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Comparative Analysis of Speed Control of PMSM using PI-Controller and Fuzzy Controller

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Abstract: This paper presents the methods used in speed control of Permanent magnet synchronous motor (PMSM) drives. Permanent magnet synchronous motor(PMSM) are widely used in AC servo drives because of its high torque to inertia ratio, high power density, high efficiency and power factor as compare to the other motors used in drives. The study shows that the methods used to improve the performance of PMSM drives, but in some case, when the dynamics of the system vary over time or with operating conditions, the performance of the PI controller will be spoiled. So that in proposed method FC controller is used in place of PI controller to improve the performance of PMSM drives. The Fuzzy Controller (FC)) used as a speed controller seems to be a promising solution in this purpose. This paper presents a Fuzzy Controller (FC) for speed control of a PMSM drive by using the Fuzzy Logic (FL) approach applied to speed control leads to an improved dynamic behavior of the motor drive system and an immune to load perturbations and parameter variations. The simulations of both the controllers have been carried out in MATLAB and Simulink. Speed responses, obtained under PI and FL speed control, are compared for a variety of operating conditions. FLC controlled PMSM generates a superior speed response and provides satisfactory output.

Keywords: Components, PI Controller , Permanent Magnet Synchronous Motor (PMSM), Fuzzy Controller (FC), Speed Control, Robustness, Sensor less control.

1 INTRODUCTION

Permanent Magnet Machines are electromechanical devices using magnets to produce a magnetic flux in the air gap. There are two major classifications of ac motors. The first one is induction motors that are electrically connected to power source through electromagnetic coupling, the rotor and the stator fields interact, creating rotation without any other power source The second is synchronous motors that have fixed stator windings that are electrically connected to the ac supply with a separate source of excitation connected to field windings when the motor is operating at synchronous speed [1-2].
Among the synchronous motor types the permanent magnet synchronous motor (PMSM) is one possible design of three phase synchronous machines. The stator of a PMSM has conventional three phase windings. In the rotor, PM materials have the same function of the field winding in a conventional synchronous machine. Their development was possible by the introduction of new magnetic materials, like the rare earth materials. The use of a PM to generate substantial air gap magnetic flux makes it possible to design highly efficient PM motors.

The permanent magnet synchronous motor (PMSM) has numerous advantages over other machines that are conventionally used for ac servo drives.The stator current of an induction motor (IM) contains magnetizing as well as torque-producing components. The use of the permanent magnet in the rotor of the PMSM makes it unnecessary to supply magnetizing current through the stator for constant airgap flux; the stator current need only be torque-producing. Hence for the same output, the PMSM will operate at a higher power factor (because of the absence of magnetizing current) and will be more efficient than the IM. The conventional wound-rotor synchronous machine (SM), on the other hand, must have dc excitation on the motor, which is often supplied by brushes and slip rings. This implies rotor losses and regular brush maintenance, which implies downtime. Note that the key reason for the development of the PMSM was to remove the foregoing disadvantages of the SM by replacing its field coil, dc power supply, and slip rings with a permanent magnet. The PMSM, therefore, has a sinusoidal induced EMF and requires sinusoidal currents to produce constant torque just like the SM. Current research in the design of the PMSM indicates that it has a higher-torque-to-inertia ratio and

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power density when compared to the IM or the wound-rotor SM, which makes it preferable for certain high-performance applications like robotics and aerospace actuators. The PMSM is smaller in size and lower in weight that makes it preferable for certain high performance applications.

The model of PMSM is however non-linear. This paper applies the concept of vector control that has been extensively applied to derive a linear model of the PMSM for controller design purposes [3-4]. The speed and current controller are then designed. The nonlinear equations of the PMSM, current and speed controller equations and real time model of the inverter switches and vector control are used in the simulation. The switches are assumed to be ideal

Throughout the paper, the following assumptions are made:

- Machine core losses are negligible.
- Rotor flux is constant at a given operating point.
- Saturation and parameter changes are negligible.
- Balanced 3 phase supply voltage is considered.
- Stator windings produce sinusoidal MMF distribution

2 MODELING OF PMSM

A. Motor Model of PMSM [5].

The unsaturated mathematical model of a sinusoidal PMSM drive can be described by the following equations in a rotor d-q reference frame.

$$Vd = Ri_d + Ld\frac{di_d}{dt} - L_q\omega_s i_q \quad (1)$$

$$V_q = Ri_q + L_q\frac{di_q}{dt} + L_d\omega_{si_d} + \omega_s\varphi_f \quad (2)$$

with:

$$\varphi_{d=L_d i_d} + \varphi_f \quad (3)$$

$$\varphi_{q = L_q} \quad (4)$$

The mechanical equation is:

$$J_m - \frac{d\omega_r}{dt} = \mathrm{Te} - T_L - f_m\omega_r \quad (5)$$

In which the electromagnetic torque is given by:

$$T_e = P[(L_d - L_q)i_d i_q + \varphi_f i_q \quad (6)$$

where, v_d, v_q = d, q-axis stator voltages;

i_d, i_q = d, q-axis stator currents;

R = stator resistance;

L_d, L_q = d, q-axis stator inductances;

T_e, T_L = electromagnetic and load torques;

J_m = moment of inertia of the motor and load;

f = friction coefficient of the motor;

P = number of pole pairs;

ω_r = rotor speed in angular frequency;

p=differential operator ($\frac{d}{dt}$).

φ_f= rotor magnetic flux linking the stator.

The inverter frequency is related as follows

$$\omega_s = P\omega_r .$$

B. PMSM Drive System

Rotor position information is very crucial for field oriented (vector) control. The coordinate transformation uses the value of the rotor position in order to handle the stator current vector projection in a rotating frame. The electrical position is not directly used in this transform but the sine and cosine values of it are used. Whether the control scheme is sensor based or sensor-less, position of the rotor is required. Control of PMSM can be categorized as sensor based and sensor-less control

1) Sensor based control: in this control method, sensors are used to indicate the position of the rotor, for instance incremental encoder, absolute encoder, resolver etc. By using mechanical sensors, it is simple to measure speed and position for feedback to the controller. Moreover, controller design complexity is not that much. However, using sensor-based control increases volume, weight of the system, connection parts between motor and controller. Mechanical sensors have noise and they need space on the shaft of the motor for position measurement. It also increases the overall cost of the drive system.

2) Sensor-less Control: position of the rotor is estimated using algorithms. It has got some advantages. To mention; it overcomes the drawbacks of Sensor based control, it has better efficiency and lower cost without position transducer and it is reliable and faster response control method. On the contrary this control system has got some demerits. This includes sophisticated design (e.g. Kalman filter), some methods fail at standstill (e.g. Back-emf method) and expensive for low cost applications and it will take time to develop.

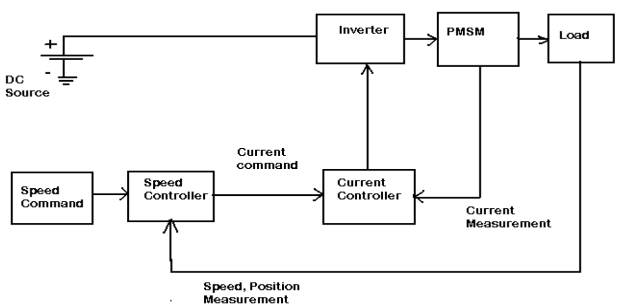

Fig. 1. Block Diagram of PMSM drive system.

C. PI speed control of the Permanent Magnet Synchronous motor

Fig. 1 describes the basic building blocks of the PMSM drive [7]. The drive consists of speed controller, reference current generator, PWM current controller, position sensor, the motor and IGBT based current controlled voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in proportional- integral (PI) speed controller.

$$e(t) = W_{ref} - W_m(t) \quad (7)$$

$W_m(t)$ is compared with the reference speed W_{ref} and the resulting error is estimated at the nth sampling instant as.

$$Tref\,(t) = [T\,(t\text{-}1) + Kp\,\{e(t)\ e(t\text{-}1)\}\ Ki\ e(t)] \quad (8)$$

where Kp and, Ki are the gains of PI speeds controller The output of this controller is considered as the reference torque. A limit is put on the speed controller output depending on permissible maximum winding currents. The reference current generator block generates the three phase reference currents ia, ib, ic using the limited peak current magnitude decided by the controller and the position sensor.

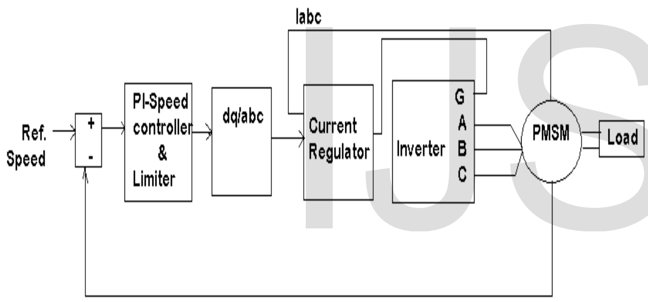

Fig. 2. PI-Speed Controller of PMSM Drive

D. PMSM with Fuzzy Logic Controller

If structure of FL controller is investigated as shown in Fig. 3 controller has two input variables; speed error e(k) and change of speed error ce(k). At the same time, change in reference phase current iq* is output Δiq*[13].

The variables *e*(*k*) and *ce*(*k*) are calculated as in Equations and for every sampling time:

$$e(k) = \omega^*(k) - \omega r(k) \quad (9)$$

$$ce(k) = e(k) - e(k-1) \quad (10)$$

where $\omega^*(k)$ is the reference speed and $\omega r(k)$ is the actual speed value. The FL controller consists of three stages: fuzzification, rule base, and defuzzification.

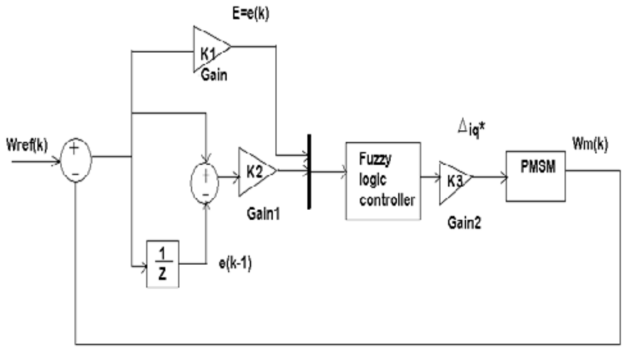

Fig..3. PMSM model with FL controller

In the first stage, the crisp variables *e*(*k*) and *ce*(*k*) are converted into fuzzy variables *e* and *ce* using the triangular membership functions shown in Figure 4 and 5 The universes of discourse of the input variables *e* and *ce* are respectively (–1,1) rad/s and (–1,1) rad/s [18]. The universe of discourse of the output variable Δ*iq** is (–1, 1) ampere. Each universe of discourse is divided into seven fuzzy sets: Negative Big (NL), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PL). Each fuzzy variable is a member of the subsets with a degree of membership μ varying between 0 and 1.

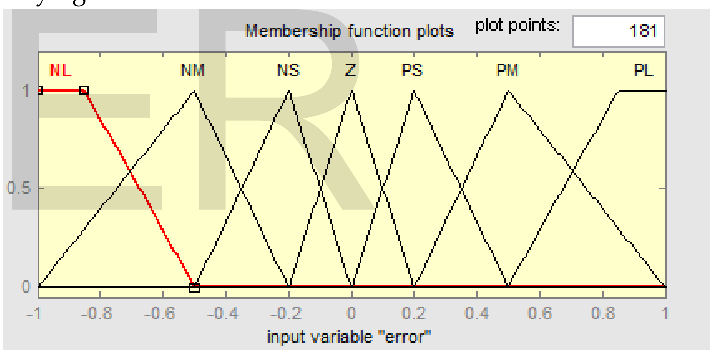

Fig.4 Membership function of input variable error

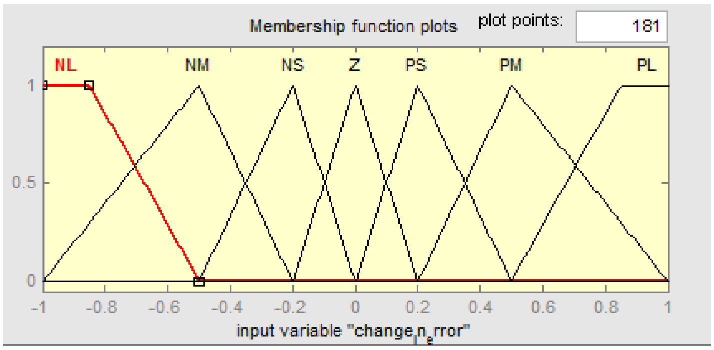

Fig. 5 Membership function of input variable change of error

In the second stage, the FL controller executes the 49 control rules shown in Table 1 taking the fuzzy variables *e* and *ce* as inputs and the output quantity Δ*iq* * is processed in the defuzzification unit [20].The rules are formulated using the knowledge of the PM synchronous motor behavior and the experience of control engineers.

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Table 1

e / ce	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

3 SIMULATED RESULTS

The system was subjected to different load conditions. The Permanent Magnet Synchronous Motor was operated for a reference speed of 52.3rad/sec under the following conditions:

CASE I: At No-Load Condition

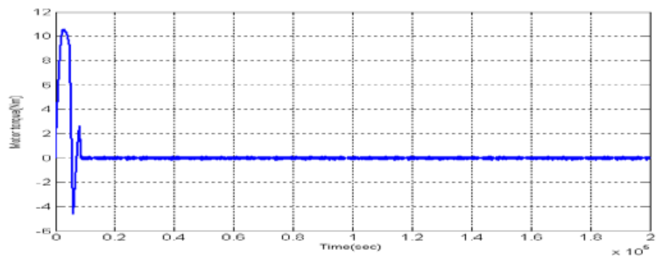
CASE II: With Change in Load Condition

CASE III: With Change in Reference Speed Condition

A. Performance with PI-Controller

CASE I: At No-Load Condition

The simulation result with controller gains are KP =5.0, KI = 1.6. with a load torque of 0 Nm is applied to the motor at0.1 sec



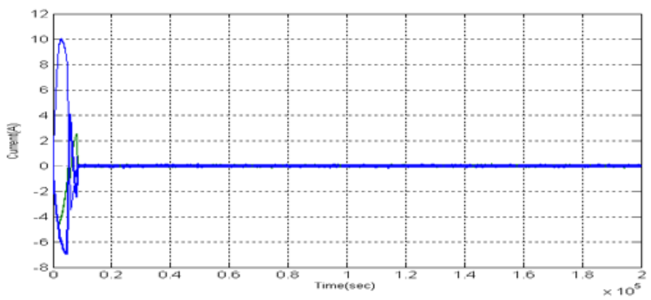
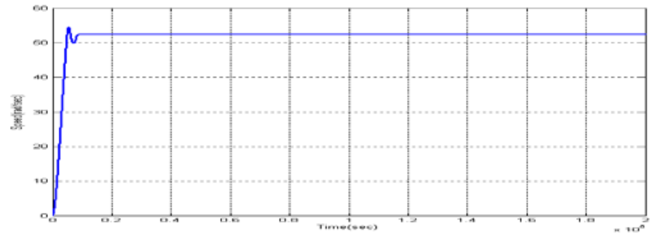


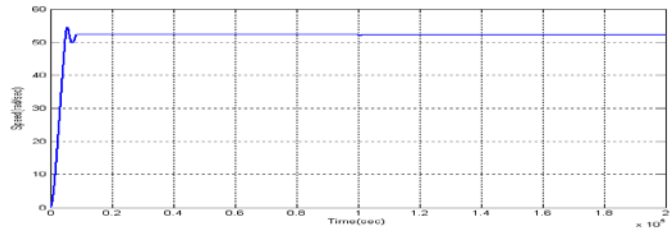
Fig. 6(a) Speed response, 6(b) Motor torque &6(c) Curent

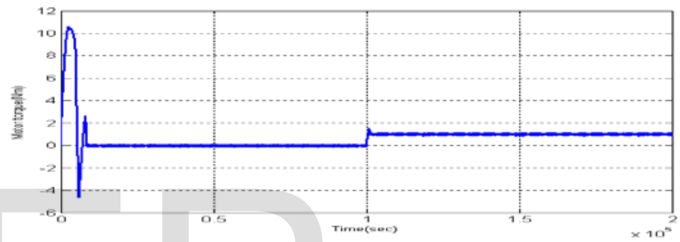
CASE-II: With change in load Condition

Sudden change in load is applied to the motor from no-load to 1 Nm load at 0.1 sec. At this point wave form is distorted for a few second or there is a fluctuation in speed



for few second and at time 0.11 sec motor again attained to normal speed 52.3 rad/sec





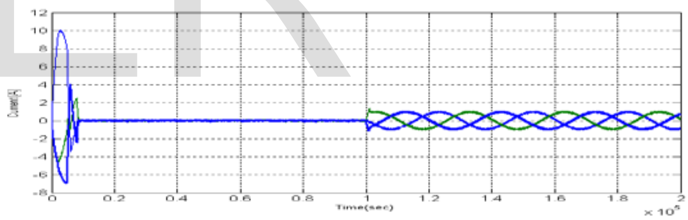
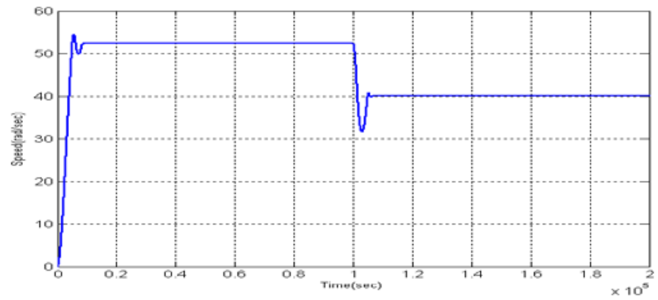


Fig. 7(a) Speed response, 7(b) Motor torque & 7(c) Current

CASE III: With change in reference speed Condition

When initial reference speed is 52.3rad/sec and it changes to 40rad/sec at t=0.1 sec. initially motor gains its normal speed 52.3rad/sec and at 0.1 sec it is shifted to 40rad/sec. That means PI-controller is able to sensitiveness to variation of the reference speed attention.



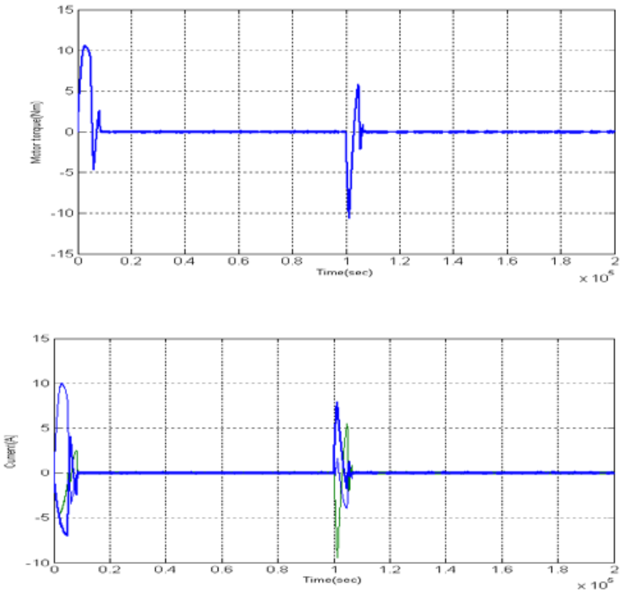


Fig 8(a) Speed response, 8(b)Motor torque & 8(c) Current

B . Performance with Fuzzy Controller

CASE I: At no-load condition

The overshoots will not occurred using FC

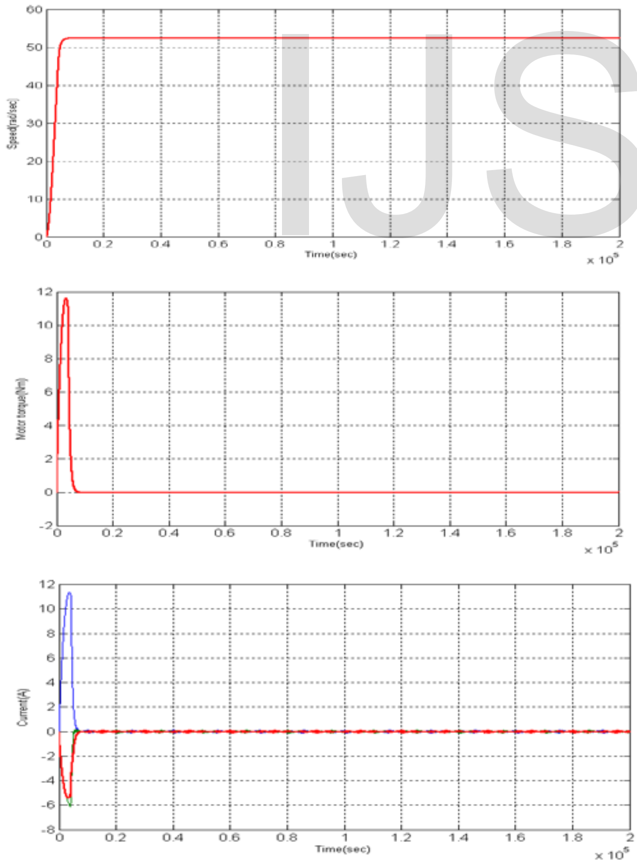


Fig 9(a) Speed response, 9(b) Motor torque & 9(c) Current

CASE II: With change in load Condition

Load is applied to the motor from no-load to 1 Nm load at 0.1 sec

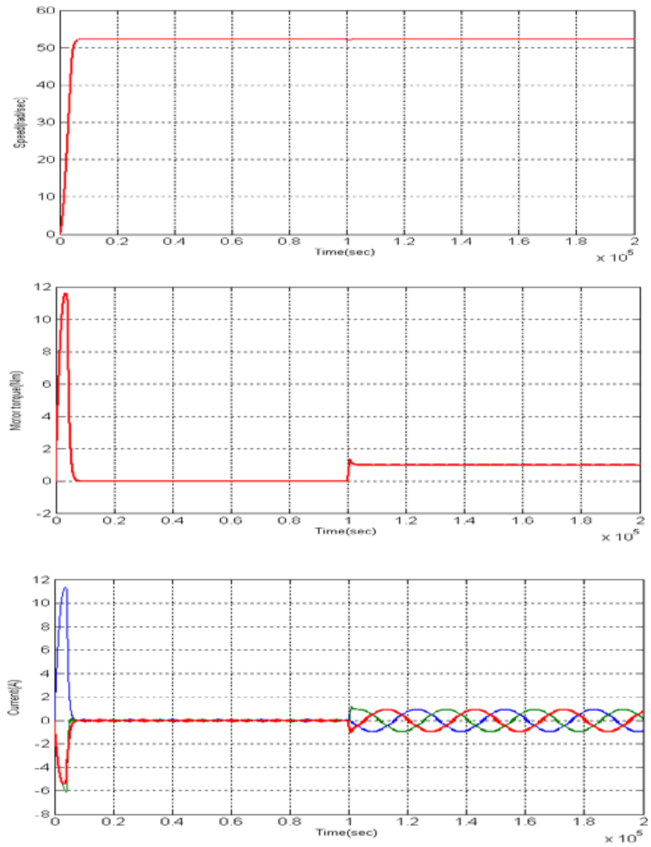


Fig.10 (a) Speed response, 10(b) Motor toque & 10(c) Current

CASE III: With Change in reference speed Conditions

When initial reference speed is 52.3rad/sec and it changes to 40rad/sec at t=0.1 sec

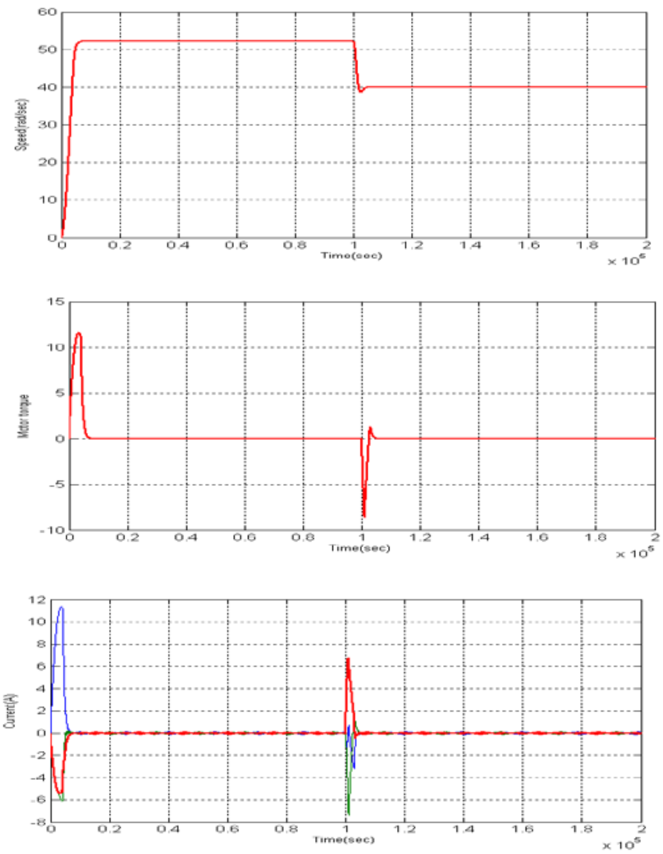


Fig. 11(a) Speed response, 11(b) Motor torque & 11(c) Current

4 CONCLUSION

In this paper, comparison of PI-Controller and Fuzzy Controller has been done for speed control of PMSM drives. The conventional Proportional-Integral (PI) controller is largely used in industry but the PMSM servo system is a nonlinear and time-varying complex system. The results of traditional PI controller as speed control of PMSM are not satisfactory to the higher degree of accuracy condition. The fuzzy control not only has the prominent advantage in complex, time varying and nonlinear system control but also don't need the mathematical model of controlled object. Effectiveness of the model is established by performance prediction over a wide range of operating conditions. A performance comparison between the fuzzy controller and the conventional PI controller has been carried out by simulation runs confirming the validity and superiority of the fuzzy logic controller for implementing the fuzzy logic controller to be adjusted such that manual tuning time of the classical controller is significantly reduced. The performance of the PMSM drive with reference to PI controller and Fuzzy controller has been compared in this paper and we found that Fuzzy logic speed controller improved the performance of PMSM drive. But in some case, when the dynamics of the system vary over time or with operating conditions, the performance of the controller will be spoiled. The Fuzzy Logic Controller (FLC) used as a speed controller seems to be a promising solution in this purpose.

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