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Implementation of Hybrid Controller Based PMSM Drive for Improved Dynamic Response

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Abstract: This paper provides a closed loop Field Oriented Control technique incorporating Fuzzy Logic Controller for torque ripple minimization and speed control of permanent magnet synchronous motor drive. The execution of the proposed FLC technique is compared with that of the conventional Proportional Integral controller. The ability of the proposed controller is analyzed in simulation for various operating conditions. The results show that FLC based PMACSM drive provides improved speed and torque response compared to conventional PI controller. The proposed technique is implemented in MATLAB/Simulink.

Key Words: Permanent Magnet AC Synchronous Motor (PMACSM), Field Oriented Control (FOC), Space Vector Pulse Width Modulation (SVPWM), Vector control, Proportional Integral (PI) controller and Fuzzy Logic Controller (FLC).

I. INTRODUCTION

Permanent magnet synchronous motors are widely used in adjustable speed drive applications owing to its advantages such as high efficiency, higher power density, robustness,higher power factor and high torque to current ratio compared to other ac motors[1-2]. These motors find a wide application in high efficiency and high performance drives such as electric vehicles, robotics, machine tools and rolling mills [3-5]. One of the essential requirements of this drive is the minimum torque ripple. These torque ripples generate mechanical vibrations, acoustic noise, induce speed variations that interrupt the system performance and limits the machine from the application that need precise and proper speed control.

The accurate speed control of PMACSM over a wide speed range becomes a difficult task due to non-linearity of machine drives, magnetic saturation and non-linear coupling among the motor winding currents and the rotor speed [6]. Several control techniques such as scalar control, field oriented control, and direct torque control is used for controlling the speed of PMACSM drive systems. Availability of these control techniques makes them more suitable for industrial and commercial applications. Though scalar control technique is easy to implement, it is not applicable for the high performance motor drives due to its low dynamic response and creation of instability of the drive system [7]. The motor performance can be improved by using vector control technique, which makes the control of ac drive analogous to dc drives.Due to simple implementation, the conventional proportional integral controller is used as speed controller in field oriented controlled PMACSM drive system[8]. The main disadvantages of the PI controller are as follows;

PI controller require proper mathematical model of the system and its design depends on the motor parameters. Controller performance is sensitive to the system disturbances.

The factors such as noise, temperature, saturation and unknown load dynamics affect the controller performance.

Due to several disadvantages, convectional proportional integral controller is replaced by FLC. The steady state error is minimized using Fuzzy Logic Controller [9-10]. Among various intelligent controllers, FLC is simple and provides better dynamic performance. The performance of the proposed FLC is compared with that of the conventional Proportional Integral (PI) controller. The FLC based vector controlled PMACSM drive reduces the overshoot and settling time of speed response compared to conventional PI controller [10]. Field Oriented Control allows smooth operation over the entire speed range of drive and fast acceleration and deceleration is achieved.

II. SYSTEM CONFIGURATION OF PMACSM DRIVE

The permanent magnet synchronous motors are mainly finding their application in high efficient and high performance drives. These motor drives require smooth rotation over the entire speed range of motor,fast acceleration and deceleration. To achieve the above mentioned qualities, vector controlled PMACSM drive system is used. The Fig.1.provides the block diagram of PMACSMdrive system. Permanent magnet synchronous motor is an ac synchronous motor which is powered by a three phase inverter. The rotor shaft position and actual speed signal is obtained through motor sensors. The deviation in required speed and actual speed is minimized through the PI speed controller.

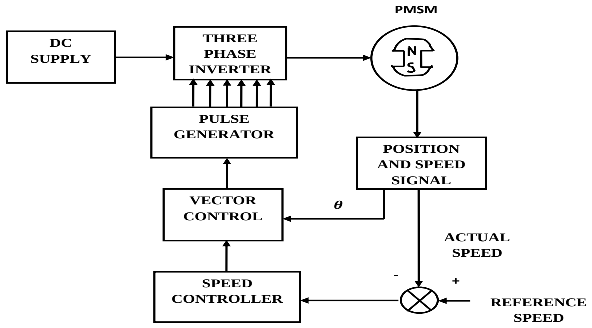

Fig.1. Block diagram of PMACSM drive system

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Vector control technique generates direct and quadrature axis reference voltages. These reference signals are given as input to SVPWM technique to generate gate pulses for the inverter operation. The inverter generates the controlled voltage which is applied to permanent magnet synchronous motor to produce the required speed.

III. MODELING OF PMACSM

The dynamic model of PMACSM is required to derive the vector control algorithm to decouple the three phase stator currents of the motor into flux and torque components.
The motor model has been developed on rotor reference frame using following assumptions.

1. The induced emf is sinusoidal.
2. Saturation is neglected.
3. There are no field current dynamics.
4. Eddy current and hysteresis losses are negligible.

In d-q rotating frame, the voltage equations of permanent magnet synchronous motor is given by,

$$V_q = R_s i_q + \omega_e \lambda_d + \frac{d}{dt}\lambda_q \qquad (1)$$

$$V_d = R_s i_d - \omega_e \lambda_q + \frac{d}{dt}\lambda_d \qquad (2)$$

where R_s is the stator resistance

λ_d, λ_q = Fluxlinkage due to d -axis and q- axis

V_d, V_q= d-axis and q-axis voltage

i_d,i_q= d-axis and q-axis current

The stator flux linkages of q and d axes in rotor reference frame is given by,

$$\lambda_q = L_q i_q \qquad (3)$$

$$\lambda_d = L_d i_d + \lambda_f \qquad (4)$$

whereL_q and L_d are the q and d axes stator inductances and λ_f is the rotor flux linkages that link the stator. Substituting (3) and (4) in (1) and (2), we get

$$V_q = R_s i_q + \omega_e\left(L_d i_d + \lambda_f\right) + \frac{d}{dt}\left(L_q i_q\right) \qquad (5)$$

$$V_d = R_s i_d - \omega_e\left(L_q i_q\right) + \frac{d}{dt}\left(L_d i_d + \lambda_f\right) \quad (6)$$

Arranging (5) and (6) in matrix form

$$\begin{pmatrix} V_q \\ V_d \end{pmatrix} = \begin{pmatrix} R_S + \frac{d}{dt}L_q & \omega_e L_d \\ -\omega_e & R_s + \frac{d}{dt}L_d \end{pmatrix}\begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} \omega_e \lambda_f \\ \frac{d}{dt}\lambda_f \end{pmatrix} (7)$$

The electromagnetic torque equation is given by

$$T_e = \frac{3}{2}\frac{P}{2}\left(\lambda_d i_q - \lambda_q i_d\right) \quad (8)$$

The mechanical torque equation is,

$$T_e = T_l + B\omega_m + J\frac{d\omega_m}{dt} \quad (9)$$

Solving the rotor mechanical speed from equation

$$\omega_m = \int\left(\frac{T_e - T_l - B\omega_m}{J}\right)dt \quad (10)$$

$$\omega_m = \omega_r\left(\frac{2}{P}\right) \quad (11)$$

In the above equation ω_r is the rotor electrical speed and ω_m is the rotor mechanical speed.

IV. IMPLEMENTATION OF HYBRID CONTROLLER BASED PMACSM DRIVE

In field oriented control scheme, the motor variables are transformed into an orthogonal set of d-q axes to control motor speed and torque separately. The hybrid controller based PMACSM drive consists of two control loops, namely an inner current loop and an outer speed loop. The outer loop consists of fuzzy logic controller for controlling motor speed and generates reference signal for the torque controller. The inner loop consists of PI controllers which controls motor torque and flux separately. The Fig.2 shows the block diagram of hybrid controller based PMACSM drive system.

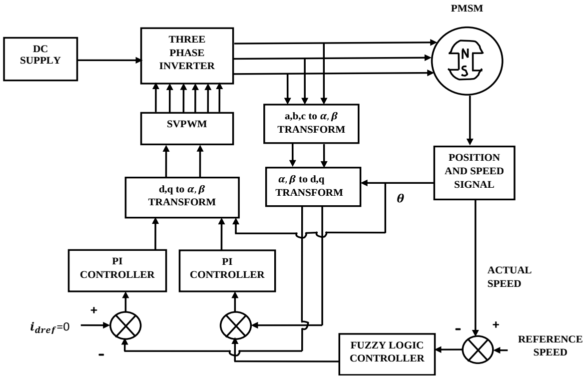

Fig.2. Block diagram of hybrid controller based PMACSM drive system

The deviation between the reference speed and actual speed is regulated through FLC. The Fig.3 shows the structure of fuzzy logic based speed controller.

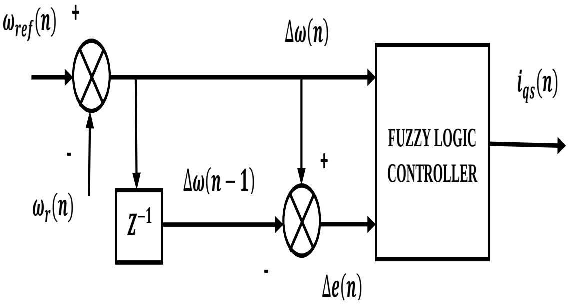

Fig.3 Structure of Fuzzy Logic based Speed Controller

The two input signals for the speed controller is the error E and change in error CE and the output signal is the quadrature axis reference current 〖 i〗 _qs (n). The centroid defuzzification algorithm is used in this paper. The rule table of FLC is listed in Table I. The input and output relation of FLC is given below,

$$E = \Delta\omega(n) = \omega_{ref}(n) - \omega_r(n) \qquad (12)$$

$$CE = \Delta e(n) = \Delta\omega(n) - \Delta\omega(n-1) \qquad (13)$$

E / CE	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

Table I: Rule Table OfFlc

The steps of Field Oriented Control algorithm is given by,

STEP 1: The FOC process starts with measurement of three phase stator currents.

STEP 2: The measured three phase stator currents are transformed into two axes orthogonal stationary reference frame components using Clarke transformation.

$$i_\alpha = \frac{2}{3} i_a - \frac{1}{3} i_b - \frac{1}{3} i_c \qquad (14)$$

$$i_\beta = \frac{1}{\sqrt{3}} i_b - \frac{1}{\sqrt{3}} i_c \qquad (15)$$

where i_α and i_β are time invariant components.

STEP 3: The stationary reference frame components are again transformed into two axis orthogonal rotating reference frame using Park transformation.

$$i_d = i_\alpha \cos\theta + i_\beta \sin\theta \qquad (16)$$

$$i_q = -i_\alpha \sin\theta + i_\beta \cos\theta \qquad (17)$$

wherei_d and i_q are time variant components.

STEP 4: The direct axis reference current (i_{dref}) is kept as zero and the quadrature axis reference axis curr1\ent is obtained from the fuzzy logic based speed controller. These currents are compared with the 0actual motor current signals and obtained error signals are processed through Proportional Integral current controllers. The outputs of the PI current controllers are the reference voltage vector signals V_d and V_q.

STEP 5: The d-q (V_d ,V_q) reference voltage signals are converted back to α,β (V_α ,V_β) using Inverse Park transformation.

$$V_\alpha = V_d \cos\theta - V_q \sin\theta \qquad (18)$$

$$V_\beta = V_d \sin\theta + V_q \cos\theta \qquad (19)$$

STEP 6: The obtained output signals are given as input to SVPWM technique to produce gating signals for voltage source inverter.

V. RESULTS AND DISCUSSIONS

The hybrid controller based PMACSM drive is established in MATLAB software. The system consists of motor model, speed and current controllers, transformation blocks, inverter and a source. Initially the required speed is set to 40 rad/sec and after 1 sec speed is changed to 80 rad/sec. An external load torque of 3.3Nm is applied throughout the time.

A. Performance of PMACSM drive using conventional PI controller

In conventional vector control based PMACSM drive, proportional integral controller is used as the outer loop speed controller. A PI controller compares the actual speed with the required speed and has a function to control the changes produced. The response of PI controller is the combination of proportional and integral of the given error signal.

The output equation of a conventional PI controller is given by

$$Y(t) = K_i \int_0^t e(t)\,dt + K_p e(t) \qquad (20)$$

where U(t) is the controller's output signal

e (t) is the controller's input error signal

K_p is the proportional control gain

K_i is the integral control gain

The Fig.4 shows the current, speed and torque response of field oriented control b

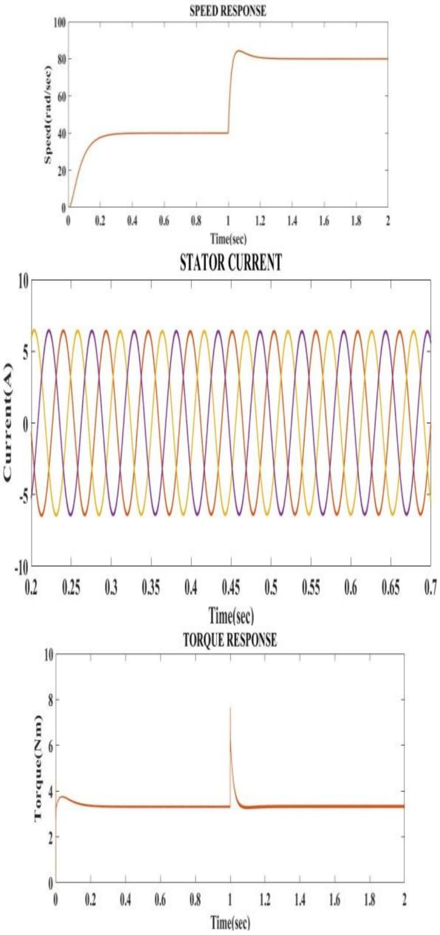

Fig.4.Response of field oriented controlled PMACSM drive using PI controller (a) Stator current (b) Speed (c) Torque

B. Performance of PMACSM drive using FLC

The dynamic response of vector controlled PMACSM drive system could be improved by replacing conventional PI speed controller with an intelligent controller. Results ustify that fuzzy logic control based PMACSM drive system provides improved speed and torque response compared to conventional controller. It is found that FLC based system provides reduced overshoot and settling time of speed response compared to PI controller.

The Fig. 5 shows the current, speed and torque response of field oriented control based PMACSM drive using fuzzy logic controller. The PMACSM parameters are given in Table II.

PARAMETER	VALUE
Stator resistance(R_s)	1.45Ω
d-axis inductance(L_d)	6.6mH
q-axis inductance(L_q)	6.6mH
Rotational inertia(J)	0.001276Kg-m^2
Permanent magnet flux(λ_m)	0.12546Wb
No. of pole pairs(P)	3
Damping coefficient(B)	0.00038818N-m-s

Table II: Pmacsm Parameters

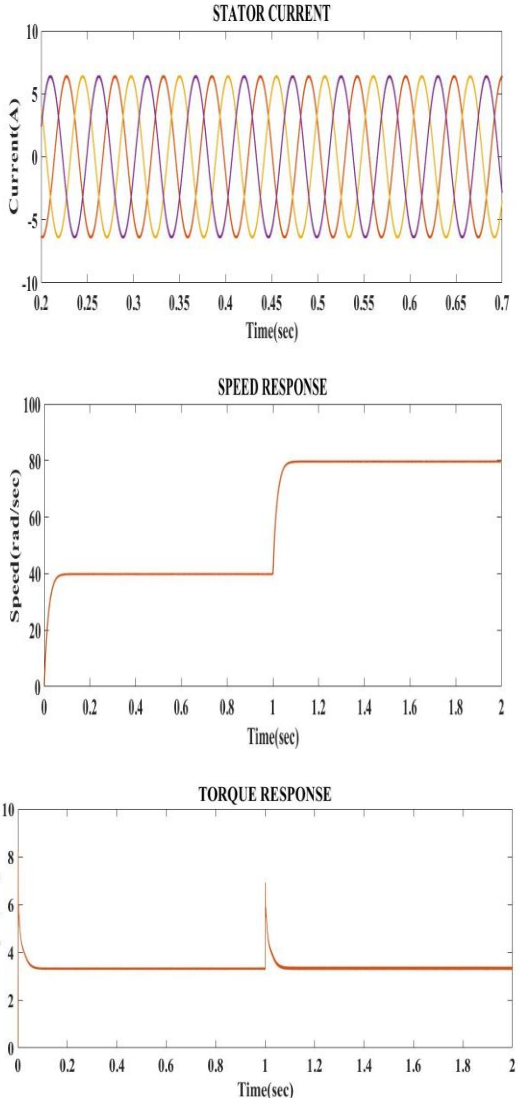

Fig.5. Response of field oriented controlled PMACSM drive using Fuzzy Logic Controller (a) Stator current (b) Speed (c) Torque

The performance comparison of different controller based PMACSM drive system is shown in Table III.

PERFORMANCE PARAMETERS	PI CONTROLLER	FUZZY LOGIC CONTROLLER
Settling Time	0.35sec	0.12 sec
Overshoot	4.2 rad/sec	No overshoot
Source current THD	3.67%	3.14%

Table III: Performance Comparision

VI. CONCLUSION

In this paper, the proposed PMACSM drive system has been implemented with hybrid controller based field oriented control. A performance comparison of both conventional PI controller and FLC based PMACSM drive system has been shown in the simulation. Simulation output gives that proposed method provides better speed and torque response compared to conventional method. The dynamic responses like overshoot, settling time of the speed response and torque ripple have been reduced in fuzzy logic controller based PMACSM drive system.

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