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Research Paper

IMPLEMENTATION OF PFC CONVERTER BASED DIGITAL SPEED CONTROLLER FOR BLDC MOTOR DRIVES

K Kamalapathi[1], P Suresh[1]* and P Venkata Vara Prasad[1]

*Corresponding Author: P Suresh ✉ suresh.penagaluru@gmail.com

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This paper provides a implementation of Power Factor Corrected (PFC) converter based digital speed controller for BLDC Motor Drives for industrial and domestic applications. In this paper, the complete procedure is implemented for sensor BLDC motor speed controllers by using DSP based controllers with real time implementation. This paper also discussed with implementation methodology and their effects in the control action were discussed in detail for each technique. This paper is intended to serve as a suitable reference for future research work in BLDC motor speed controller and its related research.

Keywords: Bridgeless (BL) converter, Brushless Direct Current (BLDC) motor, Digital Speed Controller (DSP)

INTRODUCTION

In most of the applications in electrical engineering needs electric motion control with good operating conditions. Good operating conditions includes the good operating power factor at the running conditions of the drive,that requires the Power Factor Corrected (PFC) converters. BLDC are more reliable and efficient for all the applications includes domestic and industrial purposes. The comparison table of BLDC motor with other motors is shown in the below Table1.

From the Table 1 it concludes that the BLDC motor has less maintenance, high efficiency, high speed ranges, low rotor losses and low acoustic noise are the main advantages of BLDC motors (Tashakori and Ektesabi, 2012).

Two popular types of permanent magnet synchronous motors according to the Electro Motive Force (EMI) are:

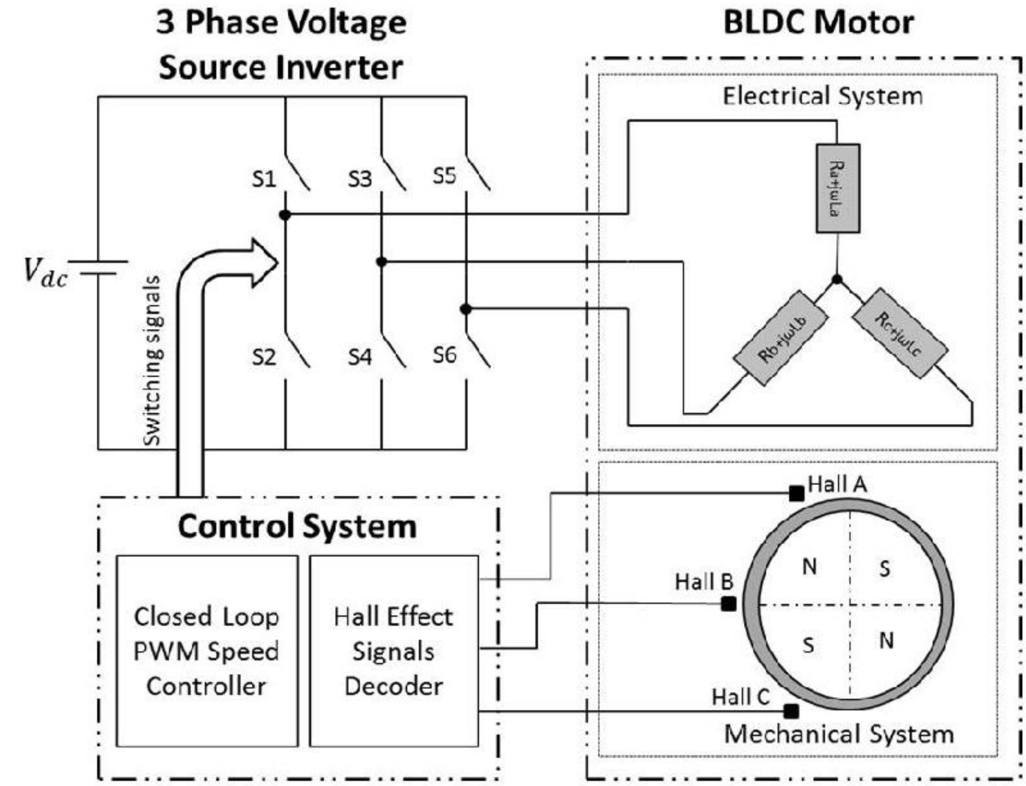
1. Permanent magnet synchronous motor with sinusoidal wave back EMF that are called as Permanent Magnet Synchronous ac Motors (PMSM).
2. Permanent magnet synchronous motor with trapezoidal wave back EMF that are called permanent magnet brushless DC (BLDC) motors.

[1] Assistant Professor, Department of EEE, SV College of Engineering, Tirupati, AP, India.

Table 1. Comparision With Other Motors

Feature	Mechanical Structure	Maintenance	Speed –Torque Characteristics	Efficiency	Commutation Method	Speed Range
Brush less dc motor	Field magnets on the stator and rotor are made of permanent magnets	Low or no maintenance	Flat-operation at all speeds with rated load	High-no losses in the brushes	Using solid state switches	High-no losses in brushes
Brushed dc motor	Field magnets on the rotor and stator	Periodic maintenance because of brushes.	Moderate-loss in torque at higher speeds	Moderate-losses in the brushes; rotor is on the inner periphery	Mechanical contacts between brushes and commutator	Moderate-losses in brushes
Induction motor	Both rotor and stator have windings	Low maintenance	Non linear	Low heat and current losses in both stator and rotor	Special starting circuits are required	Low-determine by frequency

Figure 1: Block Diagram of 3-Phase BLDC Motor



Issues of Low Power Factor

The main cause of the low power factor are the inductive loads, i.e., Induction motors, transformers and some lighting loads. Such applications requires the magnetizing current to produce the working flux and hence it works at a low power factor. If the power factor is low then the system operation is uneconomical. The main causes of low power factor are

1. Due to the power electronics converters applications the input current to the converter contains the harmonic currents which leads to the low power factor.
2. In some applications mismatch of phases are also lead to the 3-phase imbalance power. This also results in the low power factor in the system.

In this paper some of the PFC converters are presented along with the merits and demerits.

Power Factor Corrected (PFC) Converters

In present days power quality are become more important problem to be considered due to the harmonic consideration limits in the current waveform. According to the International Electromechanical Commission (IEC) 61000-3-2 (Nayanar *et al.*, 2016) for class-A equipment (<600 w,16A per phase) includes house hold and industrial applications. As per the survey of IEC, must and should the Total Harmonic Distortion (THD) in the supply current is below 19%.

Suppose a BLDC motor is connected to an voltage source inverter by an bridge rectifier with high value of the DC link capacitor. Then motor draws non-sinusoidal current which is rich in the harmonic content of 65% and a low power factor of 0.8 (Singh and Singh, 2012). Then definitely a bridge rectifier followed by the PFC converter is needed to improve the power quality of the a.c mains. By eliminating the bridge rectifier the number of switches and switching losses are reduced. Different topologies of PFC converters along with number of devices, conduction, suitability is tabulated in the below Table 2.

The different methods to control the power factor of the load is given below

1) Maximum current control

2) Mean current control

Table 2: Different Topologies of PFC Converters

Converter	Number of Devices					Conduction	Suitability
	S	D	L	C	Total		
BL-Buck (Jang and Jovanovic, 2011)	2	4	2	2	10	5	No
BL-Boost (Huber *et al.*, 2008)	2	2	1	1	6	4	No
BL-Boost (Fardoun *et al.*, 2012)	2	2	1	2	7	7	No
BL-Buck Boost (Wei *et al.*, 2008)	3	4	1	3	11	8	Yes
BL-Cuk-T-1 (Fardoun *et al.*, 2010 and 2012)	2	3	3	3	11	7	Yes
BL-Cuk-T-2 (Sabzali *et al.*, 2011; and Mahdavi and Farzaneh-Fard, 2012)	2	2	3	4	11	11	Yes
BL-Cuk-T-3 (Nalbant and Klein, 1990; and Klein and Nalbant, 1990)	2	4	4	3	13	7	Yes
BL-Cuk (Zhou and Jovanovic, 1992)	2	3	3	2	10	8	Yes
BL-SEPIC (Redl and Erisman, 1994)	2	3	1*	3	9	7	Yes

Note: In this Table 2 BL-Bridge Less, S-Switches, *coupled inductor.

3) Hysteresis current control

4) Discontinuous current PWMcontrol

5) Fly back PFC

6) CUK and SEPIC PFC

Maximum Current Control

In this control method, the input current to the controller is continuous and the bridge diodes is become slow(because of they conduct at a line frequency). More over, the freewheeling diode operates on the hard turn-off process. Due to this switching noise and losses are increased (Nalbant and Klein, 1990; Klein and Nalbant, 1990; Zhou and Jovanovic, 1992; Redl and Balogh, 1992; Redl and Erisman, 1994; and Maksimovic, 1994).

Merits

- Switching frequency is constant.
- By using the current transformer the switch current must be sensed, due to sensing resistorthe losses is reduced.
- Possibility of a true switch current limit.

De-Merits

- For duty cycles of greater then 50% the sub harmonic disturbances are not avoided. So, a compensation ramp is used (Redl and Erisman, 1994; and Maksimovic, 1994)
- It is more sensitive for the commutation noises.

Mean Current Control

In this control method, the input current is better then the mean current control.In this scheme current error amplifier is used for sensing and filtering the inductor currentand also output drives a PWM modulator (Zhou, 1989; Zhou *et al.*, 1990; Canesin and Barbi, 1991; Balogh and Redl, 1993; Thomson Microelectronics, 1993; and Wrzecionko *et al.*, 2015). In this manner the error is reduced between the reference value and mean value by using the inner current loop.

Merits

- Switching frequency is constant.
- Compensation ramp is not needed.
- Less sensitive to the commutation problems,due to current filtering.
- Input current wave form is better then the peak current control (Redl and Erisman, 1994).

De-Merits

- Current passing through inductor is must sensed.
- Current error amplifier is needed and its compensation network design must take into account.

Hysteresis Control Method

In this method, two co-sinusoidal current waveforms are taken as a references. One of this control current is valley value inductor current and the other is the peak value inductor current.

The principle of this method is,when the inductor current reaches below the valley value then the switach “S” is ON. If the inductor current value reaches above the peak value then the switch “S” is OFF. This method has a changing frequency control (Kocher and Steigerwald, 1983; Cherry Semiconductors, 1992; and Lai and Chen, 1993).

Merits

- Ramp compensation is not required.
- Input current is less distorted.

De-Merits

- Variable frequency control.

- Current passed through the inductor must be sensed.
- For commutation problems it is more sensitive.

Discontinuous Current PWM Control

In this control method, current loop which is present internally for other methods is completely eliminated. Therefore the switch is operated in a constant frequency (see Figure 2) and also working of the converter is in discontinuous conduction mode, this converter allows nearly unity power factor. One of the advantage this method is to not introduce hormonics when we use the converters like SEPIC, CUK and FLY BACK converters but with the use of boost converter it introduce distorted harmonics in the line current.

Hysteresis controller operates in voltage mode and current mode implementations.

In current mode hysteresis controller, the output inductor current integrates the differential voltage between the output voltage of the power stage and the output voltage of the amplifier.

The voltage mode hysteresis controller differs from the current mode controller by integrating the difference between the output voltage of the power stage and the input reference voltage with an active integrator, which again results in a saw-tooth shaped carrier which is fed to a hysteresis window.

Merits

- Constant switching frequency;
- No need of current sensing;
- Simple PWM control;

De-Merits

- Higher devices current stress than for borderline control.
- Input current distortion with boost topology.

The below Figure 3 shows that the digital PWM control scheme for the BLDC motor.In this control bridgeless buck-boost converter is connected at front end of the motor. The converter parameters are designed in such a way that the converter is operated in the Discontinuous Inductor Current Mode (DCIM). The main purpose of this scheme is to achieve better performance through good power factor at ac mains.

The different speeds of the drive is obtained by the control of the d.c link voltage of the Voltage

Figure 2: Discontinuous Current PWM Control Scheme

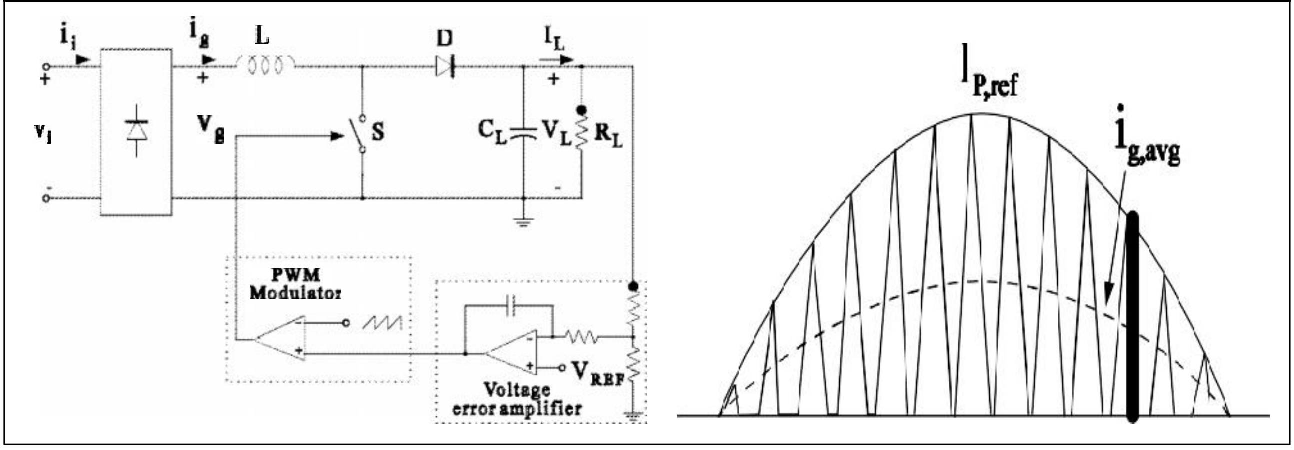
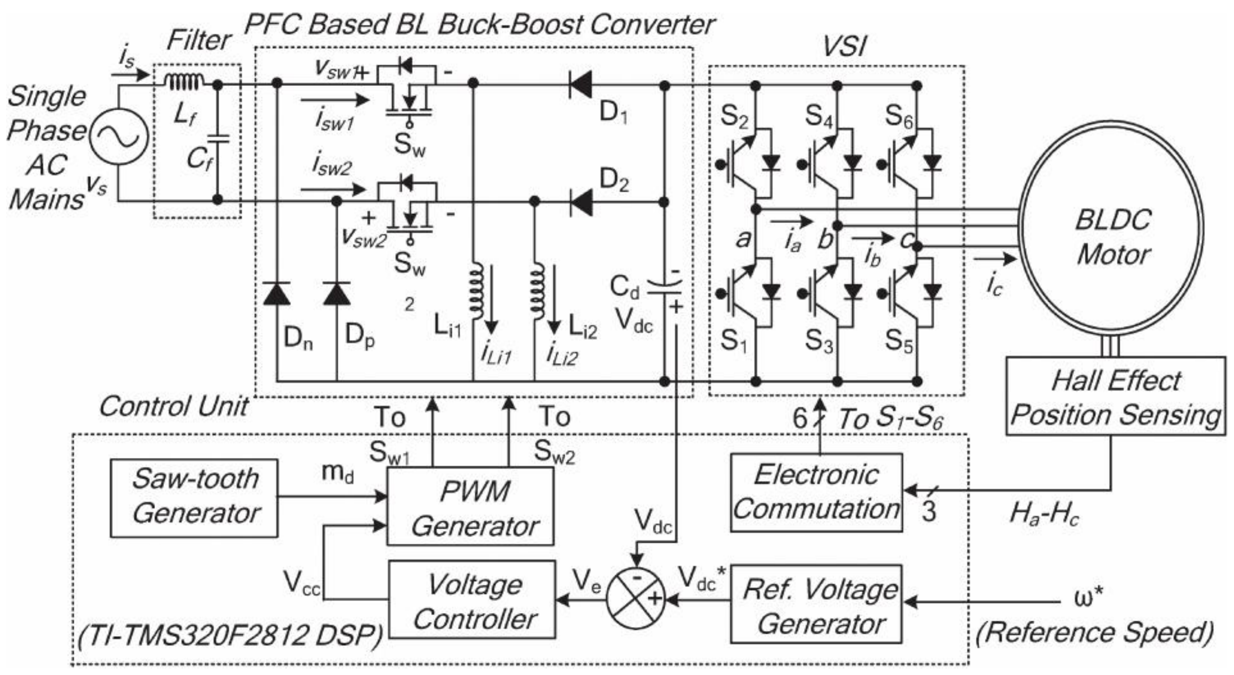


Figure 3: Block Diagram of BLDC Motor with Digital PWM Scheme



Source Inverter (VSI) fed by bridge less buck-boost converter. By using this scheme the switching losses are eliminated because of the very low frequency mode of operation of converter with electronic commutation of the drive.

The complete evaluation is carried out by the use of different speed ranges is obtained from the variation of voltages across the VSI also the improved power factor.In this scheme the number of conducting devices and components is less during every half cycle of the supply voltage.The VSI switches are operated according to position of the rotor send by hall effect position sensing (H_a–H_c) signals. The buck-boost converter switches (S_{W1}-S_{W2}). The entire control is achieved by using by the using DSP Controller.

Operation of the BUCK-BOOST Converter

The operation of the buck boost converter is based upon the negative and positive half cycles of the main supply voltage. In this scheme, the switches S_{w1} and S_{w2} are operated according to the positive and negative cycles of the supply voltage.In the period of the positive half cycle the energy is transfer to capacitor *Cd* through the switch S_{w1}, diodes D_1-D_p and inductor L_{i1}, are conducted. Similarly, in the negative half cycle of the supply voltage, switch S_{w2}, diodes D_2-Dn and inductor L_{i2}, conduct. In the DICM operation inductor L_i is operated in discontinuous mode for a certain period of the switchingcycle.

SIMULATION RESULTS

MATLAB/Simulink diagram is shown in Figure 4.

The above circuit shows a simulation of power factor corrected bridge less converter fed brushless D.C motor drive. This circuit presents effective minimization of prices for targeted industrial and domestic applications (Chen *et al.*,

Figure 4: Simulation Circuit

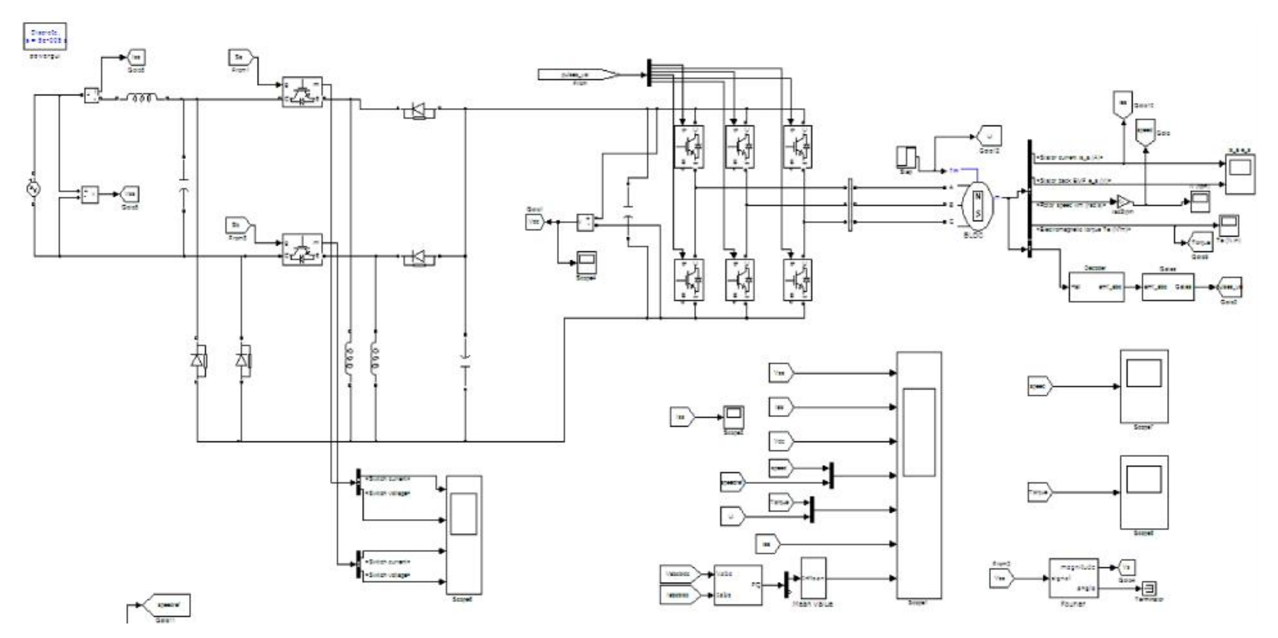
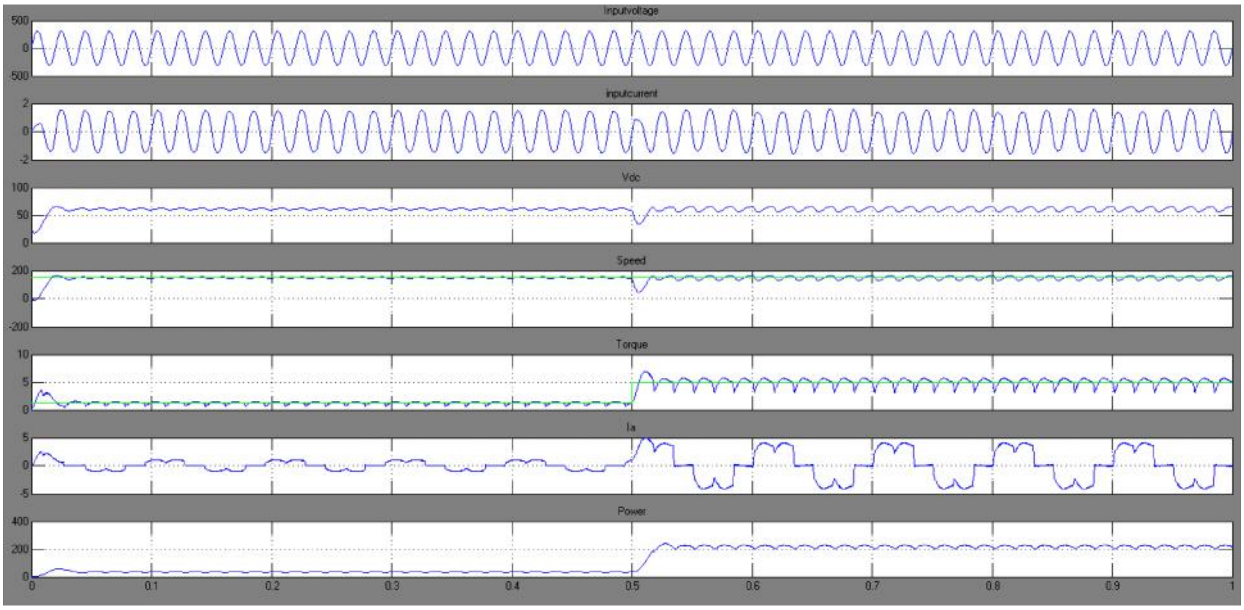


Figure 5: Speed Constant at 200 rpm at 0.5 sec Load is Changed from 1.2 to 5 N/m²

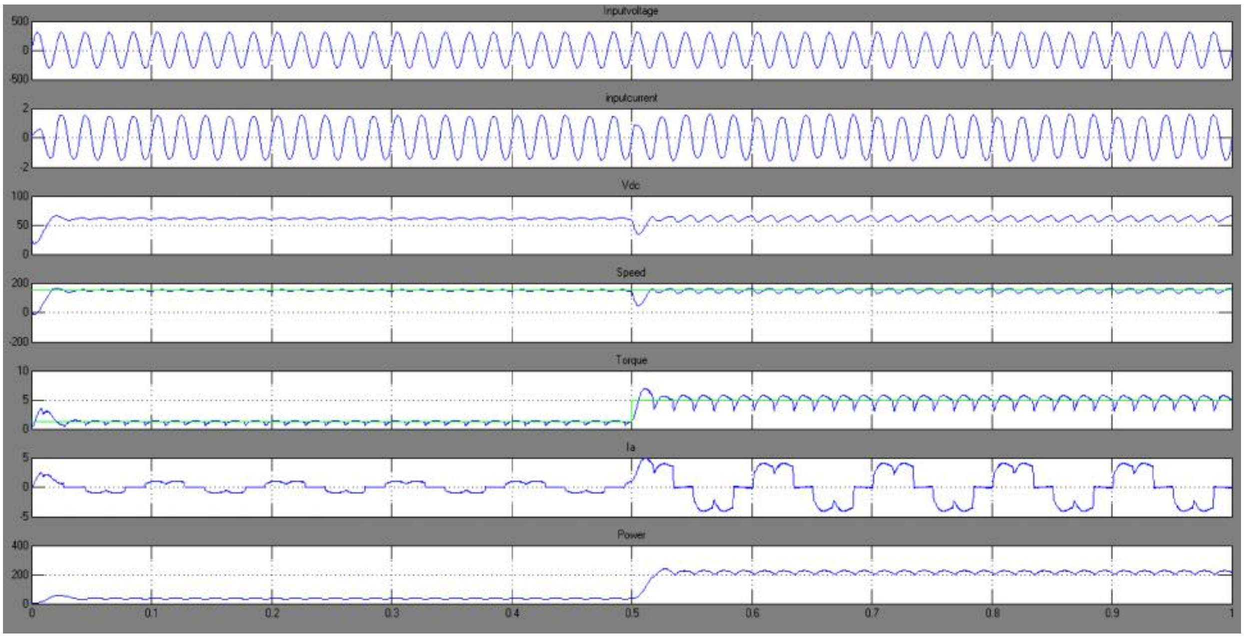


2013). The speed of BLDC motor is also controlled for different speeds by varying the D.C input voltage of the converter (Vashist Bist, 2014). The results obtained for different speeds is shown in the Figures 5 and 6.

Speed = 1500 rpm from 0 to 0.3, speed = 700 rpm from 0.3 to 0.7, speed = 1000 rpm from 0.7 to 1.

Torque = 1.2 N/m^2 from 0 to 0.5, Torque = 5 N/m^2 from 0.5 to 1.

Figure 6: Different Speed Conditions and Different Load Conditions



Motor Specifications

Number of poles = 4

Rated power = 250 W

Rated D.C link voltage = 200 V

Rated Torque = 1.2 N-m

Rated Speed = 2000 rpm

Phase resistance = 14.56 ohm

Phase inductance = 25.71 mH

CONCLUSION

In this paper, various methods of power factor corrected boost converters with merits and demerits are discussed. More-over, the bridgeless PFC buck-boost converter is simulated at various speeds considerations. In future work the same model is implemented by developed by using DSP controller with CUK,SEPIC and FLY-BACK converters. Switching losses is also reduced and maintain power quality throughout the standard ac lines targeted both industrial and domestic applications.

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