SIMULATION OF THREE PHASE SEVEN-LEVEL INVERTER WITH REDUCED NUMBER OF SWITCHES FOR BLDC DRIVE

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Abstract- **Three-phase BLDC motors are widely used for industrial applications that require medium and very high speeds and it is mostly preferred for electric vehicles as it provides high efficiency, low maintenance, long life, low weight and compact construction. This paper presents the implementation of a three-phase seven-level cascaded H-Bridge Inverter fed brushless DC motor. The main advantage of BLDC is the presence of electronic commutator. The electronic commutation instants are determined by rotor position which is either by position sensors or by sensorless techniques. In this paper, the commutation logic is implemented by using Hall signal. Finally seven levels Cascaded multilevel inverter fed Brushless dc motor drive is implemented in Matlab/ Simulink and simulation results are presented. The performance of proposed inverter is compared with conventional voltage source inverter for BLDC drive. It is found that the torque ripple and harmonics are reduced with the proposed inverter structure**.

Keywords: Cascaded H-Bridge inverter, Brushless direct current motor (BLDC).

I. INTRODUCTION

Conventional DC motors have attractive properties such as high efficiency and linear torque-speed characteristics. The control of dc motors is also simple and does not require complex hardware. However, the main drawback of the DC motor is the need of periodic maintenance. The brushes of the mechanical commutator eventually wear out and need to be replaced. The mechanical commutator has other undesirable effects such as sparks, acoustic noise and carbon particles coming from the brushes. Despite the name, BLDC motors are actually a type of permanent magnet synchronous motors.

Current commutation is done by solid state switches. The mechanical commutator is replaced by electronic commutator. The commutation instants are determined by rotor position and position of the rotor is detected either by position sensors or by sensor less techniques. BLDC motors have many advantages over conventional DC motors:

- ✓ Long operating life
- ✓ High dynamic response
- ✓ High efficiency
- ✓ Better speed Vs torque characteristics
- ✓ Noiseless operation
- ✓ Higher speed operation

For driving the BLDC motor we require inverter. In the two-level inverter, there is a problem of harmonic distortion, lower electromagnetic interference, high DC link voltage, high dv/dt , heating of rotor shaft, voltage spikes across the motor terminals etc. The increase in the number of steps of voltage is the solution of the above problem. Advantages of the MLI topology:

- ✓ Reduced number of switches compared to the conventional inverter.
- ✓ Switching power loss is reduced and efficiency is improved.

A Brushless DC (BLDC) motors, with their trapezoidal electromotive force profile, requires six discrete rotor position information for the inverter operation. These are typically generated by Hall-effect switch sensors placed within the motor.

Hall-effect position sensors typically provide the position information needed to synchronize the stator excitation with rotor position in order to produce constant torque. The rotor magnets are used as triggers for the Hall sensor and it receives hall sensor output from BLDC motor and generates the gate pulses which drive the MOSFET switches of the three-phase cascaded seven level inverter. The block diagram is shown in Figure 1.
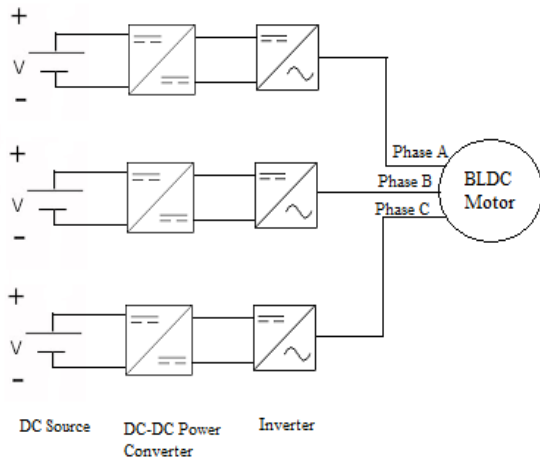
Fig 1.Shematic representation of 3 phase seven level inverter fed BLDC motor

II.   OPERATION OF THREE PHASE MLI

The structure of Three phase seven-level inverter fed BLDC motor drive system is shown in Fig.2.The operation of the single phase seven level inverter is same as three phase inverter[1] but the difference Phase B is phase shifted by 120^0 from Phase A and the Phase C is phase shifted by 240^0 from Phase A[2,3].
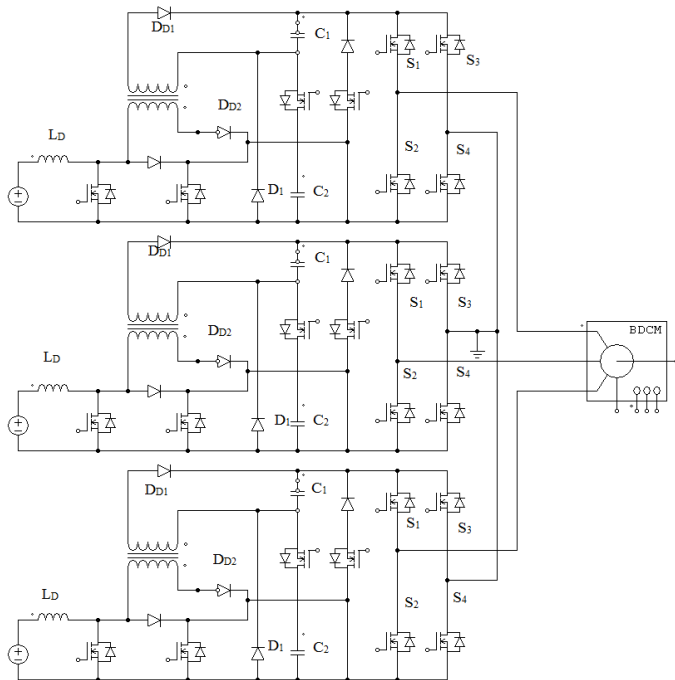
Controlling the conducting angles at different inverter levels can minimise the harmonic distortion of the output voltage. As the no of levels increases the output voltage tends to sinusoidal [4].

III.   SENSORED CONTROL OF BRUSHLESS DC MOTOR

Brushless DC motor has a permanent magnet rotor and a wound field stator and which is connected to a power electronic switching circuit. The brushless DC motor drive system is based on the rotor position, and it is obtained at fixed points typically every 60 electrical degrees for six-step commutations of the phase currents. The brushless DC motor drives have higher efficiency, less maintenance cost, less noise and simple compact construction. In a brushless DC motor, the permanent magnets produce an air gap flux density distribution that is of trapezoidal shape waveform, and result in trapezoidal back-EMF waveforms [5, 6]. Brushless DC motors use electric switches to realize current commutation, and thus continuously rotate the motor. These electric switches are usually connected in a three-phase bridge structure for a three-phase BLDC motor. There are two types of control technique for using BLDC drive system. These are position sensor control and position sensor less control but this paper insists on a position sensor control technique [7, 8]. The block diagram is shown in Fig.1.
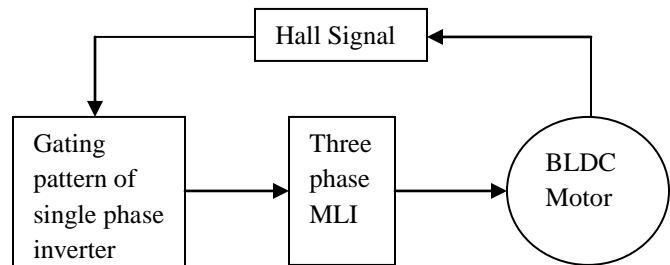

Fig 3. Sensored control of three-phase ANPCMLI fed brushless DC motor.

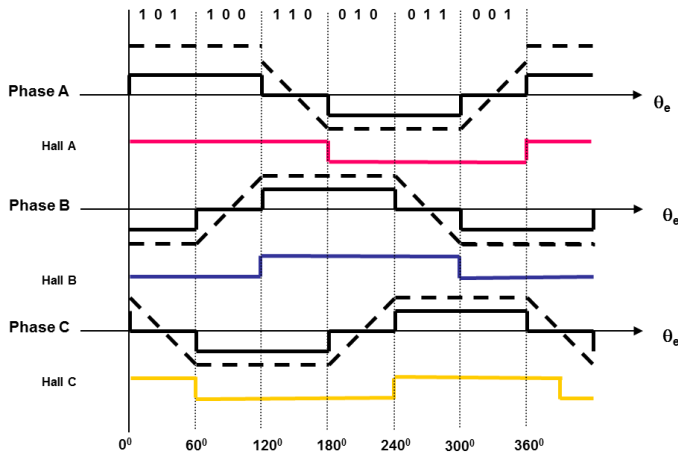Fig 2.Three phase seven level inverter fed BLDC motor

Fig 4.BLDC motor drive along with typical phase current and Back Emf signal.

A three- phase BLDC motor requires three Hall sensors to detect the rotor's position based on the physical position of the Hall sensors, there are two types of output: a 60° phase shift and a 120° phase shift. Combining these three Hall sensor signals can determine the exact commutation sequence. The commutation sequence of a three-phase BLDC motor driver circuit for counter-clockwise rotation. Figure 4 show that the BLDC motor drive along with typical phase current and hall signal. Three Hall sensors A, B, and C are mounted on the stator at 120° intervals, while the three phase windings are in a star formation. For every 60° rotation, one of the Hall sensors changes its state; it takes six steps to complete a whole electrical cycle[9,10]. In synchronous mode, the phase current switching updates every 60°.However, one signal cycle may not correspond to a complete mechanical revolution. The number of signal cycles to complete a mechanical rotation is determined by the number of rotor pole pairs. Every rotor pole pair requires one signal cycle in one mechanical rotation. So, the number of signal cycles is equal to the rotor pole pairs. The hall signal is modified into sinusoidal reference waveform by using second order Low pass filter. Then this waveform is compared with carrier signal to get gate pulses. Figure 5 shows that the gating signals of seven level inverter[11].
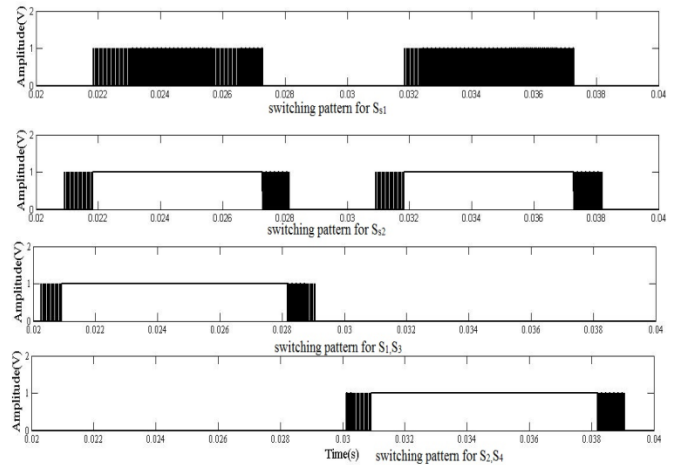

Fig 5. BLDC motor drive along with typical gate signal

IV. SIMULATION RESULTS

Three-phase seven levels with R load have been modeled in MATLAB/Simulink. Fig 6 shows Three phase MLI with R load.
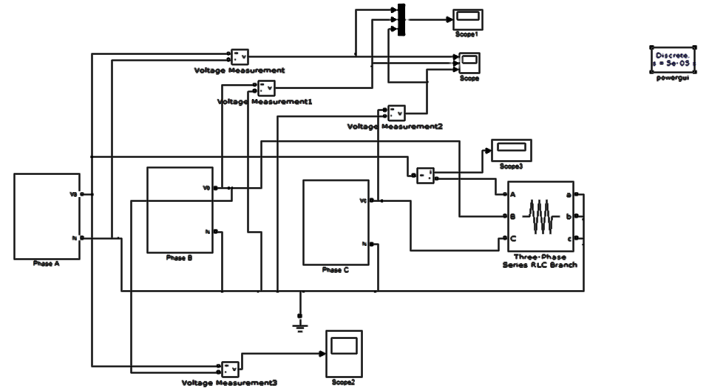

Fig 6.Three phase seven-level inverter with R load

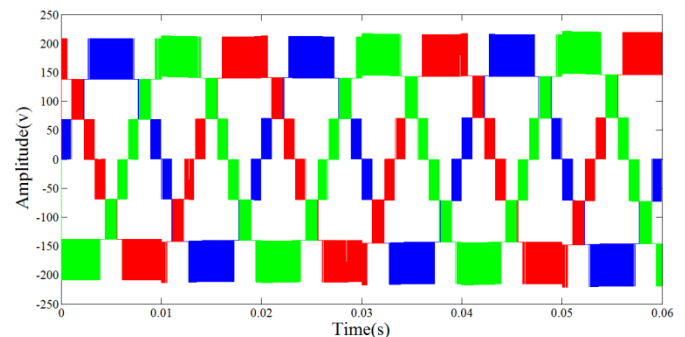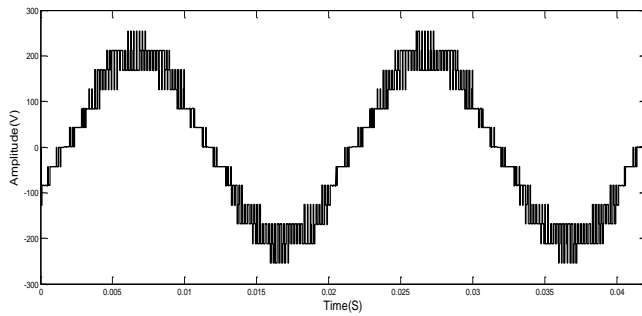Fig 7. Output phase voltage waveform for Three phase MLI

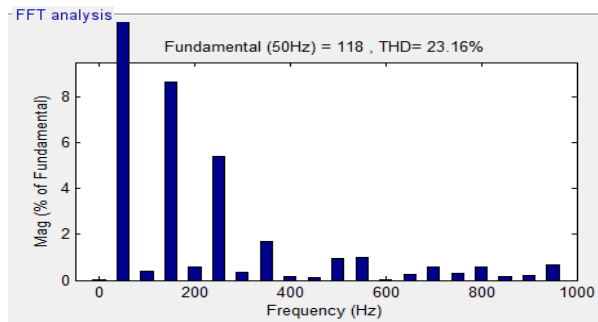Fig 8. Output line voltage waveform for Three phase MLI
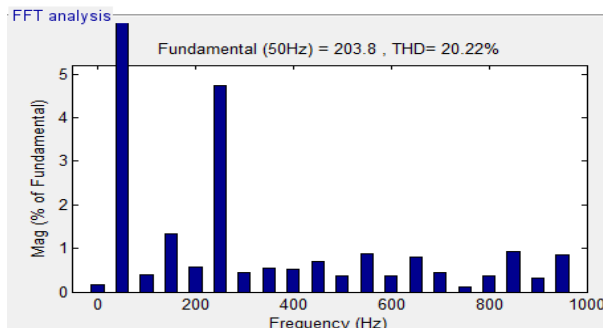

Fig 9.Phase voltage THD for three phase MLI

Fig 10.Line voltage THD for three phase MLI

V. THREE PHASE MLI FED BLDC MOTOR

Motor parameters are shown in Table 1. Simulation was performed in MATLAB SIMULINK to verify that the proposed inverter topology which is shown in Figure.

Table 1 Motor parameters

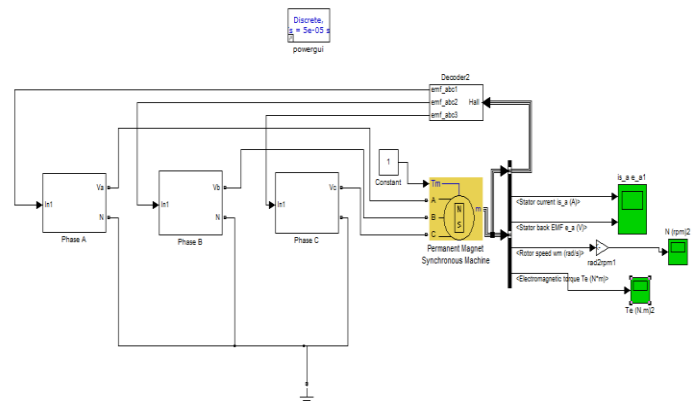| Parameters	Specifications
Stator phase resistance(r_s)	2.68Ω
Stator phase inductance(L_s)	5.31mH
voltage constant	33.5103
Torque constant	0.32Nm
Pole pairs	4

Fig 11. Simulink model of the sensored control three phase BLDC drive

The simulated results (rotor speed, electromagnetic torque, stator current and back EMF) of brushless DC motor are shown in Figures 12–15 respectively.
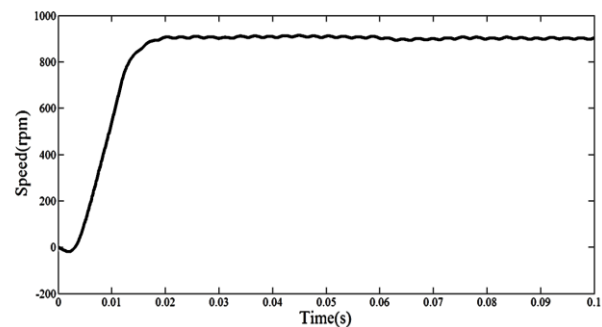

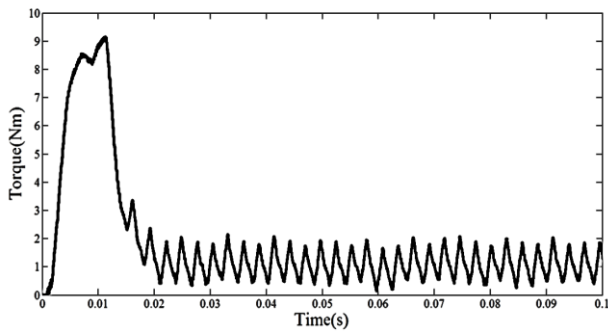Fig 12.Rotor speed for three phase MLI fed BLDC drive.

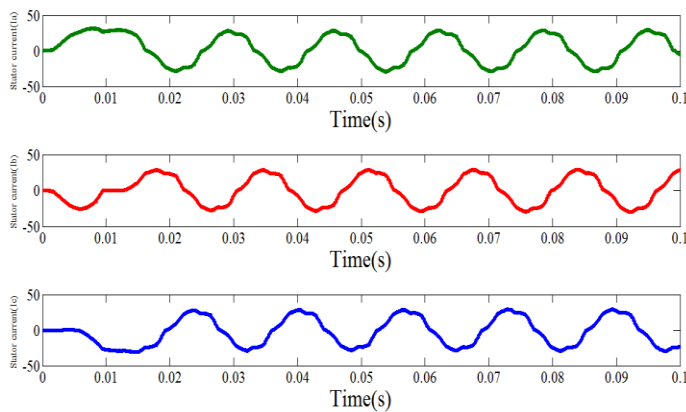Fig. 13. Motor torque for three phase MLI fed BLDC drive.

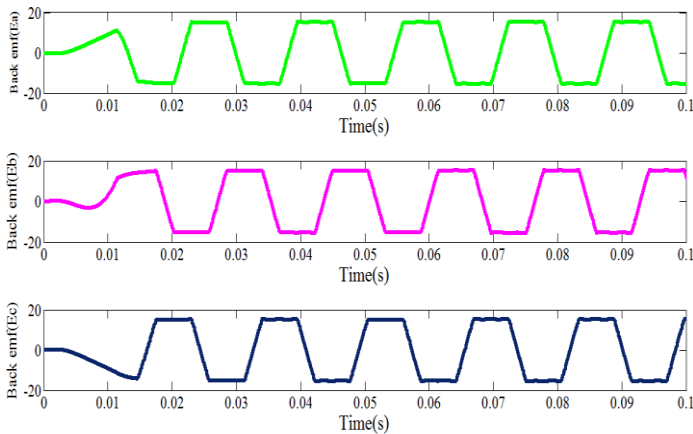Fig. 14. Stator current for three phase MLI fed BLDC drive.

Fig. 15. Back emf for three phase MLI fed BLDC drive.

Figures 12 & 13 show that the BLDC motor speed is settled 900 Rpm and the BLDC motor torque is about 3Nm. Figures 14 & 15 show that the BLDC motor stator current is about 30 A and the BLDC motor back emf voltage is about 15 V. Figure 16 shows that the stator current T.H.D of three phase BLDC drive which is about 65.46%. By employing three phase MLI fed BLDC the position sensor control technique for the spectral quality of the output voltage, stator current, torque ripple are reduced and improved motor speed compared to the conventional system[12].
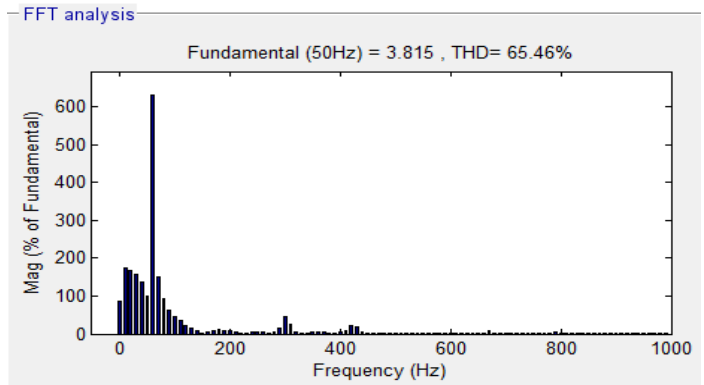

Fig. 16. Stator current T.H.D for three phase MLI fed BLDC drive.

Fig. 17. Output voltage T.H.D for three phase MLI fed BLDC drive.

Table 2. Comparison between VSI and ANPCMLI

Parameters	Three phase MLI fed BLDC motor	Three phase VSI fed BLDC motor
Output voltage THD	23.16%	35.87%
Torque Ripple	13.33%	33.12%

By employing MLI fed BLDC drive system, it was found from Table 2 that the harmonics are reduced in the output voltage then, minimized torque ripple compared to the conventional three-phase inverter fed BLDC drive system.

VI.   CONCLUSION

This paper has successfully presented the sensored control of BLDC motor. By suitably developing the commutation logic using hall signal, appropriate phase and line to line voltage output was obtained for the three-phase seven level inverter. Three phase seven level inverter fed BLDC drive was modeled by using MATLAB/Simulink and parameters such as stator current, rotor speed, Electromagnetic Torque, Back EMF results are shown. By employing three phase MLI fed BLDC the position sensor control technique for the spectral quality of the output voltage, stator current, torque ripple are reduced and improved motor speed compared to the conventional system.
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VII.   REFERENCES

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