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Modeling & Simulation of PMSM Drives with Fuzzy Logic Controller

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ABSTRACT: *The Permanent-magnet-synchronous-machine (PMSM) drives have been increasingly applied in a variety of industrial applications which require fast dynamic response and accurate control over wide speed ranges. In this thesis the control of a Permanent Magnet Synchronous Motor (PMSM) is studied. Usually, a proportional-integral (PI) controller is used as a speed controller for a Permanent Magnet Synchronous Motor (PMSM). However, a PI controller is sensitive to speed changes, load disturbances and parameters variation without continuous tuning of its gains. The conventional approach is to tune the proportional and integral gains manually by observing the response of the system. The tuning of the PI parameters must be made on-line and automatic in order to avoid tedious tasks in manual control. For this reason the design of using fuzzy logic controller (FLC) which replace the proportional-integral (PI) controller.*

KEYWORDS: *AC drives, Fuzzy logic controller (FLC), Permanent Magnet Synchronous Machine (PMSM), Pulse Width Modulation (PWM), Proportional-Integral (PI) controller.*

I. INTRODUCTION

Recent availability of high energy-density permanent magnet (PM) materials at competitive prices, continuing breakthroughs and reduction in cost of powerful fast digital signal processors (DSPs) and micro-controllers combined with the remarkable advances in semiconductor switches and modern control technologies have opened up new possibilities for permanent magnet brushless motor drives in order to meet competitive worldwide market demands [1].

The popularity of PMSMs comes from their desirable features :

- High efficiency
- High torque to inertia ratio
- High torque to volume ratio
- High air gap flux density
- High power factor
- High acceleration and deceleration rates

Permanent magnet synchronous motor requires a “drive” to supply commutated current. This is obtained by pulse width modulation of the DC bus using a DC-to-AC inverter attached to the motor windings. The windings must be synchronized with the rotor position by using position sensors or through sensor less position estimation techniques. By energizing specific windings in the stator, based on the position of the rotor, a rotating magnetic field is generated. , only two of the three stator windings are energized in each commutation sequence [1].

The fuzzy logic is a class of artificial intelligence with a recent history and application. The concept of fuzzy logic was first introduced by 1965 by a computer scientist Lotfy Zadeh, a professor at the University of California at Berkley. Fuzzy-logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Its approach to control problems mimics how a person would make decisions, much faster [2], [3], [4].

II. MATHEMATICAL MODEL OF PMSM

Equation is often written in expanded form as

$$V_{ds} = R_s I_{ds} + L_d \frac{d\, I_{ds}}{dt} - \omega_r L_q I_q$$
$$V_{qs} = R_s I_{qs} + L_q \frac{d\, I_{qs}}{dt} + \omega_r (L_d I_{ds} + \lambda_m)$$
$$V_{0s} = R_s I_{0s} + L_0 \frac{d\, I_{0s}}{dt}$$

Under balanced steady-state conditions, the electrical angular velocity of rotor ωr is considered constant and equal to that of the synchronously rotating reference frame. In this mode of operation, with the time rate of change of all flux linkages neglected, the steady state versions of above equations become

$$V_{ds} = R_s I_{ds} - \omega_r L_q I_{qs}$$
$$V_{qs} = R_s I_{qs} + \omega_r (L_d I_{ds} + \lambda_m)$$
$$V_{0s} = R_s I_{0s} = 0$$

Electromagnetic torque can be expressed with the stator variables in the rotor reference frame as

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\lambda_{ds} I_{qs} - \lambda_{qs} I_{ds})$$

Appropriate substitution of into the above torque equation yields

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left[\lambda_m I_{qs} + (L_d - L_q) I_{qs} I_{ds}\right]$$

The torque equation can also be expressed in the following way,

$$T_e = T_m + J\frac{d}{dt}\omega_r + B\,\omega_r$$

III. Pmsm Drives With Fuzzy Controller

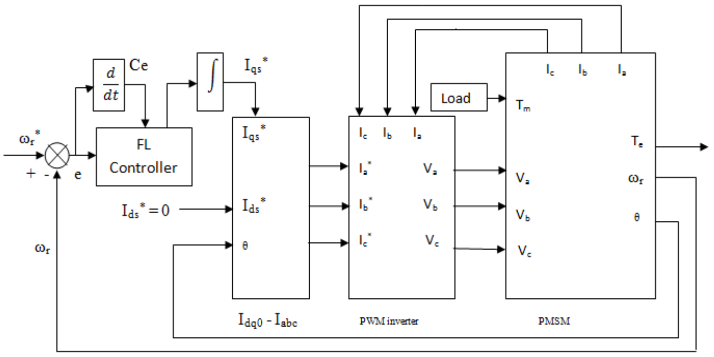


Figure 1: PMSM Drive with Fuzzy Logic (FL) controller

3.1 Pulse width modulation (PWM) technique

Pulse width modulation (PWM) technique is used to generate the required voltage or current to feed the motor or phase signals. This method is increasingly used for AC drives with the condition that the harmonic current is as small as possible. Generally, the PWM schemes generate the switching position patterns by comparing the three-phase sinusoidal wave forms with a triangular carrier.

The most widely used method of pulse width modulation are carrier based. This method is also known as the sinusoidal (SPWM), triangulation, subharmonic, or suboscillation method [5], [6].

3.2 Fuzzy Logic Controller

The FLC has two inputs speed error e(k) and change in speed error ce(k) and one output u(k) which represents the change in quadrature reference current $I_q^*(k)$.

e(k) and ce(k) are calculated as in equations for every sampling time:

$$e(k) = \omega_r^*(k) - \omega_r(k)$$

$$ce(k) = e(k) - e(k-1)$$

Where $\omega_r^*(k)$ is reference speed and $\omega_r(k)$ is actual speed value.

To obtain normalized inputs and output for fuzzy logic controller, the constant gain blocks are used as scaling factors G_E, G_{CE} and G_U as shown in Fig (2)

$$E(k) = G_E\, e(k)$$

$$CE(k) = G_{CE}\, ce(k)$$

$$U(k) = G_U\, u(k)$$

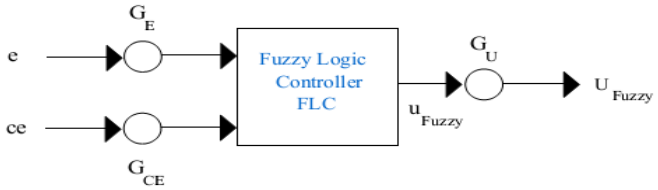


Figure 2: Scaling Factors for FLC

The FLC consists of three stages: the fuzzification, rule execution, and defuzzification. In the first stage, the crisp variables e(k) and ce(k) are converted into fuzzy variables E(k) and CE(k) using the triangular membership functions.

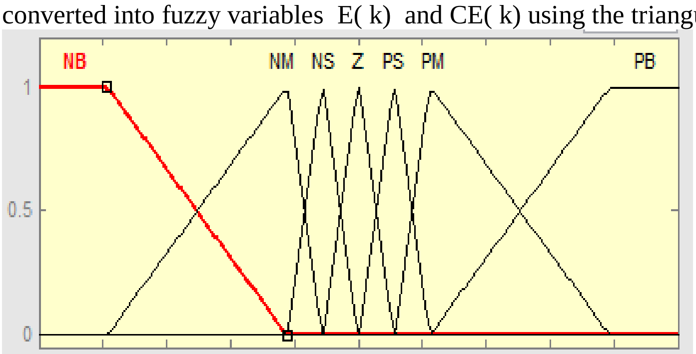


Figure 3: Membership functions of the Fuzzy logy controller-1

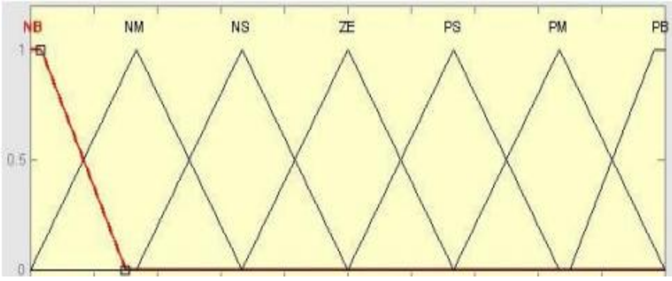


Figure 4**:** Membership functions of the Fuzzy logy controller-2

Each universe of discourse is divided into five fuzzy sets: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium) and PB (positive big).

In the second stage of the FLC, the fuzzy variables E and CE are processed by an inference engine that executes a set of control rules contained in (7 X 7) rule bases. The control rules are formulated using the knowledge of the PMSM behavior. Each rule shown in Table

Table I: Rule Base for Fuzzy Logic Controller

CE→ E↓	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Different inference algorithms can be used to produce the fuzzy set values for the output fuzzy variable u Fuzzy. In this paper, the max-min inference algorithm is used, in which the membership degree is equal to the maximum of the product of E and CE membership degree.

The inference engine output variable is converted into a crisp value U FUZZY in the defuzzification stage. Various defuzzification algorithms have been proposed in the literature. In this paper, the centroid defuzzification algorithm is used, in which the crisp value is calculated as the centre of gravity of the membership function.

The definition of the spread of each partition, or conversely the width and symmetry of the membership functions, is generally a compromise between dynamic and steady state accuracy. Equally spaced partitions and consequently symmetrical triangles are a very reasonable choice. So, we need to multiply the controller input and output variables by adjusting gains in order to accommodate these variables into the normalized intervals.

The reference current $I_q^*(k)$ for the vector control system is obtained by integrating u(k) as in equation

$$I_q^*(k) = I_q^*(k-1) + u(k)$$

IV. Simulink Models And Parameter:

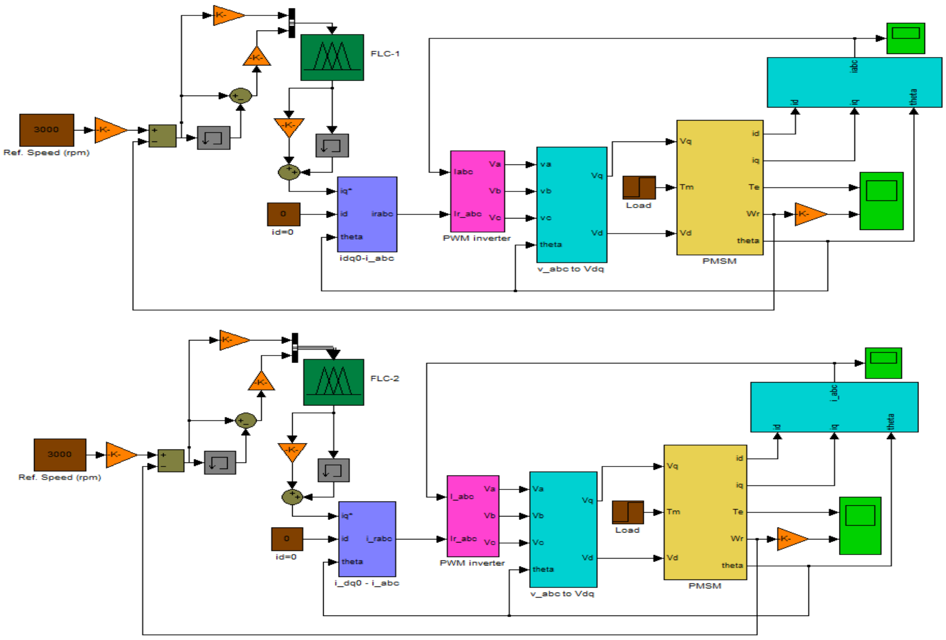


Figure 5: PMSM drive with FLC-1 and FLC-2 controller

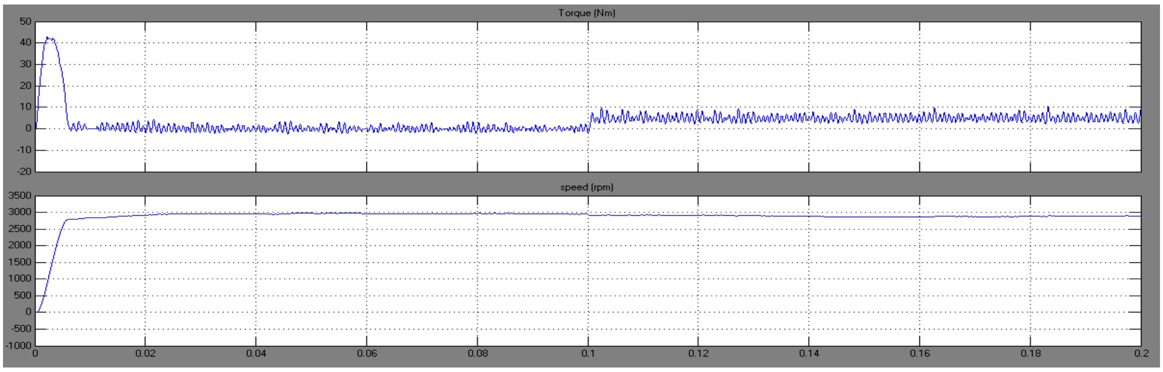
PMSM drive model are simulated in MATLAB simulink are shown above Fig 5. In PMSM Model following PMSM parameters are used.

Table II: PMSM Parameter

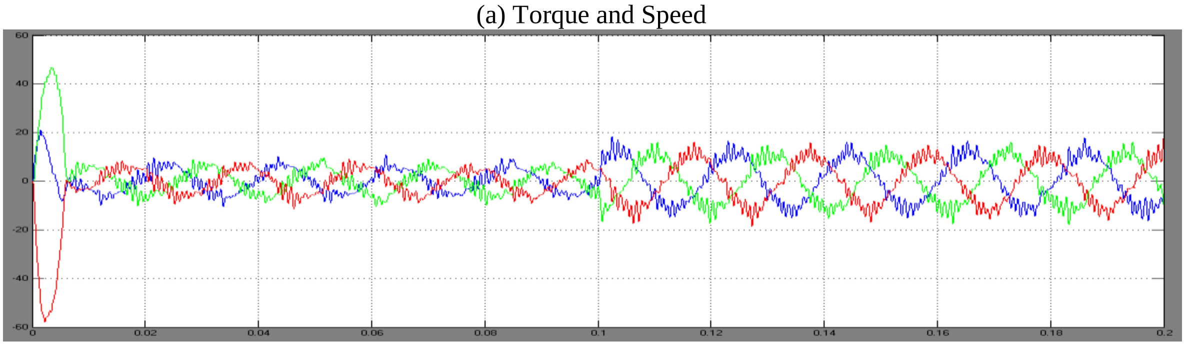
S. NO.	Parameter	Value
1.	Direct axis Resistance, R_d	1.4 Ω
2.	Quadracture axis Resistance, R_q	1.4 Ω
3.	d axis inductance, L_d	0.0066 H
4.	q axis inductance, L_q	0.0058 H
5.	Rotor permanent-magnet flux, λ_m	0.1546 (wb)
6.	Moment of Inertia, J	0.00176 ($kgm^{2)}$
7.	combined viscous friction, B	0.00038818 (Nm / (rad / s))
8.	no. of poles, P	6

V. Results And Discussion:

The simulation of PMSM drive system with Fuzzy controller has been carried out using MATLAB. The speed, torque and current responses of PMSM are observed with Fuzzy controller. The performances are observed under various speed and the results are presented.



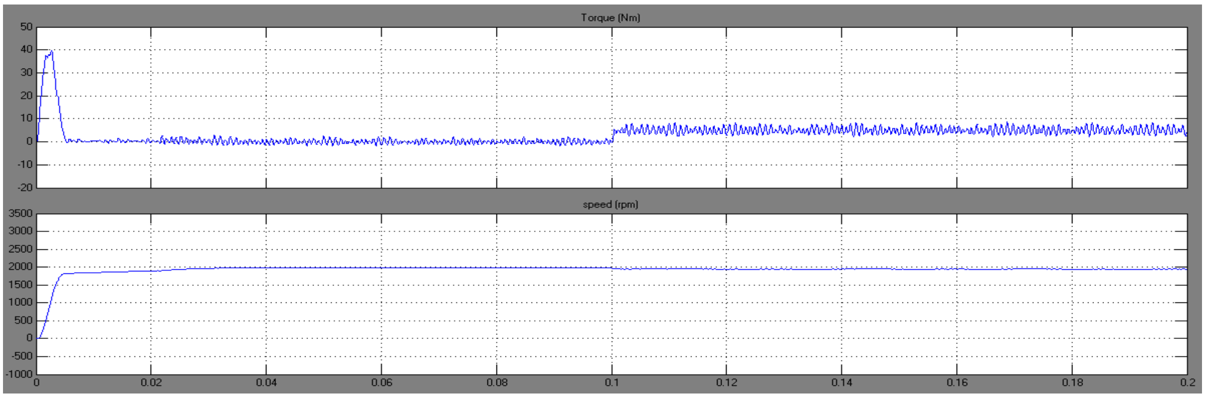
(a) Torque and Speed



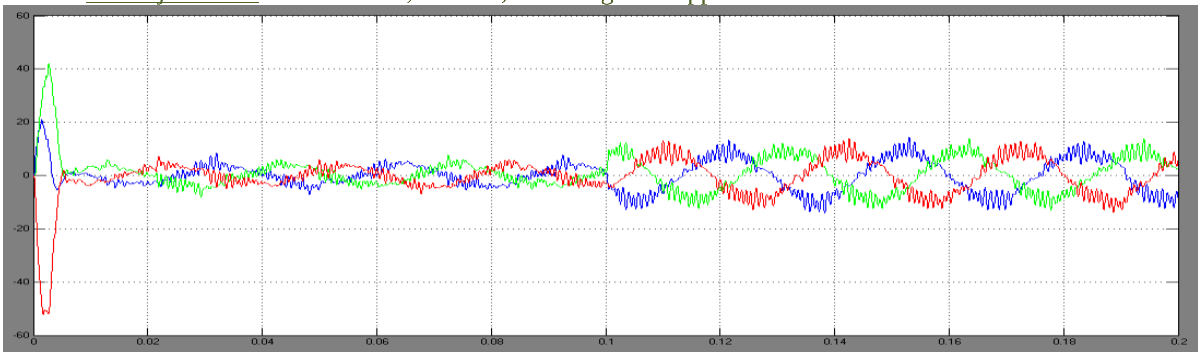
(b) Currents

Figure 6 Speed (rpm), Torque (Nm) & Current (Amp) for reference speed 3000 using FLC-1

The Fuzzy Logic controller FLC-1 performance for speed ω_r = 3000 RPM, Peak Overshoot at starting is M_p=0%, Rise Time t_r = 0.006 sec, Steady State error e_{ss} = 9, Speed drop at load is 3.6667%, Settling time after load is 0.008 sec.



(a) Torque and Speed

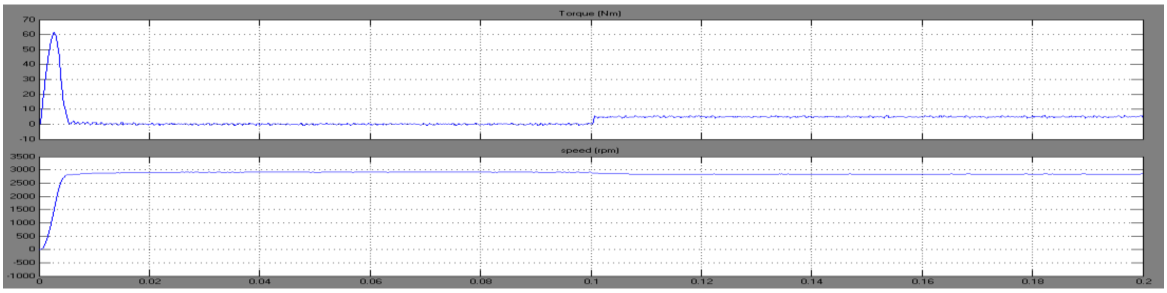


(b) currents

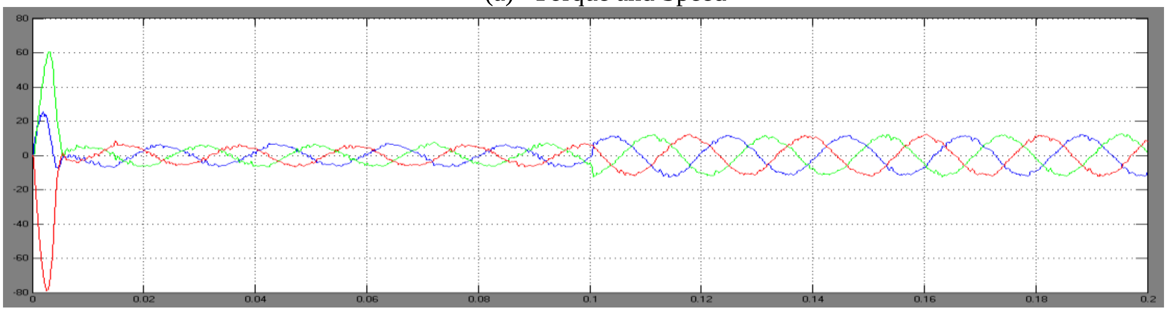
Figure 7 Speed (rpm), Torque (Nm) & Current (Amp) for reference speed 2000 using FLC-1

The Fuzzy Logic controller FLC-1 performance for speed ω_r = 2000 RPM, Peak Overshoot at starting is M_p=0%, Rise Time t_r = 0.0045 sec, Steady State error e_{ss} = 6, Speed drop at load is 2%, Settling time after load is 0.003 sec.

Performance of Fuzzy logic controller FLC-2 is shown below



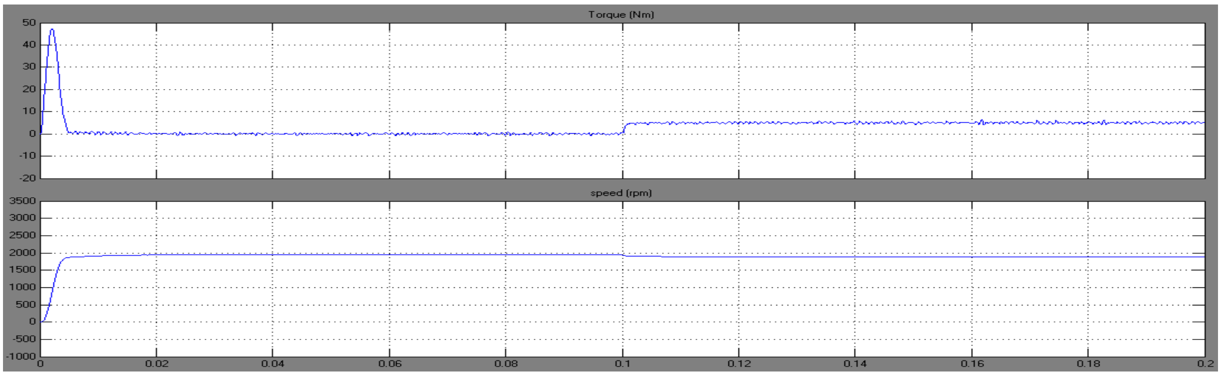
(a) Torque and Speed



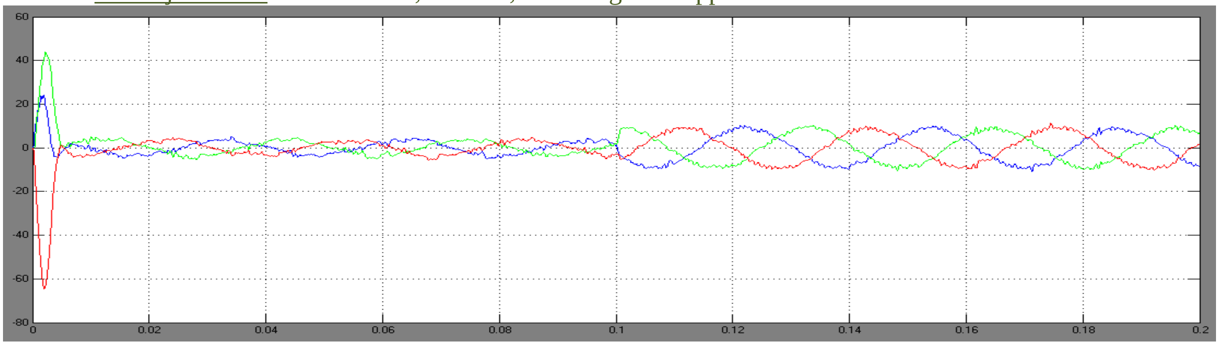
(b) Currents

Figure 8 Speed (rpm), Torque (Nm) & Current (Amp) for reference speed 3000 using FLC-2

The Fuzzy Logic controller FLC-2 performance for speed ω_r = 3000 RPM, Peak Overshoot at starting is M_p=0%, Rise Time t_r = 0.005 sec, Steady State error e_{ss} = 16, Speed drop at load is 1.6667%, Settling time after load is 0.0028 sec.



(a) Torque and Speed



(b) Currents

Figure 9 Speed (rpm), Torque (Nm) & Current (Amp) for reference speed 2000 using FLC-2

The Fuzzy Logic controller FLC-2 performance for speed ω_r = 2000 RPM, Peak Overshoot at starting is M_p=0%, Rise Time t_r = 0.0044 sec, Steady State error e_{ss} =12.3 , Speed drop at load is 3%, Settling time after load is 0.0021 sec.

VI. Conclusion

These Fuzzy Logic controllers are used successfully in speed Control system for PMSM. The design of Fuzzy logic controller and its performance shows that the error is minimized. The no overshoot in the speed curve and the ripples in the torque curve are maintained minimum.

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