

# Analysis of Torque Ripple and Speed Control of Five Phase BLDC Motor

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**Abstract** - Torque ripple is a major concern in slow speed and pointing applications. Hence This paper aims in the analysis of torque ripple of multiphase BLDC motor. A five phase 3.2 Nm, 10000 rpm Trapezoidal type BLDC motor is chosen for analysis. Simulation is carried out for controlling the speed of five phase BLDC motor in MATLAB R2013a. Block level simulation is carried out in SIMULINK with the decoder logic subsystem, controller, driver and MOSFET switches. The speed profile is analysed for various speed input commands over the full range up to rated speed. Torque ripple is studied and it is compared with the same capacity three phase BLDC motor. The input voltage required for the full range of speed upto rated speed is obtained from simulation results. Controller fine tuning is carried out for smooth and precise speed control. The results of speed profile and torque ripple is presented.

## I.INTRODUCTION

BLDC motor have a number advantages comparing with brush dc motors and induction motors [1]. The usage of strong permanent magnets leads to less energy wastage and hence increased efficiency. These motors are less weight, volume, high reliability, less noise and maintenance. Due to these advantages the BLDC motors are used in various applications [2].

BLDC motor with higher number of phases have more advantages than three phase[3]. It reduces stator current in each phase without increasing the voltage, reduces torque ripples, reduces amplitude and increases frequency of torque pulsation. For application such as in aerospace, military fault tolerant is most important consideration[4]. Speed control of motor is essential part in all servo applications as settling time and time of response is vital in deciding the system overall performance and speed of operation. Multiphase motors are more fault tolerant comparing with conventional three phase. The advantage of multiphase motors is that the motor can continue the operation normally even if one or more phases are failed thus ensuring fault tolerance.[4]

However despite these advantages the criticism against more number of phases is that its complex control scheme and higher cost. The multiphase motor drive can be good choice where high reliability and high power density are required.[5]

Torque ripple is an effect seen in many electric motor designs, referring to a periodic increase or decrease in output torque as the output shaft rotates. It is measured as the difference in maximum and minimum torque over one complete revolution, generally expressed as a percentage.[6] Many techniques have been introduced to minimize the torque ripples. 1. Modified PWM control techniques, 2. DC Bus Voltage Control, 3. Current control based techniques, 4. Torque Control Techniques, 5. Phase Conduction Methods, etc.,[7]

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]

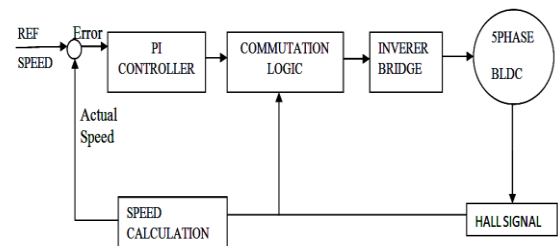


Fig 1 Block Diagram

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. Modelling 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

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

Considering five phase symmetry and non-salient rotor

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

$$L_{ab} = L_{ba} = L_{ac} = L_{ca} = L_{ad} = L_{da} = L_{ae} = L_{ea} = L_{be} = L_{eb} = L_{bd} = L_{db} = L_{de} = L_{ed} = L_{ce} = L_{ec} = L_{cd} = L_{dc} = M$$

Considering stator phase current balanced

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

Thus equation can be written as

$$V_a = R i_a + L \frac{di_a}{dt} + E_a \quad (2)$$

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  $T_l$  can be written as

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

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

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

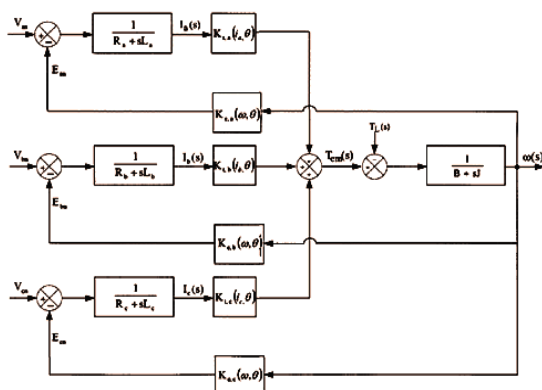


Fig 2 Model of a BLDC motor

### C. Commutation Logic

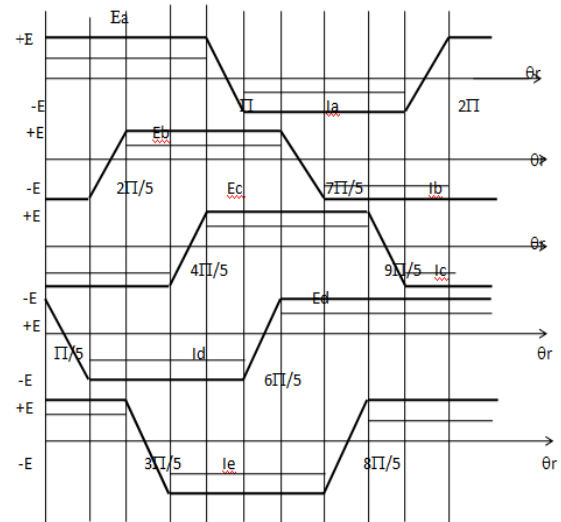


Fig 3 Trapezoidal waveform

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.

TABLE I. Commutation Logic For five phase BLDC

H <sub>A</sub>	H <sub>B</sub>	H <sub>C</sub>	H <sub>D</sub>	H <sub>E</sub>	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)

### III SIMULATION

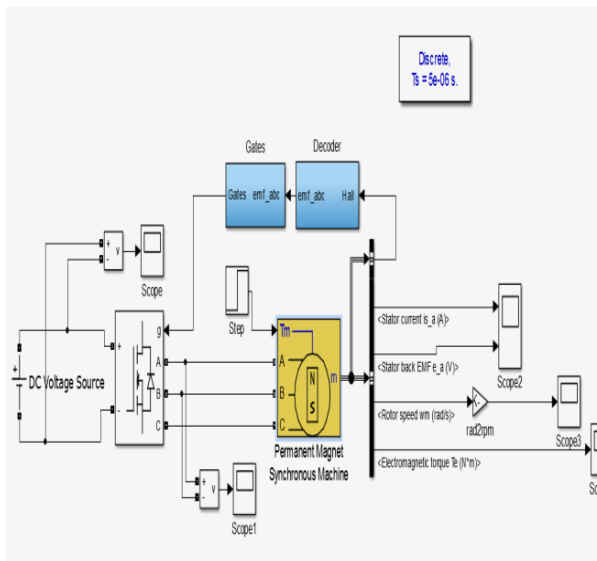


Fig4 Simulink model of three phase

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.

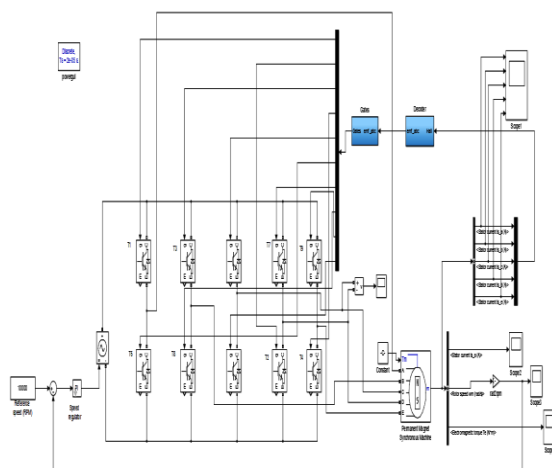


Fig 5 Simulink model of five phase

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 5 phase motor.

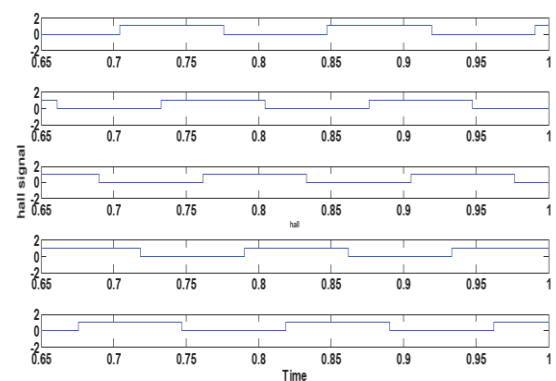


Fig 6 Hall Signal

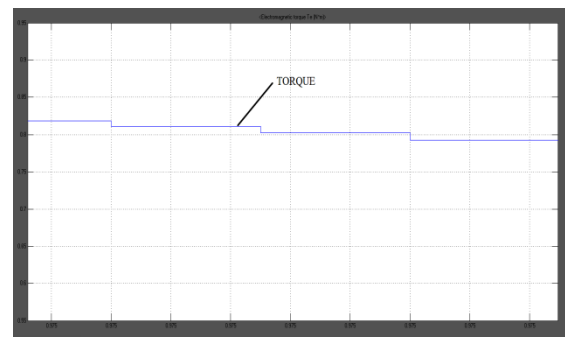


Fig 7 Three phase torque ripple

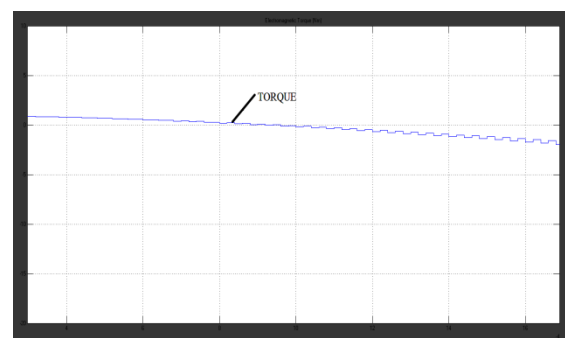


Fig 7 Five phase torque ripple

The torque profile is observed for comparing the torque ripple as in figure 6 and 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.

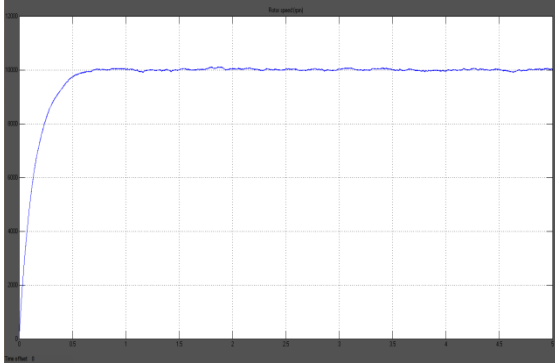


Fig 8 Rotor speed for 10,000rpm

## 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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