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PV Array Driven Water Pumping System : A Review

[1]Prashant Nayak, [2]Prof. Santosh Kumar
[1]Research Scholar, Dept of Electrical and Electronics Engineering, Millennium Institute of Technology and Science, India
[2]Assistant Professor, Dept of Electrical and Electronics Engineering, Millennium Institute of Technology and Science, India

***Abstract*— The use of photovoltaic (PV) systems for water pumping has gained significant attention as a sustainable solution to address water scarcity in rural and remote areas. This paper provides a comprehensive review of PV array-driven water pumping systems, focusing on their design, operation, and performance. The integration of PV technology into water pumping systems offers a renewable energy source that is both environmentally friendly and cost-effective. The review covers various aspects, including the types of PV water pumping systems, the selection of pumps, power electronics involved, and control strategies.**

Keywords*— Water Pumping System, Photovoltaic, Solar, Sustainable Solution, Irrigation Technology.

I. Introduction

Water is a fundamental resource necessary for human survival, agricultural production, and various industrial processes. However, in many parts of the world, especially in rural and remote areas, access to clean and reliable water sources is a persistent challenge. Traditional water pumping methods, often dependent on grid electricity or diesel-powered generators, present several limitations, including high operational costs, environmental pollution, and reliance on non-renewable energy sources. As the global focus shifts towards sustainable development and renewable energy, photovoltaic (PV) systems have emerged as a promising alternative for water pumping applications.

Photovoltaic technology, which converts sunlight directly into electricity using semiconductor materials, has seen rapid advancements over the past few decades. The decreasing cost of PV modules, coupled with improvements in their efficiency and reliability, has made PV systems an attractive option for a variety of applications, including water pumping. PV array-driven water pumping systems harness solar energy to power pumps that draw water from underground or surface sources, making them particularly suitable for off-grid areas where access to conventional electricity is limited or non-existent.

The integration of PV arrays into water pumping systems offers several advantages. First and foremost, solar energy is a renewable and abundant resource, ensuring a continuous supply of energy during daylight hours. This makes PV water pumping systems ideal for agricultural irrigation, livestock watering, and community water supply in regions with high solar insolation. Additionally, PV systems are environmentally friendly, producing no greenhouse gas emissions during operation, and they have low maintenance requirements, which contributes to their long-term viability.

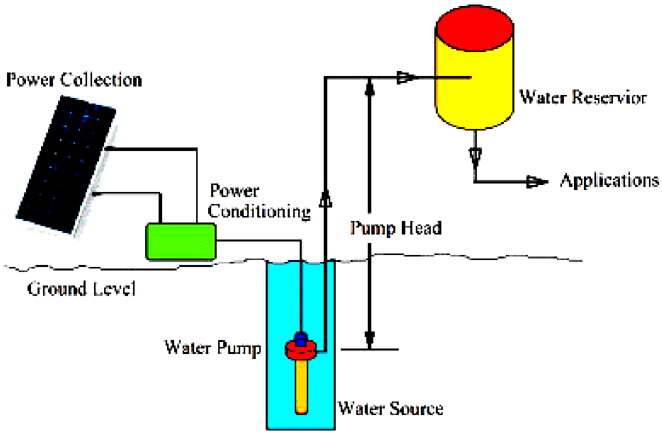

Figure 1: Solar power water pumping system

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. Nowadays, as the increasing shortage of water resources, promote water saving irrigation technology and has become the inevitable choice to fill the water crisis. 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

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

II. LITERATURE SURVEY

H. Parveen et al.,[1] Presented system provides an uninterruptable power supply to dedicated water pump and domestic loads even under grid absence by transferring control to standalone mode. As a result, smooth transition from grid-connected operation (GCO) to standalone operation (SAO) and vice versa provides higher system reliability. A second-order generalized integrator with frequency lock loop (SOGI-FLL) based control algorithm with SPV feedforward term is utilized for voltage source converter (VSC) in GC operation. Net active component of load current is extracted by SOGI-FLL current control. To make system cost-effective, a position sensorless vector control algorithm is implemented in real-time incorporating impact of saturation in motor. Multiple second-order generalized integrator (Multiple-SOGI) is utilized to estimate stator flux, from which rotor position and speed information are derived.

A. Varshney et al.,[2] provides rated water discharge throughout the day despite change in atmospheric conditions and feeds the surplus power to the three-phase utility grid. Moreover, during fault in any of the sources, the performance of the water pump remains unaffected. A high efficiency RSM drive without position/speed sensor is utilized here to drive the water pump. An intelligent power sharing concept, between the PV array and the grid, is used here, in which, automatic switching among all operating modes happens according to the availability of the PV array power and the grid supply. Moreover, the preference is given to the PV array power over the grid supply because of its availability at no cost.

A. A. Stonier et al.,[3] presented the design and implementation of Modular Multilevel Inverter (MMI) to control the Induction Motor (IM) drive using intelligent techniques towards marine water pumping applications. The proposed inverter is of eleven levels and has the ability to control the speed of an IM drive which is fed from solar photovoltaics. It is estimated that the energy consumed by pumping schemes in an onboard ship is nearly 50% of the total energy. Considering this fact, this work investigates and validates the proposed control design with reduced complexity intended for marine water pumping system employing an induction motor (IM) drive and MMI. The analysis of inverter is carried out with Proportional-Integral (PI) and Fuzzy Logic (FL) based controllers for improving the performance.

M. Kashif et al.,[4] presented, a reverse saliency (RS) spoke-type permanent magnet (PM) synchronous motor (PMSM) besides its hybrid adaptive notch filter (HANF) based self-sensing for driving a solar photovoltaic water pump system (WPS) is presented. The conventional spoke-PMSM driven WPS experiences two types of problems. Firstly, the motor is operated with a flux-weakening current to produce positive reluctance torque, thereby increasing the PM demagnetization risk. Secondly, an encoder is used to sense the rotor angle, which in turn affects the cost and reliability. To solve the first problem, the RS-PMSM is presented, which operates with a flux-intensifying current to produce positive reluctance torque. While second issue is resolved by using the HANF based rotor angle estimation.

S. Angadi et al.,[5] research towards AC motor-based Water Pumping Systems (WPS) has received a great emphasis owing to its numerous merits. Further, considering the tremendous acceptance of renewable sources, especially solar and wind, this work provides a detailed review of single-stage and multi-stage WPS consisting of renewable source powered AC motors. The critical review is performed based on the following figure of merits, including the type of motor, power electronics interface and associated control strategies. Also, to add to the reliability of solar PV WPS, hybrid Wind-PV WPS will be discussed in detail.

R. Tiwari et al.,[6] presented a coordinated multipoint JT technique as a part of a CR system in this study. An analytical model for the received signal-to-noise ratio at a CR is developed in order to determine the energy detection threshold and the smallest number of samples required for energy detection-based spectrum sensing in a CR network (CRN) with the CoMP JT technique. This is done in order to determine the energy detection threshold. The received signal-to-noise ratio at a CR can be calculated with the help of this model.

R. Rai et al.,[7] focuses on an efficient and robust speed sensorless control for a solar water pumping system consisting of solar photovoltaic (PV) array fed submersible induction motor drive (SIMD). The speed estimation and sensorless control of SIMD are quite demanding tasks. Additionally, the motor parameter variations lead to deteriorate sensorless control. Therefore, a sensorless control of submersible induction motor (SIM) requires accurate and robust stator current control. The sliding mode-based dc link voltage regulator is adopted for regulating the motor power and the speed for single stage solar PV topology.

S. Shukla et al.,[8] deals with a photovoltaic-grid integrated system operating an induction motor (IM) coupled to a water pump. A simple dc-link voltage regulation approach is adopted for the power transfer. This system is utilized to primarily feed the induction motor-driven water pump and when water pumping is not desired, the power is delivered to the utility. This system requires two current sensors and two voltage sensors in total for sensing and estimation purpose.

Induction motor phase currents are estimated from dc-link current by modified space vector modulation (SVM) technique.

S. Murshid et al.,[9] presents a single stage standalone solar photovoltaic (SPV) array fed water pumping system using a permanent magnet synchronous motor (PMSM). The vital contribution of this work includes: 1) development of the novel modified vector control, which improves the torque response of the system, 2) development of a novel single stage variable step size incremental conductance technique, which provides a fast maximum power point tracking and eliminates the need of intermediate stage DC–DC converter, and 3) introduction of SPV power feed-forward term, which accelerates the overall response of the system under dynamic conditions.

K. Khan et al.,[10] a predictive current controller (PCC) is designed and implemented to control a voltage-source inverter of the proposed system comprising of the single-stage topology of solar photovoltaic (PV) array fed an improved designed fractional kilowatt induction motor drive (IMD) coupled to a water pump. The currents, in a synchronous reference frame, are fed as inputs to the PCC after transforming it to (α–β) stationary frame. The IMD is fed from PV array, which operates at a maximum power point (MPP) using a peak power tracking perturb and observe scheme. The PCC is implemented for this system to achieve better control of motor speed, fast dynamic response, inherent decoupling between current components, and improvement in torque dynamics.

A. Varshney et al.,[11]an adaptive d -axis current control of a reluctance synchronous motor (RSyM) drive for a photovoltaic (PV) water pumping system has been presented, which incorporates impacts of the cross saturation in realtime to compensate the errors in the speed estimation. The response of the RSyM drive is optimized by adaptive d -axis current estimation. A real-time assessment of the d -axis inductance is carried out to include the cross magnetization into consideration for improving the efficiency of the motor. The d -axis current is varied for minimum value to provide the maximum output torque. Here, a two-stage solar energy conversion system is used to drive the centrifugal pump coupled to an RSyM drive.

S. Rahman et al.,[12] presents the design and implementation of solar-powered V/f controlled single-phase capacitor-start induction motor. Multilevel quasi-impedance source inverter controls the power flowing from the photovoltaic (PV) array to a single-phase induction motor. In solar powered drive systems, the main concern is stable intended operation of drive when subjected to variations in power generation of the PV array. For same environmental conditions, the PV power extraction is different at different torques for constant speed application. Due to this, the extraction of maximum power with an MPPT algorithm is not achieved with only motor load.

III. PHOTOVOLTAIC SYSTEM COMPONENTS

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".

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

- Rural and urban households for domestic purposes like lighting.
- Communities, small industries and institutions like schools, for lighting as well as for powering television sets, computers, etc.
- Water pumping systems.
- Telecommunications, as these systems are often installed in isolated places with no other access to power.
- Health center vaccine refrigeration 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

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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.

IV. APPLICATION AND LIMITATION

Advantages of PV Pumping System

PV pumping system has many advantages which are summarized as following:

(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 i.e. in hot and dry months.

(iv) Flexibility: The panels need not be right beside the well. They can be anywhere up to 20 meters 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 seconds.

V. CONCLUSION

A solar irrigation pump system method 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.

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