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Control of Four Switch Inverter Fed BLDC Motor Using Fuzzy Logic

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ABSTRCAT: A control strategy based on Fuzzy Logic Controller (FLC) is proposed for four-switch three-phase brushless DC (BLDC) motor to lower the cost and improve performance. The system's whole working process is divided into two groups. In modes 2,3,5, and 6, where phase *c* works, phase *c* current is sensed to control phase *a* and *b*, and phase *c* current is consequently regulated. In mode 1 and 4, the combination of four sub operating modes for controlling phase *c* current is proposed based on detailed analysis on the different rules that these operating modes have on phase *c* current. To control and improve performance the Fuzzy Logic Controller is developed. According to simulation results, the proposed strategy shows good self adapted track ability with low current ripple and strong robustness to the given speed reference model.

KEYWORDS: Brushless DC Motor, Four-switch three-phase Inverter, Fuzzy Logic Controller

I. INTRODUCTION

A Brushless DC motor have such good features as simple construction, high reliability, light electromagnetic pollution, and high power density, they are used extensively in servo systems and low-power dive systems[1] [2]. The performance of such motors has been significantly improved due to great development of power electronics, microelectronics, magnetic performance of magnets, and motion control technology in recent years[3][4]. Now a days, many studies have been focused on how to reduce the cost of the BLDC motor and its control system without performance degradation [5] [6].

A novel four-switch three-phase BLDC motor drive is proposed to simplify the topological structure of the conventional six-switch inverter. It is an effective try on reducing cost. BLDC motors are electronically commutated based on the rotor position. Each commutation sequence has two of three phases connected across the power supply and the third phase is left open. In [7] a new speed control method using the acceleration feed forward compensation is proposed to improve the speed response characteristic for a four-switch three-phase BLDC motor and described the structure of BLDC motor, static and dynamic torque production and different current control strategies In [8] presents an original study on the generated torque ripples due to phase commutation in the four-switch three-phase BLDC motor.

In [10] the performance of Fuzzy Logic Controller based cost effective drive system of interior permanent magnets synchronous motor for high performance industrial applications. Fuzzy Logic Controller used as a speed controller and the motor the motor is fed from a four-switch three-phase pulse width modulation inverter; this reduces the cost of inverter, switching losses, and the complexity of the control algorithms and interface circuits to generate six PWM logic signals. [12] It deals with the simulation and hardware using Fuzzy Logic. Comparison between PI and Fuzzy Logic controller is done and gives us the advantages of Fuzzy Logic. The performance of the drive system was evaluated through digital simulation by matlab/simulink, the electromagnetic torque characteristics, rotor speed, PWM pulse. To reduce complexity, the linearised models have been used for designing for controller and performance analysis.

Paper is organised as follows. Section II describes the mathematical modelling of BLDC motor and its transfer function. Section III presents four-switch inverter topology which describes about four-switch inverter operation and its working modes with respect diagrams. Section IV presents the proposed BLDC motor with Fuzzy Logic Controller with respect block diagram. Section V presents Fuzzy Logic Controller operation with BLDC motor speed control with

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respect diagrams as matlab/simulink model, Fuzzy Controller structure, simulation parameters, membership functions, rule editor and simulation results. Finally Section VI presents conclusion.

II. MATHEMATICAL MODELLING OF BLDC MOTOR

The dynamics of the machine are described by a set of differential equations the three phase star connected BLDC motor can be described by the following basic equations. To attain the electrical equations for a BLDC machine, basic circuit analysis was used to find the pre-phase voltage as shown below. These are per phase modelled equations. A per phase model is shown in figure 1.

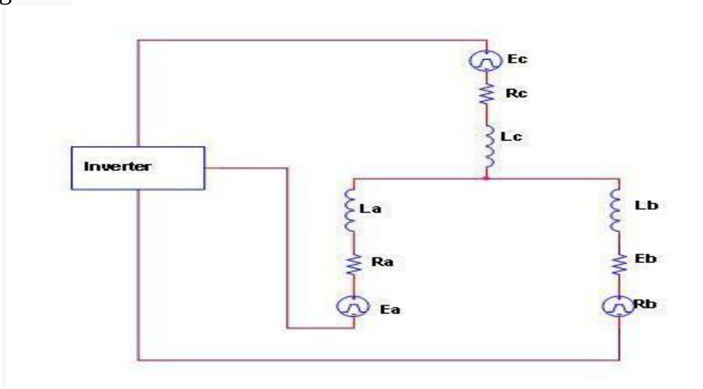

Fig 1.Equivalent circuit of BLDC motor

$$V_a = i_a(t)R_b + L_a \frac{di_a}{dt} + e_a(t) \quad (1)$$

$$V_b = i_b(t)R_b + L_b \frac{di_b}{dt} + e_b(t) \quad (2)$$

$$V_c = i_c(t)R_c + L_c \frac{di_c}{dt} + e_c(t) \quad (3)$$

$$T_{em} = B\omega(t) + J\frac{d\omega(t)}{dt} + T_L \quad (4)$$

Where V, I and e are the voltage, current and back-emf's of pahse *a*,*b* and *c*. R and L are the resistance and inductance of each phase respectively. T_e and T_L are electrical torque and load torque, j is the rotor inertia, K_f is the friction constant and w_m is the rotor speed. But we know that Electromagnetic torque and back emf are given by equations (5) and (6).

$$T_{em} = K_t i_a(t) \quad (5)$$

$$e_a(t) = K_e w(t) \quad (6)$$

Where k_t is torque constant and k_e motor constant.
Taking Laplace transformation of the respective equations and rearranging the terms equations (7) and (8) are obtained

$$\omega(s) = \frac{l_{em}(s) - T_l}{B + sJ} \quad (7)$$

$$i_a(s) = \frac{V_{an}(s) - K_e\omega(s)}{R_a + SL_a} \quad (8)$$

From the above equation it is possible to draw the model of the BLDC motor as shown in Figure 2. From the Figure2 transfer function of the system is presented in equation (9).

$$\frac{\omega(s)}{V(s)} = \frac{\frac{K_t}{JL_a}}{s^2\frac{(JR_a + BL_a)}{JL_a}s + \frac{(BR_a + K_t K_e)}{JL_a}} \quad (9)$$

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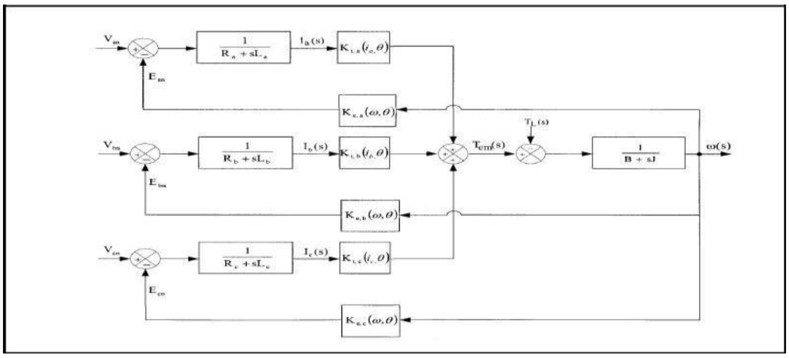

Fig 2.Transfer function model of BLDC motor

III. FOUR SWITCH INVERTER TOPOLOGY

As Shown in Fig 3, two common capacitors, instead of a pair of bridges, are used, and phase *c* is out of control because it is connected to the midpoint of the series capacitors. A conventional PWM scheme for the six-switch inverter is used for four-switch inverter topology of BLDC motor drive.

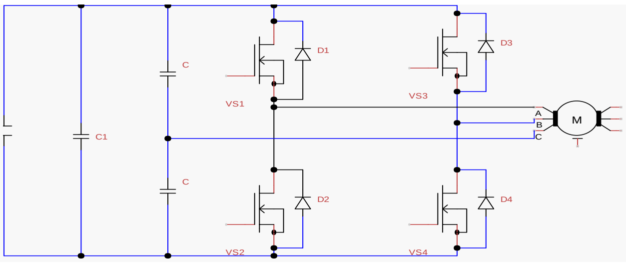

Fig 3.Four-switch three-phase inverter

The BLDC motor needs quasi-square current wave forms, which are synchronized with the back-emfto generate constant output torque and have 120° conducting and 60° non conducting regions. Also, at every instant, only two phases are conductive, and the other phase is inactive. Compared with the conventional six-switch three-phase inverter for the BLDC motor, the whole working process of the BLDC motor is divided into six modes, as shown in Table 1. Phase *c* involves four modes, including modes 2,3,4,5 and 6. Only one switch should work in four modes. Taking mode 2 for instance, switch VS_1 and diode D_2 work to conduct current in this mode.

Table 1.working mode of Four-switch three-phase BLDC motor

Mode	Working phase	Current restraint	Conducting devices
Mode 1	+a, -b	$i_a=I^*$, i_b-I^*	VS_1, VS_4
Mode 2	+a, -c	$i_a=I^*$	VS_1
Mode 3	+b, -c	$i_b=I^*$	VS_3
Mode 4	+b, -a	$i_b=I^*$, $i_a=-I^*$	VS_2, VS_3
Mode 5	+c, -a	$i_a=-I^*$	VS_2
Mode 6	+c, -b	$i_b=-I^*$	VS_4

Mode 2is divided into modes 2a and 2b, as shown in Fig 4. Switch VS_1 turns on, while $-i_c$ is less than current threshold I^*. As $i_c = -(i_a+i_b)$ and the current flows through only two phases, i_a increased i_b=0. Then, i_c is controlled indirectly. While $-i_c$ goes beyond I^*, switch VS_1 turns off, and diode D_2 conducts to make i_a and $-i_c$ drop. In this way, i_a and i_c are regulated to vary near the reference value.

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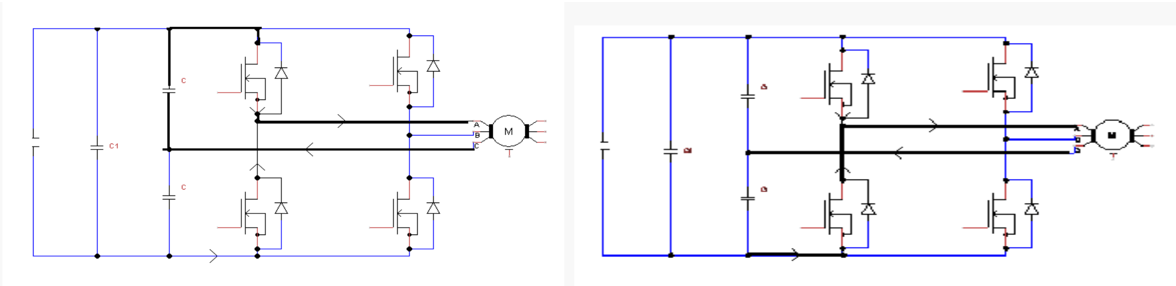

Fig 4.Sub operating modes 2a and 2b

Mode 1 is taken for instance here to demonstrate the whole working process that is identical in mode 4. Mode 1 is divided into four sub operating mode, i.e., modes 1a, 1b, 1c, and 1d, as shown in Fig 5a and 5b. According to Table 1, the four sub operating modes have different rules to phase current. In mode 1a, i_a and $-i_b$ rise quickly, and i_c varies proportionally with the back-emf of phase *c*. In mode 1b i_a and $-i_b$ drop quickly, and i_c changes proportionally with the back-emf of phase *c*. Compared with modes 1a and 1b i_c falls much quicker in mode 1c and rises much quicker in mode 1d.

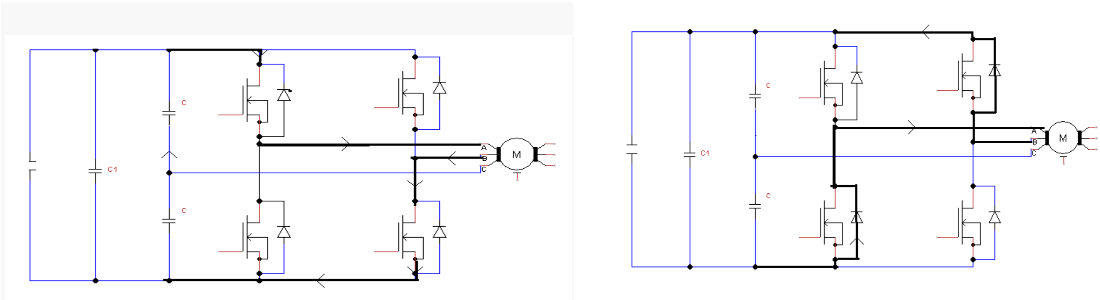

Fig 5a.Sub operating modes 1a and 1b

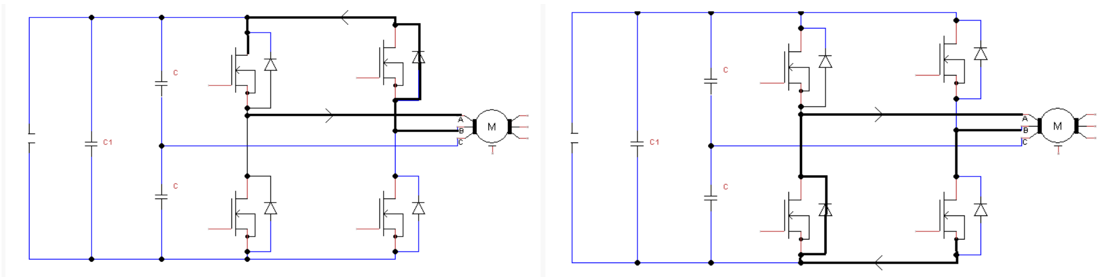

Fig 5.Sub operating modes 1a, 1b, 1c and 1d

Thus mode1 could be optimized by reasonable combination of four sub operating modes. First of all, the equation i_c =0 must be satisfied to keep the system stable as follows. When i_c deviates seriously from zero, mode 1c and 1d work. When i_c remains at zero, modes 1a and 1b work. Because i_a and i_b cannot be detected, as speed loop is used here to decide the duty of PWM signals. The same regulating method is used in mode 4, and asymmetric voltage vectors are eliminated.

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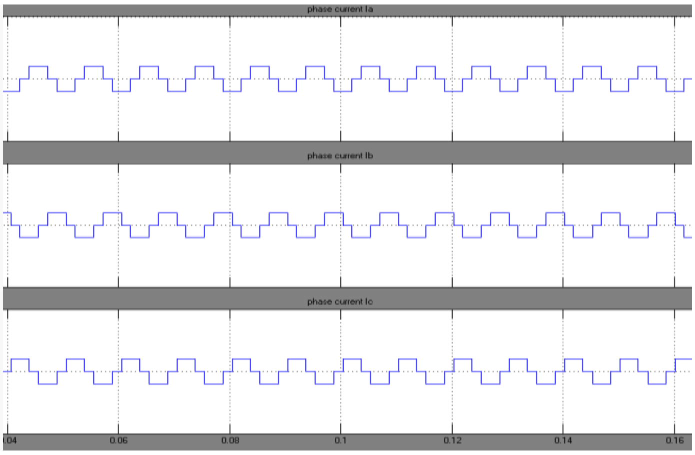

Fig 6. Phase current wave forms of Four-switch inverter fed BLDC motor

IV. PROPOSED BLDC MOTOR WITH FUZZY LOGIC CONTROLLER

The simulation of BLDC motor controlled with sensor is controlled by using Fuzzy Logic Controller. One of the reasons for popularity of Fuzzy Logic Controllers is its logical resemblance to a human operator. Three hall effect sensors are connected the other end of the motor and they are separated by 120° mechanically. Fig 7 shows the block diagram of proposed BLDC motor with FLC.

BLDC motor has three phase windings on stator and permanent magnet on rotor. In order to define the shaft position, rotor position sensor is necessary. The sensor senses the rotor shaft position and signals. The processed signals are given to current controller. The output of the controller is used to provide switching signals for the inverter from which the speed of the motor can be controlled.

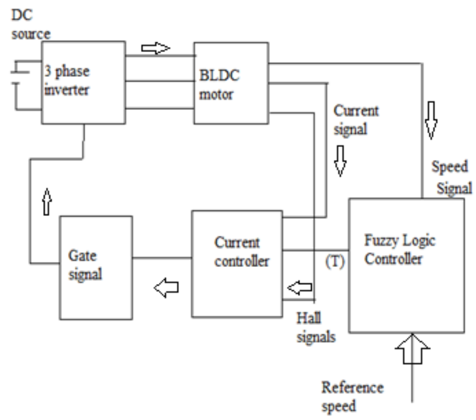

Fig 7.Proposed BLDC motor with Fuzzy Logic Controller

V. FUZZY LOGIC CONTROLLER

The Fuzzy Logic Controllers are basically put to use when the system is highly non-linear thereby making the mathematical modelling of the system very arduous. The analytical from of the system is not provided, a linguistic form is provided. The precise identification of the system parameters are required. A fuzzy Logic Controller uses fuzzy logic as a design methodology. There are basically three essential segments in Fuzzy Logic Controller. They are Fuzzification block or Fuzzifier system. Defuzzification block or Defuzzifier as shown in Fig 8.

The first step towards designing a Fuzzy Logic Controller is choosing appropriate inputs which will be fed to the same. These input variables should be such that, they represent the dynamic system completely. The two inputs given are error and change in error. The output is the reference torque for the current controller. All three membership functions are triangular. The input and output membership functions are shown in Fig 9 to 11. For the fuzzy controller necessary data required for the simulation is given in Table 2.

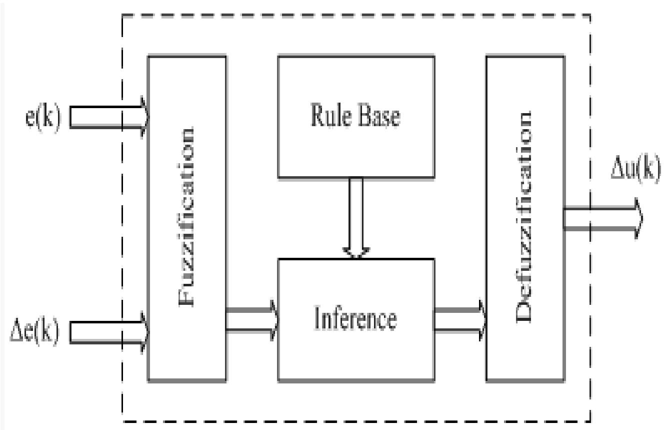

Fig 8 Structure of Fuzzy Logic Controller

Table.2 Parameters for simulation of fuzzy controller

Name	'fuzzybldc.fis'
Type	'mamdani'
and method	'min'
or method	'max'
defuzzy method	'centroid'
imp method	'min'
Aggmethod	'max'
Input	[1x2 struct]
Output	[1x1 struct]
Rule	[1x49 struct]

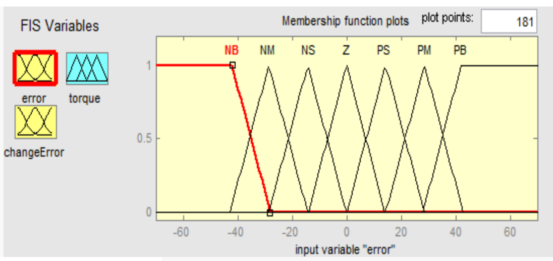

Fig 9.Membership function of error

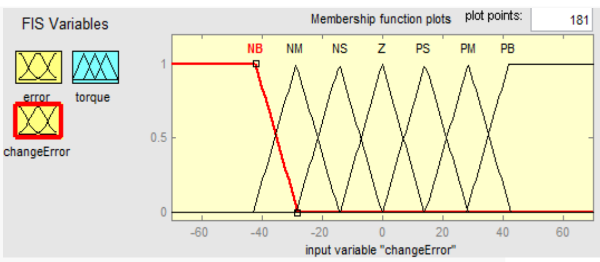

Fig 10.Membership function of change error

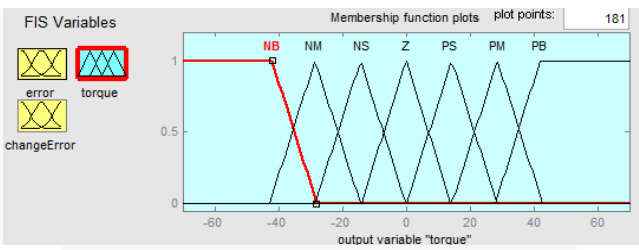

Fig 11.Membership function of reference torque

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A Defuzzifier is generally required only when the Mamdani Fuzzy mode is used for designing a controller. Mamdani model is preferred here because it follows the compositional rule of inference strictly in its fuzzy reasoning mechanism. Unlike the Mamdani model, the outputs are defined with the help of a specific function for the other two models and hence the output is crisp instead of fuzzy. This is counterintuitive since a fuzzy model should be able to propagate the fuzziness from inputs to output in an appropriate manner.

The inference system of a Fuzzy Logic Controller consists of a number of If-Then rules. IF side of the rule is called the antecedent and THEN side is called the consequence. These rules are very simple to understand and write and hence the programming for the Fuzzy Logic Controller becomes very simple. The fuzzification rule is entered using the rule editor of the fuzzy toolbox as shown in Fig 12.

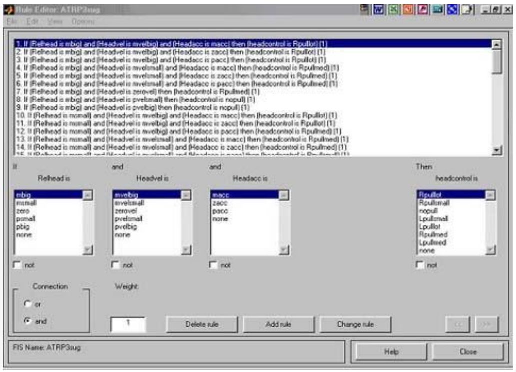

Fig 12.Fuzzy rule editor

The simulink model has the BLDC model that is shown in Fig 12. From the BLDC motor speed signal is given to Fuzzy Logic Controller as one input and other input is reference speed. These two input signals are given to the Fuzzy Logic Controller. The measured motor speed from BLDC drive is compared with reference speed producing the error. That torque signal is generated from the Fuzzy Logic Controller. This torque signal, hall effect signals and current signals are given to the current controller as three inputs. It generates gate pulses for four-switch three-phase inverter. Simulation results are shown in Fig 13 to 16.

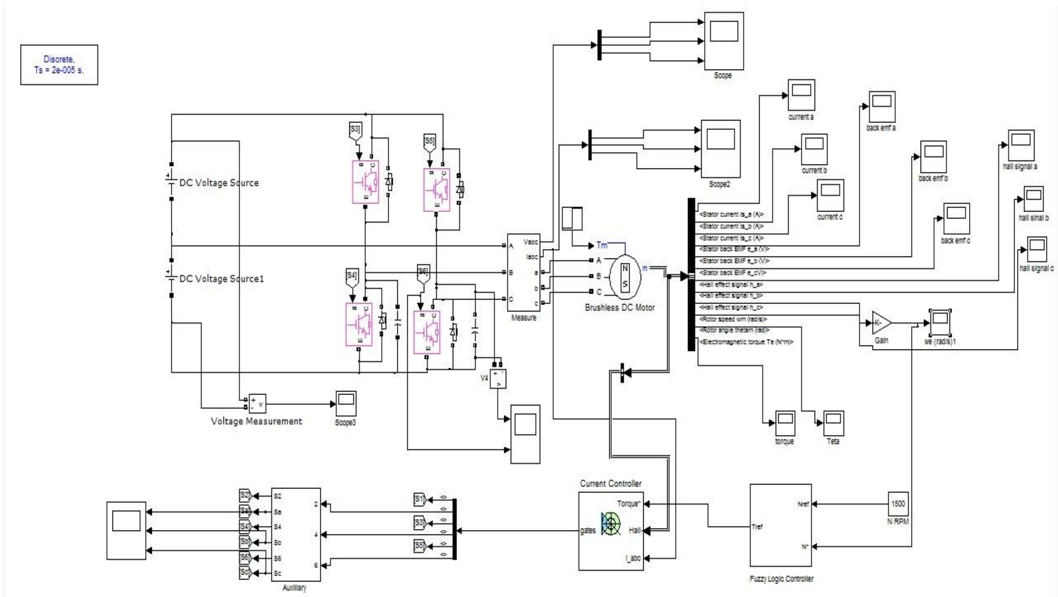

Fig 12 Simulink diagram of four-switch Inverter fed BLDC motor using fuzzy logic

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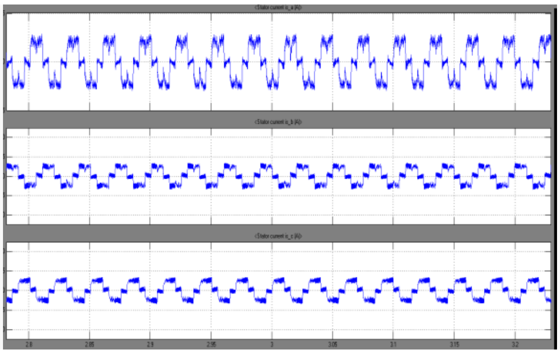


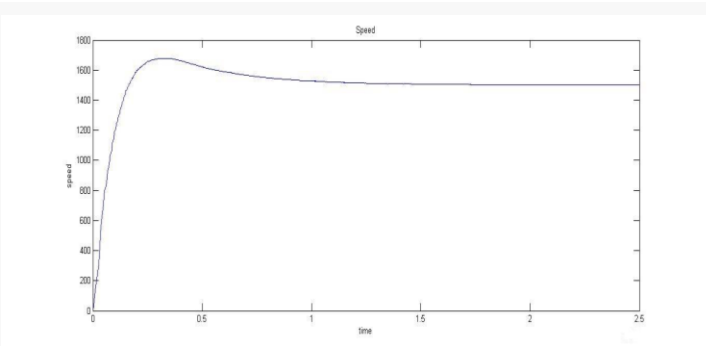
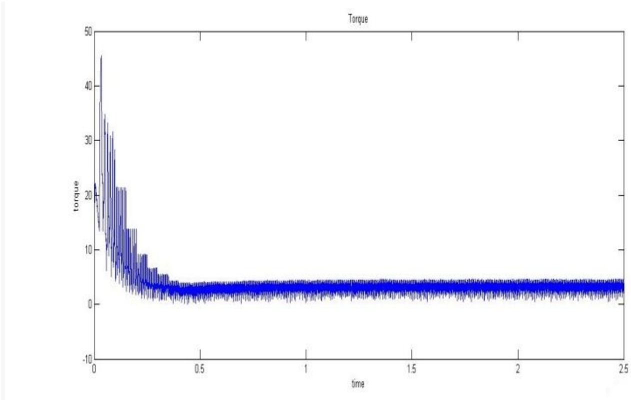


Fig 13.Phase currents using fuzzy controller Fig 14.Speed profile of the drive for fuzzy controller



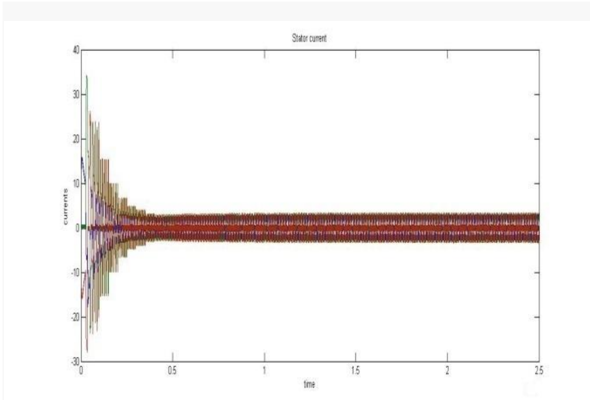


Fig 15.Torque Profile of the drive for fuzzy controller Fig 16.Stator currents of phase *a, b and c*

When the motor is started there is no back-emf induced and there is maximum current flow from the distribution lines to the motor armature and as result the motor torque will be maximum. In this case there is no resistance offered by back-emf. The only resistance available is the motor windings resistance. During normal rated speed of motor, the back-emf induced will be maximum which reduces the motor armature current to its minimum level and as result the motor torque is also reduced to its minimum level. When the load on the motor is increased, the motor speed RPM is decreased and it reduces the back-emf.

VI. CONCLUSION

In this paper, mathematical modelling of BLDC motor and four switch inverter topology presented. Four-switch inverter where it is cost saving achieved by reducing the number of inerter power switches. By using this topology switching losses reduced and voltage, current stresses also neglected. Fuzzy controller has better stability, small overshoot, and fast response. The modelling and simulation of the complete drive system is described in this paper.

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BIOGRAPHY

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