iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 Issue: III Month of publication: March 2019

DOI: http://doi.org/10.22214/ijraset.2019.3137

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue III, Mar 2019- Available at www.ijraset.com

Solar Powered BLDC Motor with HCC Fed Water Pumping System for Irrigation

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Abstract: This project deals with the cost-effective BLDC motor drive powered from solar photovoltaic system with HCC fed water pumping system for irrigation. BLDC motor is preferred over other brush-based motors for its unique features like high efficiency, high torque and simple structure with low noise. As solar power is abundant and available at any place so the solar photovoltaic (SPV) array system is considered as the source. The modified incremental conductance maximum power point technique (MPPT) is used because of its advantage of providing soft starting to BLDC motor. To extract maximum available power from SPV array a buck-boost converter is used. By using conventional control strategies torque ripples are present, by introducing Hysteresis Current Control (HCC) torque ripple can be minimised. The main objective of this paper is to minimize the torque ripples occurring in BLDC motor drive using Hysteresis Current Control, which is simulated using MATLAB/SIMULINK platform.

KEYWORDS: Solar Photo Voltaic Array, BLDC Motor, Buck-Boost DC-DC Converter, Voltage source inverter, Hysteresis Current Controller.

I. INTRODUCTION

The energy demand of the world is ever growing. The increasing energy demands put a compression on the conventional energy sources like oil, gas and coal. The usage of fossil fuels also has an environmental effect; it is the main reason of weather change due to their polluting effects. The energy consumption is employed by a release of carbon oxide (CO_2) into the atmosphere and it gives for more than of 60% of the worldwide CO_2 emitted in the atmosphere each and every year. The energy sources on the basis of fossil fuel, are however limited in extent. They are hence equally as much the prompting factors of the pollution of the environment, ensuring the limited extent of the sources of energy such as fossil fuel. The rise in global demand for energy consumption with the polluted environment concern due to fossil fuels has motive factor for scientists to search for environmental friendly sources of energy. Excessive dependence on oil, unsteady energy prices, adverse of air quality, high level of financial risk and uncertainty are other factors, frightening the use of conventional energy sources.[3] Apart from early mentioned citations of fundamental limitations encasing fossil fuel, ecological considerations in the manner of the greenhouse gases and global warming are the variant prominent forces associated with the promotion of renewable energy sources. Therefore, the use of renewable energy is a very attractive like solar photovoltaic systems and wind energy conversion systems in the rural areas of many developing countries. Standalone applications of PV energy are quite predominant. PV electricity has the maximum applicable utilities in areas like water pumping, domestic appliances, fans, enhancing usage of electricity in rural locations where the unavailability of grid connection, air conditioning, etc. is yet to be implemented.[3] However, in many poor, arid and rural areas is placed too far away from the existing grid lines. As the installation of new transformers, long transmission lines and other protection devices is very expensive. Solar PV system was installed at those places.[11] Photovoltaic energy has gaining popularity and a lot of focuses in recent years because it is an environment friendly energy source and sustainable compared to conventional energy sources.

BLDC motor is a synchronous motor with permanent magnets on the rotor and armature windings on the stator. Brushless DC (BLDC) motors are widely used in many industrial, aerospace applications and domestic appliances due to their high efficiency, excellent control accuracy and high torque to weight ratio. BLDC motor is like a DC motor turned inside out, so that the field is on the rotor and the armature is on the stator. The Brushless DC motor is basically a permanent magnet AC motor whose torque-current characteristics are similar to the DC motor. The electronic commutation system is used instead of commutating the armature current using brushes and mechanical commutator. Because of their brushless nature, the problems associated with the brush and the commutator arrangement like sparking and wearing out of the commutator-brush arrangement are removed. Due to the simplified structure, BLDC motors are more rugged than a DC motor and suitable for industrial environment. Having the armature on the stator makes the cooling of windings easy.[8] The winding of BLDC motor is much easier as compared to a conventional DC motor and Induction motor. Moreover it is very much possible to control the speed and the angle of motion of the rotor or both very accurately and precisely. Further, BLDC motor is compatible with the digital control systems and the motor characteristics can be controlled by digital systems.

The existing literature exploring Solar PV array based BLDC motor using buck-boost converter. For MPPT of a Solar PV array buck-boost DC-DC converter is used in the proposed system.[11] Three phase currents are sensed along with Hall signals feedback for control of BLDC motor, resulting in an increased cost. The additional control scheme causes increased cost and complexity, which is required to control the speed of BLDC motor. Moreover, usually a VSI is operated with high-frequency Pulse Width Modulation (PWM) pulses, resulting in increased switching loss and hence the reduced efficiency.

A DC–DC buck–boost converter is utilised to draw the maximum power available from the Solar PV array.[5] And the additional functions of buck–boost converter is soft starting and speed control of the BLDC motor, by applying the MPPT algorithm appropriately. Owing to the single switch and least number of reactive components, this converter possesses very good conversion efficiency and offers boundless region for MPPT.[1] This converter is worked in continuous conduction mode (CCM) so that stress will be reduced on its power devices and its components. Moreover, the switching loss of VSI is reduced by using fundamental frequency switching having extra power saving and improved efficiency resulting.[4] The current sensors as well as the dc-link voltage sensors are eliminated which makes system simple and economical without disturbing its performance.[6] BLDC motor speed is controlled through variable DC-link voltage without any external control. However, by proper initialization of MPPT algorithm of Solar PV array smooth starting of BLDC motor is obtained.

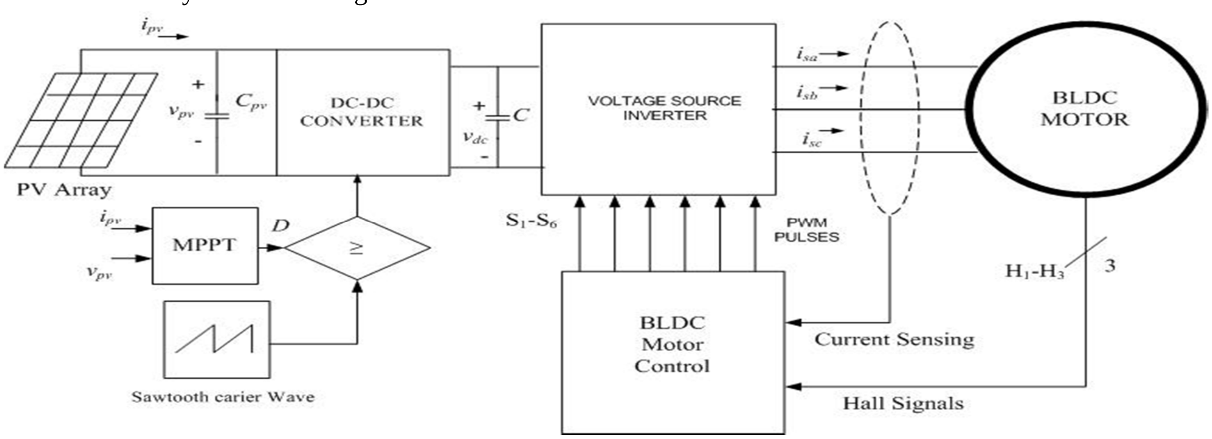


Fig. 1 Conventional Configuration of the Solar PV array fed BLDC motor.

II. CONFIGURATION OF PROPOSED SYSTEM & OPERATION

The configuration of the proposed Solar PV based buck–boost converter fed BLDC motor drive is shown in Fig.2.

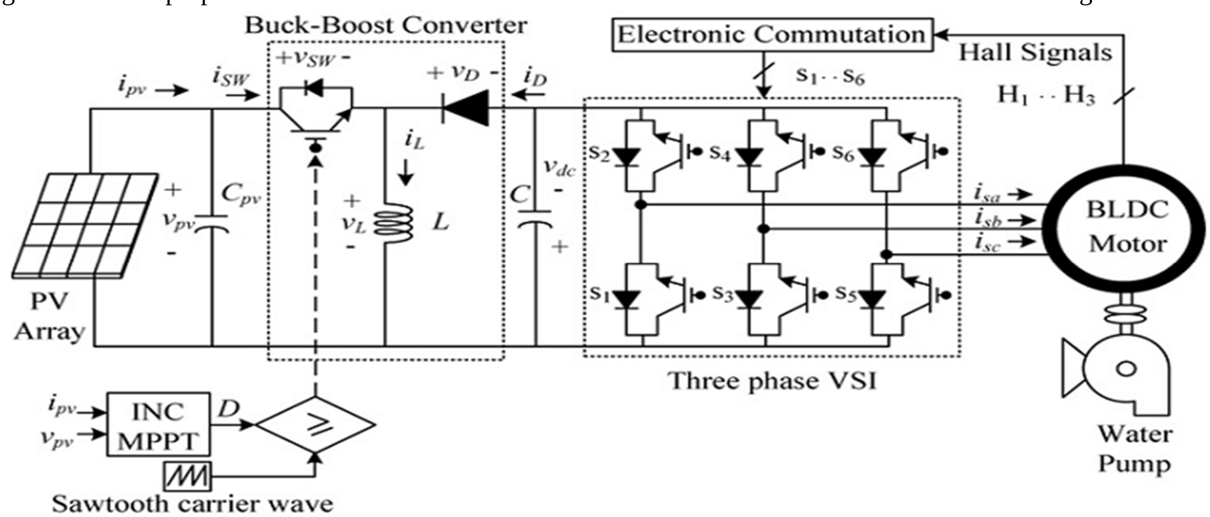


Fig. 2 Proposed Configuration of the Solar PV array fed BLDC motor

The system consists of a Solar PV array, a buck–boost DC–DC converter, a VSI, a BLDC motor. As shown in Fig.2, the Solar PV array generates the electrical energy and feeds the DC–DC buck–boost converter. The insulated gate bipolar transistor (IGBT) switch of the buck–boost converter is operated through modified incremental conductance (INC) MPPT algorithm such that the operation of the Solar PV array is optimized and the BLDC motor has the soft starting. To reduce the stress on the components and semiconductor devices buck–boost converter is operated in CCM. Furthermore, the buck– boost converter feeds power to the VSI, supplying the BLDC motor. Switching sequence for the VSI is provided by the electronic commutation of BLDC motor. An electronic commutation is a process of decoding the Hall Effect signals generated by the inbuilt encoder of the motor according to position of the rotor. The design and control of the proposed system are explained in the following sections.

III. DESIGN OF THE PROPOSED SYSTEM

The stages present in the proposed concept are shown in Fig. 2 such as the Solar PV array, the Buck–Boost converter, Halls Sensors are designed such that a satisfactory operation is always accomplished under any kind of change in solar isolation level. A BLDC motor of 0.6 KW rated power is selected and each stage of the proposed system are designed accordingly, as follows.

A. Design of Solar PV array

A Solar PV array of 0.7 KW peak power capacity is required by the BLDC motor. The BLDC motor is selected so that the performance of the system will not affected by the losses associated with the both converters and BLDC motor[19]. The parameters of the Solar PV array are estimated at the standard solar isolation level of 1000 W/m2. A PV module AP-100, manufactured by Astropower Inc. with peak power of 100 W, maximum voltage of 16.1 V and maximum current of 2.4 A is considered to design an Solar PV array of required capacity. First of all, the voltage of the Solar PV array at MPP is selected in view of the DC voltage rating of the BLDC motor same as DC-link voltage of the VSI. Selecting this voltage as V_{mpp} = v_{pv}= 300 V, the other parameters are estimated as:

The current at MPP

$$I_{mpp} = i_{pv} = \frac{p_{pv}}{v_{pv}} = 700/300 = 2.4\text{A} \tag{1}$$

Where p_{pv} = P_{mpp} = 700 W is the peak power capacity.

Numbers of modules connected in series are as

$$N_s = \frac{V_{mpp}}{V_m} = 300/16.1 = 19 \tag{2}$$

Numbers of modules connected in parallel are as

$$N_p = \frac{I_{mpp}}{I_m} = 2.4/2.4 = 1 \tag{3}$$

where V_m and I_m are voltage and current of a module at MPP.

B. Design of Buck–Boost Converter

The Solar PV array voltage at MPP, v_{pv} = V_{mpp} = 300 V appears as the input voltage source, whereas DC-link voltage of VSI, v_{dc} appears as the output voltage of the buck–boost converter. The duty ratio, D of buck–boost converter is estimated, using the input–output relationship as

$$D = \frac{V_{dc}}{V_{dc}+V_{pv}} = \frac{310}{310+300} = 0.51 \tag{4}$$

where V_{dc} = 310 V is rated DC-link voltage of VSI on the other hand, neglecting the buck–boost converter losses, an average current flowing through DC link, I_{dc} is as

$$I_{dc} = \frac{P_{mpp}}{V_{dc}} = 700/310 = 2.26\text{A} \tag{5}$$

An addition of the two currents, i_{pv} and I_{dc} flow through the inductor, L. The inductor, L is estimated as

$$L = \frac{D \times v_{pv}}{f_{sw}\Delta I_L} = \frac{0.51 \times 300}{10000\times 11\times 0.4} = 3.4\text{mH} \tag{6}$$

Where f_{sw} is the switching frequency of the buck–boost converter and ΔI_L is an amount of ripple permitted in the inductor current.

The highest and lowest frequencies of the VSI output voltage are considered to estimate the DC-link capacitor, C. The highest value of VSI output voltage frequency, ω_h(in rad/s) is calculated corresponding to the rated speed of the motor (N_{rated} = 3000 rpm) while the lowest value of VSI output voltage frequency, ω_l (in rad/ s) is calculated corresponding to the minimum speed of a motor required to pump the water (N = 1100 rpm) as

$$\omega_h = 2\pi f = 2\pi \frac{N_{rated}P}{120} = 2\pi \times \frac{3000 \times 4}{120} = 628.3\ rad/s \quad (7)$$

$$\omega_l = 2\pi f = 2\pi \frac{NP}{120} = 2\pi \times \frac{1100 \times 4}{120} = 230.38\ rad/s \quad (8)$$

Where f is the frequency of VSI output voltage in hertz, N_{rated} is rated speed of the BLDC motor and P is the numbers of poles. Since sixth harmonic component of VSI output voltage appears on DC link of VSI, limiting the voltage ripple, ΔV_{dc} in vdc to 1%, the DC-link capacitor, C is estimated corresponding to ω_h and ω_l as

$$C_{\omega_h} = \frac{I_{dc}}{6 \times \omega_h \times \Delta V_{dc}} = \frac{4.8}{6 \times 628.3 \times 310 \times 0.01} = 410.7\ \mu F \quad (9)$$

$$C_{\omega_l} = \frac{I_{dc}}{6 \times \omega_l \times \Delta V_{dc}} = \frac{4.8}{6 \times 230.38 \times 310 \times 0.01} = 1120\ \mu F \quad (10)$$

As per the estimation in, to ensure the satisfactory performance of the BLDC motor, somewhat a higher value of C = 1500 μF is selected.

IV. CONTROL OF THE PROPOSED SYSTEM

The solar PV array system is controlled by Maximum power point tracking (MPPT) and electronic commutation of BLDC motor. These are explained in the below sections.

A. *Maximum Power Point Tracking*

The MPPT technique is mostly used to optimise the utilization of Solar PV array. An INC type of MPPT technique is used here because of its high precision of tracking even under rapid changes in the atmospheric conditions. The perturbation size is wisely selected such that the oscillation around the peak power point is avoided and the soft starting of the BLDC motor is ensured under all the possible variations in the solar isolation level. A low perturbation size is selected (0.001) to control the tracking speed[18]. To achieve the soft starting of motor, the output voltage of buck– boost converter is controlled at starting by initialising the duty ratio as zero. Therefore, as the operating power point of Solar PV array moves towards MPP, the DC-link voltage of VSI increases with controlled rate. This results in a reduced rate of rise of stator current, ensuring a soft starting.

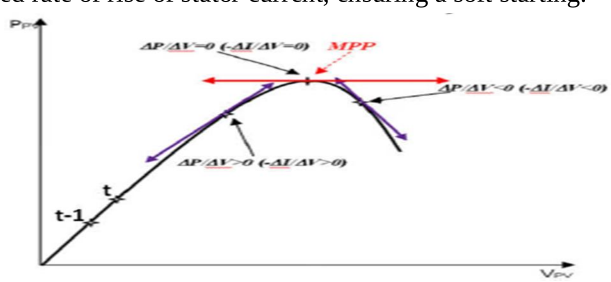


Fig.3 Illustration of modified INC-MPPT with Solar PV array P_{pv}–V_{pv} characteristics

B. *Electronic Commutation*

In VSI, electronic commutation mechanism is used to generate the switching pulses to the semiconductor devices. Three Hall Effect signals are given by the encoder with respect to the angular position of rotor of the motor[14]. The output of Hall sensors are logically converted as switching pulses and given to the semiconductor switching devices of VSI, as shown in table-1.

Θ,deg	Hall Signals			Switching States					
	H_3	H_2	H_1	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0-60	1	0	1	1	0	0	1	0	0
60-120	0	0	1	1	0	0	0	0	1
120-180	0	1	1	0	0	1	0	0	1
180-240	0	1	0	0	1	1	0	0	0
240-300	1	1	0	0	1	0	0	1	0
300-360	1	0	0	0	0	0	1	1	0
NA	1	1	1	0	0	0	0	0	0

TABLE 1 Switching states for electronic commutation of BLDC motor

V. HYSTERESIS CURRENT CONTROL OF BLDC MOTOR

In the sensored BLDC drive, to obtain the rotor position information hall sensors are used. The drive control system consists of an outer speed loop for speed control and an inner current loop for current control[18]. Three separate current sensors are used to measure the phase currents.

The torque ripple harmonics will be reduced in BLDC motor using current waveforms. Hysteresis current control strategy produces accurate torque in BLDC motor with reduced torque ripples[2]. Torque ripple in BLDC motor by non-ideal current waveform is minimized by using phase current sensors with help of feedback controllers.

VI. MATLAB/SIMULATION RESULTS

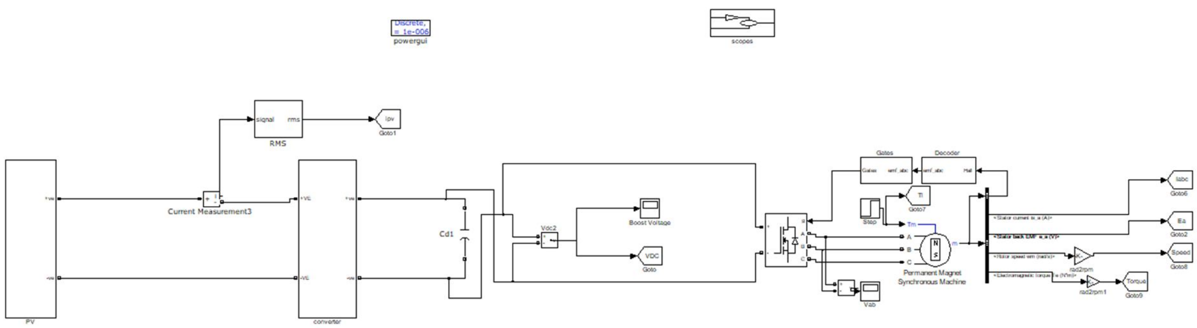
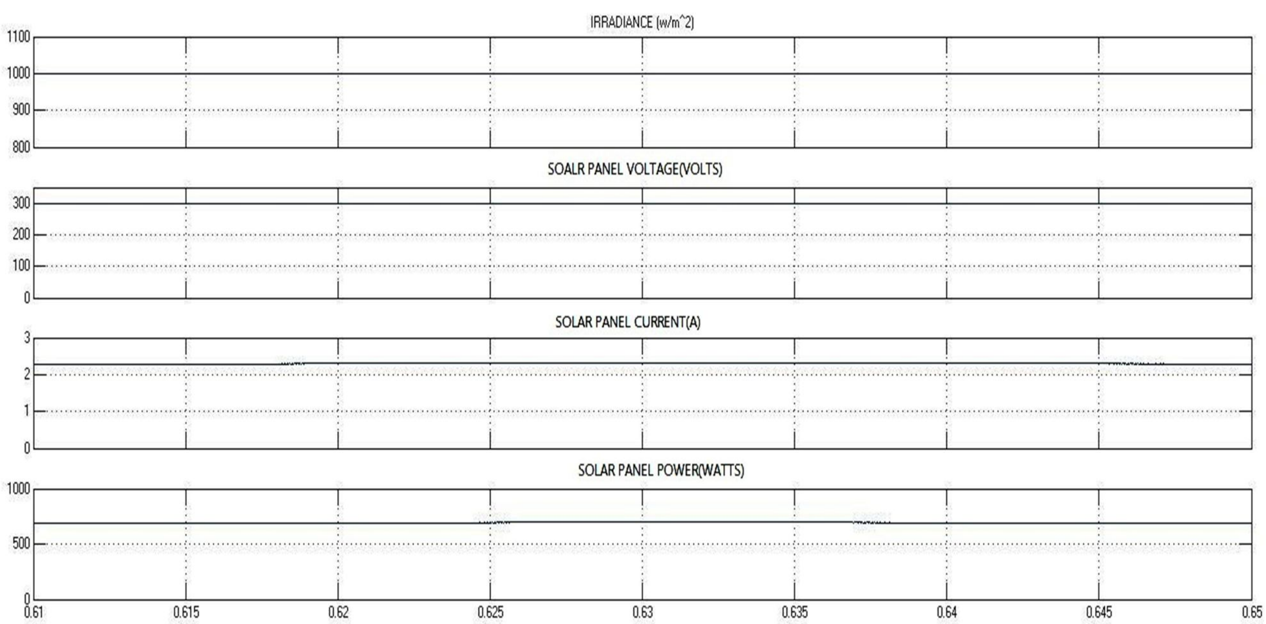


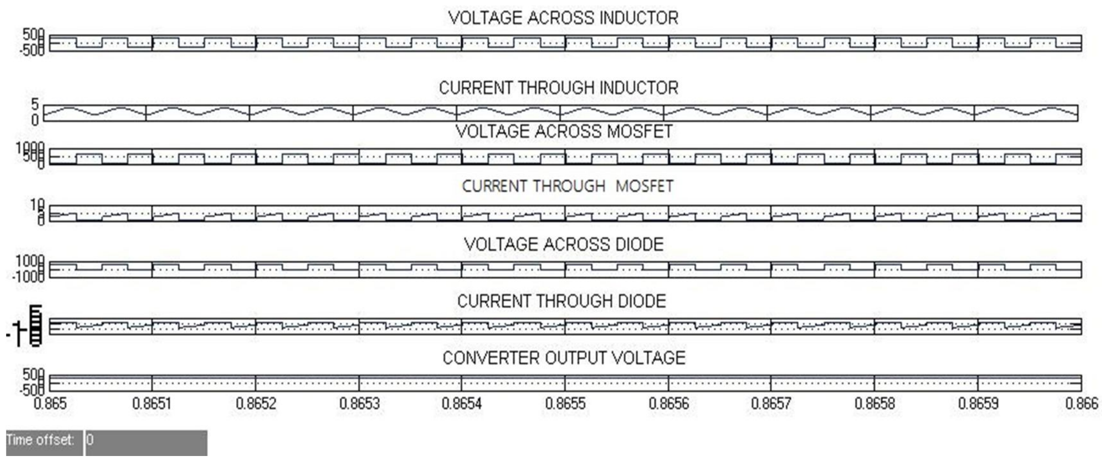
Fig. 4 Matlab/Simulink circuit of Starting and steady-state performances of the proposed Solar PV array based Buck-Boost converter-fed BLDC motor drive

The steady–state performance of Solar PV array using buck–boost converter fed VSI-BLDC motor is simulated using the Sim-power-system toolbox in the MATLAB/Simulink platform. The fig.4 circuits show the Performance of Solar PV array using buck–boost converter fed VSI-BLDC motor at 1000 W/m^2.[12] The starting and steady state performances are observed using the simulated results as shown in Figs. 5. By verifying the results the performance of the proposed system are satisfactory even under different variations in weather.



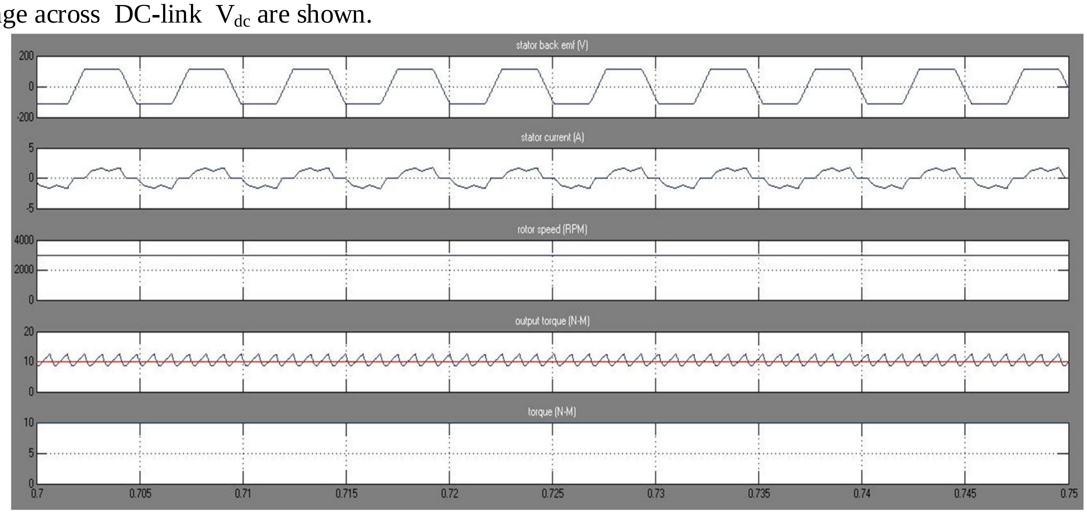
(a)

By applying modified INC-MPPT technique at 1000 W/m^2 we have good tracking performance are verified as shown in Fig. 5a.



(b)

Fig. 5b shows the steady-state performance of buck–boost converter at 1000 W/m^2. The voltage across inductor V_L, current through inductor I_L, voltage stress on the IGBT switch V_{SW}, current stress on the IGBT switch I_{SW}, blocking voltage of the diode V_D, diode current I_D voltage across DC-link V_{dc} are shown.



(c)

Fig. 5c shows the starting and steady-state behaviours of the BLDC motor at 1000 W/m^2. All the BLDC motor indices such as the back EMF e_a, the stator current I_a, the speed N, the electromagnetic torque developed T_e and the load torque T_L are shown in Fig. 5c.

Fig.5 Starting and steady-state performances of the proposed Solar PV array based buck-boost converter-fed BLDC motor drive. (a) Solar PV array variables. (b) Buck-Boost converter variables. (c) BLDC motor variables.

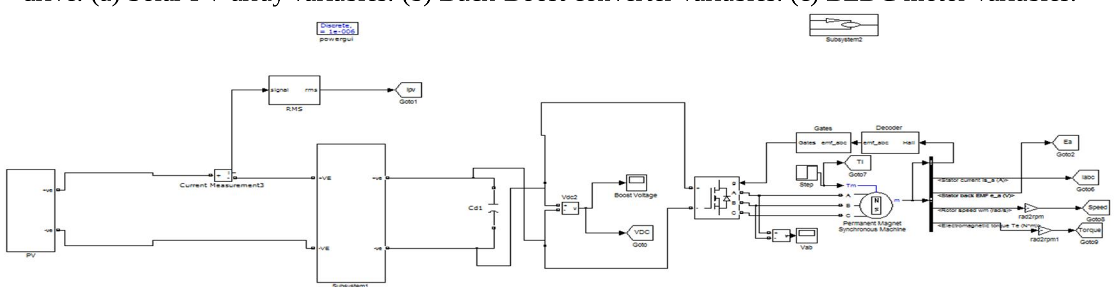
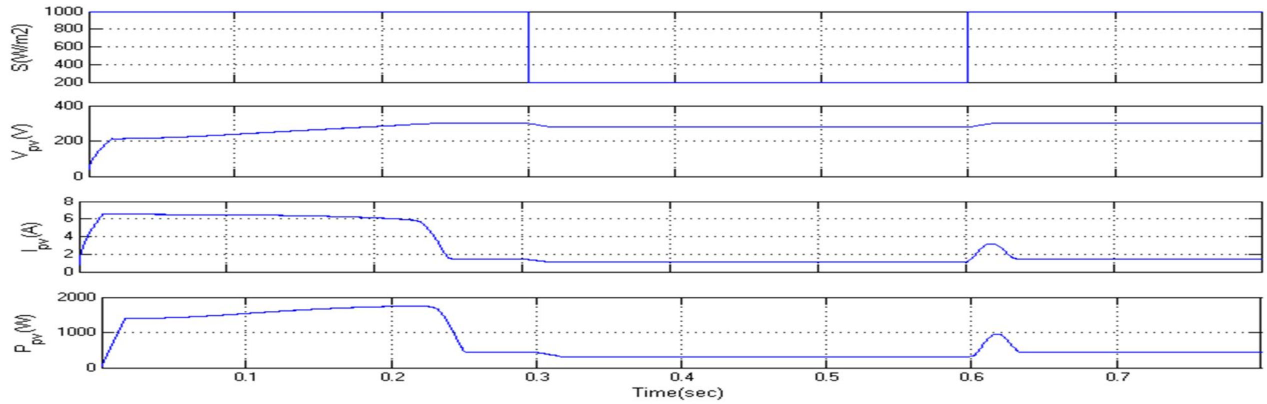
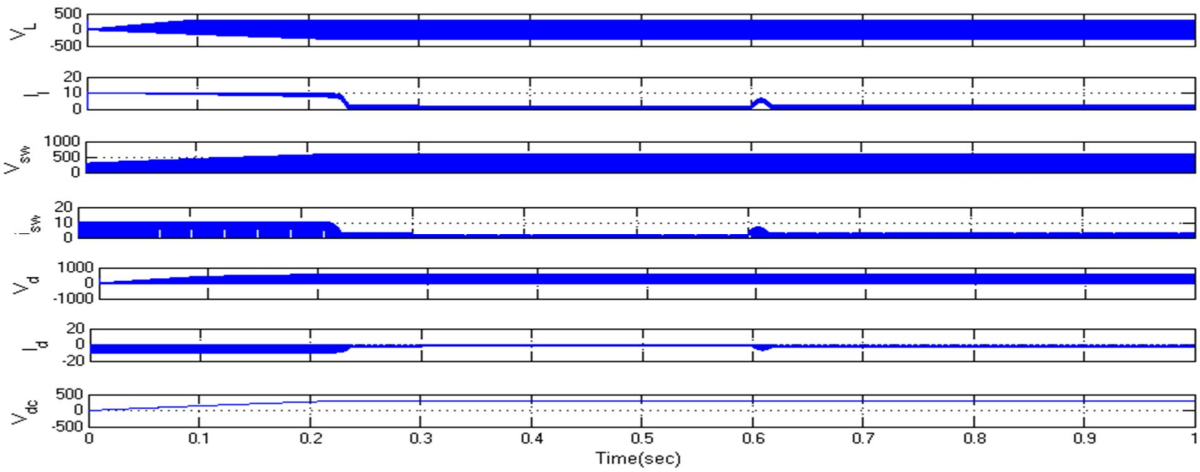


Fig.6 Matlab/Simulink circuit for Dynamic performance of Solar PV array based Buck-Boost converter-fed BLDC motor drive



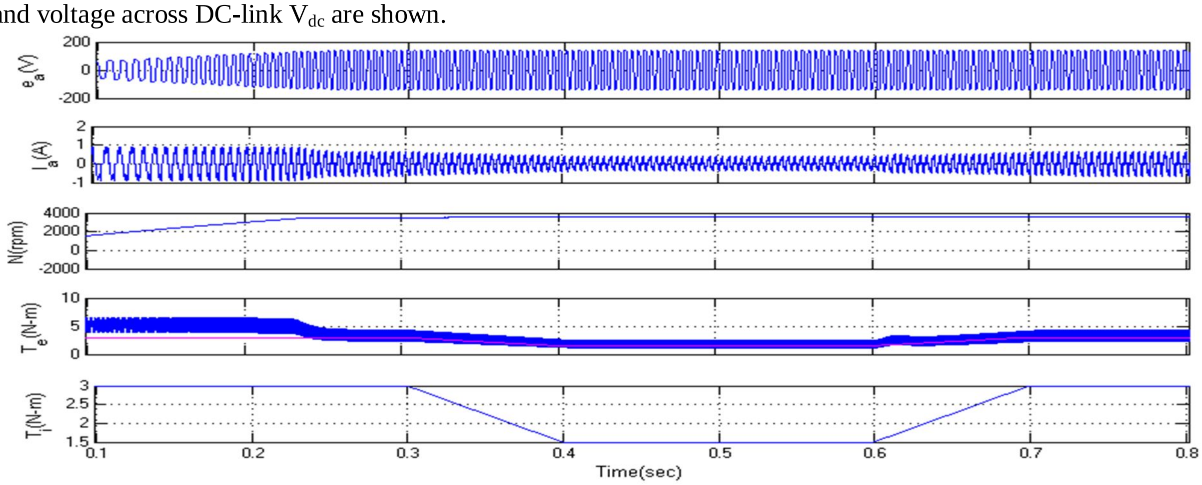
(a)

To observe the dynamic performance of the solar PV array system, the solar insolation level is varied from 1000 to 200 W/m^2 and vice versa. The dynamic state performances are observed using the simulated results as shown in Fig. 7a.



(b)

Fig. 7b shows the dynamic performance of buck–boost converter. The voltage across the inductor V_L, current through inductor I_L, voltage stress on the IGBT switch V_{SW}, current stress on the IGBT switch I_{SW}, blocking diode voltage V_D, diode current I_D, duty cycle, D and voltage across DC-link V_{dc} are shown.



(c)

Fig.7 Dynamic performances of the proposed Solar PV array based Buck-Boost converter-fed BLDC motor drive. (a) Solar PV array variables. (b) Buck-Boost converter variables. (c) BLDC motor variables.

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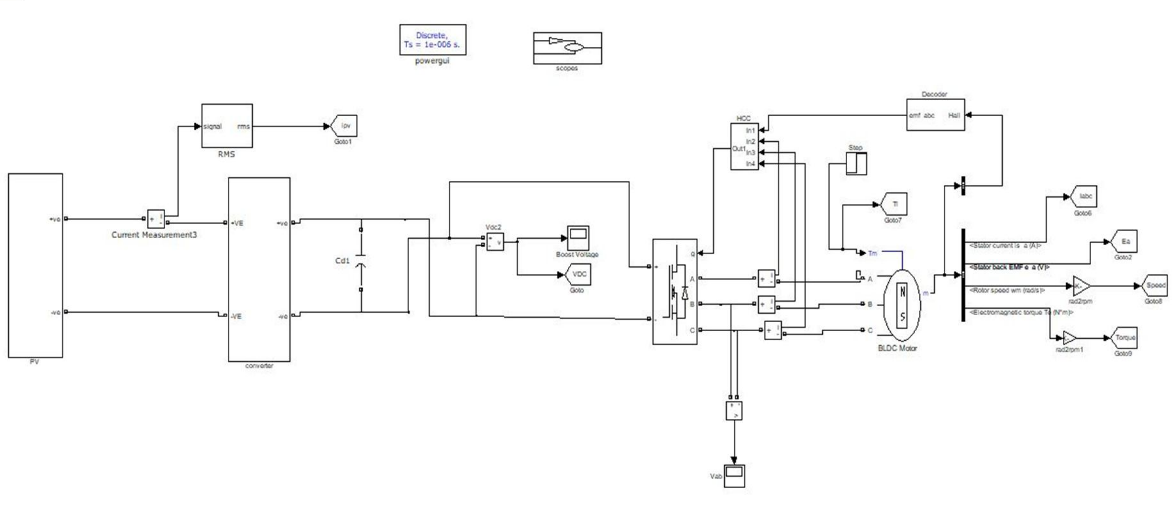

Fig.8 Matlab/Simulink circuit of Solar PV array based Buck-Boost converter-fed BLDC motor drive using hysteresis current control

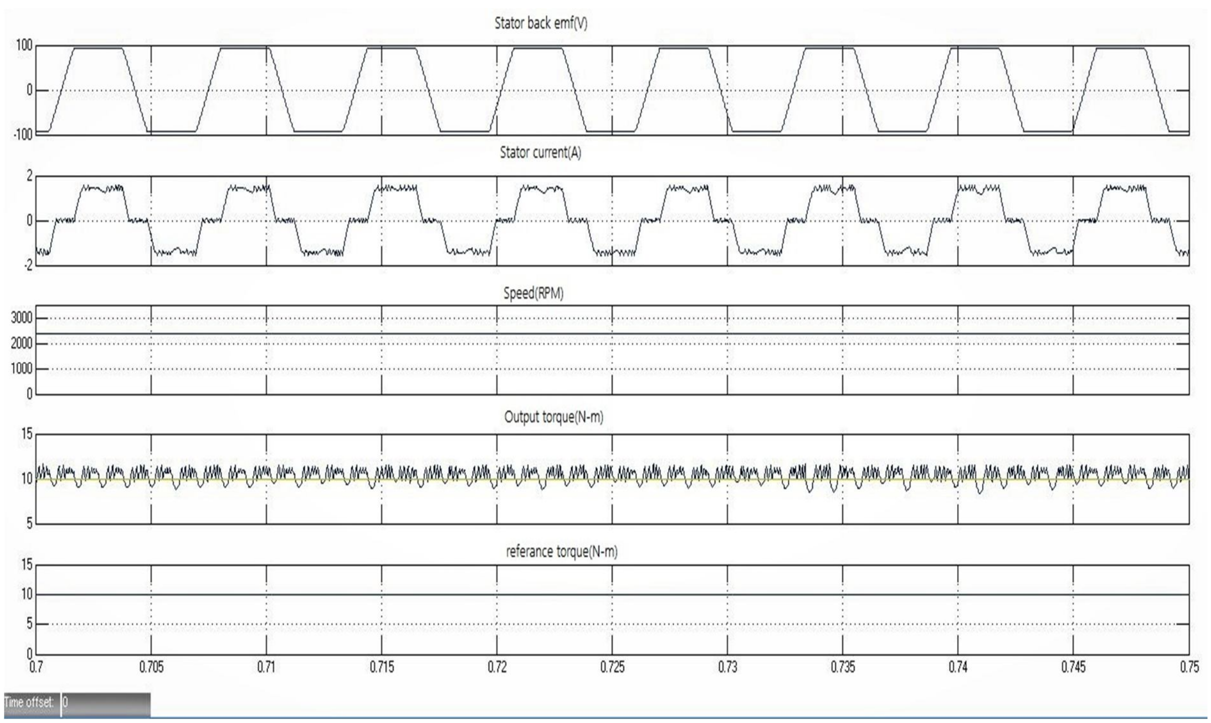

Fig.9 performances of the proposed Solar PV array-based Buck-Boost converter-fed BLDC motor drive using hysteresis current control showing BLDC motor variables.

VII. CONCLUSION

A solar photovoltaic array fed Buck-Boost converter based BLDC motor using hysteresis current control has been proposed. The proposed system has been designed, modelled and simulated using MATLAB along with its Simulink and sim power system toolboxes. Solar PV array has been designed perfectly such that system performance does not influence by the variation in atmospheric conditions and the associated losses and maximum switch utilization of Buck-boost converter is achieved. Buck-Boost converter has been operated in CCM in order to reduce the stress on power devices. Operating the VSI in conduction mode with fundamental frequency switching eliminates the losses caused by high frequency switching operation. Safe starting of BLDC motor are other important features of the proposed system. The simulation result shows that the Hysteresis Current Controller technique is more effective in reduction of torque ripples in BLDC motor. This hysteresis current control method improves the performance of system with low torque ripple so that it suitable for many applications.

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