

## RESEARCH ARTICLE

## Performance analysis of low harmonics and high efficient BLDC motor drive system for automotive application

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### Abstract

This study presents a comparative study of VSI, CSI and Buck Converter based CSI fed BLDC Motor for automotive applications. The aim of the work is to reduce the cost and size of a brushless dc motor (BLDC) drive as well as increase the reliability and ruggedness of the drive. Traditional BLDC drives use Voltage Source Inverter (VSI) that utilize hard switching, thereby generating switching losses and entail the use of large heat sinks. VSI needs a huge dc link capacitor that is inherently unreliable and is one of the most expensive components of the drive. Hence, a Current Source Inverter (CSI) is used to replace the hard switching by soft switching; thereby eliminating the heat sinks as well as the large dc link capacitor. A controlled rectifier together with a large inductor acts as a current source, the only disadvantage is the large value of the dc link inductor and the huge number of turns needed to achieve these values of the inductances lead to huge resistive losses. Therefore, it is shown that it is possible to replace the controller rectifier and the large inductor with a suitable Buck converter based current source inverter can be switched at high frequencies with much smaller value of the dc link inductor without increasing the current ripples. Hence, it is possible to have the advantage of using a CSI as well as reduce the value of the dc link inductor without a corresponding increase in the heat sink. The effectiveness of the VSI and CSI fed BLDC motor schemes are verified through the simulation results.

**Keywords:** Buck converter, brushless dc motor, current source inverter, controller rectifier, dc link inductor.

### Introduction

In recent years brushless dc (BLDC) motors are widely used in a number of industrial applications such as space operated vehicles, hard disk drives and compressors because of their high efficiency, high starting torque, reliability, lower maintenance compared to its brushed dc motor. Over the last decade, continuing improvements in power semiconductors and controllers as well as the BLDC motor production have made it to manufacture reliable cost effective solutions for a wide range of automotive applications. A brushless dc motor is a dc motor turned inside out, so that the field is on the rotor and the armature is on the stator (Bose, 1996). The brushless dc motor is actually a permanent magnet ac Motor, whose torque-current characteristics mimic the dc motor. Instead of commutating the armature current using brushes, electronic commutation is used. This eliminates the problems associated with the brush and the commutator-brush arrangement (Waikar, 2001), thereby making a BLDC more rugged as compared to a dc motor. Having the armature on the stator makes it easy to conduct heat away from the windings and if desired, having cooling arrangement for the armature windings is much easier as compared to a dc motor. In effect, a BLDC is a modified PMSM Motor with the modification being that the back-emf is trapezoidal instead of being sinusoidal as in the case of PMSM (Tseng and Chen, 2010).

The “commutation region” of the back-emf of a BLDC motor should be as small as possible, while at the same time it should not be so narrow as to make it difficult to commutate a phase of the motor when driven by a Current Source Inverter. The flat constant portion of the back-emf should be  $120^\circ$  for a smooth torque production. The position of the rotor can be sensed by using an optical position sensors and its associated logic (Kenjo and Nagamori, 1985). Optical position sensors consist of phototransistors (sensitive to light), revolving shutters and a light source. The output of the position sensor is usually a logic signal. Another option is using Hall Effect position sensors, namely Hall\_A, Hall\_B and Hall\_C each having a lag of  $120^\circ$  with respect to the earlier one (Sokira and Jaffe, 1989). Three Hall sensors are used to determine the position of the rotor field. These particular Hall position sensors, based on the Hall Effect principle, generate TTL compatible output. This study presents low cost, highly efficient BLDC motor for automotive applications (Gieras and Wing, 2005). The drive consists of buck converter, current source inverter and BLDC motor. Buck converters step down the input supply voltage. Since Buck converter used in this drive has an inductor as its front end, the input current drawn from the mains can be controlled to achieve almost unity power factor.

**Materials and methods**

**Voltage source inverter:** Voltage source inverter is one in which the dc source has small or negligible impedance. In other words a voltage source inverter has stiff dc source voltage at its input terminals (IEC, 2000). When the power requirement is high, three phase inverters are used. The gating signals for the three phase inverters have a phase difference of  $120^\circ$ . These inverters take their dc supply from a battery or from a rectifier (Fig. 1). A large capacitor connected at the input terminals tends to make the input dc voltage constant. This capacitor also suppresses the harmonics fed back to the source (Mohan and Undeland, 1995). The voltage source inverter is widely used. However, it has some conceptual and theoretical barriers and limitations. Due to the additional power converter stages the system cost increases and efficiency lowers. The upper and lower devices of each phase leg cannot be gated simultaneously by EMI noise. Dead time to block both upper and lower devices has to provide in the voltage source inverter which causes waveform distortion and ripples.

Fig. 1. Voltage source inverter.

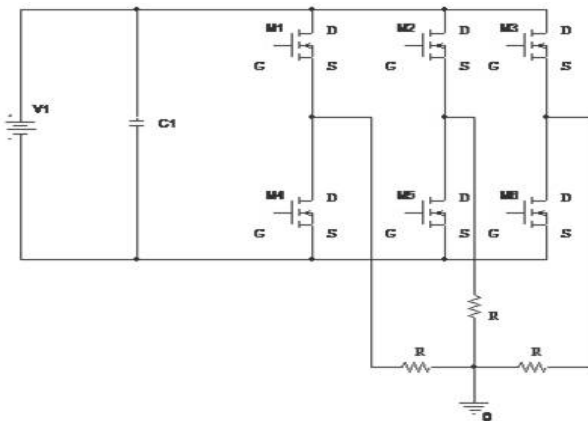
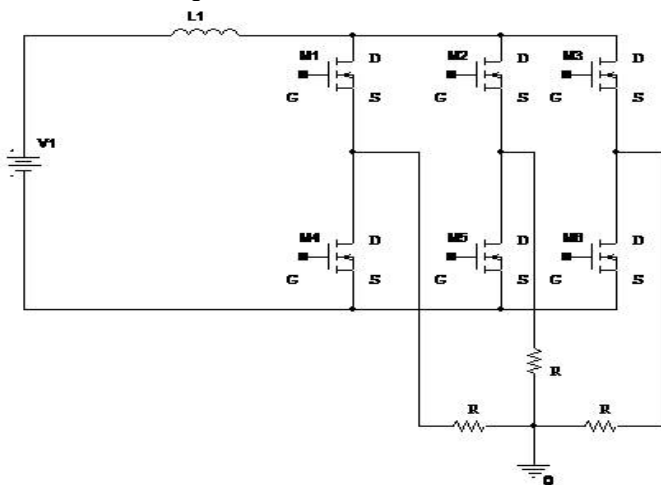


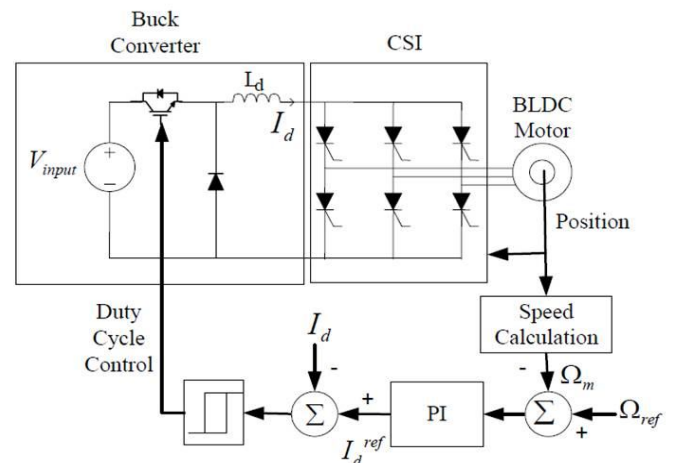
Fig. 2. Current source inverter.



**Current source inverter:** Current source inverter is fed from a constant current source. Therefore load current remains constant irrespective of the load on the inverter (Pressman, 1998). Figure 2 shows the current source inverter with resistive load. The load voltage changes as per the magnitude of load impedance. When a voltage source has a large inductance in series with it, it behaves as a current source. The large inductance maintains the constant current. A current source inverter is fed from a constant current source. Therefore, load current remains constant irrespective of the load on the inverter (MATLAB, 2009).

**Proposed buck converter based current source inverter:** The aim is to design a rugged and low-cost drive, supplied by a battery, using a BLDC motor. In figure 3, the VSI inverter uses IGBTs and requires a heat sink. A thyristorized drive is the obvious choice for ruggedness and lack of heat sinks. The use of thyristors implies that load commutation has to be utilized for proper operation of the CSI. As previously known, the relatively big size of the dc link inductor implies a sluggish dynamic response of the drive.

Fig. 3. Proposed buck converter fed CSI drive.



**Results and discussion**

The simulated results of voltage source inverter phase current waveforms, back emf, speed, torque and Hall signals are shown in figures 4, 5, 6, 7 and 8. Figure 4 shows the current wave form of the VSI fed BLDC moto. Here the current is maintained constant at 4A and the currents of the three phases are constant. Figure 5 shows the EMF waveform of the VSI fed BLDC motor. Here the back emf is obtained same as the desired input level. Figure 6 shows the speed wave form of the VSI fed BLDC motor. Here the speed is controlled at 3000 rpm and high rated speed is achieved. Figure 7 shows the Torque waveform of the VSI fed BLDC motor. The torque pulsation has some overlap due to the switching losses.

Fig. 4. Current waveform ( $I_a, I_b, I_c=4A$ ).

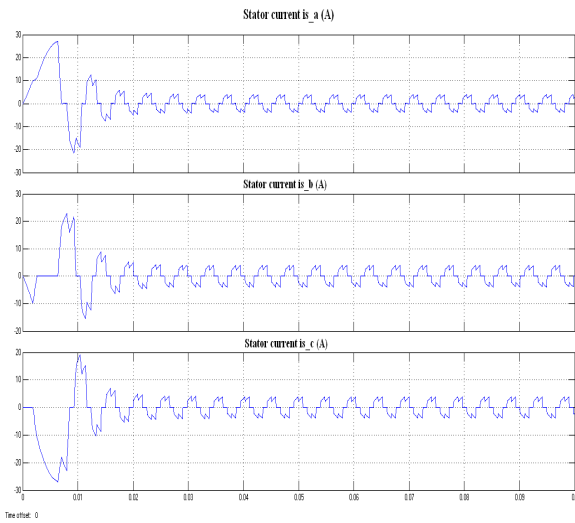


Fig. 5. Back EMF waveform ( $E=220V$ ).

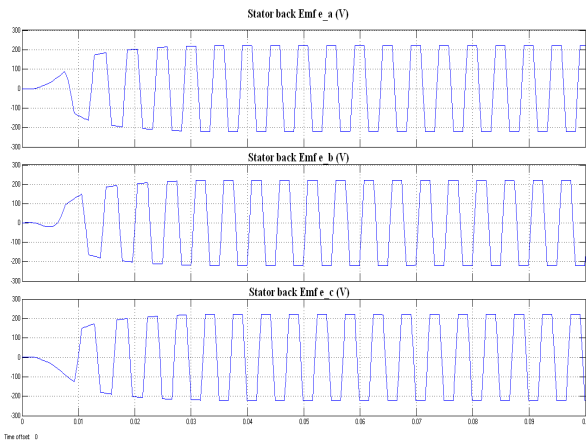


Fig. 6. Speed waveform ( $N=3000\text{ rpm}$ ).

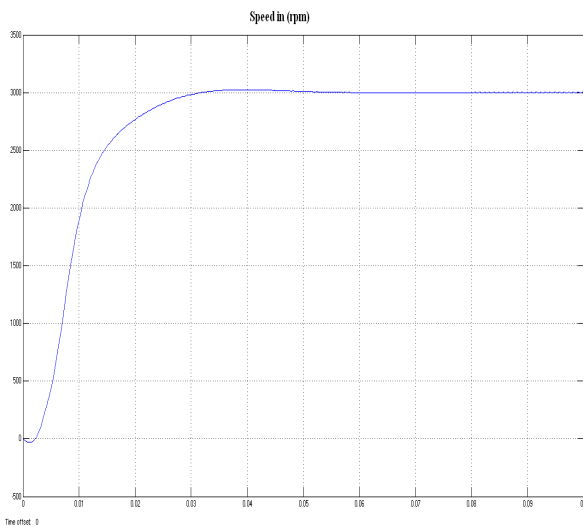


Fig. 7. Torque waveform.

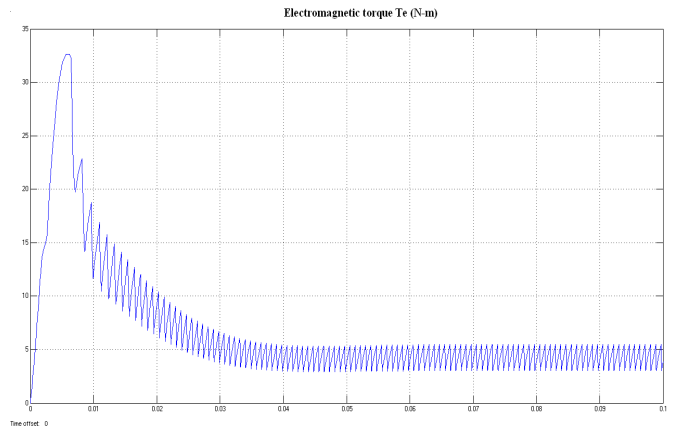


Figure 8 shows the Hall signal waveform. Here the rotor position is obtained when the hall signal is 1V. The simulated results of current source inverter phase current waveforms, Back Emf, speed, torque and Hall signals are shown in figures 9, 10, 11, 12 and 13.

Fig. 8. Hall signal waveform.

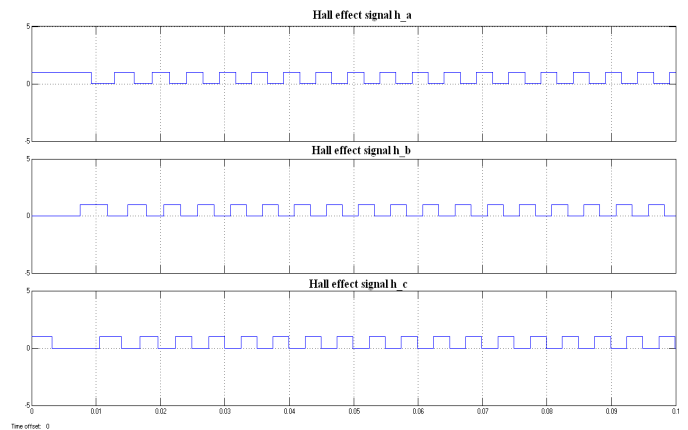


Fig. 9. Current waveform ( $I_a, I_b, I_c=4A$ ).

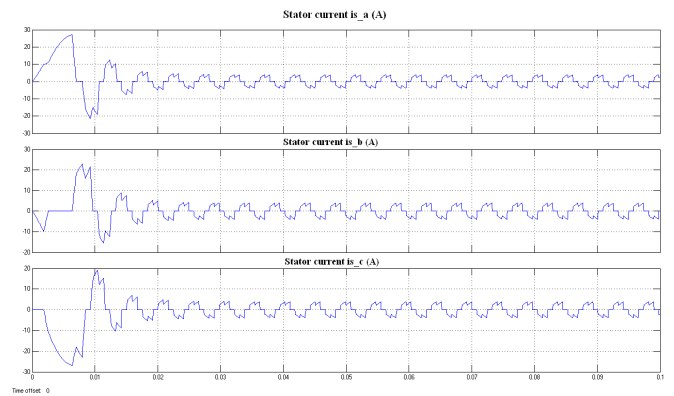


Figure 9 shows the current wave form of the VSI fed BLDC motor. Here the current is maintained constant at 4A and the currents in all the three phases are constant. Figure 10 shows the EMF waveform of the VSI fed BLDC motor. Here the back emf is obtained same as the desired input level.

Fig. 10. Back EMF waveform (E=220 V).

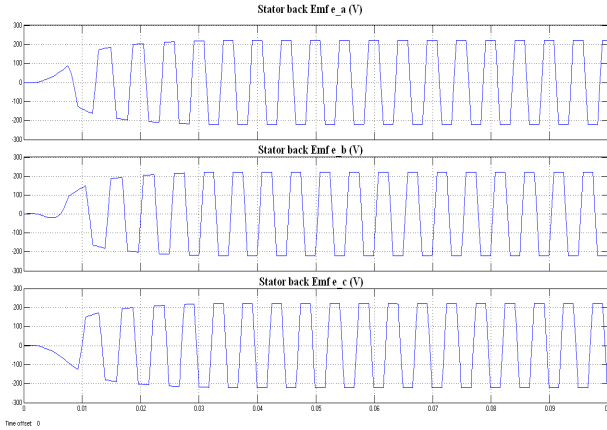


Figure 11 shows the speed wave form of the VSI fed BLDC motor. Here the speed is controlled at 3000 rpm and high rated speed is achieved.

Fig. 11. Speed waveform (N=3000 rpm).

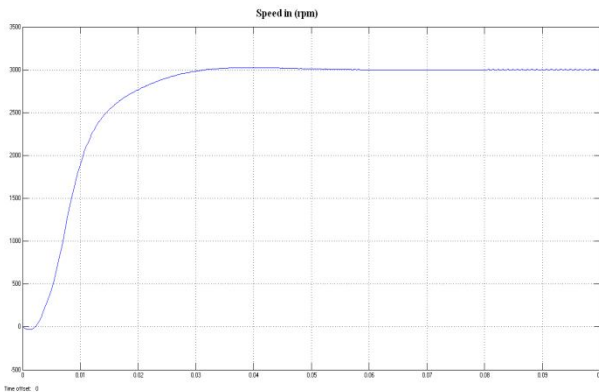


Fig. 12. Torque waveform.

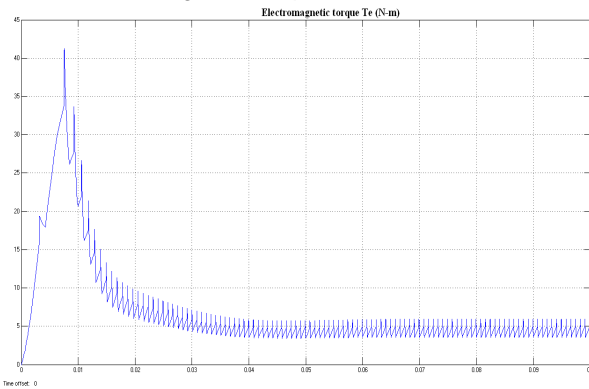


Figure 12 Shows the Torque waveform of the VSI fed BLDC motor. The torque pulsation has some overlap due to the switching losses and ripples. Figure 13 shows the Hall signal waveform. Here the rotor position is obtained when the hall signal is 1V. The simulated results of Buck converter based CSI phase current waveforms, Back Emf, speed, torque and Hall signals are shown in figures 14, 15, 16, 17 and 18.

Fig. 13. Hall signal waveform.

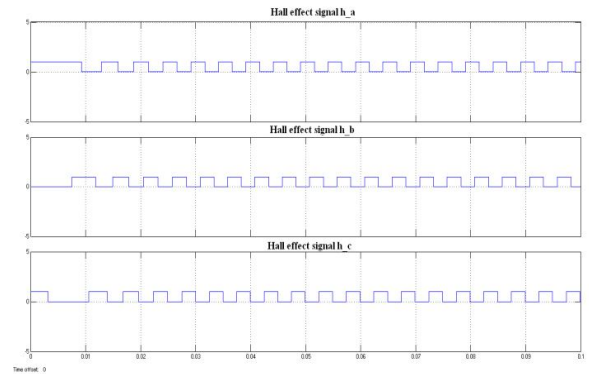


Figure 14 shows the current wave form of the VSI fed BLDC motor. Here the current is maintained constant at 4A and the currents in all the three phases are constant.

Fig. 14. Current waveform ( $I_a, I_b, I_c=4A$ ).

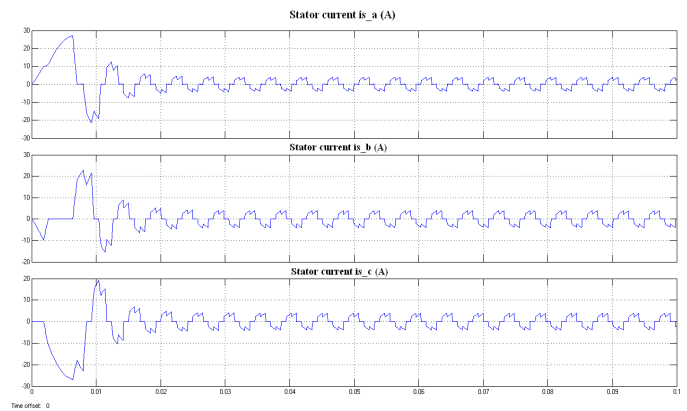


Figure 15 shows the EMF waveform of the VSI fed BLDC motor. Here the back emf is obtained same as the desired input level. Figure 16 shows the speed wave form of the VSI fed BLDC motor. Here the speed is controlled at 3000 rpm and high rated speed is achieved. Figure 17 shows the Torque waveform of the VSI fed BLDC motor. The torque waveform has no ripples as the inductor is connected in series with the inverter and switched at high frequency. Here the switching losses and ripples are reduced and a clear response is obtained. Figure 18 shows the hall signal waveform. Here the rotor position is obtained when the hall signal is 1V. Table 1 shows the simulation results of buck converter based CSI fed BLDC motor.

Fig. 15. Back EMF waveform (E=220 V).

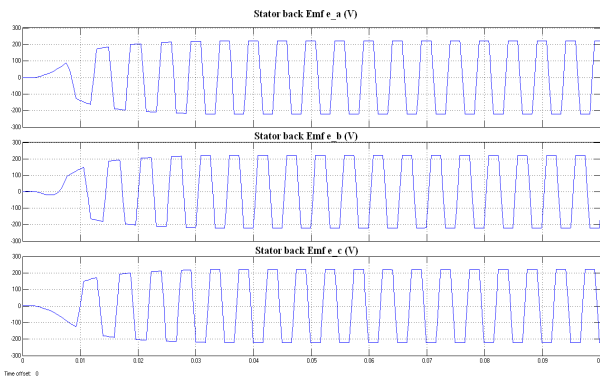


Fig. 16. Speed waveform (N=3000 rpm).

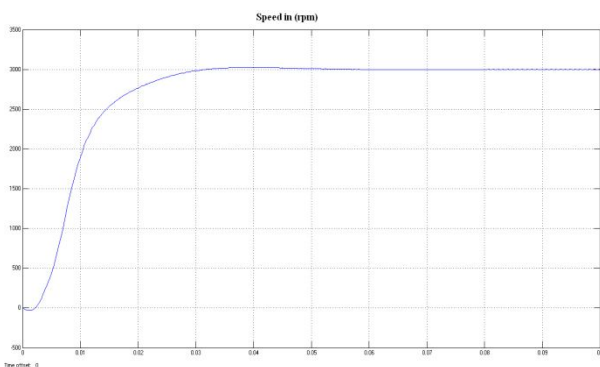


Fig. 17. Torque wave form.

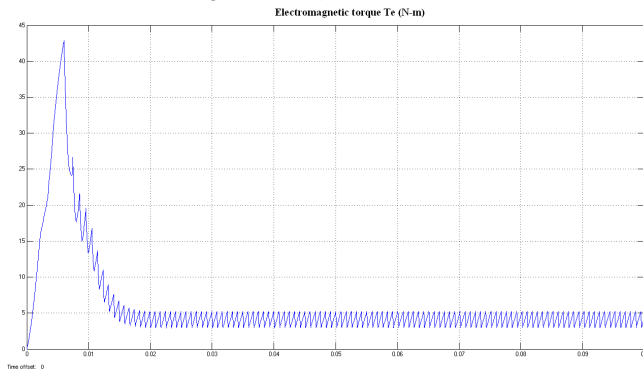


Fig. 18. Hall signals waveform.

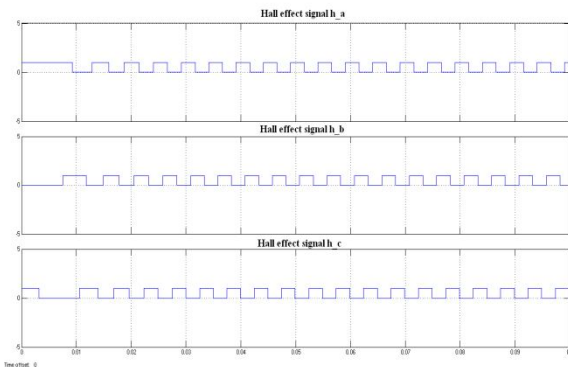


Table 1. Simulation results of Buck converter based CSI fed BLDC motor.

Measurements	Rating		
	VSI	CSI	Buck with CSI
Phase current (A)	4	4	4
DC voltage (V)	220	220	220
Speed (rpm)	3000	3000	3000
Electromagnetic Torque (N-m)	4	4	4
Hall signal (v)	1	1	1
Switching frequency (KHz)	10	10	10
Inductance (mH)	10	10	0.1

**Conclusion**

A comparative study of VSI, CSI and Buck converter based CSI fed BLDC motor for an automotive application is presented in this paper. The Buck converter based CSI fed BLDC motor significantly reduces the switching losses, value of inductance, resistive losses, current ripples, cost and improves the reliability and efficiency is proposed. This study has successfully verified with the simulation results.

**Acknowledgements**

The authors thank the Principal and Management of Sethu Institute of Technology, Pulloor, Kariapatti, Virudhunagar for their support and encouragement.

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