An Internal Current Controlled BLDC Motor Drive Supplied with PV Fed High Voltage Gain DC-DC Converter

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Article Info	ABSTRACT
	The paper presents an efficient speed control of brushless DC (BLDC) motor drive for photo-voltaic (PV) system fed system. A high-gain DC-DC converter is employed in the system to boost the PV system low output voltage to a level required for the drive system. High-gain DC-DC converter is operated in closed-loop mode to attain accurate and steady output. The converter (VSI) for BLDC is switched at fundamental frequency and thus reducing high frequency switching losses. Internal current control method is developed and employed for the speed control of PV fed BLDC motor. The appropriateness of the internal current controller for the speed control of PV fed BLDC motor is verified for increamental speed with fixed torque and decreamental speed with fixed torque operating conditions. The system is developed and results are developed using MATLAB/SIMULINK software.

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1. INTRODUCTION

Development in power electronic section of electrical engineering has led to developments in special machines and one such kind is brushless DC (BLDC) motor. The construction of brushless DC motor is quiet similar to that of conventional DC motor but the absence of brush-commutator assembly makes BLDC motor more efficient in operation. The BLDC motor is electrically commutated by power switches instead of brushes. Compared with a brushed DC motor or an induction motor, the BLDC motor has many advantages: Higher efficiency and reliability, Lower acoustic noise, Smaller and lighter construction, Greater dynamic response, Better speed versus torque characteristics, higher speed range, longer life. A rotor consists of a shaft and a hub with permanent magnets arranged to form between two to eight pole pairs that alternate between north and south poles [1], [2]. There are multiple magnet materials, such as ferrous mixtures and rare-earth alloys. Ferrite magnets are traditional and relatively inexpensive, though rare-earth alloy magnets are becoming increasingly popular because of their high magnetic density. The higher density helps to shrink rotors while maintaining high relative torque when compared to similar ferrite magnets.

BLDC motor consists of an internal shaft position sensor which initiates the control of phase excitation and time of energization. Conventional DC motor employs mechanical commutator but BLDC motor instead uses electronic commutator for its commutation making BLDC a maintenance-free motor. The two types of BLDC motor are classified based on their shape of back-EMF viz., trapezoidal and sinusoidal motors [3], [4]. The back EMF of trapezoidal BLDC motor is trapezoidal in shape and to obtain trapezoidal

back EMF, the motor should be supplied with a quaisi-square wave shaped currents for minimum torque ripple operation.

Figure 1 shows the block diagram of BLDC motor with electronic commutator and logic controller. BLDC is supplied from DC supply and electronic commutator converts the DC supply given to BLDC to AC as commutator in conventional machine. Hall sensors sense the position of the rotor and sends position signal to controller in which control action takes place [5], [6]. The controller produces gate pulses to solid-state switches in converter through driver circuit.

The DC source to be fed to BLDC motor as an input is chosen to be photo-voltaic (PV) system [7-10] in this paper. P-N junction layer arranged in a specific manner forms a PV cell and when photons from solar energy falls on PV cell, electrons in PV cell tries to move crossing the barrier junction giving rise to current flow [11-14]. Solar energy is a type of renewable energy source freely available from universe and the electrical energy generated from this type of resource is inexhaustible. PV system generates DC type of electrical power and is of low voltage. The low voltage output from solar PV system is insufficient to drive any system and thus requires a voltage booster generally a DC-DC converter. High gain DC-DC converter is employed in this paper for boosting the low voltage DC output from PV system. The complete schematic arrangement of PV cell Fed BLDC motor is shown in Figure 2.

The paper presents an efficient speed control of brushless DC (BLDC) motor drive for photo-voltaic (PV) system fed system. A high-gain DC-DC converter is employed in the system to boost the PV system low output voltage to a level required for the drive system. High-gain DC-DC converter is operated in closed-loop mode to attain accurate and steady output. The converter (VSI) for BLDC is switched at fundamental frequency and thus reducing high frequency switching losses. Internal current control method is developed and employed for the speed control of PV fed BLDC motor. The appropriateness of the internal current controller for the speed control of PV fed BLDC motor is verified for increamental speed with fixed torque and decreamental speed with fixed torque operating conditions. The system is developed and results are developed using MATLAB/SIMULINK software.
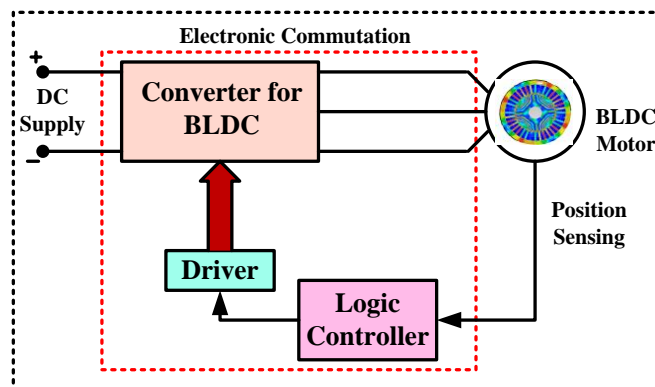

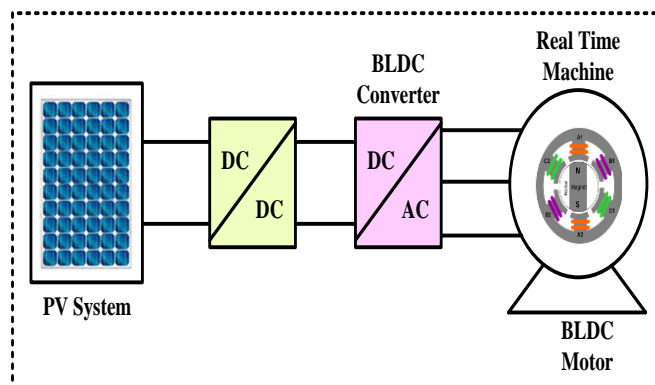
Figure 1. Block diagram of BLDC motor

Figure 2. PV cell Fed BLDC motor

2. PV FED HIGH-GAIN DC-DC CONVERTER

2.1. High-Gain DC-DC Converter

The circuit configuration of high-gain DC-DC isolated converter is shown in Figure 3. The low voltage DC from PV system is fed to isolated DC-DC converter to boost the level of voltage.
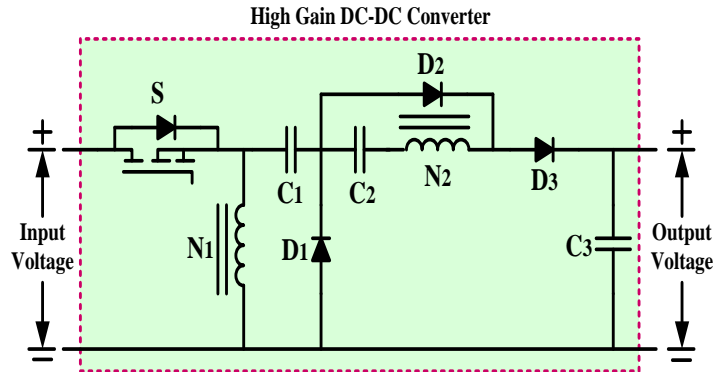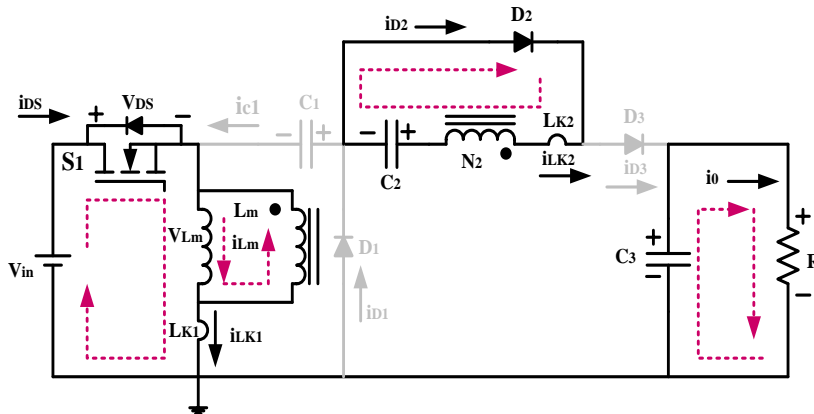
Figure 3. High gain dc-dc converter

Figure 4. High gain DC-DC converter when switch in ON

When switch S is in ON position, the primary inductor gets charged by input voltage through switch S1. At the same time the secondary inductor starts discharging and causes to charging the capacitor C2. In this case, capacitor C3 discharges and supplies to load at the output as shown in Figure 4.
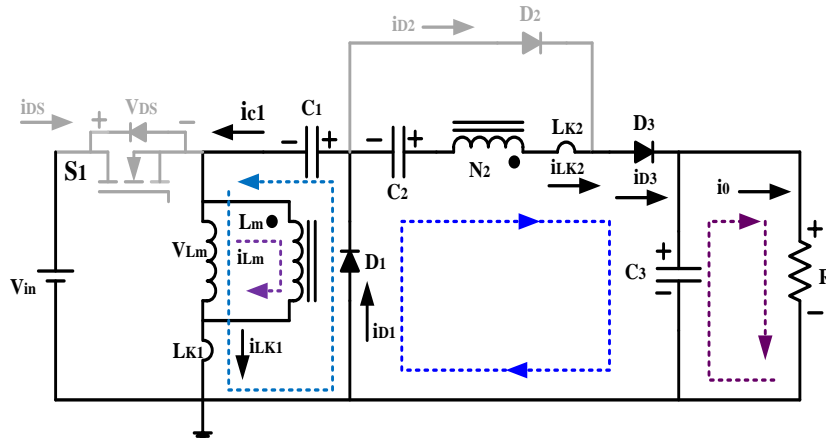
Figure 5. High gain DC-DC converter when switch in OFF

When switch S is in OFF position, then the charged primary inductor discharges through diode D1 and capacitor C1. Therefore capacitor C1 gets charges. Mean while the charged capacitor C2 starts discharging and causes to charge the secondary inductor and output capacitor C3 as shown in Figure 5.

To simplify the steady-state analysis, only modes pertaining to switch OFF is considered for CCM operation, and the leakage inductance on the secondary and primary sides are neglected.

By considering the average voltage across inductor and equating to zero during ON time and OFF time, the voltage gain for the high gain DC-DC converter is derived to be as (1), where 'n' is turns ration between primary to secondary of coupled inductor.

$$\text{Voltage Gain} = \frac{Vo}{Vin} = \frac{1+n}{1-D} \tag{1}$$

2.2. Closed-loop operation of High-Gain DC-DC Converter

Figure 6 shows the closed-loop mode of operation of high-gain DC-DC converter. The output voltage is fed back through a controller in closed-loop operation to obtain stable and constant DC output from high-gain converter. The actual output voltage is sensed across output capacitor of high-gain converter and is compared to reference DC voltage. The error of DC voltage is fed to PI controller where it produces reference voltage signal. The reference voltage signal is compared to carrier signal to produce pulses to switch in high-gain DC-DC converter. This mode of operation yields a constant output with very less ripple.
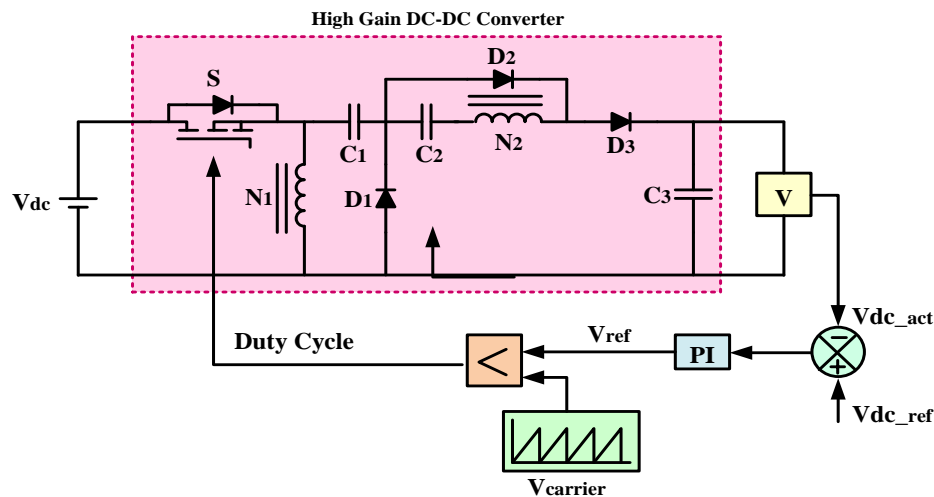

Figure 6. Closed-loop operation of high-gain DC-DC converter

2.3. PV fed High-Gain DC-DC Converter

The output of PV system is low voltage and it should be stepped-up to a certain voltage required by the system according to its configuration. The PV system connected to high-gain DC-DC converter is shown in Figure 7. A photovoltaic system, also PV system or solar power system is a power system designed to supply usable solar power by means of photo-voltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity. Photovoltaic conversion is the direct conversion of sunlight into electricity without any heat engine to interfere. Photovoltaic devices are rugged and simple in design requiring very little maintenance and their biggest advantage being their construction as stand-alone systems to give outputs from microwatts to megawatts. Hence they are used for power source, water pumping, remote buildings, solar home systems, communications, satellites and space vehicles, reverse osmosis plants, and for even megawatt scale power plants.
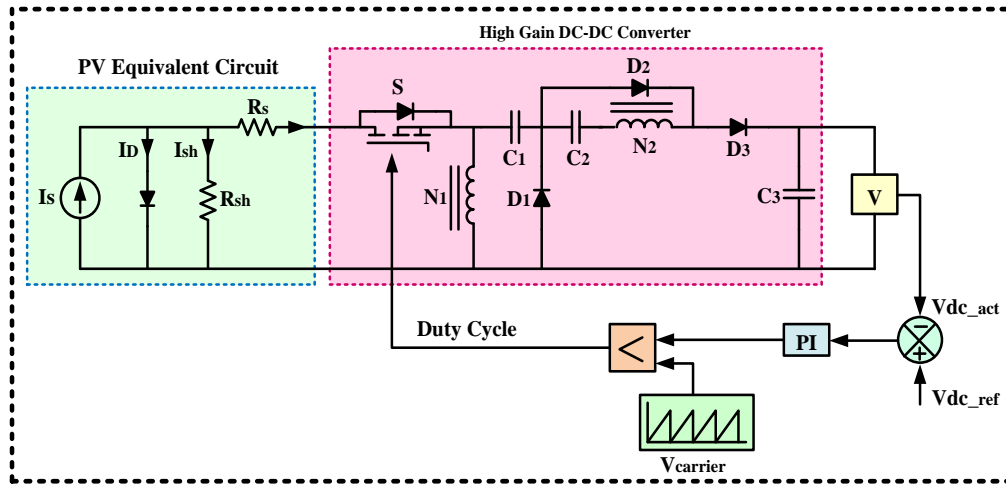
Figure 7. PV fed High gain DC-DC Converter configuration

3. SPEED CONTROL OF BLDC MOTOR WITH INTERNAL CURRENT CONTROLLER

Figure 8 shows the speed control strategy of BLDC motor with internal current controller. Primarily, the actual speed of BLDC motor is sensed from hall sensors and is compared to reference speed signal. The error generated from actual and reference speed is fed to a simple PI controller which yields reference torque signal. The obtained reference torque signal is compared with actual torque of BLDC motor and the error is fed through a gain to obtain reference current magnitude, as the current is proportional to torque signal. The obtained current magnitude and the current shape are multiplied to obtain reference current signal. The reference current signal is again compared to actual currents in stator of BLDC motor and the error is fed to hysteresis current controller to produce gate pulses to switches of voltage source converter (VSI). Thus by controlling the current of BLDC motor the speed control is achieved and motor is made to run at desired speed. The overall system with internal current controlled bldc motor drive supplied with PV fed high voltage gain DC-DC converter is shown in Figure 9. Table 1 shows system parameters for simulation of the proposed system.

Table 1. System Parameters for simulation of the system

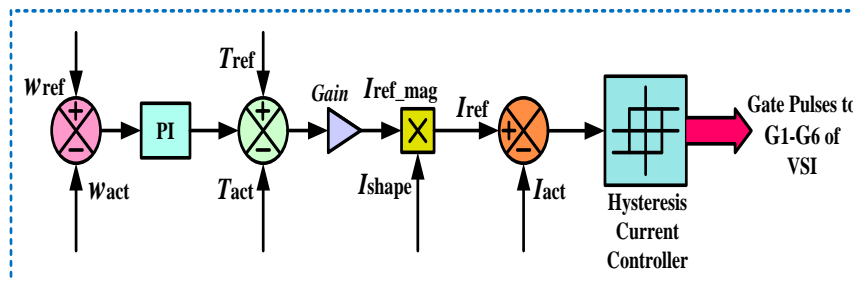| Parameters	Value
PV output voltage	40 V
DC-DC converter output	400V @ 2500 RPM
Capacitor C1, C2 of DC-DC converter	47 µF
Capacitor C3 of DC-DC converter	1000 µF
BLDC back-EMF flat area	120 deg

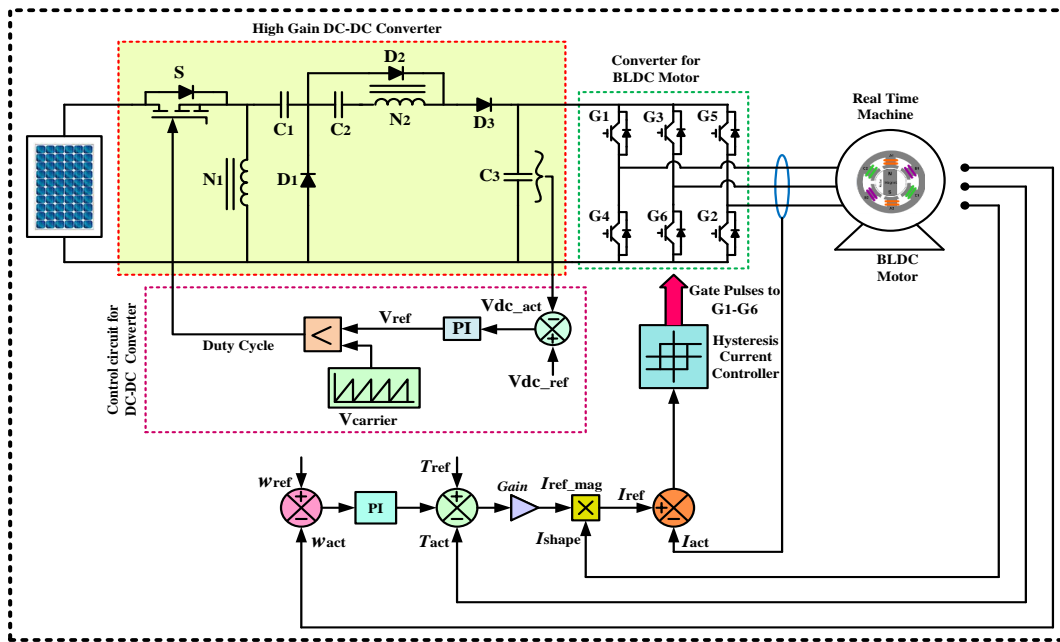Figure 8. Speed control strategy of BLDC motor with internal current controller

Figure 9. Overall system configuration with internal current controlled bldc motor drive supplied with PV fed high voltage gain DC-DC converter

4.   RESULTS AND ANALYSIS
4.1. BLDC Operating at Variable Increamental Speeds with Fixed Torque Condition

The output voltage from photo-voltaic system is shown in figure 10. PV yields the output of 40V as shown in figure.
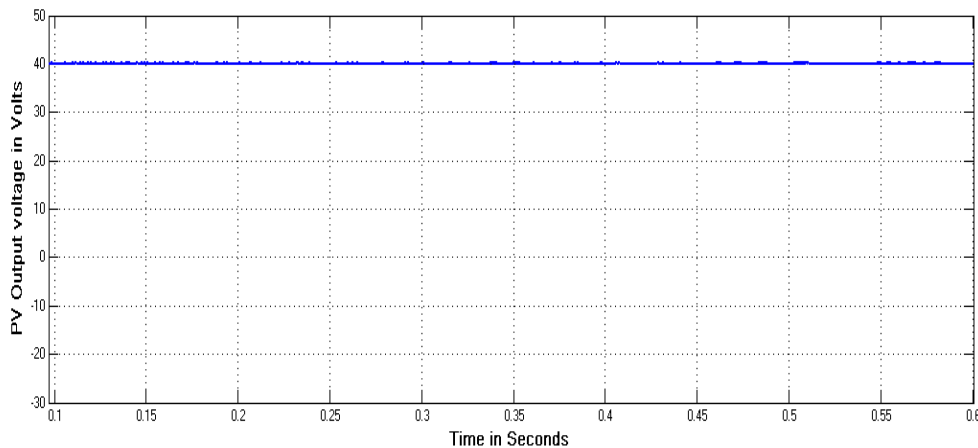

Figure 10. Output voltage from PV

The output voltage from high gain DC-DC converter is shown in Figure 11. DC-DC converter increases the level of PV voltage from 40 V and gives out the output of 400V as shown in figure. Even with speed change command, the output of DC-DC converter is maintained constant.

Stator current of one phase of BLDC motor and back EMF are shown in Figure 12. Since variable speed command is given at 0.2 sec and 0.4 sec, back EMF increase respectively with increase in speed. But the stator current drawn by the BLDC motor remains same with constant magnitude.
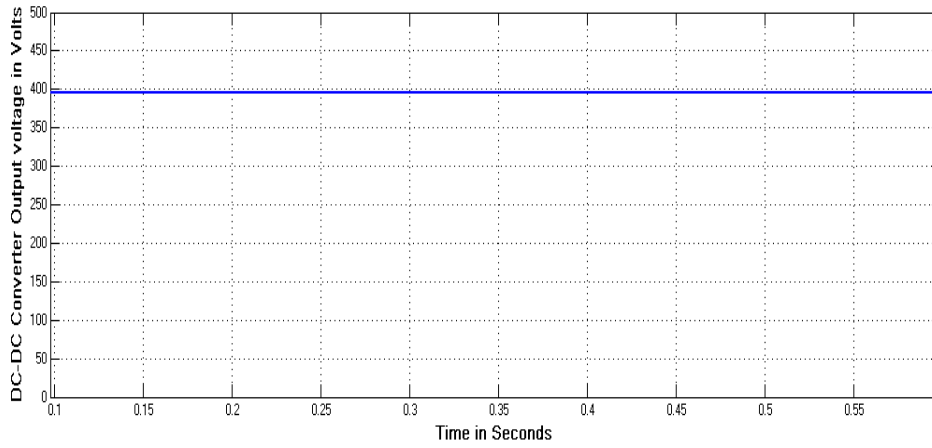
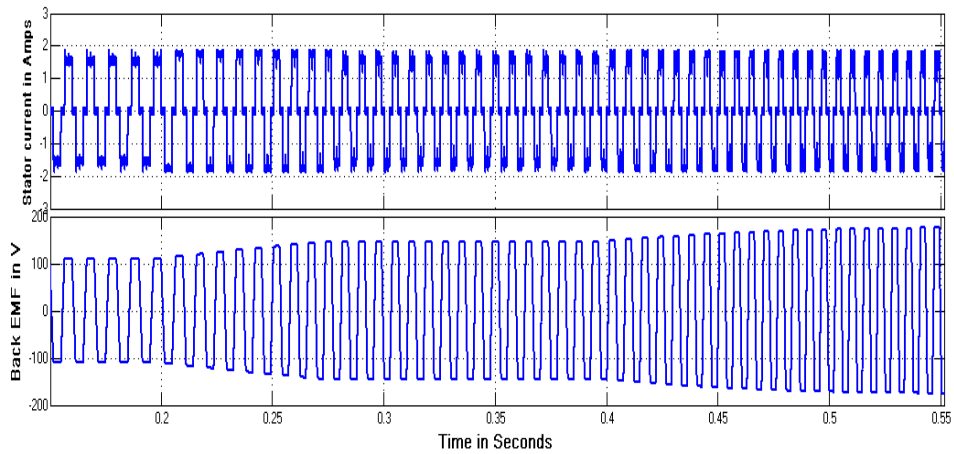Figure 11. Output voltage from DC-DC converter

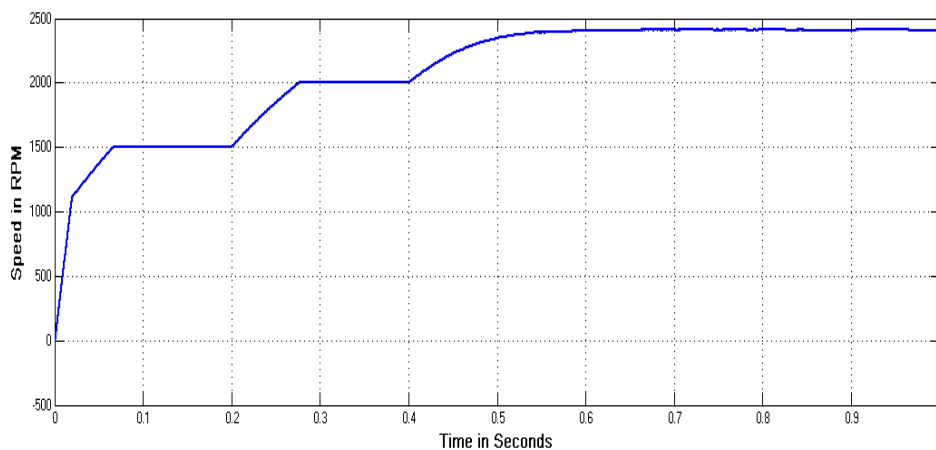Figure 12. Stator current and back EMF of BLDC motor

Figure 13. Speed of BLDC motor

Speed of BLDC motor is shown in Figure 13. Since the variable speed condition is applied, the speed changes at 0.2 sec and 0.4 sec. Incremental speed command is given at 0.2 sec and at 0.4 sec to be

initially at 1500rpm with change to 2000 rpm at 0.2 sec and 2500 rpm at 0.4 sec respectively and the actual speed follows the set speed command.
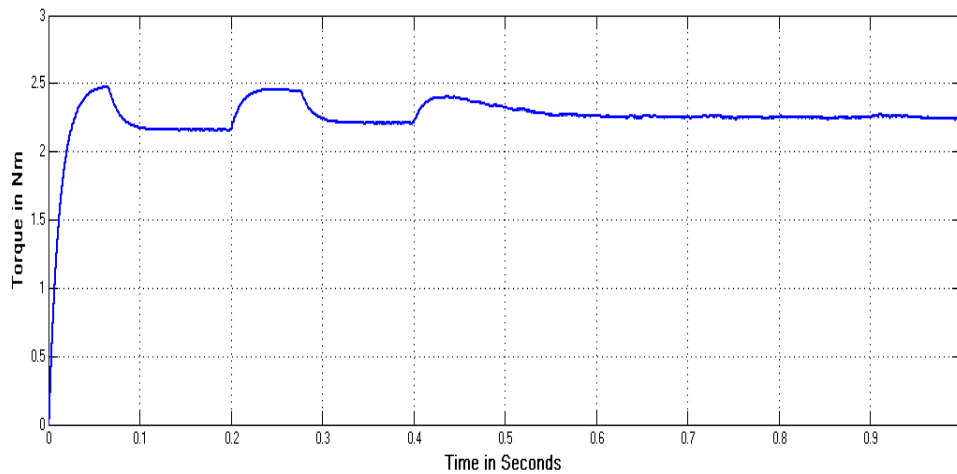

Figure 14. Torque of BLDC motor

Torque of BLDC motor is shown in Figure 14. Since the variable speed condition is applied, the change of torque is at 0.2 sec and 0.4 sec with respective speed change command but settles soon to final value. Even though, the speed changes torque remains constant apart from fluctuations.

4.2. BLDC Operating at Variable Decreamental Speeds with Fixed Torque Condition

The output voltage from photo-voltaic system is shown in Figure 15. PV yields the output of 40V as shown in figure.
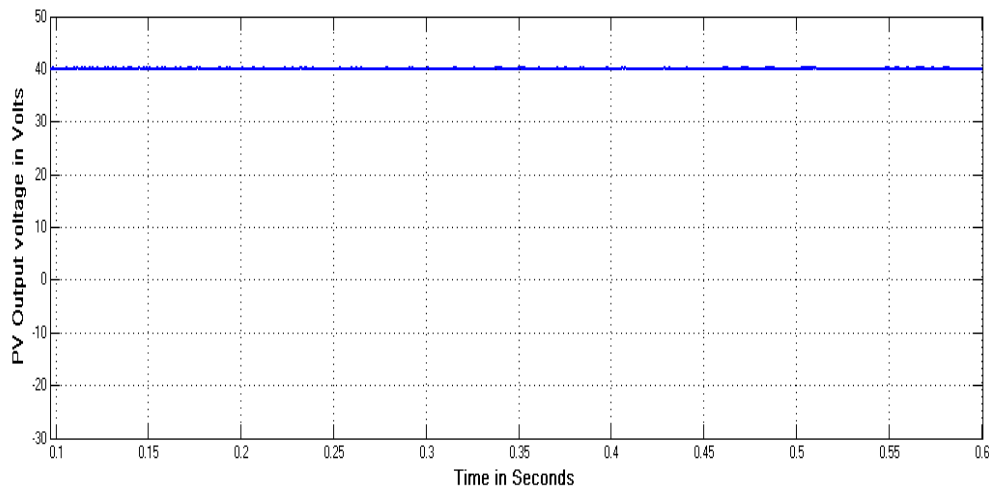

Figure 15. Output voltage from PV

The output voltage from high gain DC-DC converter is shown in figure 16. DC-DC converter increases the level of PV voltage from 40 V and gives out the output of 400V as shown in figure. Even with speed change command, the output of DC-DC converter is maintained constant.

Stator current of one phase of BLDC motor and back EMF are shown in Figure 17. Since variable speed command is given at 0.2 sec and 0.4 sec, back EMF decrease respectively with decrease in speed. But the stator current drawn by the BLDC motor remains same with constant magnitude.
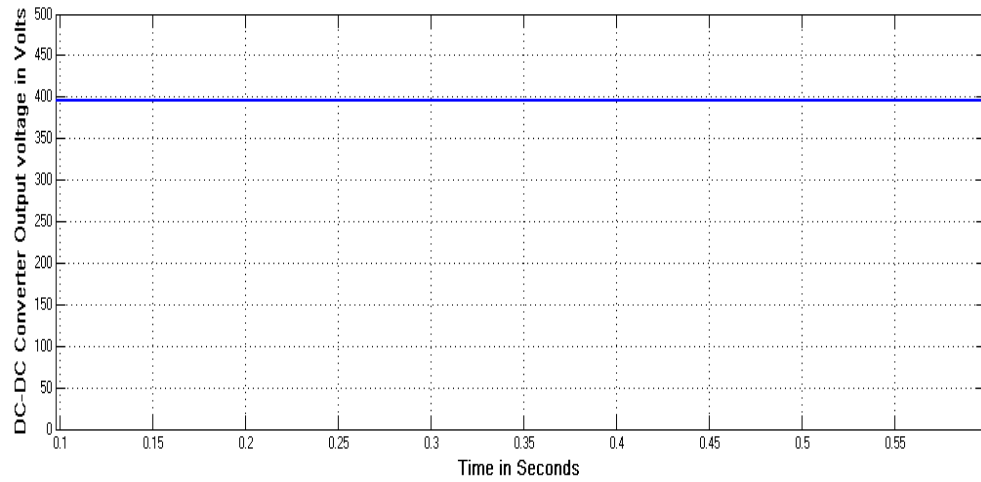
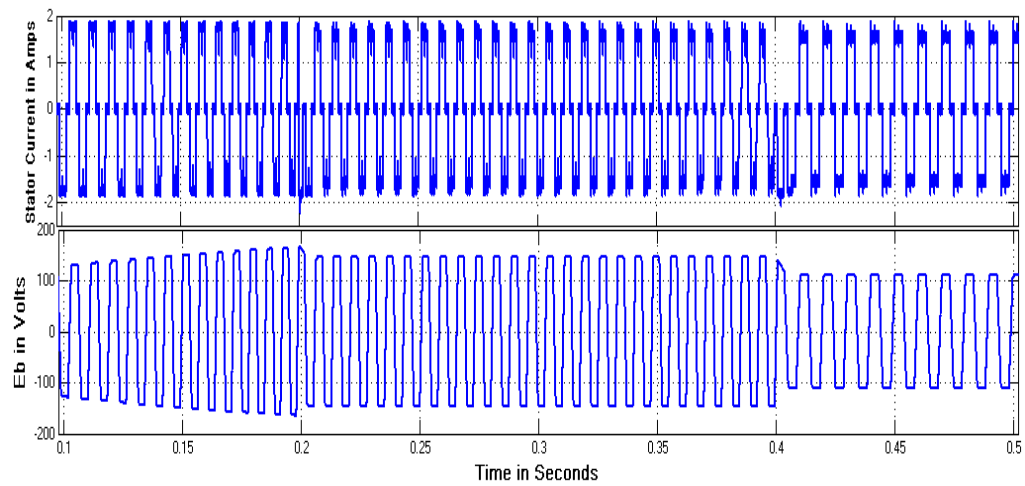Figure 16. Output voltage from DC-DC converter

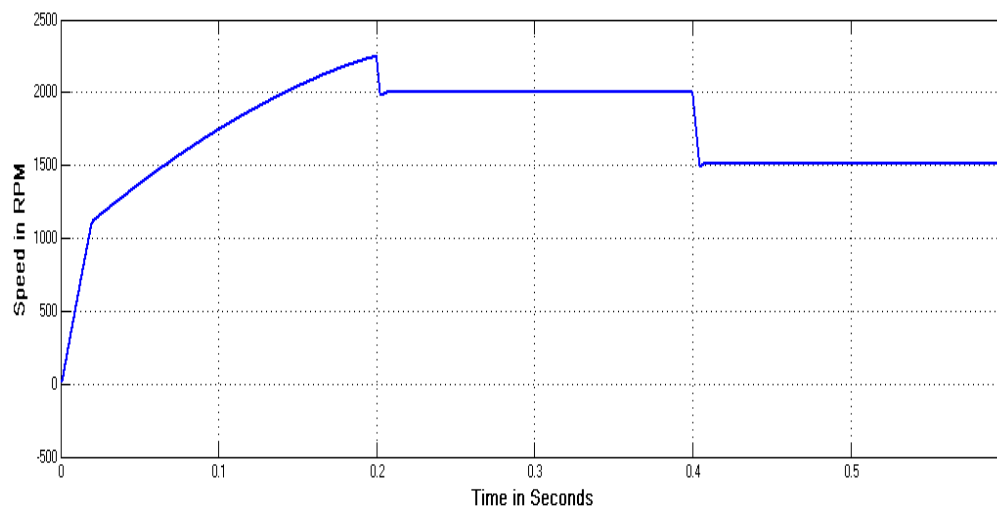Figure 17. Stator current and back EMF of BLDC motor

Figure 18. Speed of BLDC motor

Speed of BLDC motor is shown in Figure 18. Since the variable speed condition is applied, the speed changes at 0.2 sec and 0.4 sec. Decremental speed command is given at 0.2 sec and at 0.4 sec to be initially at 2500rpm with change to 2000 rpm at 0.2 sec and 1500 rpm at 0.4 sec respectively and the actual speed follows the set speed command.
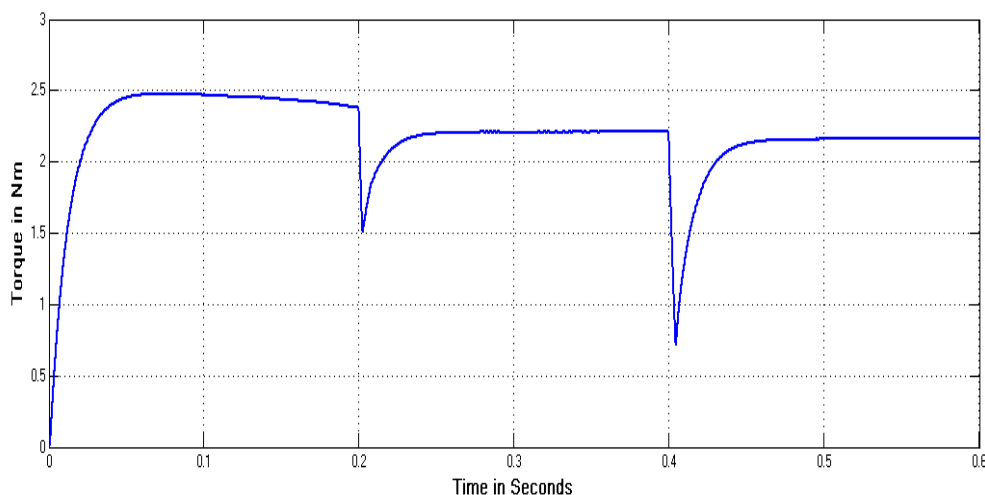

Figure 19. Torque of BLDC motor

Torque of BLDC motor is shown in Figure 19. Since the variable speed condition is applied, the change of torque is at 0.2 sec and 0.4 sec with respective speed change command but settles soon to final value. Even though, the speed changes torque remains constant apart from fluctuations at speed change.

5.   CONCLUSION

The paper presents an efficient speed control of brushless DC (BLDC) motor drive for photo-voltaic (PV) system fed system. A high-gain DC-DC converter is employed in the system to boost the PV system low output voltage to a level required for the drive system. High-gain DC-DC converter is operated in closed-loop mode to attain accurate and steady output. The 40 V output from PV system is stepped up to 400 V using high-gain DC-DC converter as shown in the result analysis. Internal current control method is developed and employed for the speed control of PV fed BLDC motor. The appropriateness of the internal current controller for the speed control of PV fed BLDC motor is verified for increamental speed with fixed torque and decreamental speed with fixed torque operating conditions and results for respective cases were depicted. With increamental and decremental speed change command issued to BLDC motor yields respective speed changes with fixed torque with the presence of internal current controller keeping the DC output voltage of DC-DC converter constant at 400V. Speed control method is found to be suitable for variable speed conditions maintaining fixed torque.

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