Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 9, August 2021: 1924 – 1934

Comparative Analysis of SVPWM Based PMSM Using Model Reference Adaptive System

[1]**Areddy Meghana** PG Student EEE Department Mahatma Gandhi Institute of Technology India, Meghananeha798@gmail.com
[2]**Dr.P.Nagasekhar Reddy** Associate Professor Department Of ELECTRICAL AND ELECTRONICS ENGINEERING MAHATMA GANDHI INSTITUTE OF TECHNOLOGY pnsreddy04@gmail.com
[3]**Dr.P.Ram Kishore Kumar Reddy** PROFESSOR DEPARTMENT OF EEE MAHATMA GANDHI INSTITUTE OF TECHNOLOGY prkumarreddy_eee@mgit.ac.in

ABSTRACT:

The Electrical system which is known for its reliability mainly prefers AC system over DC due to the stability issues concerning the respective system when DC system is implied into operation. The AC system adjourns the electrical flexibility by providing the required efficiency managing criterion which ultimately gives reason to prefer the respective system over the other. The PMSM is applied in this paper due to several considerations in no particular order like Inertia, dampening the harmonics, stabilizing the system during the operation and most importantly the synchronism within the internal structure. This paper presentsdynamic Mathematical Modelling of Permanent magnet synchronous motor (PMSM) and a space vector pulse width modulation (SVPWM) by using a Model Reference Adaptive System (MRAS). The speed control of the motor is supplied by a three phase two level voltage source inverter. The pulses generated from SVPWM is fed to Three phase two level inverter which possess easy design and ignites a output voltage with has low-frequency and also controlled frequency and amplitude at high-frequency by designing gating pulses. This paper tend to achieve mainly two purposes; primary one is to estimate the Electrical angular speed and rotor position of the PMSM, The second task is to adjust the motor's speed using the PI controller and the fuzzy controller. PI (Proportional Integral) and Fuzzy controllers (FLC) are employed in this system in order to get the required output speed. The complexity of PI controller, tuning and high response time can be overwhelmed by using FLC which has compact settling time.This is being implemented by using Matlab/Simulink.

Key words— Space vector Pulse width modulation (SVPWM), Permanent magnet synchronous motor (PMSM), model reference adaptive system (MRAS), PI controller, Fuzzy logic controller (FLC).

I. INTRODUCTION

A permanent magnet synchronous motor (PMSM) is a revolving electrical machine with phase windings in the stator and rotor has permanent magnets. Through the 3-ϕ AC, stator windings generate a spinning magnetic field [1]. The rotor magnetic field is used to give out the sine or sine wave shape. These permanent magnets provide the air gap magnetic field, which remains constant. Traditional DC motors employ a mechanical commutator to commutate themselves, whereas PMSM requires electronic commutation for current direction control through the windings [2]. Because the armature coils are located at the stator, the PMSM motors must be commutated externally using an external switching circuit, which is accomplished using a three phase inverter architecture [3][4]. A permanent magnet synchronous motor (PMSM) is a motor that generates the air gap magnetic field with permanent magnets rather than electromagnets. These motors have a number of benefits that have piqued the interest of researchers and industry for usage in a variety of applications [5]. The interaction of the two magnetic fields generates torque, which causes the motors to revolve. One magnetic field is formed by permanent magnets, while the other is created by stator coils in permanent magnet motors [6][7]. When the magnetic vector of the rotor is at 90 degrees to the magnetic vector of the stator, the maximum torque is produced. Permanent magnet synchronous motors (PMSM) are commonly used in CNC machine tools, industrial robots, and other applications due to the development of permanent magnetic materials and control technology. PMSMs have a high torque/inertia ratio, high power density, high efficiency, reliability, and ease of maintenance [8][9]. The construction of the PMSM simulation model and control system is critical for the verification of a variety of control algorithms as well as the optimization of the complete control system [10]. The PMSM drive's vector control is used to achieve great performance. The Space Vector Pulse Width Modulation (SVPWM) approach is a sophisticated, computationally intensive PWM technique that may be the best of all PWM algorithms for variable frequency drive applications [11] [12]. Because of its good stability and simplicity, the sensorless MRAS control method is utilized to remove sensor distortions. It is also used for the first preference estimation of speed. The MRAS acronym refers to two distinct variables that are used to compare outcomes. The two models that are involved in the scenario are the reference model and the adaptive model. To control the whole system 2 controllers are used PI and Fuzzy logic controller. Among these Fuzzy logic gives better performance in the perspective of tunning and steady state error.

II. MODELLING OF PMSM

For a thorough simulation of the PM motor drive system, detailed modeling is required Fig 1 shows the rotor reference frame on which the d-q model was created. The revolving rotor d-axis forms an angle of Ɵr with the fixed stator phase axis at any time t, and the rotating stator mmf makes an angle with the rotor d-axis. The rotor and the stator mmf rotate at the same speed.

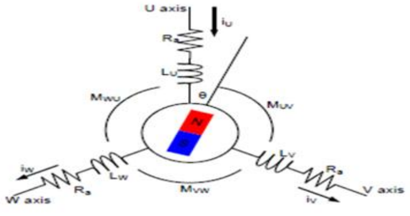

Fig 1 Three-phase Permanent Magnet Synchronous Motor conceptual diagram.

Voltage equations specified as:

$V_{qe} = R_{as} i_{qe} + \omega_e \lambda_{de} + \rho \lambda_{qe}$ 1

$V_{de} = R_{as} i_{de} - \omega_e \lambda_{qe} + \rho \lambda_{de}$ 2

Flux Linkages prescribed as:

$\lambda_{qe} = L_{qe} i_{qe}$ 3

$\lambda_{de} = L_{de} i_{de} + \lambda_f$ 4

Substitute equation3&4 into 1 & 2

$Vqe = R_{as} i_{qe} + \omega_e (L_{de} i_{de} + \lambda_f) + \rho L_{qe} i_{qe}$ 5

$V\,de = R_{as} i_{de} - \omega_e L_{qe} i_{qe} + \rho(L_{de} i_{de} + \lambda_f)$..........6

$\begin{bmatrix} V_{qe} \\ V_{de} \end{bmatrix} = \begin{bmatrix} R_{as} + \rho L_{qe} & \omega_e L_{de} \\ -\omega_e L_{qe} & R_{as} + \rho L_{de} \end{bmatrix} \begin{bmatrix} i_{qe} \\ i_{de} \end{bmatrix} + \begin{bmatrix} \omega_e \lambda_f \\ \rho \lambda_f \end{bmatrix}$..........7

The torquedeveloped by the motor is being given by

$T_{es} = \frac{3}{2}(P)(\lambda_F i_{de} - (L_{de} - L_{qe})(i_{qe} i_{de}))$..........8

$T_{es} = T_{Load} + B\omega_{me} + J_e \frac{d\omega_m}{dt}$..........9

$\omega_{ms} = \int \left(\frac{T_{es} - T_{Load} - B\omega_{me}}{Je} \right) dt$..........10

And

$\omega_{ms} = \omega_{es} \left(\frac{2}{P} \right)$..........11

III. SVPWM TECHNIQUE

The Fundamental harmonic component at any time can be feasible because of modulation technique, where output and input are sync with each other and computation is done easily. The voltage supply and frequency, which are constant characteristics in this technology, are controlled by orders that take them to the desired gate way control automatically. Frequency and voltage supply parameters apply to the voltage source inverter (VSI), which contains samples. The phase indication can be modified to suit the needs of the driver.A 3-phase 2-level VSI with dc link designmight have 8 feasible switching states (2^3=8 i.e. there are three switches which can be arranged in two different positions each), which develops output voltage of the inverter.

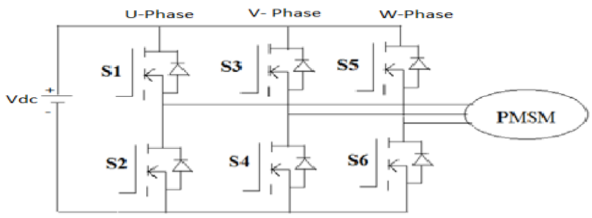

Fig 2 Three phase Inverter Fed PMSM.

At eachmoment one transistor in each bridge leg should be turned off at any given instant in order to experience an all phased current flowing. Subsequently there always lie anti-parallel diodes over each transistor to permit bi-directional current flow. Every inverter switching statesgives Space Vectors of (V1 to V6 are active vectors, V7 and V8 are zero voltage vectors) in a Space Vector plane.

$Vk = \frac{2}{3} VdcEXP(j(k-1)\frac{\pi}{3}$(K =1,2,…6) 12

The U-phase generally forms the base for the basic vector's angles at instant 0°. The incidence of the angles is the windings located inside the stator; installed around the with phase shift of 120° apart. Since each winding may have both polarities of voltage, it acquires two angles at separation of 180°, e.g. 60° and 240° is W-phase in negative and positive state appropriately.

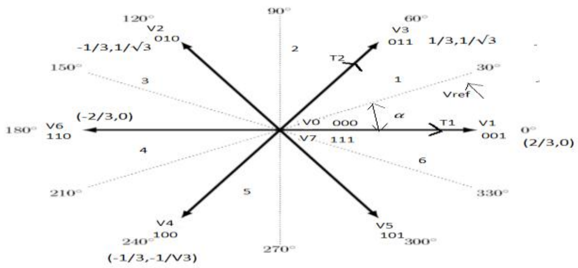

Fig 3 Sector Identification.

The magnitude and angle are generated by the inverter whose value is comprised by the reference voltage vector (Vref) by filtering in the required components at required spaces of time. The samples of magnitude and angle are always with reference to each other. Zero voltage vectors occur when these samples are generated. The limits to these samples are drawn from the reference voltage vector that is assumed and tested.In binary, these vector combinations can be described in the form of eight different binary values named from V0 to V7.

IV. MODEL REFERENCE ADAPTIVE SYSTEM

MRAS is one of the types of closed loop observer that has been extensively used in sensorless FOC. The outputs of two estimators are compared for the formation of MRAS. The first is model reference whichindependent of the observed variable. Whereas the second one is the adjustable. The adaptive mechanism is fed by the error betweenthe two models to turn out the observed variable. The rotor flux location is a key factor in determining motor voltages and currents, and the MRAS backs this up, although there is no sign dependency. The error angle is determined by a simple assumption of zero that holds true at all times. The adaptive model enters the picture, simplifying the rotor flux position and providing the necessary interface between the PI controller and the motor or drive.

Integration of rotor speed yields an approximated rotor flux angle. For a simple function, a smooth air gap machine is considered. In other words, it is assumed that the motor fulfills Lde = Lqe= Le, which is true. By demonstrating that two alternative models can be used, the current model can contain generator saliency. The reference model is the equation with no unspecified parameters, while the adaptive model is the obtained equation with unspecified parameters. The physical significance outputs of two models are identical. When both models run at the same time, the real-time parameters of the adjustable model work by adaptive law, which uses the difference between their outputs to achieve the final output of the tracing reference model with the help of output control.

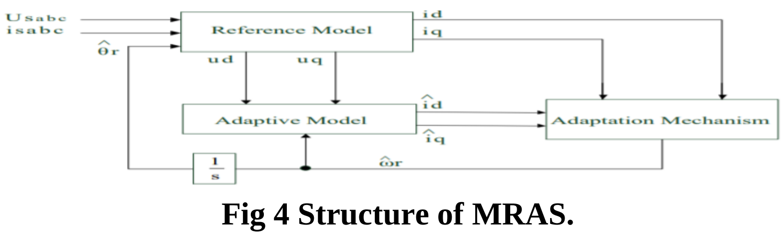

Fig 4 Structure of MRAS.

The reference and adjustable models are expressed as follows:

$$U_{de} = R_{as} i_{de} + L_{de} \frac{di_{de}}{dt} - \omega_r L_{qe} i_{qe} \quad \ldots 13$$

$$U_{qe} = R_{as} i_{qe} + L_{qe} \frac{di_{qe}}{dt} - \omega_r L_{de} i_{de} + \omega_r \psi_r \quad \ldots 14$$

The adaptive law which is obtained below

$$\widehat{\omega_r} = [K_P + \frac{K_I}{S}] i_s \widehat{i_s} = [K_P + \frac{K_I}{S}](\, i'_{de} \hat{i}'_{qe} - i'_{qe} \hat{i}'_d e) \hat{i}'_{qe} \quad \ldots 15$$

$$\widehat{\omega_r} = \left[K_P + \frac{K_I}{S}\right]\left(i_{de}\hat{i}_{qe} - i_{qe}\hat{i}_{de} - \frac{\psi_r}{Le}\left(i_{qe} - i_{de}\right)\right) \quad \ldots\ldots 16$$

$$\Theta_r = \int_0^t \omega_r dt \quad \ldots\ldots 17$$

V. PI CONTROLLER

The proportional error signal with mix of integral error signal leads to integral control of actuating signal. The transfer function of PI controller is shown as

H(S) = Kp+Ki/s……………………………………………………….…18

Here Kp is known as proportional gain constant or also called as proportional sensitivity. The process variable proportional which improves the dynamic response influences Proportional mode. Ki is integration constant, which tends the steady state error value equal to zero, thus by improving the response of steady state. With the support of integration mode, the output of the controller is as same as the error signals cost and time. The integral mode derivation evaluates the assembled proportional offset during the course of respective time which could have been formerly corrected. During this process itinfluences the controller to accelerateto the point faster when compared to a proportional controller and diminishes the steady state error. The second order parameters settling time and peak overshoot solely rely on Kp and Ki values, so the proper selection of Kp and Ki is very foremost need to design a PI controller. The diagram of PI control is shown as Figure 5.

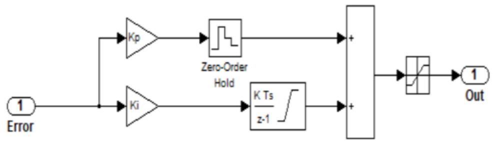

Fig 5 PI Control Scheme Block Diagram.

VI. FUZZY LOGIC CONTROLLER

Vector-controlled PMSM drives use fuzzy logic to adjust their speed. With two input variables, speed error and change in speed error, the FLC generated a change in torque current command (q-axis stator current).

$ek = \omega r{*}k - \omega r(k)$

$cek = ek - (k - 1)$……………………………………………………..……..…………...19

The error from the previous sampling is (k-1). The real value of FLC output is calculated as follows:

$iq{*}\ k = iq{*}k - 1 + \Delta iq\ {*}(k)$ ……………………………………………………………....20

The FL controller consists of three stages:

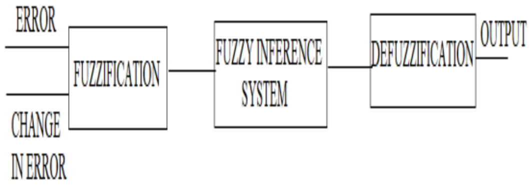

Fig 6 Fuzzy Logic Controller.

Mamdani model is used to design the Fuzzy logic controller. The control rules are established based on the PMSM behaviour knowledge. Table 1 lists each rule.

Table 1 Rule Base for Fuzzy Logic Controller.

Ce E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

VII. PROPOSEDSVPWM BASED PMSM USING MRAS

Fig 7 depicts the reference adaptive system in one of its forms, most likely a motor. The closed loop control aids in the detection of phase currents as well as the conversion to two phase stationary elements. The altered stationary elements are given to MRAS after being converted into rotating elements. The reference speed is used to compare the speed estimated by MRAS to the input reference speed. The obtained speed is utilized as the machine's actual speed.

The MRAS is served by comparing the output of two estimators. One estimator is an observed variable known as the model reference, while the other is an adjustable variable. Based on the error between the two models, the adaptive mechanism is fed to emerge the observed variable. The controllers (PI and Fuzzy Logic controllers) use a space vector control algorithm tocontrol the PWM pulses for a 3-phase inverter.

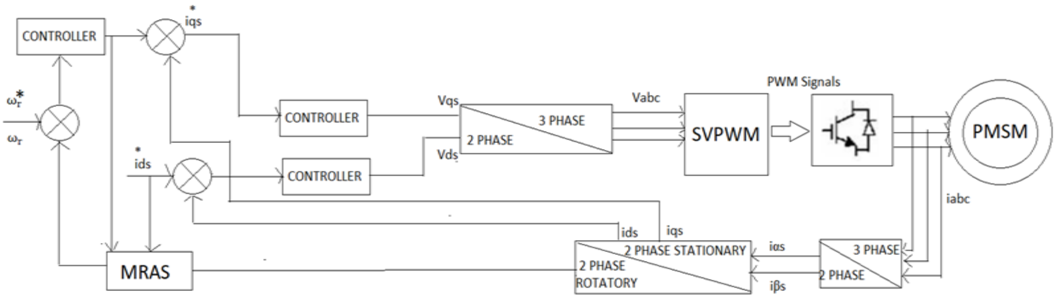

Fig 7 SVPWM-based PMSM with MRAS block diagram.

VIII. RESULTS

Table 2 Surface permanent magnet motor parameters.

Symbol	Name	Value
Vdc	DC voltage	400v
P	Number of poles	4
Rs	Stator resistance	1.2ohm
Yaf	PM flux linkage	0.2865v/rad/sec
Ld	d-axis inductance	0.0015H
Lq	q-axis inductance	0.0015H
J	Moment of inertia	0.000176Kgm2
B	Friction vicious gain	0.00038815Nm/rad/sec
Nr	Rotor speed	4000RPM

Using PI controller

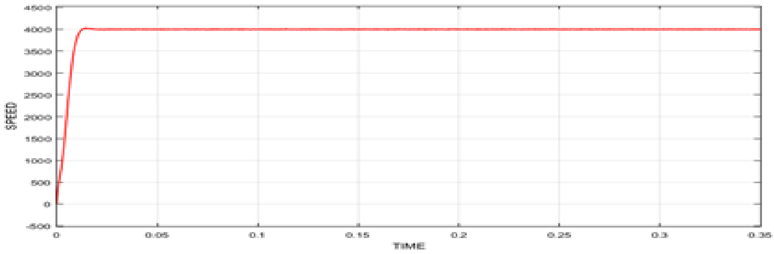

Fig 8 Actual Speeds using PI Controller.

Fig 8 depicts the change in speed over time. The load is applied at Tl = 3.2 N-M with a reference speed of 4000rpm that is gradually increased in this scenario. It takes some time for the load to reach steady state when it is applied.

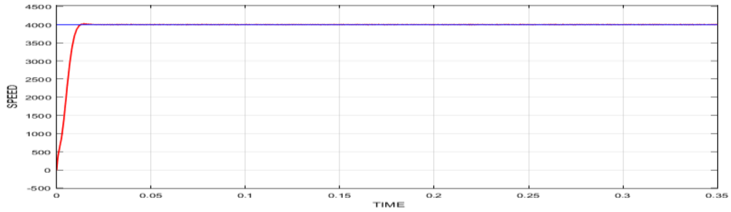

Fig 9 Actual Speed and Reference speed using PI Controller.

Fig 9 compares the actual and reference speeds to evaluate if the real speed can match the reference speed.

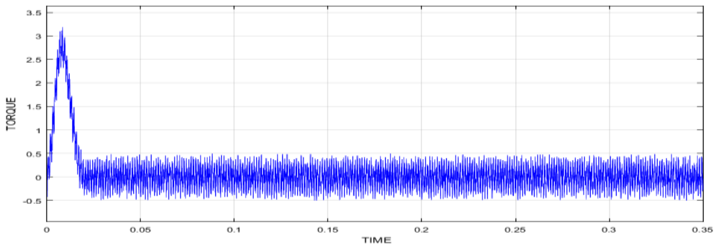

Fig 10 Electromagnetic Torque using PI Controller.

Fig 10 demonstrates the PI controller's electromechanical torque response. Because speed and torque are inversely related, when the speed reaches steady state, the torque is lowered to zero.

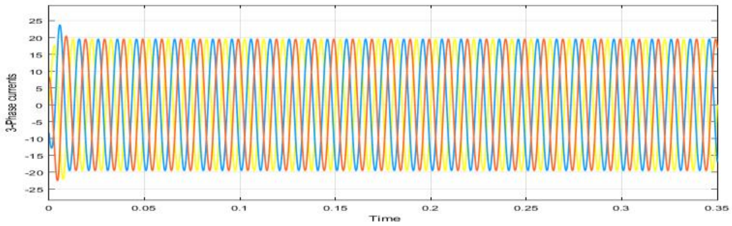

Fig 11 Iabc Currents using PI Controller.

Fig 11 shows Iabc currents of PI controller. When the motor achieves the controller instruct speed to steady state, the three phase currents are non-sinusoidal at first and then become sinusoidal.

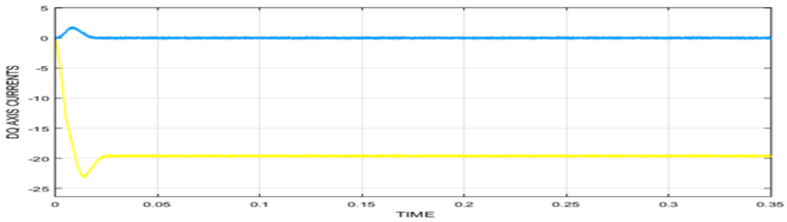

Fig 12 Idq Currents using PI Controller.

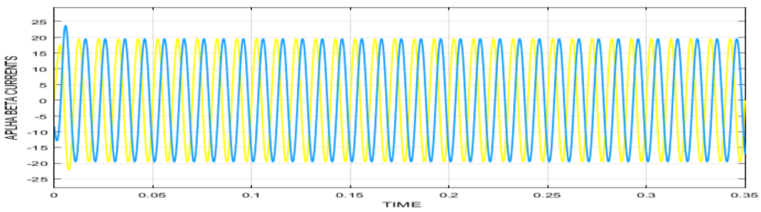

Fig 13 Alpha Beta Currents using PI Controller.

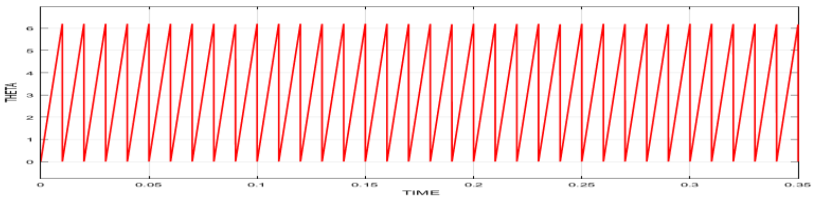

Fig 14 Rotor position using PI Controller.

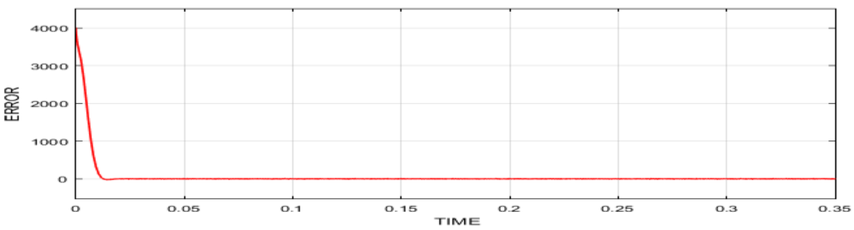

Fig 15 Speed error of PMSM drive using PI controller.

As it is field oriented control D=0, the direct axis waveform is towards the negative axis, and Alpha beta current responses, rotor position (theta), and the error between actual and reference speed are illustrated in Fig 12 13 14 15.

Using FLC

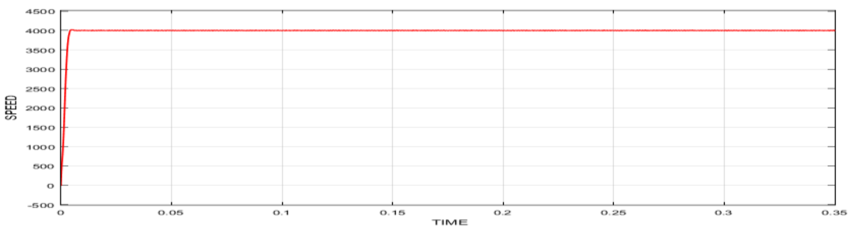

Fig 16 Actual Speeds using FLC.

As can be observed in Fig 16, the responsiveness of the Fuzzy logic controller is good, as the rising and settling times are faster than the PI controller, and there is no peak overshoot. Tl = 3.2 N-M is the load applied, and the reference speed is 4000rpm. It takes a certain amount of time to reach a stable state.

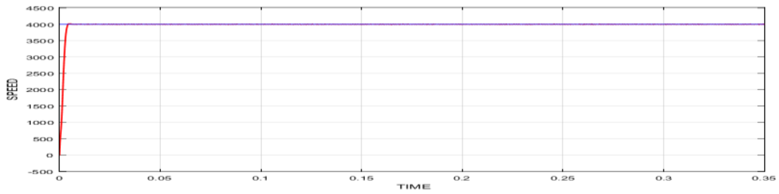

Fig 17 Actual Speed and Reference speed using FLC.

Fig 17 depicts a comparison of both speeds. As can be observed, the FLC controller has less inaccuracy than the PI controller.

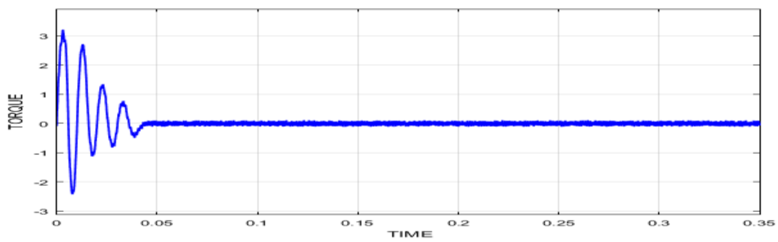

Fig 18 Electromagnetic Torque using FLC.

The electromechanical torque response for the FLC controller is shown in Fig 18. Because torque and speed are inversely connected, when the torque is lowered to zero, the speed reaches steady state. When compared to a PI controller, the torque response of the FLC is better since the PI controller has more disturbances to attain zero, whereas the FLC has fewer.

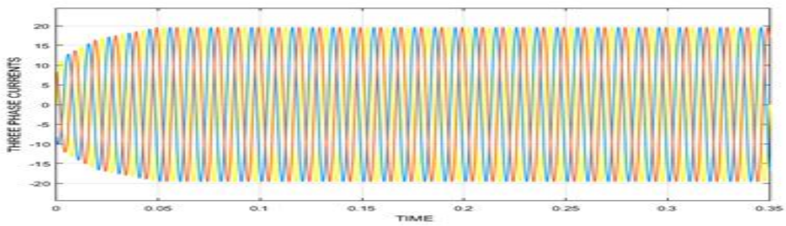

Fig 19 Iabc Currents using FLC.

The three phase currents of the PMSM are shown in Fig 19 utilizing a fuzzy logic controller. It performs better than a PI controller.

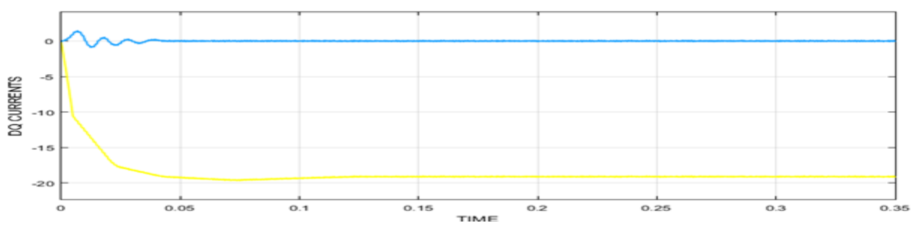

Fig 20 Idq Currents using FLC.

Fig 20 depicts the FLC's direct and quadrature axis currents, which show that it has a better reaction than the PI controller.

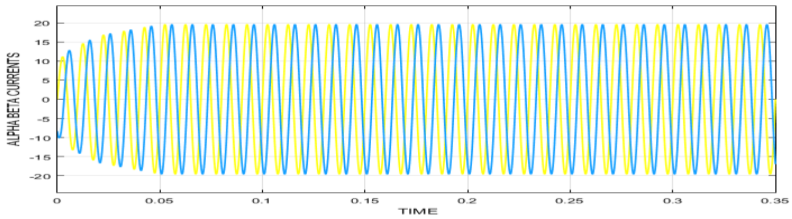

Fig 21 Alpha Beta Currents using FLC.

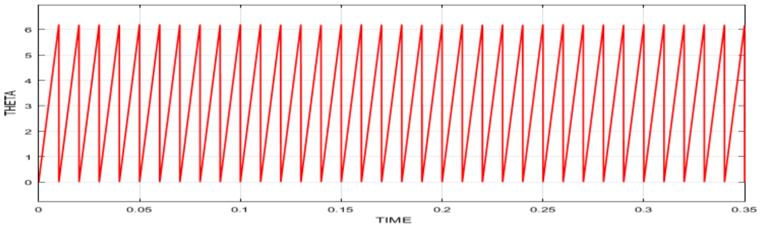

Fig 22 Rotor position using FLC.

Fig 21 22 depicts alpha and beta currents utilizing FLC, as well as the rotor position (theta) in relation to speed.

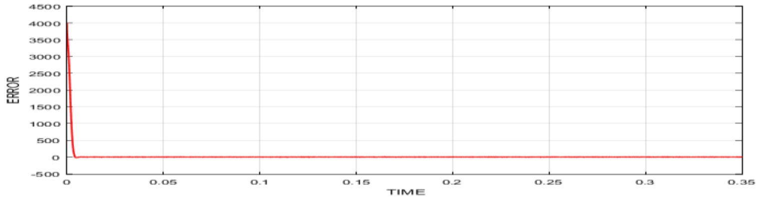

Fig 23 Speed error of PMSM drive using FLC.

Fig 23 displays the FLC's speed error, which is lower than that of the PI controller.

Table 3 Comparison of results for PI and Fuzzy logic controller.

S.NO	RESPONSE	PI controller	Fuzzy Logic controller
1	Rise Time(tr)	0.010sec	0.0050sec
2	Settling Time (ts)	0.025sec	0.012sec
3	Delay Time(td)	0.0075sec	0.0025sec
4	Peak over shoot	11.63%	4.5%
5	Torque ripples	Very low	Very very low
6	Steady state error	Very low	v.very low

IX. CONCLUSION

The Field oriented control-PMSM based SVPWM inverter using MRAS are studied. In MATLAB/SIMULINK, the entire drive system is modeled and simulated. Beginning with motor equations, the PMSM model was developed, as was the Space vector PWM model, which included some mathematical analysis such as switching sectors and time instants, as well as the MRAS model, which included some mathematical equations, 2-level inverter, Parks transformation, PI, and Fuzzy logic controller. The results of PI Control as a speed control are unsatisfactory due to high torque ripples, a long response time, and a longer time to settle down, as well as a high peak overshoots. Fuzzy logic controllers are a great way to solve these problems because they not only have a lot of advantages in terms of modifying the time, complex, and nonlinear systems, but they also don't require any mathematic analysis. FLC has a faster response time, takes less time to settle down, and has a very low peak overshoot. Due to the inaccuracy created by the speed, the suggested Sensorless FOC of PMSM Drive is steady and has good accuracy, and torque ripples are very low in FLC.

REFERENCES

[1] P. Nagasekhar Reddy "Modelling and Simulation of Space Vector Pulse Width Modulation based Permanent Magnet Synchronous Motor Drive using MRAS" International Journal of Science and Modern Engineering (IJISME) ISSN: 2319-6386, Volume-1, Issue-9, August 2013.

[2] Dr. Majid K. Al-Khatat, Ghphran Taha Ahmed Abd "Study and Comparison The Performance of Sensorless Control of PMSM Drive System" Eng. &Tech.Journal, Vol. 32, Part (A), No.10, 2014.

[3] T. Sebastian, G. Salmon, and M. Rahman, "Modelling of permanent magnet synchronous motors," Magnetics, IEEE Transactions on, vol. 22, pp. 1069-1071, 1986.

[4] T. M. Jahns, G. B.Kliman, and T. W. Neumann, "Interior Permanent-Magnet Synchronous Motors for Adjustable-Speed Drives," Industrial Applications, IEEE Transactions on, vol. IA-22, pp. 738-746, 1986.

[5] P. Pillay and R. Krishnan, "Modeling of permanent magnet motor drives," Industrial Electronics, IEEE Transactions on, vol. 35, pp. 537-541, 1988. [4] P. Pillay and R. Krishnan, "Modeling, simulation, and analysis of permanent-magnet motor drives. I. The permanent-magnet synchronous motor drive," Industry Applications, IEEE Transactions on, vol. 25, pp. 265-273, 1989.

[6] S. Ozçira, N. Bekiroglu, E. Ayçiçek "Speed control of permanent magnet synchronous motor based on direct torque control method", IEEE/ISPE, pp.268-272,2008.

[7] A. H. Wijenayake and P. B. Schmidt, "Modeling and analysis of permanent magnet synchronous motor by taking saturation and core loss into account," International Conference on Power Electronics and Drive Systems, (Volume:2) 1997.

[8] Sen, P. C. Electric motor drives and control-past, present, and future[J], IEEE Transactions on Industrial Electronics, 1990,37(1),562–575.

[9] B. Cui, J. Zhou, and Z. Ren, "Modeling and simulation of permanent magnet synchronous motor drives," 2001.

[10] Tzann-Shin Lee, Chih-Hong Lin, Faa-Jeng Lin. An adaptive H controller design for permanent magnet synchronous motor drives[J], Control Engineering Practice,2005,13 (4): 425-439.

[11] Ibrahim, E.Levi; An experimental investigation of fuzzy logic speed control in permanent magnet synchronous motor drives, European Power Electronics and Drives Journal, vol. 12, no. 2, 2002, pp. 37-42.

[12] PETROVIC, V.—ORTEGA, R.—STANKOVIC, A. M.—TADMOR, G. : Design and Implementation of an Adaptive Controller for Torque Ripple Minimization in PM Synchronous Motors, IEEE Trans. on Power Ele