Performance Analysis of BLDC Motor using Basic Switching Converters

Bikram Das, Suvamit Chakraborty, Abanishwar Chakraborti, Prabir Ranjan Kasari

Abstract *: In this paper a comparative study of CSI fed BLDC motor using Boost and Buck Converter are presented. Traditionally BLDC motor drives are fed by Voltage Source Inverters (VSI). Current Source Inverters (CSI) on the other hand does not require the huge DC link capacitor thereby reducing the cost and losses in the system. The large value of the inductor can be replaced using suitable Boost and Buck converter. In this paper a basic structure of a DC boost converter and a basic structure of a DC buck converter are proposed in PSIM to provide the nominal power to BLDC motor from a fixed DC source and to control the speed of the system. The effectiveness of proposed system is validated by simulation results.*

Keywords: BLDC, Boost, Buck, CSI, VSI, PSIM;

I. INTRODUCTION

BLDC motors has emerged as the recent choice of researchers and scientists. BLDC motors finds its applications in numerous fields like Aerospace, home appliances, defense systems, electronic gadgets etc. A BLDC motor is that which retains the characteristics of a dc motor but eliminates the commutator and the brushes [2]. Brushless DC motors can in many cases replace conventional DC motors. BLDC motors are available in many different power ratings, from very small motors as used in hard disk drives to large motors in electric vehicles. Three phase motors are most common but two phase motors also have many applications. The BLDC motors have many advantages over brushed DC motors. BLDC motors have trapezoidal back emf and uses Hall Effect position sensors to determine the position of the rotor field. Whenever the rotor magnetic poles pass near the hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three hall sensor signals, the exact sequence of computation can be determined. Every 60 electrical degrees of rotation, one of the hall sensors changes the state. Given this, it takes six steps to complete an electrical cycle. Corresponding to this, with every 60 electrical degrees, the phase current switching should be updated [2].

The analysis is based on the following assumptions for simplification.(i)The motor is not saturated (ii) Stator resistances of all the windings are equal, and self- and mutual inductances are constant (iii) Power semiconductor devices in the inverter are ideal (iv) Iron losses are negligible. Among the above-mentioned assumptions, the iron loss can be approximated using empirical equations, and the dynamic characteristics of the switching devices need to be considered for the investigation of transient state behavior. They are driven by dc voltage but current commutation is done by solid state switches i.e. electronically. The common control algorithm for a BLDC motor is PWM current control. It is based on the assumption of linear relationship between the phase current and the torque similar to that in a brushed DC motor. Thus, by adjusting the phase current, the electromagnetic torque can be controlled to meet the requirement. The switches used in PWM based drive systems are subjected to high switching stresses and high switching power loss that increases linearly with the switching frequency of the PWM. Hence these converters experience high switching losses, reduced reliability, electromagnetic interference and acoustic noise. Other significant drawback of the switch mode operation is the EMI produced due to large di/dt and dv/dt caused by a switch-mode operation. These shortcomings of switch-mode converters are overcome by increasing the switching frequency in order to reduce the converter size and weight and hence to increase the power density. Therefore, to realize high switching frequency in a converter changes its status (from on to off), when the voltage across it and/or the current through it is zero at the switching instant .DC-DC converters are nonlinear systems due to their inherent switching operation. To assure a constant output voltage, a classical linear design of a control is frequently used. The regulation is normally achieved by the pulse width modulation (PWM) at a fixed frequency. This paper presents two highly efficient, low cost BLDC motor drive system for high and low power applications.

II. BASIC SWITCHING CONVERTERS

A.BOOST Converters

Boost converter is also known as a step-up converter. In a step-up converter the output voltage must always exceed the input voltage for the devices to remain in regulation. When the transistor is on the current in inductor L, rises linearly and at this time capacitor C, supplies the load current, and it is partially discharged. During the second interval when transistor is off, the diode D, is on and the inductor L, supplies the load and, additionally, recharges the capacitor C. The components of a converter are not ideal and some of these non-idealities can be considered in a model. Only one non-ideality is considered in the model that will be used. The capacitor is modeled as an ideal capacitor in series with an ideal resistor with resistance Rc. The resistance Rc is called the Equivalent Series Resistance (ESR) of the capacitor. The ESR is used to represent all the power losses in the capacitor.Fig.1 shows the circuit diagram of the boos t converter.

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B. Das, Asst. Prof., Electrical Engg., Deptt., NIT, Agartala, Tripur, India.
S. Chakraborty, M.Tech with Electrical Engg. Deptt,NIT, Agartala, Tripura, India.
A.Chakraborti, Asst. Prof., Electrical Engg. Deptt., NIT Agartala,Tripura, India.
P. Rn. Kasari, Asst. Prof., Electrical Engg. Deptt., NIT, Agartala, Tripura, India.

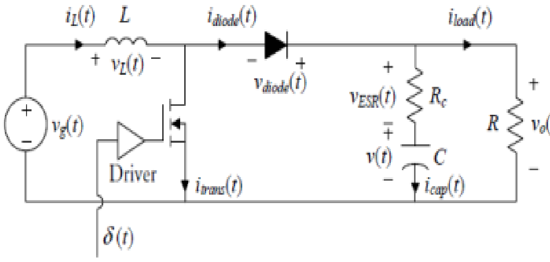

Figure 1. Circuit of the boost converter.

B. BUCK Converters

Likewise the buck converters are known as step down converters. In a step-down converter the input voltage always exceed the output voltage for the devices to remain in regulation. When the transistor is on, the input voltage appears across the inductor and current in inductor increases linearly in the same cycle the capacitor is charged. When the transistor is off, the voltage across the inductor is reversed. However, current in the inductor cannot change instantaneously and the current starts decreasing linearly. In this cycle also the capacitor is also charged with the energy stored in theinductor.Fig.2 shows the circuit diagram of the buck converter.

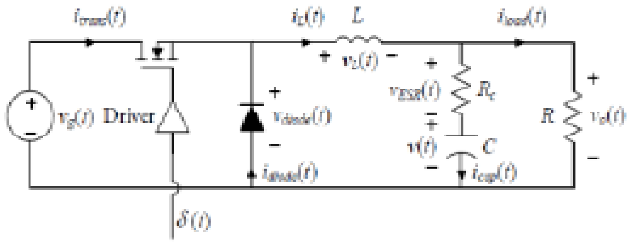

Figure 2. Circuit of the buck converter.

III. CONTROL OF BLDC MOTOR

The control of PMBLDC motors can be accomplished by various control techniques using conventional six pulse inverters which can be classified in two broad categories as voltage source inverter (VSI) and current source inverter (CSI) based topologies. The controllers can further be divided on the basis of solid state switches and control strategies. The PMBLDCM needs rotor-position sensing only at the commutation points, e.g., every 60°electrical in the three-phases; therefore, a comparatively simple controller is required for commutation and current control. The commutation sequence is generated by the controller according to the rotor position which is sensed using Hall sensors, resolvers or optical encoders. These sensors increase the cost and the size of the motor and a special mechanical arrangement is required for mounting the sensors. A circuit analysis of the inverter is also a major part of the simulation of a BLDC motor system. The current path of a BLDC motor is changed by six conduction intervals and the switching pattern of the inverter, so that the model of a BLDC motor has to be reconfigured to reflect the change in current path. Due to such complex set-up processes, the model of a BLDC motor tends to be fixed to one switching pattern in most of the existing papers [3].Fig.3 shows the block diagram of the control system.

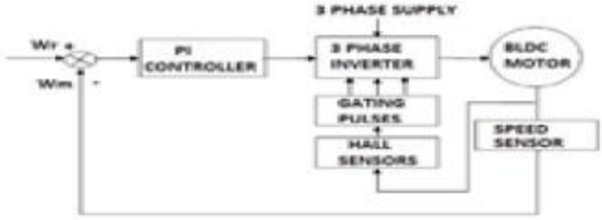

Figure 3 Block Diagram of BLDC control system

IV. MODELLING OF A BLDC MOTOR

The star-connected, 3-phase motor with a 4-pole permanent magnetic rotor is driven by a PWM inverter. The rotor position, which determines the switching sequence of the IGBT transistors, is detected by means of 3 Hall sensors mounted on the stator. The switching scheme implemented in the inverter logic is well-known. The model equations of a BLDC motor are composed of a voltage equation, a torque equation and a motion equation. The stator of a general BLDC motor has three windings like an induction motor or a permanent magnet synchronous motor. The equivalent circuit diagram of the stator winding is as shown in fig 4.[3]

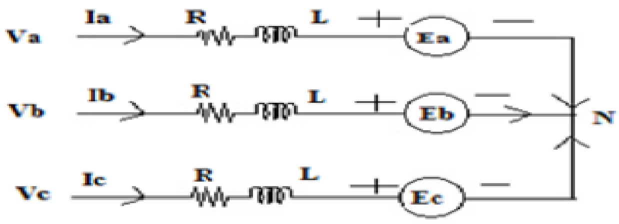

Figure 4 Equivalent circuit diagram of stator winding

The equations of the 3-phase brushless dc machine are as below.

$$V_a = I_a R + L\frac{di}{dt} + E_a \quad (1)$$

$$V_b = I_b R + L\frac{di}{dt} + E_b \quad (2)$$

$$V_c = I_c R + L\frac{di}{dt} + E_c \quad (3)$$

Where V_a, V_b, and V_c are the phase voltages, Ia, Ib, and Ic are the phase currents, R, L are the stator phase resistance, self inductance and E_a, E_b and E_c are the back emf of phase A, B, and C, respectively.

The back emf voltages are functions of the rotor mechanical speed ωm and the rotor electrical angle θr, that is;

$$E_a = K_a \times \omega_m \quad (4)$$

$$E_b = K_b \times \omega_m \quad (5)$$

$$E_c = K_c \times \omega_m \quad (6)$$

The coefficients K_a, K_b, and K_c are dependent on the rotor angle θr. In this model, an ideal trapezoidal waveform profile is assumed. The mechanical equations are

$$J\frac{d\omega}{dt} = Tem - Tl - B\omega \quad (7)$$

Where B is a coefficient, T_l is the load torque, and P is the no. of poles. The coefficient B is calculated from the moment of inertia J and the mechanical time constant Tm as below.

$$B = \frac{J}{Tem} \quad (8)$$

$$\frac{d\theta r}{dt} = \frac{P}{2}\omega_m \quad (9)$$

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Boost Converter based CSI fed BLDC motor

The control design strategy is validated with the PSIM results. The input DC voltage is 48 V which is boosted to 300V .The BLDC motor is given supply through the three phase inverters. The values of inductances are calculated theoretically. Current source inverter is fed from a constant current source. Therefore load current remains constant irrespective of the load on the inverter. The load voltage changes as per the magnitude of load impedance. When a voltage source has a large inductance in series with it behaves as a current source .The large inductance maintains the constant current [1]. Current input to CSI is almost ripple free, because of L filter is used before the source. The proposed system is suitable in remote areas for applications such as cooling fan, agricultural water pumping systems and related home applications. The simulated results of phase current waveforms speed and torque waveforms gate pulses and the boost voltage are shown in the Fig.6 below. And the PSIM model is as shown in fig.5.Table I shows the simulation results values of BLDC Motor.

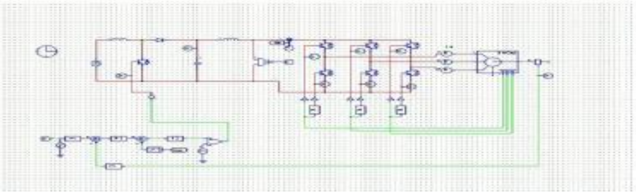

Figure 5 PSIM model of Boost Converter based CSI fed BLDC Motor

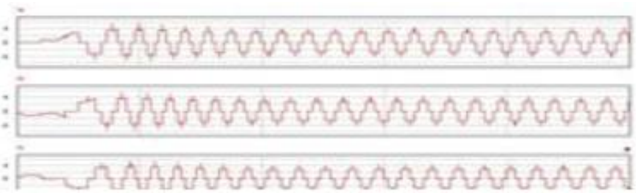

Figure 6 Phase current waveforms

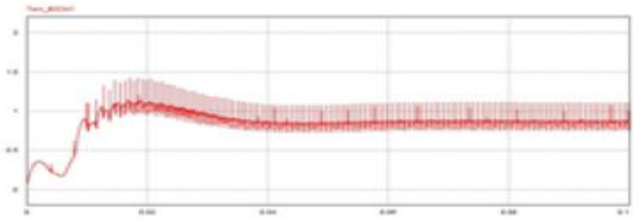

Figure 7 Torque wave form of BLDC motor

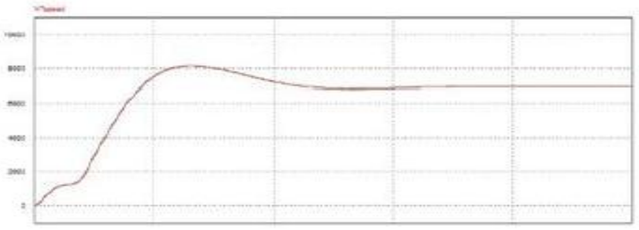

Figure 8 Speed wave form of BLDC motor

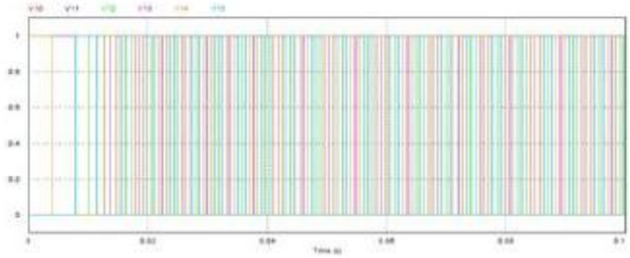

Figure 9 Gate Pulses

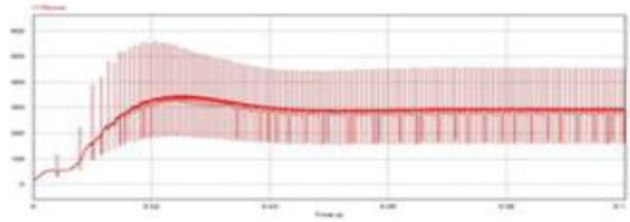

Figure 10 Boost Converter output voltage

TABLE-I Simulation results of Boost Converter based CSI fed BLDC Motor

S.No	Measurements	Rating
1	Input DC Voltage	48V
2	Phase current	3A
3	Speed	7000rpm
4	Electromagnetic Torque	0.08N-m
5	Switching frequency	10KHz
6	Inductance	50mH

A. Buck Converter based CSI fed BLDC motor

The control design strategy is validated with the PSIM results. The input DC voltage is 450 V which is stepped down to 300V .The BLDC motor is given supply through the three phase inverters. The values of inductances are calculated theoretically. Simulation model consists of BLDC motor, 6 IGBT's, speed sensor, PI controller and second order low pass filter. In order to reduce the value of inductance this scheme is used. The speed control is achieved through PI controller and maintaining high switching frequency. The proposed system is suitable in Aerospace and defense applications such as vehicle tracking, gyroscope, aircraft on board instrumentation,

valves etc. The simulated results of phase current waveforms speed and torque waveforms gate pulses and the buck voltage are shown in the Fig.11 shows the PSIM model of Buck converter.

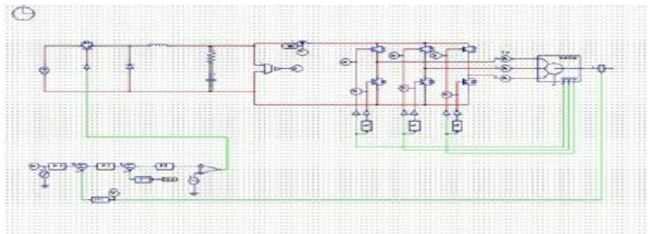

Figure 11 PSIM model of Buck converter based CSI fed BLDC motor

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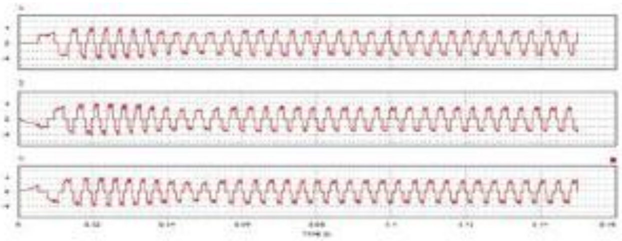

Figure 12 Phase Current waveforms

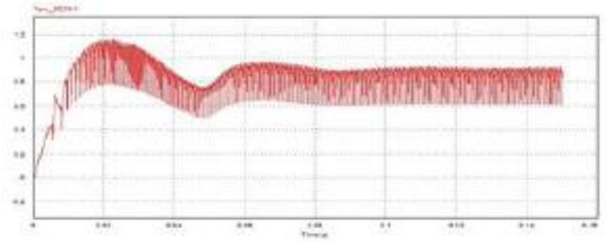

Figure 13 Buck Voltage

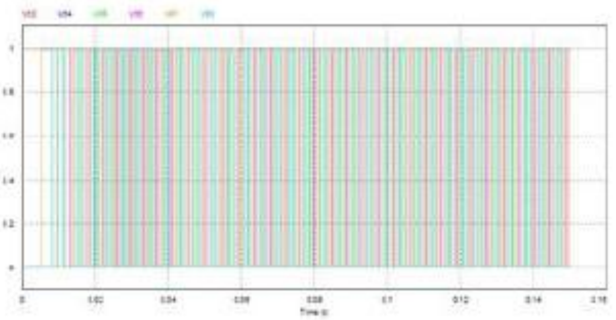

Figure 14 Gate Pulses

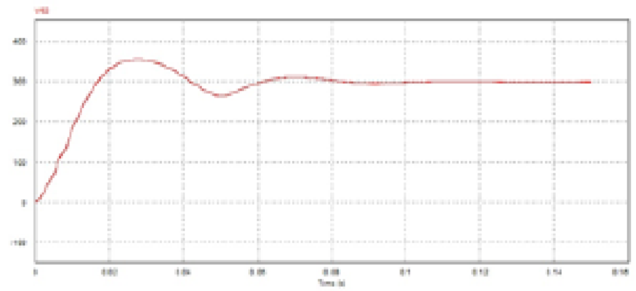

Fig.15. Speed curve of BLDC motor with buck converter.

Fig.12, 13 14 &15 shows the simulation results under of BLDC Motor when it is fed with buck converter.

TABLE - II Simulation results of Buck Converter based CSI fed BLDC Motor

S.No	Measurements	Rating
1	Input DC Voltage	450V
2	Phase current	3A
3	Speed	6000rpm
4	Electromagnetic Torque	0.08N-m
5	Switching frequency	10KHz
6	Inductance	37.5mH

V. CONCLUSION

A comparative study of CSI fed BLDC motor using Boost and Buck Converter are presented in this paper. Both the strategy significantly reduces the switching loss and cost thereby increasing the speed and efficiency of the BLDC motor drive system. The study is verified with the simulation results using PSIM software. The results of the simulation model gives help in building hardware with expected results. The simulation saves time and manpower in making hardware models at initial stages and reduces the costing of research work

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AUTHORS PROFILE

Bikram Das [dbiki81@gmail.com] was born in Udaipur, Tripura, India in 1981. He received his Bachelor Degree in Electrical Engineering from the University of Tripura, Agartala in 2003and Master degree in Power Electronics & Drives from NIT, Agartala, Deemed University in the year 2010. He is working as Assistant Prof. in with the Department of Electrical Engineering, in NIT, Agartala. His research interest is in the field of power electronics and drives, Energy sources, Special Electrical machines.

Suvamit Chakraborty [suvamit@gmail.com] was born in Kolkata, W. Bengal in 1987.He received his B.Tech degree in Electrical Engineering from West Bengal University Of Technology, Kolkata in the year 2010. He is pursuing his M.Tech from National Institute Of Technology, Agartala in Power Electronics & drives. His area of interest include Power electronics & Electrical machines.

Abanishwar Chakraborti [abanishwar@yahoo.com] was born in Agartala, Tripura, India in 1980. He received the Bachelor degree in Electrical Engg. from NERIST in 2004 and the Master degree in Control System Engineerin from IIT, Kharagpur. He is currently working as Assistant professor with the Department of Electrical Engineering His research interest is in the field of Control System Power Electronicsand Drives.

Prabir Ranjan Kasari [prkasari_s@yahoo.co.in] was born in Udaipur, Tripura, India in1983. was born in He received the Bachelor degree in Electrical Engg. from NERIST in 2005 and the Master degree in Power System from Tripura University, Agartala, in the year 2007. He is currently working as Assistant prof. with the Department of Electrical Engineering, in NIT, Agartala. His research interest is in the field of Power System and FACTs.