Permanent magnet motor which is classified as sinusoidal fed Permanent magnet synchronous motor and rectangular fed BLDC motor. In rectangular fed BLDC the windings are wound in such that the back emf is trapezoidal[8]. The torque of BLDC motor is mainly influenced by waveform of back emf and fed with rectangular stator currents.[9]

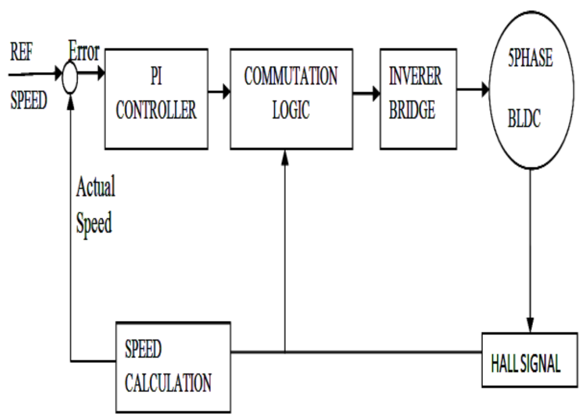

Fig. 1: Block Diagram

This paper gives modelling of a five phase BLDC motor. For modelling five phase BLDC motor parameters are selected based on specification. Position controller is obtained by designing a PI controller. The simulation results are presented using MATLAB/Simulink used as the simulation. It represents a closed loop position controller.

The error signal is produced from difference of position output measured from sensor and position command. The error is fed into PWM signal generator. The PWM generator provides gating signal to inverter. Normally in a BLDC motor electronic commutation is adapted [8] which uses hall sensor for sensing the rotor position.

II. SIMULATION OF BLDC MOTOR

A. *Modeling of BLDC Motor*

The Stator Resistance R, Self Inductance L, Mutual Inductance M, Back EMF E. The five phase balanced stator voltage equation can be expressed as follows

$$V_a = R_a\, i_a + L_{aa}\frac{di_a}{dt} + L_{ab}\frac{di_b}{dt} + L_{ac}\frac{di_c}{dt} + L_{ad}\frac{d\,i_d}{dt} + L_{ae}\frac{di_e}{dt} + E_a \qquad (1)$$

Considering five phase symmetry and non-salient rotor

$$L_{aa} = L_{bb} = L_{ee} = L_{dd} = L_{ee} = L$$

$$L_{ab} = L_{ba} = L_{ac} = L_{ca} = L_{ad} = L_{da} = L_{ae} = L_{ea} = L_{ea} = L_{ac} = M$$

Considering stator phase current balanced

$$i_a + i_b + i_c + i_d + i_e = 0$$

Thus equation can be written as

$$V_a = Ri_a + L - M\frac{di_a}{dt} + E_a \quad (2)$$

Similarly the equation of voltage for other phases can be derived.

The motion for a simple system with moment of inertia J and damping coefficient B and load torque Tl can be written as

$$T_e - T_l = J\frac{d\omega_m}{dt} + B\omega_m \qquad (3)$$

The rotor position and rotor speed can be related as

$$\frac{d\theta_r}{dt} = \frac{P}{2} * \omega_m \quad (4)$$

The back emf can be written as

$$E_a = \omega_m\, f_{\theta r}\, K_b \; (5)$$

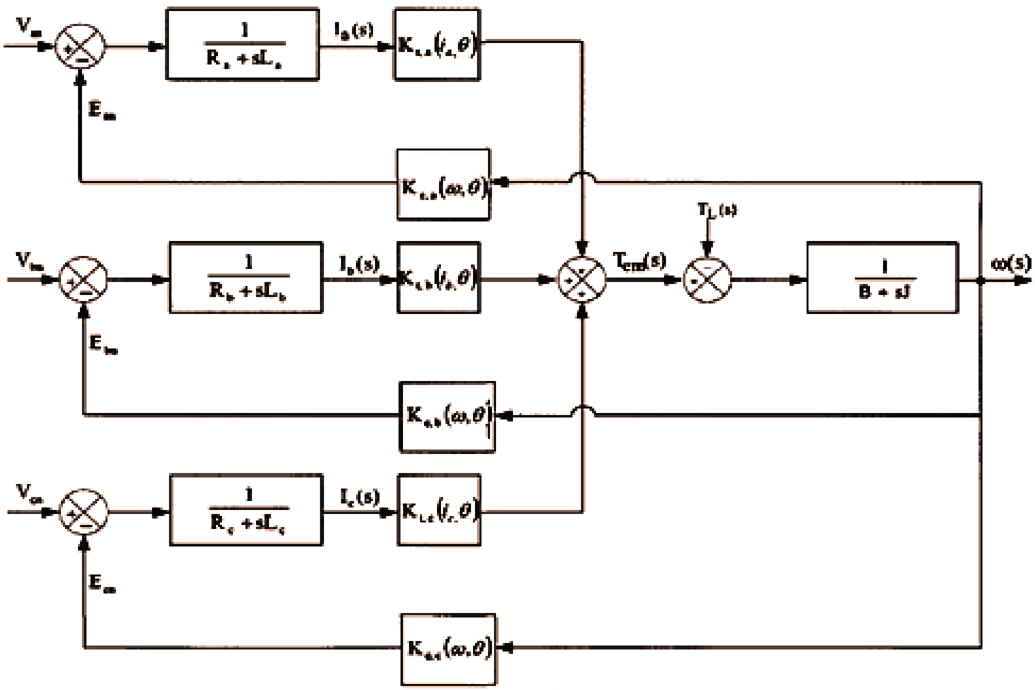

Fig. 2: Model of a BLDC Motor

Table I: Commutation Logic For Five Phase BLDC

H_A	H_B	H_C	H_D	H_E	SWITCHES	
1	0	0	1	1	A(T1)	C′(T8)
1	0	0	0	1	A(T1)	D′(T7)
1	1	0	0	1	B(T2)	D′(T7)
1	1	0	0	0	B(T2)	E′(T6)
1	1	1	0	0	C(T3)	E′(T6)
0	1	1	0	0	C(T3)	A′(T10)
0	1	1	1	0	D(T4)	A′(T10)
0	0	1	1	0	D(T4)	B′(T9)
0	0	1	1	1	E(T5)	B′(T9)
0	0	0	1	1	E(T5)	C′(T8)

B. Commutation Logic

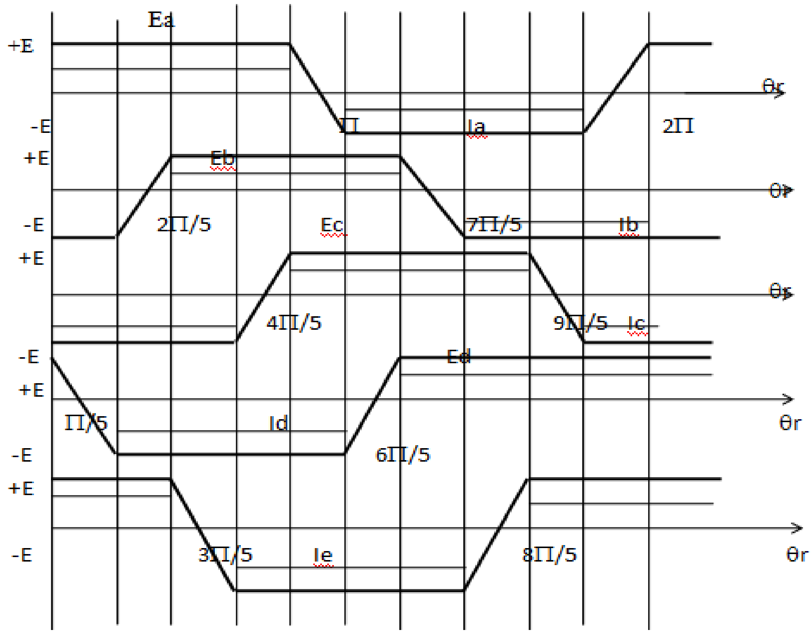

Fig. 3: Trapezoidal Waveform

The commutating logic is implementing using logic gates and output can be provided as driving signal for switches in the inverter. The position of rotor is sensed over ever 36 degree interval.

The commutating logic as in table I was developed using rotor position input data from the sensor. After determining the rotor position with the help of decoder logic particular MOSFETs are fired by issuing gate signals to the corresponding MOSFET gates of the inverter. By this a 72 degree conduction signal generator mode is implemented which can generate exact square wave switching patterns as shown in figure 3.

III. SIMULATION

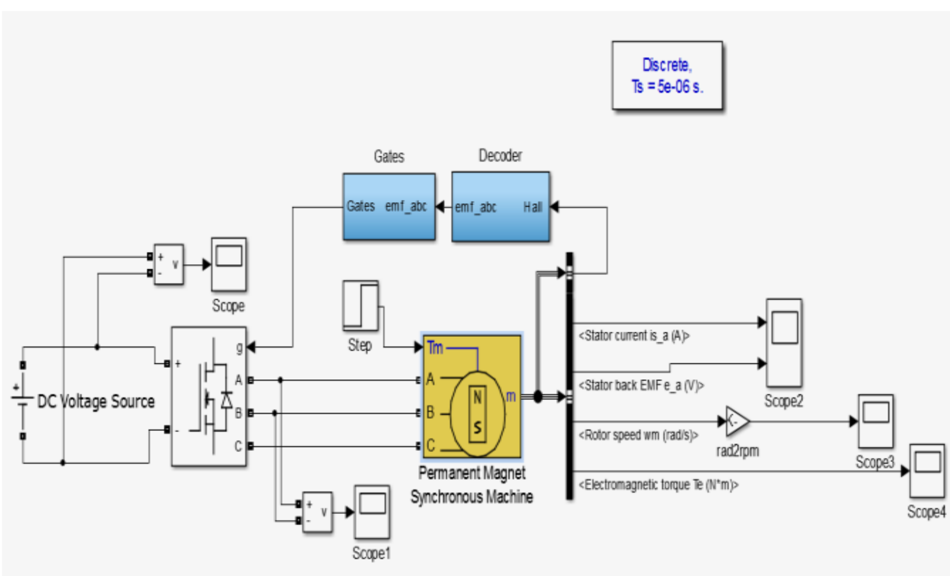

Fig. 4: Simulink Model of Three Phase

Simulink model for Trapezoidal commutation.160V DC supply is fed from DC source to the bridge block. Hall effect sensor signal from PMSM is given to decoder block, it determine the rotor position and speed, then the data is given to gate signal block, this block given the 5 phase reference signal to the Trapezoidal gate signal, output pulses from the gate signal is given to the each MOSFET. Parameters of the motor are seen in the scope.

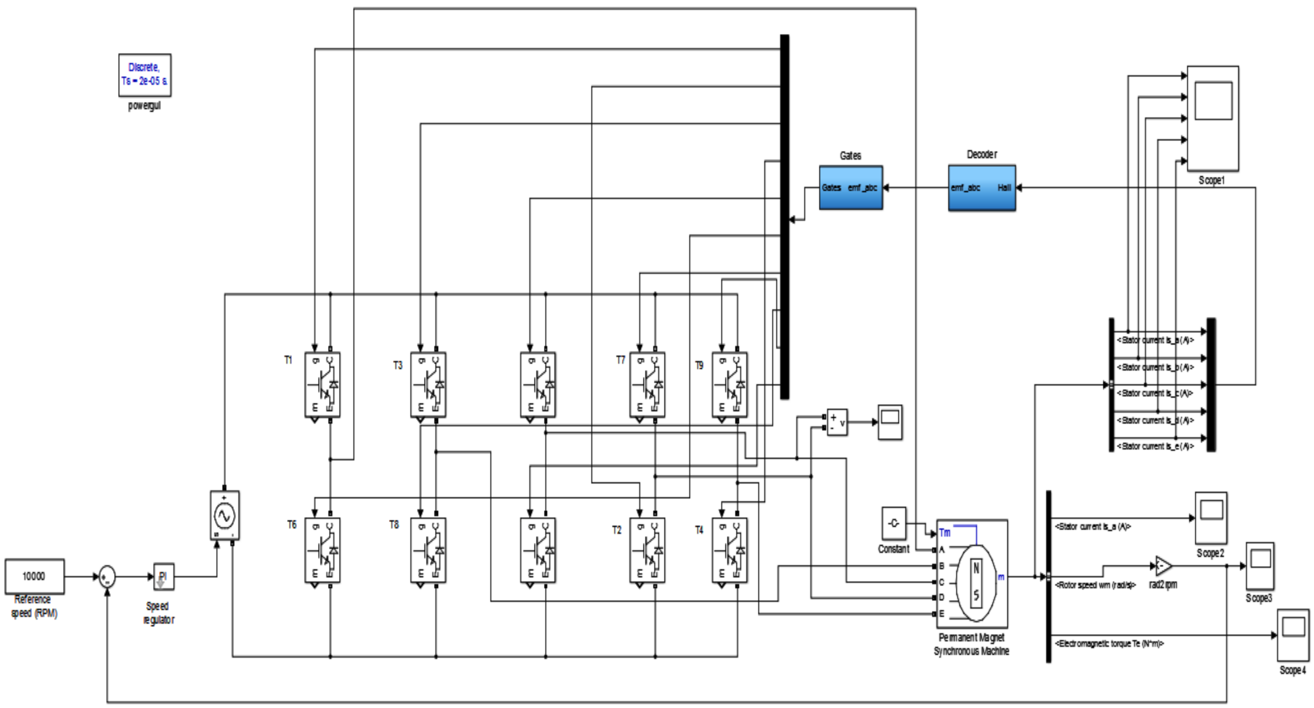

Fig. 5: Simulink model of Five Phase

MATLAB simulink model for Trapezoidal commutation is developed as shown in figure. DC supply of 160V is fed from DC source to the MOSFET bridge block. Hall Effect sensor signal from PMSM is given to decoder block, to determine the rotor position and speed of the motor. Further the data is given to gate signal block, this block gives the five phase reference signal to the Trapezoidal Back EMF signal which is processed for getting the gate pulses for the corresponding MOSFETs of inverter. The performance Parameters such as speed and torque are measured and captured using the scope.

IV. SIMULATION RESULTS

A. *Results and Discussion*

For the considered five phase 3.2 Nm, 10000rpm with an set voltage of 160V. The Hall signal of each phase is observed to be with a phase difference of 72 degree with the neighbouring phase validating 5phase motor.

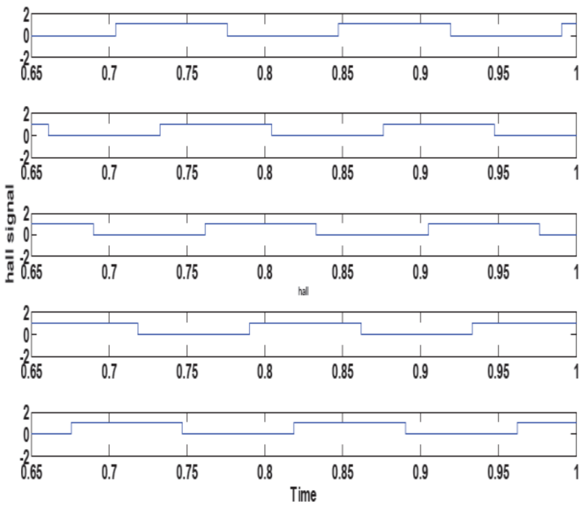

Fig. 6: Hall Signal

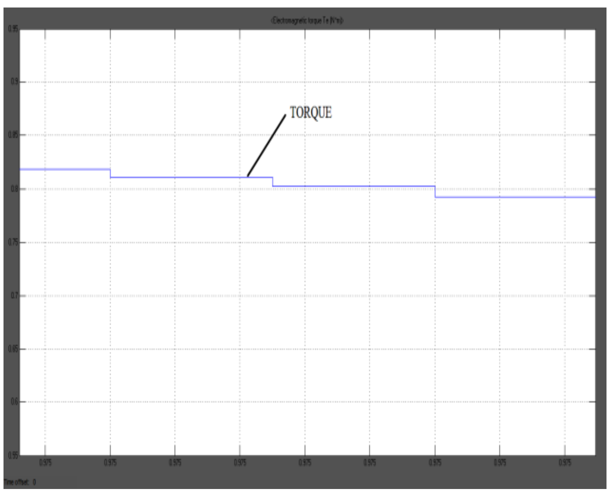

Fig. 7: Three Phase Torque Ripple

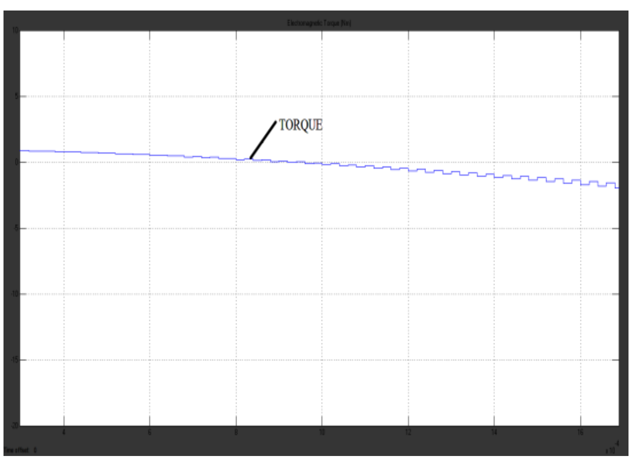

Fig. 7: Five Phase Torque Ripple

The torque profile is observed for comparing the torque ripple as in figure 6and 7. It is observed that the torque ripple is very minimal than a three phase motor. Thus multiphase BLDC motor is a perfect candidate for position application requiring smooth torque profile.

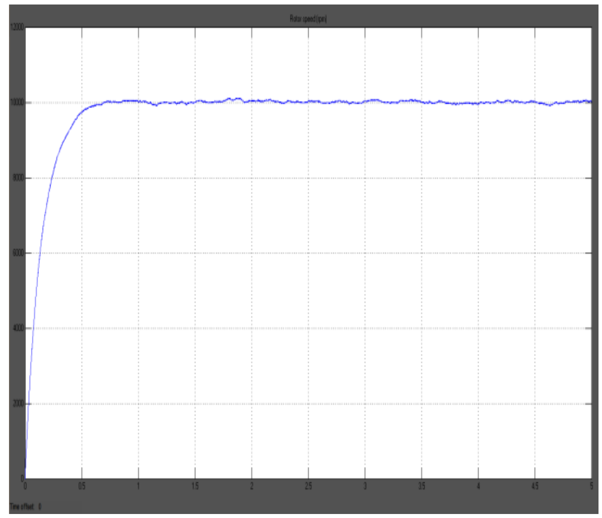

Fig. 8: Rotor Speed for 10,000rpm

V. CONCLUSION

Thus the analysis of torque ripple in this paper reveals that ripple torque can be much reduced in a BLDC motor by multiphase technique. In addition the attempt of precise speed control up to 10000 rpm of multiphase BLDC motor is presented and the voltage range required up to full speed is verified with simulation. Analysis is carried by modelling the motor in MATLAB. The simulation results of torque ripple and speed for five phase, 3.2 Nm BLDC trapezoidal motor is presented. The results reveal that a wide range of speed control is possible well within the given range of voltage. The motor settles within 1 sec to the wider spectrum of set speed. The torque profile reveals that the multiphase BLDC motor is best suited for position applications which are in need of less torque ripple.

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