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DESIGN AND IMPLEMENTATION OF SOLAR PV FED BLDC MOTOR DRIVEN WATER PUMP USING MPPT

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ABSTRACT

To optimize the solar PV generated power for BLDC motor driven water pump using MPPT [maximum power point tracking] technique. Basically solar PV fed BLDC motor needs DC-DC converter and the motor requires phase current sensors for controlling operation. By using DC-DC converter, it requires multi-stage operation. It leads to increases cost, size, complexity of the circuit and also it reduces the efficiency of the motor. Our project is single stage solar PV energy conversion system fed with BLDC motor pump, which eliminates the DC-DC conversion stage. By using voltage source inverter (VSI), it is capable of operating the solar PV array at its peak power. No additional control is need for the speed control of motor-pump and its soft start. The proposed system is expressed through its performance evaluation using MATLAB/Simulink based simulated results and experimental validation on a developed prototype, under the practical operating conditions.

Keywords: MPPT, solar PV array, BLDC motor, Water pump, Voltage source inverter (VSI)

I. INTRODUCTION

In modern era of development Renewable energy resources are decrease the demand of electricity due to continuous depletion of non-renewable resources. Now a days solar and wind energy power generations are rapidly grown when compare to the other renewable sources. Wind generation is not suitable for all the places so widely solar energy generation is used. Basically solar panels are used to generate the solar power. Solar panel absorb the sun light as a source of energy to generate electricity or heat.Solar panel work by allowing photons of light, to knock electrons free from Atoms, generating a flow of electricity. Solar panels have number of solar cells which is used for the solar power generation.

A continuous reduction in the cost of the solar photovoltaic (SPV) panels and the power electronics devices has encouraged the researchers and the industries to utilize the solar PV array generated power for different applications.SPV array generated electricity is widely used for irrigation in the fields, household applications and industrial use. The irrigation sector is one of the major sectors where solar PV (photovoltaic) power is extensively used for water pumping. Solar PV water pumping has been realized using the DC motor

A three-phase induction motor (IM) is widely used in SPV array fed water pumping for irrigation and domestic purposes due to its suitability for applications. A DC motor is also used in, but it requires high maintenance caused by the presence of brushes and commutator, it is not preferred for water pumping. However, a complicated control of IM and high efficiency of a permanent magnet synchronous motor (PMSM) than an IM has motivated the researchers to employ a PMSM drive where a high power water pumping system. Because of numbers of benefits of a permanent magnet brushless DC (BLDC) motor drive such as high efficiency, long life, high reliability, low radio frequency interference, noise and no maintenance, various researchers are focusing on this drive for SPV array based water pumping and so opted in this work. A BLDC motor is employed to drive the water pump based on SPV array in, which manifests its suitability for water pumping.

A DC-DC converter is commonly placed between the SPV array and VSI (voltage source inverter) fed BLDC motor pump in order to track the optimum operating point of the SPV array using a maximum power point tracking (MPPT) technique. Non-isolated DC–DC buck, boost, buck– boost, Cuk and SEPIC (Single Ended Primary Inductor Converter) converters used for MPPT in SPV applications are reviewed and compared.DC-DC converter to optimize the operating power point of a PV array. This power conversion causes an increased cost, size, complexity and reduced efficiency. As a unique solution of these problems, the present work proposes a single stage solar energy conversion system which demonstrated through its steady state, starting and dynamic functionalities, using MATLAB based simulation and an experimental system. It operates satisfactorily under the desired circumstances without sacrificing its performances, specially the MPP operation of PV array

II. SOLAR WATER PUMPING

Fig 1 states the block diagram of PV fed BLDC motor driven water pumping system. In this the water pump is driven by BLDC Motor. BLDC motor is an electronically commutated Motor, It takes power supply form the solar PV array. The Solar PV array directly fed to the VSI without the use of DC-DC converter. An Incremental conduction MPPT technique is adopted for the optimum utilization of solar PV array. MPPT technique used to generate optimum duty ratio, corresponding to the maximum power of the solar PV array. A diode prevents the flow of reverse current and DC link capacitor used for power transfer from PV array to the motor pump. BLDC Motor has three inbuilt hall sensors which accomplish the electronic commutation process

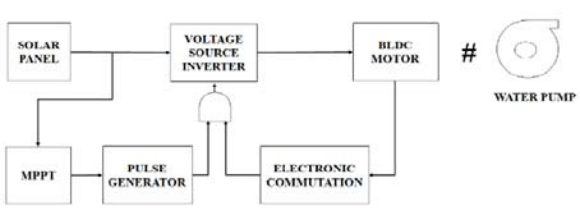


Fig 1. Block diagram

completely eliminates the DC-DC conversion stage. It is capable of operating the solar PV array at its peak power using the same VSI used for motor control.

The system under study is first designed by selecting a BLDC motor-pump set and a PV array such that it successfully operates under all the possible variations in weather conditions, and then

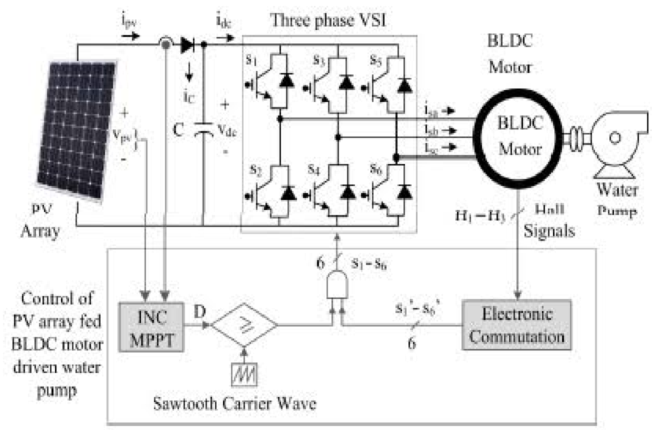
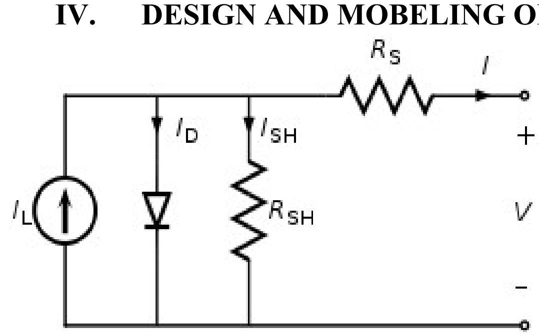


Fig 2. Schematic diagram

III. OPERATION OF THE SYSTEM

As shown in Fig 2, the solar PV array generates the electrical energy and feeds the Voltage source inverter. The IGBT (Insulated gate bipolar transistor) switch of the VSI is operated through an Incremental conductance (INC) MPPT algorithm such that the operation of the solar PV array is optimized and the BLDC motor has a soft starting. VSI supplies the power to BLDC motor which is coupled with water pump. Switching sequence for the VSI is provided by the electronic commutation of BLDC motor. Based on the position of rotor the hall Effect signals are generated. The design and control of the system explain in following sections.

IV. DESIGN AND MOBELING OF



THE SYSTEM

The elimination of DC-DC power conditioning stage makes the system simple and can categorized only in two parts , i.e. PV array and DC link capacitors converter fed BLDC drive coupled with water pump system.

4.1.PV Array Modelling

Fig 3 shows the equivalent circuit model of PV cell. It is simulated using Matlab/Simulink platform. The equivalent circuit models of PV cells are connected in series and parallel combination to reach the fixed output voltage and power of PV array.

Fig 3. Equivalent circuit of PV ell

An equivalent circuit consists of an ideal current source 'I_L' in parallel with an ideal diode. Two Resisters 'R_s' and 'R_{sh}' connected is series and parallel respectively. The values of thoseresistance depends upon the number of PV cells connected in series and parallel. And its output is constant under constant temperature and constant incident radiation of light. Current from the current source is denoted as short circuit current 'I_{sh}'. Thus, I_{ph}=I_{sc} Assume that output is in open-circuit, the current from the source is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage 'V_{oc}'. The output current 'I' from the PV cell is found by applying the Kirchoff"s current law (KCL) on the equivalent circuit

$$I_{sh} - I_d - V_d / R_p - I_{pv} = 0$$

Where,
$I_{sh}$is the short-circuit current that is equal to the current from the soure
$I_d$is the current shunted through the intrinsic diode
$V_d$is the voltage across the diode (*V*)
R_P=R_{SH} is Parallel Resistance (ohm)

The parameters V, I, io, and ipv as input to it. where, V=Operating voltage of PV cell, I=Net cell current, i_{PV}= PV current at MPP and i_o=Leakage current.
The MPP power of PV array,

$$P_{mp} = (n_s * V_{mp}) * (n_p * i_{mp})$$

We know, voltage of the PV panel

$$V_{PV} = n_s * V_{mp},$$

From above equation we can calculate the number of panel connected in series

$$n_s = V_{PV} / V_{mp}$$

The current at MPPT is given as,

$$i_{PV} = P_{PV} / (V_{PV})$$

The formula for calculate the parallel number of panels connected

$$N_p = I_{pv} / I_{mp}$$

PV modelling is done by considering the above calculations.

4.2. Design Of DC Link Capacitor

The DC link capacitor of Voltage source Inverter(VSI) connected across the PV array. It is a
Small, capacitor it carries the ripple current and it isGiven as,

$$i_C = i_{PV} - i_{dc}$$

Where, i_{PV} is the PV array current and i_{dc} the dc link current of the VSIUnder the various conditions, dc link current i_{dc} is kept zero to estimate the ripple current in the capacitor current, i.e.

$$i_C = i_{C,max} = i_{PV}$$

The capacitor required is given by,

$$C = i_{C,\,max} / f_{sw} * \Delta V_{PV}$$

f_{sw} is the switching frequency of theVSI and ΔV_{pv} is the ripple content in PV array voltage

The switching frequency, f_{sw} is selected under the factors like component size, system response, noise disruption and conversion efficiency. Switching frequency directly affecting these factors. High switching frequency make the reduction in the size of dc link capacitor. It also improves the transient response, and avoids the frequency bans in noise. High switching frequency also cause the low conversion efficiency and also the switching losses is increased. The capacitor value is quite low when compare to existing topologies

4.3.Design Of Water Pump

A water pump is acting as a load and it is coupled to the shaft of BLDC motor. This pump is designed by its power-speed characteristics as,

$$K_P = P / w^3 r$$

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A suitable water pump with these data is selected for the system.

V. CONTROL APPROACH

A control of the system has a four major parts. Those are MPPT technique control the operating point of solar PV array , BLDC motor electronic commutation, switching pulse generation for VSI, and speed control of BLDC motor. The control approach is shown in fig 4

5.1.Maximum Power Point Tracking

Mostly INC-MPPT technique is used to track the optimum operating point in solar PV array. It has excellent tracking performance in dynamically changing weather condition.

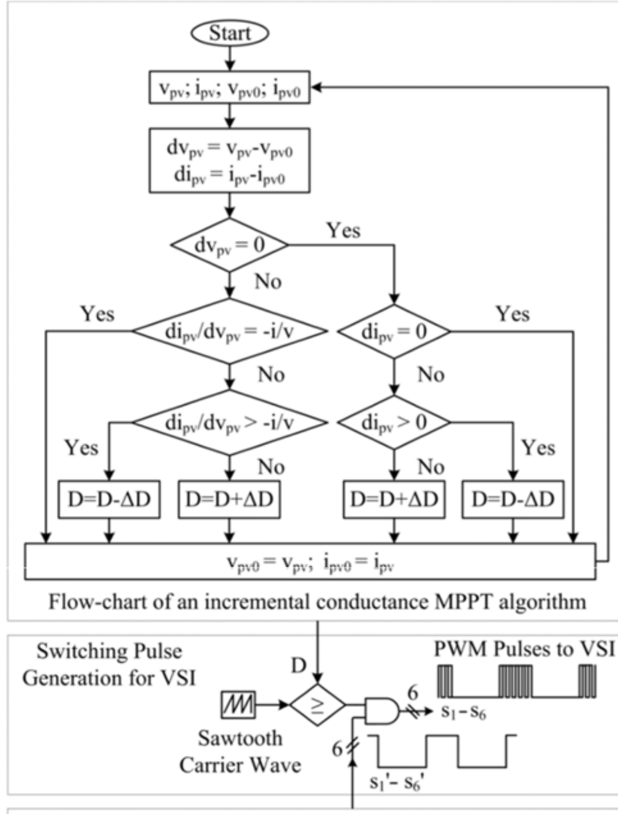
Perturbation size is randomly selected to avoid the oscillation around the peak point and the soft starting of the BLDC motor. Soft starting ensured under all the possible variation in the solar insolation level. Duty cycle control is done by INC-MPPT this method directly uses a duty cycle D, as the control variable. The perturbation size and power slope rate is fixed according the duty cycle D, until the solar PV array operating point reaches the MPP.

5.2. Electronic Commutation

Three hall sensors generates the hall signals (H1-H3) according to the rotor position in 60º interval. The six switching pulses (S_1'-S_6') are the transformation of three hall signals which is done by using decoder. These pulses are decide the switching states of VSI.

5.3.VSI Switching Pulse Generation

By linking the output, that will generate the pulse for switching the device of VSI. The execution of INC-MPPT will generate the duty ratio D, and it is compare with sawtooth carrier wave to get the PWM pulse in high frequency. It is shown in the Fig. 4, AND logic is used to generate six frequency pulses (S_1'-S_6') through electronic commutation. AND gate generate the switching pulse forVSI switches. AND operation only perform when both the input are in high. So the control of the systemrealized by INC-MPPT algorithm and electronic commutation.



θ(°)	Hall Signals			Switching States					
	H_1	H_2	H_3	S_1'	S_2'	S_3'	S_4'	S_5'	S_6'
0-60	1	0	1	0	1	1	0	0	0
60-120	0	0	1	0	1	0	0	1	0
120-180	0	1	1	0	0	0	1	1	0
180-240	0	1	0	1	0	0	1	0	0
240-300	1	1	0	1	0	0	0	0	1
300-360	1	0	0	0	0	1	0	0	1

Switching States for Electronic commutation of BLDC motor

Fig 4. Control Approach

5.4. Speed Control Of BLDC Motor

Maximum power from the solar PV array is attain the speed of BLDC motor. Variations in atmospheric conditions cause the variations in the speed of BLDC motor. Input voltage of the motor regulate the regulating the operating speed. The speed of the motor is adjusted by varying atmospheric conditions and variations in duty ratio D, depending upon the hall signal frequency variation the switching pulse is varies. And it is resulted in variation in the switching frequency.

VI. SIMULATED PERFORMANCE

The performance of the system is simulated in MATLAB/Simulink under various static and dynamic conditions.

6.1. Steady State Performance At 1000w/m^2

Steady state and starting performance of BLDC motor and PV array are shown in fig 5

6.1.1.Solar PV Array Performance*:*

The voltage V_{pv} current I_{pv} and power P_{pv} exhibits in fig 5 at an irradiance, S of 1 kW/m^2. The starting duty cycle and its step size are chosen properly to obtain safe starting motor. At steady state the six fundamental frequency have no modulation and the value of D is one.

6.1.2.BLDC Motor Pump Performance*:*

Fig 5 exhibits back emfe_a, winding current I_{sa}, speed N, Torque T_e and T_L of BLDC motor. The pump is operated in full speed at the time motor develops the rated torque. A small ripple appears in the torque because of current commutation and sensor-less operation of the motor. It causes vibration in the motor at low speed. The system is designed to run motor-pump in high speed range in order to done the successful water pumping. The motor pump is usually installed in submerged area or in agriculture field, and the noise don't cause any disturbance in the surroundings.

The torque ripple reduction may lead to an enhancement in the efficiency of motor. Motor phase current sensors and front end converters provides various solutions for the torque ripple reduction. It cause the complexity of the system and torque ripple becomes uncontrollable at higher speed range. In the proposed system minimum speed required to operate the pump. So the system gets higher efficiency at lower speed and also minimize the complexity of the system. So the BLDC motor offers good amount of water delivery even at lower speed range.

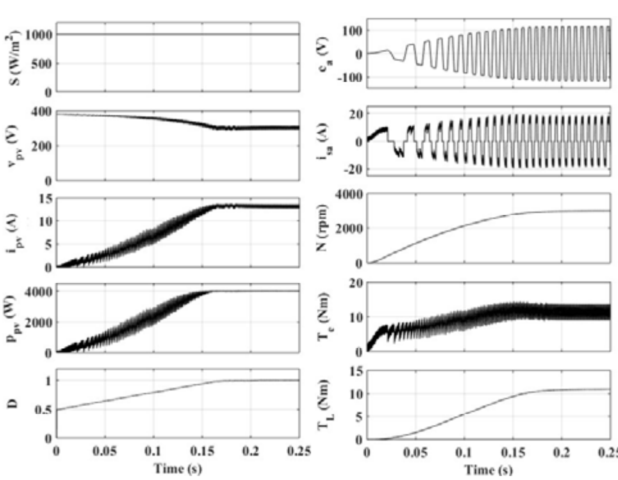


Fig 5. Steady state performance of solar PV array and BLDC motor at 1 kW/m^2

6.2. Steady State Performance At 200w/m^2

Fig 6 shows the starting performance of both solar PV array and motor pump at the ondition 200 W/m^2

6.2.1. Solar PV Array Performance*:*

The system is even performed at 20% of irradiance. The MPP well tracked at 200W/m^2 and it shown in fig 6. By adjusting the duty ratio of VSI, the speed of the water pump is controlled. This control is done by an optimum duty ratio.

6.2.2. BLDC Motor Pump Performance*:*

The motor pump attains the higher speed range and it is show in fig 6. The pumping is successfully done under 20% irradiance level. The motor speed is governed by the optimum PV array power. Moreover, a soft starting is observed under such circumstances.

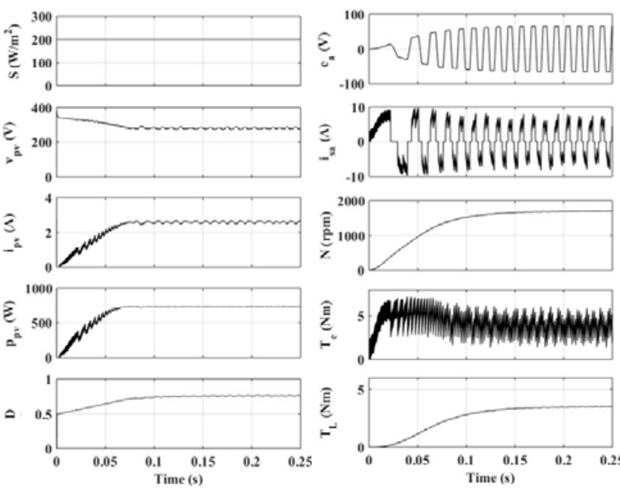


Fig 6. Steady state performance of solar PV array and BLDC motor at 200W/m^2

6.3. Dynamic Performance

Fig 7 shows the dynamic operation of the system under various irradiance conditions. The performance of solar PV array and motor-pump explains in follows.

6.3.1. Solar PV Array Performance*:*

The PV array power is optimised successfully under various dynamic conditions. The irradiance level is reduced from 1000W/m^2 to 500W/m^2. The duty ratio is generated for each irradiance level and it is used to control the speed of motor pump.

6.3.2. BLDC Motor Performance :

The motor indices when any variation occurs in atmospheric condition. Fig 7 shows smooth dynamic performance of the motor. By controlling the input voltage of the motor, the speed of motor is adjusted through the optimum duty ratio D

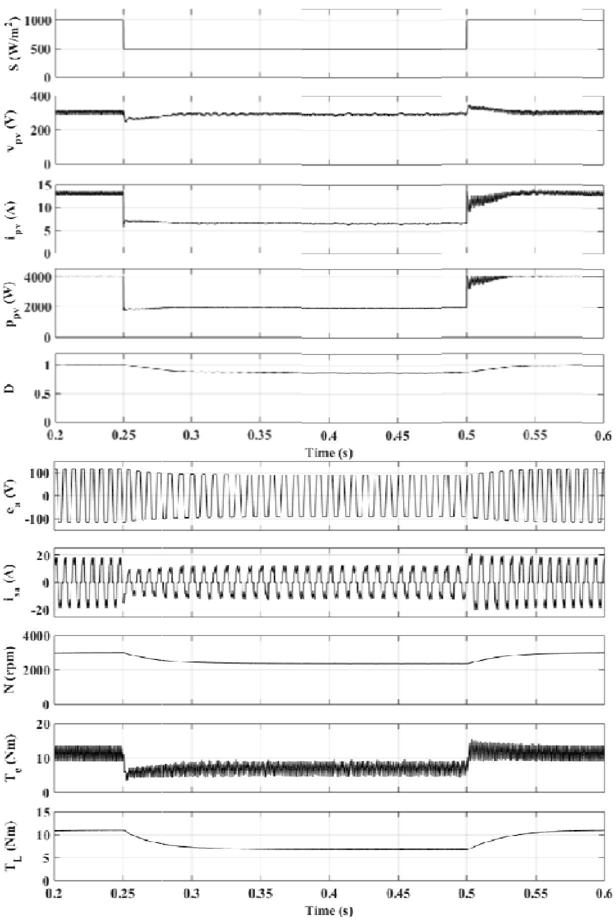


Fig 7. Dynamic performance of solar PV array and motor pump, of water pumping system

6.4.Performance Under Partial Shading

An output power of solar PV array is reduced under partial shading condition. The PV array operating at an MPP at the time motor pump is able to deliver the water. Fig 8 shows the responses of PV array and BLDC motor-pump under such conditions. The BLDC motor pump response properly according to the power from solar PV array Being high efficiency motor, the BLDC motor-pump delivers good amount of water even at low input power.

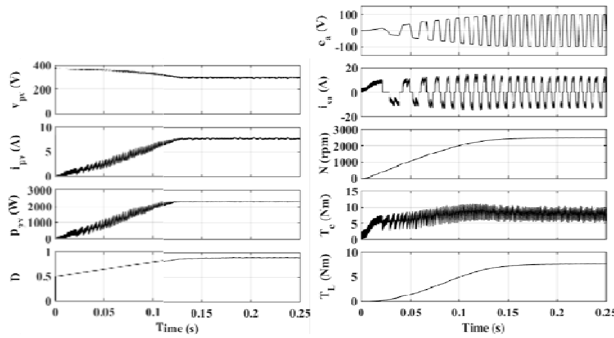


Fig 8. Responses of solar PV array and motor pump under partial shading

VII. CONCLUSION

The Design and implementation of solar PV fed BLDC motor driven water pumping system validated under static and dynamic performance in various practical operating conditions. MATLAB/Simulink used for the simulation of the system. The proposed system provides singe stage operation by neglecting DC to DC conversion stage. The soft starting and speed control of the motor pump done without any additional circuit. The system is simple and low cost, because of the elimination of phase current sensors. The system have successful operation even at 20% solar irradiance. The proposed system is very useful in farm irrigation, fish farms and street watering systems.

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