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SIMULATION AND ANALYSIS OF SINGLE STAGE SOLAR PV FED BRUSHLESS DC MOTOR FOR WATER PUMPING

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Abstract: The global energy crisis in near future due to the rapid depletion of conventional fossil fuel resources and a consistently diminishing costs of solar photovoltaic (PV)modules, motivate towards an effective utilization of solar PV technology. In order 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 conversion stage leads to an increased cost, size, complexity and reduced efficiency. Here addresses a single stage solar PV energy conversion system feeding a BLDC motor-pump, which eliminates the DC-DC conversion stage. In addition, it constitutes the attractive merits of conventional topology , such as the elimination of BLDC motor phase current sensing and soft starting. The suitability of proposed system is validated through its performance and evaluation using MATLAB/Simulink based simulated results.

Key words: MPPT, Solar PV array, BLDC motor, Water pump, VSI, Soft starting, Speed control

I. INTRODUCTION

Among the 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 humancommunity and developing utilization of electric motors have exponentially enlarged the need for electrical energy. The motors comprise more than 40% of overall electric power expenditure . Therefore, a motor plays prominent role to realize a solar PV based energy efficient and cost-effective water pumping. 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 . 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 flexibilities for control in comparison to DC motors . The brushless DC (BLDC) motor is identified as a better substitute of the DC motor and an induction motor for PV fed water pumping. This motor is compact, rugged and efficient in comparison to an AC motor. Moreover, a BLDC motor possesses several merits such as reliability, least maintenance requirement, a wide range of speed, easy-to-drive and simple control . Therefore, this motor has received increased attention for water pumping in the last decade owing to its various merits which constitute the attractive features particularly for this application.

II. CONVENTIONAL TOPOLOGY

Fig. 1 present the schematics of the conventional brushless DC motor drives for PV-water pumping .
As shown in Fig. 1, the maximum power point tracking (MPPT) is performed by a DC-DC converter. Two phase currents are required to be sensed for motor control . A DC-DC converter, as usual, is deployed to optimize the operating power of a PV array, speed control of a BLDC motor-pump, and soft starting. The speed control is performed through a variable voltage at the DC bus of voltage source inverter (VSI). However, a bulky capacitor is required at the DC link due to adopting a fundamental frequency operation of VSI. A Z-source inverter (ZSI) replaces the DC-DC converter in other components of Fig. 1 remaining unchanged, asserting a single stage solution. However, the sensing of motor phase currents and DC bus voltage is still required. On the way of sensor reduction, recently, the position sensor-free BLDC motor drive has been reported for the same application. However, those utility models are based on a two stage Power conversion.The conventional topologies adopt two stage solar energy conversion system, which essentially require an intermediate DC-DC converter to optimize the operating power point of a PV array. This power conversion causes an

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increased cost, size, complexity and reduced efficiency. As a unique solution of the above mentioned problems, the present work proposes a single stage solar energy conversion system which 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 speed of BLDC motor is controlled through the optimum power of solar PV array. The bulky capacitor at the DC link is replaced with a low valued capacitor using a pulse width modulation (PWM) switching of VSI. As of now, a single stage PV system has been proposed for an induction motor driven water pump . A replacement of an induction motor with BLDC motor in solar PV water pumping, offers simplicity, cost-effectiveness and compactness.

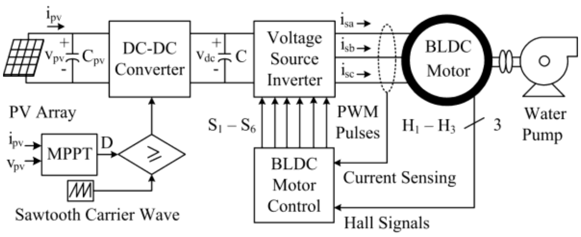

Fig.1 Conventional BLDC motor drive with phase current sensors
for water pumping based on a two stage solar PV energy conversion system.

III. SINGLE STAGE TOPOLOGY

Fig.2.illustrates the proposed brushless DC motor-water pumping based on a single stage solar PV energy conversion system. The solar PV array is directly connected to a VSI which feeds the BLDC motor-pump. A diode in series with the PV array prevents the flow of reverse current. A small DC link capacitor is connected to enable a power transfer from PV array to the BLDC motor-pump.An incremental conductance (INC) MPPT technique is adopted for optimum utilization of solar PV array. This technique uses PV voltage and current as the feedback signals to generate an optimum duty ratio, corresponding to the maximum power of solar PV array. The motor has three inbuilt Hall sensors to accomplish the electronic commutation.

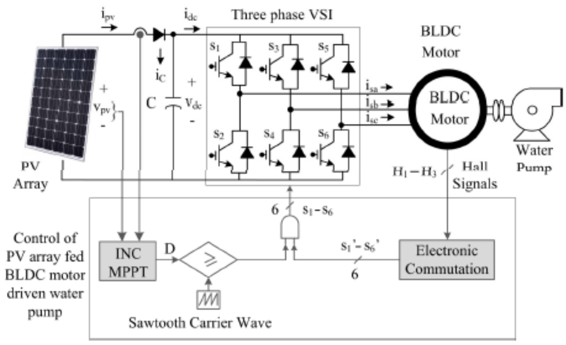

Fig.2. Proposed water pumping based on a single stage solar PV energy conversion system.

IV. DC LINK CAPACITOR DESIGN

A small capacitor is also connected across the PV array serves as the DC link capacitor of VSI. It carries the ripple current, which is given as,

$$i_c = i_{pv} - i_{dc}$$

where i_{pv} = 12.9 A, which is the PV array current at MPP, and i_{dc} is the DC link current of VSI. The worst condition is presumed, at which i_{dc} is zero, to estimate the ripple content in the capacitor current, i.e.

$$i_c = i_{c,\max} = i_{pv} = 12.9A$$

Capacitor is given by

$$c = \frac{i_{c,\max}}{f_{sw} \times \Delta v_{pv}} = \frac{12.9}{10000 \times (19.8 \times 20) \times 0.04} = 81.4 \cong 100\mu F$$

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V. CONTROL UNITS

The single stage topology has its control part classified into four major parts. Control of solar pv array by MPPT method , BLDC motor electronic commutation, switching pulse generation for VSI, and controlling the speed of BLDC motor

Maximum Power Point Tracking

An INC-MPPT approach is adopted to track the optimum operating point of solar PV array.
The below figure shows flowchart of INC.

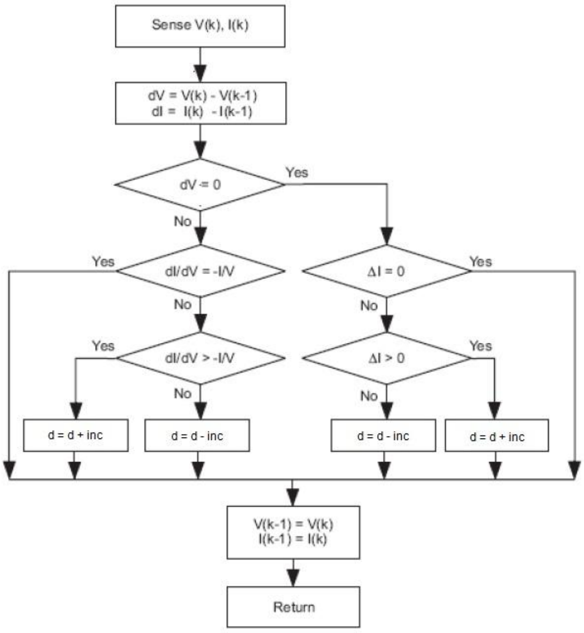

Fig.3. Flowchart of INC(incremental conductance)

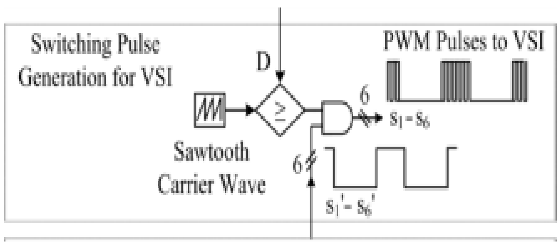

Fig.4. Switching pulse generation for VSI

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

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

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

Electronic Commutation of Brushless DC Motor

By means of an electronic commutation, a symmetrical direct current is drawn from the DC bus of VSI for 120° and placed at the centre of back-EMF (Electro-motive Force).Three Hall sensors generate a set of Hall signals (H1 - H3) at an interval of 60° in accordance with the rotor position as shown in Fig.4. Using a decoder, these signals are transformed into the six fundamental frequency pulses (S1 -S6), which decide the switching states of VSI. The only two pulses are high at any instant, resulting in a low conduction loss.

Switching Pulse Generation for VSI

The pulses for switching the devices of VSI are generated by linking the output of two controls discussed above. An optimum duty ratio, D generated by the execution of INC MPPT that is compared with a high frequency sawtooth carrier wave in order to get a high frequency PWM pulse, as shown in Fig. 4. To modulate the six fundamental frequency pulses (S_1'-S_6') generated through an electronic commutation, an AND logic is used. The AND logic gate receives a high frequency PWM pulse and a fundamental frequency pulse as inputs and ultimately provides, at the output. A high output (ON) results in only if both inputs to the AND gate are high. Therefore, the AND gate alters only the ON period of a fundamental frequency pulse with the frequency of saw-tooth wave. Thus, the control of proposed water pumping system is realized by compounding the INCMPPT algorithm and electronic commutation.

VI. SIMULATION RESULTS AND ANALYSIS

Table.1. Solar PV array Design

Characteristics	specification
V_o	19.8V
I_{sc}	4.8A
V_m	15.44V
I_m	4.3A
P_m	70W
K	0.003A/^{0}C
A	0.8
R_{sh}	10000Ω
R_s	0.011Ω

Table.2. BLDC design parameters

Parameters	specification
No.of poles (p)	4
N_{rated}	3000rpm
J	2.9Kg.cm^2
R_s	3.58Ω
L_s	9.13mH
K_e	78V/krpm
K_t	0.74Nm/A

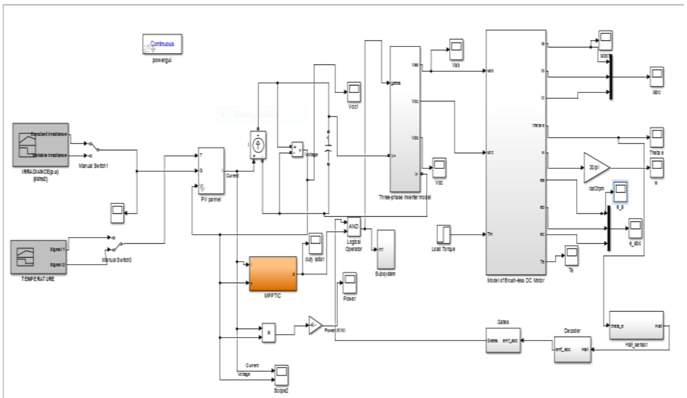

Fig.5. Simulation of the single stage topology.

The I-V curve of solar panel is plotted with open -circuit voltage of 19.8V and short circuit current of 4.8A.PV curve of solar panel is plotted in figures.6 and 7.The maximum power of 70W is obtained here.

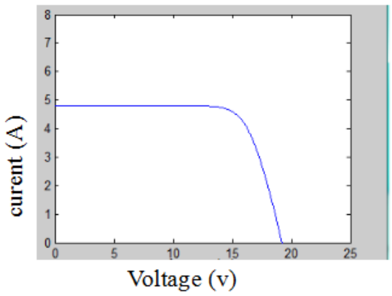

Fig.6. IV curve of solar panel

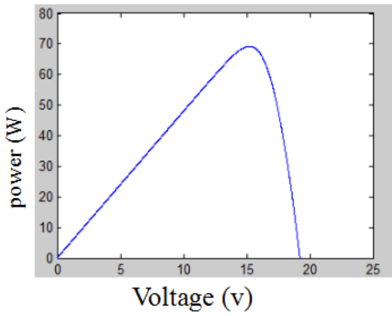

Fig.7. PV curve

The emf output of the BLDC motor is shown in fig.8. It is clearly a trapezoidal emf with a magnitude of 90V. The stator current is shown in fig..The motor speed is obtained as 2000rpm. The electromagnetic torque of 7Nm is obtained by simulation.

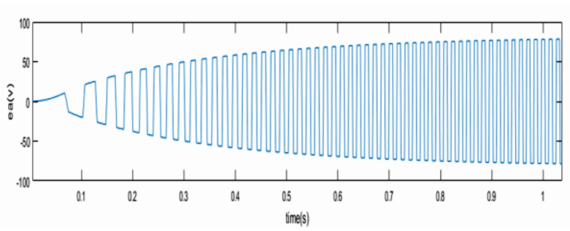

Fig.8. EMF across phase A (e_a)

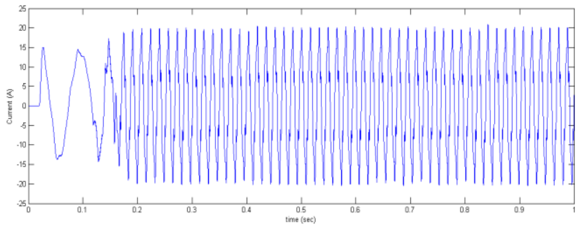

Fig.9. Current across phase A

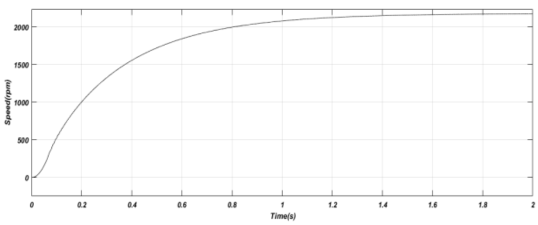

Fig.10. Motor speed in rpm

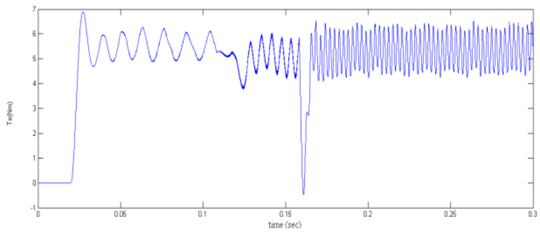

Fig.11. Electromagnetic Torque (T_e)

VII. CONCLUSION

A single stage motor driven water pumping is proposed here. PV panel and bldc motor is simulated and the corresponding outputs are obtained. The system has been simulated using MATLAB/SIMULINK. The proposed topology provides a converter less solution for solar fed BLDC driven pumping. It makes a cost effective solution by eliminating phase current sensors.

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