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Modeling and Simulation Analysis of Eleven Phase Brushless DC Motor

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Abstract: In this paper a simulation model of eleven phase BLDC motor drive is studied and actual implementation of the mathematical model with trapezoidal back emf is proposed with the help of MATLAB/Simulink software. The motor is simulated through mathematical modeling and switching to inverter is fed according to hall sensor signals. PWM current control is used to provide gating pulses for the inverter. Then the speed control of motor is developed.

Keywords: BLDC motor, PWM inverter, Multiphase, Speed Control, Cohen Coon Tuning

I. INTRODUCTION

BLDC motor have some advantages comparing with brush dc motors and induction motors. The use of strong permanent magnets energy wastage of motor is less so the efficiency will be high.These motors are less weight, volume ,high reliability,less noise and less maintenance. Due to these advantages the use of motors is growing rapidly in various applications [1]

BLDC motor with more number of phases has 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 aerospace, military applications, fault tolerant is important consideration. Multiphase motors are more fault tolerant comparing with conventional three phase. The motor can be operated normally if one or more phases are failed. [6]-[12].However despite of this advantage the criticism against higher number of phases is that its complex control scheme and higher cost. This problem can easily solved with the development of DSP controller. Thus multiphase motor drive. can be good choice where high reliability and power density required. In areas such as aerospace,,ship propulsion, military applications where requirements are not opperesive when compared with overall demands.[2].In the past review of multiphase BLDC five phase motor drive seven phase motor drive and nine phase motor are presented. In reviewing the articles a eleven phase motor drive is not yet been analysed in the previous studies. In this paper eleven phase BLDC motor drive and components of mathematical model are presented in MATLAB/Simulink software.

II. ELEVEN PHASE BLDC

The overall system configuration of eleven phase BLDC motor drive is shown in Fig 1. The PWM inverter topology composed of 22 switch voltage configuration with constant dc link voltage. The PWM inverter and position sensors are used for current commutation which replaces the function of brushes and commutator. The hall sensors are used for sensing the position and triggering the switches in the PWM inverter according to sensor signals which is electronic commutation.

The flux distribution in BLDC motor air gap is not sinusoidal, rotating field control and axial conversion used for induction and synchronous motor cannot be used for modelling BLDC motor. The harmonic modelling of BLDC require large amount of computations. Most of these methods not give clear image for current variables on inverter voltage. The method based on finite element analysis require complex mathematical equations and not capable of expressing switching behaviour of the drive system.

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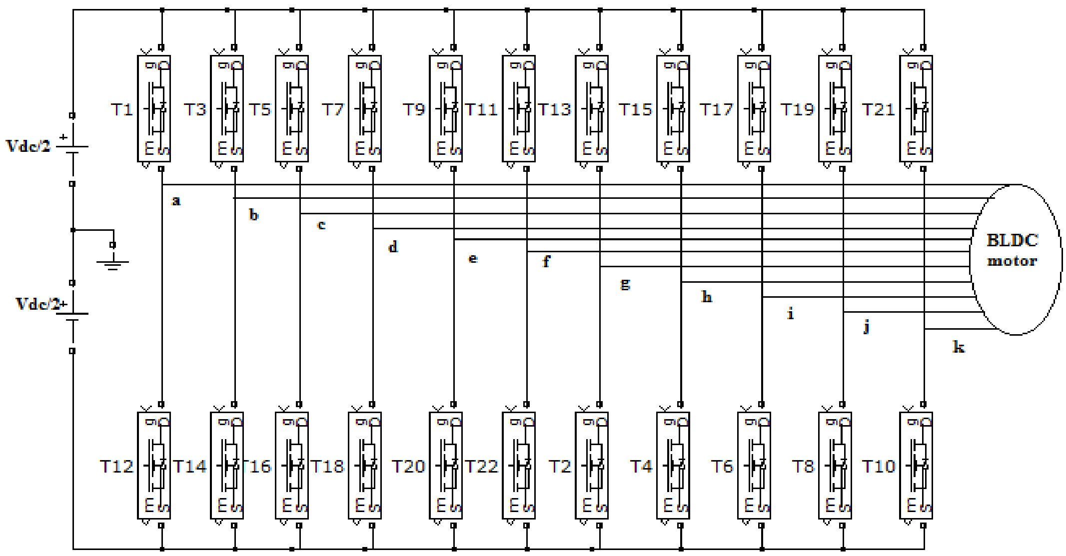

Fig 1. 11 Phase BLDC Motor

22 switch 11 phase PWM inverter is formed by generalising 5 phase, 7 phase, 9 phase models. Inverter performance includes 22 modes according to current conduction states as in fig 2

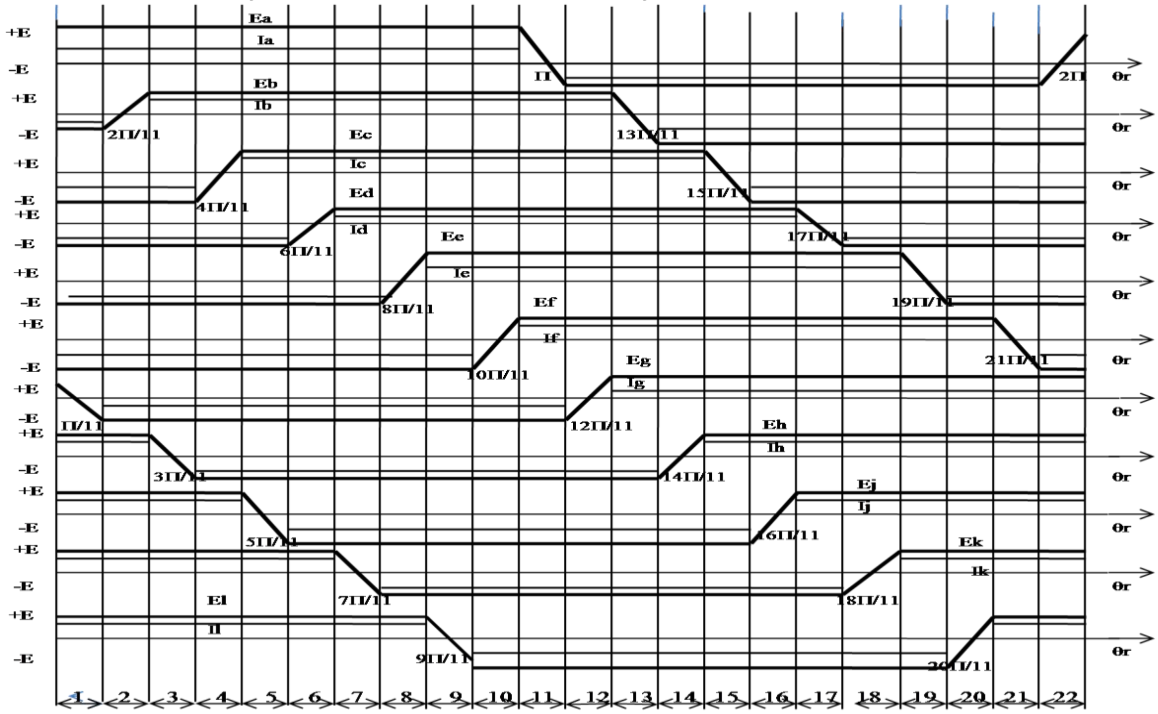

Fig.2 Back emf voltage and phase currents of 11 phase BLDC

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The BLDC motor has a permanent magnet motor and stator windings are wound in such a way that the back electromotive Therefore no particular advantage in transforming the machine equation into well known two axis equations which are done in case of machines with sinusoidal back emf.[3]-[5] force is trapezoidal. The trapezoidal back emf shows that the mutual inductance between stator and rotor is not sinusoidal .

TABLE I
PHASE CURRENTS ACCORDING to OPERATING MODES

	ia	ib	ic	id	ie	if	ig	ih	ii	ij	ik
1	+	-	-	-	-	-	0	+	+	+	+
2	+	0	-	-	-	-	-	+	+	+	+
3	+	+	-	-	-	-	-	0	+	+	+
4	+	+	0	-	-	-	-	-	+	+	+
5	+	+	+	-	-	-	-	-	0	+	+
6	+	+	+	0	-	-	-	-	-	+	+
7	+	+	+	+	-	-	-	-	-	0	+
8	+	+	+	+	0	-	-	-	-	-	+
9	+	+	+	+	+	-	-	-	-	-	0
10	+	+	+	+	+	0	-	-	-	-	-
11	0	+	+	+	+	+	-	-	-	-	-
12	-	+	+	+	+	+	0	-	-	-	-
13	-	0	+	+	+	+	+	-	-	-	-
14	-	-	+	+	+	+	+	0	-	-	-
15	-	-	0	+	+	+	+	+	-	-	-
16	-	-	-	+	+	+	+	+	0	-	-
17	-	-	-	0	+	+	+	+	+	-	-
18	-	-	-	-	+	+	+	+	+	0	-
19	-	-	-	-	0	+	+	+	+	+	-
20	-	-	-	-	-	+	+	+	+	+	0
21	-	-	-	-	-	0	+	+	+	+	+
22	0	-	-	-	-	-	+	+	+	+	+

III. MODELING OF ELEVEN PHASE BLDC

The BLDC motor produces a trapezoidal back emf rectangular stator currents needed to produce constant torque. The overall system consist of BLDC motor, inverter block, Commutation logic block

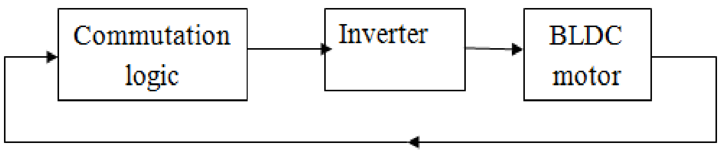

Fig. 3 Block diagram of BLDC motor model

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The assumptions made for modelling 11 phase BLDC motor are magnetic saturation is neglected, Saliences of the poles are neglected, Hysteresis and eddy current losses are not considered, Self inductances, Mutal inductances and resistances of stator windings are equal. The stator voltage across phase a can be expressed as

$$van = R_a i_a + L_{aa}\frac{di_a}{dt} + L_{ba}\frac{di_b}{dt} + L_{ac}\frac{di_c}{dt} + L_{ad}\frac{di_d}{dt} + L_{ae}\frac{di_e}{dt} + L_{af}\frac{di_f}{dt} + L_{ag}\frac{di_g}{dt} + L_{ah}\frac{di_h}{dt} + L_{ai}\frac{di_i}{dt} + L_{aj}\frac{di_j}{dt} + L_{ak}\frac{di_k}{dt} + E_{an} \quad (1)$$

$$L_{aa} = L_{bb} = L_{cc} = L_{dd} = L_{ee} = L_{ff} = L_{gg} = L_{hh} = L_{ii} = L_{jj} = L_{kk} = L$$

$L_{pq} = L_{qp} = M$ where p=a,b,c…k q=a,b,c….k

$$R_a = R_b = R_c = R_d = R_e = R_f = R_g = R_h = R_i = R_j = R_k = R$$

The stator currents are constrained to be balanced

$$i_a + i_b + i_c + i_d + i_e + i_f + i_g + i_h + i_i + i_j + i_k = 0$$

Thus voltage equation can be written as

$$V_{an} = Ri_a + (L - M)\frac{di_a}{dt} + E_{an} \quad (2)$$

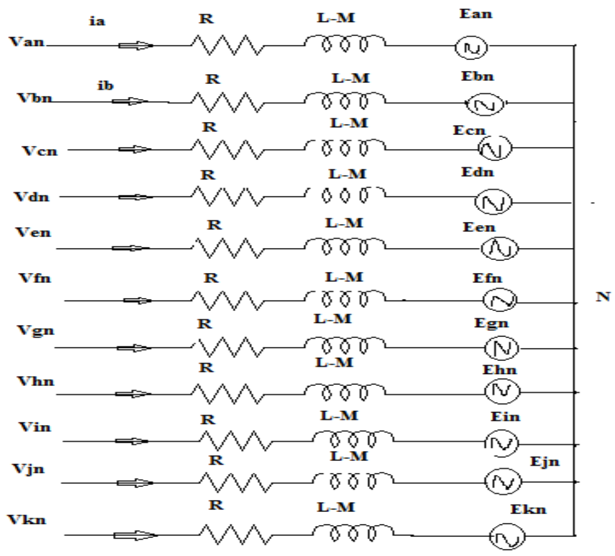

Fig. 4 Electric equivalent of 11 phase

The equation of motion of a simple system with moment of inertia J, friction coefficient B and load torque T_l

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

And electrical position and speed are related as

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

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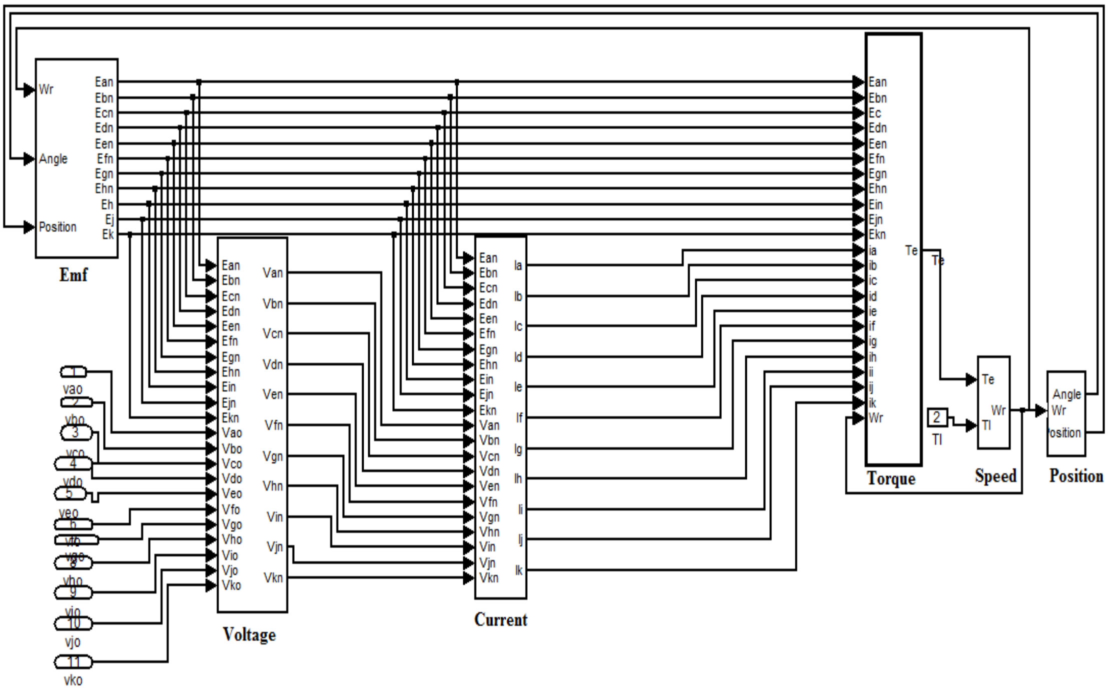

Fig 5. 11 phase BLDC motor model

IV. COMMUTATION LOGIC
V.

The limitation of brush DC motor is replaced by BLDC motor, where electronic commutation is used. Electronic commutation is the way of distribution of PWM signal to the switches in the eleven phase BLDC motor. The sequence of distribution of gate signals depends on the feedback from BLDC motor. It also depends on the type of PWM signal (bipolar or unipolar). The position of rotor is sensed during every Π/11 degrees. According to the position of rotor pulses to 22 switches, driving the BLDC motor is given. The commutation logic is developed by sensing the position of rotor. The position error is determined and compared with high frequency carrier which generates the PWM signal. After determining the position signals are generated which drive the BLDC motor. This model can generate exact square wave switching pattern. Thus generating signals for 22 switches. At each instant out of eleven phases 10 phases conduct, one phase remains unpowered.

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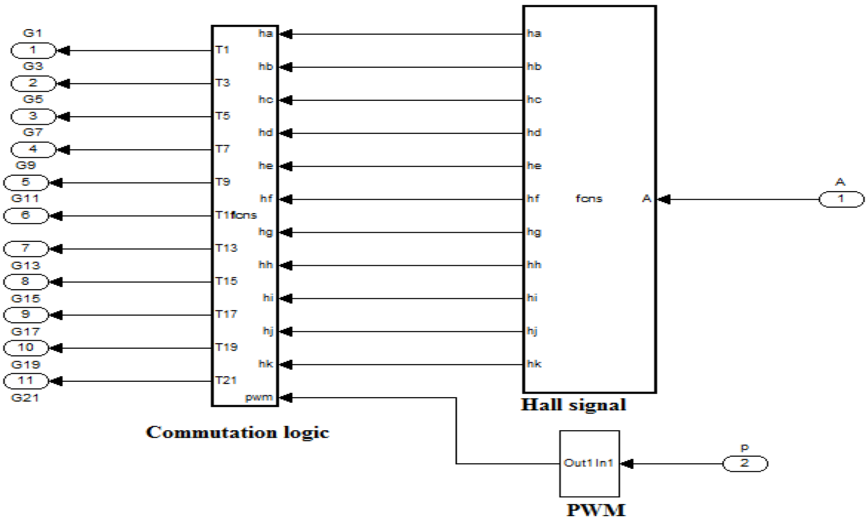

Fig. 6 Commutation logic

VI. SPEED CONTROLLER

The recommended compensation for speed control is PI compensation. The tuning of PI controller is done using Cohen coon method.

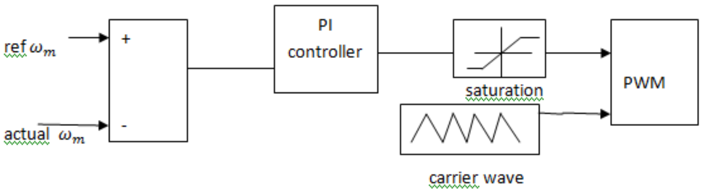

Fig. 7 Speed controller

VII. SIMULATION RESULTS

The simulation of eleven phase BLDC is done and the results are presented. The parameters are P=4, R=0.7Ω, M=1.5mH, L=2.72mH, Vdc=200V, J=0.002kgm^2, B=.002Nm/rad/sec

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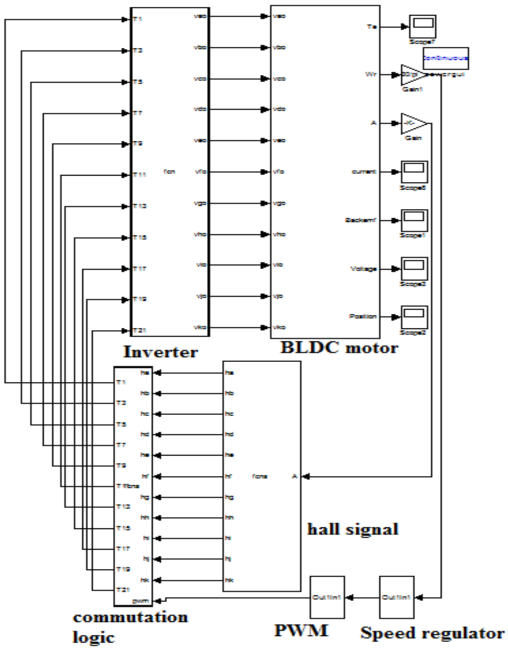

Fig .8 Simulation model of 11 phase BLDC

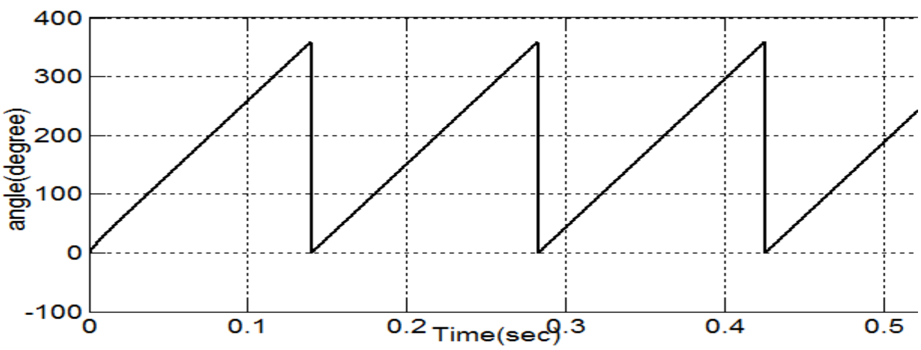

Fig. 9 Angle

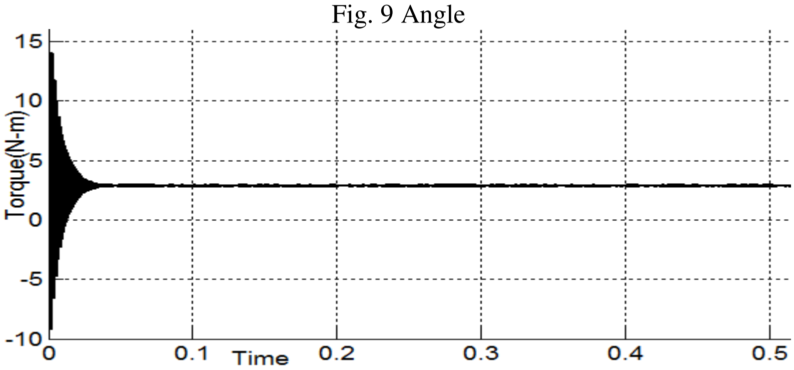

Fig. 10 Torque

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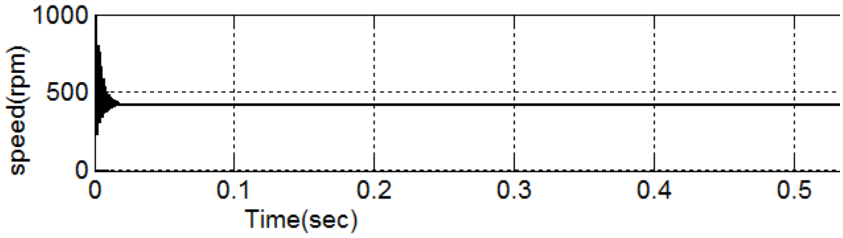

Fig 11. Speed

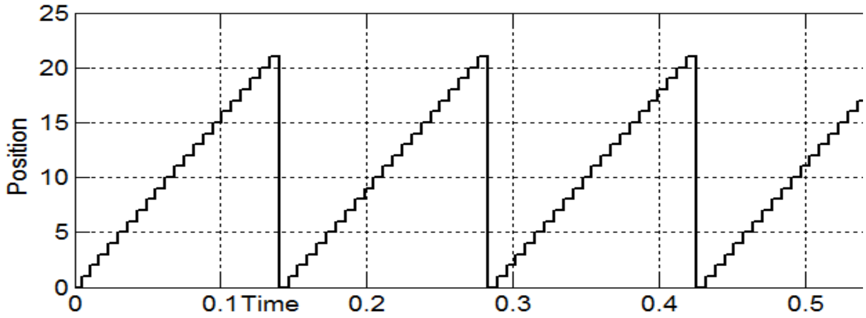

Fig. 12 Position

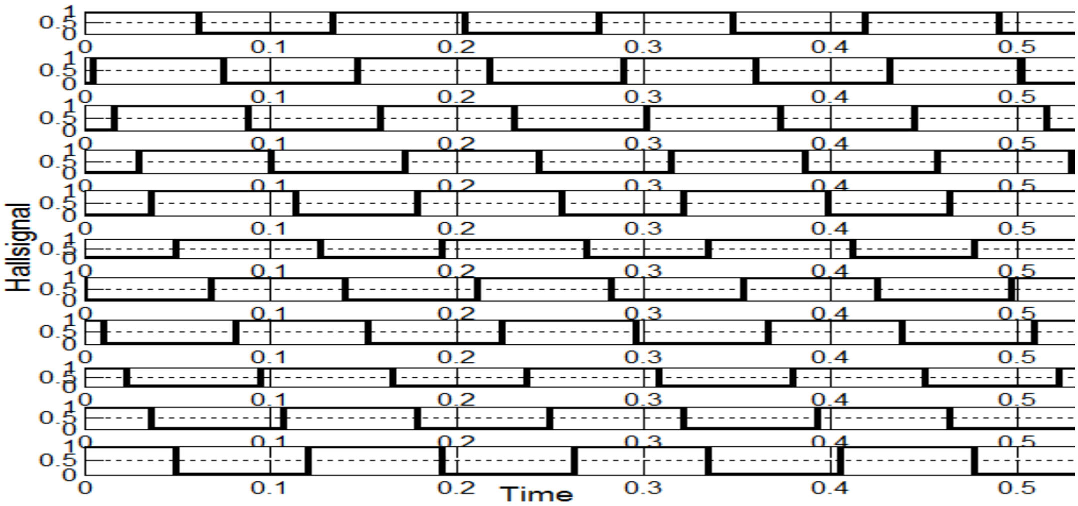

Fig. 13 Hall signals

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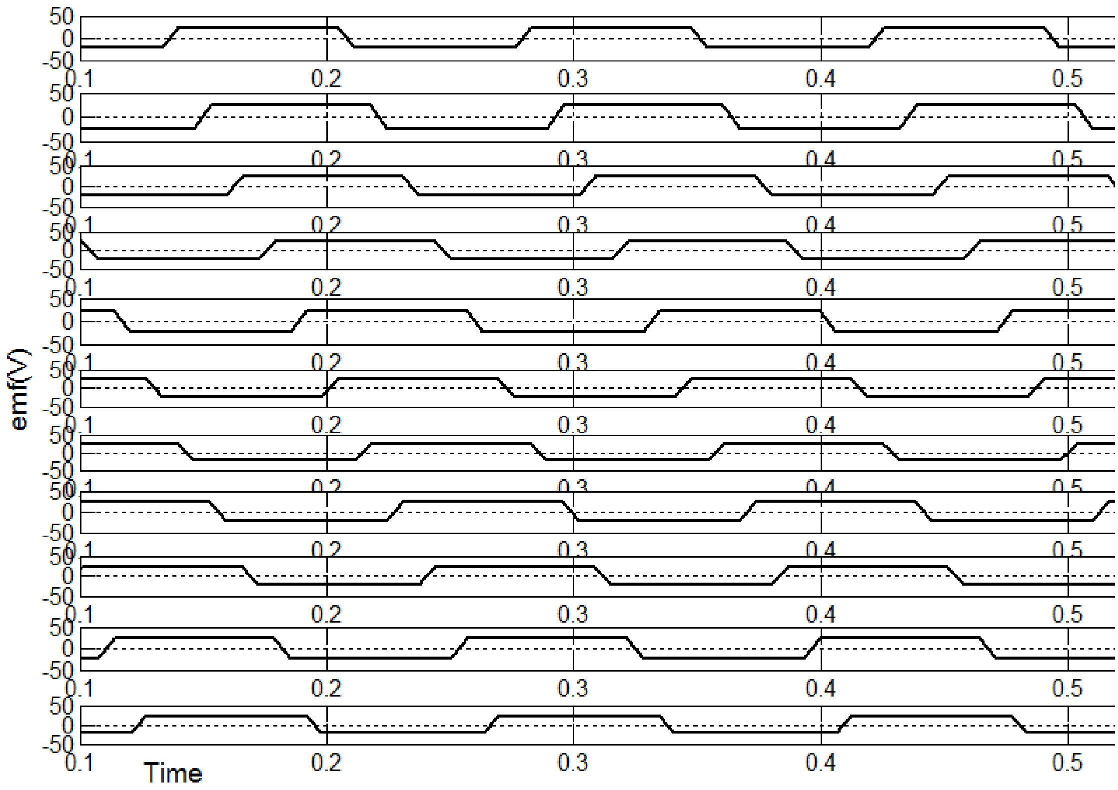

Fig. 14 Back emf

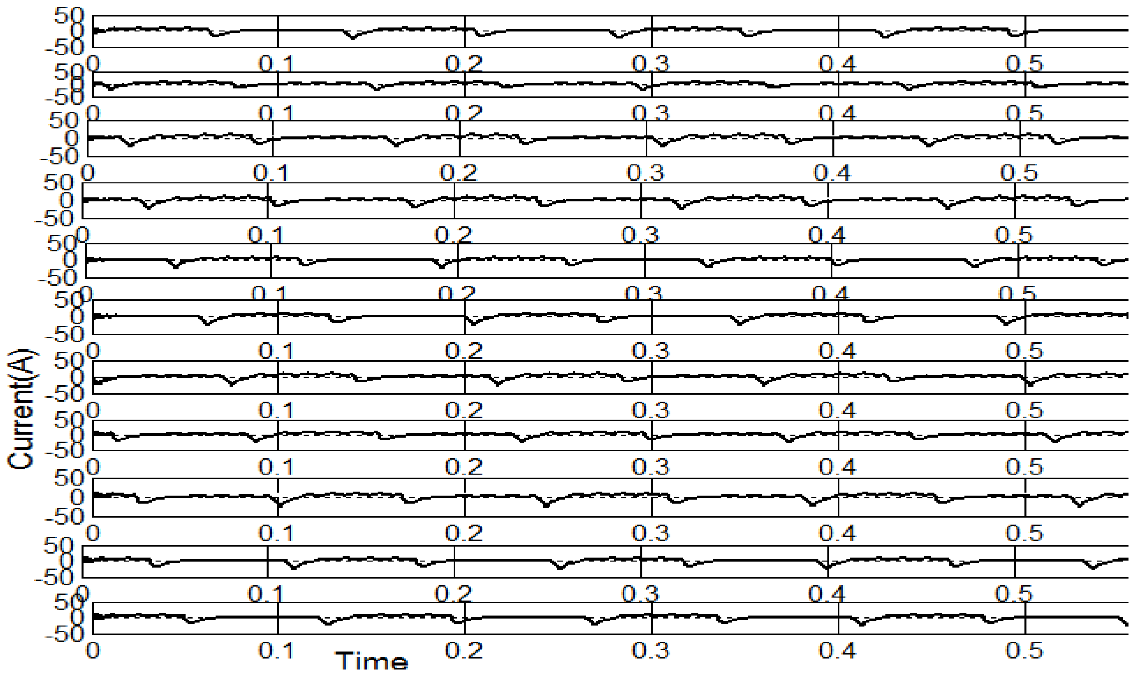

Fig. 15 Current

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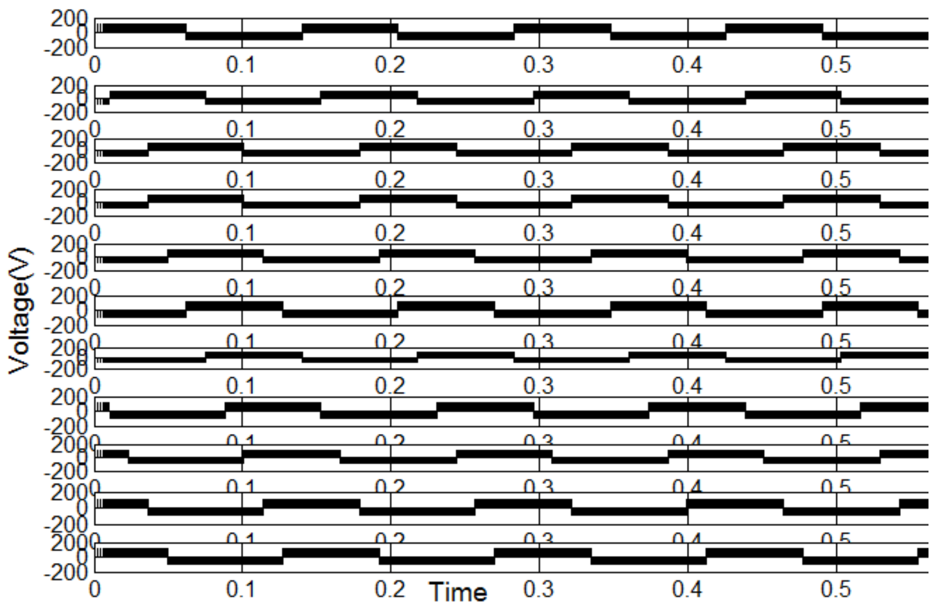

Fig 14. Voltage

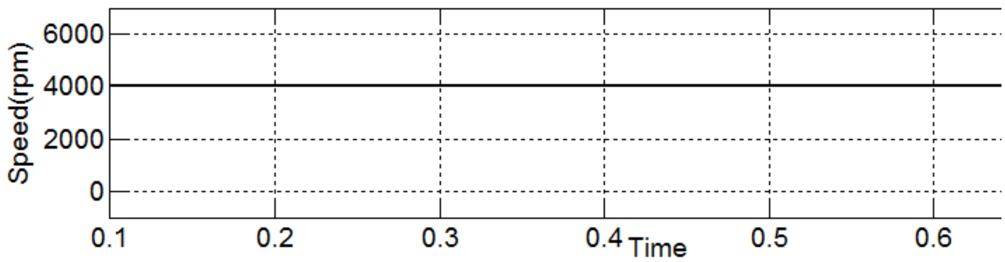

Fig 15. Speed Controling at 4000rpm

VIII. CONCLUSION

In this paper multiphase BLDC motor is designed. The simulation results of eleven phase BLDC motor are presented. Based on the mathematical model of eleven phase BLDC motor ,the modelling and simulation are studied. The simulation results shows it fit well for theoretical analysis also. The speed control of eleven phase BLDC motor is done.

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