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Closed Loop Control of Solar Pv Array Fed Simple Brushless Dc Motor Drive

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ABSTRACT

This Paper Presents Solar Photovoltaic (SPV) Array fed Water pumping System Utilizing Buck-boost DC-DC Converter in order to extract the maximum available power from Solar system.. Solar energy has the greatest availability compared to other energy sources. For such solar PV systems, maximum power point tracking control is preferred for efficient operation. This concept is dealing with INC method which is one of the MPPT methods. This study deals with a buck–boost converter controlled solar photovoltaic (SPV) array fed water pumping in order to achieve the maximum efficiency of an SPV array and the soft starting of a permanent magnet brushless DC (BLDC) motor. The current sensors normally used for speed control of BLDC motor are completely eliminated. The speed of BLDC motor is controlled through the variable DC-link voltage of a voltage-source inverter (VSI). The VSI is operated by fundamental frequency switching, avoiding the losses due to high-frequency switching, in order to enhance the efficiency of the proposed system.

KEYWORDS: *BLDC Motor, Solar PV Array, Buck-Boost Converter, Incremental & Conductance MPPT Method, Voltage source Inverter*

I. INTRODUCTION

Severe environmental protection regulations, shortage of fossil fuels and eternal energy from the sun have motivated the researchers towards the solar photovoltaic (SPV) array generated electrical power for various applications [1]. Water pumping is receiving wide attention nowadays amongst all the applications of SPV array. To enhance the efficiency of SPV array and hence the whole system regardless of the operating conditions, it becomes essential to operate SPV array at its maximum PowerPoint by means of a maximum power point tracking (MPPT)algorithm [2-4]. Various DC-DC converters have been already employed to accomplish this action of MPPT.

The PV inverters dedicated to the small PV plants must be characterized by a large range for the input voltage in order to accept different configurations of the PV field. This capability is assured by adopting inverters based on a double stage architecture where the first stage, which usually is a dc/dc converter, can be used to adapt the PV array voltage in order to meet the requirements of the dc/ac second stage, which is used to supply an ac load or to inject the produced power into the grid. This configuration is effective also in terms of controllability because the first stage can be devoted to track the maximum power from the PV array, while the second stage is used to produce ac current with low Total Harmonic Distortion (THD).

BLDC motors are preferred over DC motors and induction motors due to their advantages like long operating life, higher efficiency, low maintenance and better speed torque characteristics. Stator windings of BLDC motors are energized in a sequence from an inverter. A bulkier DC link capacitor is connected in between the dc-dc converter and inverter to get a constant voltage at the input of inverter, thus to make the voltage ripple free. But the DC link capacitor is bulkier in size and its life time is affected by operating temperature. Moreover the cost is about 5-15% of overall cost of BLDC motor drive. As an attempt to reduce the cost of motor, DC link capacitor can be eliminated at the expense of torque ripple. Thus a new torque ripple compensation technique is proposed to compensate for the torque ripple associated with the elimination of the DC link capacitor. In this method, torque ripple compensation technique is proposed to a solar PV array fed DC link capacitor free BLDC motor.

The permanent magnet brushless DC (BLDC) motor is employed to drive a centrifugal water pump coupled to its shaft. The BLDC motor is selected because of its merits [7,9]useful for the development of suitable water pumping system. This electronically commutated BLDC motor [9-11] is supplied by a voltage source inverter (VSI) which is operated by fundamental frequency switching resulting in low switching losses [12-15]. Suitability of the proposed SPV array fed water pumping system subjected to various operating and environmental conditions is demonstrated by satisfactory simulated results using MATLAB/Simulink environment.

The existing literature exploring SPV array-based BLDC motor-driven water pump is based on a configuration shown in Fig.1. A dc–dc converter is used for MPPT of an SPV array as usual. Two 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 voltage-source inverter (VSI) is operated with high-frequency PWM pulses, resulting in an increased switching loss and hence the reduced efficiency.

A DC–DC buck–boost converter is utilised to extract the maximum power available from the SPV array. And he additional functions of buck–boost converter is soft starting and speed control of the BLDC motor coupled to water pump, 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. This converter is operated in continuous conduction mode (CCM) resulting in a reduced stress on its power devices and components. Furthermore, the switching loss of VSI is reduced by adopting fundamental frequency switching resulting in an additional power saving and hence the enhanced efficiency. The phase currents as well as the DC-link voltage sensors are completely eliminated, offering simple and economical system without sacrificing its performance. The speed of BLDC motor is controlled, without any additional control, through the variable DC-link voltage of VSI. Moreover, the soft starting of BLDC motor is achieved by proper initialization of MPPT algorithm of SPV array.

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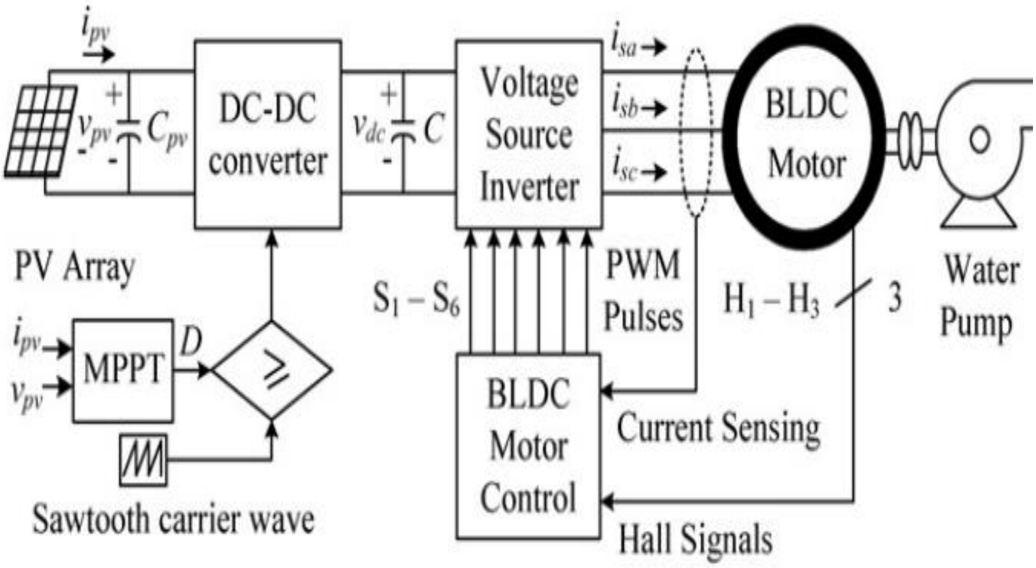

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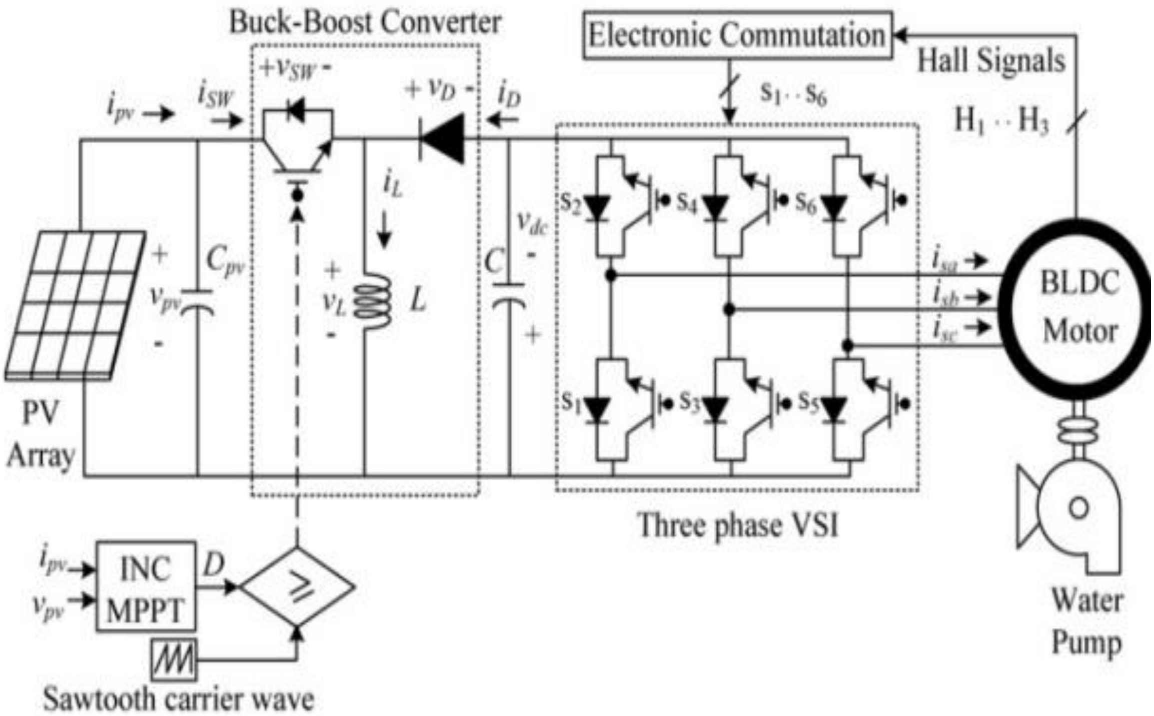

(b)

Fig. 1 Configuration of the SPV array fed BLDC motor driven water pumping system a) Conventional b) Proposed

II. CONFIGURATION OF PROPOSED SYSTEM & OPERATION

Fig. 1b shows the configuration of the proposed SPV-based buck– boost converter fed BLDC motor drive for water pumping. From left to right, the proposed system consists of an SPV array, a buck–boost DC–DC converter, a VSI, a BLDC motor and a water pump. As shown in Fig. 1b, the SPV 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 an incremental conductance (INC) MPPT algorithm such that the operation of the SPV array is optimized and the BLDC motor has the soft starting. The buck–boost converter is operated in CCM to reduce the stress on the components and semiconductor devices. Furthermore, the buck– boost converter feeds power to the VSI, supplying the BLDC motor coupled to a water pump. 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 elaborated in the following sections.

III. DESIGN OF THE PROPOSED SYSTEM

The various operating stages of the configuration shown in Fig. 1b such as the SPV array, the buck–boost converter and the water pump are designed such that a satisfactory operation is always accomplished under any kind of change in solar isolation level. A BLDC motor of 1.3 kW rated power is selected and each stage of the proposed system are designed accordingly, as follows.

Design of SPV array

An SPV array of 1.5 kW peak power capacity, somewhat more than required by the motor, is selected so that the performance of the system is not affected by the losses associated with the converters and the motor. The parameters of the SPV array are estimated at the standard solar isolation level of 1000 W/m2. A PV module AP-100, manufactured by Astro power Inc. [49] with peak power of 100 W, maximum voltage of 16.1 V and maximum current of 6.2 A is considered to design an SPV array of required capacity. First of all, the voltage of the SPV 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}= 241.5 V, the other parameters are estimated as:

The current at MPP

$$I_{mpp} = i_{pv} = \frac{p_{pv}}{v_{pv}} = 1500/241.5 = 6.2\,\mathrm{A} \qquad (1)$$

where p_{pv} = P_{mpp} = 1500 W is the peak power capacity.

Numbers of modules connected in series are as

$$N_s = \frac{V_{mpp}}{V_m} = 241.5/16.1 = 15 \qquad (2)$$

Numbers of modules connected in parallel are as

$$N_p = \frac{I_{mpp}}{I_m} = 6.2/6.2 = 1 \qquad (3)$$

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

Design of buck–boost converter

The SPV array voltage at MPP, $v_{pv} = V_{mpp}$ = 241.5 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 [50]

$$D = \frac{V_{dc}}{V_{dc} + v_{pv}} = \frac{310}{310 + 241.5} = 0.56 \tag{4}$$

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

$$I_{dc} = \frac{P_{mpp}}{V_{dc}} = \frac{1500}{310} = 4.8\,\text{A} \tag{5}$$

An addition of the two currents, i_{pv} and I_{dc} flow through the inductor, L. The inductor, L is estimated as [50]

$$L = \frac{D \times v_{pv}}{f_{sw} \Delta I_L} = \frac{0.56 \times 241.5}{10,000 \times 11 \times 0.4} = 3\,\text{mH} \tag{6}$$

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 [27, 48]. 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

$$\omega_h = 2\pi f = 2\pi \frac{N_{rated} P}{120} = 2\pi \times \frac{3000 \times 4}{120} = 628.3\,\text{rad/s} \tag{7}$$

$$\omega_l = 2\pi f = 2\pi \frac{NP}{120} = 2\pi \times \frac{1100 \times 4}{120} = 230.38\,\text{rad/s} \tag{8}$$

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

$$C\,(\text{corresponding to } \omega_h) = \frac{I_{dc}}{6 \times \omega_h \times \Delta V_{dc}} = \frac{4.8}{6 \times 628.3 \times 310 \times 0.01} = 410.7\,\mu\text{F} \tag{9}$$

$$C\left(\text{corresponding to } \omega_1\right) = \frac{I_{dc}}{6 \times \omega_1 \times \Delta V_{dc}} = \frac{4.8}{6 \times 230.38 \times 310 \times 0.01} = 1120\,\mu\text{F} \quad (10)$$

TABLE 1

Switching states for electronic commutation of BLDC motor

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

As per the estimation in (10), to ensure the satisfactory performance of the BLDC motor-pump, somewhat a higher value of C = 1500 µF is selected.

Design of water pump

A water pump is selected and is designed using its torque–speed characteristics as [15]

$$K_p = \frac{T_L}{\omega^2} = \frac{3.2}{(2 \times \pi \times 3000/60)^2} = 3.24 \times 10^{-5}\,\text{Nm}/(\text{rad/s})^2 \quad (11)$$

where K_p is a constant for selected water pump; TL is the load torque offered by pump; and ω is rotational speed in rad/s.

IV.CONTROL OF THE PROPOSED SYSTEM

The controls of the proposed system: namely, MPPT and electronic commutation of BLDC motor are elaborated in the following sections.

Maximum power point tracking

The MPPT technique is mostly used to optimise the utilization of SPV array. An INC type of MPPT technique [4–6] 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. 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 SPV array moves toward MPP, the DC-link voltage of VSI increases with a

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controlled rate. This results in a reduced rate of rise of stator current, ensuring a soft starting.

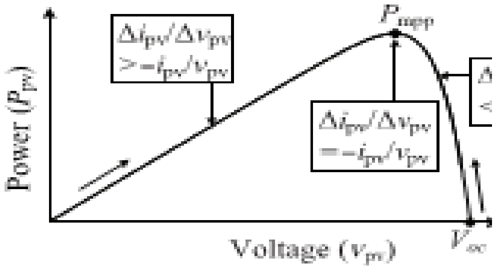


Fig.2. Illustration of INC-MPPT with SPV array P_{pv}–v_{pv} characteristics

Electronic commutation

The switching signals for the VSI are generated through the electronic commutation of the BLDC motor [33, 34]. According to the angular position of the rotor, the encoder provides three Hall Effect signals. These Hall Effect signals are logically converted into six switching pulses used to operate the six IGBT switches of the VSI, as shown in Table 1.

V. CLOSED LOOP SPEED CONTROL OF BLDC MOTOR

In the sensored BLDC drive, hall sensors or a shaft encoder is used to obtain the rotor position information. The drive control system consists of an outer speed loop for speed control and an inner current loop for current control. Conventionally three separate current sensors are used to measure the phase currents. But here only one current sensor is used, which is placed on the DC link.

VI. MATLAB/SIMULATION RESULTS

Speed control

The speed control block uses a Proportional Integral (PI) controller. A PI controller attempts to correct the error between a measured process variable and desired set point by calculating and then outputting a corrective action that can adjust the process accordingly. The PI controller calculation involves two separate modes the proportional mode and the integral mode. The proportional mode determine the reaction to the current error, integral mode determines the reaction based recent error. The weighted sum of the two mode output as corrective action for the control element. The PI controller is widely used in the industry due to its ease in design and simple structure. The PI controller algorithm can be implemented as

$$output(t) = K_p e(t) + K_I \int_0^t e(\tau) d\tau$$

(12)

Here the input to speed controller is the speed error. The output of the controller is considered as a reference torque. A limit is put on the speed controller output depending on permissible maximum winding currents.

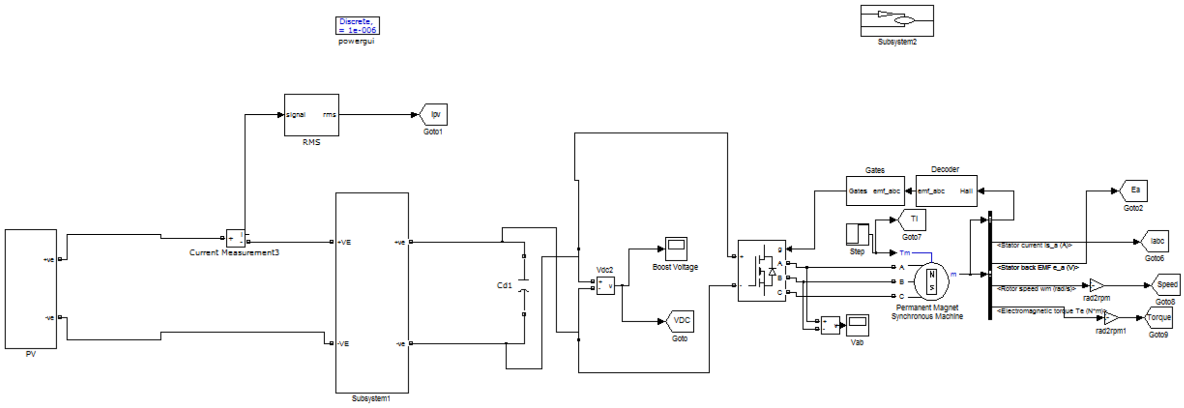
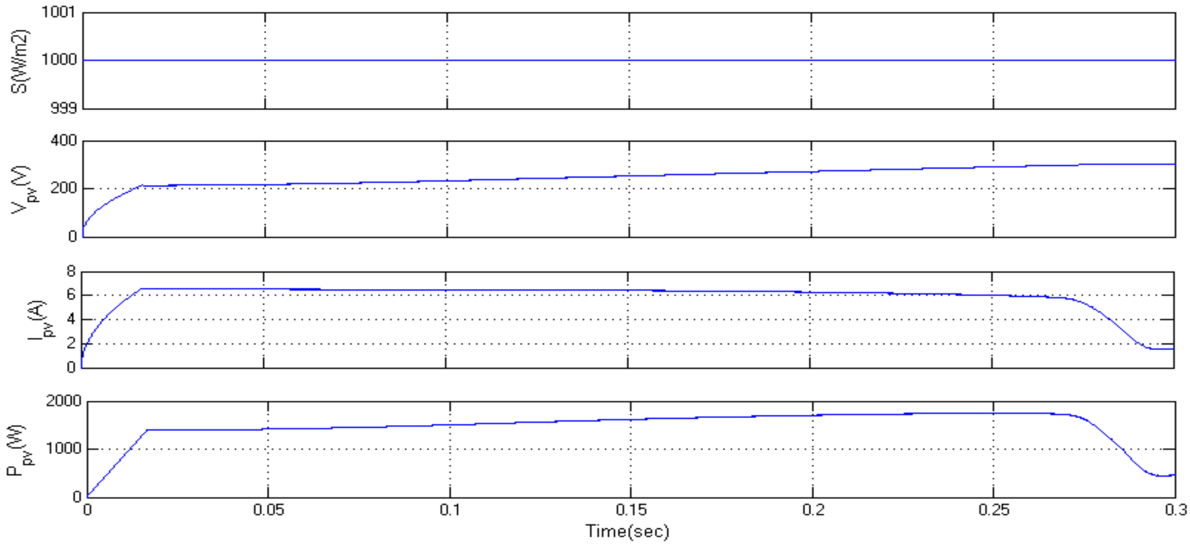


Fig. 3 Matlab/Simulink circuit of Starting and steady-state performances of the proposed SPV array based Buck-Boost converter-fed BLDC motor drive for water pump



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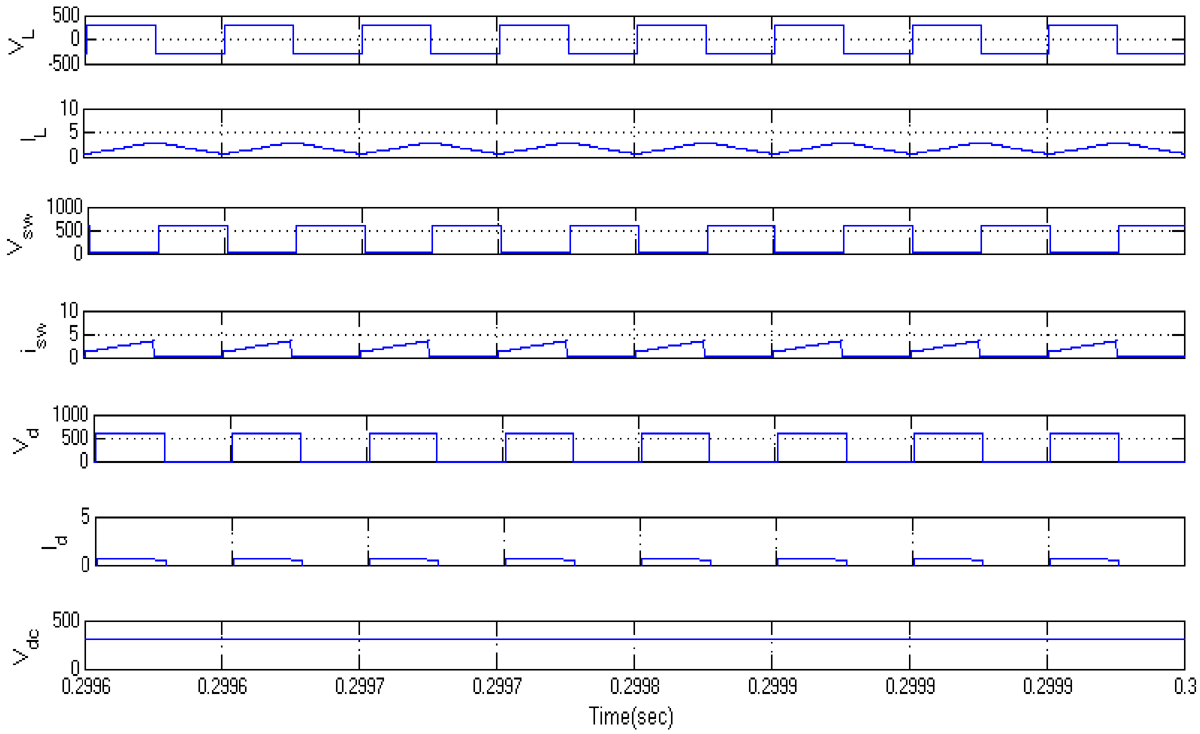

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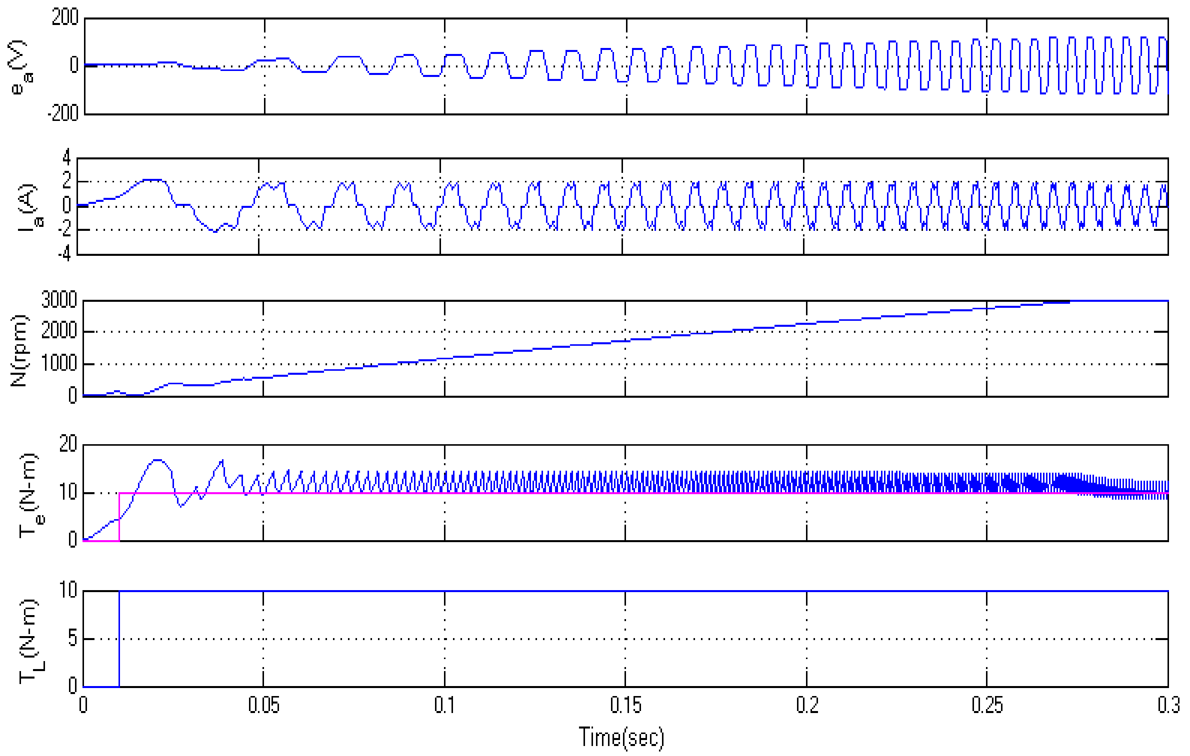

(c)

Fig.4 Starting and steady-state performances of the proposed SPV array based zeta converter-fed BLDC motor drive for water pump. (a) SPV array variables. (b) Buck-Boost converter variables. (c) BLDC motor-pump variables.

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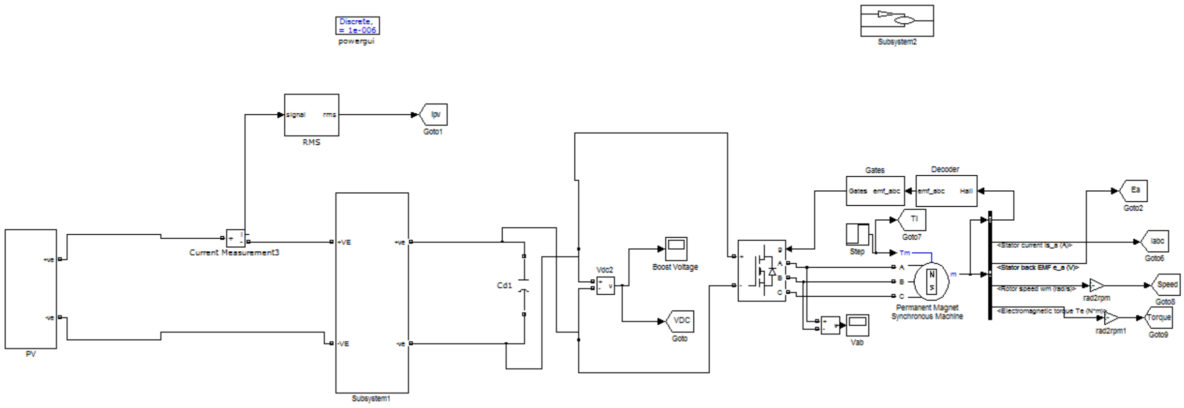
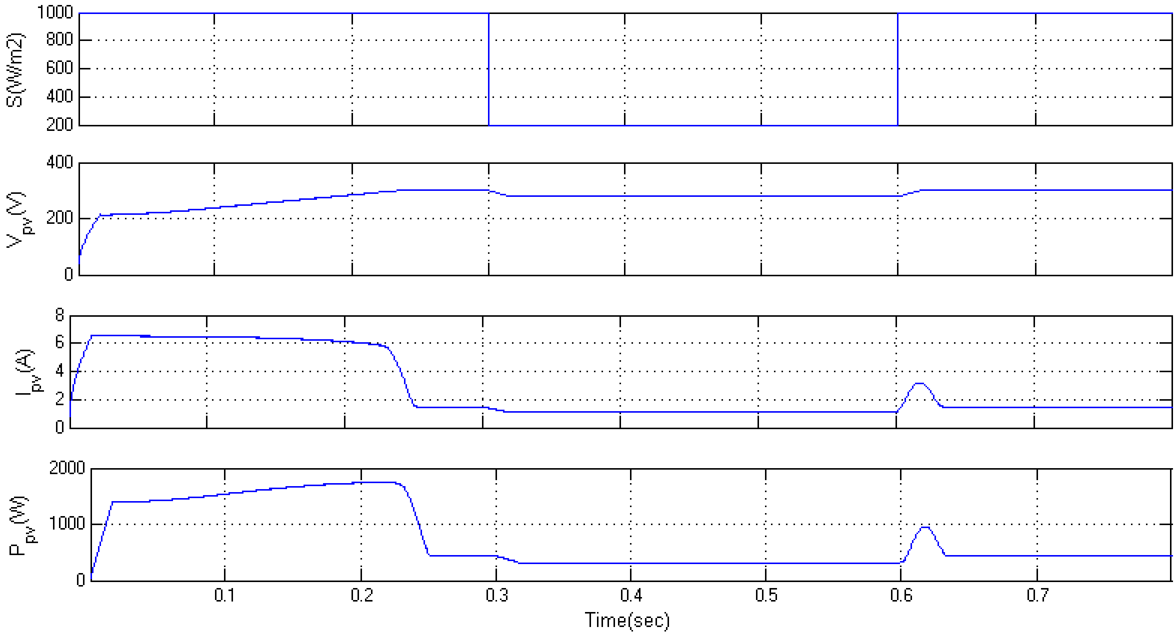


Fig.5 Matlab/Simulink circuit for Dynamic performance of SPV array-based Buck-Boost converter-fed BLDC motor drive for water pump



(a)

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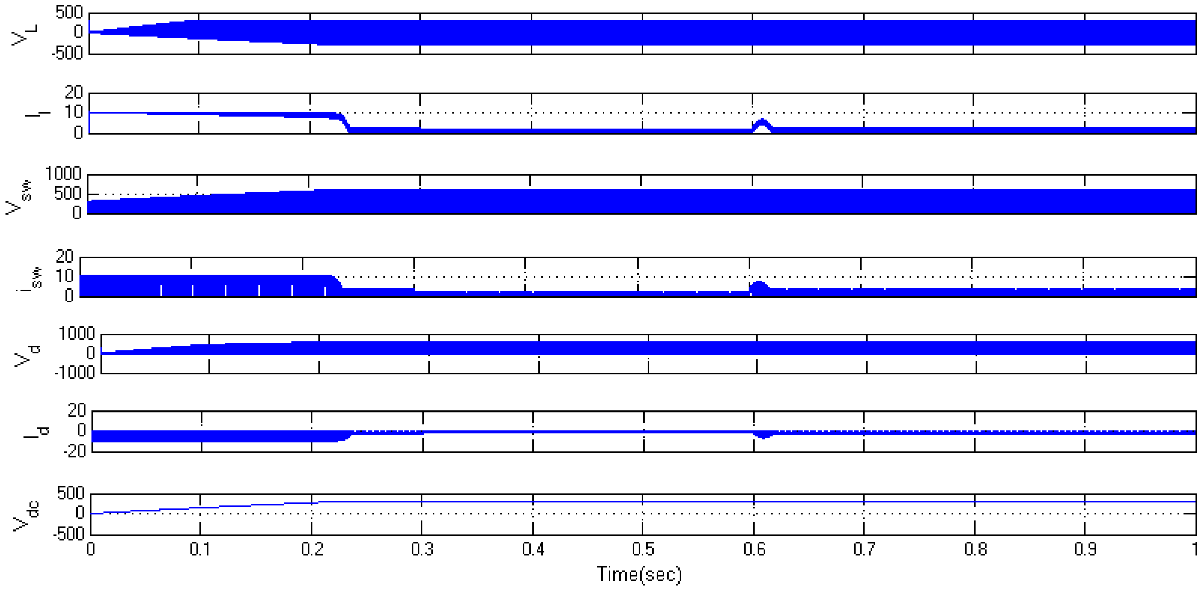

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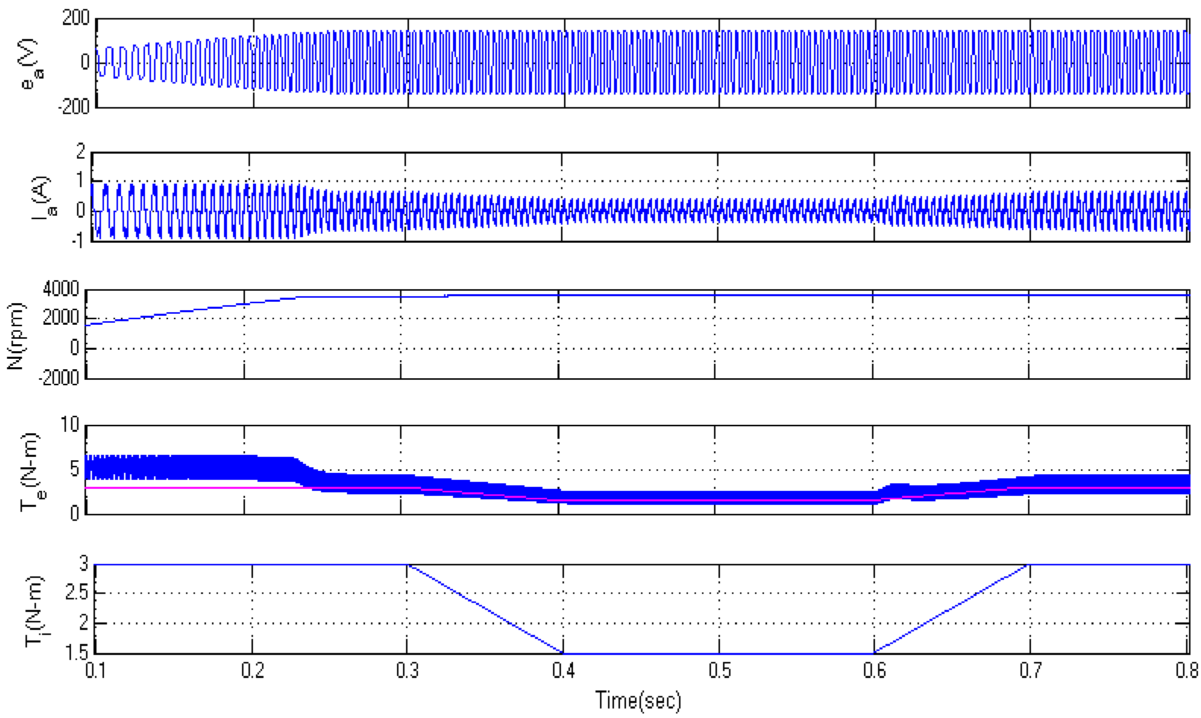

(c)

Fig.6 Dynamic performances of the proposed SPV array-based zeta converter-fed BLDC motor drive for water pump. (a) SPV array variables. (b) Buck-Boost converter variables. (c) BLDC motor-pump variables

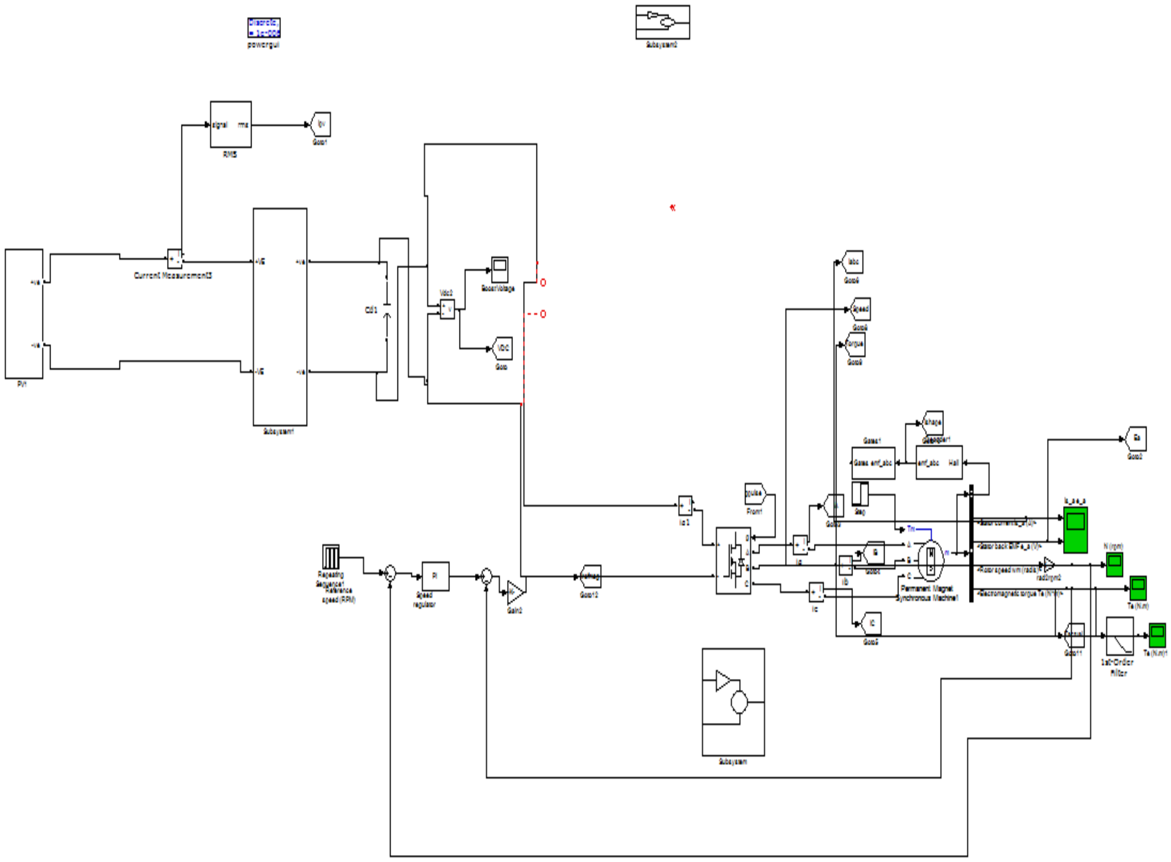

Fig.7 Matlab/Simulink circuit of SPV array-based Buck-Boost converter-fed BLDC motor drive Closed loop control for water pumping system

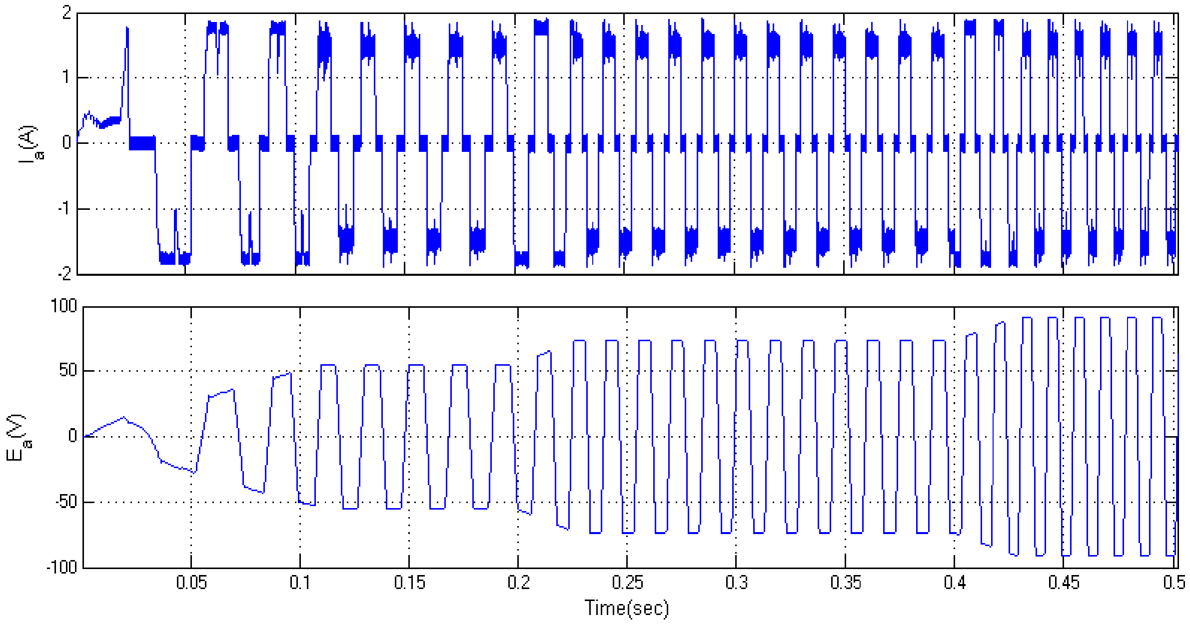

Fig.8 Stator current and emf

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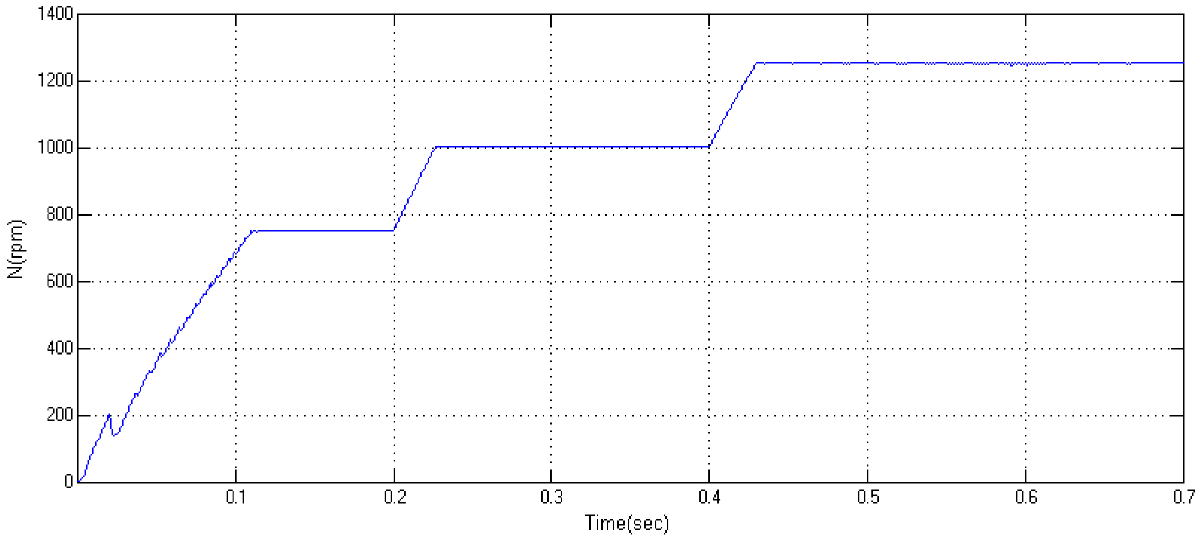

Fig.9.Speed

VII. CONCLUSION

A solar photovoltaic array fed Buck-Boost converter based BLDC motor has been proposed to drive water-pumping system. The proposed system has been designed, modelled and simulated using MATLAB along with its Simulink and simpower system tool boxes. Simulated results have demonstrated the suitability of proposed water pumping system. SPV array has been properly sized such that system performance is not influenced 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. Stable operations of motor-pump system and safe starting of BLDC motor are other important features of the proposed system.

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