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Comparative Analysis onVSI and CSI based Solar Photovoltaic Source Fed BLDC Motor Drive with Boost Converter for Water Pumping System

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ABSTRACT

In this paper, analysis of solar power fed Brushless DC motor (BLDC) motor drive with a boost converter is presented for water pumping application in irrigation system. Nowa days, the usage of renewable PV source is increasing gradually, due to the encouragement of eco-friendly energy sources by providing subsidies for the installation in the initial states. In the agricultural sector, the water pump system requires a 3-ϕ power supply, for that we need a separate transmission line and transformers to meet the load demand. In this paper, a solar power fed BLDC motor water pumping system with boost converter and Voltage source Inverter (VSI) is presented which reduces the converter switch stress by increasing the voltage transfer gain ratio. VSI needs a huge dc link capacitor that is inherently unreliable and is one of the most expensive components of a drive.A MPPT controller is required to extract maximum power from the high penetrating renewable PV source and also proposes the Current source inverter (CSI) fed water pumping system is developed and examine with same operating conditions. A comparative analysis view in existing method of system replace the VSI with CSI. The performance of system is analyzed with speed settling times at same operating conditions. The proposed work is carried out in the MATLAB/Simulinksoftware. A comparative analysis is also presented in lucid manner.

KEYWORDS: *MPPT; BLDC motor; Boost converter; PV system; VSI;CSI*

I. INTRODUCTION

The usage of solar energy increases drastically in the recent decade, the total grid-tied installed solar energy capacity is 23,022.83 MW, as of 30th June 2018. The total grid-tied installed capacity in India is reached 71,187.12 MW [1,2]. The economy of the nation depends on the agricultural sector, which intern depends on the availability of water resource to the field [3,4]. So, many researchers are focusing on the solar power fed water pumping drive applications for effective irrigation pumping application [5].

Authors in [6], dispense a literature survey on solar PV water pumping system current status. The detailed information of solar PV water pumping system, its mechanisms and advantages are illustrated with a summarization of factors affecting the performance of the developed system. The effective utilization of alternative green energy sources, different optimization methods are illustrated with numericaldata.

An integrated PV, wind and hydroelectric power station based water pumping system is developed in [7], the authors developed a mixed integer mathematical model of proposed hybrid water pumping system and introduced an optimization method to denigrate the encounter of renewable energy sources on the national conventional power system network and to inspect the impact of specific parameters on energy exchange with the grid.

Authors in [8], scrutinized a PV fed water pumping system in the agricultural sector, a vector controlled method is used to control the BLDC motor for water pumping applications and for extracting maximum solar power under distinct solar irradiation level, P&O algorithm is used. The entire system performance is analyzed in MATLAB/Simulink environment by considering the contrasting solar irradiation data and a constant DC link voltage is fed to the VSI, by connecting battery bank across the DC linkcapacitor.

In [9], the authors proposed a dual MPPT controller for dual PV source fed water pumping system. In this system, a 3-ϕ open-end winding induction motor coupled to a centrifugal pump is used and it is connected to the two level 3-ϕ inverter. As different PV sources are used for power supply, it provides different levels of voltages. The inverter is controlled by PWM techniques along with v/f control, in addition to the proposed dual MPPT techniques.

A back stepping control algorithm is proposed in [10], to control the centrifugal water pump system fed with the solar PV and grid-tied system. The following are the main objectives of the proposed controller, (i) to control the water flow rate by tracking the reference signal, (ii) regulating the rotor flux, (iii) regulation of DC link to obtain maximum power and (iv) power factor correction. In order to do the system performance evaluation, the whole system is developed in the park-coordinates.

A solar PV fed water pumping system using switched reluctance motor drive with dual output buck-boost converter has been implemented in [11], the main advantage of the proposed dual output converter is it able to optimize the PV array power and to provides the soft starting to the reluctance motor. During the continuous current mode operation, the implemented system reduces the current and voltage stress on the converter components and slashes the electromagneticinterference.

A single stage PV fed BLDC motor drive centrifugal pump system is implemented in [12]. The entire system is implemented in MATLAB/Simulink model by considering the 4 kW PV system with INC method as maximum power point tracking algorithm and BLDC motor is controlled by the Hall sensor signals. The performance analysis is done in both simulation and experimentally by considering the different solar irradiation data levels.

A detailed literature review is done in this section by considering the all the aspects in designing the solar PV fed water pumping system in the irrigation sector. From the literature review, many solar power fed water pumping systems have been implemented by considering the interfacing or connecting power electronic converters, PV array modeling, different types of motors (BLDC, switches reluctance), different control and MPPT controltechniques.

A solar power fed water pumping system requires a DC-DC converter, to obtain maximum and constant DC power from the high penetrating PV source and a voltage source inverter (VSI) for the BLDC motor, to transfer power from the PV source to the water pump[13]. A double boost DC-DC converter is considered in this paper, which provides the high voltage transfer gain compared to the conventional boost converter [14- 26].

In this proposed solar power fed BLDC motor drive water pumping system, a 1.2 kW PV source is considered with a double boost converter, the maximum power extraction is regulated by the ANFIS based MPPT controller to maintain constant DC power, then the hall effect based VSI is placed between the DC-DC converter and BLDC motor. In orderto analyze the performance of the entire system a constant 1000W/m^2 irradiation level is considered with the temperature of 25^{o}C.

This paper is divided into 5 sections to explain the system design and performance. In section-1, introduction to the renewable energy sources fed water pumping system. In Section-2, Design of PV array system and boost converter. Section- 3, explained about the proposed PV fed BLDC motor water pump design with aexplains the proposed PV fed water pumping system control with different inverter topologies system like VSI and CSI. Final simulation and results discussion are explained in section-4 followed by a conclusion section.

II. PROPOSEDGRID INTERACTIVE PV FED WATER PUMPING SYSTEMDESIGN

Figure 1(a) illustrates the Grid interactive solar PV fed water pumping system with the considered 1.2 kW PV array, developed boost power converter, P&O MPPT controller to extract maximum power, a 3-phase VSI with hall signal control connected to BLDC motor with water pumping system.

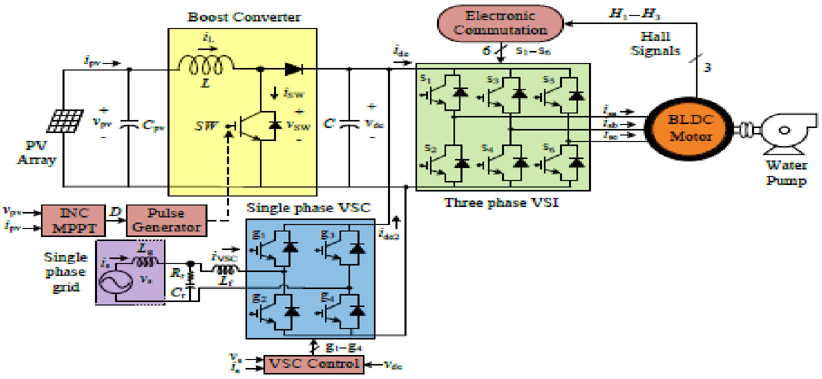


Figure 1(a). Block Diagram of Proposed PV Fed Water Pump Application

2.1.PV System

A SunPower SPR-305-WHT PV panel is considered to design a 1.2 kW PV system, the detailed specifications of the PV module are listed in Table 1. Figure 1(b) shows the equivalent circuit of a PV cell [17,18].

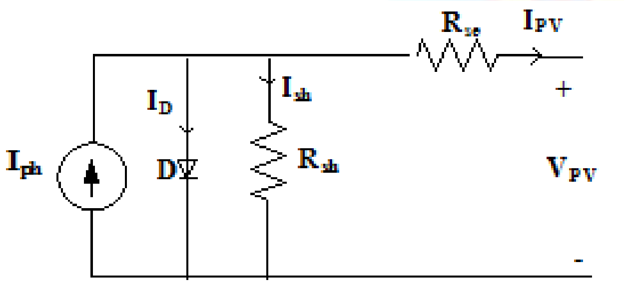


Figure 1(b). PV Cell Equivalent Circuit

In order to analyze the system, a constant 1000 W/m² PV irradiation is considered without any shading effect on the PV panels in MATLAB as shown in illustrated. 3. Figure 4 represents the Sun Power SPR-305-WHT 1.2 kW PV Module I-V and P-V characteristics at 25°C with different solar irradiation levels from 0.25 kW/m² to 1 kW/m².

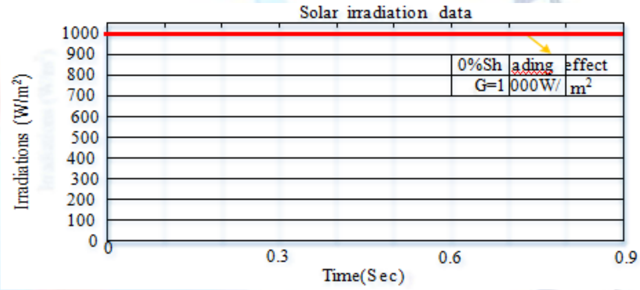


Figure.2. Solar Irradiation Data

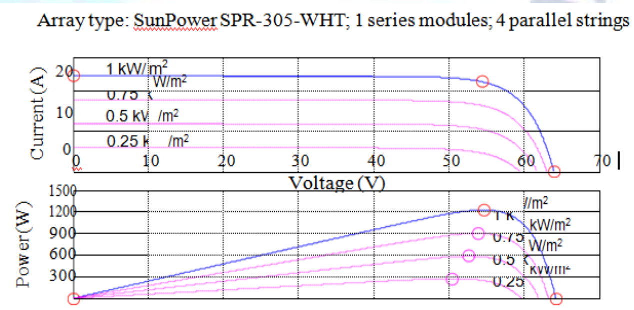


Figure.3. 1.2 kW SPR-305-WHT Model P-V and I-V Characteristics

Table 1. Specifications of SunPower SPR-305-WHT 1.2 kW PV Module

Parameter Description	Rating
Maximum power (P_{MP})	1.2 k W
Maximum current (I_{MP})	5.58 A
Maximum voltage (V_{MP})	54.7 V
Short circuit current (I_{SC})	5.96 A
Temperature (T)	25^0 C
Open circuit voltage (V_{oc})	64.2 V
Number of cells per module	96

Parallel strings	4
Series-connected modules per string	1
Series resistance (R_s)	0.037998
Parallel resistance(R_p)	993.51
Solar irradiation (G)	1000 W/m^2

2.2.BoostConverter

In order to extract maximum power from the high penetrating renewable PV source and to step-up the low voltage renewable energy source voltage to required level voltage tomeettheloaddemand,ahighstep-upDC-DCconverterisrequired.Inthissection,aboost converter is developed to achieve the proposed target in the solar powered water pumping system.

The double boost DC-DC converter is the combination of conventional boost and the switched capacitor. The double output voltage is achieved by this double boost converter without operating it in extreme duty cycle [19].

The schematic diagram of the double boost converter is shown in Fig. 4. It consists of a single switch (S), a single inductor (L), three capacitors (C1, C2, and C3) and three diodes (D1, D2 and D3) as the circuit arrangement is shown in the schematic diagram. The voltage transfer gain of the double boost converter is given in Eq. 1.

Voltage Transfer Gain, M = $V_0/V_s = 2/(1-D)$

It operates in two modes based on switch (S) condition in charging and discharging mode of the inductor (L) as explained in the following subsections.

Mode-I: Switch (S) is ON

Mode-I is a discharging mode, in this mode, an inductor (L) is charged by the supply voltage (VS) through a switch (S) and capacitor (C2) is charged by a capacitor (C1) through the diode (D2) and switch (S) as shown in the Fig. 6. In this mode capacitors (C1 and C3) are in discharging mode through the load. The current flow diagram of Mode-I is shown in Figure 5.

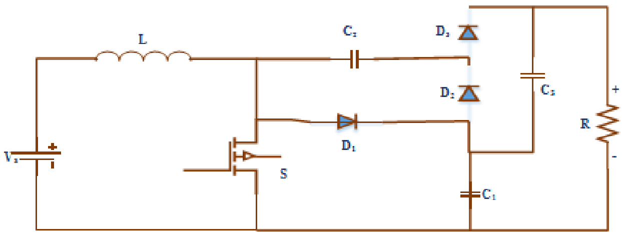


Figure.4. Schematic diagram of Boost Converter

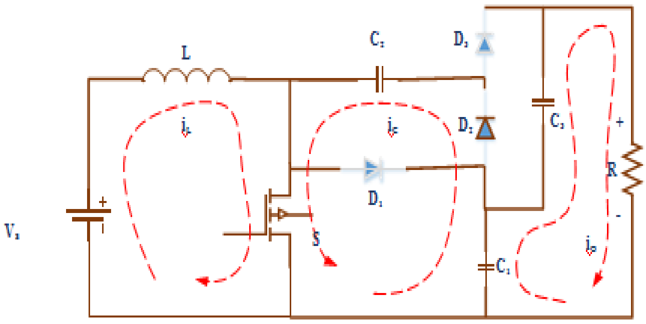


Figure.5. Mode-1: ON state, Boost Converter

Mode-II: Switch (S) is OFF

Mode-II is a charging mode, in this mode, the capacitor (C1) is in charging mode, through supply voltage (VS), inductor voltage (VL) and diode (D1). The capacitors (C1 and C3) are in charging mode through supply voltage (VS), a capacitor (C2) and diode (D3). The current flow diagram of Mode-II is shown in Figure6. (1)

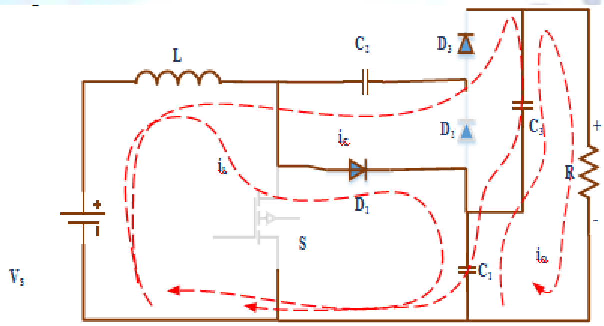


Figure.6. Mode-2: OFF state, Boost Converter

The above section gives the detailed operation of the developed single switch double boost DC-DC power converter in both ON and OFF switching conditions and twice the voltage transfer gain is achieved for step-up the low voltage renewable energy sources to the desired level to m0031 eet the load demand and to extract maximum power from the renewable energy sources.

III. Proposed PV Fed Water Pumping SystemControl

3.1 Grid Interfaced Solar PV Fed VSI-BLDC Motor Drive for Water Pumping

The aim is to design a rugged and low-cost drive, supplied by a battery, using a BLDC motor. In Fig. 7, The most popular drive for a BLDC motor is the topology supplied by a Voltage Source Inverter [3, 4], illustrated in Fig. 16 and the control part is shown below the inverter and the motor. The main components of a VSI are the six transistor switches and an antiparallel diode across each switch to maintain the current continuity. It consists of an inner current loop — three current sensors, *Ia*,*Ib*and *Ic*, and compared constantly with the reference currents **Ia*, * *Ib*and * *Ic*(obtained from the speed control) by means of hysteresis Schmitt Trigger. The speed is controlled by means of an outer speed loop that generates a speed error from the difference between the desired speed and the speed measured from Hall position sensor outputs using a PI regulator.

The position of the rotor shaft field is sensed by means of Hall position sensors, thus synchronizing the back-emf and the respective phase currents, and a rectangular 120° current waveform is supplied to each of the phases of the BLDC motor. The current profile is maintained by means of PWM switching of the VSI switches. Since a VSI needs sufficient deadband between the turning-off of a switch and theturning-on of the complementary switch in the same inverter leg, this topology may suffer from a fatal short circuit in any of the inverter legs. Also, in order for the current to follow a rectangular profile, high switching frequency has to be used. If the switching frequency is high, the anti-parallel reverse recovery diodes have to be of the fast-recovery type.Thedisadvantages are obviously, the switching losses in the inverter switches. In order to reduce the switching stresses, particularly at turn-off, snubbers(consisting of capacitors,diodes and resistors to reduce the voltage spikes due to the inductive elements in the circuit) have to be used across the power switches. These switching losses entail the use of heatsinks for dissipating the power generated in the hard switchings [5]. A high switching frequency also gives rise to undesirable high frequency electromagnetic noise that may require to be suppressed. The VSI inverter uses IGBTs and requires a heatsink. A thyristorizeddrive is the obvious choice for ruggedness and lack of heatsinks.

It is very pertinent to note that the dc supply be relatively constant, else a larger size ofthe dc link inductor would be required, thus degrading the response of the system.The schematic of the grid interactive PV array based water pumping system using a VSI-BLDC motor drive is given in previous section.

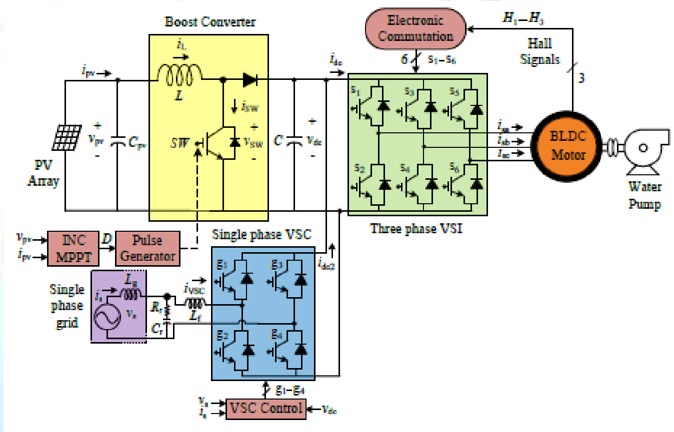


Figure 7.Schematic of the grid interactive PV array based water pumping system using a VSI-BLDC motor drive

3.2.Hall Effect Controller forVSI

In BLDC motor, electronic commutation is generally used for commutating the current flow through the windings. In order to energize the next winding sequence, Hall Effect signals are used, which are generated by the inbuilt encoder by sensing the rotor position. Based on the sensed rotor position three hall signals will be generated and used for the six switch VSI control. Table 2. show the electronic commutation of BLDC motor switch states at different rotor positions with hall signals.

Table 2. BLDC motor Hall Signals for Electronic Commutation

Degree, θ	Hall sensor signals			Switching states					
	H1	H2	H3	S1	S2	S3	S4	S5	S6
NA	-	-	-	-	-	-	-	-	-
0-60	-	-	*	-	-	-	*	*	-
60-120	-	*	-	-	*	*	-	-	-
120-180	-	*	*	-	*	-	-	*	-

180-240	*	-	-	*	-	-	-	-	*
240-300	*	-	*	*	-	-	*	-	-
300-360	*	*	-	-	-	*	-	-	*
NA	*	*	*	-	-	-	-	-	-
Where,	NA= Not Applicable			* = 1			- = 0		

3.3. Grid Interfaced Solar PV Fed CSI-BLDC Motor Drive for Water Pumping

The CSI drives the BLDC motor Drive by supplying it with a three-phase rectangular waveform. The schematic of the grid interactive PV array based water pumping system using a CSI-BLDC motor drive is shown in fig(8).The size of the dc link inductor is determined by the difference in voltage across the inductor, that is, the maximum difference between the motor back-emf and theinput supply voltage. The controlled rectifier could be either a three-phase rectifier or a single-phase rectifier [32]. Since the voltage ripple in a three-phase rectifier arrangement is lower than that of a single-phase rectifier arrangement, for a given BLDC motor and load, the value of the three-phase dc link inductor is less than the value of a single-phase dc link inductor.

If the phase current leads the phase back-emf, natural commutation of power switch cantake place This is essential for CSI, since the next power switch has to be gated a few degrees before it is supposed to be switched on, else it may not have sufficient time to turn on and the desired switching state may not be achieved. Since no heatsink is required for power switch, the cost and weight of the inverter is reduced substantially. The main advantage of this topology is that the switching losses are kept to minimum. In this system also, the Hall effect controller is used with same specifications is as shown in Table 2.

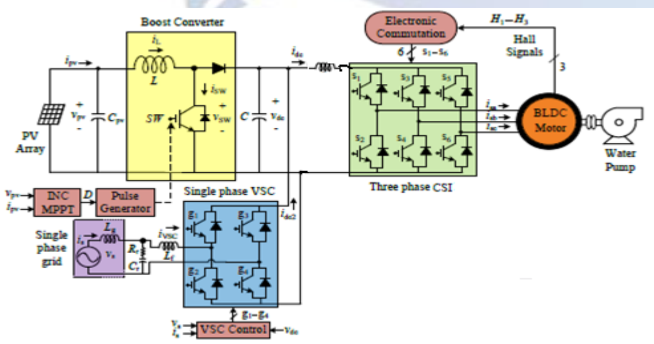


Figure 8. Schematic of the grid interactive PV array based water pumping system using a CSI-BLDC motor drive

IV. SIMULATION RESULT ANDDISCUSSION

To validate the proposed Grid interactive PV source fed VSI-BLDCwater pump system with boost converter topology and PV source fed CSI-BLDCwater pump system a MATLAB/Simulink model is developed and performance analysis is carried out in simulation by considering the constant solar irradiation data without any shading effect on it.Figure 10 shows the 1.2 kW PV system output voltage, current and power waveform.The PV system output voltage is 54V and power is 1200W.The SIMULINK diagram of proposed model is shown in figure(9)

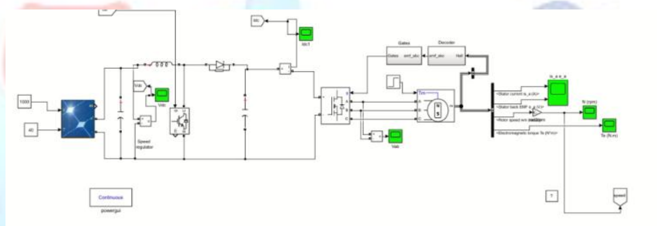


Figure 9. SIMULINK diagram of proposed PV Tied BLDC Motor Drive

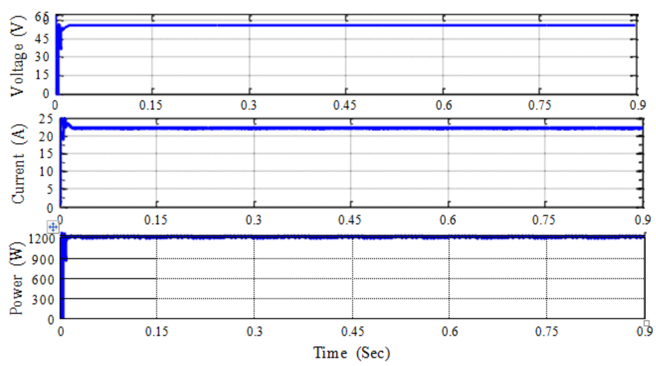


Figure 10. 1.2 kW PV System Output Voltage, Current and Power Waveforms

Figure 11 shows the stator back EMF of 240.6V and current of 0.32A. The Hall Effect signals for the electronic commutation in the voltage source inverter are shown in Figure12.

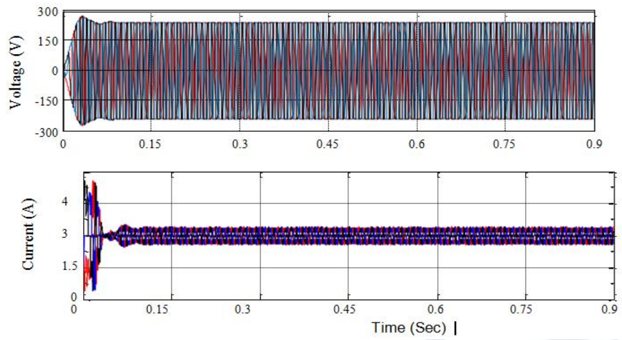


Figure 11. Stator Back EMF and Current Waveform of BLDC motor

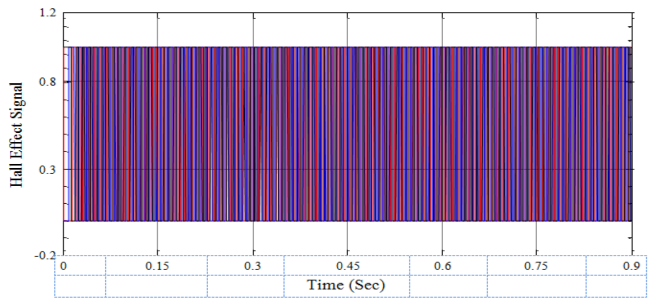
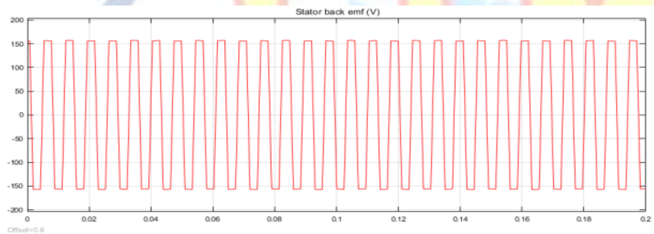
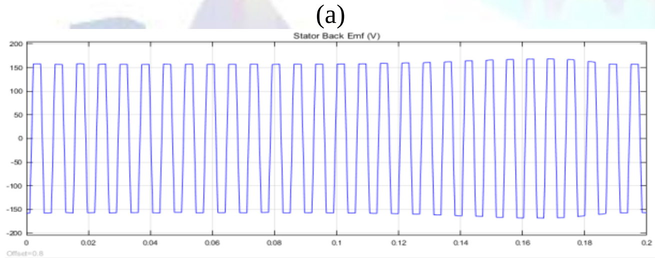


Figure 12. Hall Effect Signal of BLDC motor

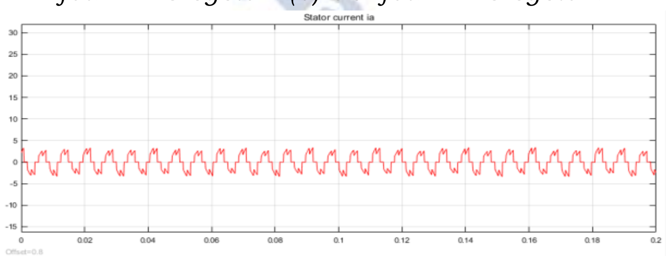


(a)

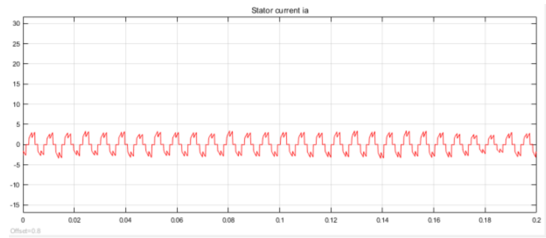


(b)

Figure 13. Stator Back EMF of BLDC Motor (a) VSI fed BLDC system (b) CSI fed BLDC system

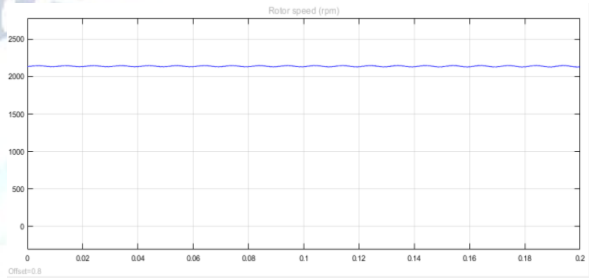


(a)

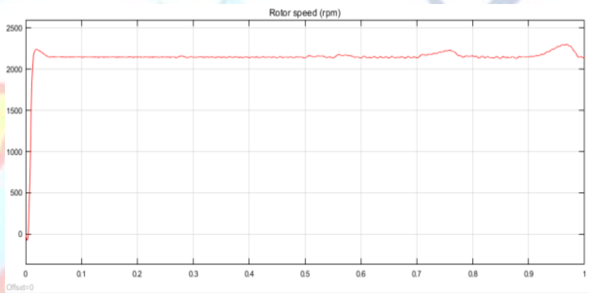


(b)

Figure 14. Stator current of BLDC Motor (a)VSI fed BLDC system (b) CSI fed BLDC system



(a)



(b)

Figure 15. BLDC Motor Speed in RPM (a) VSI fed BLDC system (b) CSI fed BLDC system

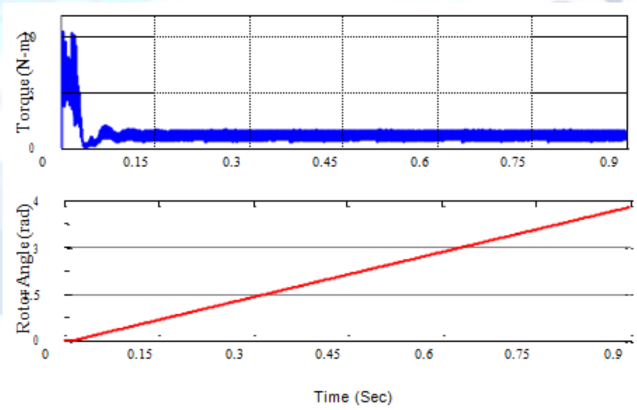


Figure 16. Torque and Rotor Angle of BLDC motor for Water Pump Application

Figure 13. Presents the Stator back emf of BLDC motor , when two topologies applied. Figure 15 gives the BLDC motor speed in RPM and rad/sec and the BLDC torque and rotor angle of the system is shown in Figure 16. From the performance analysis done in MATLAB/Simulink, PV fed BLDC motor different performance characteristics are presented in the simulation and result in the

analysis section. The DC link voltage, current, and power values are tabulated with different MPPTtechniques.

Table 3. Performance Comparison of VSI-BLDC and CSI-BLDC sytems

Stator Back Emf(V) ,Stator Current (Ia)and speed comparison				
	Stator Back Emf(V)	Stator Current (Ia)	Speed(rpm)	Settling time(sec)
VSI-BLDC system	150	4	2200	0.001
CSI-BLDC system	150	4	2200	0.003

As illustrated in Table 3, the obtained performance of control techniques. From the comparison, the speed settling time of the proposed PV fed VSI fed water pumping system with boost DC-DC converter and CSI fed water pumping system performances in satisfactory range.

V. Conclusion

In this paper, PV source fed BLDC motor with boost converter is designed and performance analysis has been done in MATLAB/ Simulink model. In boost converter max. voltage gain is obtained by operating at its maximum duty cycle with high switching stress, this stress can be reduced by using a double boost converter. A water pump system with PV fed BLDC motor performance has been analyzed and discussed in this paper. In order to extract maximum power from the PV source, MPPT controller is used and the obtained results are compared with the most commonly used P&O MPPT method. From thedeveloped system simulation analysis, water pump system with Grid interactive PV fed BLDC motor with VSI &CSI topologies gives the better results. The Performance comparisons are also given in detail. The reference speed (2200 rpm) reaches in very tiny time in both techniques and they were shown satisfactory performance.

APPENDIX

Parameters of Solar Array

Peak power = 1.2 kW; Open circuit voltage = 254.8 V; MPP voltage = 200 V; Short circuit current = 8.15 A; MPP current = 7.5 A.

Specifications of Motor

Poles = 4; Speed = 2200 rpm; Stator resistance = 3.58 Ω; Stator inductance = 9.13 mH; Voltage constant = 68 V/krpm.

Grid Interfacing Components

Interfacing inductor = 3.3 mH; R-C filter = 5 Ω, 5 µF; DC bus capacitor = 4700 µF.

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