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Speed Control of PMSM Drive Using Adaptive Fuzzy Logic Controller

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Abstract: Permanent Magnet Synchronous Motors (PMSM) are widely used in low and mid power applications such as computer peripheral equipment, robotics, adjustable speed drives and electric vehicles. The growth in the market of Permanent Magnet motor drives has demanded the need of simulation tools capable of handling motor drive simulations. Simulations have helped the process of developing new systems including motor drives, by reducing cost and time. In a closed loop system the speed of a Permanent Magnet Synchronous Motor can be controlled by measuring the actual speed of the motor. PI (Proportional Integral),PID (Proportional Integral Derivative) and Fuzzy controllers are commonly used for the speed control. In this paper the speed responses of a PMSM is obtained using adaptive fuzzy PID controller. A parallel combination of two controllers- fuzzy PD controller and a fuzzy PI controller forms the adaptive fuzzy PID controller. Switching action take place between the two controllers based on the error in the speed. MATLAB/Simulink is used for the simulation. A comparison and analysis is made between PI controller and adaptive fuzzy logic controller.

Keywords: Permanent Magnet Synchronous Motor (PMSM), PI Controller, Adaptive fuzzy, speed control.

I. INTRODUCTION

Permanent Magnet Synchronous Motors (PMSM) are similar to Brushless DC motors (BLDC). PMSM are rotating electrical machines that have a wound stator and permanent magnet rotors that provide sinusoidal flux distribution in the air gap, making the Back EMF inform a sinusoidal shape. The armature windings, which are mounted on the stator, are electronically switched according to the rotor position. However permanent magnet motors which have permanent magnet on the rotor have the following advantages over induction motor.[2]

1. The torque to inertia ratio of these permanent magnet machines is higher.
2. The permanent magnet machine has a higher efficiency than an induction machine.
3. Better speed versus torque characteristics
4. The permanent magnet machine is smaller in size than an induction motor of the same capacity.

One of the salient features of the Permanent Magnet Synchronous Motor is the rotor position sensors, based on the rotor position and command signals which may be a torque command, voltage command, speed command and so on; the control algorithms determine the gate signal to each semiconductor in the power electronic converter. Many varieties of control techniques such as PI, PID, fuzzy logic controller and adaptive fuzzy controllers have been introduced for the speed control of the PMSM[1].The adaptive controllers are found to be more efficient in tracking the speed under conditions of external disturbance.

II. MODELLING OF PMSM

Equivalent circuits of the motors are used for study and simulation of motors. From the d-q modeling of the motor using the stator voltage equations the equivalent circuit of the motor can be derived. Assuming rotor d axis flux from the permanent magnets is represented by a constant current source as described in the following equation illustrated in the below Figure. The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

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

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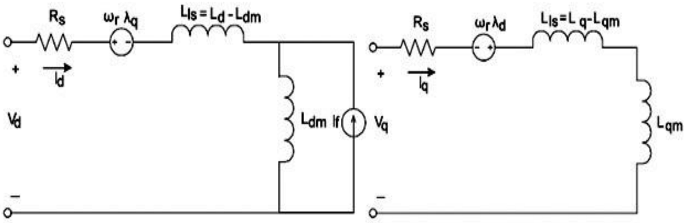

Fig.1 Equivalent Circuit of Permanent Magnet Synchronous Motor

Voltage equations are given by

$$V_q = R_s i_q + \omega_r \lambda_d + p\lambda_q \quad (1)$$

$$V_d = R_s i_d - \omega_r \lambda_q + p\lambda_d \quad (2)$$

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

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

WhereV_q is the q-axis voltage, V_d is the d-axis voltage, R_s is the stator resistance, i_d is the d-axis current, i_q is the q-axis current, L_d is the d-axis inductance, L_q is the q-axis inductance, ω_r is the synchronous electric speed . Using the method of field-oriented control of the PMSM, the d-axis current is usually controlled to be zero.

The developed torque motor is being given by

$$T_e = \frac{3}{2} \times \frac{P}{2} \left(\lambda_d i_q - \lambda_q i_d \right) \quad (5)$$

The mechanical Torque equation is

$$T_e = T_L + B\omega_m + J\left(\frac{d\omega_m}{dt} \right) \quad (6)$$

Where, ω_m is the mechanical speed, , Jis the inertia, T_L is the external load and B is the viscous coefficient.

III. PMSM SPEED CONTROL

The speed control loop of a Permanent Magnet Synchronous Motor adjusts the applied voltage in order to reach the reference speed. The difference between the actual speed and reference speed determines the error. By increasing or decreasing the duty cycle of the inverter switches, the applied voltage can be changed so as to minimize the error.PI,PID,fuzzy controllers are generally used in the speed control loop.

IV. PROPOSED SCHEME

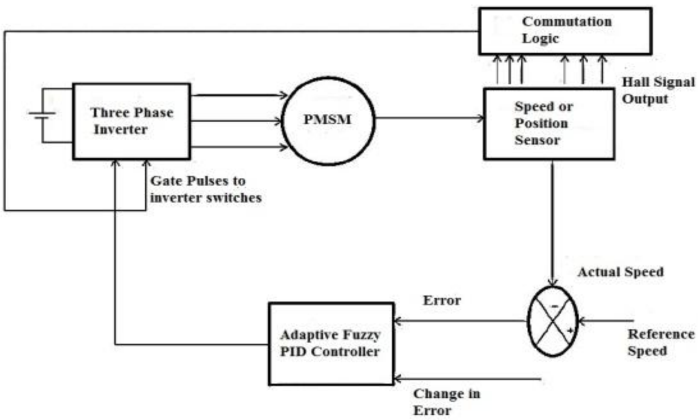

Fig.2 Block diagram of the proposed scheme

The proposed system ,as shown in fig 2,consists of Permanent Magnet Synchronous Motor, three phase voltage source inverter, speed controller, commutation logic and position sensor. Permanent Magnet Synchronous Motor is fed by a three phase MOSFET/IGBT based inverter. The PWM gating signals for firing the power semiconductor devices in the inverter is generated by the commutation logic block. The hall sensors are used as the position sensors. They detect the rotor position. Whenever rotor magnetic poles (N or S) pass near the hall sensor, they generate a high (1) or low (0) level signal, which can be used to detect the position of shaft. The commutation logic block generates emf based on the hall signals. The gating pulses are then generated based on the emf. Generation of emf based on hall signal as well as gate signal generation based on emf is as depicted in tables I&II. The actual speed is sensed and the speed controller block process the error signal (difference between the reference and actual speed).Adaptive fuzzy PID controller is used as the speed controller in the proposed system. For comparison purpose, a PI controller is also incorporated. The proposed controller is a parallel combination of two controllers-fuzzy PI controller and fuzzy PD controller. Speed error and change in speed error are given as inputs to the two controllers. Switching takes place between these controllers based on the error signal.

H_A	H_B	H_C	E_A	E_B	E_C
0	0	0	0	0	0
0	0	1	0	-1	1
0	1	0	-1	1	0
0	1	1	-1	0	1
1	0	0	1	0	-1
1	0	1	1	-1	0
1	1	0	0	1	-1
1	1	1	0	0	0

Table-I EMF generation based on hall signal output

E_A	E_B	E_C	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	-1	1	0	0	0	1	1	0
-1	1	0	0	1	1	0	0	0
-1	0	1	0	1	0	0	1	0
1	0	-1	1	0	0	0	0	1
1	-1	0	1	0	0	1	0	0
0	1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

Table-II Gate signal generation from EMF

Speed error (e) and change in speed error (ce) are used as the inputs to the speed controller. The output of the fuzzy-based proportional integral controllers is the gain FKPI. The fuzzy variable error has seven sets: positive big (PB), positive medium (PM), positive small (PS), zero (ZE), and negative small (NS), negative medium (NM) and negative big (NB), with each set having its own membership function. The fuzzy variable change in speed error has also seven sets: PB, PM, PS, ZE, NS, NM and NB, with each set having its own membership function. Triangular membership functions are normally used. As the next step, the fuzzy IF–THEN inference rules are chosen. The number of fuzzy rules that are required is equal to the product of the number of fuzzy sets that make up each of the two fuzzy input variables. The conjunction of the rule antecedents is evaluated by the fuzzy operation intersection, which is implemented by the min operator. The fuzzy rules are evaluated using the fuzzy inference engine and an output for each rule is computed. The multiple outputs are transformed to a crisp output by the defuzzification interface. The process of decoding the output to produce an actual value for the controller gain FKPI is referred to as defuzzification. Thus, a fuzzy logic controller based centre-average defuzzifier is implemented. The fuzzy output variable FKPI has seven sets: PB, PS, PM, ZE, ZS, ZM and ZB. The membership function for the fuzzy set is represented by triangular function. Mamdani type of fuzzy controller with 49 rules is designed.

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	NM	ZE	ZE
NM	PB	PB	PB	PM	PS	ZE	ZE
NS	PB	PM	PS	PS	PS	ZE	ZE
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	ZE	ZE	NM	NS	NS	NM	NB
PM	ZE	ZE	NS	NM	NB	NB	NB
PB	ZE	ZE	NM	NB	NB	NB	NB

Table- III Rules for fuzzy PI controller

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	ZE
NM	PB	PB	PB	PM	PS	ZE	NS
NS	PB	PB	PM	PS	ZE	NS	NM
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	PM	PS	ZE	NS	NM	NB	NB
PM	PS	ZE	NS	NM	NB	NB	NB
PB	ZE	NS	NM	NB	NB	NB	NB

Table- IV Rules for fuzzy PD controller

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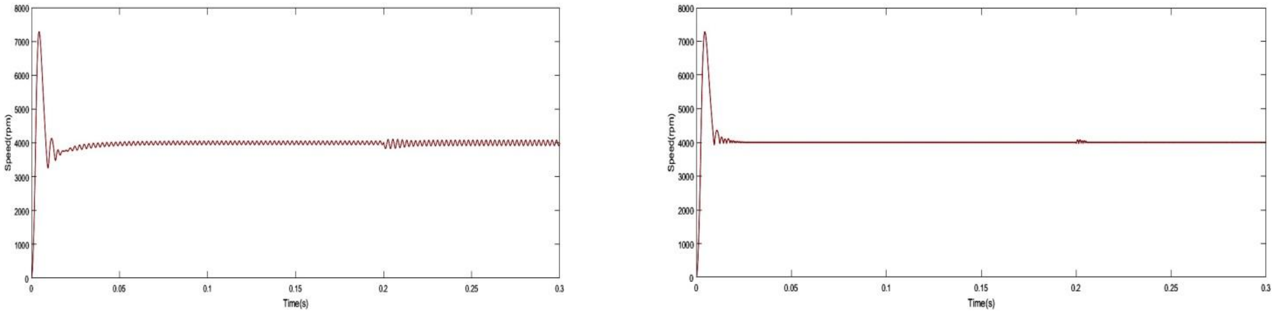
The fuzzy PD controller also uses speed error and change in speed error as the inputs. The output of the fuzzy-based proportional derivative controller is the gain FKPD. The fuzzy variable error has seven sets: positive big (PB), positive medium (PM), positive small (PS), zero (ZE), and negative small (NS), negative medium (NM) and negative big (NB), with each set having its own membership function. The fuzzy variable change in speed error also has the same seven sets: PB, PM, PS, ZE, NS, NM and NB, with each set having its own membership function. Triangular membership functions are used in this case also. The fuzzy output variable FKPD also has the same seven sets. The rules for a fuzzy PD controller are given in Table IV. Here also Mamdani type of fuzzy controller with 49 rules is used.[1]

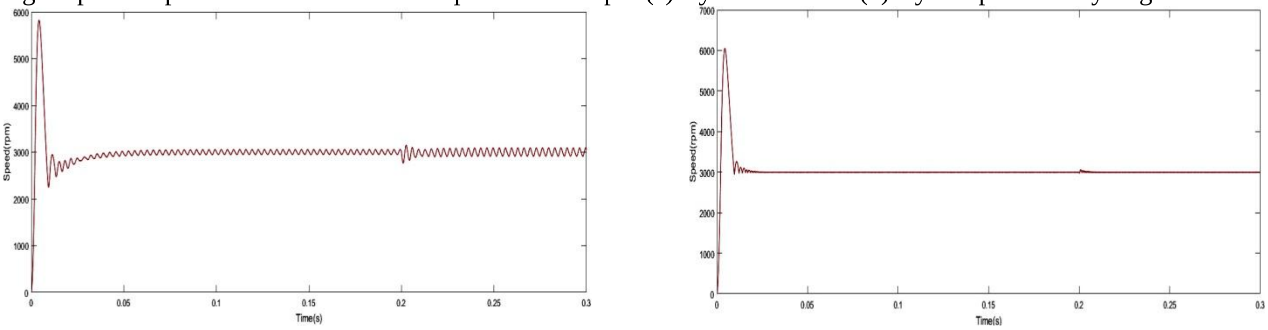
V. SIMULATION RESULTS

The simulation of the entire system is obtained using MATLAB/SIMULINK.The simulation is performed with a Permanent Magnet Synchronous Motor of 1.07 kW, 3000rpm rated speed. The simulation results obtained with the PI controller and adaptive fuzzy PID controllers are compared.



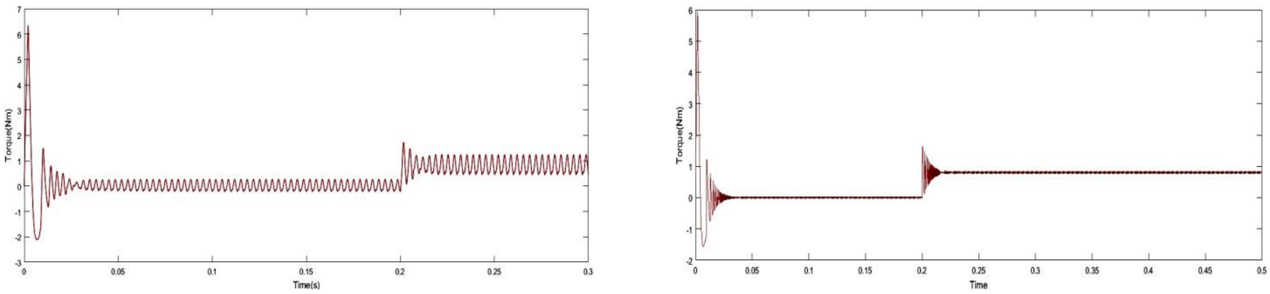
(a) (b)

Fig.3 Speed response when the reference speed is 4000 rpm (a) By PI controller (b) By Adaptive Fuzzy Logic controller



(a) (b)

Fig.4 Speed response when the reference speed is 3000 rpm (a) By PI controller (b) By Adaptive Fuzzy Logic controller



(a) (b)

Fig.5 Torque response when a load torque of 0.8 Nm is applied at 0.2s (a) By PI controller (b) By Adaptive Fuzzy Logic controller

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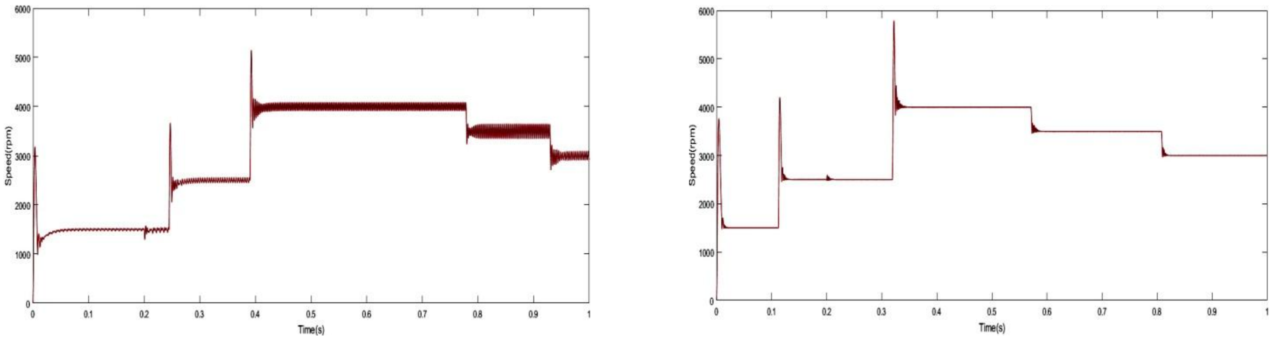

(a) (b)

Fig.6 Controlled Speed response (a) By PI controller (b) By Adaptive Fuzzy Logic controller

VI. CONCLUSION

The performance of three phase Permanent Magnet Synchronous Motor with adaptive fuzzy PID and PI speed controllers are analysed. Adaptive fuzzy PID controller is the parallel combination of fuzzy PD and fuzzy PI controller and has the combined advantages of both. It is found that the control concept with adaptive fuzzy logic PID controller outperforms classical PI controller in most of the aspects. Simulation results of the two controllers have been presented.

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