Modelling and Position Control of Five Phase Brushless DC Motor

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Abstract

This paper presents the position control of five phase Brushless DC Motor. The simulation model of five phase BLDC motor is studied and actual implementation of mathematical model is done with trapezoidal backemf is proposed with the help of MATLAB/SIMULINK software.The inverter for five phase BLDC motor is designed and switching sequence according to rotor positioning signals. Hall sensors are used for sensing the position. PWM current control is used for providing gating pulses.Position control is done using Cohen Coon tuning method.

"1.Introduction"

BLDC motor have a number advantages comparing with brush dc motors and induction motors. The usage of strong permanent magnets leads to less energy wastage so the efficiency will be high.These motors are less weight, volume ,high reliability,less noise and maintenance. Due to these advantages the motors is using in various applications [6]

BLDC motor with higher number of phases have more advantages than three phase. It can reduces stator current in each phase without increasing the voltage, reduces torque ripples, reduces amplitude and increasing frequency of torque pulsation. For application such as in aerospace, military fault tolerant is most important consideration. Multiphase motors are more fault tolerant comparing with conventional three phase. The motor can continue the operation normally if one or more phases are failed. [5]-[8]

However despite of these advantage the criticism against more number of phases is that its complex control scheme and higher cost. This problem can easily solved with the help of DSP controller. Thus multiphase motor drive can be good choice where high reliability and high power density are required.

The brushes dc motor suffer from lower reliability, since brushes wear down by operation and need time to time maintenance or replacement. This draw back of dc motor can be eliminated by using Brushless Dc Motor. The BLDC motor possess advantage such as long life time, faster response, better speed versus torque characteristics and can used in high speed drive. The arrival of new switching device,digital technology, microprocessor popularise the use of BLDC motor.[1]-[3]

Permanent magnet motor which are classified as sinusoidal fed Permanent magnet synchronous motor and rectangular fed BLDC motor.In BLDC the windings are wound in such that the back emf is trapezoidal. The torque of BLDC motor is mainly influenced by waveform of back emf and fed with rectangular stator currents. However in practise torque ripple exist, mainly due to emf waveform imperfections. The current ripple result from PWM or hysteresis control. The emf waveform imperfections result from variation in shape of slot, skew, and magnets of BLDC motor subject to design purposes[7]-[8]

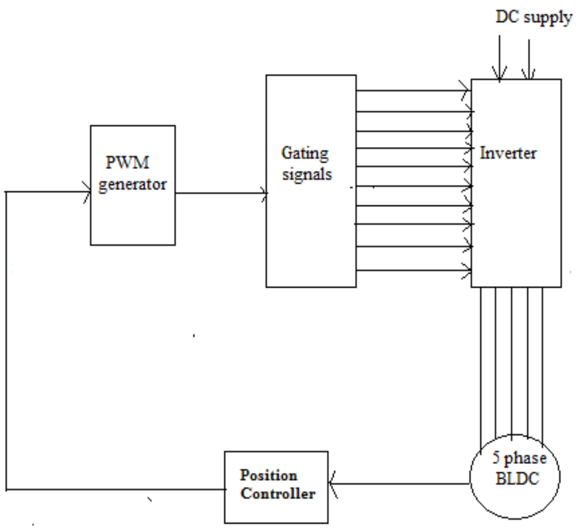

Fig 1 Block Diagram

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. The overall diagram is shown in figure. It represent 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. The BLDC motor electronic commutator is used. It uses hall sensor which senses the rotor position.

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"2. Simulation BLDC motor"

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2.1 Modeling of five phase BLDC Motor

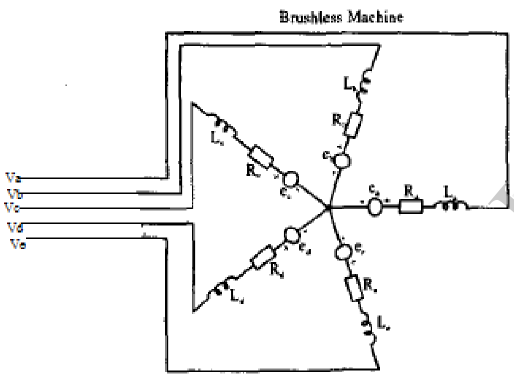

Fig 2: Equivalent circuit

The assumptions made are all the five phase windings are symmetrical, Eddy current loss and hysteresis loss are neglected, Magnetic saturation is not taken into account. The Stator resistance R, Self inductance L, Mutal inductance M. The five phase balanced stator voltage equation can be expressed as follows

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

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

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

The equation of voltage for other phases can be written

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

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

The rotor position and rotor speed can be related as

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

The back emf can be written as

$$E_a = \omega_m f_{\theta_r} K_b \qquad (5)$$

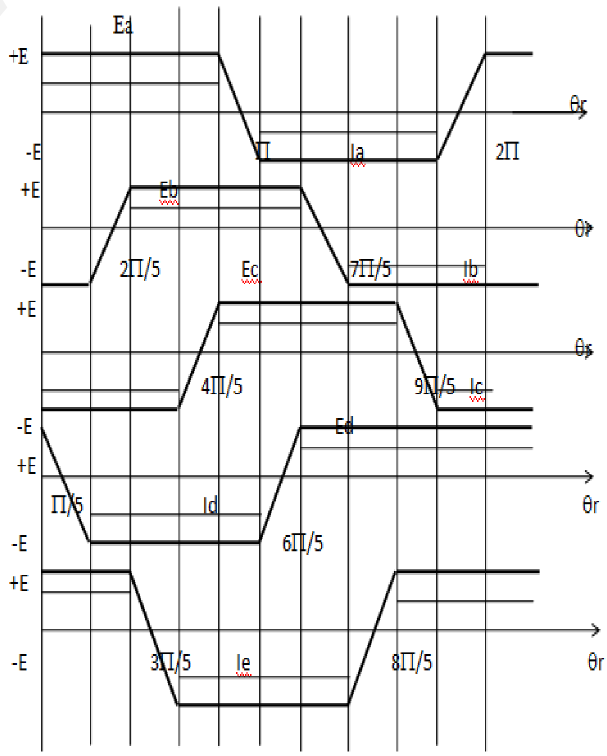

Fig 3 Trapezoidal wave

Where f_{θ_r} can be written from the trapezoidal back emf wave

$$
\begin{aligned}
f_{\theta_r} &= 1 && 0 \le \theta_r < \frac{\pi}{5} \\
&= 1 && \frac{\pi}{5} \le \theta_r < \frac{2\pi}{5} \\
&= 1 && \frac{2\pi}{5} \le \theta_r < \frac{3\pi}{5} \\
&= 1 && \frac{3\pi}{5} \le \theta_r < \frac{4\pi}{5} \\
&= (\pi - \theta_r)\frac{10}{\pi} && \frac{4\pi}{5} \le \theta_r < \frac{5\pi}{5} \\
&= -1 && \frac{5\pi}{5} \le \theta_r < \frac{6\pi}{5} \\
&= -1 && \frac{6\pi}{5} \le \theta_r < \frac{7\pi}{5} \\
&= -1 && \frac{7\pi}{5} \le \theta_r < \frac{8\pi}{5} \\
&= -1 && \frac{8\pi}{5} \le \theta_r < \frac{9\pi}{5} \\
&= (\theta_r - 2\pi)\frac{10}{\pi} && \frac{9\pi}{5} \le \theta_r < \frac{10\pi}{5}
\end{aligned}
$$

Similarly equation for other phases as functions of rotor position are written. The above equation can be used to model the five phase BLDC motor.

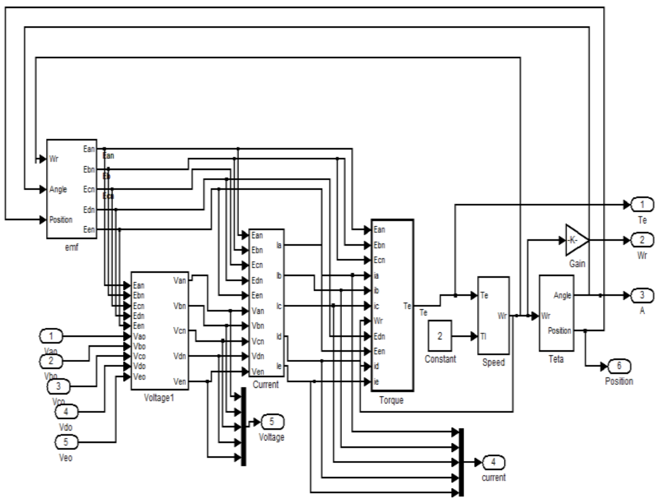

Fig 4 Five Phase BLDC motor

2.2 Commutating Logi

The electric commutation means a way of PWM signal distribution to switches in inverter circuit. The sequencing depends upon signal which are sensed and feedback. The other factor it depends on is kind of PWM signal (unipolar/bipolar). 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 was developed using sensing rotor position. After determining the rotor position it will start giving driving signals for switches in the inverter. By this a 72 degree conduction signal generator mode is implemented which can generate exact square wave switching patterns. The frequency of carrier signal is 5KHZ. The inverter is driven by 10 gating signal derived from the commutating logic.The diagram shows a five phase inverter and the output of five phase feed the five phase BLDC motor

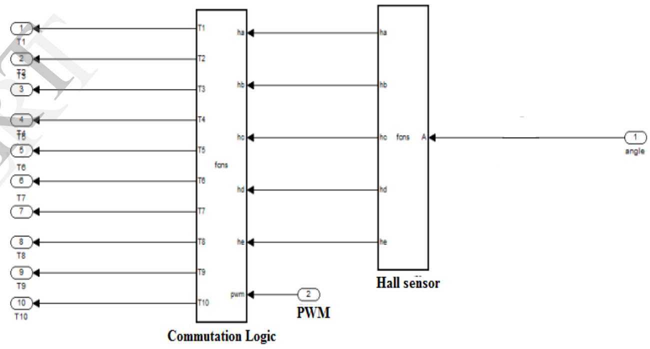

Fig 5 Commutation logic

2.3 Voltage Source Inverter

The inverter in the system is modelled by considering conduction 72 degree. Two positive and two negative phase conduct at a time. Bipolar switching is used.

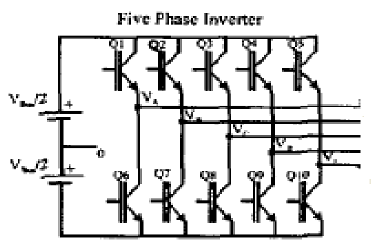

Fig 6 Voltage Source Inverter

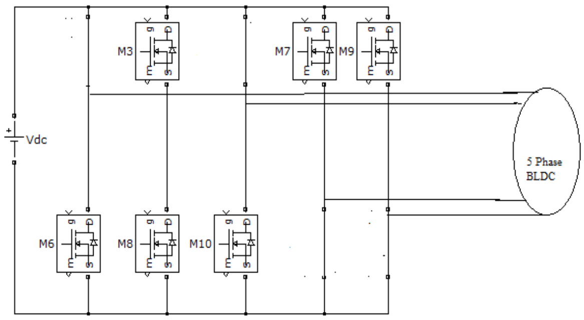

Fig 7 Switching action

2.4 Position Controller

The compensation selected for postion controlling is PI compensation. Integral compensation reduces steady state error and tracking position which increases the accuracy of the system. The tuning method used is Cohen coon method.

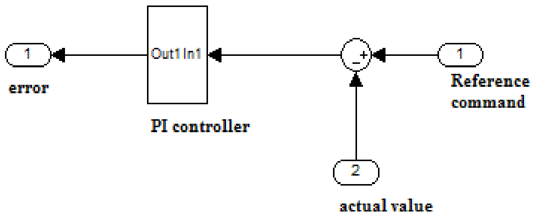

Fig 8 Position Controller

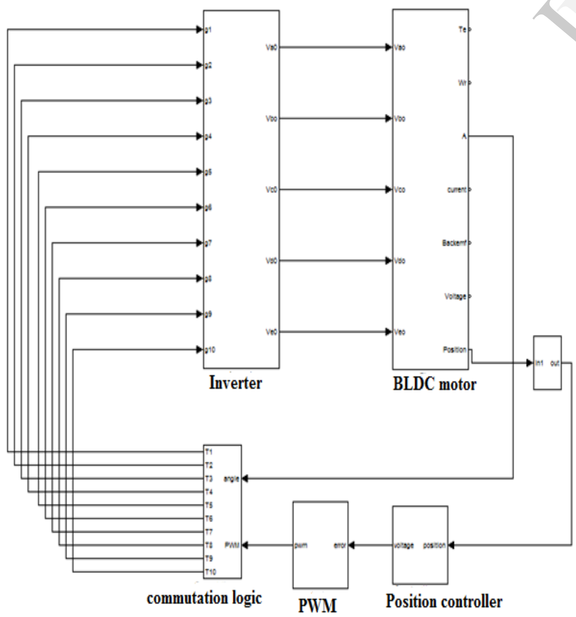

Fig 9 Simulink model of five phase BLDCM

"3.Simulation Results"

The model of closed loop system of three phase BLDC is explained and simulation work have been conducted. The electrical input corresponding to actuator position is obtained as shown in figure. The simulation result of backemf ,current ,position are shown below.

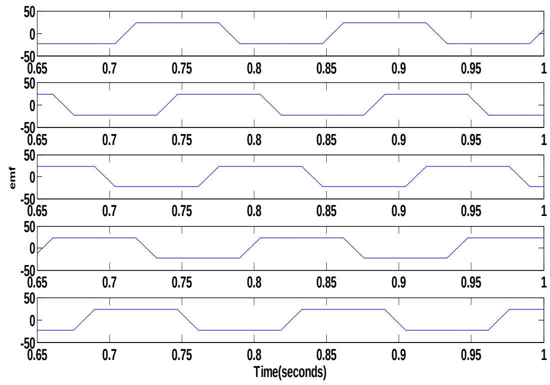

Fig 10 Emf

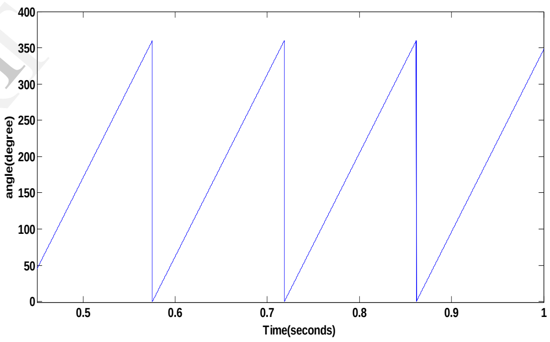

Fig 11 Angle

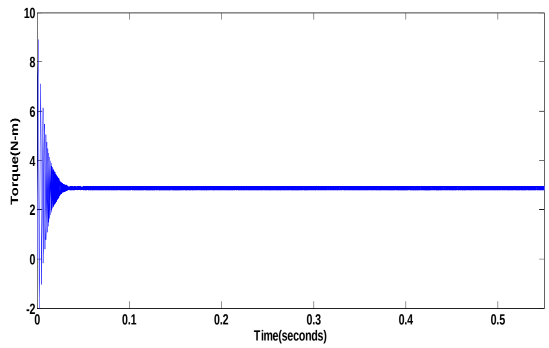

Fig 12 Torque

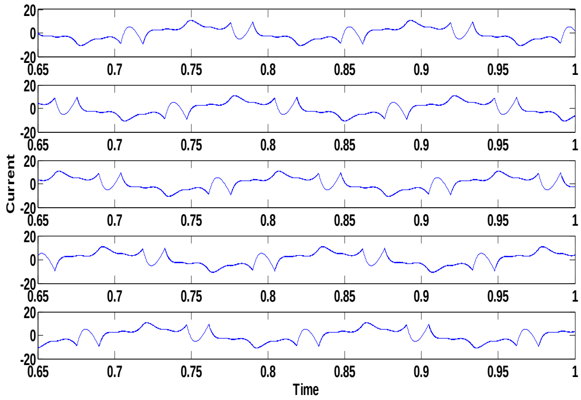

Fig 13 Current

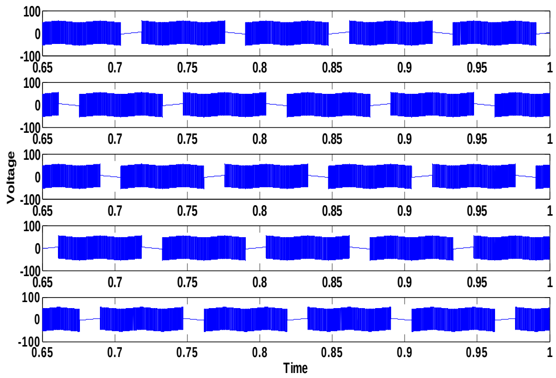

Fig 14 Voltage

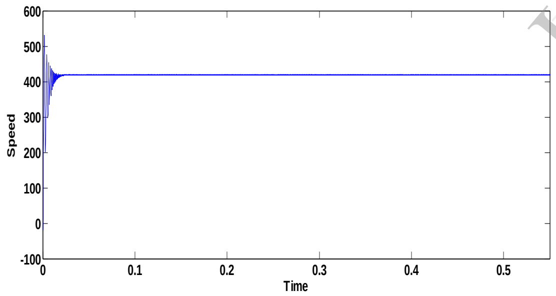

Fig 15 Speed

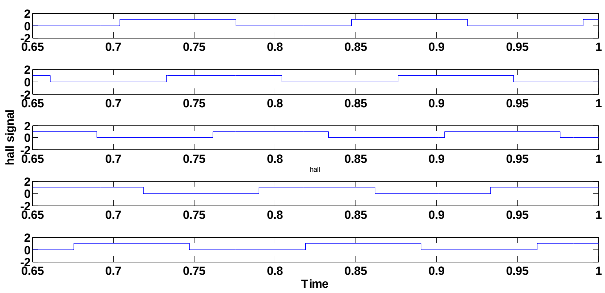

Fig 16 Hall signals

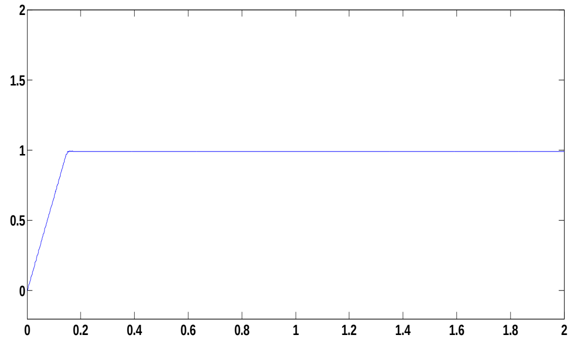

Fig 17 Position Control for input of 1V

Conclusion

In this paper Five phase BLDC motor is designed. The simulation results of five phase BLDC motor are presented. Based on the mathematical model of five phase BLDC motor,the modeling and simulation are studied. The simulation results shows it fit well for theoretical analysis also.The position control of eleven phase BLDC motor is done. The position controller provided will give a stable response with rise time less than 200ms and reduced steady state error.

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