JOURNAL OF AL-QADISIYAH FOR
ENGINEERING SCIENCE

Vol. 11, No.3
ISSN: 1998-4456

SPEED CONTROL OF DTC-SVM FOR INDUCTION MOTOR DRIVE USING SELF-TUNING FUZZY PI CONTROLLER ANN ANFIS

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Abstract: This paper deals with the performance analysis of three phase Induction Motor (IM) with Direct Torque Control based Space Vector Modulation (DTC-SVM). The DTC-SVM scheme is a kind of high-performance control of IM drives to improve the ripples of torque and flux in steady state, which one drawback of conventional DTC. DTC-SVM has three Proportional-Integral (PI) controllers, one used as the PI speed controller and other PI flux controller and PI torque controller, which are utilized to produce the stator voltage references (V_{ds} and V_{qs}) respectively. To improve the performance of motor we used the Self-Tuning Fuzzy PI (STFPI) controller and Adaptive Neuro Fuzzy Inference System (ANFIS) controller instead of PI controllers in DTC-SVM. The simulation results carried out using MATLAB/Simulink software package show that the response of speed motor with ANFIS is improved, more robustness, and reaches to the reference value faster than a conventional PI controller and STFPI controller and also reduced the torque ripple and less steady state error.

Keywords: Induction Motor, DTC-SVM, PI Controller, Self Tuning Fuzzy PI Controller, ANFIS.

INTRODUCTION

This Induction Motors (IMs) are broadly utilized, particularly poly phase IMs, which are commonly utilized in industrial drives. IMs are now the favorite option for industrial motors in accordance with their robust building, nonexistence of brushes and thanks to modern power electronics that are able to the control of the motor speed [1]. The IM control was treated with different techniques. This contains simple linear techniques for example Direct Torque Control (DTC), Field Oriented Control (FOC) and more complicated nonlinear techniques for example input-output linearization back stepping, sliding mode and passivity. Most of the suggested controllers utilize the speed sensor and require the constant the motor parameters. This hypothesis leads to poor control performances, particularly through transient operation. The common of these controls require utilization of coordinate transformation, whereas DTC approach can be utilized to directily control for flux and torque without current controllers [2]. The DTC method was first suggested for IM. DTC method for medium and low power applications is presented by Takahashi and Noguchiand, while DTC method for high power applications is presented by Depenbrock and it is commonly utilized in industry [3]. Conventional DTC usages the magnitude errors of the stator flux and torque as the inputs for hysteresis comparators to determine the voltages of stator vector (V_{qs} and V_{ds}) are applied to terminals of the motor. The complex plane is divided into 6-sectors, and a switching table is purposed to get the required vector based on the outputs of the hysteresis comparators [4]. The most common drawbacks of conventional DTC are a high ripple of torque and slow transient response to torque changes during startup. The performance of torque is improved by developed several techniques. One of the developed techniques utilized for reducing the ripples is DTC with Space Vector Modulation (SVM). SVM was first suggested by a researchers group from Germany in 1980s.

SVM techniques offer several benefits, including the torque ripple is less, better DC bus utilization, less losses of switching, minimum Total Harmonic Distortion (THD) in the AC motor current and easier implementation in digital systems [3]. In DTC-SVM approach, the PI controllers are utilized instead of the hysteresis comparators for torque and flux in conventional DTC. However, the main disadvantages of DTC-SVM with a simple PI controllers are the performance sensitivity to variations of the system parameters and the insufficient rejection load changing and external disturbances [5]. The disadvantages of the conventional PI controllers are performance sensitivity to covariance in parameters of the system, and the actuality that when utilizing fixed of the controller gains may not offer the required performance of speed under covariance in the operating conditions and parameters of the motor [6]. FLC can be utilized to eliminate the disadvantages of conventional PI controller [7]. FLC has demonstrated its effectiveness in non-linear, complex and inaccurate processes which it is impossible to utilize the standard model based control techniques impractically [8]. FLC based intelligent controller can be utilized instead of the PI controller. FLC has some advantages over conventional controllers such as simplicity of control, low cost, and the capability to design without knowledge the precise mathematical model of the plant [9]. FLC is utilized in the controller design autonomously or hybrid with PI controller. FLC provides faster control and superior but the major problem of design is to specify a consistent and complete set of rules and in the form of Membership Functions (MFs). A lot of trials and errors must be made to get the desired response that takes a long time [10]. The Artificial Neural Networks (ANNs) have the advantages of very fast parallel computation, impunity from input harmonic ripples and fault tolerance characteristics [11]. However, ANN only is inadequate if the training data are not adequate to deal with all the operating modes. The disadvantages of FLC and ANN can be eliminated by the usage of ANFIS [10]. ANFIS is a fuzzy scheme that usages a learning procedure resulting from the principle of ANN to know its parameters (fuzzy sets and rules) by dealing with data examples. By mingling both FLC and ANN, it is probable to obtain the benefits of together controls in one implementation [12]. There are several studies related to DTC_SVM and PI controller ,STFPI controller and ANFIS such as: In 2010 Fayez G. Areed, e.t al., suggested a direct torque of the IM drive controlled by ANFIS. The suggested control scheme employs amplitude of the stator flux and the torque errors by using an ANFIS to change the angle and the amplitude of the required reference voltage. The simulation outcomes by utilization ANFIS are compared with the conventional DTC. The comparison results of DTC with ANFIS showed a reduction in the ripples of torque and flux in transient and steady-state response and fast stator flux response in the transient state [13]. In 2013, Arun Kumar R, and Febin Daya J. L., compared between conventional PID, Fuzzy, and STFPID controllers based speed control system for a current source PWM inverter fed IFOC of IM Drives. In this study, the PI control system was substituted by STFPID based intelligent controller. The FLC uses various forms of Membership Functions (MFs) for all parameters in order to obtain an efficient controller. By comparing the results with the PID and FLC, these results showed that the suggested STFPID controller recognizes a good performance at the sudden variations with a quick settling time. As well, it has no overshoot and better behavior than FLC and PID controller [14]. In 2015, A. Durga Bhavani, et. al., presented an intelligent control scheme with ANFIS controller to regulate the speed of the DTC of IM drive. The performance of conventional DTC in IM drives containing PI controller has a complex tuning and overshoot. Therefore, this controller employs the error that obtained from the reference speed and estimated speed which produces the estimated torque and compared with the actual torque. The suggested ANFIS based IM drive is providing better performance and provide less THD in steady state current ripple when compared with conventional DTC algorithm [15]**.**

1. INDUCTION MOTOR MODELING

The equivalent circuit of the Squirrel Cage Induction Motor (SCIM) in $(d-q)$ axis is shown in Fig.1. The three phase voltage stator of an IM can be given by the following equations [16].

$$V_{a=}V_m \ \sin(\omega t) \tag{1}$$

$$V_{b=}V_m \ \sin\left(\omega t-\frac{2\pi}{3}\right) \tag{2}$$

$$V_{c=}V_m \ \sin\left(\omega t+\frac{2\pi}{3}\right) \tag{3}$$

These three phase balance voltages are transferred into the two phase stationary reference frame of $(d-q)$ axis. This can be given by Eq. (4) and Eq. (5).

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{4}$$

Then, the voltage in the $(d-q)$ axis

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{5}$$

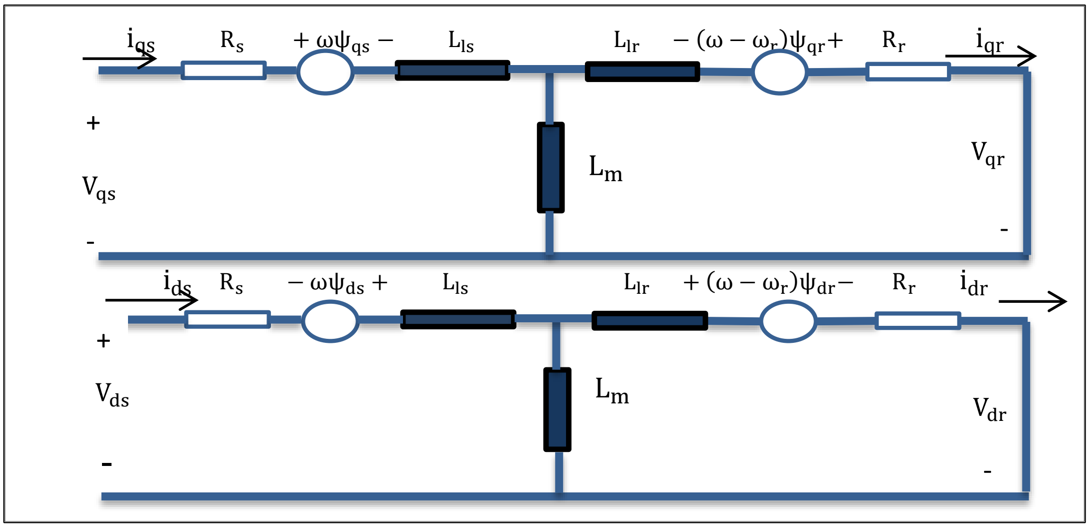


Figure 1 Equivalent Circuit of SCIM in $(d-q)$

The mathematical model of three- phase SCIM in the stationary reference frame $(d-q)$ can be given by the following Eqs. [17].

$$V_{ds} = (R_s + pL_s)i_{ds} + pL_m i_{dr} - \omega\psi_{ds} \tag{6}$$

$$V_{qs} = (R_s + pL_s)i_{qs} + \omega\psi_{qs} + pL_m i_{qr} \tag{7}$$

$$V_{dr} = 0 = (R_r + pL_r)i_{dr} + pL_m i_{ds} - (\omega-\omega_r)\psi_{dr} \tag{8}$$

$$V_{qr} = 0 = (R_r + pL_r)i_{qr} + (\omega-\omega_r)\psi_{qr} + pL_m i_{qs} \tag{9}$$

$$L_s = L_{ls}+L_m \quad \& \quad L_r = L_{lr}+L_m \tag{10}$$

Where ψ_{ds} , ψ_{qs} are the stator flux linkages in the $(d-q)$ frame in Eq.(11) and ψ_{dr} , ψ_{dr} are rotor flux linkages in the $(d-q)$ frame in Eq.(12) , while $p = d/dt$.

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \quad \& \quad \psi_{ds} = L_s i_{ds} + L_m i_{dr} \tag{11}$$

$$\psi_{qr} = L_r i_{qr}+L_m i_{qs} \quad \& \quad \psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{12}$$

The torque and speed can be determined as following equations [17,5]

$$T_{em} = \frac{3}{2}\frac{P}{2}L_m(i_{qs}i_{dr} - i_{ds}i_{qr}) \tag{13}$$

$$T_{em} = \frac{2}{P}Jp\omega_r + T_l \tag{14}$$

$$\frac{d\omega_r}{dt} = \frac{P}{2J}(T_{em} - T_l) \tag{15}$$

Where V_{ds} , V_{qs}, and V_{dr} , V_{qr} are the voltages for stator and rotor in the $(d-q)$ frame respectively, while R_s, R_r, ω_r, ω are stator resistance, rotor resistance ,rotor angular speed, and the electrical angular speed respectively. The stator, rotor and mutual inductance are L_s, L_r and L_m, respectively.

2. DIRECT TORQUE CONTROL WITH SPACE VECTOR MODULATION (DTC-SVM)

DTC usas the hysteresis band to directly control the torque and flux of the machine. The main benefits of DTC are the rapid response for torque and robust, no requisites for coordinate transformation no requisites for current regulators and PWM pulse generation. The main drawback of the DTC drive is the ripples of the flux and the torque in steady state. The torque and flux pulses impact the accuracy of the speed estimation. There are two approaches to reduce the ripples for flux and torque of the DTC drives. The first approach is multi-level inverter and the second approach is SVM. In the first approach, the complication and the cost will be rised while in the second approach the ripples of flux and torque can be decreased [4]. The suggested DTC-SVM system that is shown in the Fig. 2 has used three PI controllers for processing errors of speed, flux and torque. The torque reference (T_e^*) is generated by speed error, that it is processed through the PI speed controller ,while the PI flux controller and PI torque controller are producing the command voltages V_{ds} and V_{qs} respectively [18].

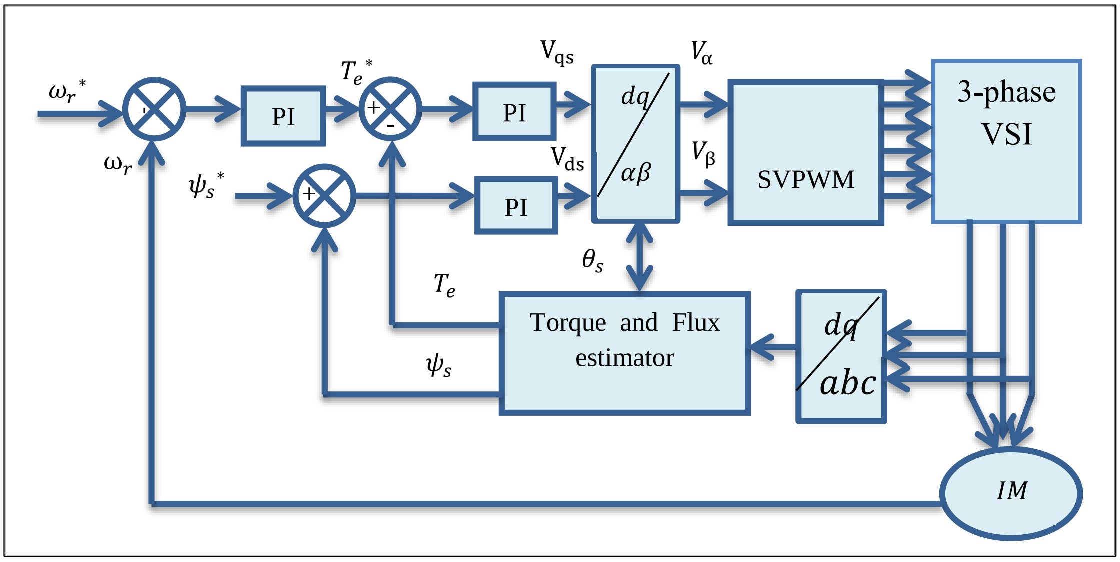


Figure 2 The suggested DTC_SVM with PI controller

The flux estimator model is dependent on stator resistance (R_s) only, the stator flux linkages ψ_{ds} and ψ_{qs} can be determined from Eq.(16) and Eq.(17) respectively, while the magnitude of the stator flux linkage ψ_s and the phase angle of the stator flux linkage θ_s are given in Eq.(18) and Eq.(19) respectively [19].

$$\psi_{ds} = \int (V_{ds} - i_{ds}R_s)dt \quad (16)$$

$$\psi_{qs} = \int (V_{qs} - i_{qs}R_s)dt \quad (17)$$

$$\psi_s = \sqrt{\psi_{ds}{}^2 + \psi_{qs}{}^2} \quad (18)$$

$$\theta_s = \tan^{-1}\frac{\psi_{qs}}{\psi_{ds}} \quad (19)$$

3. PI CONTROLLER

Proportional-Integral (PI) controller is easy to design, simple structure and low cost. It is most broadly utilized in industrial application because of these benefits for PI controller. The output signal of PI controller consists of a sum of errors and the integral of that errors [7].

The transfer function for PI controller is given by Eq.(20)

$$\frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} \quad (20)$$

where: K_p & K_i are the proportional and the integral gains respectively, U(s) is the output control signal which represents torque reference $(T_e{}^*)$ in DTC-SVM drive and $E(s)$ is the error which represents the difference among the desired and the actual of motor speed and it is specified by Eq.(21)

$$E = \omega_r{}^* - \omega_r \tag{21}$$

The proportional controller will decrease the steady-state error and rise time. But, will never remove the error. The integral control will decrease the error close to zero. But, it has a negative effect on the response of the speed and overall stability of the system [20].

4. SELF-TUNING FUZZY PI (STFPI) CONTROLLER

The STFPI controller is a mixture from the concept of fuzzy logic and the conventional PI controller [20]. FLC utilized to tune the parameters of the PI controller; it gets scaled values of the error (E) and change of error (dE/dt). Its output is updating the parameters of PI controller based on a set of rules to keep good control performance even in the existence of drive non-linearity and variation of parameters. [13,14]. The FLC is comprised of four main stages: Fuzzification, knowledge base, decision making and defuzzification as demonstrated in Fig.3 [21]. Fuzzy model is a collection of if – then rules with indistinguishable predicates that use a fuzzy reasoning such as Mamdani and Sugeno models. Mamdani type systems can be utilized to model any inference system in which the output Membership Functions (MFs) are either linear or nonlinear whereas Sugeno type produces either linear or constant output [14].

The performance of STFPI controller can be shown as following [4].

1- Dynamically adjusts the PI controller parameters to guarantee the stability of system over the wide speed range.

2- Fast response of speed.

3- Small errors for steady state and less overshoot.

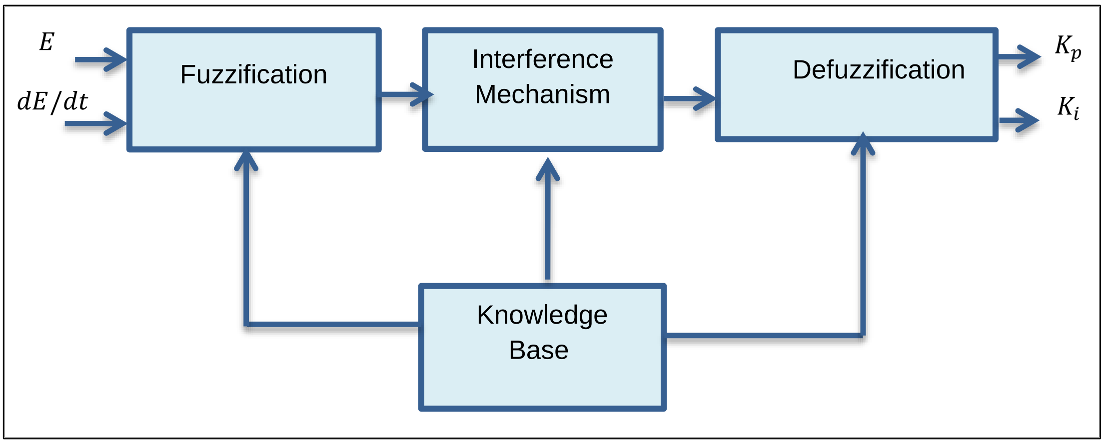


Figure 3 Block diagram of FLC

The fuzzy tuner has two inputs $(E \;\&\; dE/dt)$ and two outputs: K_{pf} a& K_{if}. The structure of STFPI controller is shown in the Fig.4.

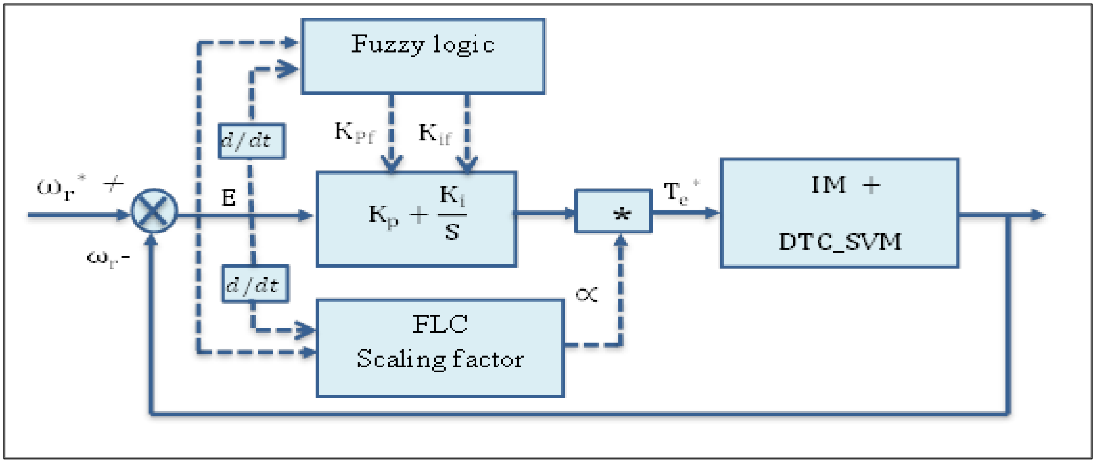


Figure 4 The structure of STFPI controller

The equations for the STFPI controller process are given below[21].

$$T_e^* = K_{pnew}\, E(t) + K_{inew} \int E(t)\ dt \tag{22}$$

$$K_{pnew} = \left(K_p + K_{pf}\right) * \propto \tag{23}$$

$$K_{inew} = (K_i + K_{if}) * \propto \tag{24}$$

Where: $\propto$ is the scaling factor is obtained from the FLC. K_{pf} & K_{if} are obtained from the FLC, while K_{pnew} & K_{inew} are the new gains of PI controller

5. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

ANFIS put forward by Jang in the early 90s, mixing the concepts of FLC and ANNs to form a hybrid intelligent system that improves the capability to learn and adapt automatically [8]. ANFIS is one of the best reciprocating among ANN and FLC, which provides the adaptability and interpolation in accordance with the ANN and smooth control in accordance with the FLC. Some of the benefits of ANFIS are compactness of model, they require a faster convergence and less size of training set than typical feed forward neural network. The non-linear cartographical in a ANFIS is obtained by utilizing a fuzzy MF based ANN [10]. The ANFIS is an adaptive network multilayer in Fig.5. There are two different types of nodes according to their features: square (adaptive) nodes and circular nodes. The first type contains parameters, while the second type has no paramters [22]. The Fuzzy Inference System (FIS) usually utilized in ANFIS is first order Sugeno fuzzy model due to its easiness, efficiency of computational and built-in optimization techniques and adaptation [23]. The Sugeno FIS is like to Mamadani format but that the output MFs are singleton spikes instead of a distributed fuzzy set. Utilization singleton output simplifies the defuzziflation step [24].

ANFIS system uses the following rule base [23].

$$\text{If } x \text{ is } A_1 \text{ and } y \text{ is } B_1 \text{ then } f_1 = f_1(x,y) = a_1x + b_1y + r_1 \tag{25}$$
$$\text{If } x \text{ is } A_2 \text{ and } y \text{ is } B_2 \text{ then } f_2 = f_1(x,y) = a_2x + b_2y + r_2 \tag{26}$$

$$f = \frac{w_1f_1 + w_2f_2}{w_1 + w_2} = \overline{w}_1f_1 + \overline{w}_2f_2 \tag{27}$$

Where A_i and B_i are linguistic variables, while a_i , $b_i$and r_i are constants

The ANFIS comprises five layers; the functions of these layers can be listed below [25].

Layer1: Every node of this layer transforms the input signal x or y utilizing MF (fuzzification). The most commonly utilized MF is a bell-shaped or Gaussian function.

Layer2 : Each node of this layer, discriminated as Π, performs the intersection of the input signals, simulates a logical AND operation, and sends a value to the output:

$$w_i = \mu_{Ai}(x).\mu_{Bi}(y)\ ;i = 1,2 \qquad (28)$$

Essentially, every node specifies an activating rule force w_i. In actuality, any operator of T-norm, which summarizes the AND operation can be utilized in these nodes.

Layer3: Every node in this layer determines the weight of the normalized rules.

$$\overline{w}_i = \frac{w_i}{w_1+w_2};\ \ i = 1,2 \qquad (29)$$

Layer4: In this layer, nodes produce the output variables values:

$$O_i{}^4 = \overline{w}_i f_i = \overline{w}_i(a_i x + b_i y + r_i) \qquad (30)$$

Layer 5. In this layer is obtained the neural network output and carried out the defuzzification:

$$O_i{}^5 = \text{overall output} = \textstyle\sum_i \overline{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \qquad (31)$$

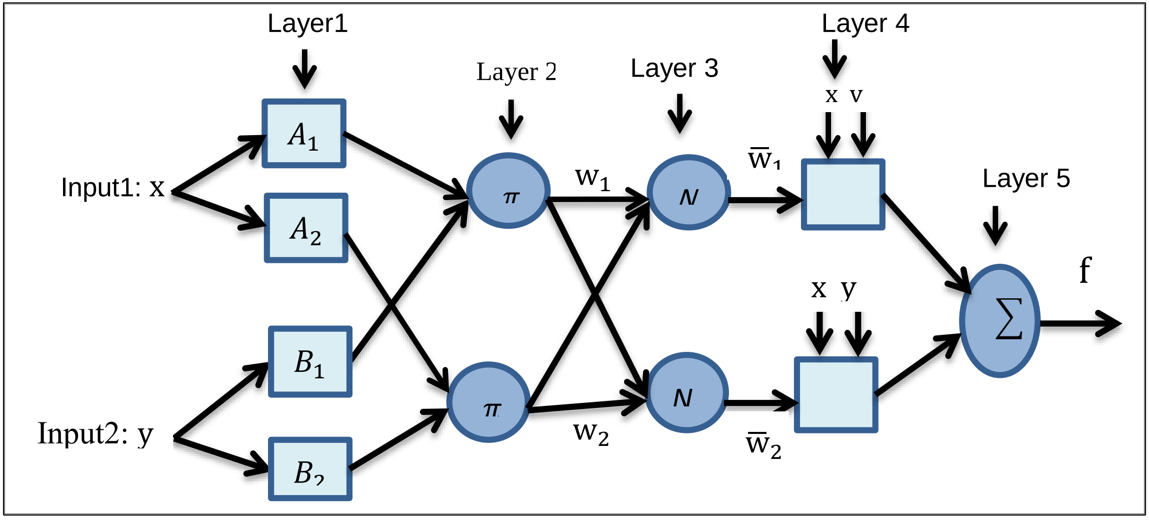


Figure 5 Input MF and outputs of proposed ANFIS controller

6. SIMULATION AND RESULT

Simulink implementation of the DTC-SVM for IM drive is shown in Fig. 6, it was carried out using MATLAB/SIMULINK software. The speed reference and stator flux reference value are 350 rad/sec and 0.476 Wb. respectively. The motor is unloaded at startup and the torque load (T_l) 8 Nm is applied at t 2s. The switching frequency of SVM is 10 kHz, while the paramters of IM are used in this paper as shown in table-1. The results of simulation show the comparison between the conventional PI controller (trial and error), STFPI controller and ANFIS based on DTC-SVM of IM drive. The Simulink model of DTC-SVM for IM drive in Fig. 6 is replacing all PI controllers by STFPI controllers. Three STFPI controllers are observing the pattern of the errors for speed , flux and the torque and correspondingly updates the outputs K_p and K_i .The structure of STFPI controller for speed, torque and flux is the same and shown in Fig. 7. MATLAB/Fuzzy Logic Toolbox is employed to simulate MF of FLC is choosing the triangular shape and No. of MFs are five for inputs and outputs as shown in Fig. 8, while the value of K_{pf} and K_{if} are calculated from a fuzzy rule base defined in function of the control (E and dE/dt) as shown in the table-2. The Centroid defuzzification method is employed here. The Simulink model of DTC-SVM for IM drive in Fig. 6 is replacing all PI controllers by ANFIS controllers to achieve precision speed control. The ANFIS controller produces one output such as the reference torque (T_e^*), V_{ds} or V_{qs} based on $(E$ and $dE/dt)$ for speed, torque and flux respectively. The ANFIS designed through the ANFIS editor, the grid partition is utilized to produce FIS when the hybrid method is used for optimization. In ANFIS controller utilized 25 if –then rules, Gaussian MF type and the number of training Epochs are used 2000 epochs. Result ANFIS turning is shown in Fig. 9. While Fig. 10 and Fig. 11 show that input MFs and ANFIS model structure respectively. Figure 12 to Fig. 15 show the response of speed and torque at various loaded when using conventional PI controller (trial and error), While Fig. 16 to Fig. 19 illustrate the simulation results of speed and torque under same load variation. The simulation results of the speed and torque at various load using ANFIS are given in Fig. 20 to Fig. 23. The results of simulation show that the ANFIS controller realizes a good response of motor speed to sudden changes without overshoot, a fast settling time, the settling time is 0.166 s while the settling time for STFPI controller and conventional PI controller are 0.33s and 0.46s respectively, less steady state error, less ripple in torque response and improved the performance of motor when compared with both PI and STFPI controllers.

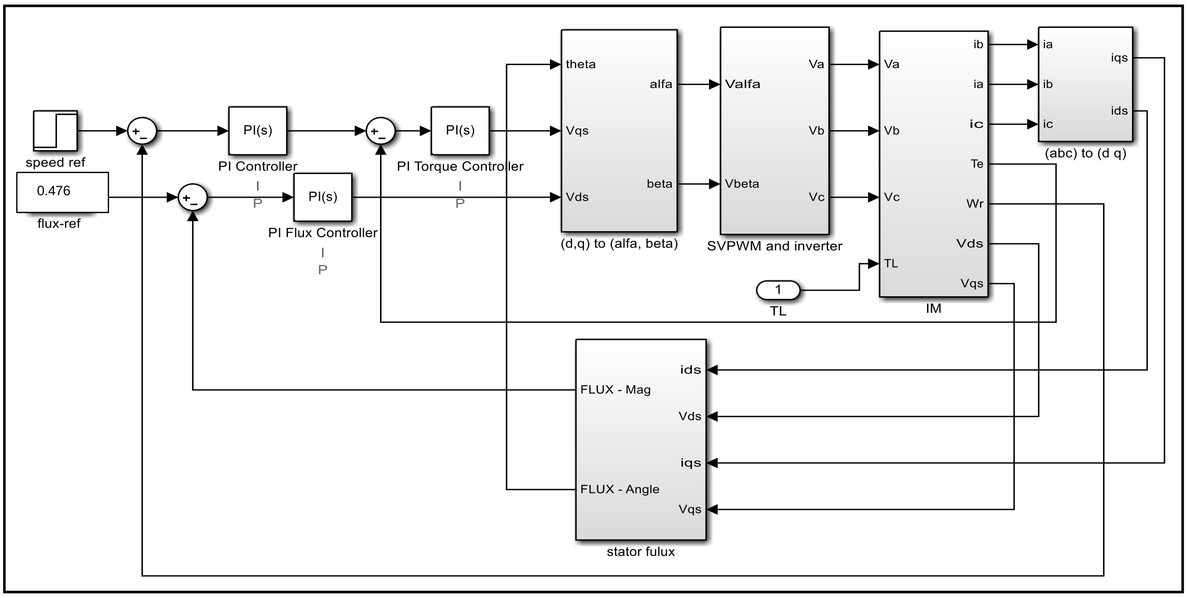


Figure 6 The Simulink model of the DTC_SVM for IM drive

Table-1 Parameters of IM

Parameter	Value
The power rating of IM	3 hp
Voltage applied	220 V
Frequency	60 Hz
No of poles(P)	4
Stator Resistance(R_s)	0.435 Ω
Rotor Resistance(R_r)	0.816 Ω
Stator leakage inductance(Ll_s)	0.002 H
Rotor leakage inductance(Ll_r)	0.002 H
Mutual inductance (L_m)	0.0693 H
Inertia moment (J)	0.089kg.m^2

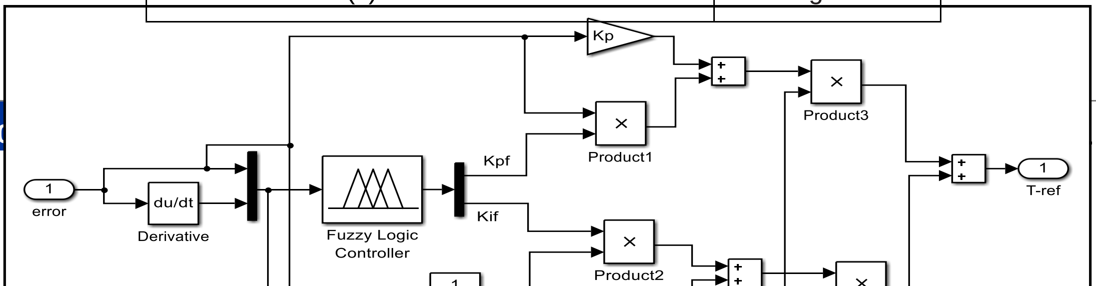


Figure 7 The Simulink model of STFPI controller

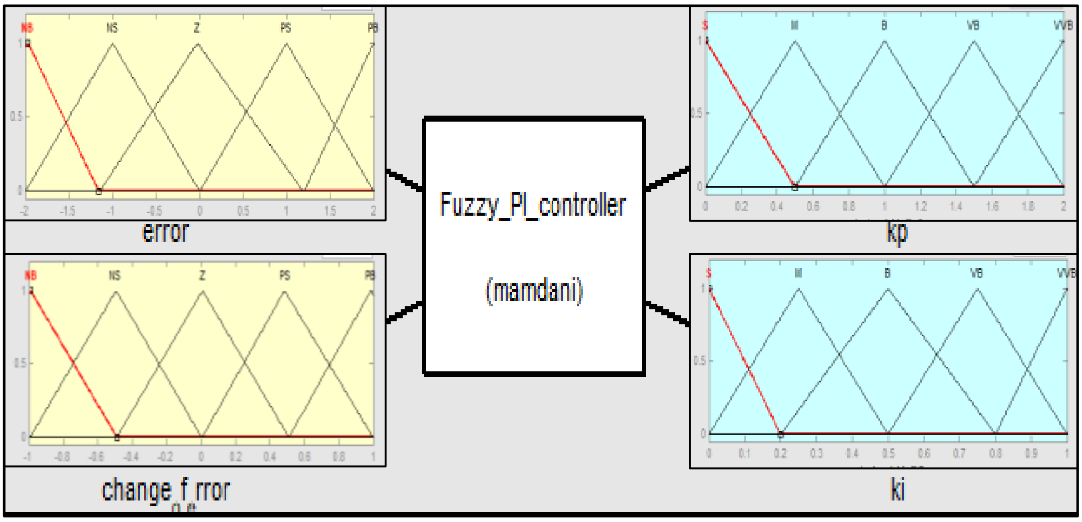
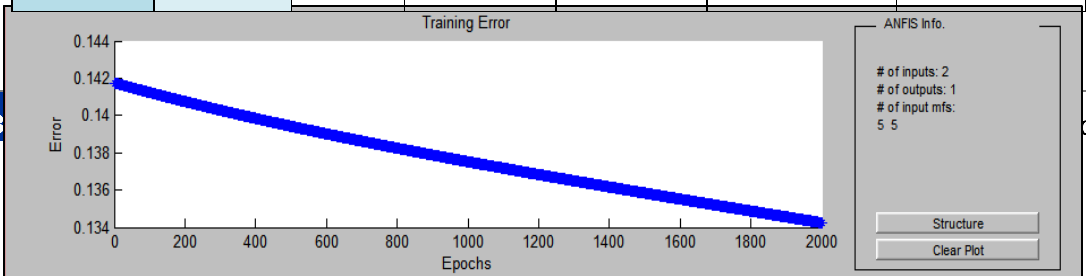


Figure 8 Inputs and output of MF for FLC

Table-2.The Rule base of $K_p$and K_i

		Error				
Change of error	kp, ki	NB	NS	Z	PS	PB
	NB	S,S	S,S	M,S	M,M	B,M
	NS	S,S	M,S	M,M	B,B	VB,VB
	Z	M,S	M,M	B,B	VB,VB	VB,VVB
	PS	M,M	B,B	VB,VB	VB,VVB	VVB,VVB
	PB	B,B	VB,VB	VB,VBB	VVB,VBB	VVB,VBB



# of inputs: 2
# of outputs: 1
# of input mfs:
5 5

Figure 9 Result ANFIS turning

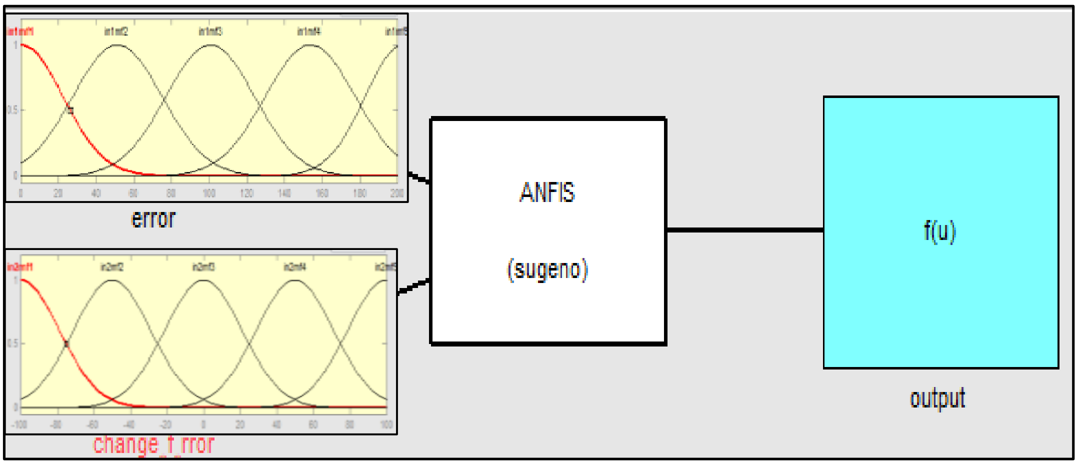


Figure 10 Inputs MF and outputs of proposed ANFIS controller

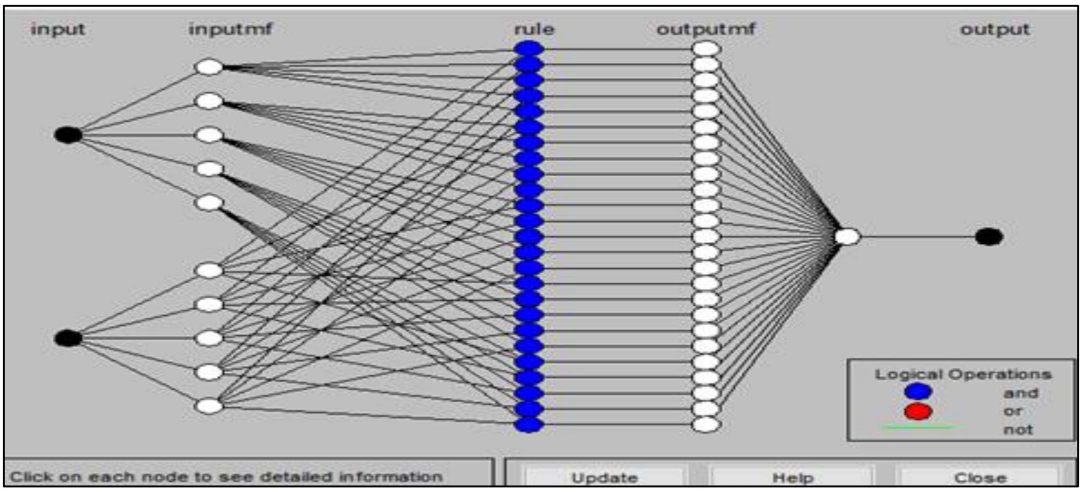


Figure 11 ANFIS model structure

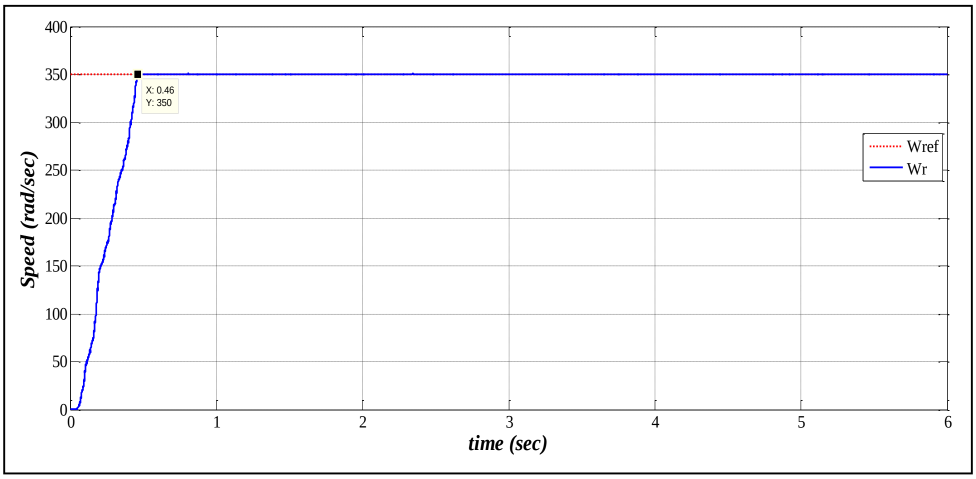


Figure 12 The speed response for used conventional PI controller at no-load

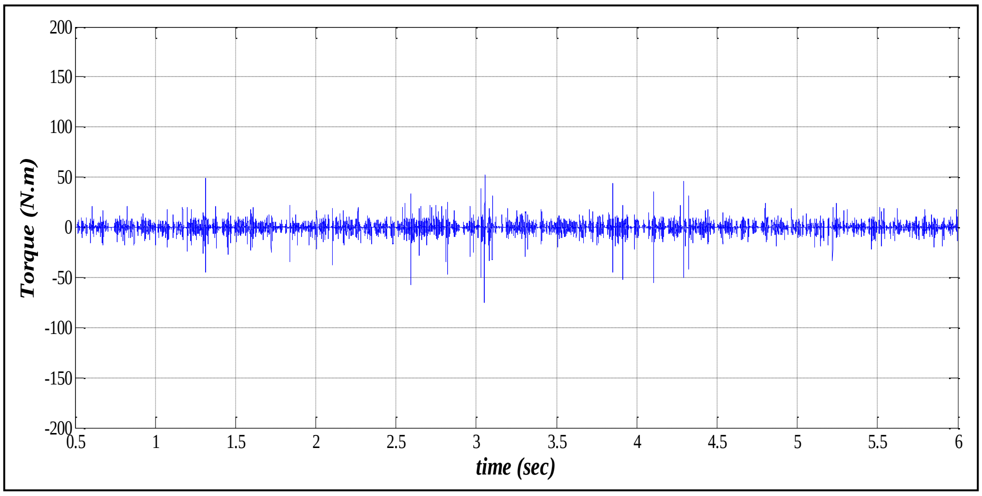


Figure 13 The torque response for used conventional PI controller at no-load

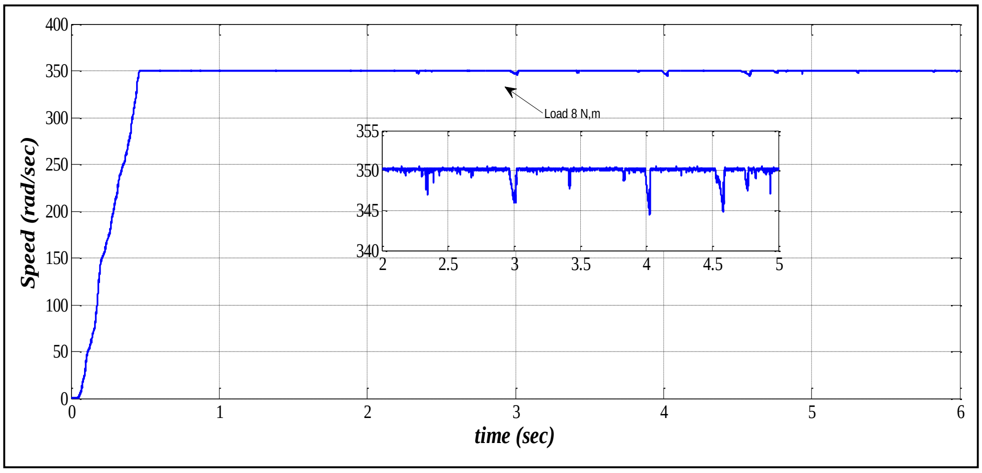


Figure 14 The speed response for used conventional PI controller with T_l =8 Nm at t 2s

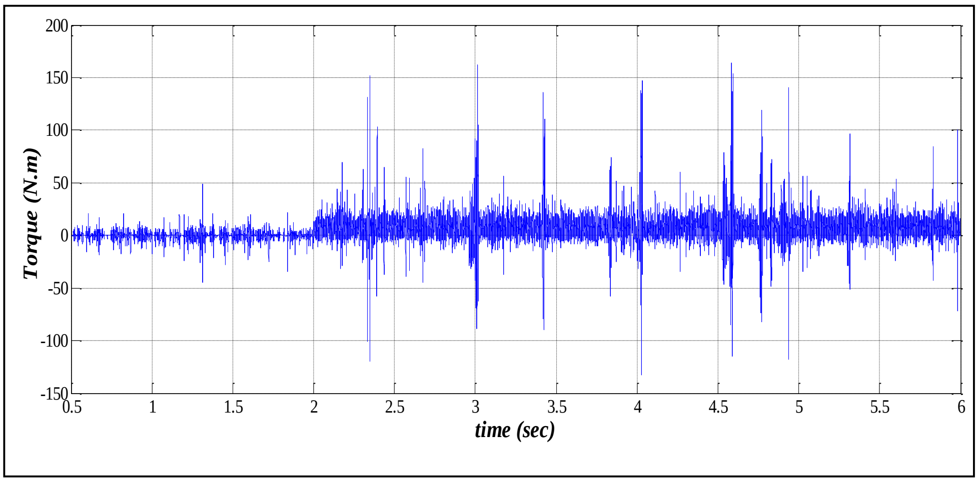


Figure 15 The torque response for used conventional PI controller with T_l =8 Nm at t 2s

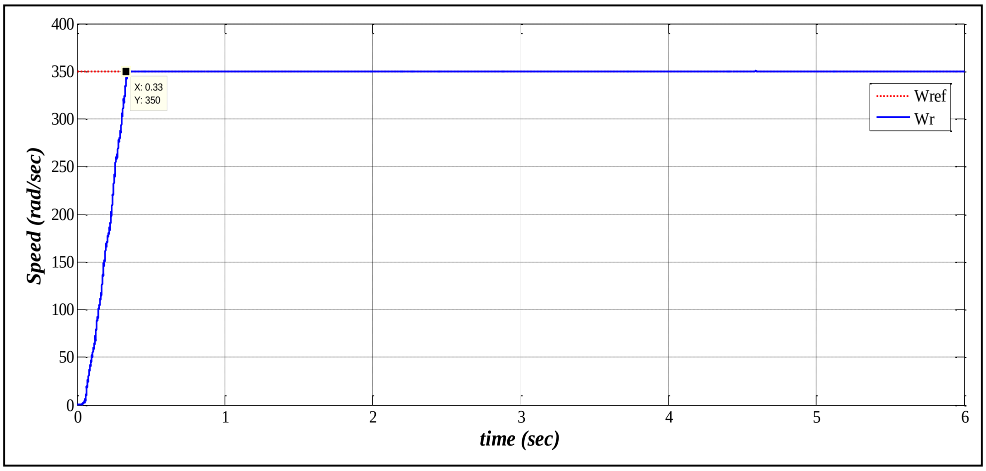


Figure 16 The speed response for used STFPI controller at no-load

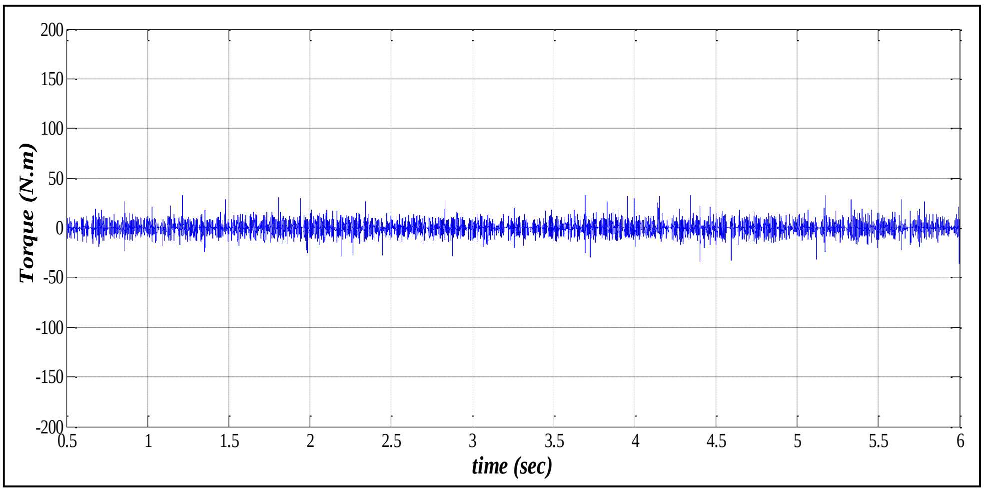


Figure 17 The torque response for used STFPI PI controller at no-load

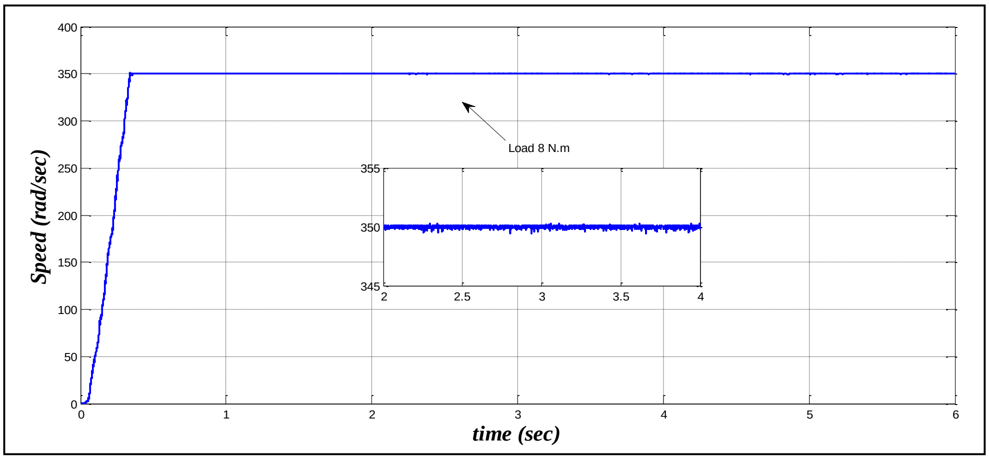


Figure 18 The speed response for used STFPI controller with T_l =8 Nm at t 2s

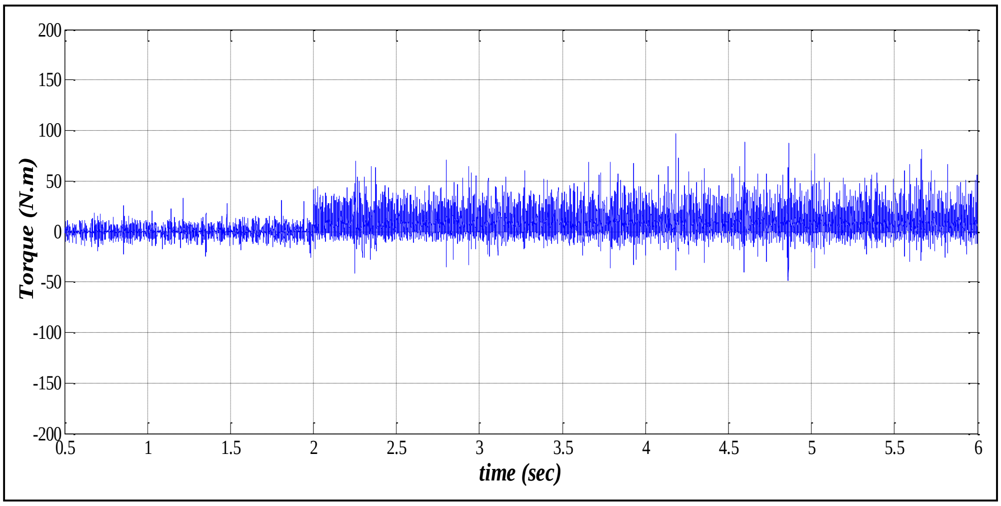


Figure 19 The torque response for used STFPI controller with T_l =8 Nm at t 2s

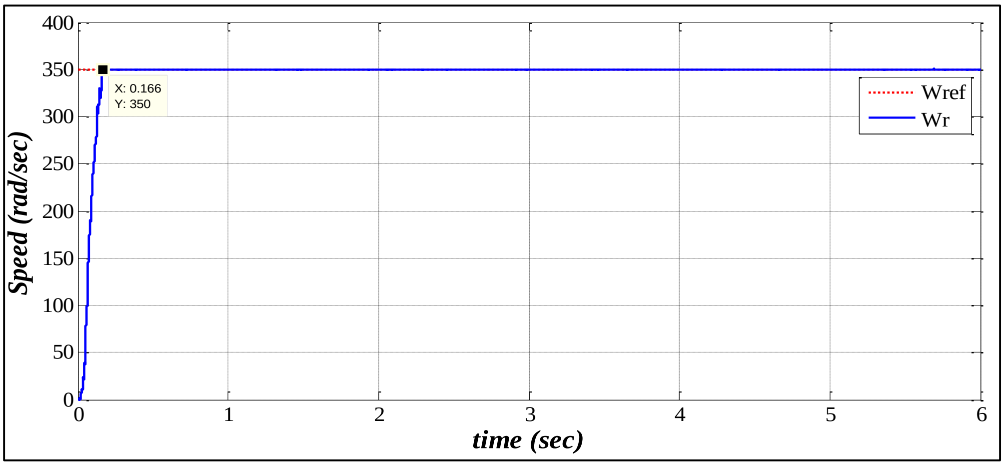


Figure 20 The speed response for used ANFIS at no-load

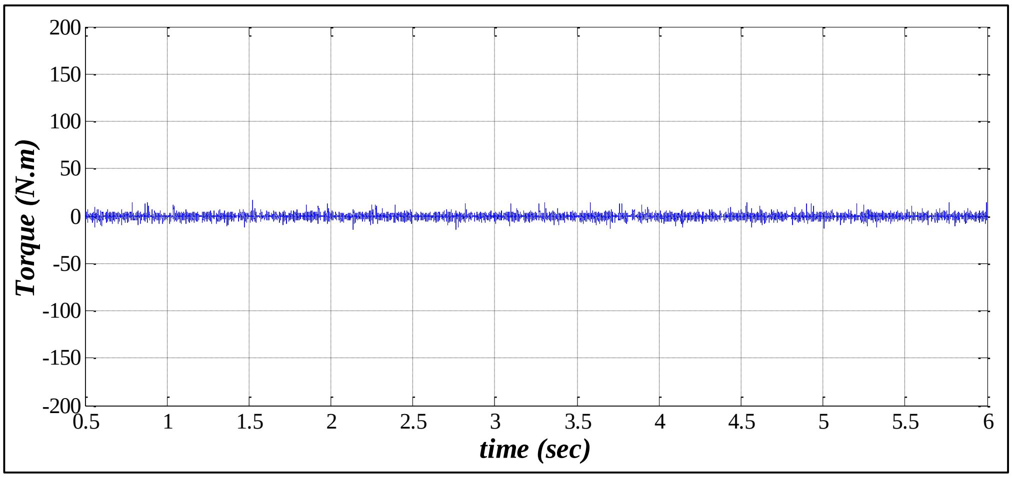


Figure 21 The torque response for used ANFIS at no-load

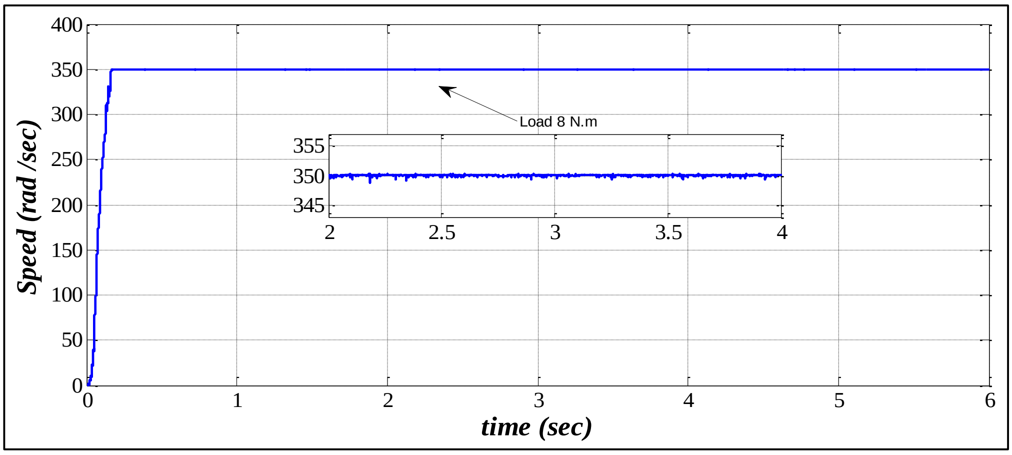


Figure 22 The speed response for used ANFIS controller with T_l =8 Nm at t 2s

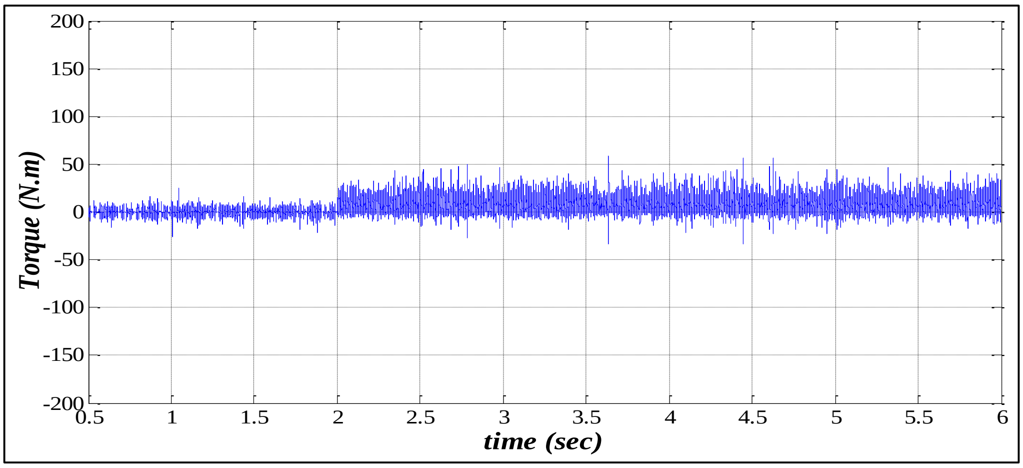


Figure 23 The torque response for used ANFIS controller with T_l =8 Nm at t 2s

CONCLUSION

In this paper, the proposed ANFIS based DTC-SVM for speed control of IM drive and compared the results of the simulation with the conventional PI controller (trial and error) and STFPI controller. STFPI controller is employed for adjusted the parameters of PI controller to guarantee the stability of system over the wide speed range.With results obtained from simulation, it is clear that for the same operation condition of induction motor, STFPI controller has better performance than the conventional PIcontroller. By comparing. ANFIS controllers with STFPI controller ,it has been better performance, smaller settling time, less ripples of torque and more robust for sudden changes in load.

REFERENCES

1**-Hanumanji Kantari**, "Direct Torque Control of Induction Motor Using Space Vector Modulation (SVM-DTC)". International Journal of Modern Engineering Research (IJMER), Vol.2, pp-3747-3768, 2012.

2-**Abderrahmane Ouchatt, Ahmed Abbou, Mohammed Akherraz and Abderrahim Taouni**, "Sensorless Direct Torque Control of Induction Motor Using Fuzzy Logic Controller Applied to Electric Vehicle", Renewable and Sustainable Energy Conference (IRSEC), International, IEEE, pp.366-372, 2014.

3-**Emre Ozkop and Halil I.Okumus**, "Direct torque control of induction motor using space vector modulation (SVM-DTC)". Power System Conference, MEPCON. 12th International Middle-East, IEEE, pp.368-372, 2008.

4-**Jagan Mohana Rao Malla, Dr. Manoj Kumar Sahu and Prof. P K Subudhi,** "DTC-SVM of Induction Motor by Applying Two Fuzzy Logic Controllers", Electrical, Electronics, and Optimization Techniques (ICEEOT), International Conference on, IEEE, pp.4941-4945, 2016.

5-**Fatma Ben Salem and Nabil Derbel**, "Investigation of SM DTC-SVM performances of IM control considering load disturbances effects". Systems, Signals & Devices (SSD), 13th International Multi-Conference on. IEEE, pp. 59-65, 2016.

6-**Ahmed J. Fattah and Ikhlas Abdel-Qader**, "Performance and comparison analysis of speed control of induction motors using improved hybrid PID-fuzzy controller" IEEE International Conference on Electro/Information Technology (EIT), pp. 575-580, 2015.

7--**Ahmed J. Fattah**, "Design and Analysis of Speed Control Using Hybrid PID-Fuzzy Controller for Induction Motors",M.S.C Thesis Western Michigan University, 2015.

8-**Kılıç, E., Yılmaz, Ş., Özçalık, H. R., and Şit, S,** "A comparative analysis of FLC and ANFIS controller for vector controlled induction motor drive". Electrical Machines & Power Electronics (ACEMP), Intl Conference on Optimization of Electrical & Electronic Equipment (OPTIM) & Intl Symposium on Advanced Electromechanical Motion Systems (ELECTROMOTION), Intl Aegean Conference on , IEEE, pp.102-106 ,2015

9**-Priya C. Patel and Virali P. Shah,** "Induction Motor Drive Using Indirect Vector Control with Fuzzy PI Controller" International Journal of Engineering Development and Research (IJEDR) , Volume 2, Issue 2, 2014.

10-**Gupta, R. A., Kumar, R., & Surjuse, R. S.** " ANFIS based intelligent control of vector controlled induction motor drive", Emerging Trends in Engineering and Technology (ICETET), 2nd International Conference on. IEEE, pp. 674-680, 2009.

11-**Yi, L., and Yonghong, P**. "Application of fuzzy neural network in the speed control system of induction motor", Computer Science and Automation Engineering (CSAE), IEEE International Conference on. IEEE, Vol.3, pp.673-677, 2011.

12-**Arun Shankar V.K, Umashankar S, Sanjeevikumar P,and Paramasivam S,** "Adaptive Neuro-Fuzzy Inference System (ANFIS) Based Direct Torque Control of PMSM Driven Centrifugal Pump" International Journal of Renewable energy Research,Vol.7, No.3, 2017.

13- **Fayez G. Areed, Amira Y. Haikal and Reham H. Mohammed, "**Adaptive neuro - fuzzy control of an induction motor", Ain Shams Engineering Journal, ,Vol 1, No.1, pp.71-78, (2010).

14- **Arun Kumar R and Febin Daya J L**,"A novel self-tuning fuzzy based PID controller for speed control of induction motor drive", In Control Communication and Computing (ICCC), 2013 International Conference on, IEEE, pp. 62-67, (2013).

15- **A.Durga Bhavani, Mrs. G. Durga Devi and Dr.K.Satyanarayana**," An Improved Speed and Torque Performance of ANFIS based Direct Torque Controlled Induction Motor Drive**"**, International Journal of Scientific & Engineering Research, Volume 6, Issue 12,2015.

16-**Tripti Rai and Prashant Debre,** "Generalized modeling model of three phase induction motor", International Conference on Energy Efficient Technologies for Sustainability (ICEETS). IEEE, pp. 927-931, 2016.

17-**Manoj Datta; Md. Abdur Rafiq and B. C. Ghosh,** "Genetic algorithm based fast speed response induction motor drive without speed encoder". International Conference on Power Engineering, Energy and Electrical IEEE, pp.146-151, 2007.

18-**Hongxia Yu and Zhicheng Chen,** "Three-Phase Induction Motor DTC-SVPWM Scheme with Self-tuning PI-Type Fuzzy Controller" International Journal of Computer and Communication Engineering, Vol.4, No.3, 2015.

19-**Naveen Goel; Saji Chacko and R. N. Patel,** "Performance enhancement of Direct Torque Control IM drive using Genetic Algorithm". Annual IEEE India Conference (INDICON). IEEE, pp. 1-6, 2015.

20-**Abolfazl Ranjbar Noei and Hedyeh Agheh Kholerdi,** "Practical intelligent modeling of three-phase induction machine". Information and Knowledge Technology (IKT), 7th Conference on. IEEE, pp.1-6, 2015.

21-**Ayushi PG**, "Speed Control of Induction Motor using Fuzzy Logic Controller", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, Issue 4, 2015.

22-**Boussada, Z., Hamed, M. B., and Sbita, L**. " Adaptive neuro-fuzzy inference system into induction motor: Estimation". Electrical Sciences and Technologies in Maghreb (CISTEM), International Conference on , IEEE, pp. 1-5, 2014.

23-**Sujatha, K. N., and Vaisakh, K.** ,"Implementation of Adaptive Neuro Fuzzy Inference System in Speed Control of Induction Motor Drives". Journal of Intelligent Learning Systems and Applications, Vol.2, No. 2, pp.110-118, 2010.

24-**Mohamed Mahmoud. Ismail,** "Speed Sensor less observer using Lyapnov design and ANFIS for DTC of magnetically saturated induction motor", Computer Engineering Conference (ICENCO), Seventh International, IEEE, pp.62-71, 2011.

25-**Zgurovsky, M. Z., and Zaychenko, Y. P**,"The Fundamentals of Computational Intelligence: System Approach", Springer, Vol. 652, pp. 1-371, 2017.