Discrete space vector modulation Direct Torque Control for Permanent Magnet Synchronous Motor drive using Various Controllers.

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Abstract

This paper consist of permanent magnet motor drives mathematical modeling equations derived and modeled In this paper by considering improved discrete space vector modulation technique with Direct Torque Control method(DSVM-DTC) has more advantages than general techniques applied to electrical drives, along with the minimization of switching frequency through the employment of hysteresis comparators and robustness with the respect to parameter variations than space vector modulation technique. But it has some complications in controlling the lowering of Flux and Torque variations. Mathematical equations are derived for the Permanent magnet synchronous as torque, flux, speed and modelled in Matlab simulation. In this investigation, an intelligent approach is introduced for the representation of the DSVM DTC for a (PMSM)Permanent Magnet synchronous machine. In this research PMSM using Proportional plus integral controller (PI controller), fuzzy logic controllers, and a Hybrid fuzzy controller is modeled based on the fuzzy input and output variabes, and results with various controllers are compared which gvies better performance in Matlab/Simulink domain.

***Keywords*:** Power Electronics, DSVM DTC, *Proportional plus integral, Fuzzy system ,Hybrid system, modelling of motor, matlab/simulink*

NOMENCLATURE

q - axis voltage (V)	J	Moment of inertia
d - axis voltage (V)	i_{abcs}	Stator phase currents (A)
q- axis current (A)	λ_{abcs}	Flux linkage of the stator phase winding
d- axis current (A)	λ_q	Stator flux linkage in q-component (wb)
Inductance in d- component (mH)	λ_m	Rotor flux linkage (wb)
Inductance in q- component (mH)	V_{abcs}	Stator phase voltages (V)
Stator flux linkage in d-component (wb)	r_s	Stator winding resistance (Ω)
Load torque (N-m)	Ψ_s	Stator flux linkage (wb)
Electro-magnetic torque (N-m)	U_{dc}	DC- link voltage (V)
Number of poles	ω_r	Electrical angular velocity (rad/sec)

INTRODUCTION

Nowadays almost all the power is produced, transmitted, distributed, and utilized in the scheme of AC. Due to this reason, the maximum application of the motor is ac motors. In this work, Permanent magnet motor drives are modeled. Permanent magnet motor drives are also the most applicable. By considering a PM synchronous motor obtain higher efficiency by producing the rotor magnetic flux with rotor magnets, it is applicable in many appliances like pumps, fans, and other appliances that require high reliability and efficiency. As per many researchers, there are some important and basic control techniques like (FOC) Field Oriented Control Technique and Direct torque control technique (DTC). DTC is more advantages than FOC[1-4]. Permanent magnet (PM) synchronous motors are generally used in huge-enforcement drives such as industrial automation and machine tools.

The Direct Torque Control (DTC) method have been primarily considered for induction machines (Takahashi and Noguchi [l], Depenbrock [2]). Because (DTC) direct torque control was presented during the 1980s, it has been generally used for AC electrical drives. Moreover, its affability, DTC is capable to generate rapid torque (τ) and flux control, and, in the case that the torque (τ) and flux linkage (λ) can be predicted correctly, DTC becomes robust. In this research paper, DSVM-DTC and FOC are reviewed DTC control of a permanent magnet synchronous machine is predicated on the set calculation of the best control sequence applied to the switches of a voltage inverter providing the change between the reference and the real value of torque(τ) and flux linkage(λ). This choice is usually due to hysteresis comparators whose objective is to check the system status, which is the amplitude of the stator flux and electromagnetic torque (τ_e).

The main aim of this paper is to control speed and reduce flux and torque ripples by using fuzzy controllers. This paper consists of DSVM-DTC as per many researchers it has been proven that DSVM-DTC is the best control method rather than FOC but still it requires better performance due to that reason this work includes intelligent approaches like Fuzzy logic controller with Improved DSVM Technique and results were discussed for DSVM-DTC.

While using fuzzy with a proportional plus integral controller in PMSM has many advantages that fuzzy controller gives good and fast response than conventional methods. Speed controlling is possible easily than other methods and also this paper includes a hybrid fuzzy logic controller, which gives better torque, flux, and speed response of the Permanent magnet synchronous motor drives. All these controller results are compared by using Matlab simulation Software [5-6].

2. MATHEMATICAL MODELLING OF PERMANENT MAGNET SYNCHRONOUS MOTOR

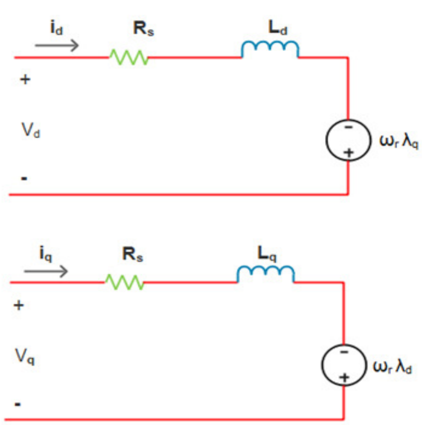

Figure 1. Equivalent Circuit of permanent magnet synchronous motor

Mathematical modeling equations of the permanent synchronous motor are obtained from the equivalent circuit of PMSM as shown in figure 1. Voltage equations of PMSM in the arbitrary reference frame to the stator is[6]

$$V_{abcs} = r_s\, i_{abcs} + \frac{d}{dt}(\lambda_{abcs}) \quad (1)$$

Voltage equations of PMSM in D-axes and Q- axes i.e., (DQ) frame to the stator

$$V_q = r_s\, i_q + \omega_r \lambda_d + \frac{d}{dt}(\lambda_q) \quad (2)$$

$$V_d = r_s\, i_d - \omega_r \lambda_q + \frac{d}{dt}(\lambda_d) \quad (3)$$

Flux linkage equations on D-Q frame for the stator is

$$\lambda_q = L_q\, i_q \quad (4)$$

$$\lambda_d = L_d\, i_d + \lambda_m \quad (5)$$

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\Psi_d\, i_q - \Psi_q\, i_d\right) \quad (6)$$

Here equations (1), (2), and (3) voltage equations and equations(4) and (5) represent flux linkage of D-Q components. Equation (6) represents the electromagnetic torque(τ_e) of the permanent magnet synchronous motor drive.

$$\Psi_s = \sqrt{\left(\Psi_d{}^2 + \Psi_q{}^2\right)} \quad (7)$$

$$\Psi_d = \int (V_d - r_s\, i_d)\, \mathrm{dt} \quad (8)$$

$$\Psi_q = \int \left(V_q - r_s\, i_q\right) \mathrm{dt} \quad (9)$$

$$\mathrm{J}\frac{d}{dt}(\omega_r) = \left(\frac{P}{2}\right)(T_e - T_L) \quad (10)$$

from the equations (1), (2), (3), (4), (5), (6), (7), (8), (9), and (10) the permanent magnet synchronous motor drive is modeled by using software Matlab simulation.

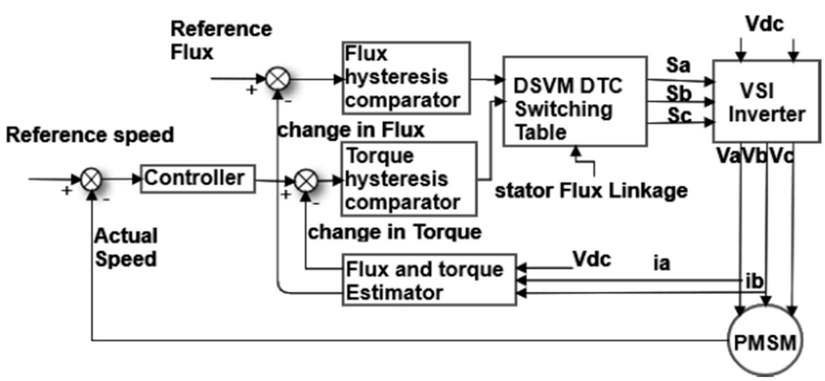

Figure 2. Basic Block Diagram of Permanent Magnet Synchronous Motor Drive

Figure 2 represents the basic block design of PMSM which consists of various blocks. Based on these block diagrams we can design the modeling of pmsm and flux and torque errors are estimated and that estimated errors are applied to the DSVM-DTC switching table and the gain of switching table is given to the inverter which produces three-phase voltages. These voltages Va, Vb, and Vc are applied to the (PMSM) Permanent magnet synchronous motor as a three-phase supply.

3. DISCRETE SPACE VECTOR MODULATION TECHNIQUE – DIRECT TORQUE CONTROL FOR PMSM

Space vector modulation technique SVMT is one another most important and applicable modulation techniques which is a conventional technique that is applied to the inverter but this space vector modulation technique has more disadvantages like it produces switching losses, transient response of the system is slow and more ripples[7-11]. To overcome all these disadvantages DSVM-DTC Discrete Space vector modulation direct torque control method was proposed with controlling techniques PI, Fuzzy Logic Controller, and Hybrid Fuzzy Controller.

In a voltage source inverter, we get eight switching combinations two of which produce null vectors remaining six vectors space equally voltage vectors with equal magnitudes. The voltage vectors in the DQ reference frame can be constituted as shown in below equations (11) and (12)

$$V_{qs} = \frac{2}{3} U_{dc}(2S_A - S_B - S_C) \quad (11)$$

$$V_{ds} = \frac{2}{\sqrt{3}} U_{dc}(S_B - S_C) \quad (12)$$

Where S_A, S_B, and S_C, are switching signals of upper Switches for a, b and c phases respectively and U_{dc} is the DC link voltage. The black dots in figure 3 represent the ends of the coordinated voltage vectors. As an illustration, the symbol "56Z" stand for the voltage vector, which is arranged by using the voltage space vectors V_5, V_6 and V_z individually applied for one-third of the sampling period.

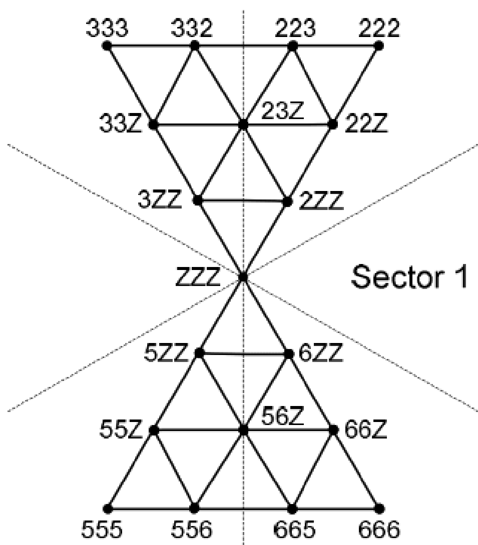

Figure 3. Voltage Vectors acquired by Using DSVM

An improved switching table for the optimized sequence of synthesized voltage vectors is shown in Table 1. In addition to selecting suitable voltage vectors in DSVM-DTC, it also depends upon the speed of the machine at which it operates at Different ranges which are mentioned in the switching table. Table 1 says that flux and torque errors are estimated in different sectors by mentioning speed at different ranges. When the speed of rotor Nr is greater than $1\frac{1}{2}$ of the synchronous speed Ns, it belongs to the high-speed range. When the rotor speed is in between half of the synchronous speed and $1/6^{th}$ of the synchronous speed, it belongs to the medium speed range and when the rotor speed is lower than $1/6^{th}$ of the synchronous speed, it belongs to the low-speed range [11-13].

TABLE 1. Switching table for DSVM-DTC for Sector 1

Speed	**Sector**	**Flux**	**Torque**				
			-2	-1	0	+1	+2
Low	1	-1	555	5ZZ	ZZZ	3ZZ	333
		+1	666	6ZZ	ZZZ	2ZZ	222
Medium	1	-1	555	ZZZ	3ZZ	33Z	333
		+1	666	ZZZ	2ZZ	22Z	222
High	1-	-1	555	3ZZ	23Z	332	333
		+1	666	2ZZ	22Z	222	222
	1+	-1	555	3ZZ	33Z	333	333
		+1	666	2ZZ	22Z	222	222

4. IMPLEMENTATION OF VARIOUS CONTROLLERS FOR PMSM

Figure 4 represents the block diagram of the PMS motor with the PI controller. Speed of the machine can be controlled by using the PI controller which gives better performance, fast response and can also reduce the flux and torque ripples of the PMS motor. Base on these block diagrams PMSM is designed in simulation by using Proportional plus integral controller Kp, Ki as gain constants e(t) is the error signal[14-15].

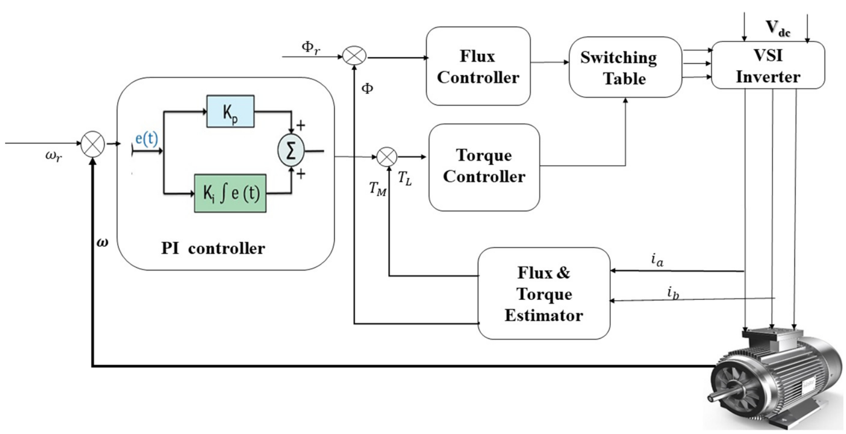

Figure 4. Block Diagram of Permanent Magnet Synchronous Motor Drive with PI controller

Figure 5 represents that PMS motor drive with a fuzzy logic controller FLC this controller consists of a total of 49 rules with Mamdani model and triangular membership functions the inputs to FLC is speed variation $e_{\omega r}$ and change in speed variation $\Delta e_{\omega r}$. The output of the Fuzzy logic controller is given to the voltage source which is used to convert the input signal into an equivalent output voltage to regulate the speed of PMSM. Fuzzy logic controller (FLC) gives good and fast response than PI controller based on block diagram which is shown in figure 5 PMSM is designed in Matlab simulation.

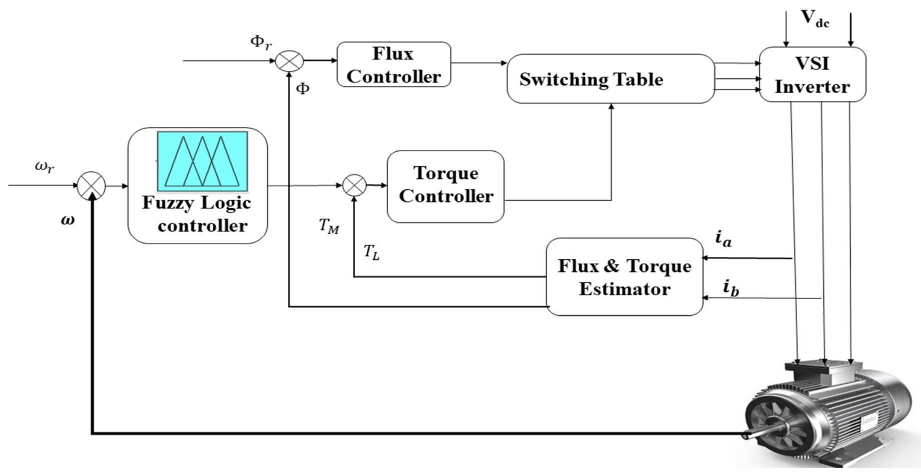

Figure 5. Block Diagram of Permanent Magnet Synchronous Motor Drive with Fuzzy Logic controller.

Figure 6 shows that the design of PMSM using the DSVM DTC technique and with various controllers by using MATLAB simulation. Based on the figure of PMSM this simulation diagram is designed. From this simulation diagram we can observe the actual speed of the machine can be controller with reduced steady-state error using a PI controller and also the ripple contents in torque and flux is reduced but in PI the response of the machine is slow to over these drawback here fuzzy logic controller is also implemented which give good response and the design is also simple. This fuzzy controller has 2 input, deviation in voltage and change in deviation voltage and that produces one output. Fuzzy logic controller with 49 rules Mamdani model triangular membership functions are taken into account. By applying all these rules membership functions fuzzy logic controller is implemented.

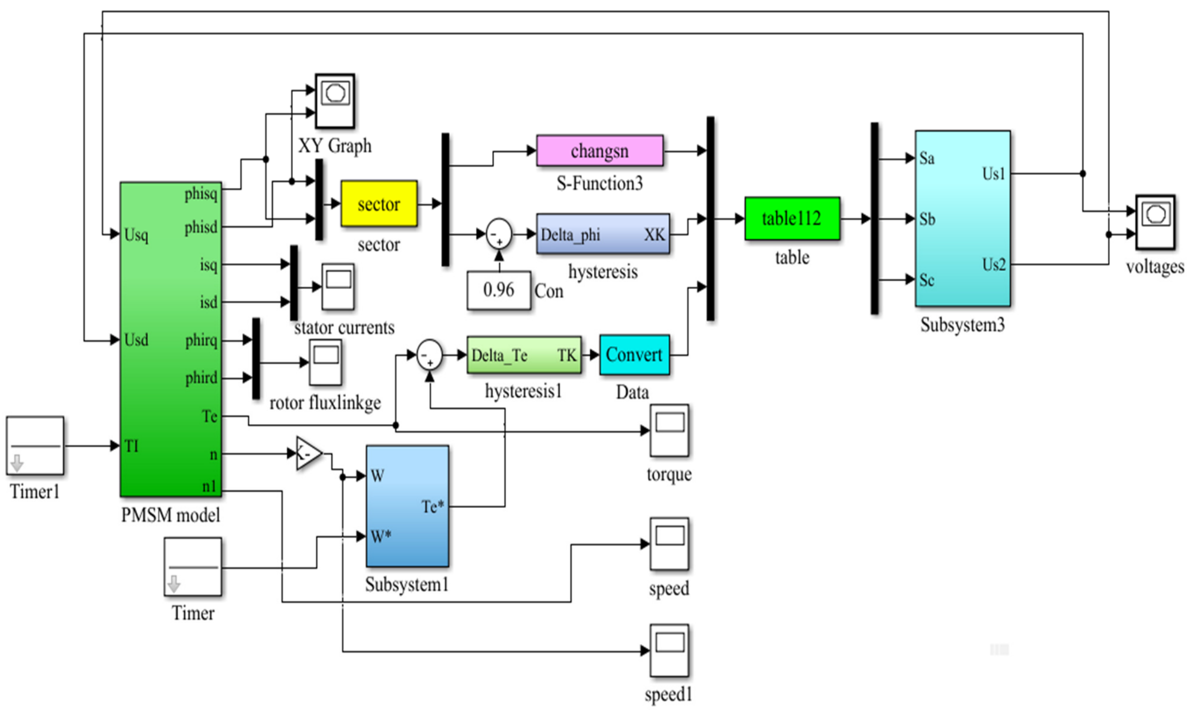

Figure 6. Simulation Diagram of Permanent Magnet Synchronous Motor Drive with PI, Fuzzy Logic controller and Hybrid fuzzy- PI controller.

5. RESULTS

Figure 7 shows the torque response of PMSM using PI and Fuzzy logic controller. Here PI controller gives a fast response but large overshoot compared to the fuzzy logic controller

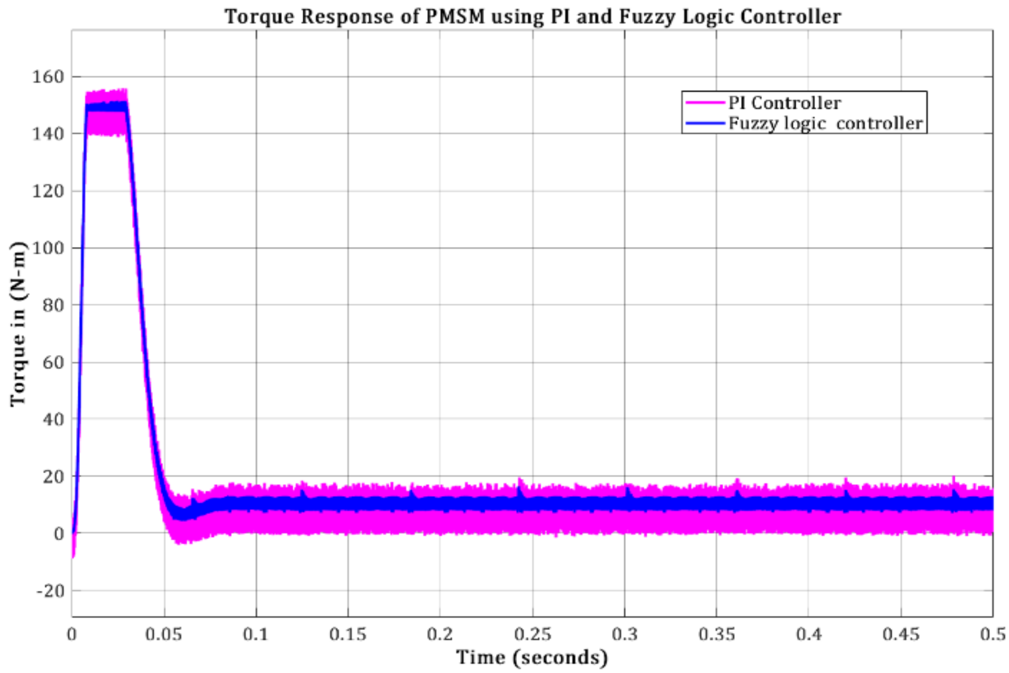

Figure 7. Torque response of Permanent Magnet Synchronous Motor Drive with PI controller and Fuzzy Logic Controller

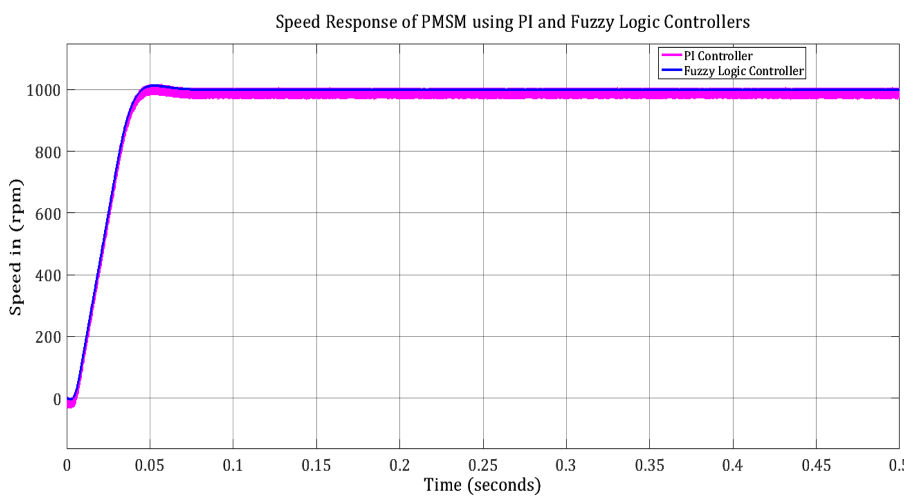

Figure 8. Speed response of Permanent Magnet Synchronous Motor Drive with PI controller and Fuzzy Logic Controller.

Figure 8 shows the speed response of PMSM with PI and Fuzzy logic controller. Here speed with pi takes more rise time and peak overshoot compared to the fuzzy logic controller. Figure 9 shows stator currents of PMSM with PI and Fuzzy Logic Controller. Here there are little bit variations in Iq and Id for the stator of permanent magnet synchronous motor PMSM.

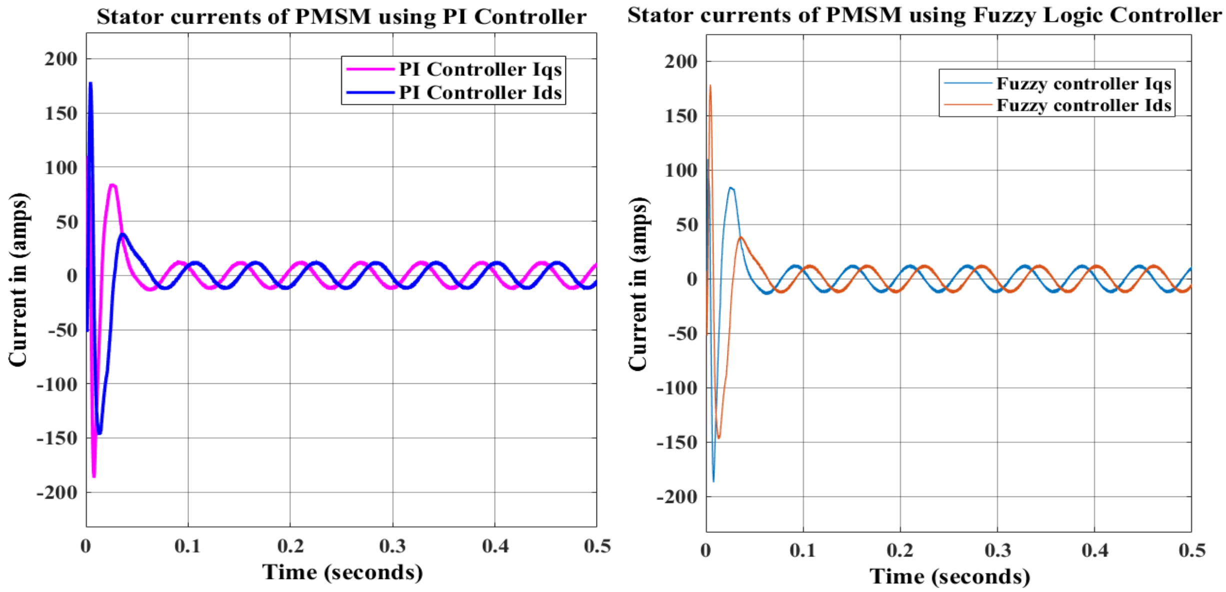

Figure 9. Stator currents of Permanent Magnet Synchronous Motor Drive with PI controller and Fuzzy Logic Controller

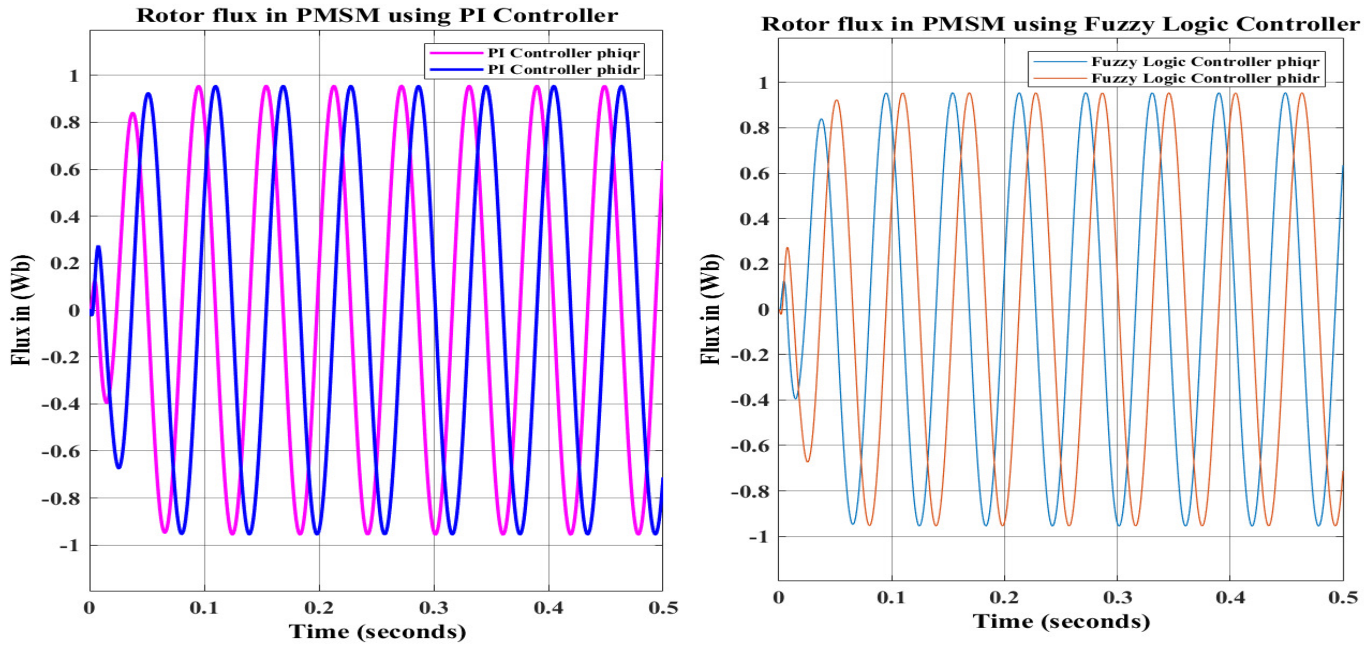

Figure 10. Rotor flux of Permanent Magnet Synchronous Motor Drive with PI controller and Fuzzy Logic Controller.

Figure 10 shows the rotor flux of PMSM with PI and Fuzzy Logic Controller. Here as Speed is controlled the rotor flux of PMSM is also controlled due to the outer we considered as speed and inner loop as current and flux of PMSM little bit variations in flux due to the variation of torque, current and speed.

5.1. Comparision of Results With Different Controllers

Table 2 shows the comparision of PMSM with Various controllers. Here are the specifications of motor. Rated power output: 1000 W,

Rated current :6.5 A,

Rated voltage: 128 V,

Rated torque :4.5 N-m ,

Number of poles: 6 poles.

Table.2 Comparision of Results With Different Controllers

S.No	Speed (rpm)		Torque(N-m)	
	PI Controller	FLC	PI Contoller	FLC
Rise time in (ms)	2.27	1.27	4.04	3.4
Over Shoot in(%)	63.19	46.2	8.96	1.41

6. CONCLUSION

The DSVM-DTC with PMSM is modeled by using Matlab simulation. Results of PMSM are compared with various controllers. PMSM results with a conventional PI controller are performed and compared with a Hybrid fuzzy logic controller which gives better steady-state performance and speed and torque ripples are reduced.

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