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Review

Solar photovoltaic water pumping system for irrigation: A review

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Irrigation is a well established procedure on many farms and is practiced on various levels around the world. It allows diversification of crops, while increasing crop yields. However, typical irrigation systems consume a great amount of conventional energy through the use of electric motors and generators powered by fuel. Photovoltaic energy can find many applications in agriculture, providing electrical energy in various cases, particularly in areas without an electric grid. In this paper the description of reviews on a photovoltaic irrigation system, is presented. Photovoltaic water pumping system is one of the best alternative methods for irrigation. The variation of spatial and temporal distribution of available water for irrigation makes significant demand on water conservation techniques. Hence solar powered Automated Irrigation System provides a sustainable solution to enhance water use efficiency in the agricultural fields using renewable energy system removes workmanship that is needed for flooding irrigation. The use of this photo-irrigation system will be able to contribute to the socio-economic development. It is the proposed solution for the energy crisis for the Indian farmers. This system conserves electricity by reducing the usage of grid power and easy to implement and environment friendly solution for irrigating fields.

Key words: Solar photovoltaics, water pumping system, irrigation, photovoltaic (PV) pumping system

INTRODUCTION

Solar energy is the most abundant source of energy in the world. Solar power is not only an answer to today's energy crisis but also an environmental friendly form of energy. Photovoltaic (PV) generation is an efficient approach for using the solar energy. Solar panels (an array of photovoltaic cells) are now extensively used for running street lights, for powering water heaters and to meet domestic loads. The cost of solar panels has been constantly decreasing which encourages its usage in various sectors. One of the applications of this technology is used in irrigation systems for farming. Solar powered irrigation system can be a suitable alternative for farmers in the present state of energy crisis in India. This is green way for energy production which provides free energy once an initial investment is made (Harishankar et al., 2014).

Today the generation is heading towards ultra-technologies. Water pumping has a long history; so many methods have been developed to pump water. People have used a variety of power sources, namely human

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energy, animal power, hydro power, wind, solar and fuels such a diesel for small generators.

The most common pumps used in remote communities are:

i) Hand pumps
ii) Direct drive diesel driven borehole pumps
iii) Electric submersible pumps with diesel generator
iv) Solar submersible pumps

Photovoltaic cells

Photovoltaic cells are devices which 'collect the light and convert it into electricity. The cells are wired in series, sealed between sheets of glass or plastic, and supported inside a metal frame. These frames are called solar modules or panels. They are used to power a variety of applications ranging from calculators and wrist-watches to complete home systems and large power plants. PV cells are made of thin silicon wafers; a semi-conducting material similar to that used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the "photovoltaic effect".

PV applications

Solar panels are used in a variety of applications. The applications vary from small simple lanterns to large elaborate power plants.

i) Rural and urban households for domestic purposes like lighting.
ii) Communities, small industries and institutions like schools, for lighting as well as for powering television sets, computers, etc.
iii) Water pumping systems.
iv) Telecommunications, as these systems are often installed in isolated places with no other access to power.
v) Refrigeration of vaccines at health center in rural areas. Such solar refrigerators are also utilized to store blood plasma. WHO supports programmers that install solar power for medical purposes.

System components

The whole system of solar pumping includes the panels, support structure with tracking mechanism, electronic parts for regulation, cables, pipes and the pump itself.

i) Solar panels or modules: Solar panels are the main components used for driving the solar pump. Several solar panels connected together in arrays produce DC electricity, interconnections are made using series or parallel combinations to achieve desired voltage and power for the pump.
ii) Solar pump: Centrifugal or submersible pumps are connected directly to the solar array using DC power produced by the solar panels. Solar pumps are available in several capacities depending upon the requirement of water.
iii) Support structure and tracking mechanism: Support structure provides stability to the mounted solar panels and protects them from theft or natural calamities. To obtain maximum output of water, a manual tracking device is fixed to the support structure. Tracking increases the output of water by allowing the panels to face the sun as it moves across the sky.
iv) Foundations (array and pump): Foundations are provided for support structures and pump.
v) Electrical interconnections: A set of cables of appropriate size, junction boxes, connectors and switches are provided along with the installation.
vi) Earthing kit: Earthing kit is provided for safety in case of lightning or short circuit.
vii) Plumbing: Pipes and fittings required to connect the pump come as part of the installation.

How the solar pump system works

A 50-watt photovoltaic solar panel can power a 12-volt pump, which can move 1,300 to 2,600 L/h. Standard plastic fittings and half-inch piping connect these elements to a water saving tank of 500 to 1,000 L. A sturdy stand should be built for the water tank to provide gravity flow, and a frame should also be constructed to provide the best angle for the solar panels. Multiple filters are needed to protect the life of the pump and minimize clogging in sprinkler emitters and tubes. A solar pump combined with affordable drip irrigation kits can be used with a wide variety of high-value crops to increase water efficiency, minimize fertilizer loss, and irrigate hilly terrains.

Aspects

In general, the investment required for a PV pumping system is Rs 250-300/Wp (where Rs is the Indian rupee and Wp is watts peak). For example, the cost of a 900 Wp unit would be Rs 225,000-270,000, but with subsidies, this will be reduced to Rs 50,000. To make the best use of solar energy, the PV system, the groundwater pump and the water distribution system have to be well matched. The PV power provided must cover the power demand of the pump adequately. This is determined by the relationship between the required discharge flow, the total head and the pump efficiency. This depends on the

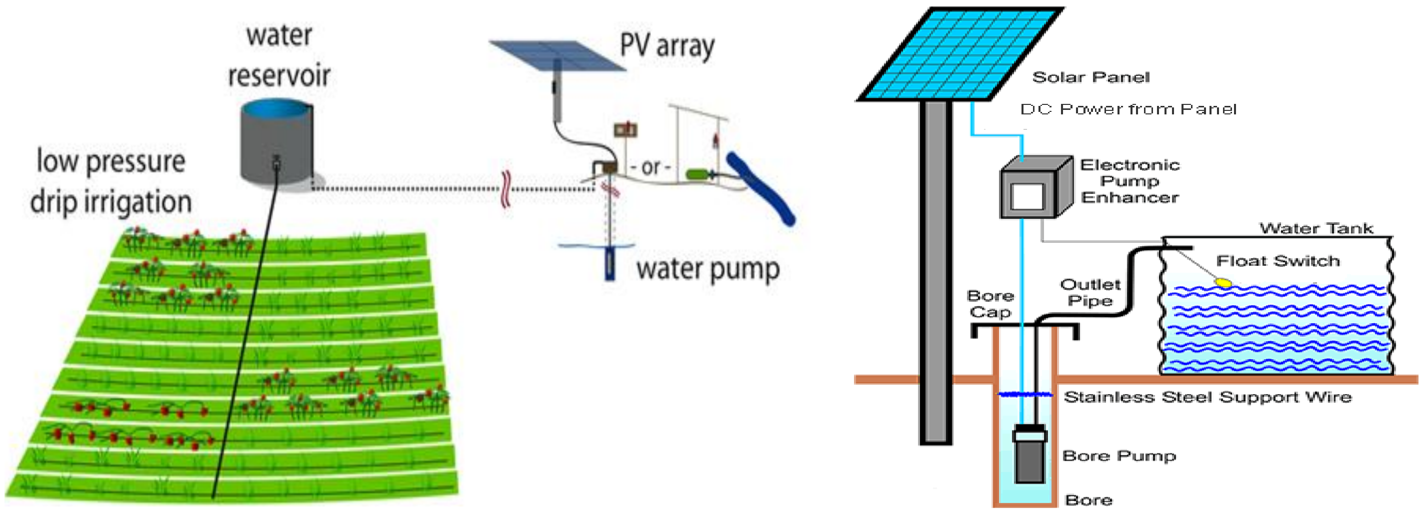

Figure 1. Components of solar PV irrigation system.

type of pump, which in turn depends on the depth of the available water source. Although positive displacement pumps are preferred for large heads, centrifugal pumps are most commonly used for this as shown in Figure 1.

Photovoltaic (PV) panel electrical outputs are rated according to industry Standard Test Conditions (STC) of 1000 W m^{-2} incident solar radiation at an operating cell temperature of 25°C and under an absolute air mass of 1.5. Environmental conditions met outside the laboratory will cause a decrease in PV performance from the STC rating, the magnitude of which depends on the module technology. Many additional losses are incurred due to the inefficiencies in transferring energy from the PV panels to a load, such as a pump or battery bank, thus resulting in a secondary decline of performance. Though there have been studies measuring outdoor performance of PV modules, there is a great need for further field studies of complete PV systems.

Another important aspect would be the ability to model the potential solar radiation, PV power output, and subsequent water output for the purpose of irrigation scheduling. Photovoltaic powered water pumping systems (photo-irrigation) have been studied by researchers for many years. Studies mostly concentrated on DC motors because energy obtained from solar panel is DC (Lawrance et al., 1995; Dursun and Saygin., 2005). These are shown that better results were obtained for performance analysis (Kolhe et al., 2004; Kolhe et al., 2000). Photo-irrigation system has advantages over flood irrigation, for bringing efficient utilization of water sources, preventing erosion and growing of weeds (Cuadros et al., 2004), decreasing moisture stress (Pande et al., 2003), no operation cost, providing opportunity for local energy sources and exhibiting a parallel point of view with water requirement (Ghoneim, 2006). In terms of automation, developed wireless technologies, researches focused on automatic irrigation with sensors in agricultural systems (Kim and Evans, 2009; Stone et al., 1985).

The advantages of using wireless sensor is to reduce wiring and piping costs, and easier to install and maintain especially over large areas (Dursun and Ozden, 2010). Energy of pumps used for the agricultural irrigation is generally provided from electrical energy or fossil fuels. Solar energy that is sensitive to environment, clean and requiring no maintenance is an alternative renewable energy source especially for countries like Turkey having a high amount of annual solar irradiation rate. Means for requirement for irrigation PV pumping systems has advantage of water demand (Anis and Metwally, 1994). In summer months obtained solar energy increases and also naturally water requirement of trees increases.

The cost of solar PV has come down and cost of diesel has been regularly increasing. At present the cost of solar PV is very much less than diesel, solar PV cost shall be half of diesel within three to four years, since approaching towards grid parity. 400,000 telecom towers are associated with diesel generating sets having capacity 3 to 5 kW. 60% Telecom towers located in urban and semi urban areas and 100% located in the villages are run by diesel generating sets. In fact, off-grid potential is unlimited in India and is about 20 to 25% potential of the world (Arora, 2014). Solar water pumps are often thought of as being an expensive technology, which is not able to pump enough water and which is not durable. However, solar water pumps have come a long way in 25 years and today there are solar pumps on the market which have improved on previous technology, e.g.: Submersible pumps which can pump up to 200 m heads; pumps that are able to pump larger volumes of water, e.g.: At 100 m, about 10,000 L/day; At 50 m, about 20,000 L/day. Above performance can be doubled through dual systems (if the borehole allows this).

i) Low maintenance requirements (3 to 5 years);
ii) Good performance which means fewer solar panels to pump the same amount of water;
iii) Some of the pump models can be backed-up by a genset to pump additional water with the same pump during the night or during overcast days;
iv) Good quality and reliability
v) Simple to install.

Furthermore, solar pumps are well known for having the following features:

i) Require minimal attention as they are self-starting;
ii) Solar pumps are "good" for boreholes as they pump over the whole day;
iii) Weak boreholes can be used effectively with a low volume pump due to pumping 8 to 10 h a day;
iv) In most cases, a solar pump offers an ideal solution to the diesel option which requires operating funds (with uncertainty about future diesel prices), time investment for operating pump (manual starting etc.) and logistics for fuel, maintenance, installation and de-installation;
v) Tracking arrays can be used to increase daily water pumping rates;
vi) Solar pumps offer clean solutions with no danger of borehole contamination.

Photovoltaic (PV) technology is used for generating electricity from the incoming solar radiation. Several attempts have been made to evaluate, monitor and improve the performance of different components of a PV system: a PV module (Abdallah, 2004; Vick and Clark, 2004; Huang and Sun, 2007; Hansen et al., 2000; Lorenzo, 1994), a controller (Hohm and Ropp, 2003), a battery (Copetti et al., 1993; Gergaud et al., 2003; Achaibou et al., 2012), a pump (Vick and Clark, 2011), and a pump motor (Bhat et al., 1987). These, and similar studies have been effective for improving the efficiency of the PV system components. However, several factors need to be considered for an optimal PV system design to achieve the desired reliability of the system in a given environment. This involves a detailed investigation of all interacting physical (plant and soil type, irrigation system specifications, PV system sizing, site attributes), meteorological (solar radiation, air temperature, relative humidity, wind speed, precipitation) and managerial (irrigation scheduling) variables with the aim of achieving the desired reliability of the PV system. Ultimately, a technique that combines the center pivot irrigation system characteristics, daily crop water requirements, soil moisture status, irrigation applications, PV array output, load demands, and energy storage is required for evaluating a solar-powered center pivot irrigation system in terms of its reliability. This sort of holistic approach could be very beneficial for effective sizing of the system.

Environmental conditions met outside the laboratory will cause a decrease in PV performance. Important environmental conditions to consider are the insolation, ambient temperature, and wind speed (Van Dyk et al., 2005).

The setup of a PV system is also very flexible. The most efficient use of solar energy is when the panels are directly connected to the load. In fact, the success of water pumping lies partly with the elimination of the intermediate phase, namely the battery bank, for energy storage. With a direct connection between the PV array and the pump, water can be pumped during sunlight hours. The most efficient form of direct-connect systems is when the water is being pumped to an elevated storage tank, thus the electrical energy from the panels is converted to potential energy of the elevated water, to be used on demand, often by gravity (Hamidat et al., 2003). The overall efficiency, from sunlight to water flow, has been recorded to exceed 3% (Daud and Mahmoud, 2005).

This system is easy to implement and environment friendly solution for irrigating fields. The system was found to be successful when implemented for bore holes as they pump over the whole day. Solar pumps also offer clean solutions with no danger of borehole contamination. The system requires minimal maintenance and attention as they are self-starting. To further enhance the daily pumping rates tracking arrays can be implemented. This system demonstrates the feasibility and application of using solar PV to provide energy for the pumping requirements for sprinkler irrigation. Even though there is a high capital investment required for this system to be implemented, the overall benefits are high and in long run this system is economical (Harishankar et al., 2014).

After economic analyzing, it is shown that photovoltaic pumping system for irrigation in Bangladesh is more feasible than diesel engine pumping system. In economic view point, PV pumping system for only one season irrigation is a little bit higher than the diesel engine pumping system due to high cost of PV module and its components (Haque, 2001). The automation of an irrigation system will largely reduce the gap between requirement and consumed energy and further conserves the resources thereby reducing the wastage of resource. The main advantage of this project is optimizing the power usage through water resource management and also saving government's free subsidiary electricity. This proves an efficient and economy way of irrigation and this will automate the agriculture sector (Yalla et al., 2013).

India, developing a grid system is often too expensive because rural villages are frequently located too far away from existing grid lines. Even if fuel is available within the country, transporting that fuel to remote, rural villages can be difficult. There are no roads or supporting infrastructure in many remote villages. The use of renewable energy is attractive for water pumping applications in remote areas of many developing countries. Transportation of renewable energy systems, such as photovoltaic (PV) pumps, is much easier than the other types because they can be transported in pieces and reassembled on site (Khatib, 2010). The life cycle cost analysis done that covered both systems proves that the PV water pumping system is the more economical choice over the diesel water pumping system (Narale et al., 2013).

According to Cuadros et al. (2004), this method was suitable for determining the size and thus viability of these solar powered irrigation systems since the cost of photovoltaic (PV) systems is fairly high. Not only is the viability looked at in terms of the cost of PV systems but also the land area required for implementation. Glasnovic and Margeta (2009) investigated the maximum areas which could be economically irrigated. Similar work done by Kelley et al. (2010) suggested that PV irrigation was technically and economically feasible, provided that there was enough land available for the solar array. One of the concerns regarding the use of solar panels for producing power is the amount of panels required and the area they would occupy. In the case of agriculture this is especially important since it directly impacts the area that would be left for planting This work showed that only a small percentage would be required on the two-acre plot for the panels. This demonstrates the feasibility and application of using solar PV to provide energy for the pumping requirements for drip irrigation.

Some of the factors were taken into consideration to calculate the pumping requirement and thus the solar panel area included the crop chosen, the size of the planting region, the number of peak sun hours, the efficiency of the solar array and its electronics, the pumping elevation and the pump efficiency. These factors would thus affect the feasibility of such systems. This study showed encouraging results for the use of solar panels in terms of the area required to house them to be used to generate power for the pumping requirement for drip irrigation of hot peppers on a two acre plot (Persad et al., 2011). Specific studies have looked at using PV systems on small farms (Roul, 2007) and previous feasibility studies evaluated either the economic feasibility or the technical feasibility of PV irrigation. Most of the studies were system size-specific and location-specific. Studies focusing on systems with power requirements on the order of 1 kW have been conducted for sites in Namibia, Jordan and India (Mahmoud, 1990; NAMREP, 2006; Meah et al., 2008). Most of the literature concluded that PV irrigation is both technically feasible for very small systems in the order of one acre (Kelley et al., 2010). Solar pumps have been talked about in India for some time. According to one 2005 estimate (Purohit and Michaelowa, 2005), some 7000 were already in operation in the field. However, solar-powered tube wells in actual use by farmers are not easy to find. With the cost of photo voltaic (PV) cells following the More's Law and falling steadily and the price of diesel soaring, solar- powered pumping has emerged as an economically feasible idea.

Water pumping has long been the most reliable and economic application of solar-electric (photovoltaic, or PV) systems. Most PV systems rely on battery storage for powering lights and other appliances at night or when the sun is not shining. Most PV pumping systems do not use batteries – the PV modules power the pump directly. Without batteries, the PV pumping system is very simple. It consists of just three components: the solar array, a pump controller and the pump. The only moving part is the pump. The solar modules are warranted to produce for 20 to 25 years. The expected life of most controllers is 5 to 10 years. Pump life can vary from 5 to 10+ years (and many are designed to be repaired in the field). Unless the pump or controller fails, the only maintenance normally required is cleaning the solar modules every 2 to 4 weeks. This task obviously can be done cheaply by non-skilled local labor (Aligah, 2011). Recently, Hammad (1999), presented a study related to the usage of photovoltaic generated electricity for pumping water from 13 wells spread across the east and south east desert which is far from the national grid, as well as in the southern parts of the Jordan which has a complicated topographical situation. These pumps are capable of pumping 40–100 m^3 of water per day individually to meet the daily demands of individuals living in those areas. A fully automated irrigation system is designed, built and tested using solar PV cells and a digital controller. The system is economical, reliable, portable, and compact. Savings in electricity bills and water bills can justify the initial cost, which may be a bit more than the conventional system, over a period of time. It causes less damage to the environment and releases the public utility from an extra load. It can be used in small or big farms, gardens, parks and lawns. Also, it can be used as a universal solar-based-controller to control building doors, water heaters, and air-conditioning control systems (Ali, et al., 2001).

The solar water-pumping technology is commercially available, has-proven record of reliability, require, minimal skilled manpower once in operation, and operation and maintenance cost is also very minimal and affordable. The photovoltaic pumps have many advantages including they operate on freely available sunlight and therefore incur no fuel or electrical costs. They are also environmentally friendly, reliable and have a long working life (Yingdong et al., 2011). The advantage of using solar energy for pumping the water is that major quantities of water are required during day time and that too during time when the sun is on top of our head, and during these times the PV panels produce maximum energy and hence the water quantity. These solar pumps can be installed in locations which are not connected to national electric grid (Ahmet, 2012).

PV systems for the pumping of groundwater are also used in Upp er Egypt, proving that the cost of the water unit pumped by PV systems is significantly lesser than that pumped by diesel systems (Yingdong, 2011). 9 million pump sets for irrigation run by diesel out 21 million pump sets in India (3.73 kW (5 HP)). Out of these 9 million diesel pump sets 75% are assumed to be in solar resource region; total number of diesel pump sets in solar resource region comes to 6.75 million. Out of 6.75 million diesel pumps, 70% have land for installation of PV System; total numbers of pump sets in solar resource region and have land for installation of solar PV comes to 4.725 million, that is, 16,785 mW (just half of diesel pumps). The replacement of 4.5 million diesel pumps saves 223,800 million liter of diesel and 469.98 billion kg carbon dioxide per annum (Arora, 2013). The procedures reported above have shown that the optimal nominal electric power of the PV generator, for reference parameters in the Arilje region, with decade average daily water requirements of 12.8 m^3 ha^{-1} day^{-1}, that would satisfy the raspberry demands throughout the entire irrigation observed period (Gajic et al., 2013). At annual operation of 2000 h, Claro Energy's 8.5 kW solar pumps costing Rs. 1 million will save some 17000 kWh of electricity each per year valued at Rs. 85000/year (Mukherji, 2007).

Advantages

i) Low operating cost: One of the important advantages is the negligible operating cost of the pump. Since there is no fuel required for the pump like electricity or diesel, the operating cost is minimal.
ii) Low maintenance: A well-designed solar system requires little maintenance beyond cleaning of the panels once a week.
iii) Harmonious with nature: Another important advantage is that it gives maximum water output when it is most needed, that is, in hot and dry months.
iv) Flexibility: The panels need not be right beside the well. They can be anywhere up to 20 m away from the well, or anywhere you need the water. These pumps can also be turned on and off as per the requirement, provided the period between two operations is more than 30 s.

Limitations

i) Low yield: Solar pumping is not suitable where the requirement is very high. The maximum capacity available with solar is very low. However, the output of the solar DC pump is more than a normal pump.
ii) Variable yield: The water yield of the solar pump changes according to the sunlight. It is highest around noon and least in the early morning and evening. So it should be operate during noon time.
iii) Theft: Theft of solar panels can be a problem in some areas. So the farmers need to take necessary precautions. Ideally, the solar system should insured against theft as well as natural hazards like lightning. It should be avoided by keeping fencing around it.

Conclusions

Photovoltaic systems are especially designed to supply water and irrigation in areas where there is no mains electricity supply. Their main advantages over hand pumps or internal combustion engine pumps are their practically zero maintenance, their long useful life, that they do not require fuel, that they do not contaminate, and finally that they are straightforward to install. Another important characteristic is that, as they use the sun as their energy source, the periods of maximum demand for water coincide with the periods of maximum solar radiation. When compared to diesel powered pumping systems, the cost of solar PV water pumping system without any subsidy works out to be 64.2% of the cost of the diesel pump, over a life cycle of ten years. Solar pumps are available to pump from anywhere in the range of up to 200 m head and with outputs of up to 250 m^3/day. In general photovoltaic pumps are economic compared to diesel pumps up to approximately 3 kWp for village water supply and to around 1 kWp for irrigation. Solar photovoltaic (SPV) sets represent an environment-friendly, low-maintenance and cost effective alternative to irrigation pump sets which run on grid electricity or diesel. It is estimated that India's potential for Solar PV water pumping for irrigation to is 9 to 70 million solar PV pump sets, that is, at least 255 billion litres/year of diesel savings.

A solar irrigation pump system methods needs to take account of the fact that demand for irrigation system water will vary throughout the year. Peak demand during the irrigation system seasons is often more than twice the average demand. This means that solar pumps for irrigation are under-utilized for most of the year. Attention should be paid to the system of irrigation water distribution and application to the crops. The irrigation pump system should minimize water losses, without imposing significant additional head on the irrigation pumping system and be of low cost.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Abdallah S (2004). The effect of using sun tracking systems on the voltage-current characteristics and power generation of flat plate photovoltaics. Ener. Conver. Manage. 45:1671-1979.
Achaibou N, Haddadi M, Malek A (2012). Modeling of lead acid batteries in PV systems. Energy Procedia 18:538-544.
Ahmet ZS, Shafikur R (2012). Economical Feasibility of Utilizing Photovoltaics for Water Pumping in Saudi Arabia. Hindawi Publishing Corporation. Int. J. Photoener. pp. 59-67.

Ali AR, Rehman S, Al-Agili MH, Al-Omari M, Al-Fayezi (2001). Usage of photovoltaics in an automated irrigation system. Renewable Ener. 23:17-26.
Aligah MA (2011). Design of Photovoltaic Water Pumping System and Compare it with Diesel Powered Pump. Jordan J. Mech. Ind. Eng. 5(3):273-280.
Anis WR, Metwally HMB (1994). Dynamic performance of a directly coupled PV pumping system. Solar Energy 53:369-377.
Arora PR (2013). World's Highest Off-grid Solar PV Potential in India-Search and Penetrate. Int. J. Scient. Res. Pub. 3(8):1-7.
Bhat SR, Pittet A, Sonde BS (1987). Performance optimization of induction motor-pump system using photovoltaic energy source. IEEE Transactions on Industry Applications IA-23:995-1001.
Copetti JB, Lorenzo E, Chenlo F (1993). A general battery model for PV system simulation.Progress in photovoltaic. Res. Appl. 1:283-292.
Cuadros F, López-Rodríguez F, Marcos A, Coello J (2004). A procedure to solar-powered irrigation (photo-irrigation) schemes. Solar energy 76(4):465-473.
Daud AK, Mahmoud MM (2005). Solar powered induction motor-driven water pump operating on a desert well, simulation and field tests. Renew. Energy 30:701-714.
Dursun M, Saygin A (2005). System Analysis of switched reluctance motor driver with boost converter for a photovoltaic array irrigation system. 3rd Renewable Energy Sources Symposium, Mersin pp. 57-62.
Dursun M, Ozden S (2010). A Prototype of PC Based Remote Control of Irrigation, International Conference on Environmental Engineering and Application (ICEEA), Singapore, IEEE Press: pp. 255-258.
Gaji B, Tomi Z, Sredojevi Z (2006). A simple method estimates and economic indicators of photovoltaic systems for drip irrigation. Econ. Agric. 53(3):223-239.
Gergaud O, Robin G, Multon B, Ahmed HB (2003). Energy modeling of a lead acid battery within hybrid wind/photovoltaic systems. SATIE-Brittany branch, ENS de Cachen- Ker Lan Campus: ISBN 90-75815-07-7.
Ghoneim AA (2006). Design optimization of photovoltaic powered water pumping systems. Ener. Conver. Manage. 47:1449-1463.
Hansen AD, Sorensen P, Hansen LH, Binder H (2000). Models for a standalone PV system. Riso-R-1219 (EN)/ SEC-R-12.
Glasnovic Z, Margeta J (2009). Maximum area that can be economically irrigated by solar photovoltaic pumping system. J. Irrigat. Drain. Eng. 135(1):44-49.
Hamidat A, Benyoucef B, Hartani T (2003). Small-scale irrigation with photovoltaic water pumping system in Sahara regions. Renew. Ener. 28:1081-1096.
Hammad MA (1999). Characteristics of solar water pumping in Jordan. Energy 24:85-92.
Harishankar S, Sathish Kumar R, Sudharsan KP, Vignesh U and Viveknath T (2014). Solar Powered Smart Irrigation System. Advan. Electr. Elect. Eng. 4(4):341-346.
Haque MM (2001). Photovoltaic water pumping system for irrigation, 4th International Conference on Mechanical Engineering, December 26-28, Dhaka, Bangladesh: I:21-26.
Huang BJ, Sun FS (2007). Feasibility study of one axis three positions tracking solar PV with low concentration ratio reflector. Ener. Conver. Manage. 48:1273-1280.
Kelley LC, Gilbertson E, Sheikh A, Eppinger SD, Dubowsky S (2010), On the feasibility of solar-powered irrigation. Renewable and Sustainable Ener. Rev. 14:2669-2682.
Khatib T (2010). Design of photovoltaic water pumping system at minimum cost for Palestine: a review. J. Appl. Sci. 10(22):2773-2784.
Kim Y, Evans RG (2009). Software design for wireless sensor-based site-specific irrigation. Comput. Electr. Agric. 66:159-165.
Kolhe M, Kolhe S, Joshi JC (2000). Determination of magnetic field constant of DC permanent magnet motor powered by photovoltaic for maximum mechanical energy output. Renew. Ener. 21:563-571.
Kolhe M, Joshi JC, Kothari DP (2004). Performance analysis of a directly coupled photovoltaic water-pumping system. IEEE Trans. On Energy Conver. 19:613-618.
Lawrance W, Wichert B, Hgridge D (1995). Simulation and performance of a photo-voltaic pumping system. Power Electr. Drive Syst. 1:513-518.
Narale PD, Rathore NS, Kothari S (2013). Study of Solar PV Water Pumping System for Irrigation of Horticulture Crops. Int. J. Eng. Sci. Invention 2(12):54-60.
Mahmoud M (1990). Experience results and techno-economic feasibility of using photovoltaic generators instead of diesel motors for water pumping from rural desert wells in Jordan, Proceedings of the IEE Conference on Generation, Transmission and Distribution, 37(6):391-394.
Meah K, Ula S, Barrett S (2008). Solar photovoltaic water pumping: opportunities and challenges. Renewable and Sustainable Ener. Rev. 12:1162-1175.
Mukherji A (2007). The energy-irrigation nexus and its impact on groundwater markets in Eastern Indo-Gangetic basin: Evidence from West Bengal, India. Energy Policy 35(12):6413-6430.
NAMREP (2006). Feasibility Assessment for the Replacement of Diesel Pumps with Solar Pumps - Final Report, Ministry of Mines and Energy Barrier Removal to Namibian Renewable Energy Programme, September.
Purohit P, Michaelowa A (2005). CDM potential of SPV pumps in India. Institute of International Economics, Hamburg, Germany: P. 4.
Pande PC, Singh AK, Ansari S, Vyas SK, Dave BK (2003). Design development and testing of a solar PV pump based drip system for orchards. Renew. Ener. 28:385-396.
Persad P, Sangster N, Edward C, Ramkhalawan A and Maharajh A (2011). Investigating the Feasibility of Solar Powered Irrigation for Food Crop Production: A Caroni Case. J. Assoc. Profess. Eng. Trinidad Tobago 40(2):61-65
Roul R (2007). India's solar power - Greening India's future energy demand. EcoWorld Inc., http://www.ecoworld.com/fuels/indias-solar-power.
Stone KC, Smajstrla AG, Zazueta FS (1985). Microcomputer-based data acquisition system for continuous soilwater potential measurements. Soil Crop Sci. Soc. Fla. 44:49-53.
Van Dyk EE, Gxasheka AR, Meyer EL (2005). Monitoring current voltage characteristics and energy output of silicon photovoltaic modules. Renew. Ener. 30:399-411.
Vick BD, Clark RN (2004). Effect of panel temperature on a solar-PV AC water pumping system. ASES Solar 2004: A Solar Harvest Growing Opportunities. July 11-14. Portland.
Vick BD, Clark RN (2011). Experimental investigation of solar powered diaphragm and helical pumps. Solar Ener. 85:945-954.
Yalla SP, Ramesh B, Ramesh A (2013). Autonomous Solar Powered Irrigation System. Int. J. Eng. Res. Appl. 3(1):060-065.
Yingdong Y, Jiahong L, Hao W and Miao L (2011). Assess the potential of solar irrigation systems for sustaining pasture lands in arid regions – A case study in Northwestern China. Institution of Water Resources and Hydropower Research, Beijing, China. www.ctara.iitb.ac.in/tdsl/pastreports/autumn2012/solarpvpumpingsurvey.pdf