Speed Control of BLDC Motor Using Switched Capacitor Based DC-DC Converter

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Abstract. This paper discusses about switched capacitor based front end converter for BLDC motor drive application. The front end converter is used to provide controlled dc voltage with minimal dc voltage source for VSI feeding BLDC motor with sensors. Hall sensors is used to commutate the motor electronically. Voltage controlled technique is used to control dc link voltage as well as speed of BLDC motor. Both the results of switched capacitor front end converter fed BLDC motor and Boost converter fed BLDC motor have been discussed and switched capacitor based converter is outperforming boost fed BLDC motor. The simulation is carried out using MATLAB/Simulink simpower system blocksets.

Keywords: BLDC motor · Hall Sensor · Switched capacitor based con- verter

1 Introduction

In the recent past decades focus of electrical engineer is on the power elec- tronic devices as by using power electronics devices supply side can meet the demand easily, Also its application is very vast as from industrial point of view to the home appliances and its contribution towards electrical side can be bet- ter explained by explaining its contribution towards generation, transmission, distribution and utilization. In generation sector most of the renewable energy system uses devices to boost up the output voltage and also in excitation control of generation sector it plays very vital role.

Development of FACTS devices[1] is itself evidence that due to power electronic devices HVDC and HVAC lines are possible as there switched inductor and switched reactor configuration has been used. In Distribution sector power quality improvement [2] always remains main area of focus and again power elec- tronics devices is being used for same and utilization sector consist of end user and here there are lots of possibility of using power devices but in this article speed control of drive control is the main area of focus and it is achieved by using non-isolated DC-DC converter.

Both isolated and non-isolated DC-Dc converter is used for drive applications of motors here in this paper switched capacitor based DC-DC converter are used for

speed control application of BLDC motor. BLDC motor works on the principle as of DC motor but there is constructional wise difference as it uses electronic commutation instead of using mechanical commutation that is being used in DC motor by using

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brushes which contributes to sparking problem, losses etc. To control the BLDC motor various speed control technique has been proposed and that is too by using front end converter [3–6].] A BLDC motor feeded by using filter capacitor through diode bridge rectifier. DC link voltage have to be made constant because whenever the supply voltage is greater than DC link voltage, for short duration of time it pulls electricity and this results into induction of harmonics and ultimately power factor also decreases [3].

A novel PFC (Power Factor Corrected) Converter uses a single voltage sensor to control the voltage of a DC link capacitor between a Zeta DC-DC converter and a VSI to achieve speed control of a BLDC motor [4].Two current sensors are necessary for a BLDC motor with a SEPIC converter using variable voltage for control. It is suggested to control the BLDC motor in [5] using a modified-Zeta converter or a Luo converter, however these have the switches connected in se- ries with the mains supply, which causes more interference issues and requires for more filtering. The suggested control strategy for BLDC motor with variable DC link voltage for VSI resolves the high switching losses and PQ issues at the supply side [6].

This paper proposes front end converter based BLDC motor in which front end DC-DC converter is a modified form of boost converter as at the output side switched capacitor with one inductor is added and as a result conversion ratio of voltage has been increased to 1:5 as boost converter has limitations of not going beyond a particular value of duty ratio that restricts its voltage conversion ratio here here converted voltage at dc link of output side of converter circuit not only used to fed inverter of BLDC motor but also it is used to control the speed of that motor for wide range of speed.

2 Proposed Scheme for Speed Control of BLDC Motor

Figure 1 depicts the proposed methodology for sensored BLDC motor fed by switched capacitor converter. In order for the voltage source inverter to operate the BLDC motor, the front end converter must keep the dc link voltage set to the refer- ence voltage. It is necessary to trigger the front end converter's switch at a high switching frequency for efficient control and small component sizes, such as in- ductors. Due to this reason MOSFET is used as a switch for front end converter while the VSI uses a IGBT as it require a low frequency operation. The pro- posed method controls the rotor speed to match the predominant speed while maintaining the constant voltage at DC link by using simple voltage controlled technique. Hall sensors are installed on the BLDC motor's rotor to track the position of the rotor during electronic commutation.

A voltage controlled technique is employed in which the motor's actual speed is controlled and is compared with reference speed and thus error is generated which is fed to PI controller and the it is compared to the current sensor output that is sensed at input side of inductor thus the error generated is finally passed by relay and switching pulse is generated for switching purpose of front end converter switch. Use of front end converter to regulate dc link voltage and for speed control of BLDC motor is explained in two operations i.e. on mode and off mode of converter and is discussed.

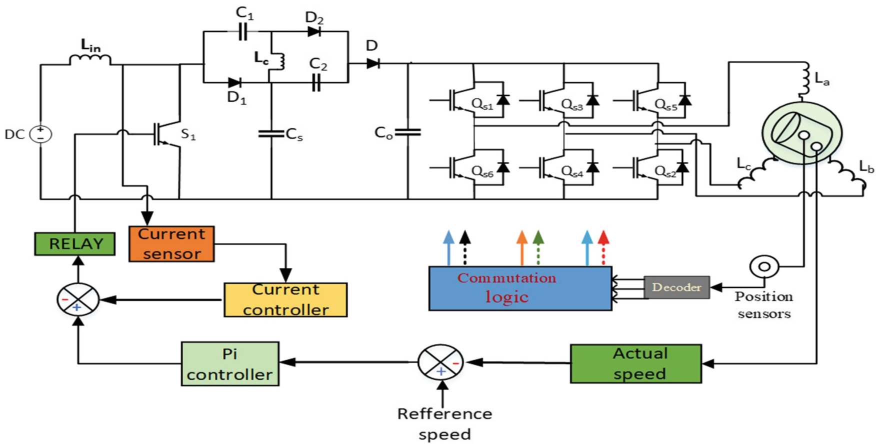


Fig. 1. Proposed front end converter with BLDC motor

2.1 ON Mode Operation

When switch is triggered capacitor c_s charges to input voltage value V_{in} and all the diode i.e. D_1, D_2 and Do Are in reverse biased mode and it is not conducting thus making capacitor c_1 cs and inductor l_c in series and making capacitor to be charged in series with inductor. There is two kvl loop possible to develop input and output voltage equations i.e. is show in Fig. 2. And equations are discussed below.

$$v_{in} = v_L in \tag{1}$$

$$v_{in} = L\frac{dL_{in}}{dt} \tag{2}$$

$$\Delta I_{Lon} = \frac{v_{inDT_s}}{L_{in}} \tag{3}$$

from loop 2 we have

$$v_{Lc} = v_{C1} - v_{Cs} \tag{4}$$

2.2 OFF Mode Operation

When switch is off and capacitor cs is charged up to voltage vin all the diodes are now in forward biased and connecting the dc link capacitor co to the input side thus making it possible to develop two kvl to develop equations and it is shown in Fig. 3. Also the equations are discussed below.

From inner loop 1 we have

$$V_{L_{in}} = V_{in} - V_{c_s}$$

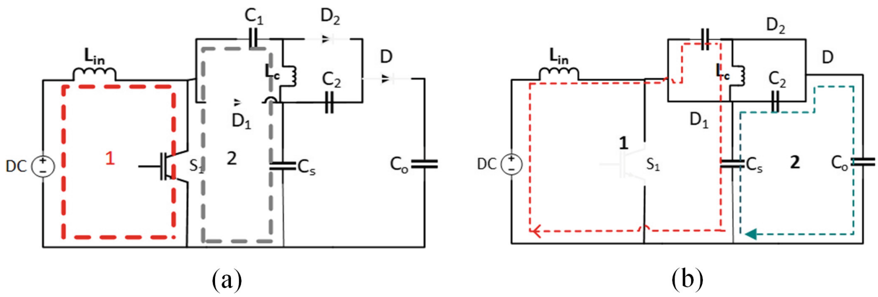


Fig. 2. (**a**) On mode operation, 2(**b**) off mode operation of front end converter.

$$\Delta I_{LOFF}=\frac{(V_{in}-V_{c_s})(1-D)T_s}{L} \tag{5}$$

Average inductor current is zero so from equation (3) and (5) we have

$$\Delta I_{L_{ON}}+\Delta I_{L_{OFF}}=0$$

$$V_{c_s}=\frac{V_{in}}{1-D} \tag{6}$$

From bridge switched capacitor we can write

$$v_{c_1}=v_{L_c}=-v_{c_2} \tag{7}$$

From outer loop 1 we can write

$$v_{in}-v_{L_{in}}-v_{c_1}-v_{L_c}c-v_{c_s}$$

Substituting equation (6) value in above equation and assuming all inductance value same we can write above equation as

$$v_{in}-2v_L-\frac{v_{in}}{1-D}-v_{c_1}=0$$

$$\Delta L_{OFF}=\frac{(v_{in}(1-D)-v_{in}-v_{c_1}(1-D))T_s}{2} \tag{8}$$

From equation (1) and equation (8) we can again write it as average inductor current is zero i.e.

$$\Delta I_{L_{ON}}+\Delta I_{L_{OFF}}=0$$

$$v_{in}D+\frac{v_{im}(1-D)}{2}-v_{im}-v_{c1(1-D)}=0$$

$$2v_{in}D+v_{in}(1-D)-v_{in}-v_{c1(1-D)}=0$$

$$v_{in}(2D + 1 - D - 1) = v_{c1(1-D)}$$

$$v_{in}3D = v_{c_1}(1 - D)$$

$$v_{c_1} = \frac{3v_{in}D}{1 - D} \tag{9}$$

from equation 7 we have

$$v_{c_1} = -v_{c_2}$$

$$\mathrm{V}_{c2} = \frac{-3v_{in}D}{1 - D} \tag{10}$$

From outer loop 2 we can write

$$v_{c_s} - v_{c_2} - v_{c_o} = 0$$

$$v_{c_o} = v_o$$

$$v_o = v_{c_s} - v_{c_2}$$

Putting value of equation of (6) and equation (10) in above equation we get

$$v_o = \frac{v_{in}}{1 - D} + \frac{3v_{in}D}{1 - D}$$

$$v_o = \frac{v_{in}(3D + 1)}{1 - D} \tag{11}$$

let us assume D = 0.5 and put it on above equation we have gain as follows

$$v_0 = 5v_{in}$$

The duty ratio D for the proposed converter is given by

$$D = \frac{v_o - v_{in}}{3v_{in} + v_o} \tag{12}$$

Value of Inductance can be calculated as follows using ripple currents and duty ratio are as follows

$$L_{in} = L_c = L = \frac{(1 - D)v_{in}}{f_s \Delta I_{L_{in}}} \tag{13}$$

where
$\Delta I_{L_{in}} = 4 - 10\%$ of I_o

$$C_1 = C_2 = C = \frac{D.I_o}{f_s.\Delta v_c} \tag{14}$$

2.3 Controller Part for Proposed Topology

For speed control of BLDC motor using switched capacitor front end converter a very simple technique has been used using PI controller and current sensors and it is indirectly is related to generation of switching pulse for the converter circuit i.e. Speed of the rotor is compared to the reference value and thus error is generated and this error signal is passed through PI controller and generated signal is then summed with incoming input coming from current sensor that is passed by controller finally it is summed such that error is generated and finally it passed through relay thus switching pulse is generated for switch.

3 Conventional Converter Based BLDC Motor

Boost Converter is generally used in DC-DC voltage conversion application and also for power factor correction method due to its simple construction and less number of power electronic devices used in the circuit. But the main problem is its conversion gain ratio cannot go beyond certain limit as duty ratio can be increased beyond certain limit because the switching off time for switch will reduces and also conduction loss will increase. Block diagram for simulation have are shown in Fig. 3. And various equations have been discussed related to boost converter duty ratio.

$$D = 1 - \frac{v_{out}}{v_{in}} \quad (15)$$

V_{out} is the output voltage across dc link capacitor. And V_{in} is the input supply voltage.

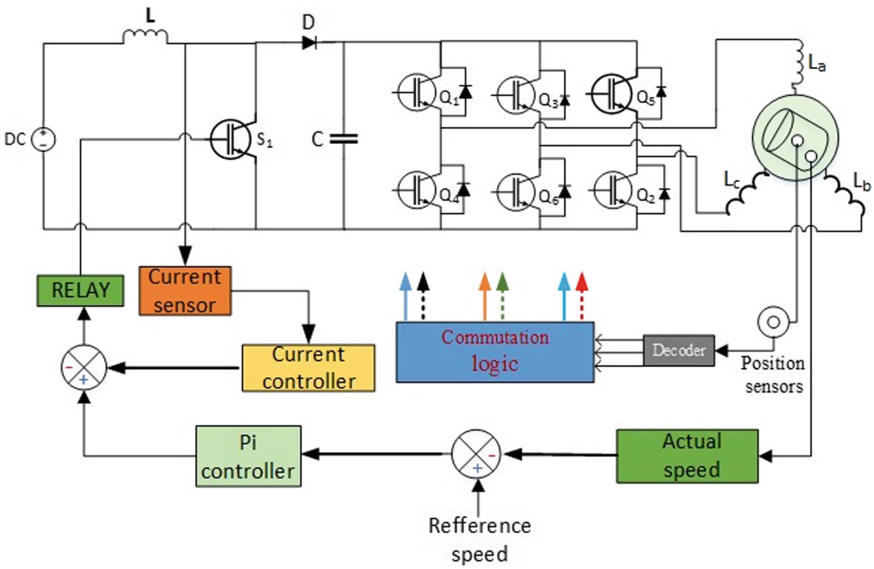


Fig. 3. Boost Converter Based BLDC Motor

The value of inductance and capacitance can be calculated by using duty ratio, ripple current and ripple voltage respectively and it is given as

$$L = \frac{v_{in}.D}{f_s.\Delta i_o} \tag{16}$$

$$C = \frac{i_o.D}{f_s.\Delta v_c} \tag{17}$$

$$\Delta I_{L_{in}} = 4 - 10\%$$

4 Working Principle of BLDC Motor

BLDC motor working principle is same as the DC motor but the major difference is the constructional part that here rotor consist of permanent magnet and stator is wound for a specific number of poles also the controller circuit is connected with stator winding. One the most major difference is the electronic commutation instead of using mechanical commutation here brushes are not used as it is used in DC motor which makes it free from sparking and losses caused due to brushes. For the better understanding working of BLDC motor by learning about its controller unit as shown in Figs. 4 and 5.

4.1 Commutation Part

To determine the position of the rotor, hall sensors are mounted on rotor and finally decoding that hall signals into back thus generating switching pulse for the VSI and making electronic commutation possible. Here block commutation or 120 degree commutation is used in which single phase will conduct for 120 degree and graph and table for this commutation is shown in Fig. 6. Thus this unique working process of BLDC

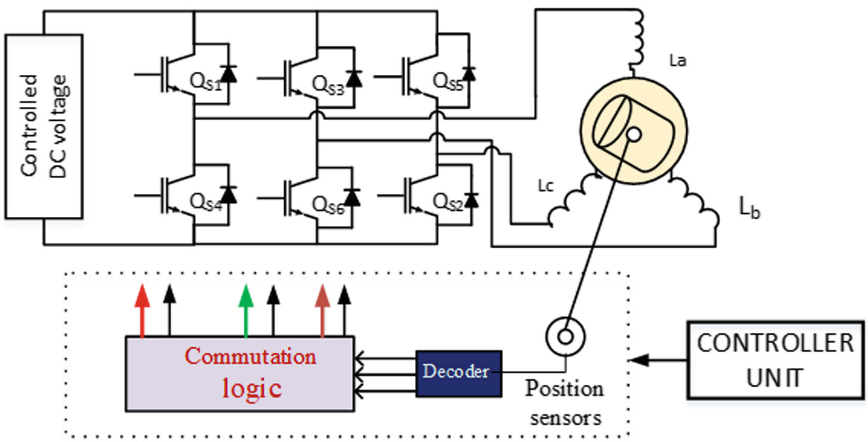
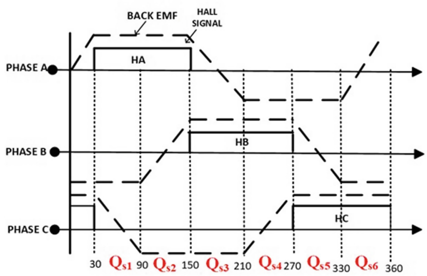


Fig. 4. Basic Block Diagram of BLDC motor



(a)

h_a	h_b	h_c	e_a	e_b	e_c	Phase A		Phase B		Phase C	
						Q_{s1}	Q_{s2}	Q_{s3}	Q_{s4}	Q_{s5}	Q_{s6}
0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	-1	+1	0	0	0	1	1	0
0	1	0	-1	+1	0	0	1	1	0	0	0
0	1	1	-1	0	+1	0	1	0	0	1	0
1	0	0	+1	-1	0	1	0	0	0	0	1
1	0	1	0	+1	0	1	0	0	1	0	0
1	1	0	+1	-1	0	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0	0	0	0

(b)

Fig. 5. (**a**) Waveform For Six Step Commutation and Fig. 5(**b**) Logic Table For Hall Sensor

motor makes it different from other motors and also its higher torque to weight ratio, less noise and maximum torque generation has its own advantages. Various equations for torque and back emf is shown below.

$$v_{as} = I_{as}R_{as} + L\frac{dI_{as}}{dt} + e_{as} \tag{18}$$

$$v_{bs} = I_{bs}R_{bs} + L\frac{dI_{bs}}{dt} + e_{bs} \tag{19}$$

$$v_{cs} = I_{cs}R_{cs} + L\frac{dI_{cs}}{dt} + e_{cs} \tag{20}$$

where v_{as}, v_{bs} and v_{cs} are the phase voltages and e_{as}, e_{bs} and e_{cs} are the back emf respectively. by using relation between back emf and stator current i.e

$$e_{as} = k_{as}\omega_a f(\Theta)$$

and

$$\psi_{as} = LI_{as} + M(I_{bs} - I_{cs})$$

using above flux leakage equations where L and M are self and mutual in- distances, Ia, Ib and Ic are the stator currents respectively. Torque equation for BLDC motor can be derived are as follows:-

$$\tau_{es} = \frac{1}{\omega_m}(e_{as}.I_{as} + e_{bs}.I_{bs} + e_{cs}.I_{cs}) \tag{21}$$

5 5. Simulations Results and Discussion

The Simulated response of the BLDC motor with six step inverter fed boost and switched capacitor based converter is discussed in above shown figures. MATLAB simpower system blocksets is used to carry out the speed control loop of BLDC motor. Power

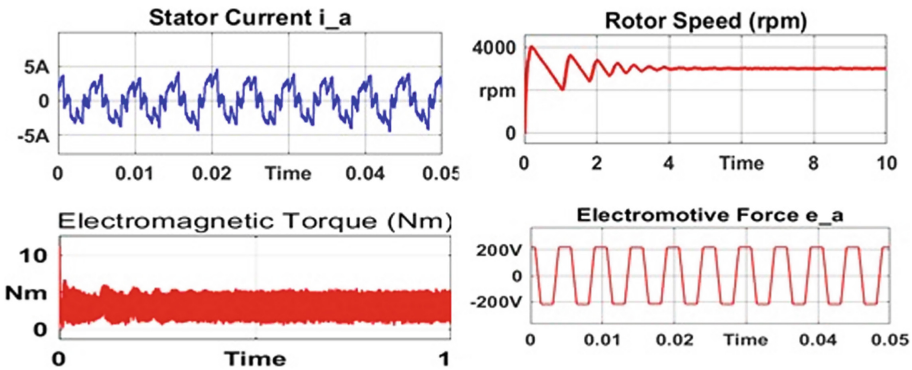


Fig. 6. Current, voltage, EMT torque and back emf of boost converter fed BLDC motor

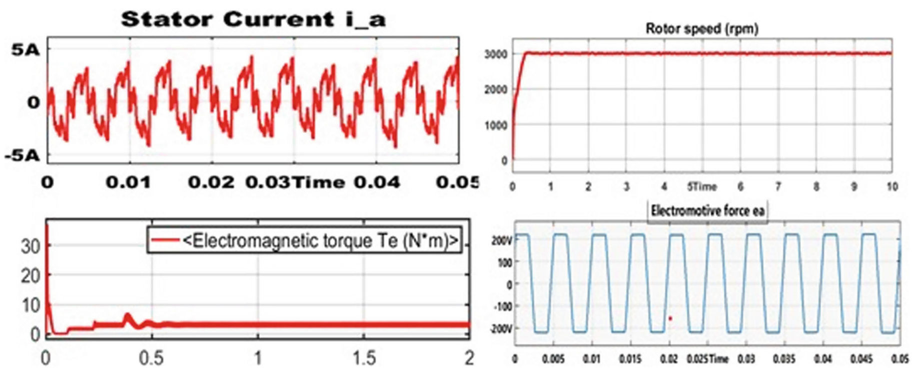


Fig. 7. Current, voltage, EMT torque and back emf of switched capacitor based converter fed BLDC motor

electronics blocksets are used to carry put the simulations of pro- posed converter , boost converter circuit and Voltage source Inverter.

In Fig. 6.Stator current, rotor speed in revolution per minute following the set reference speed of 2000 revolution per minute, electromagnetic torque in N-M and trapezoidal Back emf voltage waveform for boost fed BLDC motor has been

Depicted for different values of time.

In Fig.7.Stator current, rotor speed in revolution per minute following the set reference speed of 3000 revolution per minute, electromagnetic torque in N-M and trapezoidal Back emf voltage waveform for Switched Capacitor converter fed BLDC motor has been depicted for different values of time. It can been seen from from Fig .6. And Fig. 7. That ripple contents are very high and distorted waveform is there in compare to boost converter rather than in proposed converter.

6 Conclusion

The switched capacitor fed BLDC motor with six step inverter is proposed in this paper. The performance characteristics of BLDC motor such as speed, cur- rent, trapezoidal back emf and electromagnetic torque simulation is carried out using Matlab Simulink software. To generate gating pulse for voltage source in- verter electronic commutation have been done using hall sensors. Comparative analysis have been carried out by analyzing simulation results of performance characteristics of proposed and conventional Boost converter fed BLDC motor, also equations have been compared and from this study it can been concluded that proposed converter outperforms conventional boost converter.

References

1. T. Joseph, C. E. Ugalde-Loo, J. Liang and P. F. Coventry, "Asset Management Strategies for Power Electronic Converters in Transmission Networks: Application to HVDC and FACTS Devices," in IEEE Access, vol. 6, pp. 21084-21102, 2018, doi: https://doi.org/10.1109/ACCESS.2018.2826360.
2. "IEEE Guide for Application of Power Electronics for Power Quality Improvement on Distribution Systems Rated 1 kV Through 38 kV," in IEEE Std 1409–2012 , vol., no., pp.1–90, 27 April 2012, doi: https://doi.org/10.1109/IEEESTD.2012.6190701.
3. R. Pireethi and R. Balamurugan, "Power Factor Correction in BLDC motor drives using DC-DC converters," 2016 International Conference on Computer Communi- cation and Informatics (ICCCI), Coimbatore, India, 2016, pp. 1–5, doi: https://doi.org/10.1109/IC-CCI.2016.7480034.
4. B. Singh and V. Bist, "A single sensor based PFC Zeta converter Fed BLDC motor drive for fan applications," 2012 IEEE Fifth Power India Conference, Murthal, India, 2012, pp. 1-6, doi: https://doi.org/10.1109/PowerI.2012.6479540.
5. B. Singh, V. Bist, A. Chandra and K. Al-Haddad, "Power quality improvement in PFC Bridgeless-Luo converter fed BLDC motor drive," 2013 IEEE Industry Appli- cations Society Annual Meeting, Lake Buena Vista, FL, USA, 2013, pp. 1-8, doi: https://doi.org/10.1109/IAS.2013.6682498.
6. B. Chokkalingam, A. Yusuff, M. Tariq and T. Bhekisiph, "Torque-Ripple Mitigation for BLDC using Integrated Converter Connected Three-Level T Type NPC-MLI," 2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON), Aligarh, India, 2019, pp. 1–6, doi: https://doi.org/10.1109/UPCON47278.2019.8980096