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Photo-Voltaic Fed Interleaved Boost Converter with Simple Speed Control in BLDC Motor Drive

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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 closed-loop interleaved Boost DC-DC converter for BLDC motor drive application and BLDC motor drive is controlled using a simplified speed control strategy. The output of interleaved boost 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 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 in this paper for speed control of BLDC motor drive founds very much suitable for fixed torque with variable speed conditions but found not much for variable torque and fixed speed conditions through simulation analysis. Proposed system was developed and results are analysed using MATLAB/SIMULINK software.**

Index Terms—**BLDC, interleaved boost, DC-DC, 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 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.

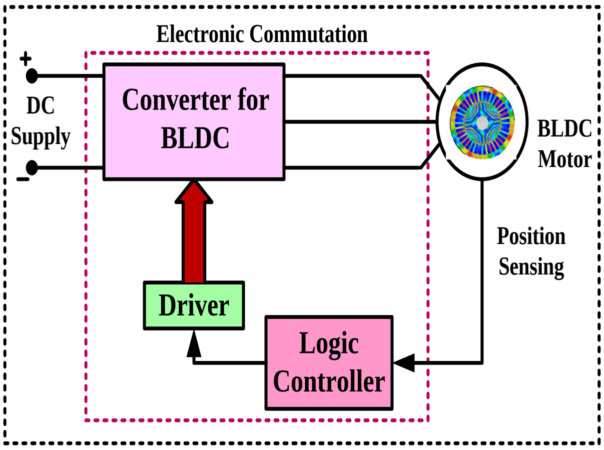


Figure 1: Block diagram of BLDC motor

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 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.

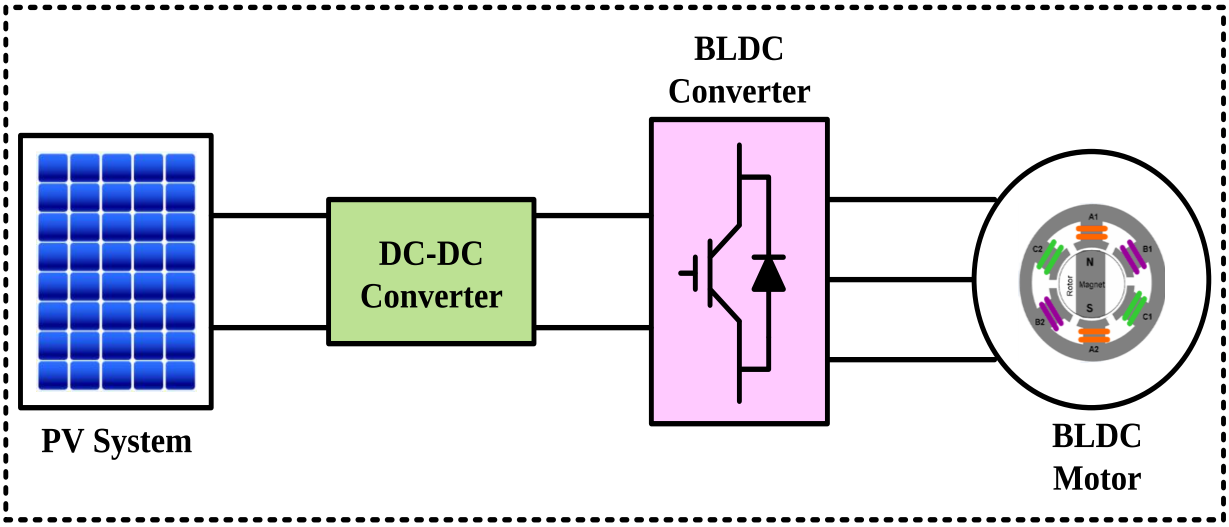


Figure 2: Block diagram of proposed system with PV with DC-DC converter fed BLDC motor.

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. Interleaved boost 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 interleaved boost closed-loop DC-DC converter for BLDC motor drive application [8-10] as shown in figure 2 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 an interleaved boost 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 analysed using MATLAB/SIMULINK software.

PV FED INTERLEAVED BOOST CONVERTER

A. Interleaved Boost converter

The circuit configuration of interleaved DC-DC boost converter is shown in figure 3. The low voltage DC source is fed to interleaved boost DC-DC converter to rise-up the level of voltage.

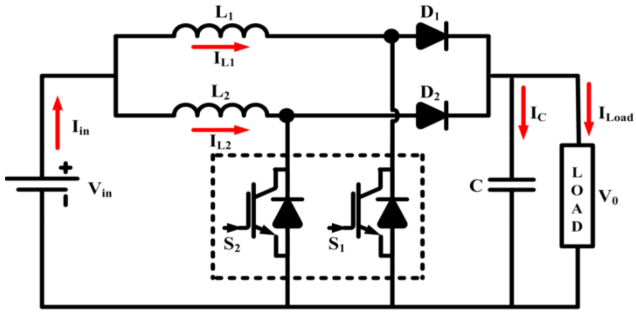
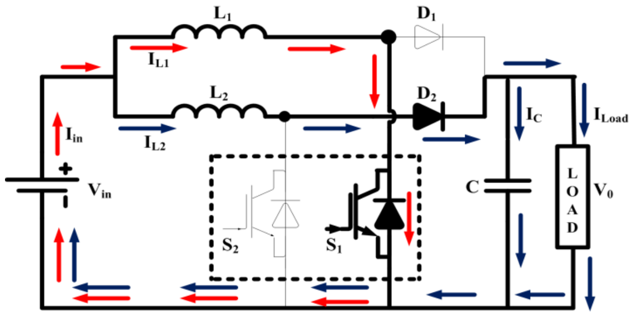
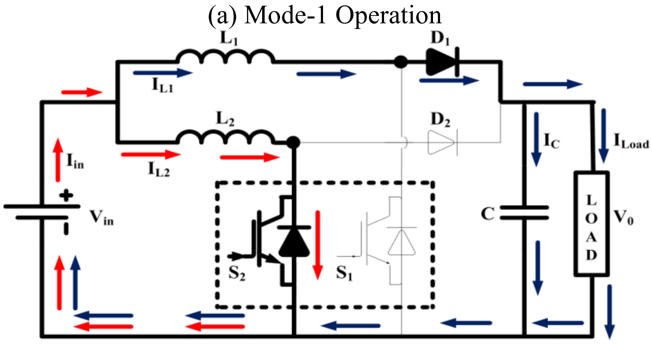


Figure 3: Schematic Diagram of Interleaved DC-DC Boost Converter



(a) Mode-1 Operation



(b) Mode-II Operation

Figure 4: Modes of operation of interleaved boost converter

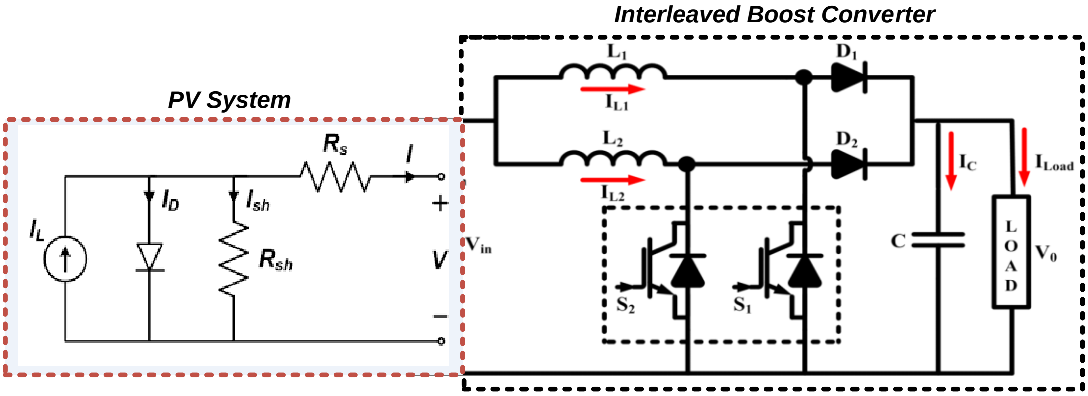


Figure 5: PV fed interleaved boost converter

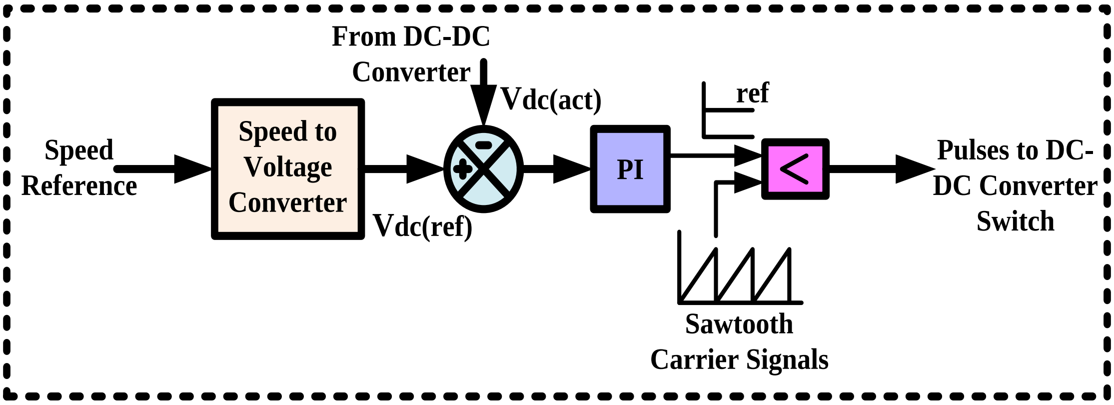


Figure 6: Simplified control strategy for speed control of BLDC motor.

The conventional DC-DC boost converter has more voltage factor, etc. Based on these favourable disadvantages, the formal DC-DC boost converter is replaced by proposed interleaved boost DC-DC converter and used in DG application. The proposed interleaved DC-DC boost converter has been evaluated in recent reliability, modular, low stress, ripple current reduction in both output/input components. Achieving the high efficiency is by replacing the dual circuits into 'N' component level, subsequently minimizing the inductor & I^2R losses. The ripple component of the input current is reduced by employing the interleaving inductors; makes minimizing the input side filter size would be boost DC-DC converter is generally employed in high rated input current as well, greater input-outcome voltage transformation applications. The dual-phase sequences of the interleaved converter are driven by 180° out of phase sequences, for this reason the phase shifting is provided. The phase shifting angle is possible as the number of phase sequences. The basic schematic diagram of dual-phase interleaved DC-DC converter is depicted in Figure 3. The operating principle of proposed Interleaved DC-DC converter is comprised of two modes, for DG application by using photo-voltaic (PV) system.

Mode I: At position t=0; the switch $S_1$of first phase is conducted (ON-state) by gate pulse provided by gate pulse generator. The current at the inductor L_1 linearly rising, the switch S_2 is at second phase as non-conducted (OFF-state) and the energy stored in inductor L_2 is moved to load via phase L_1 goes to rise linearly and charging, other side the inductor L_2 goes to discharge the energy to load via followed diode D_2. The mode of operation during switch $S_1$of first phase is conducting (ON-state) and switch S_2 of second phase is not conducted (OFF-state) is shown in figure 4 (a).

Mode II: At time $t=t_1$; the switch S_1 of first phase is non-conducting position & second phase of switch S_2 is conducted by proper gate pulse generation as shown in figure 4 (b). The current at inductor L_2 is linearly raising, the inductor is to be charged with respect to duty ratio of the switch. At same situation, the switch S_1 of first phase is un-conducted and the inductor current discharged linearly to load. Transform the stored energy in inductor t_1, the switch S_1 is non-conducted or switched OFF. The inductor of other phase L_2 goes to rise linearly and charging, other side the inductor L_1 under discharging to load via followed diode D_1.

B. PV Fed Interleaved Boost converter

A photovoltaic system, also PV system or solar power system is a power system designed to supply usable solar power by means of photo-voltaic. 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.

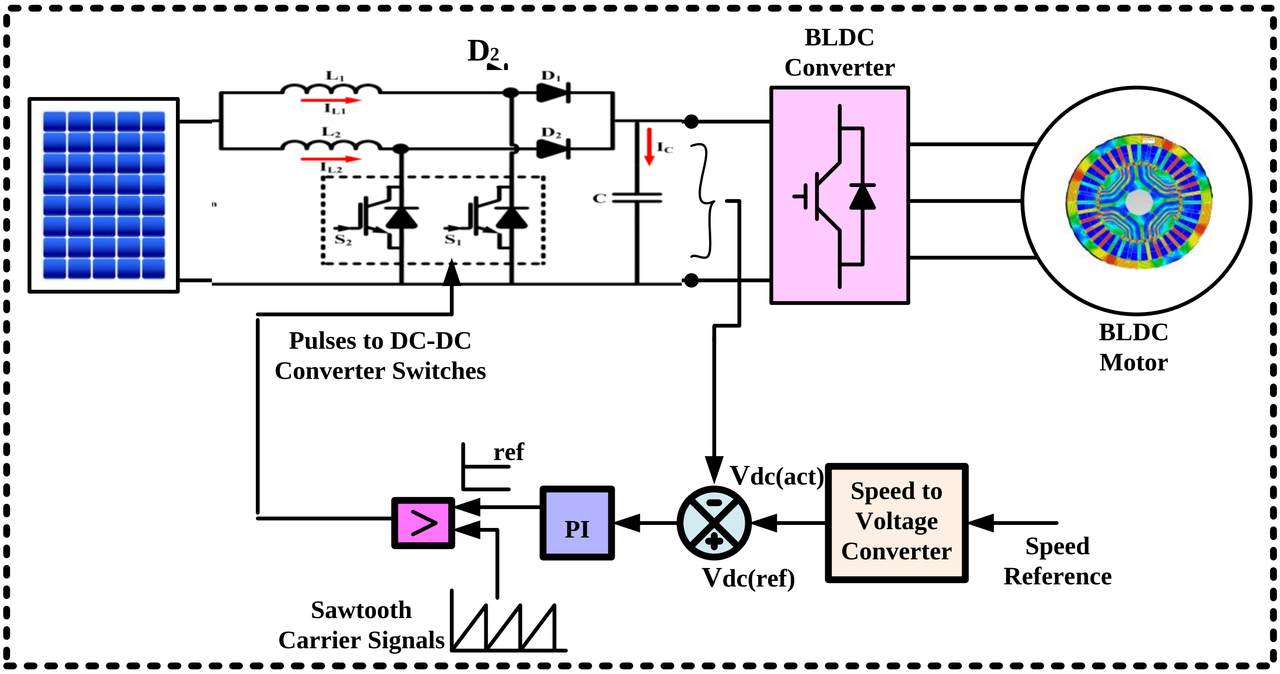


Figure 7: Schematic arrangement of PV fed interleaved boost DC-DC converter for BLDC motor drive with simplified control scheme

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. PV fed interleaved DC-DC boost converter is shown in Figure-5. PV system generally produces the output voltage at low voltage level. The low voltage output of PV system is fed to interleaved DC-DC boost converter to boost the voltage at required level.

SPEED CONTROL OF BLDC DRIVE

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 6. 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 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 DC-DC converter. The DC-DC converter 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 interleaved boost (closed-loop) DC-DC converter for BLDC motor drive with simplified control scheme is depicted in figure 7. Low voltage DC output from photo-voltaic (PV) system is stepped-up to desired value using a interleaved boost 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 interleaved boost DC-DC converter to yield required voltage level that will be sufficient to drive BLDC motor at required speeds.

RESULTS AND ANALYSIS

C. Variable incremental speed with fixed torque

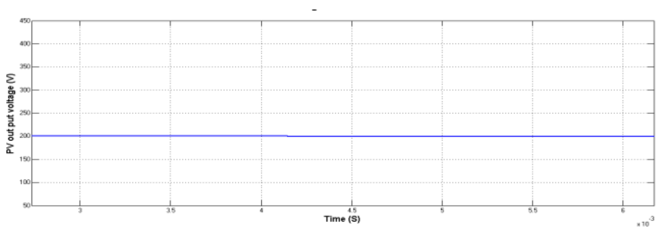


Figure-8. Output voltage from PV.

The output voltage from photo-voltaic system is shown in Figure-8. PV yields the output of 200V as shown in figure.

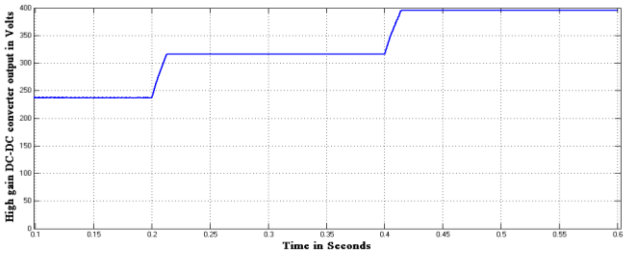


Figure-9. Output voltage from DC-DC converter.

The output voltage from interleaved boost DC-DC converter is shown in figure 9. 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.

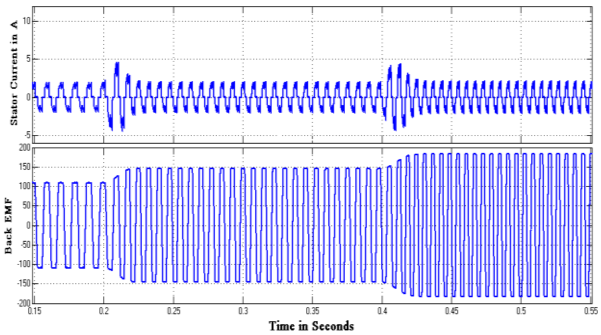


Figure-10. Stator current and back EMF of BLDC motor.

Stator current of one phase of BLDC motor and back EMF are shown in Figure-10. 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.

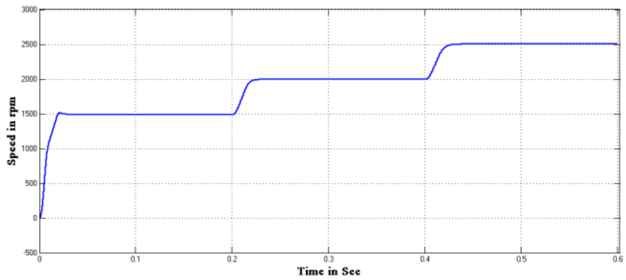


Figure-11. Speed of BLDC motor.

Speed of BLDC motor is shown in Figure-11. 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.

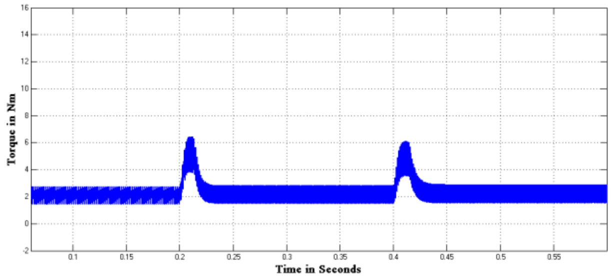


Figure-12. Torque of BLDC motor.

Torque of BLDC motor is shown in Figure-12. 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.

D. Variable decremental speed with fixed torque

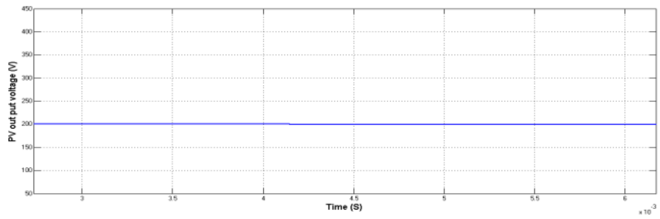


Figure-13. Output voltage from PV

The output voltage from photo-voltaic system is shown in Figure-13. PV yields the output of 200V as shown in Figure.

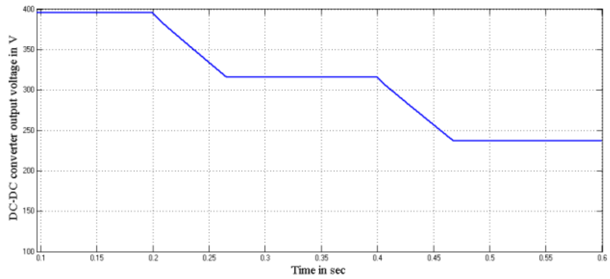


Figure-14. Output voltage from DC-DC converter.

The output voltage from interleaved boost DC-DC converter is shown in Figure-14. 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.

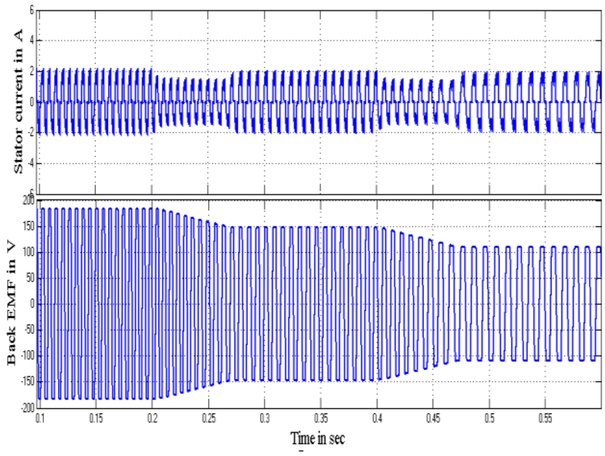


Figure-15. Stator current and back EMF of BLDC motor.

Stator current of one phase of BLDC motor and back EMF are shown in figure 15. 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.

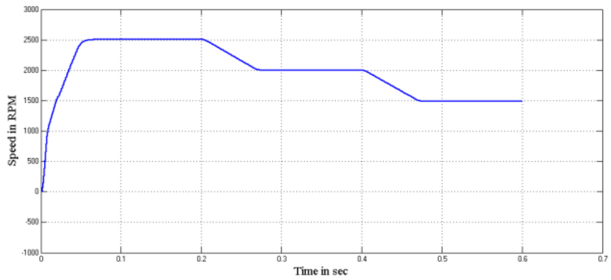


Figure-16. Speed of BLDC motor.

Speed of BLDC motor is shown in Figure-16. 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.

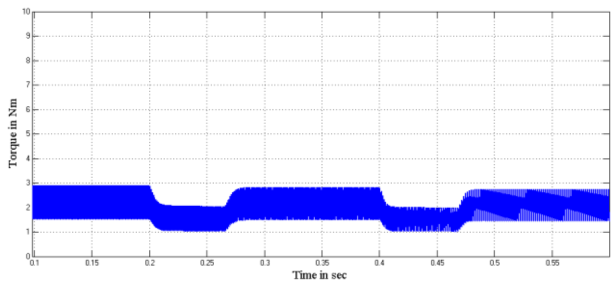


Figure-17. Torque of BLDC motor.

Torque of BLDC motor is shown in Figure-17. 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.

E. Variable torque fixed speed

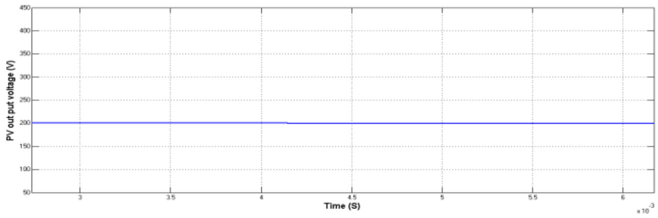


Figure-18. Output voltage from PV.

The output voltage from photo-voltaic system is shown in Figure-18. PV yields the output of 200V as shown in figure.

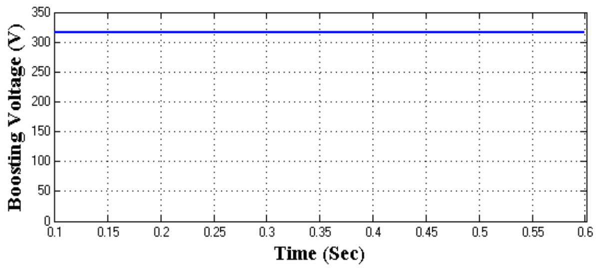


Figure-19. Output voltage from DC-DC converter.

The output voltage from interleaved boost DC-DC converter is shown in Figure-19. DC-DC converter increases the level of PV voltage from 200 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.

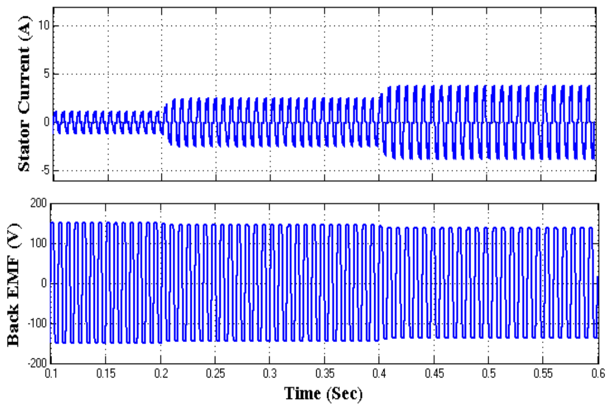


Figure-20. Stator current and back EMF of BLDC motor.

Stator current of one phase of BLDC motor and back EMF are shown in Figure-20. 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.

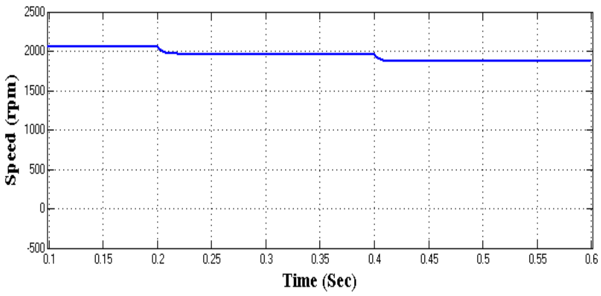


Figure-21. Speed of BLDC motor.

Speed of BLDC motor is shown in Figure-21. 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 varies when torque is varied.

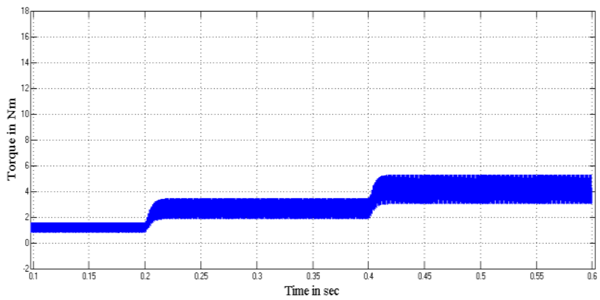


Figure-22. Torque of BLDC motor.

Torque of BLDC motor is shown in Figure-22. 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.

CONCLUSION

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 interleaved boost closed-loop DC-DC converter for BLDC motor drive application and BLDC motor drive is controlled using a simplified speed control strategy. Low voltage DC output from photo-voltaic (PV) system is stepped-up to desired value using an interleaved boost closed-loop DC-DC converter. The simplified speed 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.

REFERENCES

[1] P. K. Sharma and A. S. Sindekar. 2016. Performance analysis and comparison of BLDC motor drive using PI and FOC. *2016 International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC)*, Jalgaon, India. pp. 485-492.

[2] D. Kamalakannan, N. J. Singh, M. Karthi, V. Narayanan and N. S. Ramanathan. 2016. Design and development of DC powered BLDC motor for Mixer-Grinder application. *2016 First International Conference on Sustainable Green Buildings and Communities (SGBC)*, Chennai. pp. 1-6.

[3] M. K. Kim, H. S. Bae and B. S. Suh. 2006. Comparison of IGBT and MOSFET inverters in low-power BLDC motor drives. *2006 37th IEEE Power Electronics Specialists Conference*, Jeju. pp. 1-4.

[4] A. Bag, B. Subudhi and P. K. Ray. 2016. Grid integration of PV system with active power filtering. *2nd International Conference on Control, Instrumentation, Energy & Communication (CIEC)*, Kolkata. pp. 372-376.

[5] D. Noel, F. Sozinho, D. Wilson and K. Hatipoglu. 2016. Analysis of large scale photovoltaic power system integration into the existing utility grid using PSAT. *Southeast Con 2016*, Norfolk, VA. pp. 1-7.

[6] V. S. Bugade and P. K. Katti. 2015. Dynamic modelling of microgrid with distributed generation for grid integration. *International Conference on Energy Systems and Applications*, Pune. pp. 103-107.

[7] N. Eghtedarpour, E. Farjah. 2012. Control strategy for distributed integration of photovoltaic and energy storage systems in DC micro-grids, *Renewable Energy (Elsevier).* 45: 96-110.

[8] R. Kumar and B. Singh. 2016. BLDC Motor-Driven Solar PV Array-Fed Water Pumping System Employing Zeta Converter. in *IEEE Transactions on Industry Applications*. 52(3): 2315-2322, May-June.

[9] M. Ouada M. S. Meridjet N. Talbi. 2013. Optimization photovoltaic pumping system based BLDC using fuzzy logic MPPT control Proc. Int. Renew. Sustain. Energy Conf. (IRSEC) pp. 27-31 Mar.

[10] A. Terki A. Moussi A. Betka N. Terki. 2012. An improved efficiency of fuzzy logic control of PMBLDC for PV pumping system Appl. Math. Modell. 36(3): 934-944 Mar.