimum voltage/current through isolating different parts while also protects the motor from running dry and conserves water by turning off the system when the tank is full.

Direct coupled DC solar pumping was first introduced in the field in the late 1970s. Earlier PV water pumping systems have limitations of overall performance of the system due to lack of proper design. Since then, manufacturers have refined their products to improve the performance and reliability. The steady fall in prices of PV panels have resulted in making solar pumping economically viable for an increasingly wide range of applications. Direct coupled DC solar pumps are simple and reliable but cannot operate at maximum power point of PV generator as the solar radiation varies during the day from morning till evening.However, adding maximum power point tracker(MPPT) andcontrols/protections improve the performance of a PV pump(Chandel et al., 2015)(Muhsen et al., 2017).

Table 3.Comparison between water pumping systems powered by PV and diesel generator.

PVPS	Pumping system based on DG
High initial cost	Moderate initial cost
Low maintenance and operation cost	High maintenance and operation cost
Low environmental pollution	High environmental pollution
Low life cycle cost in remote areas	High life cycle cost
Does not require fuel	Required fuel continuously
Does not require frequent site visits	Required frequent site visits
Rapid installation and movable technology	Rapid installation and movable technology

2.1 Photovoltaic array

PV technology is used for generating electricity from the incoming solar radiation. Numerous attempts have been made to evaluate, monitor and improve the performance of different components of a PV systems: a PV module(Shinde & Wandre, 2015).The source of electrical energy of the SPVWPSs is the PV arrays(Errouha et al., 2020). The maximum power point (MPP) depends on several factors including on site solar radiation, temperature, and the connected load if the load is directly connected(Zaghba et al., 2017). For the same amount of power, array size depends on the efficiency of the cell. Solar cells could be divided into three categories according to the type of crystal: mono-crystalline, polycrystalline and amorphous. The level of efficiencies in production is about 7%, 15%, and 17% for amorphous, polycrystalline, and mono-crystalline silicon, respectively(Li et al., 2017).The performance of solar PV powered water pumping systems strongly depends upon the configuration of PV array. Photovoltaic configuration refers to the series-parallel arrangement of PV modules in the collector array. Several PV modules can be connected in series whereas several series modules can be connected in parallel to achieve the desired current and voltage from the array(Aliyu et al., 2018).The design of the PV array depends upon the desired power supply to the pump and energy losses. It may be designed in such a way that it could provide the required power to the pump in every hour of the day. If the regulator and batteries are also used, the PV array sizing will be larger. Further the addition of an inverter to run an AC motor would also increase the demand of power. A tracking system may also be used in connection with PV array to optimize the system performance. The whole system is assembled on a moving framework which follows the sun path or aimed at the brightest area of the sky during partly cloudy weather(Li et al., 2017).

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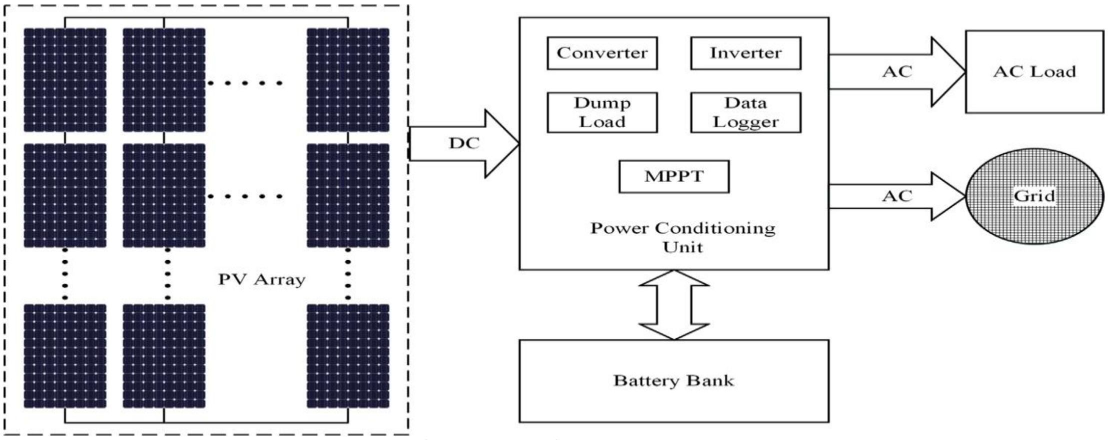

Figure 2. Power flow diagram of photovoltaic system(Rawat et al., 2016).

2.2 Power control system

In general, it is important to control SPVWPS optimally so as to achieve optimal operation of the system and consequently reliable system.It consists of charge controller, energy storage unit, inverter, etc. The charge controller is used to charge batteries from solar panels. They prevent the battery to be over charged and stops charging process when battery is fully charged. In large scale PV panel systems, advanced charge controllers are used. They give complete statistics of volt and ampere while charging battery. They automatically disconnect the battery when it is going to be empty. Many control approaches have been developed by researchers toefficiently operate SPVWPS.These approaches include MPPT algorithms, voltage regulation, frequency control and load matching(Muhsen et al., 2017)(Poompavai & Kowsalya, 2020).

Maximum power point tracking(MPPT) controllers can track maximum possible power from the Photovoltaic panel array. Inverterconverts the direct current of PV system into alternating current whichenables the use of AC operated instruments. Apart from these, fewsimple interconnections are also used like switches, cables, connectors (Nyein & Ya, 2019).The MPPT algorithms can be classified into conventional(normally effective in the case of not having any shading objectives) algorithms and algorithms that are based on stochastic and Artificial intelligence (AI) techniques(Chand & Kalamkar, 2016)(Terki et al., 2012).

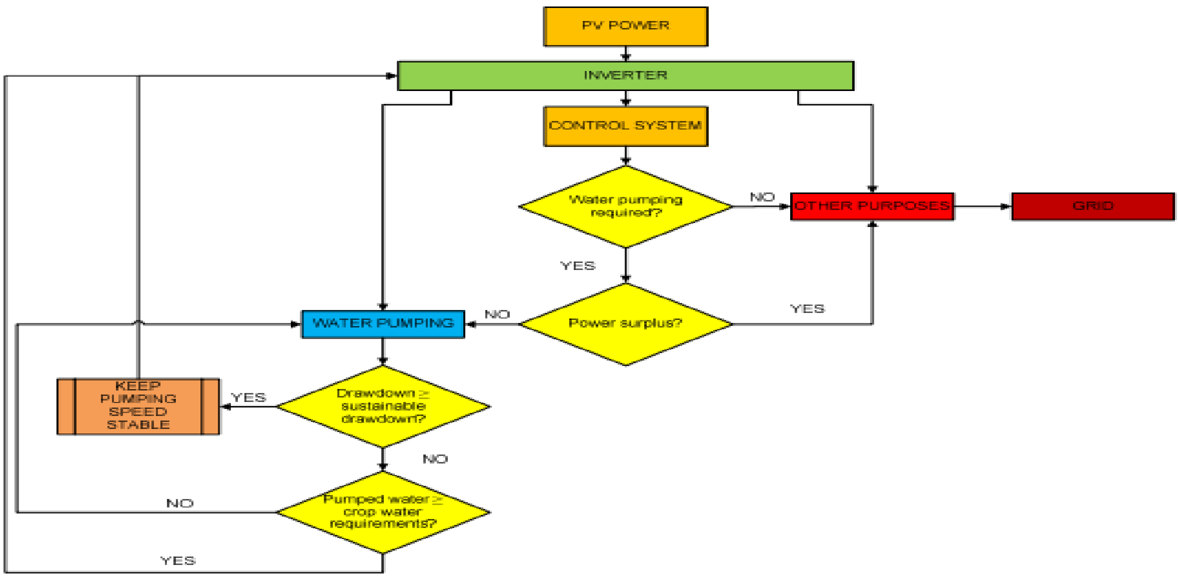

Figure 3. The strategy of the control system(Aliyu et al., 2018)

In (Muhsen et al., 2017) an electronic circuit is used to produce a fixed duty cycle ratio for the step-up converter to enable the PV array to operate at MPP regardless of solar radiation variations. The quality of matching DC motor drive a volumetric/centrifugal pump which is directly coupled with a photovoltaic is demonstrated by comparinginstantaneous conductance characteristics of PV array and motor-pump(Elia et al., 2014).

Table 4.Illustrates the various control methods reported by the researchers.

Authors	Types of control	Research finding
(Mazouz & Midoun, 2011)	Intelligent algorithm	The algorithm implementation approach extends the pumping period of 5h/day
(Errouha et al., 2020)	Fuzzy logic technique	The solar photovoltaic energy utilization for water pumping system will improve the performance and photovoltaic efficiency
(Narvarte-ferna, 2010)	Programmable logic circuit	It controls the maximum power point tracking, pumping system operation, system power balance and battery and charge-discharge monitoring
(Zaghba et al., 2017)	Proportional-integral, fuzzy logic speed controller	Its study showed improved performancecompared to conventional PI controller
(Terki et al., 2012)	Fuzzy optimization	Fuzzy optimization maximizes the global efficiency by increase the drive speed and the water discharge rate
(Narvarte-ferna, 2010)	Standard frequency converter and PLC	The addition of standard frequency converter and PLC will avoid the stopping of the system when the solar intensity falls suddenly

2.3 Motors and pumps

The studies reported on different types of motors and pumps used in SPWPSs are discussed in this section.

2.3.1 Motors for PV based pumps

Several types of DC motors (i.e., brushed and brushless permanent magnet, variable switch reluctance) and AC motors (synchronous and a synchronous) are available for SPWPSs(Short & Oldach, 2015).The selection ofthemotorisdependentonthesize,the efficiency requirements,theprice,thereliabilityandtheavailability. DC motorsareattractivebecausetheycandirectlyconnecttothephotovoltaicarray.PV modules produce direct current so DC motors are most commonly used in a low power solar water pumping system(S. Kumar et al., 2020). Solar pump systems below 5kW generally use DC motors. These motors are of two types: DC motor with brushes and without brushes. DC motor with brushes requires frequent maintenance due to commutator and sliding brush contacts especially in submersible applications where the pump has to be removed frequently from the water well for replacing brushes(Periasamy et al., 2015).

A permanent magnet synchronous (PMSM) brushless DC motor coupled to a centrifugal pump is found to be a better alternative than a DC motor for low power direct coupled PV water pumping systems. This type of motor is small in size and rugged as compared to an AC motor. The cost and maintenance problems of DC motors have resulted in the use of induction motors (IM) which require an inverter to be used between PV array and the motor. PV pumping system based on induction motor is rugged, reliable and maintenance free with increased efficiency and provides more possibilities forcontrolstrategiesincomparisontoDCmotors(Chandel et al., 2015)(Poompavai & Kowsalya, 2020).

The studyon performance characteristics of a brushless asynchronous reluctance motor run by a PV generator under different insolation levels and proposed a control strategy to maintain the motor voltage within a permissible range and PV array to operate as close to the maximum power point (MPP).They have found that using this type of motor leads to improvement in the performance of PV pumping system(Micheli et al.,2013)(Meunier et al., 2019).Table 5below consolidates the study investigations reported on different types of motors used in SPWPSs.

Table 5.Study of SPVWPSwith different types of motors.

Authors	Types of motor used	Conclusion
(Nisha & K, 2020)	Brushless DC motor.	Improvement in efficiency of SPVWPS reported.
(Poompavai & Kowsalya, 2019)	Asynchronous AC motor and Brushless DC motor	SPVWPS using brushless DC motor was superior and more efficient than the system using conventional ASM.
(Elia et al., 2014)	Permanent Magnet Brushless DC(PMBLDC)	Cost of drive system to drive SPV pump has reduced using PMBLDC. Efficiency of SPVWPS was more even at low value of solar radiation.
(Errouha et al., 2020)	Permanent magnet DC induction motor and AC induction motor.	Pumping system using permanent magnet DC(PMDC) motor had more efficiency than system usinginduction motor(IM).
(Hamidat & Benyoucef, 2009)and (Koreboina et al., 2016)	ASM	The SPVWPS using asynchronous motor found suitable to fulfill drinking water demand and irrigation water requirement of small crops in Sahara region.
(Periasamy et al., 2015)	DC motor and induction motor.	Induction motor gave more mechanical power by drawing more power from PV array and hence efficient compare to DC motor
(Ebaid et al., 2013)	Induction motor	Overall efficiency of SPVWPS found to increase more than 3% by using induction motor
(V. Kumar & Hundal, 2019)	Permanent Magnet Synchronous Motor (PMSM) and ASM	ASM machine drive and speed controller had shown good transient and steady state performance.

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2.3.2 Solar water pump

Solar water pumping is based on PV technology that converts sunlight into electricity to pump water. The PV panels are connected to a motor (DC or AC) which converts electrical energy supplied by the PV panel into mechanical energy which is converted to hydraulic energy by the pump.The capacity of a solar pumping system to pump water is a function of three main variables: pressure, flow, and power to the pump. For design purposes pressure can be regarded as the work done by a pump to lift a certain amount of water up to the storage tank. The elevation difference between the water source and storage tank determines the work, a pump has to do. The water pump will draw a certain power which a PV array needs to supply(Chand & Kalamkar, 2016).

Table 6. Types of pumps used in SPVWPS

Authors referred	Type of Pump	Finding
(Tiwari & Kalamkar, 2016)and(Vick & Clark, 2011)	Diaphragm and helical pumps	Diaphragm performs better than helical pumps
(Fiaschi et al., 2005)	Divided shaft pump and standard centrifugal pumps	Divided shaft pumps performed better than standard centrifugal pump
(Hamidat & Benyoucef, 2009)	Centrifugal and positive displacement pump	The efficiency of PDPs is higher compared to centrifugal pumps. Energy losses in PDP are less compared to CP

In Solar water pumping system, three types of pumps are mostly used; submersible, centrifugal and positive displacement pump. A submersible pump draws water from deep wells, and a surface pump draws water from shallow wells, springs, ponds, rivers or tanks, and a floating water pump draws water from reservoirs with adjusting height ability. The motor and pump are built in together in submersible and floating systems. In the surface system, pump and motor can be selected separately to study the performance of system along with controller and PV panel. A pump produces a unique combination of flow and pressure i.e. high-flow/low-head to low-flow/high-head for a given power input.A solar pump is selected according to required discharge, head and other conditions. The submersible pumps offer high discharge and heads. There is no problem of cavitation but they have shorter life because it is located inside the pond and pumping up from the pond. Its maintenance is also difficult which leads to corrosion and seal damage. The centrifugal pumps operate on low head and high discharge conditions. It has relatively poor suction power(Li et al., 2017).

Broadly, pumps can be classified under two categories based on operating principle: dynamic pumps and positive displacement pumps.Dynamic pumps operate by developing a high liquid velocity and pressure in a diffusing flow passage. The efficiency of dynamic pumps is lower as compared to positive displacement pumps but have comparatively lower maintenance requirements. Positive-displacement pumps operate by forcing a fixed volume of fluid from the inlet pressure section of the pump into the discharge zone of the pump. These pumps generally tend to be larger than equal-capacity dynamic pumps. Centrifugal pumps and axial flow pumps are dynamic pumps(Sontake et al., 2020).

In centrifugal pumps, water is sucked by the centrifugal forcecreatedbyimpellerandthecasingdirectsthewatertothe outlet as theimpellerrotates.Waterleaveswithahighervelocity and pressurethanithadwhenitentered.Centrifugalpumps directly interfacedwiththesolarpanelsareusedforlow-head applications.

Acentrifugalpumphastheabilitytomatchwiththe output of solargenerator.Theoperationofsuchpumpstakesplace for longer periodsevenatlowinsolationlevels,andload characteristic isincloseproximitytoPVmaximumpowerpoint (MPPT). Centrifugal pumpshaverelativelyhighefficiency,butdecreases at lowerspeeds,whichcanbeaproblemforapumpingsystem at low insolation.Centrifugalpumpsareeconomicalfromshallow to medium lifts(upto80m)withlarge flow rates.AxialFlow Pumps aredynamicpumpsthatusethepropellertocreatealiftaction of the fluid inthepipe.Thesepumpsareoftenusedin wet-pit drainage,low-pressureirrigation,andstorm-waterapplications(Chandel et al., 2015).Screw pump and Piston pump are positive displacement pumps. A displacement pump also called volumetric pump, has different speed-torque characteristics and are not well suited to be connected directly to PV panels(Nyein & Ya, 2019). When such pumps are used a power conditioning unit and maximum power point tracking system has to be incorporated between the solar panel and pump.These pumps are of the rotating impeller type, which throws the water radially against a casing shaped in such a way that the momentum of water is converted into useful pressure for lifting. InDisplacement pumps, the water output is directly proportional to the speed of pump, but almost independent of head(Bora et al., 2017)(Chandel et al., 2015).In a screw pump, a screw traps water in suction side of the pump casing and force sit to the outlet. In a piston (diaphragm)pump the motion of piston draws water into a chamber using the inlet valve, and expels sittotheoutletusingtheoutletvalve.Pistonpumpsaremuch morecomplexwithalotofmovingpartsandrequireoillubrication insidethepumpwhichmightbeapotentialriskinwaterwell.Typicallytheseareusedinlowvoltage(24-48 V)applications withsmalldaily flows(up to 5m³/day) forliftsupto150m(max.2m³/day)(Chandel et al., 2017).The selectionofapumpforsolarwaterpumpingisdependenton waterrequirement,heighttoliftwaterandwaterquality.Anoptimumsolarpumpistobeselectedwhichcanmeetthedailywater flow andpumpingheadrequirements(Gopal et al., 2013).

Table 7. Summary of reported investigation on performance assessment of solar pump with different ratings of PV panel.

Authors	Aim of the study	Outcome
(Sontake et al., 2020)	Development of algorithm showing the relation between balancing parameter, array size and battery size	Using this algorithm 22%, cost-saving of SAPS has been reported
(Abdolzadeh & Ameri, 2009)	Investigation of the effect of water spraying over Solar PV panel on the performance of SPVWPS.	Overall efficiency of SPVWPS is improved
(Elrefai & Hamdy, 2016)	Study to assess the energy losses due to mismatching between the PV array and the pump motor.	Because of losses actual work from PV array is 84% of the work potential available from PV array.
(Hassan & Kamran, 2018)	TRNSYS based simulation model to investigate SPVWPS performance under different operating conditions and PV array size.	Selection of optimum array size ensures better efficiency and economy of SPVWPS.
(Kordzadeh, 2010)	Investigation of the effect of cooling solar PV panel by a thin film of water.	Daily volume of water and pumping head has been stated to increase.
(Phiri et al., 2020)	Design procedure to estimate most optimum size of solar panels required to power a water pumping system for the drip irrigation system of an Olive tree	Procedure can be adopted for drip irrigation system for any crop in any county's geographical location, provided soil characteristics and specific crop parameters are well known.
(Bakelli et al., 2011)	Investigation of effect of solar radiation correction to the PV array sizing and power output.	Significant difference was reported in the solar PVarray system sizing withmeasured data and most appropriate correction to the solar radiation.

2.4 *Optimization of overall solar PV water pumping system*

The efficiency of solar PV panel is usually very low (10-18%), hence the PV power should be utilized very efficiently.This can be achieved by selecting each component of SPVWPS with optimum operating parameters.Investigations are discussed in subsequent paragraphs.

(Mazouz & Midoun, 2011)investigated the performance of commercially available mono block CP connected to DC series motor to utilize PV energy. They tested 3 optimization techniques, namely (i) Optimum Value of Motor Constant (ii) Reconfiguration of photovoltaic modules and (iii) Changing the water head. They reported that none of the optimization techniques was viable for existing pump sets.

(Bouzidi, 2011)used the LLP method to optimize the PVPS for the different sites of Algeria. The LLP was defined as the ratio of time of water deficit divided by the total time of water supply requirement. This technique presented a generalized and practical graphical tool for sizing of SPVWPS. They reported that the PV array size for southern location was smaller than the northern location due to availability of high solar radiations. Furthermore, it was suggested that LLP method could be effectively used in any geographical area for sizing the PVPS.

(Bakelli et al., 2011)developed size optimization model using MATLAB for SPVWPS under the meteorological conditions of Ghardaia, Algeria.This model was based on different configurations (number of PV modules and number of storage days) by loss of power supply probability (LPSP) and LCC analysis.

2.5 *Overview of performance analysis research*

In this section performance evaluation methodologies used in various studies are reviewed to provide further insight to the researcher.

(Chandel et al., 2015)developed a methodology for performance predictionof a direct coupled PV water pumping system in South Sinai, Egyptusing a computer simulation program. The program simulates thehourly performance of the system at any day of the year, under different PV array orientations. The system is found to be capableof pumping 24.06 l/day, 21.47 l/day and 12.12 l/day in summersolstice, equinoxes and winter clear sky days respectively. Thecalculated PV array efficiency ranges from 13.86% in winters to13.91% in summers.

(Bora et al., 2017)analyzed the performance of a solar waterpumping system consisting of a PV array, sun-tracker, apermanent-magnet (PM) DC motor, a helical rotor pump andfound that the performance of the system is enhanced whenmaximum power point tracker (MPPT) and a sun-tracker areadded to the system. The analysis of the PV array was carriedout using PSPICE software. Theoretical results are verified byfield tests.

(Caton, 2014)developed and tested an algorithm toestimate the long-term monthly performance of a solar photovoltaic water pumping system without any battery storage systemfor fourlocations by using average monthly solar insolationinput data and estimated the total monthly volume of waterpumped with hourly simulation.

(Senol, 2012)designed a solarphotovoltaic water pump by adding a DC-DC buck converter toprovide current boosting to the DC pump. No battery and inverterare used in the system so as to reduce the cost and maintenance.The highest no-load speed goes up to 3000-3200 revolutions perminute (rpm). The results from the no load test revealed that theintegration of DC motor with the centrifugal pump has matchedquite perfectly. A direct coupled system without a Power Conditioning Unit (PCU) is compared with DC-DC convertor typesystem. The DC motor operating voltage, operating current, shaftrpm and the discharge rate at different pressures during differenttimes of a day for both systems are measured and improvement inthe electrical power output is found in the designed DC waterpumping system(Chandel et al., 2015).

(Boutelhig et al., 2017)analyzed the performance of different PVwater pumping systems for four different locations in Algeria using typical meteorological year(TMY) data. The study is carried out for three different profiles: threetank capacities; two PVmodules types; two PV array configurations and several pumping heads applied to two centrifugal pumpsand concluded that PV generator costs can decrease if the simulation program accounts for the type of pump, pumping head anddaily load profile. The system can be optimized by studyingindividual requirements using computer program based on mathematical models of a motor pump, PV generator.

(Odesola, 2019)designed and developed a PV pump operateddrip irrigation system for arid regions considering different designparameters like pump size, water requirement, diurnal variation inpump pressure due to change in irradiance and pressure compensation in the drippers. Authors reported that a PV system with(900 Wp PV array, 800 W DC motor-pump mono-blocks) canprovide 70-100 kPa pressure at the delivery side with a dischargeof 3.4-3.8 l/h from each dripper during different hours of the day.The emission uniformity was found to be 92-96% in a field of 1ha.It is suggested that PV water pumping systems need to beextensively tested for water harvesting tanks with lower suctionhead for growing orchards in arid region.

(Sontake et al., 2020)studied and analyzed the performance of aPV-powered DC motor coupled with a centrifugal pump atdifferent solar intensities and corresponding cell temperatures.The experimental results obtained are compared with calculatedvalues, and found that this system has a good match between thePV array and the electro-mechanical system characteristics. Theauthors reported that through manual tracking i.e., changing theorientation of PV array, three times a day to face Sun, the outputobtained is 20% more as compared to the fixed tilted PV array.

(Errouha et al.,2020)investigated the steady-state performance of a PV powered DC motor driving an isolated three-phaseself-excited induction generator (SEIG) and found that SEIG is aperfect load match for a PV powered DC motor with the PVgenerator formaximum utilization of efficiency. The use of a SEIGavoids the need for matching devices or peak power trackerswhich increases the total system cost. It is found that due to theunique torque speed characteristics of the SEIG, the utilizationefficiency is close to maximum at all insolation levels with nopeak-power tracking.

The proposed arrangement is useful as partof an integrated renewable energy system.

(Micheli et al., 2013)presented control system of electricalpower supplied by PV to a single-phase induction motor which isused for water pumping applications. The overall performance of aphotovoltaic system can be improved with dynamic models for the Z-source inverter, single phase induction motor and neural network based maximum power point tracking.

(Pansal et al., 2020)highlighted the potential of solar PV water pumping systems in Indiaand concluded that there is a vast scope of replacing traditionaland diesel pumps with solar pumps for low and medium headpumping applications but the capital costs are very high. Solarwater pumping systems are found to be more suitable for drinkingwater and minor irrigation requirements due to their cost, sizefactors considerations

(Hassan & Kamran, 2018)studied the performance of a PV waterpumping system in a village at 30 km of Keita (Niger) to meet thewater needs of 500 persons and reported that the cost of one cubicmeter of water pumped by the PV system is more advantageousthan other systems. PV water pumping is found to be well suitedfor arid and semi-arid areas due to the existence of undergroundwater potential, and large solar energy potential of more than6 kWh/m².

(Jafar, 2000)presented a simple method for modeling the outputof a solar photovoltaic water pumping system, which relies oneasily measurable data. The procedure is applied to a Solar Star1000 pumping system to develop a model that predicts thevolume flow rate for a given head and irradiance. The modelpredicts the flow rates within 8% of the measured values. Thesmall deviation is attributed to fluctuations in the solar irradianceand unsteady module temperatures during the measurements.The highlights and research findings of performance evaluation studies of PV based water pumps in different countries are summarized in Table 8.

Table 8.Summary of PV water pumping system performance evaluation studies.

Authors	Applications	Outcomes
(Tawfik et al., 2014.)	Domestic use	Computer simulation program is used to simulate the performance of a proposed PV water pumping system.
(Bouzidi, 2011)	Irrigation	Algorithm is developed to estimate the water pumped as per insolation.
(Bora et al., 2017)	Domestic use	System efficiency increases with MPPT and sun tracker.
(Caton, 2014)	Irrigation	System efficiency increased by orientation and sizing of PV array and motor pump system.
(Senol, 2012)	Domestic use	System efficiency is increased by adding DC-DC buck converter for a direct coupled PV water pumping system
(Boutelhig et al., 2017)	Domestic use	Predicted monthly water pumped by a system within 6% of software prediction based on hourly data.
(Odesola, 2019)	Irrigation	System efficiency increased by orientation and sizing of PV array and motor pump system.
(Sontake et al., 2020)	Irrigation	Two important design aspects for PV water pumping system are identified; analyzing piping system to determine the type of pump to be used and power system planning.
(Pansal et al., 2020)	Domestic	Configuration of the photovoltaic system can be improved with dynamic models for inverter, single phase induction motor and neural network based maximum power point tracking.
(Hassan & Kamran, 2018)	Domestic use	System performance and efficiency can be improved by matching the output characteristics.

2.6 Cooling of solar photovoltaic panels

The solar photovoltaic cells become heated during energy conversion and also due to the effect of solar radiation. The performance of the system is highly affected by heat generation. Thus, it is essential to maintain the temperature of photovoltaic cells to attain the maximum power output (Teo et al., 2012). Many investigations have been reported with cooling of solar photovoltaic panels(Gopal et al., 2013),(Micheli et al., 2013).

To attain a good performance of SPWPSs,(Abdolzadeh & Ameri, 2009) made an attempt by spraying water over the frontpanels of photovoltaic panels. It has been reported that the solarPhotovoltaic efficiency, the subsystem efficiency and the total efficiency were improved by 3.26%, 1.40% and1.35%, respectively, at a head of 16m. The study also reported that a maximum solar Photovoltaic efficiency of approximately13.5% was achieved in their work.In similar work,(Kordzadeh, 2010) studied the performance of a SPVWPS with a film layer of water over the cell surface.

The performance of the system was evaluated under the meteorological conditions of Kerman city in Iran. It has been reported thatthe performance of the SPVWPS was increased significantly byproviding a film layer of water over the photovoltaic cells.A recent review of work on cooling of solar photovoltaic panels reported that carbon Nano-tubes and a high conductive coating provide the best cooling performance for solar photovoltaic panels(Gopal et al., 2013).

3. TECHNO-ECONOMIC ASPECT

According to the high price of the PV panels in irrigations and domestic use by considering the characteristic of the soil-type, crop and the elevation of pumping(Elia, Li, et al., 2015).

(Mekhilef et al., 2013) reviewed techno-economic aspect SPVWPS and came up with photo- irrigation theory for the first time which is the arrangement with three main levels: (a) settling the requirements of irrigation based on the climatic condition and soil type characteristic, (b) due to the depth of the aquifer sources pumping estimating the hydraulic analysis and (c) ultimately calculating the peak photovoltaic power required for irrigation. With refer to their analysis, it was shown that photo-irrigation system has the potential of being the immense strategies in irrigation and improves crop production, efficiency of using the source of solar energy and water in order to make a suitable occasion for rural sustainable development.

(Elia, Li, et al., 2015)studied the techno-economic aspects of different components of SPVWPS in remote regions. He carried out extensive experimentation with submerged, surface and piston pump sets run by DC or AC motor. The pump was a critical component and had associated losses during its operation. Also, there is limit of conversion of solar energy by PV system. The author concluded that required size of PV system and pump rating should always be more than the design value to get desired volume flow rate for given head Author emphasized that the complete knowledge of the energy flow and losses during the operation, helped the designer to arrive at optimum size of components of SPVWPS.

(Boutelhig et al., 2017)investigated some factors affect the feasibility of the system such as type of crop, geographic location, climatic condition, depth and the rate of recharging water, costs of conventional energy, government procedures and rule i.e. the taxes of carbon and as the same as other, studies proved that solar irrigation system is feasible when low power needed, which means that from shallow wells or low flow rate pumping from deep wells. Following the method of sizing the PV panel, they concluded the area of solar array necessary land either which is the only important parameters for the technical feasibility of the system. On the other hand, geographic location and the type of crop verify economic feasibility of the system.

Table 9.Comparing different energy sources technically and economically.

Source of energy	Economic feasibility	Technical feasibility
Solar water pump	The capital cost is higher than diesel and electrical grid while the Maintenance and operating cost is negligible. Moreover the price of solar panels decreases everyday which make the system more beneficially.	No technical barrier for solar installation except (1) the availability of the land and solar insolation which is the radiation received over the course of a day at the surface of earth and is measured in kWh/m^2/day and is a critical factor and (2) the area of solar array.
Diesel generator	The price of the fossil fuels increased significantly each year which affect the economic feasibility of the system who works with diesel generator. In addition, since diesel generator consist of air, oil, fuel, water separator filters with lubricant oil change and engine coolant change which all affect the operating and maintenance cost of the system and total cost will be the sum of all of them.	As this system consist of many factors, Diesel generator is feasible technically when all the parameters are feasible.
Electrical grid connection	The maintenance and operating cost of the system is negligible.	Same as the diesel generator.

4. ECONOMIC ANALYSIS

The economic analysis is very important to compare quantitative cost and benefit information. The objective function of standalone solar PV-Battery system is the cost of energy; CoE. The COE is most commonly used energy matric. It is also a benchmark tool to assess the cost-viability of different energy projects.COE states the unit price of energy by considering the present value of total incurred cost over lifetime of the project such as, investment cost, O&M cost, and replacement cost(Elia, Leduc, et al., 2015). In general, the COE is defined as follows:

$$\text{COE} = \frac{\mathit{Life\ Cycle\ Cost}}{\mathit{Life\ time\ Energy\ Production}} \quad (1)$$

There are two commonly used methods to determine the COE. One is the "discounting" method; second is the "annuitizing" method. In the discounting method as exhibited in Eq. (2), the present value of all expenditures, i.e. investment and O&M cost incurred during lifetime, C_t is divided by the present value of electricity production during lifetime, M_t. Since, the discounting or present value of power generation seems unintelligible and therefore, the idea can be understood that the electricity produced indirectly corresponds to the revenue from the sale of this energy(Bhayo et al., 2019).

$$COE_{Discounting} = \frac{PrVal(Costs)}{PrVal(Output)} = \frac{\sum_{t=0}^{n}(C_t/(1+r)^t)}{\sum_{t=0}^{n}(M_t/(1+r)^t)} \quad (2)$$

In the "annuitizing" method as exhibited in Eq.(3), the present value of all expenditures incurred during project lifetime is determined and further converted to an equivalent annuity, using standard annuity formula such as capital recovery factor (CRF).

$$COE_{Annuitizing} = \frac{Ann(Costs)}{Avg(Output)} = \frac{(\sum_{t=0}^{n}(C_t/(1+r)^t))\times CRF}{(\sum_{t=1}^{n}(M_t)/n)} \quad (3)$$

The capital recovery factor (CRF) is determined as follows

$$CRF = \frac{r\times(1+r)^t}{(1+r)^t-1} \quad (4)$$

The annuitizing methods convert the expenditure costs to a constant flow over time. This leads to appropriate results, when the flow of electricity output is constant. Generally, it is presumed that the annual electricity output is constant. However, the electricity output from renewable energy technologies varies drastically from day to-day due to variations in the metrological conditions. Therefore, it can be justified that discounting method is more appropriate than the annuitizing methods for the COE calculations especially for the renewable energy systems(Bouzidi, 2011).

One of the misconceptions in COE calculation is that the summation does not begin from zero (0) i.e. t=0 to consider the project cost at the beginning of the first year(Bhayo et al., 2019).The cost incurred in the first year should not be discounted to reflect present value and there is no system energy output to be degraded.Therefore, the investment cost which is one-off payment and that occurs at the beginning of first year should be taken out from discounting. In this regard, the $COE_{Discounting}$ and $COE_{Annuitizing}$can be written as follows:

$$COE_{Discounting} = \frac{I_0+\sum_{t=0}^{n}\left(\frac{A_t}{(1+r)^t}\right)}{\sum_{t=0}^{n}\frac{M_t}{(1+r)^t}} \quad (5)$$

$$COE_{Annuitizing} = \frac{I_0+\sum_{t=0}^{n}\left(\frac{A_t}{(1+r)^t}\right)*CRF}{\frac{(\sum_{t=1}^{n}M_t)}{n}} \quad (6)$$

5. CONCLUSIONS

A review of current status of solar photovoltaic water pumping system technology research and applications is presented.Photovoltaic water pumping systems are especially designed to supply water and irrigation in areas where there is no mainselectricity supply. Their main advantages over handpumps or internal combustion engine pumps are theirpractically zero maintenance, their long useful life, thatthey do not require fuel, that they do not contaminate,and finally that they are straightforward to install. Anotherimportant characteristic is that, as they use the sun astheir energy source, the periods of maximum demand forwater coincide with the periods of maximum solarradiation. When compared to diesel powered pumpingsystems, the cost of solar PV water pumping systemwithout any subsidy works out to be 64.2% of the cost ofthe diesel pump, over a life cycle of ten years. Solarpumps are available to pump from anywhere in the rangeof up to 200m head and with outputs of up to 250m³/day. In general, photovoltaic pumps are economiccompared to diesel pumps up to approximately 3kWp forvillage water supply and to around 1kWp for irrigation.SPVWPS sets represent an environmentfriendly, low-maintenance and cost effective alternative toirrigation pump sets which run on grid electricity or diesel.A solar irrigation pump system method needs to takeaccount of the fact that demand for irrigation systemwater will vary throughout the year. Peak demand duringthe irrigation system seasons is often more than twice theaverage demand. This means that solar pumps forirrigation are under-utilized for most of the year. The irrigationpump system should minimize water losses, withoutimposing significant additional head on the irrigationpumping system and be of low cost. Therefore, by permanent increasing in the cost of conventional energy, majority of governments become more interested to associate with renewable energy sources to support their industries and society requirements,which causes a considerable improvement in the solar sector.

6. SCOPE FOR FURTHER RESEARCH PERSPECTIVE

From the cited literatures in this review paper, the following research avenues are identified in the field of SPVWPS and can be broadly classified in following three areas:

1. Research on pump improvement.

(i) Development of hybrid pump (auto setup ability) which has characteristics of both centrifugal and helical rotor pumps to utilize PV electricity efficiently.

(ii) Reduction of losses by manufacturing pump from zero friction resistance material.

(iii) Development of small capacity pumps for nuclear family, requiring low power input and hence requires low wattage PV panels.

2. Research on power source improvement.

(i) Development of cheap and simple tracking mechanisms for PV panel.

(ii) Enhancement of SPVWPS performance by theapplication of different coolants over the PV panel fronts.

(iii)Development of cheap techniques to prevent/clean formation of dust on the PV panel front surface.

3. Research on power management/matching improvement.

(i) Development of cheap and simple technology MPPT/ controllers

(ii) Development of new optimization methods for sizing solar PV panel.

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