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PHOTO-VOLTAIC SYSTEM FED HIGH VOLTAGE GAIN DC-DC CONVERTER FEEDING BLDC DRIVE WITH SIMPLIFIED SPEED CONTROL

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ABSTRACT
Brush-less DC (BLDC) motor, now-a-days has become a predominant choice in usage of electrical motors in many applications due to its simple construction and high speed capable operations. This paper presents a photo-voltaic fed high voltage gain closed-loop DC-DC converter for BLDC motor drive application and BLDC motor drive is controlled using a simplified control strategy. Low voltage DC output from photo-voltaic (PV) system is stepped-up to desired value using a high-gain closed-loop DC-DC converter. The configuration of high-gain DC-DC converter with its closed-loop operation is depicted. The output of DC-DC converter is fed to BLDC motor through a converter for BLDC motor drive. Speed control of BLDC motor is achieved using a simplified speed control method in this paper and speed control is achieved without actually sensing the actual motor speed. This type of motor drive is very much suitable for air-conditioner applications. Simulation analysis for the proposed system is carried out for variable incremental/decremented speed with fixed torque and for variable torque with fixed speed conditions. The proposed simplified control strategy for speed control of BLDC motor drive in this paper is found very much suitable for fixed torque with variable speed conditions but found not very much suitable for variable torque and fixed speed conditions through simulation analysis. Proposed system was developed and results are analyzed using MATLAB/SIMULINK software.

Keywords: BLDC, high-gain, DC-DC converter, photo-voltaic, speed control.

INTRODUCTION
Brushless DC (BLDC) motor is a superior choice for many engineers these days especially when come to the matter of motor control technology. High efficiency, high speed operation capability, fast response with low maintenance makes brushless DC motors taking an edge over conventional brushed DC motors. These BLDC motors are an eminent part of modern drive technology, most commonly employed for actuating drives, machine tools, electric propulsion, robotics, computer peripherals and many more. With the development in semi-conductor technology, these motors became reliable, cost effective and less sized efficient motor compared to other conventional electrical motors [1-2].

Conventional DC motors consists of mechanical commutator with static brush for commutation purpose and the presence of mechanical commutator and brush assembly generates unwanted losses in the machine and requiring regular maintenance. Conventional brush/commutator assembly in conventional DC motors is replaced with solid-state electronic commutation in BLDC motor forming a brushless DC motor and thus reducing the losses and cost of the machine. Electronic commutator in BLDC motor sequentially switches the phases of armature windings.

Brushless DC motors are permanent magnet synchronous machine supplied from DC type of electrical supply. In BLDC motor, stator is a armature windings and the rotor is permanent magnet rotor. The phases of armature of BLDC are excited from electronic commutator. When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.

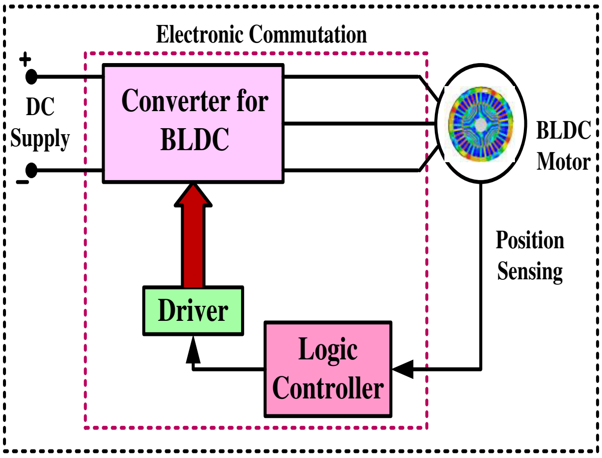

Figure-1. Block diagram of BLDC motor.

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

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sense the position of the rotor and sends position signal to controller in which control action takes place [3-4]. The controller produces gate pulses to solid-state switches in converter through driver circuit.

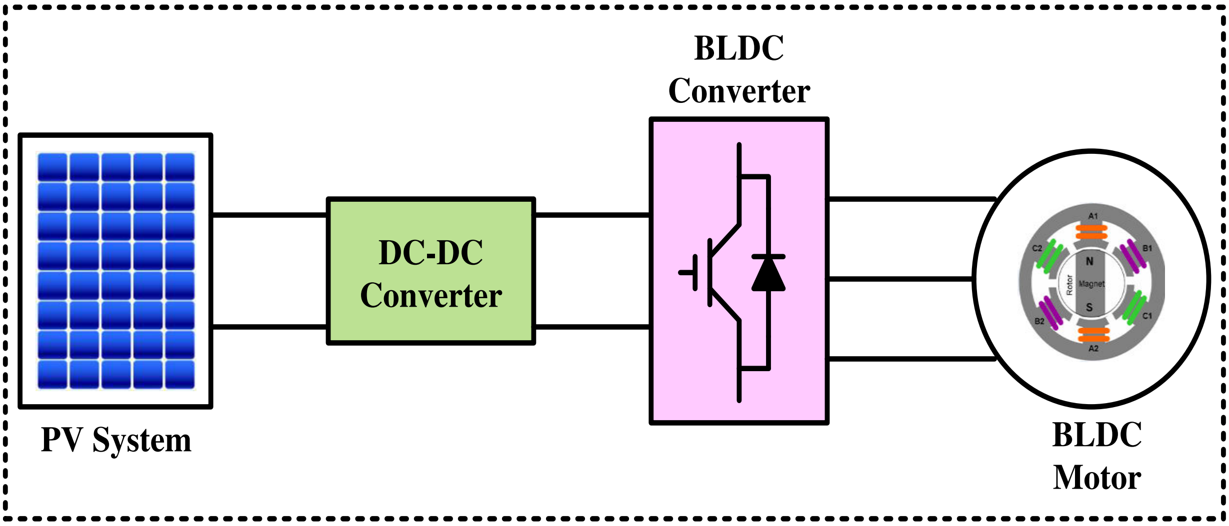

Figure-2. Block diagram of proposed system with PV with high gain DC-DC converter fed BLDC motor.

The DC source to be fed to BLDC motor as an input is chosen to be photo-voltaic (PV) system [5-6] 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 [7]. 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.

This paper presents a photo-voltaic fed high voltage gain closed-loop DC-DC converter for BLDC motor drive application [8-10] and BLDC motor drive is controlled using a simplified control strategy. Low voltage DC output from photo-voltaic (PV) system is stepped-up to desired value using a high-gain closed-loop DC-DC converter. The output of DC-DC converter is fed to BLDC motor through a converter for BLDC motor drive. Speed control of BLDC motor is achieved using a simplified speed control method in this paper and speed control is achieved without actually sensing the actual motor speed. This type of motor drive is very much suitable for air-conditioner applications. Proposed system was developed and results are analyzed using MATLAB/SIMULINK software.

HIGH GAIN DC-DC CONVERTER FED WITH PV SYSTEM

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.

(a) High gain DC-DC converter configuration

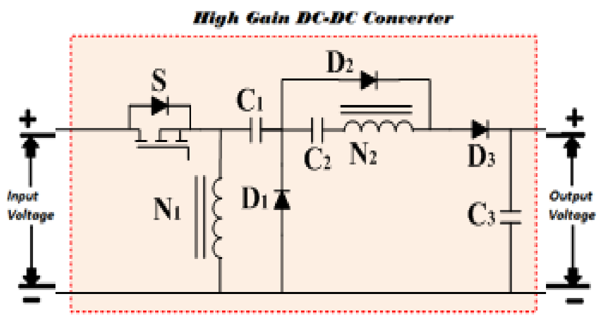

Figure-3. High gain DC-DC converter configuration.

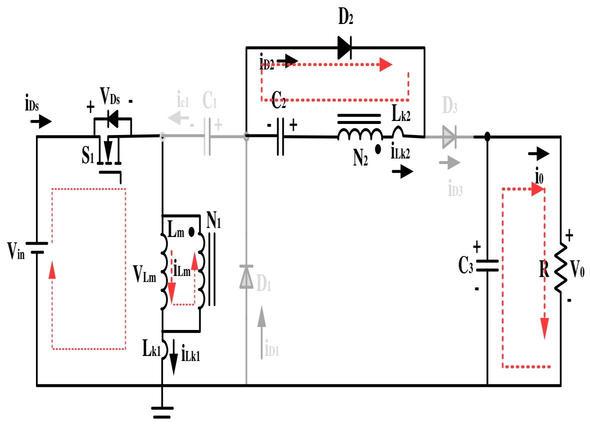

Figure-4. High gain DC-DC converter when switch in ON.

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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.

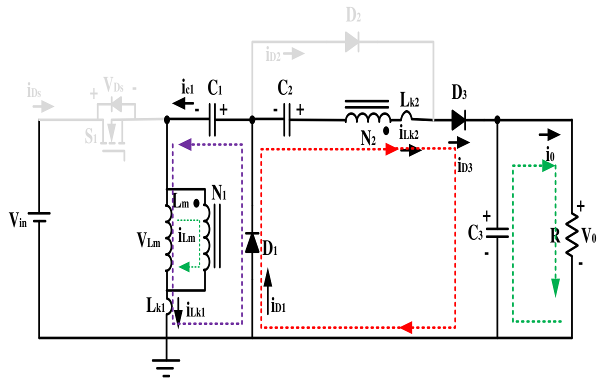

Figure-5. High gain DC-DC converter when switch in OFF.

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.

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

With the duty cycle value of 0.5, the voltage output can be obtained as high as 13 times of input voltage.

(b) PV fed high gain DC-DC converter

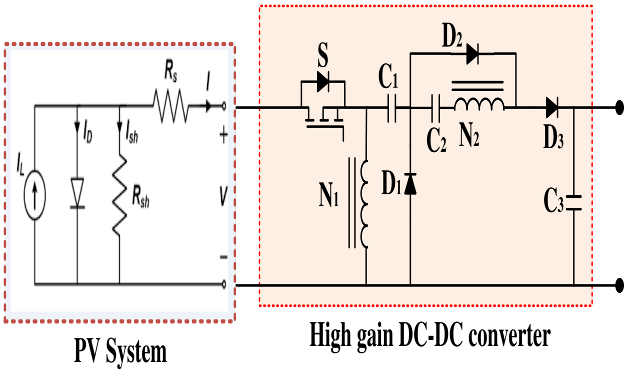

Figure-6. PV fed high gain DC-DC converter configuration.

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

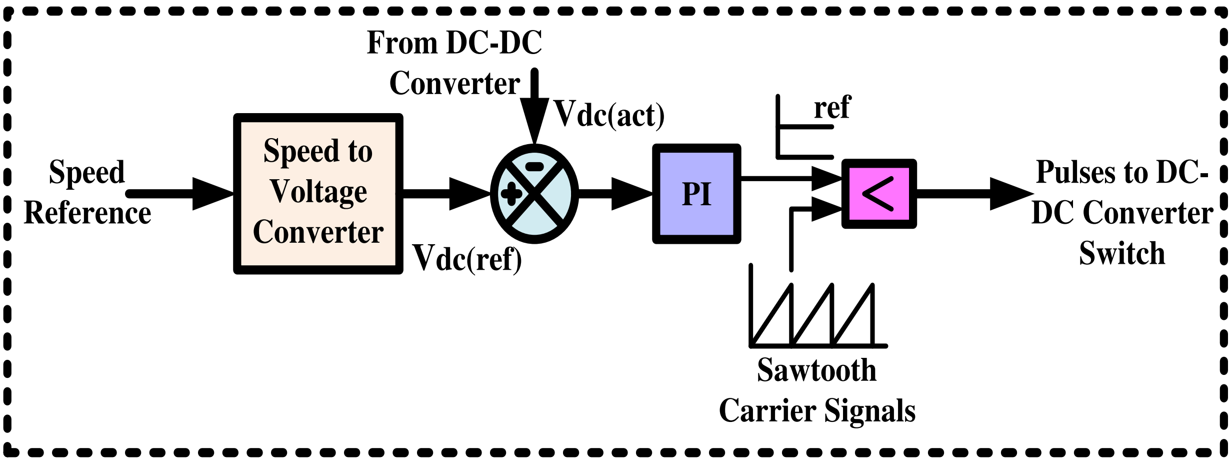

Figure-7. Simplified control strategy for speed control of BLDC motor.

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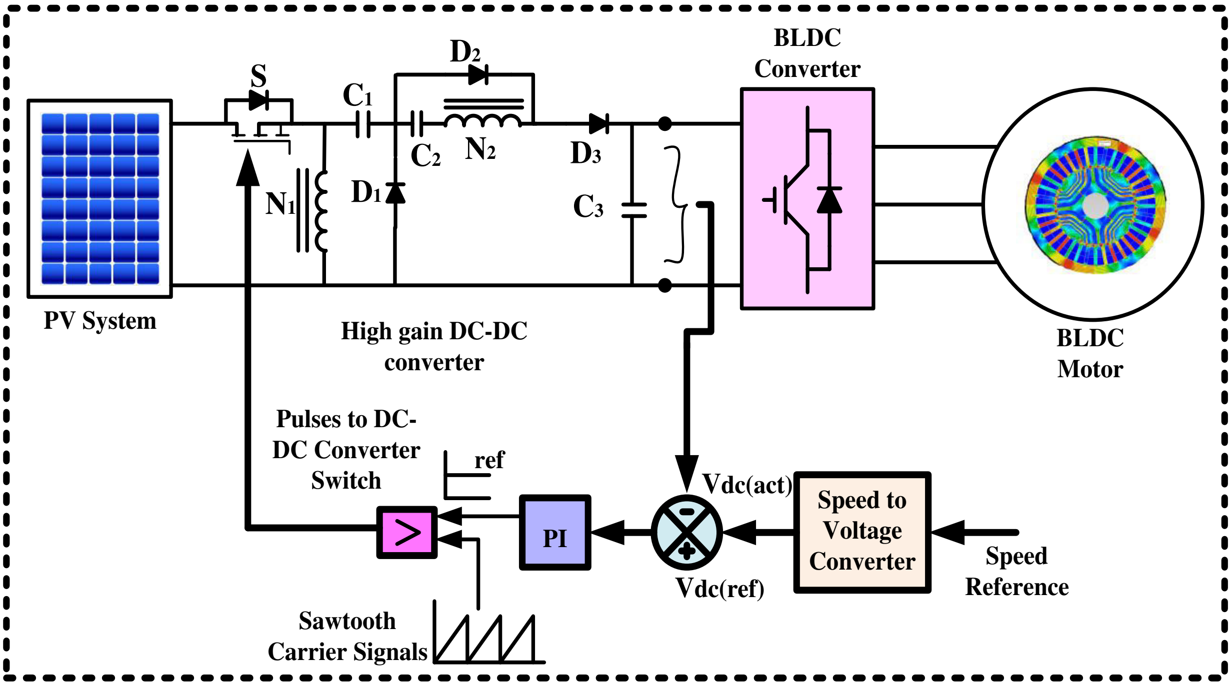

Figure-8. Schematic arrangement of PV fed high voltage-gain DC-DC converter for BLDC motor drive with simplified control scheme.

PV fed high gain DC-DC converter is shown in Figure-6. PV system generally produces the output voltage at low voltage level. The low voltage output of PV system is fed to high gain DC-DC converter to boost the voltage at required level.

SIMPLIFIED CONTROL STRATEGY FOR SPEED CONTROL OF BLDC MOTOR

The simplified control strategy proposed in this paper for speed control of BLDC motor does not sense actual speed of the motor. The simplified control strategy proposed in this paper for speed control of BLDC motor is depicted in Figure-7.

The reference speed is set to rotate the BLDC motor at required speed. By using speed to voltage transducer, the reference speed signal is converted to reference voltage signal. The reference voltage signal is compared with actual voltage output obtained from high voltage gain DC-DC converter. The error signal is passed through PI controller and the PI controller reduces the error and yields a reference signal for pulse generation. This reference signal is related with carrier signal (saw-tooth shape) with the help of a relational operator to produce pulses to solid-state switch in high gain DC-DC converter. The DC-DC converter with high voltage gain switches according to triggering pulses and operates to give out required voltage level that will be sufficient to drive BLDC motor at required speeds. If the speed of the BLDC needs to be changed, the reference speed signal is varied accordingly and the whole process continues to yield sufficient output voltage to drive BLDC motor at set speed as explained in the above procedures. In the whole process of speed control of BLDC motor, the actual speed of the motor is not sensed and thus this type of speed control of a machine is suitable only for fixed torque with variable speeds but not very much applicable for variable torque with fixed speed conditions.

The complete schematic arrangement of photo-voltaic fed high voltage gain closed-loop DC-DC converter for BLDC motor drive with simplified control scheme is depicted in figure 8.Low voltage DC output from photo-voltaic (PV) system is stepped-up to desired value using a high-gain closed-loop DC-DC converter. The output of DC-DC converter is fed to BLDC motor through a converter for BLDC motor drive. The simplified control strategy explained in the previous section produces gate pulses to high voltage gain DC-DC converter to yield required voltage level that will be sufficient to drive BLDC motor at required speeds.

RESULTS AND DISCUSSIONS

Table-1. System parameters.

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

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Case 1: Variable incremental speed with fixed torque

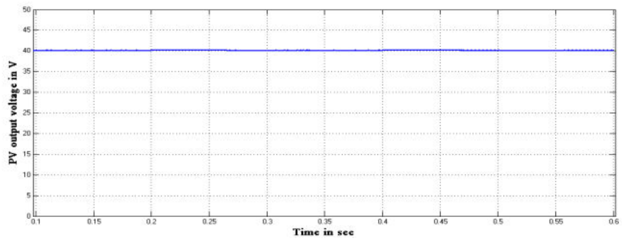

Figure-9. Output voltage from PV.

The output voltage from photo-voltaic system is shown in Figure-9. PV yields the output of 40V as shown in figure.

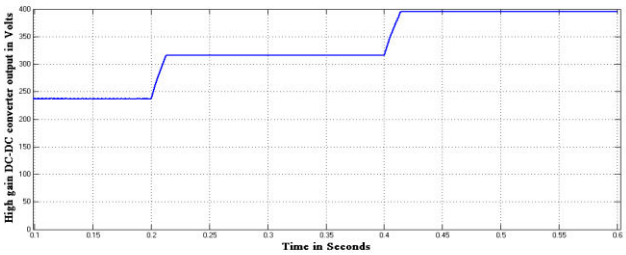

Figure-10. Output voltage from DC-DC converter.

The output voltage from high gain DC-DC converter is shown in figure 10. DC-DC converter increases the level of PV voltage and gives out the output as shown in figure. Since the variable speed condition is applied, the DC-DC converter voltage 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. Accordingly, the DC-DC converter yields output voltage of initially at 240 V with change to 320 V at 0.2 sec and to 400 V at 0.4 sec corresponding to respective speeds.

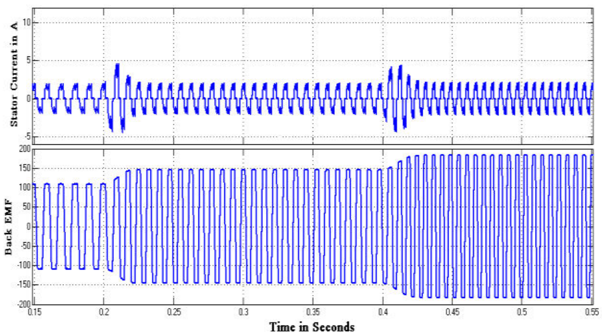

Figure-11. Stator current and back EMF of BLDC motor.

Stator current of one phase of BLDC motor and back EMF are shown in Figure-11. Since variable speed commands are given, the stator currents vary at respective times of 0.2 sec and 0.4 sec. Back EMF increase respectively with increase in speed.

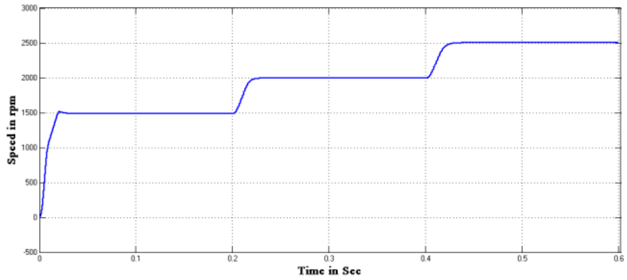

Figure-12. Speed of BLDC motor.

Speed of BLDC motor is shown in Figure-12. Since the variable speed condition is applied, the 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.

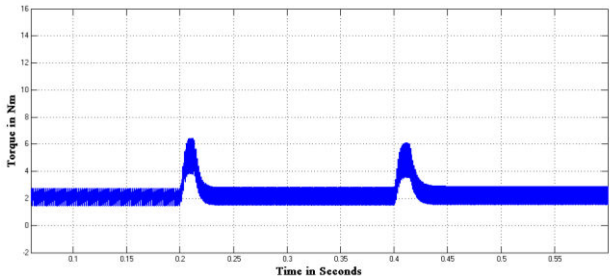

Figure-13. Torque of BLDC motor.

Torque of BLDC motor is shown in Figure-13. Since the variable speed condition is applied, the change at 0.2 sec and 0.4 sec the torque fluctuates at 0.2 sec and 2500 rpm at 0.4 sec but settles soon to final value. Even though, the speed changes torque remains constant apart from fluctuations.

Case 2: Variable decremented speed with fixed torque

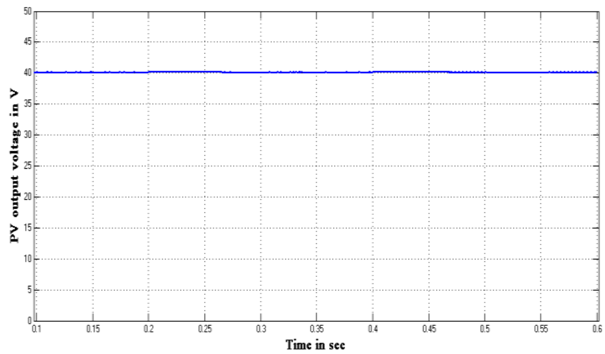

Figure-14. Output voltage from PV.

The output voltage from photo-voltaic system is shown in Figure-14. PV yields the output of 40V as shown in Figure.

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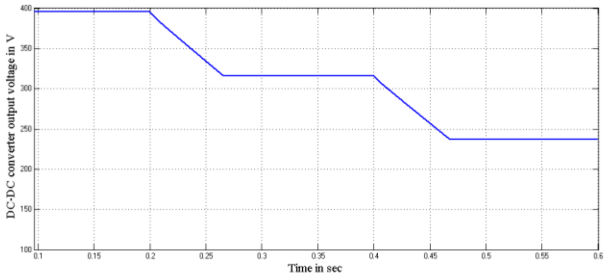

Figure-15. Output voltage from DC-DC converter.

The output voltage from high gain DC-DC converter is shown in Figure-15. DC-DC converter decreases the level of PV voltage and gives out the output as shown in figure since the variable speed condition is applied. The DC-DC converter voltage changes at 0.2 sec and 0.4 sec. Decremented 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. Accordingly, the DC-DC converter yields output voltage of initially at 400 V with change to 320 V at 0.2 sec and to 240 V at 0.4 sec corresponding to respective speeds.

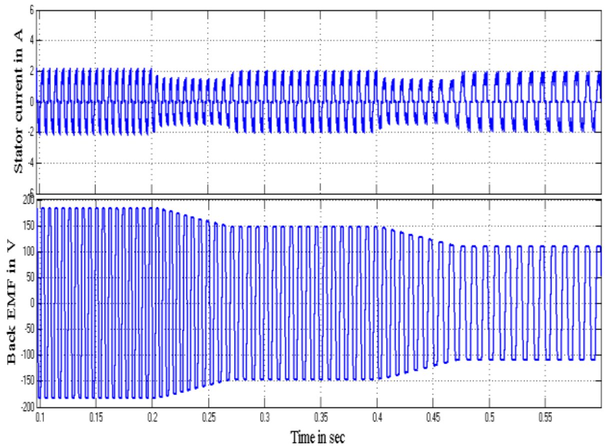

Figure-16. Stator current and back EMF of BLDC motor.

Stator current of one phase of BLDC motor and back EMF are shown in figure 16. Since variable speed commands are given, the stator currents vary at respective times of 0.2 sec and 0.4 sec. Back EMF decrease respectively with decrease in speed.

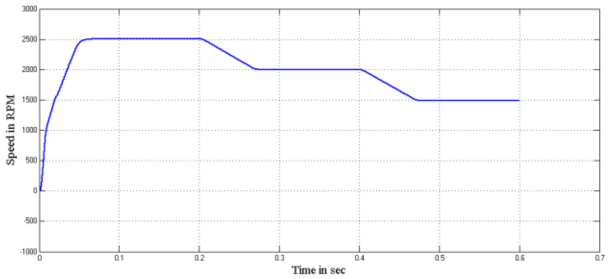

Figure-17. Speed of BLDC motor.

Speed of BLDC motor is shown in Figure-17. Since the variable speed condition is applied, the changes at 0.2 sec and 0.4 sec. Decremented 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.

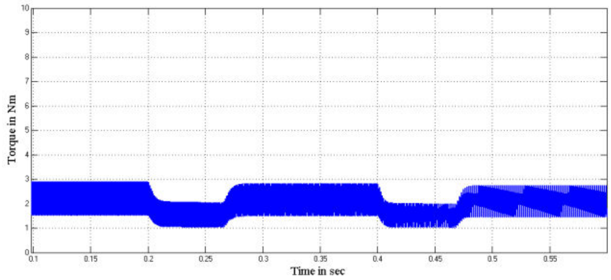

Figure-18. Torque of BLDC motor.

Torque of BLDC motor is shown in Figure-18. Since the variable speed condition is applied, the change at 0.2 sec and 0.4 sec the torque fluctuates at 0.2 sec and 2500 rpm at 0.4 sec but settles soon to final value. Even though, the speed changes torque remains constant apart from fluctuations.

Case 3: Variable torque with fixed speed

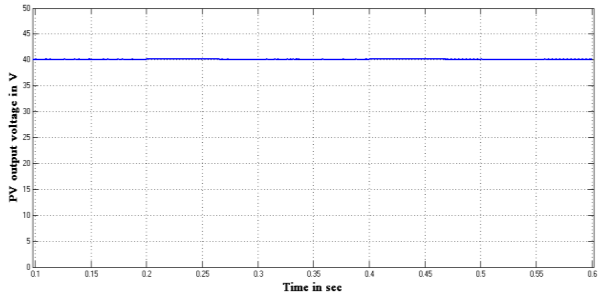

Figure-19. Output voltage from PV.

The output voltage from photo-voltaic system is shown in Figure-19. PV yields the output of 40V as shown in figure.

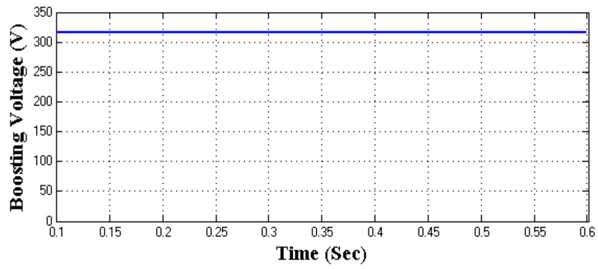

Figure-20. Output voltage from DC-DC converter.

The output voltage from high gain DC-DC converter is shown in Figure-20. DC-DC converter increases the level of PV voltage from 40 V and gives out the output of 320V as shown in figure. With no speed change command, the output of DC-DC converter is constant.

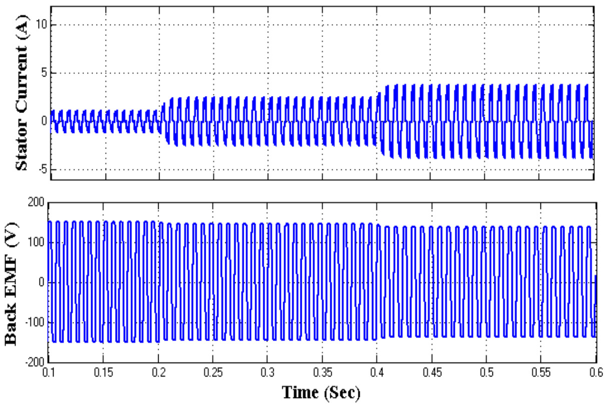

Figure-21. Stator current and back EMF of BLDC motor.

Stator current of one phase of BLDC motor and back EMF are shown in Figure-21. Since speed command is maintained constant, back EMF is also constant. Torque is varied and thus stator currents are also varied at 0.2 sec and at 0.4 sec respectively.

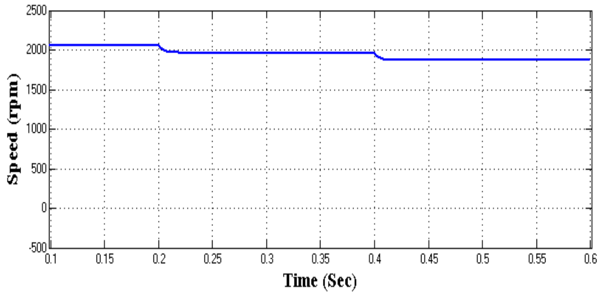

Figure-22. Speed of BLDC motor.

Speed of BLDC motor is shown in Figure-22. The torque is varied with fixed speed condition; the actual speed is varied at 0.2 sec and at 0.4 sec. Since actual speed of BLDC is not measured and involved in control methodology, speed varied when torque is varied.

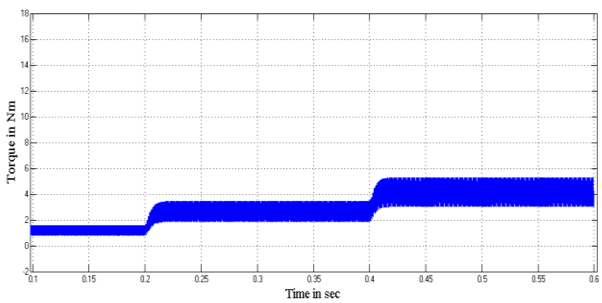

Figure-23. Torque of BLDC motor.

Torque of BLDC motor is shown in Figure-23. Torque variable command is given at 0.2 sec and 0.4 sec and hence the torque varies respectively at that particular time periods. As BLDC is run with variable torque and fixed speed condition and when the torque is varied the result shows it is not possible to keep speed fixed or constant.

CONCLUSIONS

The use of BLDC motors are been increasing these days due to its advantages over other conventional motor types. This paper presents a photo-voltaic fed high voltage gain closed-loop DC-DC converter for BLDC motor drive application and BLDC motor drive is controlled using a simplified control strategy. Low voltage DC output from photo-voltaic (PV) system is stepped-up to desired value using a high-gain closed-loop DC-DC converter. The simplified control strategy is explained and the control strategy proposed does not actually sense the actual speed of BLDC motor. Simulation analysis for the proposed system is carried out for variable incremental/decremented speed with fixed torque and for variable torque with fixed speed conditions. The proposed simplified control strategy for speed control of BLDC motor drive in this paper is found very much suitable for fixed torque with variable speed conditions but found not very much suitable for variable torque and fixed speed conditions through simulation analysis. This type of motor drive is very much suitable for air-conditioner applications

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