PERFORMANCE ANALYSIS OF DIRECT TORQUE CONTROLLED PMSM DRIVES USING FUZZY LOGIC

P.Thamizhazhagan **Dr.S.Sutha**
Assistant professor, University College of engineering, Panruti, Tamilnadu, India
Assistant Professor [SG], University College of engineering, Dindigul, Tamilnadu, India
thamizhme@gmail.com

Abstract: *Permanent Magnet Synchronous Machines (PMSM) has been utilized as a part of various particular applications. In any case, lately PMSMs have turned out to be more alluring because of improvements in new materials for permanent magnets and in semiconductor innovation for converter design. Late examinations have proposed a few executions applying the Direct Torque Control (DTC) procedure to PMSM engine drives, offering a quick and exact control. This paper exhibits an altered DTC conspire, utilizing fuzzy rationale with Pulse Wide Modulation (PWM) to enhance stator flux and the electric torque by fundamentally decreasing their ripple. The proposed strategy viability has been confirmed by MATLAB Simulation reproductions. These outcomes are contrasted and the ones got with an adjusted DTC utilizing a PI controlled PWM with current limit*

Keywords: *PMSM, DTC, PWM, fuzzy logic.*

1. INTRODUCTION

Amid the most recent decade, the utilization of PMSMs has been relentlessly developing in modern applications, supplanting DC and Induction machines. The important focal points of these machines are their low latency and high effectiveness, power density and unwavering quality. Also, PMSMs are perfect for applications where quick and precise torque control is required.

The utilization of space vectors and field arranged changes has been altogether produced for applications requiring quick dynamical reaction [1-3]. The primary restrictions of these methods are because of the change reliance upon machine demonstrate parameters and the requirement for a rotor position sensor, expanding the framework cost. The utilization of DTC in PMSMs was proposed in the late nineties [3-5]. DTC [5-6] enhances the machine controller execution and decreases the impact of parameter variety amid its operation, utilizations of an inverter connect exchanging table that sets the converter yield contingent upon the flux/torque errors and flux point. The blast conduct delivered by the set number of states accessible in the inverter connect (just seven distinct states) creates an unmistakable electrical ripple torque. To tackle this issue, in this paper a space vector PWM-DTC with fuzzy control is proposed to create an impact proportional to the incorporation of extra states in the inverter connect. This is accomplished by modifying the subsequent amplitude of the stator voltage. The aftereffects of the proposed fuzzy DTC technique are contrasted and the ones got utilizing a standard DTC with on-off current confinement, and with a changed DTC utilizing a PI controlled PWM with current limit.

2. MODELLING OF PMSM

The voltage conditions portray the execution of Induction and synchronous machines. The co-efficient of the differential conditions that depict the conduct of these machines are time fluctuating with the exception of when the rotor is slowed down A change of variable is regularly used to decrease the multifaceted nature of these differential conditions. This general change alludes machine factors to a frame of reference that pivots at a discretionary angular velocity. Genuine changes are acquired from this change by just doling out the speed of the revolution of the reference frame.

$$\psi_d = L_d i_d + \psi_f$$

$$\psi_q = L_q i_q$$

$$u_d = R_s i_d + \frac{d\psi_d}{dt} - \omega_r \psi_q$$

$$u_q = R_s i_q + \frac{d\psi_q}{dt} - \omega_r \psi_d$$

$$T_e = \frac{3}{2} n_p (\psi_d i_q - \psi_q i_d) \qquad (١)$$

Where

ψ_d, ψ_q = Stator, Rotor flux in dq frame

ψ_f = stator back EMF constant

L_d, L_q = inductances

ω_r =Rotor Speed

R_s =Stator Resistance

n_p =no. of poles

i_d, i_q =Stator current vector in dq frame

T_e =Electro-magnetic torque

T_m =Motor load torque.

The equation of dynamics of the motor:

$$T_e - T_m = J \frac{d\omega_r}{dt} + B\omega_r$$

$$\psi_\alpha = \int (u_\alpha - R_s i_\alpha) dt$$

$$\psi_\beta = \int (u_\beta - R_s i_\beta) dt$$

$$T_e = \frac{3}{2} n_p (\psi_\alpha i_\beta - \psi_\beta i_\alpha)$$

$$T_e = \frac{3}{2} n_p (\psi_s * i_s)$$

$$T_e = \frac{3}{2} n_p (|\psi_s| * i_{sqc}) \qquad (٢)$$

In DTC, the ideal voltage space vector for the whole exchanging period controls the torque and flux autonomously and the hysteresis band keeps up the blunders. Just a single vector is connected for the whole examining period, in the traditional technique. Along these lines, for little blunders, the upper or lower torque farthest point might be surpassed by the motor torque. Rather, the torque ripple can be decreased by utilizing more than one vector inside the inspecting time frame. The inclusion of zero vector definitely controls the slip frequency [8]. For a littler hysteresis band, the frequency of operation of the PWM inverter could be high. The width of the hysteresis band causes variety in the switching frequency.

Direct torque control in view of space vector modulation preserves DTC transient benefits, moreover, deliver better quality steady state execution in a wide speed extend. At every cycle period, SVM strategy is utilized to acquire the reference voltage space vector to precisely compensate the flux and torque errors. The torque ripple of DTC-SVM in low speed can be expressively improved.

3. DTC-SVM CONTROL STRATEGY

In traditional DTC, a solitary stator voltage vector of the inverter standard topology is chosen amid each control examining period, and it is kept up steady for the entire time frame. By this switching system, in light of hysteresis, huge and little torque is not separated, which causes an additional torque ripple in motor steady state operation. In the proposed control conspire, a reference stator voltage space vector is figured. This is done in every inspecting period by legitimately selecting the switch conditions of the inverter and the count of the appropriate time and period for every state. The coordinate change from the a-b-c axis to the x-y pivot is given by

$$\begin{pmatrix} u_x \\ u_y \end{pmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix}$$

$$u_x = \frac{2}{3} \left[v_a - 0.5(v_b + v_c) \right]$$

$$u_y = \frac{\sqrt{3}}{3} \left(v_b + v_c \right) \qquad (٣)$$

The space vector representation as

$$u(t) = v_m e^{j\omega t} \qquad (٤)$$

Which is a vector of magnitude v_m rotating at a constant speed in ω radian per second. Utilizing the three stage to two stage change and the line voltage as the reference, the α-β parts of the rms yield voltage can be communicated as the elements of q_1, q_2, q_3. On the off chance that the yield voltages are absolutely sinusoidal, then the execution vector U gets to be $U^* = Me^{jwt}$ Where M is the modulation index (0<M<1)for controlling the amplitude of the yield voltage and is the yield frequency in radian every second

$$\begin{pmatrix} v_{l\alpha} \\ v_{l\beta} \end{pmatrix} = \frac{2}{3}\sqrt{\frac{3}{2}}v_s \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{pmatrix} q_1 \\ q_2 \\ q_3 \end{pmatrix} \qquad (٥)$$

4. FUZZY DIRECT TORQUE CONTROL

At first every machine is working with zero input torque with the excitation held settled at the esteem that gives rated open-circuit terminal voltage at synchronous speed. The rotor speed starts to increment promptly taking after the progression increment in input torque, where upon the rotor edge increments. The rotor accelerate until the accelerating torque on the rotor is zero. The rotor point is the relocation of the rotor by and large referenced to the most extreme positive estimation of the fundamental components of the terminal voltage of phase a. Accordingly, the rotor angle expressed in radians is $\delta=\theta_r-\theta_{ev}$. Even however the accelerating torque is zero right now, the rotor is running above synchronous speed, subsequently δ and consequently Te will keep on increasing. The increase in Te, which is an increase in the power yield of the machine make them rotor decelerate towards synchronous speed. However when synchronous speed is achieved, the size of rotor angle has ended up bigger than should be expected to satisfy the input torque. Thus, the rotor keeps on decelerating underneath synchronous speed and therefore load angle starts to lessening, which thusly diminishes Te. Damped motions of the machine variable proceed, and another steady state working point is at long last achieved.

Amid start up, high torque ripple and ease back transient response to the progression changes in torque are the normal hindrances of routine DTC [7-8]. The change of torque execution can be brought out by the improvement of a few strategies.

The stator flux amplitude and the electro-magnetic torque error, through the fuzzy rationale controllers, are utilized by the proposed fuzzy DTC conspire. This is to create a voltage space vector by following up on both the amplitude and the angle of its parts which is utilized by a space vector modulation to produce the inverter switching states.

5. DESIGN OF FUZZY LOGIC CONTROLLER

The numerical apparatus for the FLC is the Fuzzy set hypothesis presented by Zadeh. When contrasted with the MTPA (Maximum Torque per Ampere) and their versatile adaptations the FLC has a few favorable circumstances, for example, it needn't bother with any correct framework scientific model, it can took care of nonlinearity of discretionary many-sided quality, it depends on the semantic principles with an IF-THEN broad structure, which is the premise of human rationale.

The fuzzy rationale can be considered as a hypothesis which is mix of multi-esteemed rationale, likelihood, and manmade brainpower which mimic the human approach for the arrangement of numerous issues by the utilization of a surmised thinking [9]

Fuzzy logic control comprises of fuzzification process, linguistic rule base, and Defuzzification process. The input variables for fuzzy logic controller are speed error and change of speed error .The speed is fed to the fuzzy speed estimator. The speed error and change in speed error are defined as

$$e(k) = \omega(k)^* - \omega(k)$$
$$\Delta e(k) = e(k) - e(k-1) \qquad (٦)$$

The two input variables are e(k), Δe(k) and output variable e T are divided into different fuzzy segments shown in fig respectively.

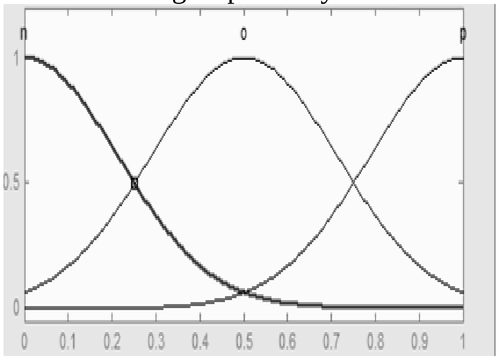

Fig. 1. Input error in speed.

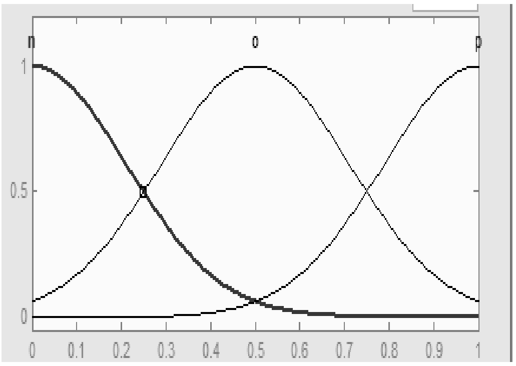

Fig. 2. Change in error in speed.

5.1 Membership Functions

The FLC converts the crisp error and change in error into fuzzy variables and maps them to linguistic labels. Membership functions are linked with each label which comprises of 2 inputs and 1 output.

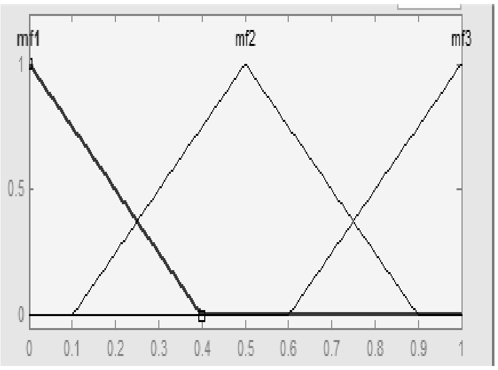

Fig. 3. Output variable Membership Function.

5.2 Knowledge base rule table

The mapping of the inputs into the required output is derived by the help of a rule base .Each rule of the FLC has an IF part, known as antecedent, and a THEN part popularly the consequent

Error/change in error	N	O	P
N	MF(1)	MF(3)	MF(3)
O	MF(2)	MF(2)	MF(1)
P	MF(1)	MF(1)	MF(3)

Table 1. Knowledge base rule table

In these run the show,

On the off chance that error will be N &change in mistake will be N, THEN Membership function (1) in yield. In the event that error will be O and change in error will be O, THEN Membership function (2) in yield. In the event that error will be P &change in error will be P, THEN Membership function (3) in yield. On the off chance that mistake will be N &change in error will be O, THEN Membership function (3) in yield. On the off chance that error will be N &change in mistake will be P, THEN Membership function (3) in yield. In the event that error will be O &change in mistake will be N, THEN Membership function (2) in yield. On the off chance that mistake will be O &change in error will be P, THEN Membership function (1) in yield. On the off chance that blunder will be P &change in mistake will be O, THEN Membership function (1) in yield. In the event that blunder will be P &change in mistake will be N, THEN Membership function (1) in yield.

5.3 Defuzzification

Normally the output is fuzzy in nature and hence is converted back into a crisp by the use of Defuzzification technique

6. SIMULATION RESULTS AND DISCUSSION

The nature of an inverter is ordinarily assessed regarding the execution parameters like harmonic element, Total harmonic distortion (THD), the above parameters gives the total Harmonic content, yet it doesn't show the level of every harmonic component. A recreation work has been completed on a permanent magnet synchronous machine, to demonstrate the viability of the fuzzy DTC technique. The proposed plan is recreated with MATLAB/SIMULINK

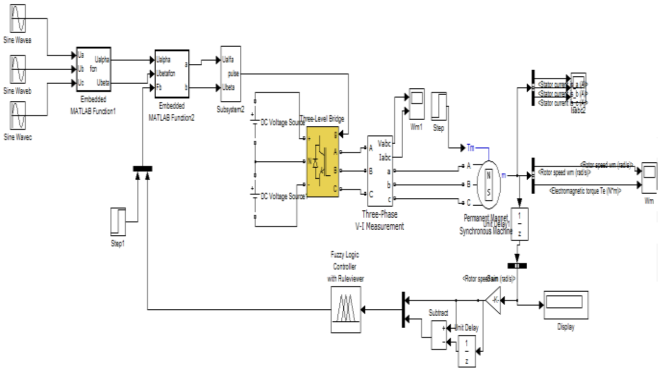

Fig. 4. Schematic block diagram of fuzzy based DTC.

6.1 Output of Fuzzy Based DTC Control

Figure 5 shows the performance characteristics of PMSM when a constant load torque of 0.8N-m and reference speed of 900rpm is given to the system. The system being stable achieves the required values and also reduce torque and flux error. Figure 6 shows the characteristics of PMSM stator current, when a constant load torque of 0.8N-m and reference speed of 900rpm is given to the system. Figure 6 shows the characteristics of PMSM Speed waveform, when a constant load torque of 0.8N-m and reference speed of 900rpm is given to the system.

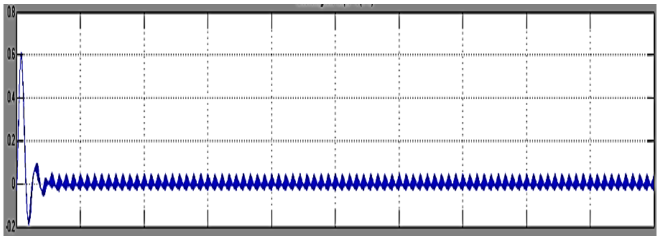

Fig. 5. Torque waveform for Fuzzy based DTC

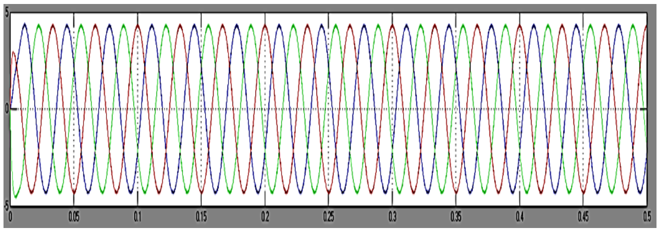

Fig. 6. Stator currents for fuzzy based DTC

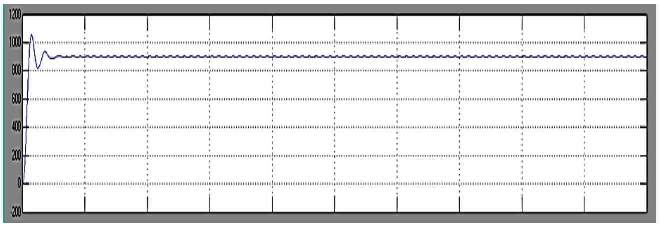

Fig.7. Speed Waveform for fuzzy based DTC

6.2 Simulation Results of SVPWM-DTC

The Simulation results for the Conventional SVPWM DTC with a constant load of 0.8 N m and a reference speed of 900 rpm is shown. Figure 8 and 9 are the Torque and Stator Currents for the SVPWM DTC Method.

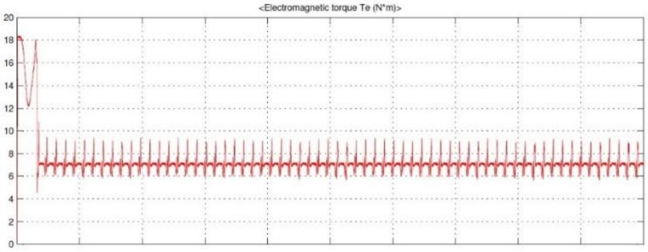

Fig. 8. Torque output of Conventional SVPWM DTC

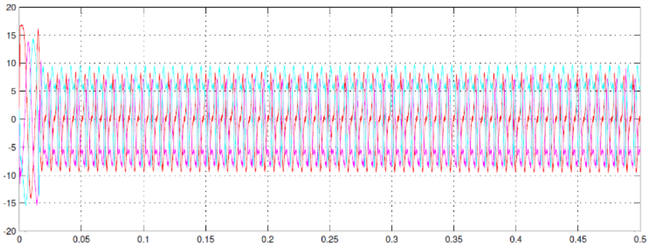

Fig. 9. Stator currents for Conventional SVPWM DTC

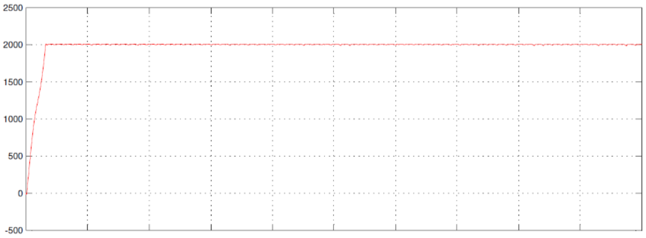

Fig. 10. Speed for Conventional SVPWM DTC

6.3 Simulation Result Analysis

The behavior of the PMSM with conventional and fuzzy method are illustrated in fig.5 to Fig.10. The motor operate at a speed of 900 rpm. By comparing the two figures, the torque ripple is reduced nearly 80 % by using the proposed method. Similarly the THD is also reduced to a considerable amount. The torque and speed response for conventional DTC is shown in the fig.8 and Fig 10. Here the torque response has more distortion and it settled down at around 0.027sec and the speed response is at 0.022sec. And the result of Fuzzy DTC-SVM control method is shown in fig.5, Fig.6, fig.7. Here the torque response has lesser distortion and it settled down at 0.012sec and the speed response is at 0.013sec.The THD is 31.08%. The settling time is reduced by approximately 50%.The simulation results show that the proposed DTC has less torque ripple, and reduced THD while maintaining a good torque response s compared to the normal DTC method.

7. CONCLUSION

In this control method, fuzzy controller scheme has been developed for the permanent magnet drive system. Here, a SVPWM inverter is used to feed the motor, the stator flux and torque errors are fully compensated by the obtained stator voltage vector. The stator flux amplitude and the electro-magnetic torque errors, through the fuzzy logic controller, are used by the proposed method to generate a voltage space vector by acting on both the amplitude and the angle of its components, which is used by a space vector modulation to provide the inverter switching states. The torque ripple is smaller than that of the conventional DTC. Comparisons through simulations with conventional DTC have been carried out The results show that the torque and flux ripples are drastically reduced by the proposed DTC, while still one of the main characteristics of the performance of DTC method have a good dynamic torque response .

REFERENCES

1. Z.Zhang and R.Tang , *Novel Direct Torque Control Based on Space Vector Modulation with Adaptive stator Flux Observer for induction motors*, IEEE Transactions on Magnetics., vol.46,no.8,pp.3133- 3137,2010.

2. L.Zhong, and M.F.Rahman, A *Direct Torque controller for permanent magnet synchronous motor drives* IEEE Trans.Energy conversion.,vol 14, pp.637-642,1999

3. I. Takahasi and T. Noguchi, A *new quick-response and high efficiency control strategy of an induction motor*, IEEE Transaction on Industrial Application Volume IA-22, no.5, pp.820-827, 1986.

4. X.Qu, J.Zhu and H. Mao, *Neural network Based Fuzzy Sliding Mode Direct Torque Control of PMSM*, In: Proceedings of IEEE conference, vol.2, pp.13-17,2010.

5. G. Buja and M.P .Kazmierkowski, *DTC of PWM inverter fed AC motors-A survey*, IEEE Transactions on Industrial Elect Vol.51, no.4, pp.744- 757, 2004.

6. A. Gupta, A.M. Khambadkone, *A Space Vector PWM Scheme for Multi-level inverters based on two level space vector PWM*, IEEE Transactions on Industrial Electronics,Vol.53,no.5,pp. 1631-1639, 2006.

7. Do-Hyun Jang, Duck-Yong Yoon, *Space Vector PWM technique for two phase inverter fed two phase induction motor*, IEEE. Transactions on Industrial Applications vol.39, No.2, pp. 542-549, 2003.

8. D. Casadei and G. Serra, *Implementation of a Direct Torque Control Algorithm for Induction Motors based on Discrete Space Vector Modulation* , IEEE. Transactions on Power electronics. vol.15, no.4, pp.769-777, 2000.

9. F. Zidani and R.N. Said, *Direct Torque Control of induction motor with Fuzzy minimization torque ripple*, Journal of Electrical Engineering, vol.56, no.7-8, pp.183-188, 2005.

10. G.S. Buja and M.P. Kazmierkowski, *Direct torque control of PWM inverter-fed AC motors-A Survey*, IEEE Transactions on Industrial Applications, Vol.51, No.4, pp.744-757, 2002.