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Analysis of Fuzzy Control for Permanent Magnet Synchronous Motor

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Abstract :
This paper presents the design, analysis and speed control of a permanent magnet synchronous (PMSM) motor with a speed controller to improve the performances of the motor. To reduce torque ripples and improve dynamic performance, a fuzzy controller for permanent magnet synchronous motor drive is presented, which replaces the conventional hysteresis controller. Results of simulation are provided to demonstrate that the proposed drive has quick response performance with a good torque.

1. INTRODUCTION

For a high-performance drive system, not only a fast response is required, but also the ability of quick recovery of the speed from any disturbances and insensitivity to parameter variation is essential [1-2]. Direct torque control drive of PMSM can present a fast dynamic performance, the speed controller used in PMSM drive system plays an important role to meet all the requires mentioned above.
All the types of controllers can improve the performance of the motor drive system. However, they are usually based on the parameters and structure of the system model. It will lead to complex computation when the system model is uncertainty. The fuzzy controllers have received increased applications on the system modeling and control system [2]. To replace the conventional controller, some persons put forward an approach of designing speed controller for PMSM drive through tuning the weights of the artificial-neural-network on-line to meet the system's dynamic characteristics. Generally, it will lead to the complex computation To overcome this difficulty, this paper present an approach of designing adaptive fuzzy controller that solve this problem.
Among the current control strategies, fixed band hysteresis most extensively used method to control the phase motor currents for AC machine drives. Some significant advantages of hysteresis controllers over other types of controllers designed with linear or non-linear control techniques are as follows:

- *Fast response and good accuracy because it acts quickly.*
- *Switching behavior of the power inverter can be directly taken into account at the design level.*
- *Robustness to load and motor parameters variations.*

Nevertheless, a current controller with fixed hysteresis band has two main disadvantages. The switching frequency varies during the fundamental period, resulting in irregular operation of the inverter. The current ripple is relatively large and theoretically can reach a double value of the hysteresis bands. As a result, the load current contains harmonics that cause additional machine heating [3] [4] [5].
The aim of this paper is to present an effective fuzzy controller scheme with improved performance over the entire range of speed and torque.

2. PRINCIPLE

If we assume that the effect of permanent magnet is on d axis, it can be illustrated with the following figure:

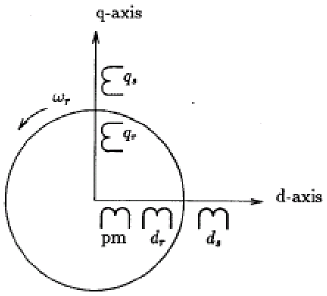

Figure 1: PMSM model

Now for achieving the mathematical model we can follow these equations:

$$\begin{bmatrix} \lambda_{qs} \\ \lambda_{ds} \\ \lambda_{os} \\ \lambda'_{qr} \\ \lambda'_{dr} \\ \lambda'_{pm} \end{bmatrix} = \begin{bmatrix} L_{ls}+L_m & 0 & 0 & L_m & 0 & 0 \\ 0 & L_{ls}+L_m & 0 & 0 & L_m & L_m \\ 0 & 0 & L_{ls} & 0 & 0 & 0 \\ L_m & 0 & 0 & L'_{lr}+L_m & 0 & 0 \\ 0 & L_m & 0 & 0 & L'_{lr}+L_m & L_m \\ 0 & L_m & 0 & 0 & L_m & L'_{lpm}+L_m \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{os} \\ i'_{qr} \\ i'_{dr} \\ i'_{pm} \end{bmatrix} \quad (1)$$

$$v_{qs} = R_s \cdot i_{qs} + \frac{1}{\omega_b} \cdot \frac{d}{dt} \psi_{qs} + \frac{\omega}{\omega_b} \cdot \psi_{ds}$$

$$v_{ds} = R_s \cdot i_{ds} + \frac{1}{\omega_b} \cdot \frac{d}{dt} \psi_{ds} - \frac{\omega}{\omega_b} \cdot \psi_{qs}$$

$$v'_{qr} = R_r \cdot i'_{qr} + \frac{1}{\omega_b} \cdot \frac{d}{dt} \psi'_{qr} \quad (2)$$

$$v'_{dr} = R_r \cdot i'_{dr} + \frac{1}{\omega_b} \cdot \frac{d}{dt} \psi'_{dr}$$

$$v'_{pm} = R_{pm} \cdot i'_{pm} + \frac{1}{\omega_b} \cdot \frac{d}{dt} \psi'_{pm}$$

We can see the rotor assembly of such permanent magnet synchronous motor in the following figure :

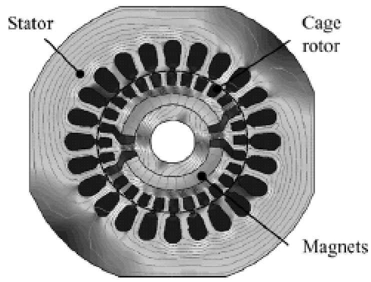

Figure 2: Rotor assembly of PMSM

3. Fuzzy Controller

This paper uses fuzzy controller to obtain proper dynamic response. Two inputs are: electromagnetic torque and speed error. The output of fuzzy controller is i_{qref} *. The fuzzy controller comprises fuzzification part, fuzzy inference part and defuzzification part. There are three zones for speed error, first zone show that error is very large, second show speed is about nominal and the last show error is negative. For torque there are two zones.*
The following figure show the membership functions of speed error:

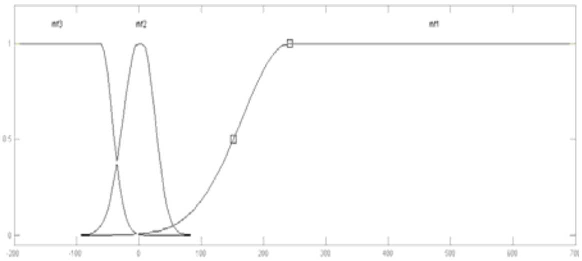

Figure 3: Membership functions of speed error

There are some rules in fuzzy controller that make output. Three dimension surface of this rule show in the following figure:

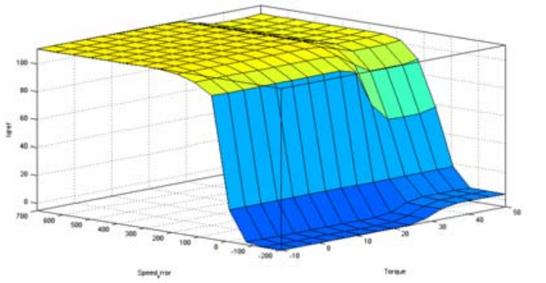

Figure 4:Surface view of rules

4. Simulation results

A block diagram of the proposed PMSM drive is shown in Fig 5, 6. The parameters of PMSM used in this paper are shown in Table 1.

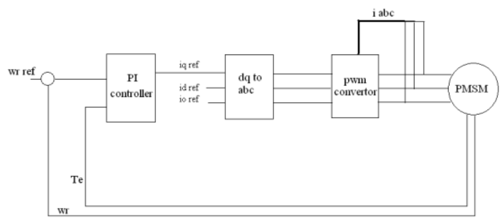

Figure 5: Block diagram of PMSM based on PI controller

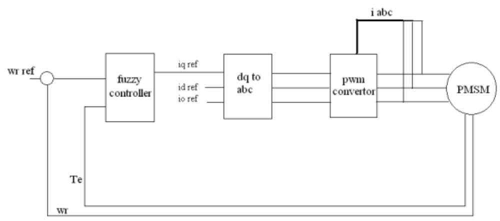

Figure 6: Block diagram of PMSM based on fuzzy controller

Table 1: Parameters of PMSM

Rated power PN (kW)	1
Rated voltage (V)	110
Number of pole pairs	4
Stator resistance *Rs* (Ω)	2.875
D-axis stator inductance *Ld* (mH)	8.5
Q-axis stator inductance *Lq* (mH)	6.4
Rotor flux linkage Ψf (Wb)	0.175

It is to be noted that w_r and T_e are the two parameters of the speed controller. First we use PI controller for controlling of speed (as show in figure 5). In this case simulation results can be obtained.

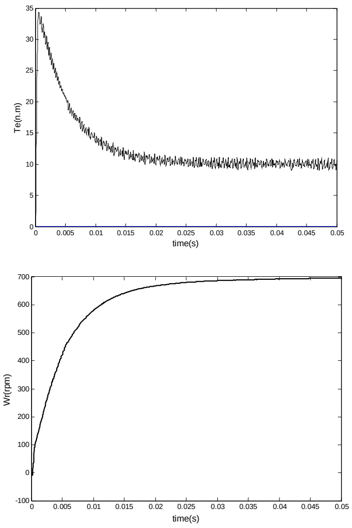

Figure 7:Speed and Torque with PI controller

As we see in figure 7 speed reach to its reference with a good starting torque. Now we replace PI controller with a FUZZY controller. Result show that the dynamic response with this controller is better that one and torque stay at maximum level until speed approach to its nominal value, and it is a better factor.

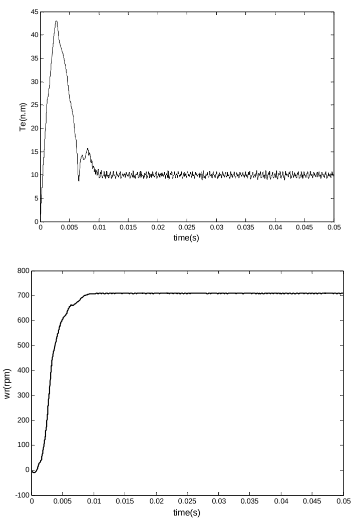

Figure 8: Speed and Torque with FUZZY controller

As we see in figure 3 when speed error is large output of controller will become large, but when speed error and torque are large output of controller will have lesser value.

5. Conclusion

In this paper, pi and fuzzy Controllers for the PMSM drive has been presented. Fuzzy controller with the respect of actual speed and torque feed the i_{qref} to system, so we can obtain to this results with a good dynamic. In fuzzy controller we define three membership functions for speed error and two membership functions for torque.

In this type of motors we have no control on rotor flux and should control stator parameter.

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