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Artificial Intelligence Based Modeling and Analysis of BLDC Motor Drive

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Abstract

In this paper proposed about intelligent based modeling and analysis of BLDC motor drives. BLDC Motors are widely used as electric drives in industries. Features of these motors like precise speed regulation, improved power factor, absence of slip high mechanical power density and cost effectiveness its makes them popular in the industrial world. Mathematical models of the drive system are developed and analyze the performance of the proposed drive. The hall sensor signals are used to sense the rotor position. A shunt resistor is used to sense the actual current entering into the motor. Both the outer velocity control loop and inner current control loop uses fuzzy based controller that has been implemented by MATLAB. The proposed intelligent drive performance is studied.

Key words: Fuzzy logic, BLDC Modeling, Hall sensor, Mathematical model.

1. INTRODUCTION

BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are:

- Better speed versus torque characteristics
- High dynamic response
- High efficiency

- Long operating life
- Noiseless operation
- Higher speed ranges

In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors.

BLDC motor uses an electric commutator rather than a mechanical commutator, so it is more reliable than the DC motor. In a BLDC motor, rotor magnets generate the rotor's magnetic flux, so BLDC motors achieve higher efficiency. Therefore, BLDC motors may be used in high-end white goods (refrigerators, washing machines, dishwashers, etc.), high-end pumps, fans and in other appliances which require high reliability and efficiency.

The use of Brushless DC (BLDC) motors is continuously increasing. The reason is obvious: BLDC motors are having a good weight/size to power ration, have excellent acceleration performance, requires little or no maintenance and generates less acoustic and electrical noise than universal (brushed) DC motors. In a Universal DC motor, brushes control the commutation by physically connecting the coils at the correct moment. In BLDC motors the commutation is controlled by electronics. The electronics can either have position sensor inputs that provide information about when to commutate or use the Back Electromotive Force generated in the coils. Position sensors are most often used in applications where the starting torque varies greatly or where a high initial torque is required. Position sensors are also often used in applications where the motor is used for positioning. Sensorless BLDC control is often used when the initial torque does not vary much and where position control is not in focus, e.g. in fans.

2. MODELING OF BLDC MOTOR DRIVE

In general, the analysis of a BLDC motor is conducted in phase variables due to its non sinusoidal back-EMF and current. Fig. 1 shows the equivalent circuit of a BLDC motor and a power inverter. The analysis of the BLDC motor drive is based on the following assumptions for simplification:

- The motor is not saturated,
- The motor windings have a constant resistance, self inductance, and Mutual inductance. The resistance and inductance of all phases are Identical.
- All three phases have an identical back-EMF shape,
- Power semiconductor devices in the inverter are ideal,
- Iron losses are negligible,
- Eddy current and hysteresis effects are neglected.

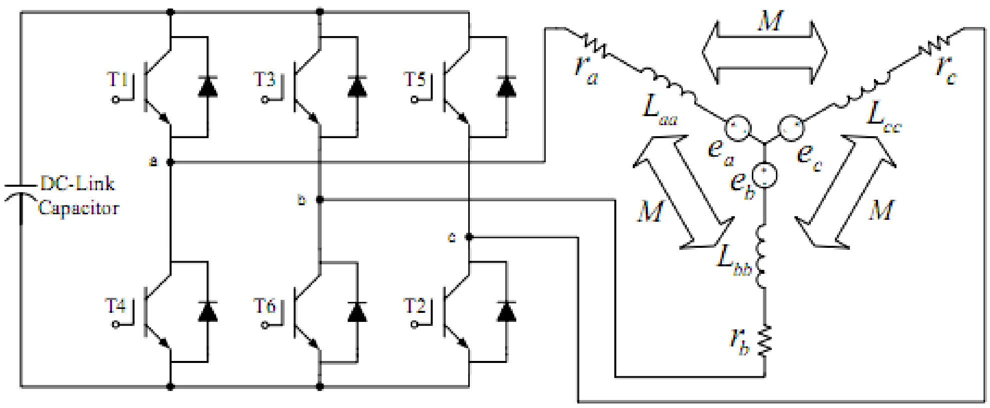

Fig 1 Equivalent circuit of the BLDC drive (R, L and back-EMF)

The BLDC motor is modeled in the 3-phase abc variables, equation 1 − 4 The generator volt-ampere equation for the circuit shown in the Figure 1 can be expressed as:

$$V_{an} = Ri_a + p\lambda_a + e_{an} \tag{1}$$

$$V_{bn} = Ri_b + p\lambda_b + e_{bn} \tag{2}$$

$$V_{cn} = Ri_c + p\lambda_c + e_{cn} \tag{3}$$

Where v_{an}, v_{bn} and v_{cn} are phase voltages and may be defined as:

$$\begin{aligned} V_{an} &= V_{a0} - V_{n0}, \\ V_{bn} &= V_{b0} - V_{n0}, and \\ V_{c0} &= V_{c0} - V_{n0.} \end{aligned} \tag{4}$$

Where v_{ao}, v_{bo}, v_{co} and v_{no} are three phase and neutral voltages with respect to the zero reference potential at the mid-point of dc link (0) shown in the Figure 1. R is the resistance per phase of the stator winding, **p** is the time differential operator and e_{an}, e_{bn} and e_{cn} are phase to neutral back emfs. The λ_a, λ_b and λ_c are total flux linkage of phase windings a, b and c respectively. Their values can be expressed as:

$$\lambda_a = L_S i_a - M(i_b + i_c) \tag{5}$$

$$\lambda_b = L_S i_b - M(i_a + i_c) \tag{6}$$

$$\lambda_c = L_S i_c - M(i_a + i_b) \quad (7)$$

Where, Ls and M are the self and mutual inductances, respectively. The PMBLDC motor has no neutral connection and hence this results in:

$$i_a + i_b + i_c = 0 \quad (8)$$

Substituting equation (8) into equations (5), (6) and (7) the flux linkages are given as :

$$\begin{aligned} \lambda_a &= i_a(L_S + M), \\ \lambda_b &= i_b(L_S + M), and \\ \lambda_c &= i_c(L_S + M) \end{aligned} \quad (9)$$

By substituting equation (9) in volt-ampere equations (1) - (3) and rearranging these equations in a current derivative of state space form, gives :

$$pi_a = 1/(L_S + M)(V_{an} - Ri_a - e_{an}) \quad (10)$$

$$pi_b = 1/(L_S + M)(V_{bn} - Ri_b - e_{bn}) \quad (11)$$

$$pi_c = 1/(L_S + M)(V_{cn} - Ri_c - e_{cn}) \quad (12)$$

The developed electromagnetic torque may be expressed as 1 − 4

$$T_e = (e_{an} i_a + e_{bn} i_b + e_{cn} i_c) / \omega_r \quad (13)$$

Where, ωr is the rotor speed in electrical rad/sec. substituting the back emfs in normalized form, the developed torque is as:

$$T_e = K\{f_a(\theta_r)i_a + f_b(\theta_r)i_b + f_c(\theta_r)i_c\} \quad (14)$$

The mechanical equation of motion in speed derivative form can be expressed as :

$$p\omega_r = (P/2)(T_e - T_L - B\omega_r)/J \quad (15)$$

Where P is the number of poles, T1 is the load torque in Nm, B is the frictional coefficient in Nm/rad, and J is the moment of inertia in kg-m2.The derivative of the rotor position (θr) in state space form is expressed as:

$$p\theta_r = \omega_r \tag{16}$$

The potential of the neutral point with respect to the zero potential (vno) is required to be considered in order to avoid imbalance in the applied voltage in simulating the performance of the drive. This can be obtained by substituting equation (4) in the volt-ampere equations (1) to (3) and adding them together to give:

$$\begin{aligned} &V_{a0} + V_{b0} + V_{c0} - 3V_{n0} = R(i_a + i_b + i_c) + \\ &(L_S + M)(pi_a + pi_b + pi_c) + (e_{an} + e_{bn} + e_{cn}) \end{aligned} \tag{17}$$

Substituting equation (8) in equation (16) results in :

$$\begin{aligned} &V_{a0} + V_{b0} + V_{c0} - 3V_{n0} = (e_{an} + e_{bn} + e_{cn}) \\ &\Rightarrow V_{n0} = [V_{a0} + V_{b0} + V_{c0} - (e_{an} + e_{bn} + e_{cn})]/3 \end{aligned} \tag{18}$$

The set of differential equations mentioned in equations (10), (11), (12), (14) and (15) defines the developed model in terms of the variables i_a, i_b, i_c, ω_r, θ_r and time as an independent variable.

3. ANALYSIS OF BLDC DRIVE SYSTEM

The drive system considered here consists of Fuzzy based speed controller, the reference current generator, PWM current controller, BLDC motor and an IGBT inverter. All these components are modeled and integrated for simulation in real time conditions.

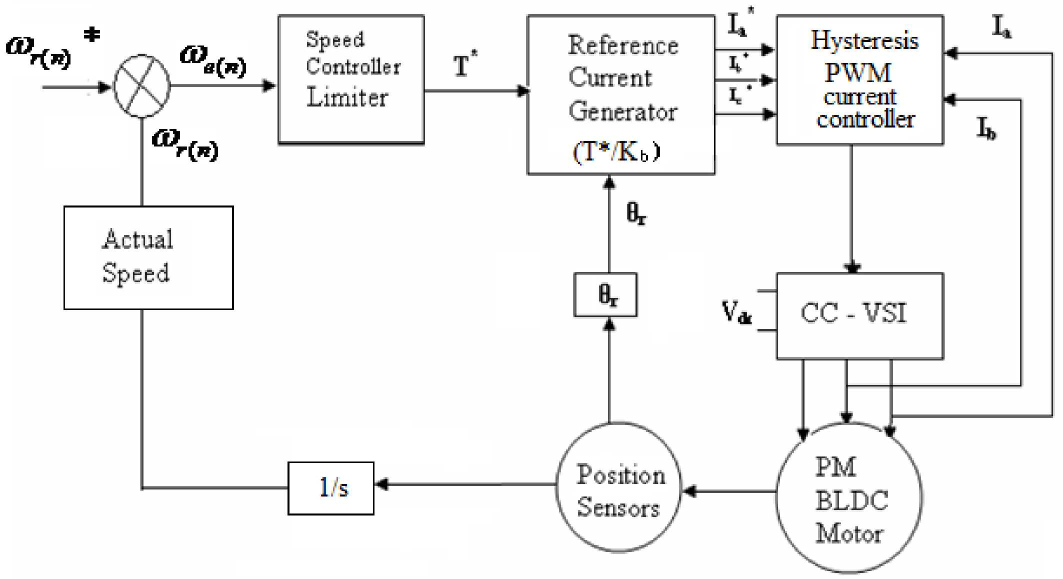

Fig 2 Functional block diagram of BLDCM drive system

3.1 Fuzzy logic controller

Fuzzy logic is a powerful problem solving methodology with a myriad of applications in embedded control and information processing. Fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions.

Membership Function (MF) specifies the degree to which a given input belongs to a set. Here, seven membership function have been used to explore best dynamic responses, namely Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZO), Positive Small (PS), Positive Medium (PM) and Positive Big (PB). Fuzzy rules are conditional statement that specifies the relationship among fuzzy variables. These rules help us to describe the control action in quantitative terms and have been obtained by examining the output response to corresponding inputs to the fuzzy controller.

The degree of membership function used for fuzzification is shown in Fig.3 and Fig.4 and membership function for defuzzification is shown in Fig.5.

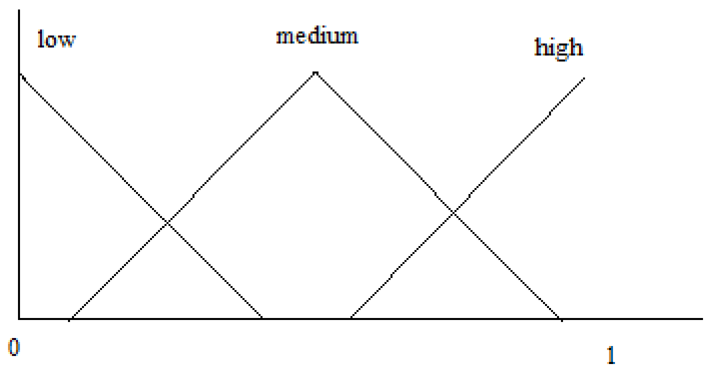

Fig.3Membership function for input 1

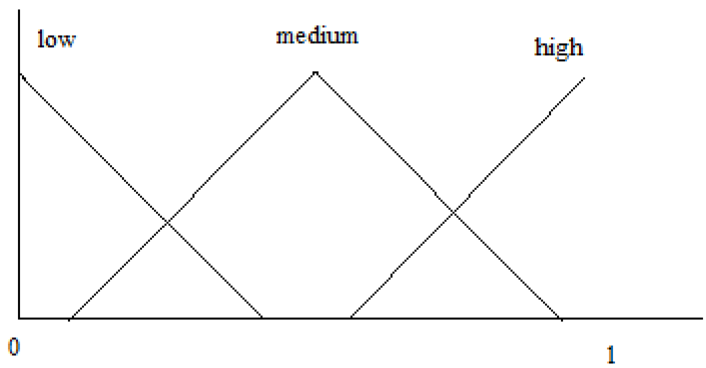

Fig.4.Membership function for input 2

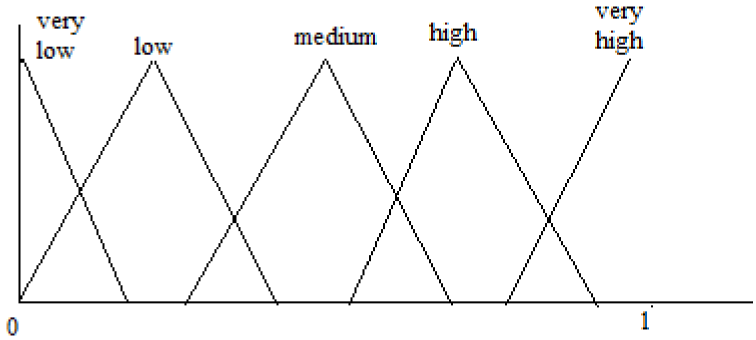

Fig.5.Membership function for output

3.2 Reference Current Generator

The magnitude of the three phase current (I^*) is determined by using reference torque (T^*) and the back emf constant (K_b) as $(I^*)=T^*/K_b$. Depending on the rotor position, the reference current generates block generates three-phase reference currents (i_a^*, i_b^*, i_c^*) by taking the value of reference current magnitude as I^* ,$-I^*$ and zero. The reference current generation is shown in below table.

Table 1 Rotor Position signal vs Reference Currents

Rotor Position Signal θ_r	***Reference Currents*** (i_a^*, i_b^*, i_c^*)		
0° - 60°	I*	–I*	0
60° - 120°	I*	0	–I*
120° -180°	0	I*	–I*
180° - 240°	–I*	I*	0
240° - 300°	–I*	0	I*
300° - 360°	0	–I*	I*

These reference currents are fed to the PWM current controller.

3.3 PWM Current Controller

The PWM current controller contributes to the generation of the switching signals for the inverter devices. The switching logic is formulated as given below.

If $i_a < (i_a^* - h_b)$ switch 1 ON and switch 4 OFF

If $i_a > (i_a^* + h_b)$ switch 1 OFF and switch 4 ON

If $i_b < (i_b^* - h_b)$	switch 3 ON and switch 6 OFF
If $i_b > (i_b^* + h_b)$	switch 3 OFF and switch 6 ON
If $i_c < (i_c^* - h_b)$	switch 5 ON and switch 2 OFF
If $i_c > (i_c^* + h_b)$	switch 5 OFF and switch 2 ON

Where, $\mathbf{h_b}$ is the hysteresis band around the three phase reference currents.

3.4 Modeling of Back emf using Rotor Position

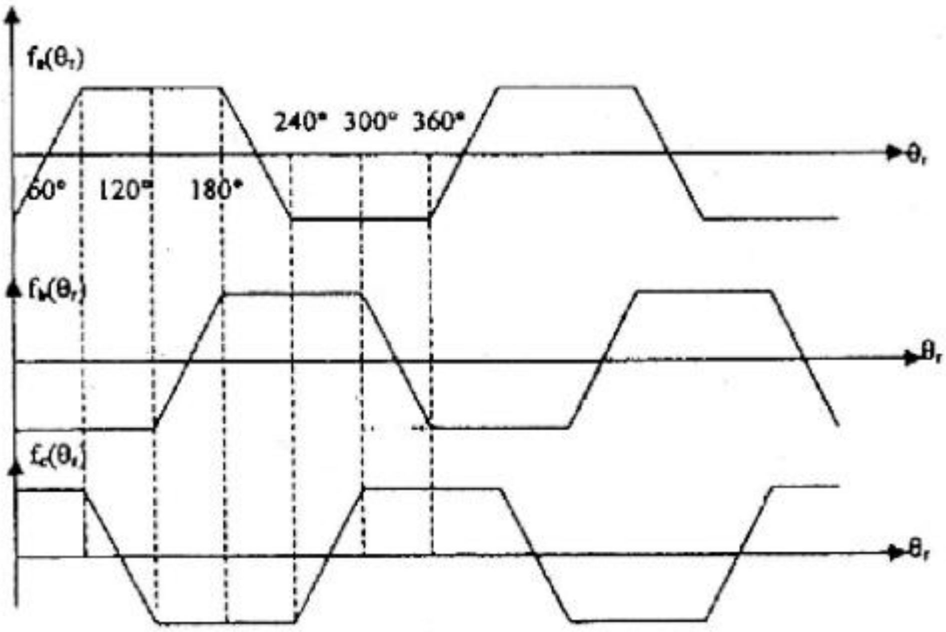

Fig 6 Functions of back EMF of BLDC motor

The phase back emf in the PMBLDC motor is trapezoidal in nature and is the function of the speed (ωr) and rotor position angle (θr) as shown in Figure 2. The normalized function of back emfs is shown in Figure 6. From this, the phase back emf ean can be expressed as :

$$
\begin{aligned}
& f_a\ \theta_r = E && 0^0 < \theta_r < 120^0 \\
& f_a\ \theta_r = (6E/\pi)(\pi - \theta_r r) - E && 120^0 < \theta_r < 180^0 \\
& f_a\ \theta_r = -E && 180^0 < \theta_r < 300^0 \\
& f_a\ \theta_r = (6E/\pi)(\theta_r r - 2\pi) + E && 300^0 < \theta_r < 360^0
\end{aligned}
\qquad (19)
$$

Where, E = Kb ωr and ean can be described by E and normalized back emf function fa (θr) shown in Figure 5. ean = E fa (θr). The back emf function of other two phases ebn and ecn are defined in similar way using E and the normalized back emf function fb (θr) and fc (θr) as shown in Figure 7.

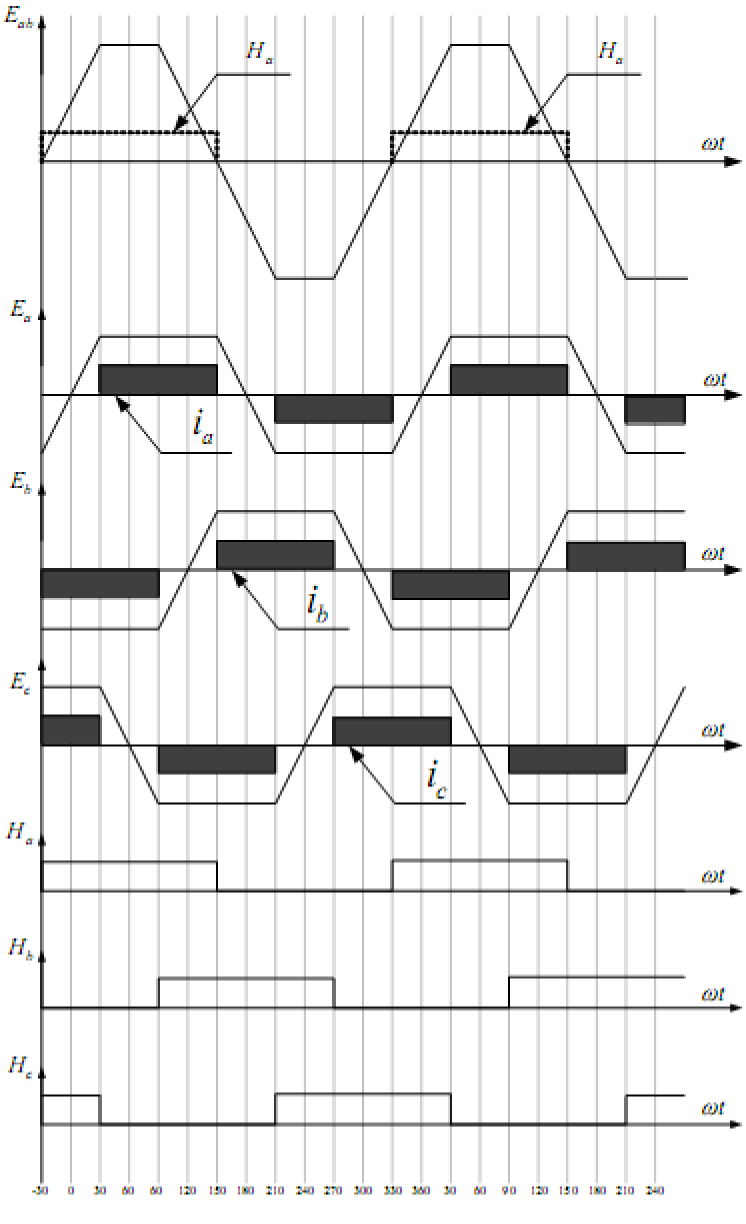

Fig. 7 Line-to-line back-EMF (E_{ab}), phase back-EMFs, phase current waveforms and hall-effect position sensor signals for a BLDC motor.

4. CONCLUSION

Fuzzy based algorithm is developed to simulate the drive model with fuzzy based speed controller. The set of equations representing the model of the drive System has been discussed. Simulation results are verified with theoretical results.

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