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# Single Stage PV Fed BLDC Motor Water Pumping Application

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**Abstract**: The growth of the solar industry has expanded the importance of PV system design and its application for more reliable and efficient way. BLDC motor is a better substitute of the DC motor and induction motor for PV fed water pumping. A DC-DC conversion stage is required in PV fed water pumping which is driven by a BLDC, for optimise the power using Maximum Power Point Tracking (MPPT). Cost, size, complexity and efficiency is reduced due to power conversion stage. This paper deals about a single stage PV energy conversion system fed BLDC motor, by omitting DC-DC stage. The PV array is operated at its peak power using a Voltage Source Inverter (VSI) and also battery backup is provided. The implemented control cancelled out the need of BLDC motor phase current sensor. No additional control is involved for soft starting and speed control. Performance is evaluated using MATLAB/Simulink based simulation under various operating conditions.

**Keywords**: Block diagram, Control approach, MPPT, Simulation

## I. INTRODUCTION

Renewable energy sources particularly photovoltaic are proven to be both clean and economical due to new advanced technological and efficient cells. Solar energy is obviously environmentally advantageous relative to any other energy source. Among the application of PV energy, a standalone PV power water pumping system is suitable for various areas such as rural farm irrigation, urban street watering and fish farms. Development of human race in past decade gives rise to the bulk demand of the electrical energy. 40% of overall electrical power is utilised by motors. Therefore, a motor drive which is fed by solar power reduce the energy consumed by motor from the power grid. An efficient motor drastically minimizes the number of solar modules for a given power demand and hence its capital cost. The DC motors are mostly used in a low power solar PV water pumping. Regular maintenance is required in DC motor due to the sliding brush contact and the commutator, and also decrease the efficiency. In comparison with DC motor induction motor offer good reliability, rigged maintenance free with better efficiency and provide more flexible control. in the case PV fed water pumping, abetter substitute for the DC motor and induction motor is BLDC motor. This motor is rigged, compact and flexible in comparison to an AC motor. BLDC motor has received large attention in last decade some special features like reliability, a wide range of speed, low maintenance and easy control. The conventional BLDC motor drive is mentioned in fig 1 and 2. Output of the PV array changes due to the dependence of output with varying atmospheric temperature and solar radiation DC-DC converter is used in both methods to produce a constant DC voltage. Since the input of the BLDC is rectangular pulses a VSI is used after DC-DC converter. This power conversion stages decrease the efficiency and increase the complexity of control. Moreover, a current sensor is used to identify the rotor position. The variable voltage generated by voltage source inverter at the DC bus is used for speed control. Since conventional methods adopting a fundamental frequency operation of VSI lead to the use of bulky capacitor Conventional methods don't provide battery back so night time water pumping is not possible. Two stage solar energy conversion, which necessarily need an DC-DC converter to optimise the operating power point of PV array. This conversion stage causes an increase in cost, size complexity and reduces efficiency. This paper deals a single stage solar energy conversion system by eliminating DC-DC conversion stage. The new system is capable of operating the PV array at its peak power using the same VSI used in conventional method. Optimum power of the solar PV array controls the speed of BLDC motor. The DC link capacitor is replaced by low value capacitor using pulse width modulation switching of VSI. A battery bank is given as back up for night time operation. Replacing an induction motor with BLDC motor in PV fed water pumping gives the following advantages. A high efficiency power conversion is promised in comparison with an induction motor driven system. For induction motor, light load causes excitation loses to dominate which leads to the reduce volume of delivered water. Since BLDC motor uses permanent magnet no expiation loss occurred. The size of the PV array depends on the efficiency of the motor i.e. size of PV array reduces with increase in motor efficiency and hence reduction in installation cost of PV array, concluding that less number of PV array is needed for

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BLDC than induction motor. Since rectangular pulse is given as input the BLDC motor possess high power factor than induction motor and DC bus voltage utilisation is high. This helps in the reduction of voltage rating of DC don't depends on the frequency. So rated speed of BLDC motor can be designed higher, so capacity increase of size decrease, making it a compact one. Control method are much simpler in case of BLDC motor.

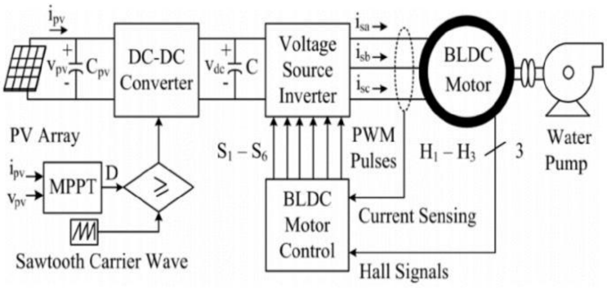
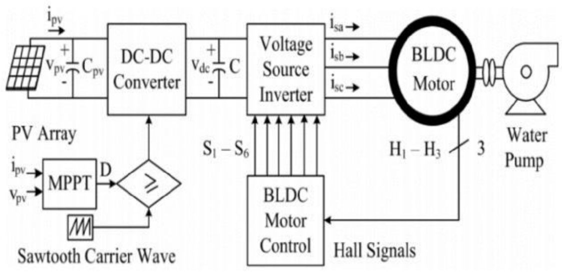



Fig. 1 Conventional BLDC motor drive with Phase current sensors for water pumping based on a two stage solar PV energy conversion system




Replacing an induction motor with BLDC motor in PV fed water pumping gives the following advantages. A high efficiency

## II. BLOCK DIGRAM CONFIGURATION

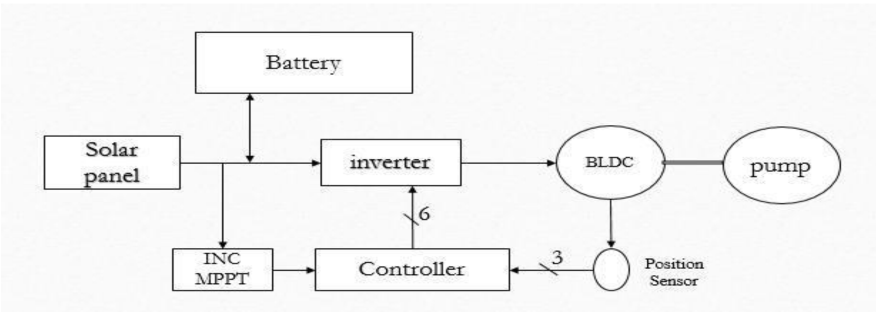



Fig 3 block diagram

Fig 3 represent the block diagram of single stage BLDC motor water pumping. The PV array is directly connected to BLDC through the VSI. Current and voltage from the PV array are sensed and given to controller for the analysis of MPPT. A battery bank is connected in between PV array and VSI which is charged according to constant current method. Optimum utilisation of solar PV array is adopted using incremental conductance MPPT.

## III. CONTROL APPROACH

a) Electronic commutation and switching pulse generator for VSI

Three Hall sensors are placed inside the motor in 120degree angle produce three hall signals representing the rotor position. Since the VSI consist of six switches (IGBT). Six individual pulses are produced using the three hall signals. In controller six individual pulses are created and the duty ratio of each rectangular pulse is determined by the MPPT algorithm. This rectangular pulses are mixed with high frequency sawtooth carrier by using AND logic. A high output (ON) result in only if both inputs to the AND gates are high.

b) Maximum Power Point Tracking

Optimum operating point of solar array is obtained by adopting an INC-MPPT approach. The flow diagram for this MPPT algorithm is shown where Vpv and Ipv are the present values where as Vpvo and Ipvo are the past value of PV voltage and current respectively. The dVpv denotes the increment PV voltage and dIpv represents the incremental PV current corresponding to consecutive intervals. The technique states that the power slope of PV array is characterised by null at MPP, negative at right of MPP and positive at left of MPP. A duty cycle control is adopted to realize INC-MPPT. Duty cycle D is directly used as control variable. The duty cycle, D is perturbed with fixed perturbation size and rate according to the power slope until the operating point of solar PV array reaches MPP.

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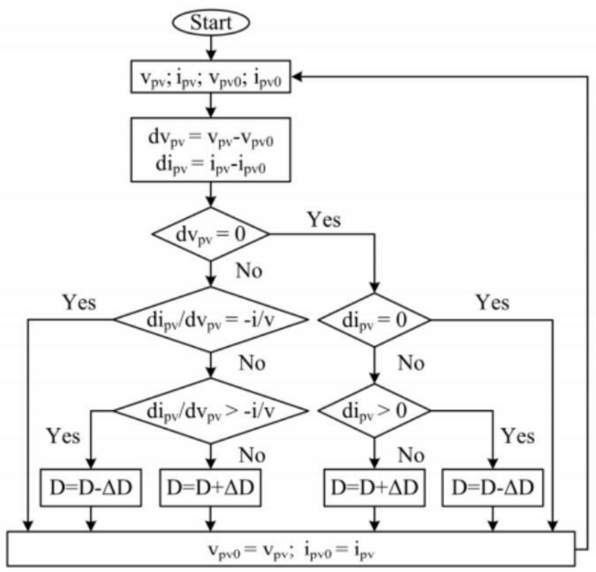
$$p_{pv} = v_{pv} \times i_{pv}$$

$$\frac{dp_{pv}}{dv_{pv}} = i_{pv} + v_{pv} \times \frac{di_{pv}}{dv_{pv}} = 0$$

$$\frac{di_{pv}}{dv_{pv}} = -\frac{i_{pv}}{v_{pv}} \text{ at MPP}$$

$$\frac{di_{pv}}{dv_{pv}} > -\frac{i_{pv}}{v_{pv}} \text{ at the left of MPP}$$

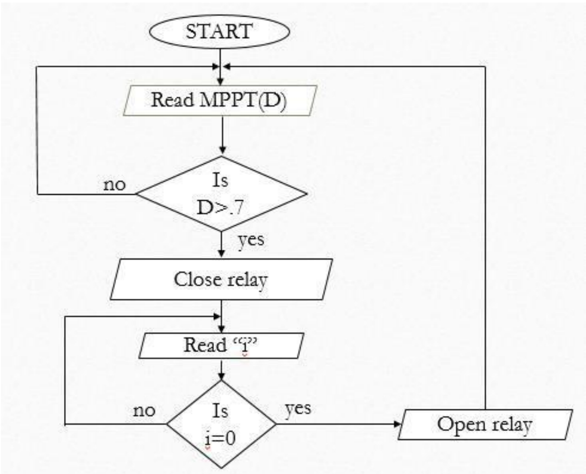
$$\frac{di_{pv}}{dv_{pv}} < -\frac{i_{pv}}{v_{pv}} \text{ at the right of MPP}$$




c) Speed control of BLDC pump

The available maximum power from solar PV array is used to govern the speed. The power from the PV array depends on the atmospheric condition and hence speed of BLDC pump varies with change in atmospheric condition. MPPT algorithm generates an optimum duty ratio acting as a duty ratio for the VSI, regulates input voltage to the pump by chopping action of the VSI. The operating is speed is regulated by the motor input. The speed of the motor is adjusted by varying the duty ratio by the MPPT algorithm following the atmospheric condition. In addition to that variation in the frequency of hall signal result in variation in fundamental frequencies of the six pulses This can be achieved by altering the pulse width of S1-S6 using AND logic.

d) Charging control for battery




Flow chart for battery charging

Battery control is done according to above flow chart. A constant current control method is employed. Charging is done when the duty ratio D is greater than 0.7. When this condition is reached, battery will begin to charge. Each passing moment the controller checks the status of the charging current if the current reads zero, charging procedure is stopped. Discharging is done manually using mechanical switch.

## IV. SIMULATED PERFORMANCE

The proposed water pumping system is modeled in MATLAB/Simulink and its performance under varies steady state, starting and other dynamic conditions are simulated.

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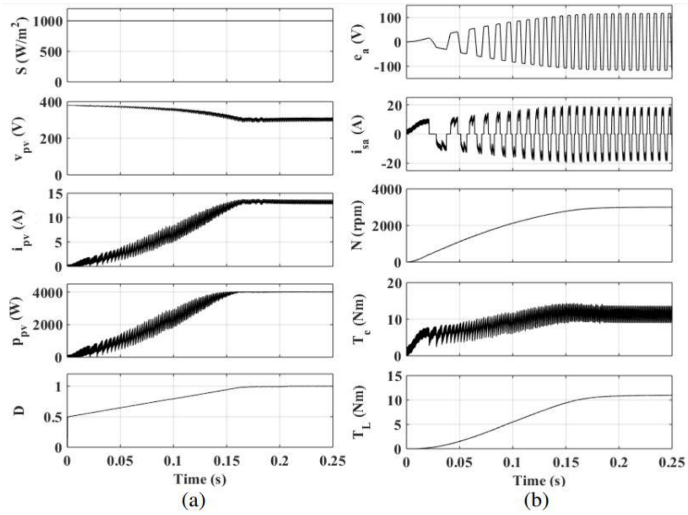


Fig 4 steady state and starting performance of (a) PV array and (b) motor pump at 1000W/$m^2$

A. Starting performance and steady state at 1000W/$m^2$

The starting response and steady state of the BLDC motor pump and PV array is shown below and is described in the following subsection.

1) PV array performance

Figure 4 shows the voltage Vpv, current Ipv and power Ppv of PV array at an irradiance S of 1000W/$m^2$. a fine tracking of the MPP is demonstrated in this indices. To obtain a safe starting of the motor initial duty cycle and its step shape are choosing properly. At steady state condition, D is 1 and all other modulation in pulse width of the six fundamental frequency pulses take place.

2) Performance of BLDC Pump

The varies indices of BLDC motor such as back emf, ea; winding current, isa; speed, N; torque, Te and load torque, Tl are shown in figure 4. When the motor develops a rated torque then the pump is operated at it full speed.

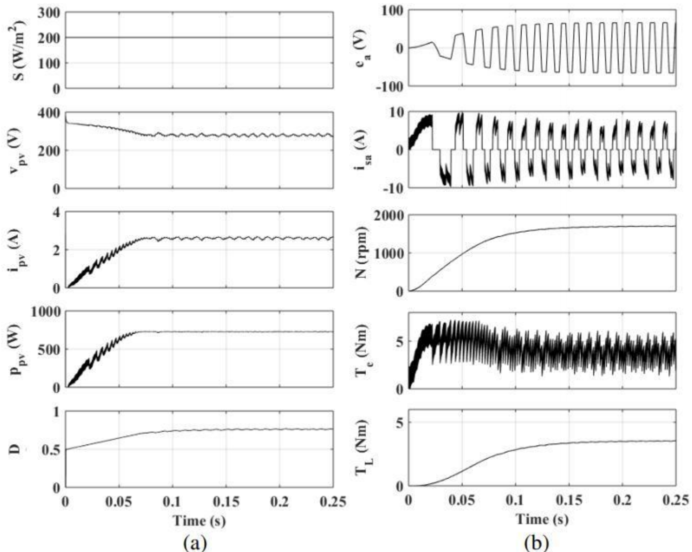


Fig 5 starting state and starting response of (a) PV array (b) motor pump at 200W/$m^2$

A small ripple in the torque appears because of phase current sensor less operation of motor and phase current commutation. This cause vibration and acoustics in the motor, normally at low speed. At higher speed there is no significance of these physical phenomena as the motor gains sufficient kinetic energy because of its speed and inertia. This system is designed to run motor pump at higher speed rage in order to provide sufficient water pumping. The motor is usually placed in an isolated area such as agricultural field or submerged hence there is no disturbance in the surroundings due to noise. Therefore, the level of commutation ripple is quite acceptable for water pumping applications.

B. Starting performance and steady state at 200W/m$^2$

1) PV array performance: As shown in fig MPP is well tracked at 200W/m$^2$ also. The motor pump speed is controlled by adjusting the duty ratio of VSI.

2) Performance of BLDC Pump: The minimum speed required to be attained by a motor to pump water is 1100 rpm. Here the motor attains a speed higher than 1100 rpm as shown in figure 5. Optimum PV array power is required to governed to motor speed. Therefore, soft starting is observed under these circumstances.

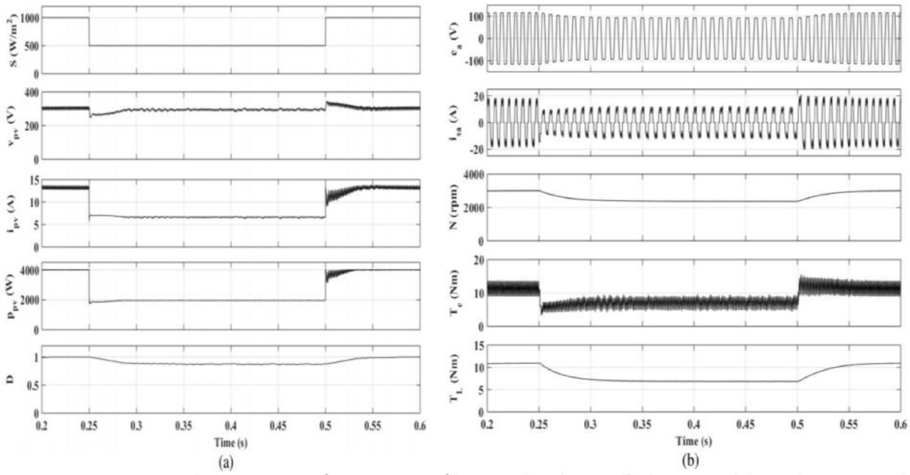

Fig 6 dynamic performance of (a) PV array and (b) BLDC motor

C. Dynamic performance

The system exhibits an excellent dynamic operation under varying the irradiance conditions. They are:

1. PV array performance: As shown in figure 6 the irradiance level is reduced to 500W/m$^2$ from 1000W/m$^2$ and then increased back to 1000W/m$^2$. Under the considered dynamics the PV array is optimized successfully. An optimum duty ratio is generated for each irradiance level which is used in the motor speed control.

2. Performance of BLDC Pump: Any variation in the atmospheric condition is strictly guided by the motor indices as shown in figure. PV array power governed the motor pump speed and is adjusted through the optimum duty ratio by controlling the motor input voltage.

## V. CONCLUSION

Single stage PV powered BLDC driven water pumping has been validated through a demonstration of its varies steady state, starting and dynamic performance. This system has been stimulated using MATLAB toolboxes. The system stands as a solution for DC-DC converter-less PV fed BLDC motor driven water pumping. Simplicity is achieved by eliminating the current sensor. Speed control and soft starting of motor pump can be achieved without any additional circuit.

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