iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 Issue: VI Month of publication: June 2021

DOI: https://doi.org/10.22214/ijraset.2021.35986

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI June 2021- Available at www.ijraset.com

Comparative Analysis of various Water Pumping Systems

Harshal K. Wankhade
Department of Electrical Engineering, Government College of Engineering, Amravati, India

Abstract: India is a country which is rewarded with a huge amount of solar energy that varies between 2000 hours to 3000 hours yearly. Solar photovoltaic (SPV) based water pumping is the most appreciated application of solar energy. This paper gives information of various solar photovoltaic (PV) based water pumping systems (WPS) with advantages, issues and more prominent solar PV based WPS driven by a special machine with factors affecting whole system performance. For power conditioning in WPS, the power electronics based DC-DC converters, DC-AC converters, microprocessor and microcontroller are used. The Landsman converter permits excellent tracking of solar radiation using maximum power point tracker (MPPT) with changing insolation levels. This paper gives review on the comparative analysis of different motors used based on reliability, maintenance, and cost-effectiveness. Due to systematic operation emphasis is given to the Brushless DC motor.
Keywords: Renewable energy, solar PV array, PV pumping systems, MPPT, power optimization, BLDC motor pump

I. INTRODUCTION

Non-renewable technologies are on a state of being demolished. Renewable energy technologies like solar photovoltaic (PV), wind energy are on their mature stage of development. Among different forms of renewable energy sources solar energy contributes higher specific energy density with respect to the Indian Region. Hence in a moment the use of solar photovoltaic energy based applications will gain popularity hugely [1]. The popular application of solar energy is solar water pumping and due to the government support, evolution in PV technologies and cost-effectiveness it became economically available. On 15th August 2018 Government of India started a scheme called KUSUM (i.e. Kisan Urja Suraksha Evam Utthan Mahaabhiyan). It supplies 27.5 lakh solar pumps out of which 17.50 lakh standalone with 10 lakh grid connected [2]. Standalone PV based WPS remains hinder; to get constant uninterrupted full volume delivery throughout a day, while grid connection can be provided as a backup supply.

Farmers are facing several issues concern water pumping. In rural India, agricultural irrigation is shackle due to irregular supply of electricity. Farmers get only 7 – 8 hours of electricity supply per day due to which pumping is difficult for the crops when it required most due to unavailability of electricity, instead, crops are being watered when the electricity is made available. This results an adverse effect on crops and leads to a waste of water. Due to increased prices of oil, diesel pumps are not economically beneficial. SPV based WPS can be a solution.

There are numerous freely available and convenient renewable sources which can be used to feed water pumps like tidal energy, wind energy, solar photovoltaic, etc. Table I shows the water pumping capacity of the pumping system using different energy sources.

TABLE I. Pumping Capacity of Renewable Energy Sources

Energy Sources	Water Pumping Capacity (liters per second)
Moving water energy	0.2-0.6
Wind energy	3.2-4.0
Solar energy	Depends on rating

The paper is standardized into nine sections. The introduction narrates the problem statement for WPS. While in the second section historical background of WPS is listed. The third section discussed the types of solar-powered WPS. Different PV technologies with problems link with it and the role of power electronics in PV based WPS are represented in the fourth and fifth section respectively. Comparative analysis of DC converter and motor drives are introduced in the sixth section. Factors influencing the PV based WPS are discussed in the seventh section. In the eighth section efficiency improving techniques of PV water pumping systems.

II. HISTORICAL BACKGROUND AND RESEARCH PROGRESS

The first SPV based WPS having a small head and flow rates developed in the Soviet Union in September 1964 [3]. Author Bahadori sorted the PV WPS into two different categories. First is direct conversion systems (DCS) and second solar thermodynamic systems. To convert solar thermal energy into electrical energy either AC/DC for running pumps and motors the DCS is used. Pentane, an organic substance which has a low boiling point is used as a working fluid in a solar thermodynamic system pump [4]. In 1977, the first huge PV based WPS was installed in Mead village in Nebraska, USA. It was totally on the trial and error basis. The pumping capacity of this system was 3.8
m^3/min and able to run for 12 hours a day [3].

According to their environmental conditions extensive development in technology and feasibility studies have been carried out on SPV based WPS at different parts of the world. It is noticed that the progressive cavity pumps are a successful solution for WPS [5]. Five different PV based WPS with different capacities were designed in Wyoming, the USA for five places. After a deep study of two years on WPS, the authors tells that the SPV based WPS was the best alternative for WPS. The similar observation was reported in Egypt [6].

During 1970-1980s, transformation of solar thermal energy to mechanical or electrical energy was accomplish successfully. But during that decade most of the studies focused on solar thermodynamic conversion systems, the reports showing the DCS for solar WPS were very few [3]. The research and development of DCS for solar energy started after the 1990s. Various allied fields carried out researchers for making SPV based WPS cost efficient and more effective. Table II is summarizes the different performance metrics of SPV based WPS and another types of solar pumping systems.

TABLE II. Summary of Performance Metrics Investigated of Water Pumping Systems

Summary	Conclusion	Source
Conventional water supply can be replaced by SPV based WPS in a village and a workshop.	A new approach is effectively given to meet the required demand for pumping.	R. Mankbadi and S. Ayad, 1998
An economical, single step and low voltage PV system with an Induction motor drive were tested out.	The system was successful in optimizing the flow rate of the pump.	A. Chikh and A. Chandra, 2009
A comparative study between the centrifugal pump and a positive displacement pump was carried out to choose the proper pump for pumping applications.	Centrifugal pump can supply a continuous and smooth torque without any torque pulsations, unlike positive displacement pump.	Walter V. Jones, 2013
Different methods of MPPT were given to extort a large amount of solar power available.	The best amount of solar energy extraction can be achieved by Incremental Conductance method	Mohamed A. Eltawil, 2013
An inexpensive, stand-alone PV system was tested out. The system used the Zeta Converter.	The system turned out to be efficiently realistic, more capable, required low input voltage, and robust.	Rajan Kumar and Bhim Singh, 2016
A PV pumping system was optimized using a single stage solution for a three-cascade inverter.	The system runs near MPP, using a three-level cascade inverter is more efficient than a two-level inverter.	Piyush Choudhary et al., 2016
A hybrid technology of PV and CSP is being developed and modeled.	This has the advantages of PV and CSP hybrid combination and system performed continuously without interruption during low irradiance conditions, cloudy days and at night.	Xing Ju et al., 2017
Solar PV based irrigation system with grid connection and BLDC pump set was employed.	The system fulfills the requirement of water for irrigation as well as provides a regular source of income.	M.Hari Krishna and S.Manmadharao, 2018

III. TYPES OF PHOTOVOLTAIC FED WATER PUMPING SYSTEM

A. Direct Coupled PV Fed WPS

This type of system is comparatively simple since PV is directly coupled to the water pump. This system does not require Batteries and major power conditioning equipment. Water is pumped when the enough solar radiations are available. The amount of water pumped based on total solar insolation. The intensity of solar radiations varies throughout the day. There is no arrangement for the storage of electrical energy [7]. The system is advantageous because of its reliability, simplicity and low cost but the system is needed to be designed correctly for greater efficiency. The main drawback of this system is the availability of energy during day time only. Hence, in cloudy days or during night time system efficiency will drop out. Fig. 1 shows the design of the direct coupled SPV based WPS.

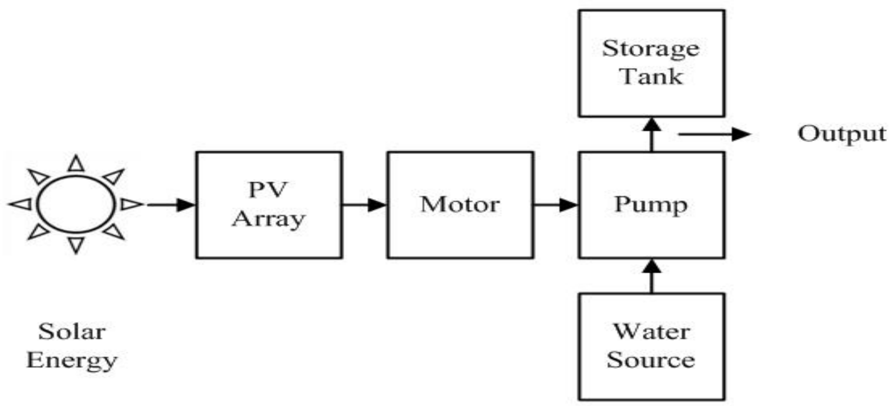

Fig. 1. Directly coupled water pumping system.

B. Battery Coupled PV Fed WPS

Battery coupled PV based WPS contains of solar panel, batteries, water pump, charge controllers and control regulator for the pump. There are two modes of operation: 1) during day time when solar energy is enough to produce electric current by the PV panel, it provides power to feed and charges the batteries. 2) During night time or bad climatic condition charged batteries to supply power to pump when required. The disadvantage of direct coupled WPS can be overcome by this system. The system is more favorable as it extend the period of pumping regardless of the changing atmospheric conditions. The voltage of the battery is boost with the help of a pump controller in battery coupled PV based WPS system. The use of batteries having its own drawbacks like overall system efficiency gets decrease because the operating voltage is controlled with the help of batteries and not by the photovoltaic arrays. The supply voltage of the batteries is one to four volts less compare to the voltage produced by PV panels during maximum sunlight conditions. The schematic of the battery coupled SPV based WPS is shown in Fig. 2.

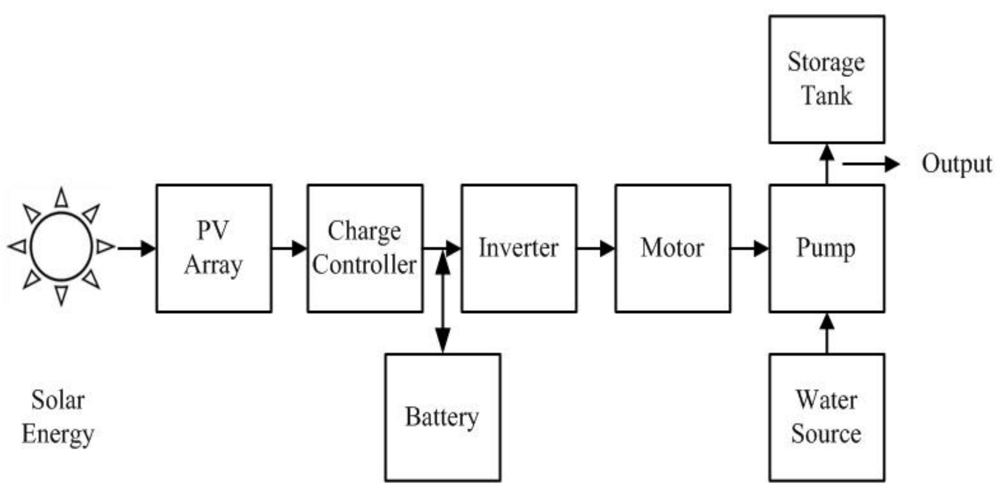

Fig. 2. Battery coupled water pumping system [9].

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI June 2021- Available at www.ijraset.com

C. Grid-Connected WPS

Grid-connected PV systems are receiving high popularity as the infrastructure of installation becomes an increasingly mature and drastic reduction in PV prices. The primary blocks in a grid-connected SPV fed WPS consist of the solar panel itself, DC-DC converter, voltage source inverter which is MOSFET driven, motor drive, a control circuit, utility grid, and power factor corrected (PFC) converter. The inverter, MPPT, switches and power devices are combined to make a compact power conditioning unit [10]. In Fig. 3 the design of a water pumping system shown is acceptable in the areas where the utility grid connection is available.

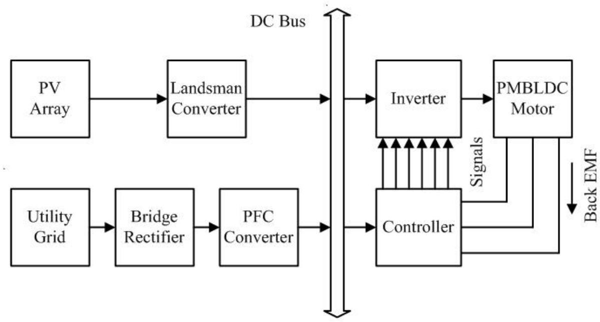

Fig. 3. The block representation of grid-connected photovoltaic based water pumping system [11].

The process of water pumping is indicate with three simple steps as-

1) The PV array feeds permanent magnet brushless DC (PMBLDC) motor pump through VSI at full irradiance and hence grid support is not required.
2) At night and during rainy season only utility grid supply full power to PMBLDC motor pump.
3) To gain continuous full volume delivery regardless of climatic condition PFC converter block can be used [11].

IV. PHOTOVOLTAIC TECHNOLOGY

The availability of specialty materials required in the manufacture of photovoltaic cells will depend on the PV technology. Problems of material availability can probably happen in thin-film technologies having rare elements, such as indium and selenium and tellurium. These materials occur in low concentrations and are typically take out as by-products of mining more common metals, such as Bauxite and Copper. Thus, their availability in large quantities for the photovoltaic industry will be very much reliant on the demand and extraction of the more common materials with which they occur. This problem may possibly be reduced in future due to technological advances, such as the use of less amount of such limited materials, reclaiming of wasted material during cell fabrication and material replacement in the coming years. The emission of pollutants in the process of manufacturing PV is negligible. Energy payback time (EPBT) is another issue to be considered with all renewable energy resources. It is a major driver for PV technology development also. The EPBT of a renewable energy base system is the time require in years for the energy invested in manufacturing and installing the system to be retrieved. Photovoltaic cells and modules form the core of a photovoltaic system. In order for PV to become an important player in electricity generation, it is compulsory that efficient, durable and low-cost cell/module technologies which meet the environmental concerns of resource availability, low emission of pollutants and energy payback time are developed. An individual PV cell can generate 3W powers that mean it produces only up to 0.5V and about 6A. There are rare applications for which a single PV cell can be useful. Hence, a module is formed. A typical module made up of 36 cells in series. Combination of multiple modules forms a panel. PV modules can be fabricated in parallel to increase current and in series to increase voltage. The distinction between PV cells, module, and array are shown in Fig. 4.

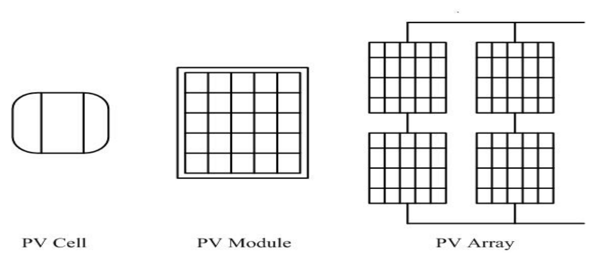

Fig. 4. Formation of a photovoltaic array [12].

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI June 2021- Available at www.ijraset.com

Under Standard Test Conditions (STC), capacity of SPV array should be in the range of 200Wp to 5kW. To achieve the desired PV power output, the required PV modules be supposed to be connected both in series or parallel and also in a series-parallel manner. PV modules with an output of higher ranges are more desirable.

Naturally formed PV modules having multi-crystalline structured silicon solar cells used to construct PV array for the SPV based WPS. The array used in the SPV based WPS should have national or international standards certificate with specifications as per IEC 61215. From a safety point of view, the array must qualify to IEC 61730 part I and II standards. The array should have a minimum efficiency of 14% and the fill factor must be greater than 70% [2].

An equivalent circuit of an SPV cell consists of a real diode which is in parallel with an ideal current source as shown in Fig. 5.

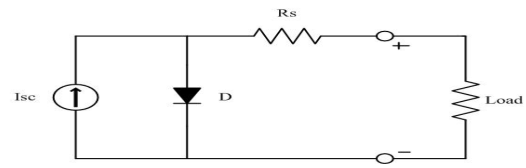

Fig. 5. Equivalent circuit diagram of solar photovoltaic cell [12].

To describe the current-voltage corelation of the PV cell, the mathematical model can be given by equations 1-3 [13].

$$I \qquad (1) \qquad -Io\left[e^{\frac{qV}{kT}}-1\right]$$

$$V_t \qquad (2) \qquad \frac{}{q}ln\left(\frac{I_{sc}}{I_o}+1\right)$$

$$P \qquad (3) \qquad -VI_o\left(e^{\frac{qV}{kT}}-1\right)$$

Where,

I : output current (A)

V : output voltage (V)

I_{sc} : short circuit current (A)

I_o : reverse saturation current (A)

V_{oc}: open circuit voltage (V)

P : total power of the SPV cell (W)

q : charge of the electron (1.602×10^{-19}) (C)

k : Boltzmann constant ($k = 1.381 \times 10^{-23}$) $\left(\frac{J}{K}\right)$

T : operating temperature (K)

Fig. 6 gives the I-V characteristics for a SPV cell with limitation such as short circuit current (I_{sc}) and open circuit voltage (V_{oc}). The power delivered by the PV module is also shown. At both sides of the I-V curve, the total power is zero because at those points either current or voltage is zero. When the power reaches its highest value, it is given by maximum power point (MPP) near the lap of the I-V solar cell curve. At MPP the module extracts and delivers the maximum power under STC.

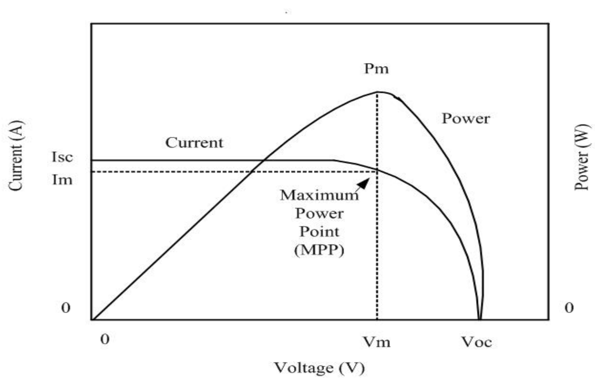

Fig. 6. Solar cell I-V characteristics [13].

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI June 2021- Available at www.ijraset.com

V. ROLE OF POWER ELECTRONICS IN PV BASED WATER PUMPING SYSTEM

Power Electronics (PE) based converters and inverters can be used at various stages for power conditioning in SPV based WPS. Therefore, PE-based converters and inverters play a crucial role in the WPS. Installation of SPV based WPS system uses PE based DC to DC converter, DC to AC converters, microcontroller, and a microprocessor as shown in Fig. 7. An MPPT with advanced automatic control algorithm adjusts the power interfaces. The maximum solar power harvest, during the time to time variations of light intensity, temperature and shading effect of the PV module is also attain by using MPPT. Each new value of output power can be compared with the previous value of the PV array by MPPT. The array voltage is step up in the same direction if the output power is increased else it remains at the original position [14-15].

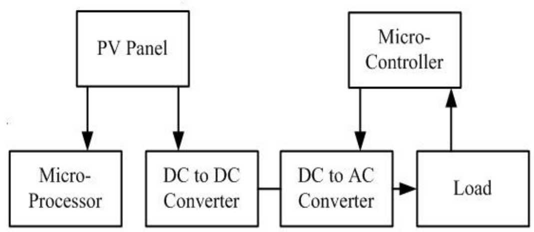

Fig. 7. Illustration of the control circuit in the water pumping system [6].

VI. COMPARATIVE ANALYSIS OF DC CONVERTERS AND MOTOR DRIVES

For conversion of DC to DC, DC-DC converters are employed. They are simply called as DC converters. DC converters provide a fast dynamic response, smooth acceleration control and high efficiency. They are at the heart of MPPT from the power electronics point of view [12].

DC converters are classified into two different classes depending upon the number of inductors present. Buck-Boost, Canonical Switching Cell (CSC) converters form one class as they are having a single inductor and other is two inductor converters such as Landsman, Single Ended Primary Inductance Converter (SEPIC), Cuk and Zeta molded in another class. All these converters are compatible to attain higher efficiency with good regulation but the output current ripples are low only in case of landsman converter which is the extension of a CSC converter with respect to other converters [16]. Table III represents the comparative analysis of various DC-DC converters in account with a number of components like inductor (L), a capacitor (C), a diode (D), switch (S), the thyristor (T) and driver complexity in detail.

TABLE III. Comparison Of Different Configurations Of Dc Converters [17]

Configuration	**Number of Passive Elements**					**Drive Complexity**
	L	***C***	***D***	***S***	***T***	
Buck-Boost	1	1	1	1	4	High
CSC	1	2	1	1	5	High
Landsman	2	2	1	1	6	High
Cuk	2	2	1	1	6	High
SEPIC	2	2	1	1	6	Low
Zeta	2	2	1	1	6	Low

A motor plays an crucial role to fulfil a cost-effective and highly efficient grid-connected PV based WPS. More than 40% parts of total electrical power expense are comprised of motors and hence the proper selection of motor minimizes the total count of a solar panel for a power requirement and its capital cost.

For water pumping various AC motors and DC motors can be used. More advantageous are electronically commutated motors (ECM). These are brushless motors with highly improved controllers and electronically commutated feedback techniques. PMBLDC is preferable for this pumping system due to its features like high efficiency, minimum losses, low capital cost and maintenance free. The magnetic material which is used to develop permanent magnet is an alloy of Neodymium iron and Boron having 30% better magnetic performance compared to the traditional magnetic material. The overall performance of brushless motors is perfect to brushed DC motors and AC motors and hence it becomes considerably attentive [17].

VII. FACTORS AFFECTING THE PV BASED WATER PUMPING SYSTEM

There are several factors which affect the PV based WPS as shown in Table IV [6-12].

TABLE IV. Factors Affecting PV Based Water Pumping Systems

Factors	Description
Environmental factors	Environmental conditions manipulate the performance of the solar system. During designing of a solar PV system, the environmental factors must be considered as input data.
Solar irradiation	Solar irradiation is the amount of solar energy incident per unit area on the earth's surface (W/m^2). Solar irradiance level is different at different parts of the world. The total amount of solar irradiance for a particular location is very important for optimization of a PV system. Electricity production increases with increased solar irradiation.
Meteorological conditions	The fraction of global irradiance to the corresponding extra-terrestrial irradiance radiated from the sun is called a clearness index. The clearness index affects the intensity of solar insolation, and its distribution.
Air mass	Air mass is a measure of how much distance the rays of the sun have to pass through the atmosphere on their way to the surface of the earth. Particles in the atmosphere absorb and scatter light rays. More the atmospheric solar radiation passes through on its way to the surface of the earth, less is the expected solar energy.

VIII. EFFICIENCY IMPROVING TECHNIQUES OF PV WATER PUMPING SYSTEMS

Progress in PV based water pumping will decrease dependency on grid power and fossil fuel generated electricity. To increase the efficiency, development of hybrid pumps (having components of the centrifugal and helical pump) rotor is needed. Zero friction pump material can improve performance index of pumps. PV based WPS having small capacities are certainly going to help the small scale agriculture, residential and commercial fields, and industries as well. Condition monitoring technology to detect faults in the motor is of great help.

Sunlight trackers for PV system are quite expensive. So, from an economic point of view, we can go for an inexpensive tracking system which will enhance efficiency without increasing cost. A booster mirror can also be used to raise system efficiency. Dust accumulation prevention in case of a PV system is needed to be investigated further. The cheaper controller should also be taken into consideration. Upcoming technology like Photovoltaic-Concentrated Solar Power (PV-CSP) will need further development as it is going to club two technologies [18-19].

IX. CONCLUSION

Complete work has been carried out in the field of SPV based WPS since the 1970s. The development of power electronics has led to a revolution in pumping systems and its breathtaking reduction in cost. The current developement in PV technologies like thin film amorphous solar PV materials and its reduction in cost opened up new platforms to interface PV panel and the overall control units within the same compact system. BLDC motor WPS is gaining huge popularity due to its reliability, low maintenance, and cost-effectiveness. The designing of grid interfaced WPS depends on the nearer availability of utility grid, total water pumping demand, mode of protection for switching devices and PV array selection.

REFERENCES

[1] Vaishali S. Mahadik, P.K.Katti, "Performance enhancement of SPV based water pumping with multifunction converter", IEEE International Conference on Power Energy, Environment and Intelligent Control (PEEIC), pp. 392 – 397, April 2018.

[2] Ministry of New and Renewable Energy (MNRE), Government of India.

[3] J.T. Pytlinski, "Solar energy installations for pumping irrigation water", Solar Energy, vol. 21, pp. 255 – 262, May 1978.

[4] Mehdi N. Bahadori, "Solar water pumping", Solar Energy, vol. 21, pp. 307 – 316, March 1978.

[5] Vimal Chand Sontake, Vilas R. Kalamkar, "Solar photovoltaic water pumping system - a comprehensive review", Renewable and Sustainable Energy Reviews, pp. 1038 – 1067, 2016.

[6] Piyush Choudhary, Rakesh Kumar Srivatava, Somnath De, "Solar powered induction motor based water pumping system: a review of components, parameters and control methodologies", 4th IEEE Uttar Pradesh Section International Conference on Electrical, Computer, and Electronics (UPCON), pp. 666 – 678, October 2017.

[7] S.G. Malla, C.N. Bhende and S. Mishra, "Photovoltaic based water pumping system", IEEE, pp. 1 – 4, July 2011.

[8] A. Chikh, A. Chandra, "Optimization and control of a photovoltaic powered water pumping system", IEEE Conference on Electrical power & Energy, pp. 1 – 6, July 2009.

[9] M. Hari Krishna, S. Manmadharao, " Grid integrated solar irrigation system by using BLDC motor pump set", IEEE International Conference on Inventive Research in Computing Applications (ICIRCA), pp. 1261 – 1264, 2018.

[10] Rajan Kumar, Bhim Singh, "BLDC motor-driven solar PV array-fed water pumping system employing zeta converter", IEEE Transactions on Industry Applications, vol. 52, pp. 2315 – 2322, 2016.

[11] Rajan Kumar, Bhim Singh, "Grid interfaced solar PV based water pumping using brushless DC motor drive", IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), pp. 1 – 6, July 2016.

[12] Gilbert M. Masters, Renewable and Efficient Electric Power Systems, Stanford University, John Wiley & Sons, 2004.

[13] Duy C. Huynh, Matthew W. Dunnigan, "Development and comparison of an improved incremental conductance algorithm for tracking the MPP of a solar PV panel", IEEE Transactions on Sustainable Energy, vol. 7, pp. 1421 – 1429, October 2016.

[14] Aouatif Ibnelouad, Abdeljalil El Kari, Hassan Ayad, Mostafa Mjahed, "A comprehensive comparison of the classic and intelligent behavior MPPT techniques for PV systems", IEEE 14th International Multi-Conference on Systems, Signals & Devices (SSD), pp. 526 – 531, 2017.

[15] Mohamed A. Eltawil, Zhengming Zhao, "MPPT techniques for photovoltaic applications", Renewable and Sustainable Energy Reviews, pp. 793–813, 2013.

[16] M. H. Rashid, Power Electronics Handbook: Devices, Circuits, and Applications, Delhi, India: 3rd ed. Pearson Education, 2006.

[17] Praveen Kumar Singh, Bhim Singh, Vashist Bist, "Brushless DC motor drive with power factor regulation using landsman converter", IET Power Electronics, vol. 9, pp. 900–910, 2016.

[18] Xing Ju, Chao Xu, Yangqing Hu, Xue Han, Gaosheng Wei, Xiaoze Du, "A review on the development of photovoltaic/concentrated solar power (PVCSP) hybrid systems", Sol. Energ. Mat. Sol. C., vol.161, pp. 305–327, March 2017.

[19] M. Pozuelo Monfort, et al., "Modelling and evaluating performance of large off-grid PV systems for water pumping", IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), October 2018.

[20] Reda R. Mankbadi, Samir S. Ayad, "Small scale solar pumping: the technology", Energy Convers. Mgmt, vol. 28, pp.171 – 184, January 1998.

[21] Walter V. Jones, "Motor selection made easy: choosing the right motor for centrifugal pump applications", IEEE Industry Applications Magazine, vol. 19, pp. 36 – 45, August 2013.