SCHEMING OF CONTROLLER FOR SINGLE STAGE SOLAR PV FEDBLDC MOTOR-DRIVEN WATER PUMP

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ABSTRACT

To optimize the solar photovoltaic (PV) generated power using a maximum power point tracking (MPPT) technique, a DC-DC conversion stage is usually required in solar PV-fed water pumping which is driven by a brushless DC (BLDC) motor. This power reformation stage leads to an increased cost, size, difficulty, and decreased efficiency. As a unique solution, this work addresses a single-stage solar PV energy conversion system feeding a BLDC motor pump, which eliminates the DC-DC conversion stage. A simple control technique capable of operating the solar PV array at its peak power using a common voltage source inverter (VSI), is proposed for BLDC motor control. The proposed control eliminates the BLDC motor phase current sensors. No supplementary control is associated with the speed control of the motor pump and its soft start. The speed is controlled through the optimum power of the solar PV array. The suitability of the proposed system is exhibited through its performance evaluation using MATLAB/Simulink-based simulated results.

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

I. INTRODUCTION

The foreseen global energy crisis soon due to the rapid depletion of conventional fossil fuels resources and the consistently diminishing costs of solar PV modules, power electronic devices, and microprocessors motivate the researchers and industrialists toward effective utilization of solar PV technology. Among various applications of solar PV energy, a standalone PV-powered water pumping system seems to be the most promising and attractive in various areas such as rural farm irrigation, urban street watering, and fish farms. modernization of the human community and the developing utilization of electric motors have exponentially enlarged the need for electrical energy. The motors comprise more than 40% of overall electrical power expenditure. Therefore, a motor plays a prominent role to realize solar PV-based energy-efficient and cost-effective water pumping.

The dc motor with brushes possesses a low efficiency, and it requires regular maintenance due to the sliding brush contacts and the commutator. An induction motor-based PV pumping system is reliable, rugged, and maintenance-free with better efficiency and offers more flexibility for control in comparison to dc motors. A BLDC motor possesses several merits such as reliability, least maintenance requirement a wide range of speeds, ease to drive, and simple control.

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, but it requires high maintenance caused by the presence of brushes and commutator, it is not pre- ferred for water pumping. However, a complicated control of IM and the high efficiency of a permanent magnet synchronous motor (PMSM) than an IM. 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 the SPV array, 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 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 evaluated and compared. DC-DC converter to optimize the operating power point of a PV array. This power conversion causes an increased cost, size, difficulty, and decreased efficiency. As a unique solution to these problems, the present work proposes a single-stage solar energy conversion system which is demonstrated through its steady-state, starting, and dynamic functionalities, using MATLAB-based simulation. It operates satisfactorily under the desired circumstances without sacrificing its performance, especially the MPPT operation of the PV array

II. SOLAR WATER PUMPING

Fig 1 shows 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 from the solar PV array. The Solar PV array is straightly fed to the VSI without the use of a DC-DC converter. An Incremental conduction MPPT technique is adopted for the optimum utilization of solar PV array. MPPT technique is used to generate an optimum duty ratio, corresponding to the maximum power of the solar PV array. A diode prevents the flow of reverse current and the DC link capacitor is used for power transfer from the PV array to the motor pump. BLDC Motor has three inbuilt hall sensors which accomplish the electronic commutation process

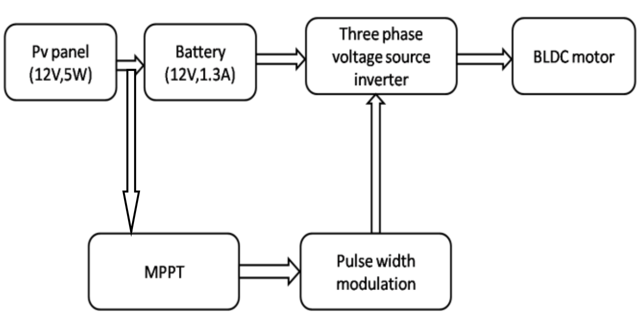


Fig 1. Block diagram

completely get rid of 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.

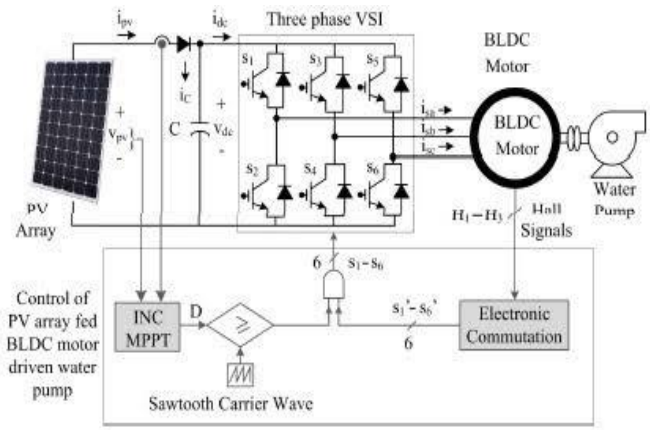


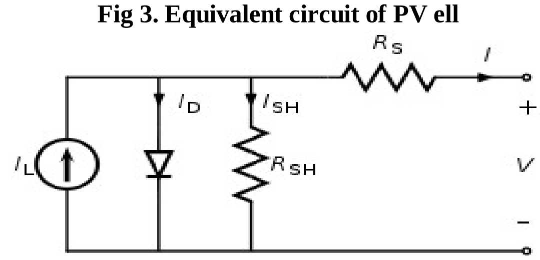
Fig 2. Schematic diagram

III. OPERATION OF THE SYSTEM

Fig 2 shows that 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 the BLDC motor which is coupled with a water pump. The switching sequence for the VSI is provided by the electronic commutation of the BLDC motor. Based on the position of the rotor the hall Effect signals are developed. The design and control of the system explain in the following sections.

IV. DESIGN AND MODELING OF THE SYSTEM

Fig 3. Equivalent circuit of PV ell



The elimination of the DC-DC power conditioning stage makes the system simple and can be divided only into 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 a PV cell. It is simulated using the MATLAB/Simulink platform. The equivalent circuit models of PV cells are connected in series and parallel combinations to reach the fixed output voltage and power of the PV array.

An equivalent circuit consists of an ideal current source 'I_L' in parallel with an ideal diode. Two Resisters 'R_s' and 'R_{sh}' are connected in series and parallel respectively. The values of that resistance depend 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 Kirchhoff'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 source

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 I_{pv} as input to it. where, V=Operating voltage of PV cell, I=Net cell current, I_{PV}= PV current at MPPT, and i_o=Leakage current.

The MPPT power of the 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 the above equation, we can calculate the number of panels 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 calculating the parallel number of panels connected

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

PV designing is done by considering the above calculations.

4.2. Design Of DC-Link Capacitor

The DC-link capacitor of the Voltage Source Inverter(VSI) is connected across the PV array. It is small, capacitor carries the ripple current and it is given as,

$$I_C = I_{pv} - Idc$$

Where, i_{PV} is the PV array current and IDC is the dc-link current of the VSI Under the various conditions, dc-link current $_{IDC}$ is kept at 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 the and ΔV_{pv} is the ripple content in PV array voltage

The switching frequency is selected under the factors like component size, system re-response, noise disruption, and conversion efficiency. Switching frequency directly affects these factors. High switching frequency reduces the size of the dc-link capacitor. It also improves the transient response and avoids the frequency bans in noise. High switching frequency also causes low conversion efficiency and also switching losses are increased. The capacitor value is quite low when compared 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 the BLDC motor. This pump is designed by its power-speed characteristics as,

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

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

V. CONTROL APPROACH

Control of the system has four major parts. Those are the MPPT technique that controls 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 PowerPoint Tracking

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

MPPT:

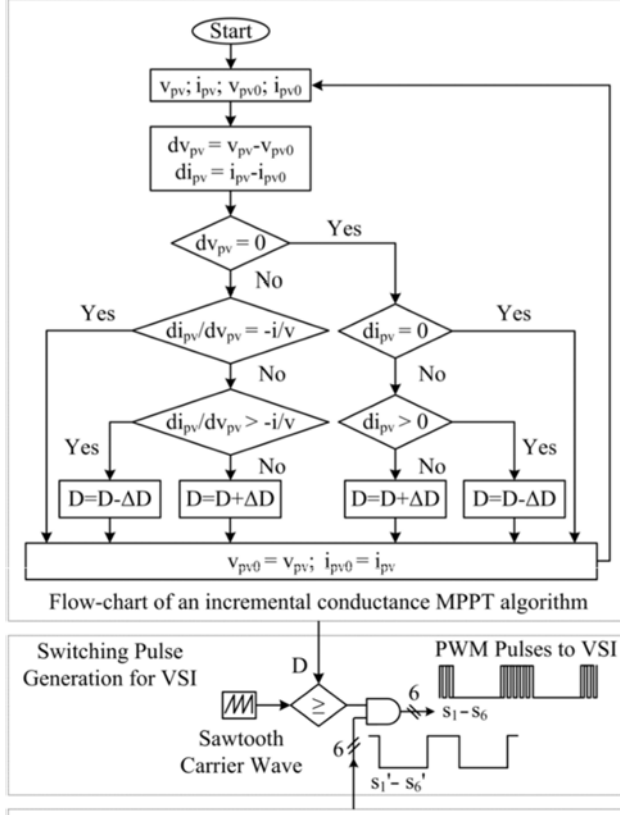
Maximum power point tracking (MPPT) is a technique that charge controllers use for wind turbines and PV solar systems to employ and maximize power output. PV solar comes in different configurations. The most basic version is one where power goes from collector panels to the inverter (often via a controller) and from there directly onto the grid. A second version might split the power at the inverter. This is called a hybrid inverter.

5.2. Electronic Commutation

Three hall sensors generate the hall signals (H1-H3) according to the rotor position in 60º intervals. The six switching pulses (S_1'-S_6') are the transformation of three hall signals which is done by using a decoder. These pulses are deciding 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 ex-elution of INC-MPPT will generate the duty ratio D, and it is compared with the sawtooth carrier wave to get the PWM pulse in high frequency. It is shown in Fig. 4, AND logic is used to generate six frequency pulses (S_1'-S_6') through electronic commutation. AND gate generates the switching pulse for VSI switches. AND operation only performs when both the input is high. So, the control of the system is realized by the INC-MPPT algorithm and electronic commutation.



Flow-chart of an incremental conductance MPPT algorithm

θ(°)	Hall Signals H_1	H_2	H_3	Switching States 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 attained at the speed of the BLDC motor. Variations in atmospheric conditions cause variations in the speed of the BLDC motor. The input voltage of the motor regulates 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 varied. And it has 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 is shown in fig 5

6.1.1. Solar PV Array Performance*:*

The voltage V_{pv} current I_{pv} and power P_{pv} are exhibited 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 a safe starting motor. At a steady-state, the six fundamental frequencies have no modulation and the value of D is one.

6.1.2.BLDC Motor Pump Performance*:*

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

In the proposed system minimum speed is required to operate the pump. So, the system gets higher efficiency at a lower speed and also minimizes the complexity of the system. So, the BLDC motor offers a good amount of water delivery even at a lower speed range.

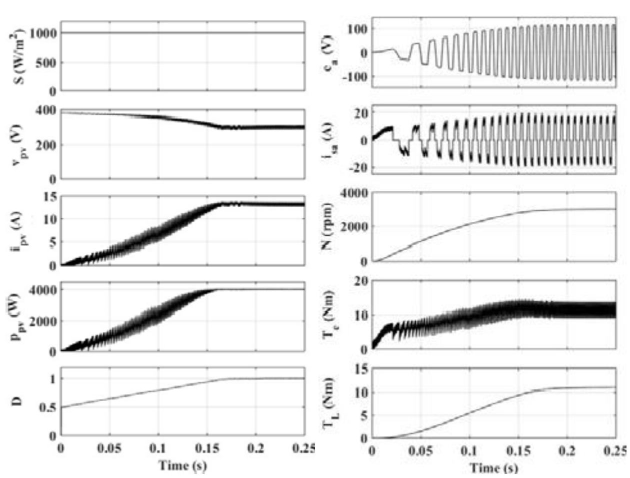


Fig 5. Steady-state performance of solar PV array and BLDC motor at 1 kW/m^2

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

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

6.2.1. Solar PV Array Performance*:*

The system is even performed at 20% of irradiance. The MPP was well tracked at 200W/m^2 and is 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 a higher speed range and is shown in fig 6. The pumping is successfully done under a 20% irradiance level. The motor speed is governed by the optimum PV array power. Moreover, a soft starting is observed under such circumstances.

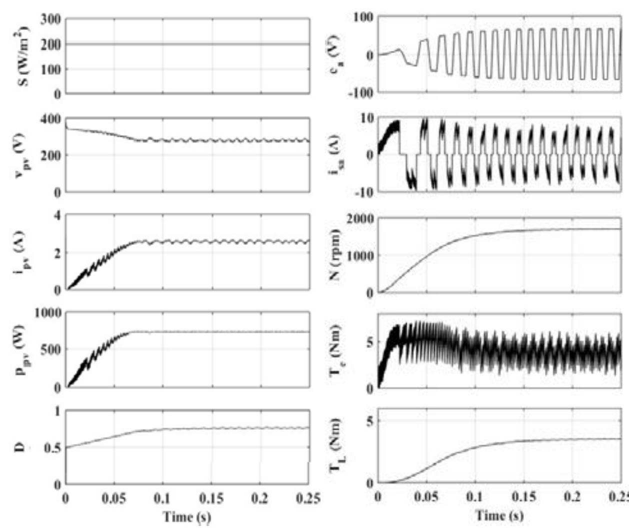


Fig 6. Steady-state performance of solar PV array and BLDC motor at 200W/m^2

6.3. Dynamic Performance

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

6.3.1. Solar PV Array Performance*:*

The PV array power is optimized 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 ir-

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radiance level and it is used to control the speed of the motor pump.

6.3.2. BLDC Motor Performance :

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

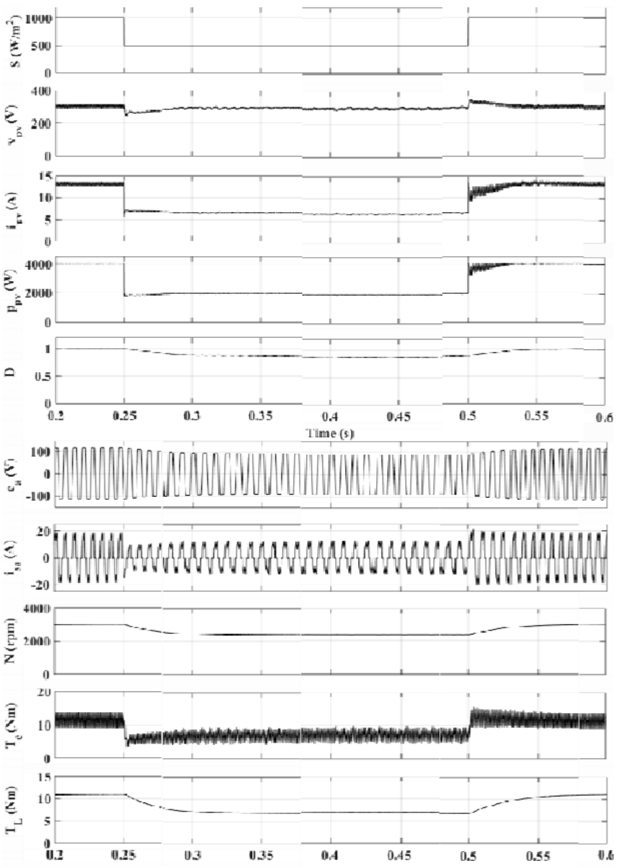

Fig 7. Dynamic performance of solar PV array and motor pump, of the water pumping system

6.4.Performance Under Partial Shading

The output power of the solar PV array is reduced under partial shading conditions. The PV array operates at an MPP at the time the motor pump can deliver the water. Fig 8 shows the responses of PV array and BLDC motor-pump un- der such conditions. The BLDC motor pump responds properly according to the power from the solar PV array Being a highly efficient motor, the BLDC motor pump delivers a good amount of water even at low input power.

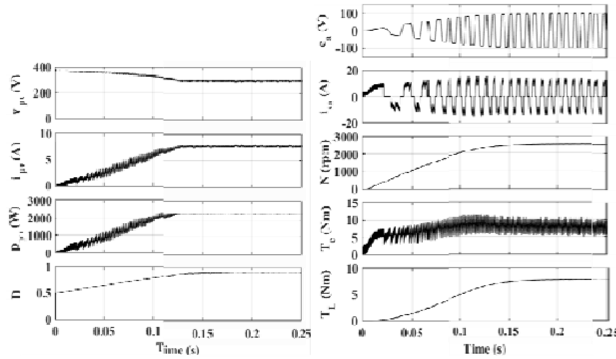

Fig 8. Responses of the solar PV array and motor pump under partial shading

VI. CONCLUSION

The Design and implementation of a single-stage solar PV fed BLDC motor-driven water pumping system was validated under static and dynamic performance in various practical operating conditions. MATLAB/Simulink was used for the simulation of the system. The proposed system provides single-stage operation by neglecting DC to DC conversion stage. The soft starting and speed control of the motor pump is done without any additional circuit. The system is simple and low cost, because of the elimination of phase current sensors. The system has a 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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