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AUTONOMOUS SOLAR WATER PUMPING SYSTEM USING BLDC DRIVE

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Abstract: Renewable energy (RE) generation and effective utilization of available energy resources, have emerged as an exemplary panacea for increasing carbon footprint, depleting fossil fuels, increasing global warming and changing climatic conditions. SPV integrated water pumps experience some of the potential challenges such as reduced efficiency, increased DC link voltage instability, sluggish response and high capital cost. The evolution of permanent magnet motors has led to a reduction in losses up to a greater extent. Permanent Magnet Synchronous Motor (PMSM) and Brushless DC motor (BLDC) are the two mostly used variants of permanent magnet machines. Solar water pumping system includes a SPV array, a three-phase inverter, a BLDC motor and a pump. SPV array converts solar energy into electrical energy. Maximum Power Point Tracking (MPPT) from the SPV is implemented by using Single Ended Primary Inductor Converter (SEPIC). The inverter acts as Power Processing Unit (PPU), which supplies desired currents to drive the BLDC motor. As the motor rotates, the pump coupled to the motor accomplishes the objective of water pumping. The controller used for the system is ESP32. The MPPT and motor control algorithms are loaded into the controller. It generates the gate pulses for the SEPIC and inverter switches. The use of BLDC for driving the pump has increased the system efficiency, and has reduced the system size, consequently resulting in reduction of cost, complexity and further increase in the system efficiency and compactness. The system is cost efficient and switching to a normal grid must be provided when there is low irradiance.

***Keywords* – Renewable energy, Permanent Magnet Synchronous Motor, Brushless DC motor, Maximum Power Point Tracking, Single Ended Primary Inductor Converter, Power Processing Unit**

I. INTRODUCTION

Clean nature, noiseless operation and abundant availability even at remote locations, have made the solar energy best form of Renewable energy available in the present scenario. Decreasing capital cost, minimal maintenance cost and zero operating cost, have made Solar Photo Voltaic (SPV) system an excellent conceivable way to harness solar energy. Recently, SPV fed water pumping is receiving wider attention. For areas having no accessibility to the grid and good solar insolation availability for most of days in a year, the Solar Water Pumping (SWP) is meeting the water requirement for daily basic activities. Moreover, SWP is providing a great boost to agricultural and industrial activities.

Solar energy is a remarkably exclusive form of renewable energy source which has procurement increasing attention in modernistic year. The power generation from solar source is always clean; free from pollution furthermore a bend in nature due to that solar source is mostly used in many places, where it gives maximum benefits from source. In recent years, the price of solar PV panels has been going downwards which increases attention to use solar PV application in modernistic year. Renewable energy sources-based application used in industries and hometown application. Among all other application based solar PV system, water pumping is the most effective, crucial and cost-effective application for power generation by Solar PV array. For water pumping systems generally induction motor and dc motor are used in rural areas as well as grid connected. For pumping load, simple, low cost and efficient motor is generally used. Basically, for pumping section, induction motor is generally preferred it is easily available in market furthermore gives good performances for any load condition but when induction motor is preferred for solar PV based application, it suffers from overheating phenomenon of motor, if voltage of motor is going to low, due to that it requires a complicated control. The brushless DC motor is ideal choice for application that requires high reliability, high efficiency and power to volume ratio. Generally, a BLDC motor is well thought-out to be a high concert motor that is proficient at providing enormous amounts of torque more than a vast speed range. For Solar PV based applications, BLDC motor is undoubtedly competing with any other motor for pumping application as it gives superior performance of motor along with soft starting. BLDC motor is an advancement of most of the DC motor and they have almost same torque and speed usual curve uniqueness. The key variation between the two is the use of brushes. BLDC motor for pumping system technique along with solar PV source, both combinations increase its utilization and reliability.

II. CONFIGURATION OF SOLAR WATER PUMP

The solar water pumping system includes an SPV array, SEPIC, three phase inverter, BLDC motor and a pump. SPV panels are used to capture sunlight and convert it into electrical energy. The SEPIC is an electronic device that regulates the voltage and current from the SPV panels to provide the appropriate level of power to the BLDC motor. Inverter acts as a power processing unit, which supplies desired currents to drive the BLDC motor from SPV. The BLDC motor is an efficient type of motor that uses magnets to rotate a shaft, which is coupled with the water pump. The water pump is responsible for drawing water from the source and delivering it to the desired location. Further advancements can be made by adding a float sensor to sense the water level in a tank and maintain a certain water level in the tank by the operation of the system. A block diagram of the system is shown in Fig.1.

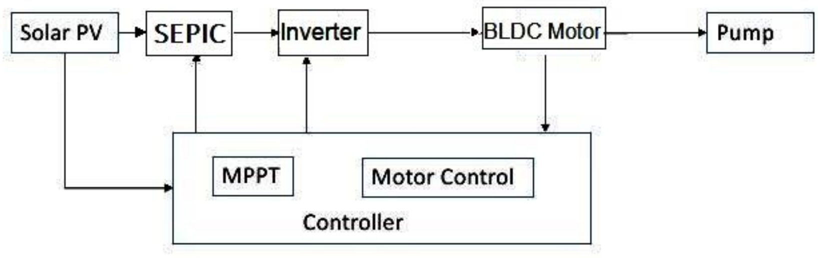

Figure 1: Configuration of solar water pumping system

III. CONTROL STRATEGY

An ESP32 based controller can be used in a solar energy system to monitor and control various aspects of the system. The ESP32 is a low cost, low power microcontroller that is commonly used in Internet of Things (IoT) applications due to its built-in Wi-Fi and Bluetooth capabilities. The program for the MPPT and speed control are loaded on it. It generates the gate pulse for the SEPIC and Pulse Width Modulated (PWM) signals for the inverter switches. It receives the information of the rotor position from hall sensors mounted on the BLDC. Controller circuit works on an auxiliary 5V supply.

The voltage and current from the SPV is measured using a voltage divider circuit and a current sensor respectively. The controller compares these parameters with the output of the SEPIC and generates the gate pulses for the SEPIC switch to extract maximum power from the SPV. Likewise, the hall sensor signals are fed back to the controller as it generates the PWM gate signals for the inverter switches to accomplish the motor control. The code starts by defining some constants for pins and PWM settings. In the setup function, the code initializes the LED pin and PWM channels for all the required pins. In the loop function, the code reads the potentiometer value and calculates the duty cycle for the PWM signal. The code then reads the input from three pins (Ha, Hb, Hc). The code checks the value of Ha, Hb, and Hc and chooses the appropriate case to execute. For each case, the code writes the appropriate PWM signal to the corresponding pins. The code then continues to the next iteration of the loop and repeats the process.

IV. SIMULATION AND RESULTS

The system simulated in MATLAB/SIMULINK is shown in Fig.2. The performance of this system is investigated through simulation studies. The complete system is simulated using MATLAB/Simulink and its performance is studied during starting and steady states at different insolation levels. The performance is analyzed by assessing the variation in SPV array parameters: insolation (S), SPV array voltage (Vpv), SPV array current (Ipv) and SPV array power (Ppv); BLDC parameters: motor current (iabc), motor speed (m), load torque (Tl) and load power (Pl); and reference parameters: reference DC link voltage (Vref) and reference motor current (iref).

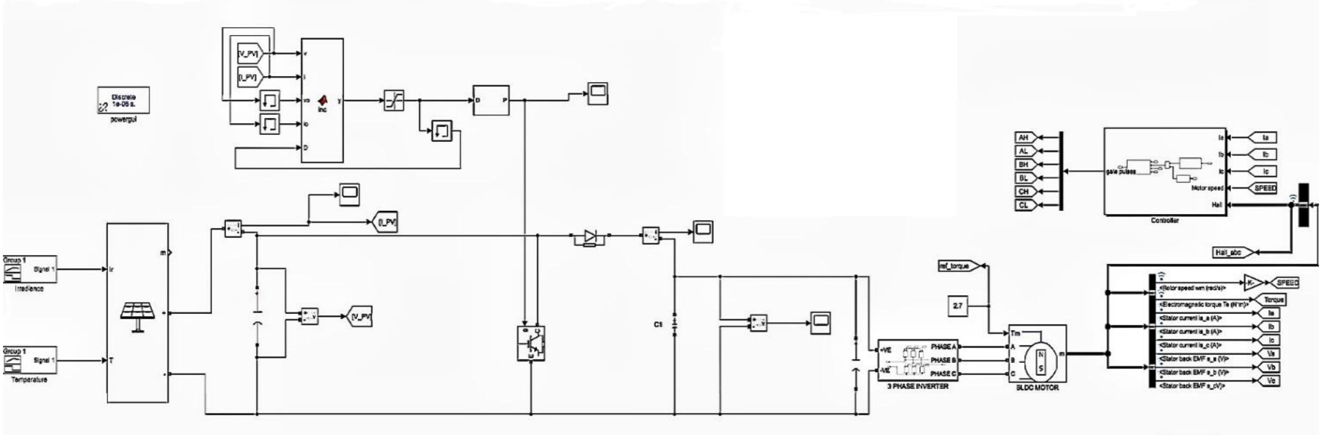

Fig.2: SIMULINK model solar water pumping system

The results of simulated system consist of inverter, converter, and BLDC motor outputs. Each section results are extracted from the proposed system by using MATLAB /SIMULINK. Speed controller compares the actual speed and reference speed and controls the system accordingly. The measured speed reaches the reference speed at almost 0.2s. The stator back emf of the BLDC motor is trapezoidal in shape. The other two phases also have the same waveform result. The signals from the hall sensors mounted on the motor. It generates a low high binary signal for the three phases. These signals are then fed back to the controller.

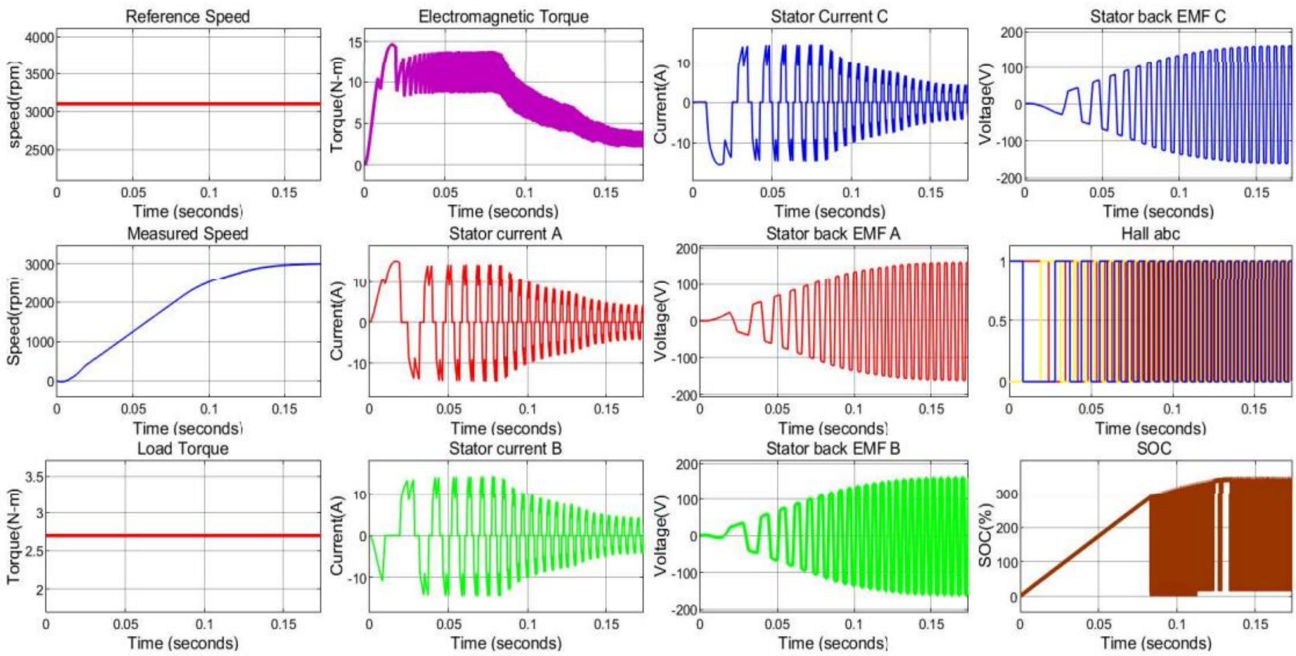

Fig.3: Simulation output

Performance of the simulated system is shown above. The proposed system is simulated in MATLAB; above results are obtained. The system simulation consists output of solar PV array, inverter, converter, and BLDC motor pumping output. Each section results are obtained from the system by using Simulink. Simulation is a crucial step in the design and development process for any electrical project, as it helps to identify potential problems and optimize the system's performance. The simulation of the system is done and the obtained results are acceptable.

V. HARDWARE

The circuitry of the system is divided into three subcircuit boards. First one is of the SEPIC, second is inverter circuit consists of MOSFETs, gate drivers and protection circuits and the third one is control board which is having ESP32 as shown in Fig.4. SEPIC circuit consists of two toroidal inductors, Schottky diode, capacitors, MOSFET and a gate driver. The importance of SEPIC converters in these systems lies in their ability to efficiently regulate and convert the DC voltage output from the solar panels to a level that can be used to power the water pump. Gate of the MOSFET is controlled by the ESP32 controller. The input of this circuit is fed by the solar panel. SEPIC extract maximum power from the SPV. The SEPIC is responsible for boosting or bucking the voltage to the appropriate level for the controller and inverter. The gate driving circuit works on an auxiliary 12V supply.

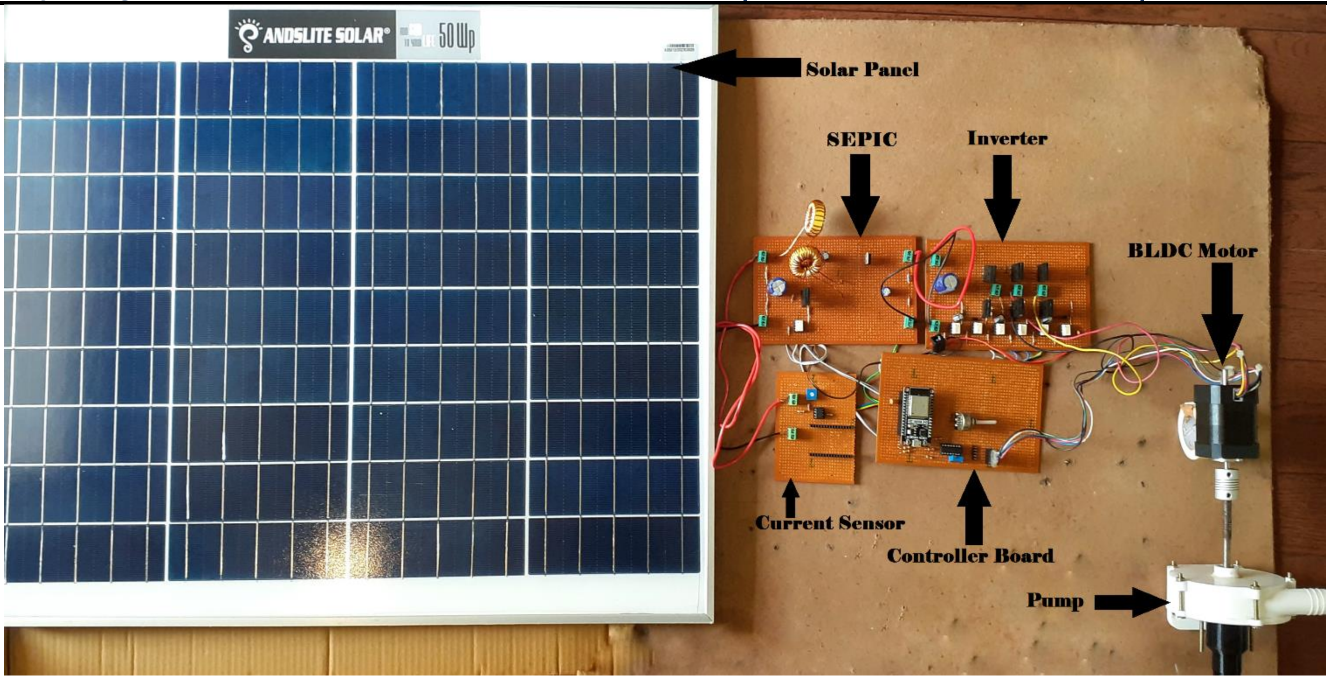

Fig.4: Hardware prototype

The inverter circuit contains six MOSFET switches, six gate drivers, resistors, and bootstrap capacitor. The inverter circuit helps to regulate the voltage and frequency of the AC output, which is essential for ensuring that the water pump operates at the correct speed and power output. Here, the high side switches are driven by bootstrapping technique. The inverter is fed by the SEPIC and it converts the DC supply to three phase supply to drive the BLDC motor. And the gate driving circuit works on a 12V supply. The controller board consists of ESP32, comparator and a potentiometer. Controller is responsible for monitoring and controlling the operation of the system. The hall sensor signals are compared with a standard voltage by the comparator to minimize the errors. The output of the comparator is given to the ESP32. Signals from the SEPIC unit is also fed to the ESP32. And the controller produces the gate pulses for the MOSFET switches. This circuit works on an auxiliary 5V supply. Motor is coupled with the pump using a coupler. The shaft and coupler are important components in a pump as they play a crucial role in transferring the rotational motion from the motor to the impeller, which is responsible for moving the fluid. Different parts of the pump are 3D printed structures which are adhered by silicon adhesive. The outlet of the pump has a 2 cm diameter. The shaft is typically made of high strength materials to withstand the stresses and strains of high-speed rotation. The coupler is a device that connects the motor shaft to the pump shaft. Proper selection, installation, and maintenance of the shaft and coupler are essential for ensuring the long-term performance and reliability of the pump. The speed and power output of the pump are controlled by the controller.

VI. Conclusion

Private households and farms need stable and consistent water supply; however, this can be particularly difficult in areas far off cities where there is no regular city like water pipe supply systems available but only resources in forms of wells deep in the ground. During hot months and in hot areas the requirement for water is high. Moreover, in some scarcely inhabited areas where regular irrigation for watering feels is crucial, often meager electricity infrastructure makes regular irrigation complicated, significantly driving operational and maintenance costs. Countering such complications and difficulties, solar water pumps are the optimal solution to both offset infrastructural limitations and reduce operational or maintenance costs. Solar PV water pumps have become increasingly relevant in the current scenario due to several factors. Firstly, the world is facing a growing water crisis, with many areas experiencing water scarcity and unreliable access to electricity. Solar PV water pumps offer a sustainable and cost-effective solution to these problems, allowing farmers and communities to pump water from rivers, wells, and boreholes for irrigation, livestock, and domestic use. Additionally, solar PV technology has become more efficient and affordable, making it a viable option for powering water pumps in remote and off-grid locations. By reducing reliance on fossil fuels and providing access to clean water, solar PV water pumps have the potential to improve the lives and livelihoods of millions of people around the world. The SEPIC gives reliable trapping as well as efficient from SPV panel by using suitable incremental conductance MPPT algorithm is properly tracked. The MPPT tracking gives result along with little bit drop which fed to inverter gives exact result to inverter then inverter output fed to BLDC Motor. The proposed system gives smooth and soft starting of BLDC motor. The proposed system having centrifugal pump load gives smooth speed and power performances of BLDC Motor. The use of BLDC for driving the pump, has increased the system efficiency, and has reduced the system size.

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