Performance Analysis of a 4- Switch, 3-Phase Inverter Fed Induction Motor Drive System Using Anfis Controller

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Abstract- *This paper introduces a Adaptive Neuro Fuzzy Inference System (ANFIS) based speed controlling for Indirect Field Oriented Control (IFOC) of Induction Motor (IM) dries which fed by a four-switch three phase (FSTP) inverter. The advantages of neural and fuzzy networks to enhance the dynamic performance, robustness, insensitivity to load changes and overall drive performance when compare to traditional PI controller and fuzzy logic controller at identical conditions. In this proposed approach, the IM drive system is fed by FSTP inverter rather than the conventional Six-Switch Three-Phase (SSTP) inverter for a practical low power applications. This reduces the cost of the inverter, switching losses and the complexity of the controller interface circuit to generate PWM logic signals. The total IFOC strategy consolidating the ANFIS controller for IM drives fed by the FSTP inverter is worked in MATLAB/SIMULINK. The dynamic performance of the proposed IM drive system has been examined using simulation results under various operating conditions. A fair performance comparison between the classical PI controller, fuzzy logic controller and ANFIS controller is also provided at identical conditions.*

Keywords- FLC, ANFIS, Total Harmonic distortion, FSTP inverter, parameters variation, IFOC.

I. INTRODUCTION

Over the years induction motor has been working consistently in the industry due to its robust structure and acceptable operational efficiency. Now-a-days three phase inverters play a vital role in case of variable speed ac drives. The conventional structure of a three phase voltage inverter comprises of three legs, six power switches, a complementary pair for each phase. This involves the losses of the six switches as well as the complexity of the control schemes and they require building interface circuits to produce six PWM pulses [1-3]. The cost is also high and there is lack of simplicity and flexibility. The improvement of minimal effort motor drive systems is an essential theme, especially for a low-control extend. In this manner, the three-phase inverter with diminished segment for driving an IM was displayed in [1]. Additionally, decreased switch tally has been reached out for a rectifier– inverter system with dynamic information current molding [2]. Three distinct designs of IM drives fed from a four-change inverter to execute minimal effort drive systems for low-power range applications have been exhibited in [3].

A new three-phase to single-phase converter for ac motor drives is proposed which employs only six switches extraordinary research attempts to plan new power converters for limiting misfortunes and expenses have been proposed. Four-switch three-phase (FSTP) inverters rather than SSTP inverters have been utilized as a part of motor drives [4].

The main features of this FSTP converter over the conventional SSTP inverter are:

1) Reduced switch and freewheeling diode count;
2) Potential for reduced price because of the reduction in number of switches;
3) Simpler control schemes to produce logic pulses;
4) Reduction of conduction losses dependent on the power semiconductor devices;
5) Limited switching misfortunes.

PWM technique for FSTP inverters is enhanced. A strategy to deliver PWM pulses to control the FSTP-inverters and remuneration of capacitor unbalance has been proposed [5]. A DC– AC FSTP SEPIC-based inverter has been displayed. This inverter enhances the usage of the dc transport contrasted with the customary FSTP inverter. Motor current unbalance of FSTP inverters has been considered with a pay strategy using current input [6].

The control of IMs is a testing issue because of their nonlinear model and parameters variety. In traditional control systems utilizing proportional– integral (PI) and PI– derivative

(PID) controllers, the controller execution is fundamentally dependent on the IM models. Not with standing, the vast majority of these models are overcome the problems and parameter variations. Likewise, they utilize a few suspicions that reason incorrectness in the scientific model.

Along these lines, the model-based controllers, for example, a customary PI and PID controllers, can't give acceptable execution under speed following changes, load effect, and parameters variations. A few attempts to outline the speed controller of electrical motor drives to conquer the issue of settled increases PI controllers are as of late proposed, for example, a sliding mode control with disturbance compensation [7], adaptive PID controller [8], model predictive direct control [9], on-line inertia ID calculation for PI parameters advancement [10] , and an information based PI controller.

Nowadays, broad research works have been displayed to execute simulated insightful controllers (AICs) attributable to their benefits contrasted with great PI and PID controllers. The significant benefits of AICs are that they are free of the plant numerical model and their exhibitions are strong under system nonlinearities and vulnerabilities [11]. AICs procedures for SSTP inverters sustained IM drive systems incorporate FLC, Self-Tuned Neuro-Fuzzy Controller [12-14], Emotional Intelligent Controller [15], and Adaptive Fuzzy Sliding-Mode Control [16]. Likewise, FLC for IPMSM-based FSTP inverters has been created.

Many researchers have recently studied intelligent controller in order to solve problems with classical methods of control, and what remarkable of all is fuzzy control using expert's knowledge or experience or linguistic variables and neural network with learning capability. The characteristics of fuzzy control are: First, approximate knowledge of plant is required. Second, knowledge representation and inference is simple with plural forms of IF-THEN. Fuzzy control and neural network control have many advantages as above, but fuzzy control also has a drawback that you have to set new control law and membership function every time as types of system change. To overcome the shortcomings of fuzzy and neural networks it is wised to use the combination of both, which leads to neuro-fuzzy controller. The basic concept of neuro fuzzy control models is first to use structure-learning to the membership functions. ANFIS-Based Controller with Fuzzy Supervisory Learning for Speed Control [17] especially at low speeds.

The rotor flux is basic for an exact operation of IFOC of IM drives. The field introduction system needs exact machine parameters to ensure precise decoupling of the stator current vector in connection to the rotor motion vector. Utilizing sensors for coordinate estimation of the rotor transition gives adjust an incentive without affectability to machine parameters. All things considered, this technique is dangerous, expensive and inclined to mistakes in boisterous conditions. Thusly, motion estimation in view of the dynamic model of the IM is exceedingly required for superior IFOC of IM drives. An issue is that real machine parameters shift with working conditions. It is conceivable that the machine control execution debases because of the parameters crisscross and the system moves toward becoming detuned. The motion estimation with its distinctive strategies is a test for both speed-sensored and speed-sensorless drives.

In the low speed area, the impact of changing the motor parameters (stator and rotor resistances and snapshot of dormancy) is particularly recognizable on low speed of operation. For speeds lower than 2/3 greatest motor speed, the execution of FSTP inverters is like SSTP inverters in light of the fact that the most extreme basic mode voltage from FSTP is 2/3 of most extreme basic mode voltage from conventional SSTP inverters. At that point, the steady operation of FSTP inverters is till 2/3 of most extreme speed. For speeds over 2/3 greatest motor speed, it needs additional DC interface voltage for FSTP inverters to accomplish IFOC and build up a similar execution of the drive system with SSTP inverters.

Past works have been accounted for on the use of FLC-based IM drive. Likewise, few works have been introduced for the FLC-based IM sustained from FSTP inverter. Be that as it may, these works were limited to fast area, and low speed locale is not inspected. Accordingly, it is basic to grow FLC-based IM drives amid low and high speeds. Additionally, these works don't give any outcomes about the adequacy of FLC under parameters variations in the low speed mode. Accordingly, there is a solid requirement for successful advancement and ongoing execution of the FLC-based IM fed from FSTP inverter, which will be suitable for effective cost low power real applications. Consequently, the most essential commitment of this paper contrasted with different works is with research the dynamic execution of FSTP inverter sustained IM drives utilizing FLC, especially at low speeds.

II. SYSTEM CONFIGURATION, MOTOR DYNAMICS AND CONTROL SCHEME

A. Mathematical model of IM and Control Scheme

The description of the IM in a d–q axis was utilized, and the control structure depends on the backhanded field situated control (IFOC). Points by point clarification of IFOC demonstrate was displayed in for non-reiteration. The control structure of the proposed FLC-based IFOC of acceptance motor bolstered by FSTP voltage source inverter (VSI) is shown in Fig. 1. The blunder between the reference speed, motor speed and the subsidiary of speed mistake are the contributions to the FLC and its output is the reference torque T_e^*. The reference currents in d-q axis are changed into the reference motor currents and flows in a-b-c axis by opposite Park's change. The reference motor currents and their comparing genuine motor currents and flows the contrasts between these currents and flows are the contributions to hysteresis groups of current controlled VSI to produce pulse width-adjustment paired signs, which are used to actuate the status of FSTP inverter. The motor voltages are created utilizing FSTP inverter.

B. FSTP Inverter

The power circuit of a FSTP-VSI fed IM is shown in Fig. 1. This circuit is formed from two sides. The primary side is a half-wave voltage doubler fed from single-phase AC power supply. The frequency of the info ac voltage is settled; this voltage is redressed utilizing rectifier switches Qr1 and Qr2. The rectifier circuit is used to charge the capacitor bank in the DC-connect. The second side is the FSTP-VSI. The FSTP inverter uses four switches: Q1, Q2, Q3, and Q4, separately, as outlined in Fig. 1. Phase "a" and phase "b" of the IM are associated through two appendages of the inverter, while phase "c" is associated with the midpoint of the capacitors bank. The FSTP inverter utilizes four separated entryways bipolar transistors (IGBTs) and four freewheeling diodes to get the two line-to-line voltages Vac and Vcb. Notwithstanding, the third line to line voltage (Vba) is gotten utilizing Kirchhoff's voltage law from a split capacitor bank. The greatest dc connect voltage over every capacitor keeps up equivalent to Vdc. The created three-phase output voltages utilizing FSTP inverter are adjusted with flexible voltage and frequency. In the present investigation, the FSTP inverter switches are used as perfect switches. The three-phase output voltages of the FSTP inverter are gotten utilizing the DC-interface voltages Vdc and the double flags of the two appendages of the FSTP inverter. The created phase voltages encouraged IM can be communicated as an element of the switching conditions of the inverter and Vdc as takes after :

$$V_a = \frac{V_{dc}}{3}(4S_a - 2S_b - 1)$$
$$V_b = \frac{V_{dc}}{3}(-2S_a + 4S_b - 1)$$
$$V_c = \frac{V_{dc}}{3}(-2S_a - 2S_b + 2) \qquad (1)$$

Where Vdc is the pinnacle voltage over the capacity capacitors; Sa and Sb are the real conditions of the two phases "an" and "b" speaks to by two twofold logic factors, which decide the conduction condition of the inverter. At the point when Sa is 1, switch (Q1) is led and switch (Q4), is not, and when Sa is 0, switch (Q4) is directed and switch (Q1). Sb has a similar standard of operation, and Va, Vb, Vc are motor phase voltages.

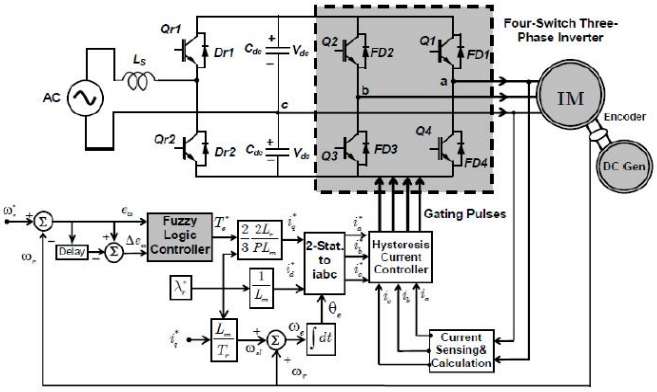

Fig. 1.Block diagram of the proposed FLC-based IFOC scheme of IM drive fed by FSTP voltage source inverter.

For the adjusted created voltages, the four real mixes of the inverter status are prompt four voltage vectors as appeared in Fig. 2.

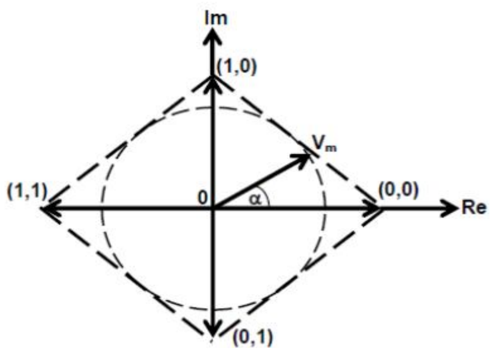

Fig. 2 Switching vectors for a FSTP voltage source inverter.

SWITCHING SEQUENCE

Table I shows the different mode of operation corresponding output voltage vector of the inverter

Switching Function		Switch on		Output Voltage Vector		
Sa	S_b			V_a	V_b	V_c
0	0	Q_4	Q_3	$-V_{dc}/3$	$-V_{dc}/3$	$2V_{dc}/3$
0	1	Q_4	Q_2	$-V_{dc}$	V_{dc}	0
1	0	Q_1	Q_3	V_{dc}	$-V_{dc}$	0
1	1	Q_1	Q_2	$V_{dc}/3$	$V_{dc}/3$	$-2V_{dc}/3$

III. SPEED CONTROL METHODS

A. Conventional PI controller

Determination of the PI controller parameters will impact the speed reaction, its settling time, overshoot esteem and load torque dismissal, so they ought to be changed in accordance with have ideal reaction for a reasonable correlation with the proposed FLC.

To design the PI controller, the schematic graph of the speed controller of the IM drive is outlined in Fig.ure 3 . The open-circle exchange capacity of has one zero at $-K_{i\omega}/K_{p\omega}$ and two shafts at zero and $-B/J$. The PI controller parameters are tended to have ideal reaction utilizing pull locus technique for post zero areas as cleared up in Fig. 7. The root-locus plot has been utilized to choose the additions of and to give the required execution. It is discovered that the PI picks up are $K_{i\omega} = 15$ and $K_{p\omega} = 8$ to give the best unique reaction.

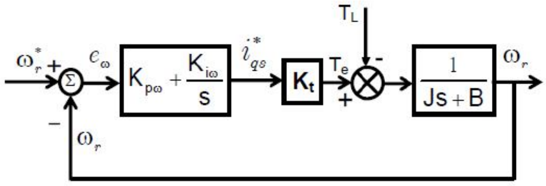

Fig. 3 Block diagram for the speed controller of the IM drive.

B. FLC Algorithm

FLC is utilized with IM to pulse the issue of creating precise scientific depiction because of load unsettling influences and parameters evolving. The contributions to FLC square are the deviation between the reference and real motor speeds (speed mistake) and speed blunder subordinate. These two sources of info are used to deliver the order torque of IM (output of FLC). As delineated in Fig. 1, the reference torque and reference motion are utilized to compute the two reference current parts in quadrature and direct axis (iq*, id*), separately. These two currents in blend with the unit vector esteem are used to ascertain the three phase reference currents and flows (ia*, ib*, ic*) in light of converse Park's change to keep the required speed. The fundamental capacity of FLC is to keep the motor speed lined up with the coveted speed, thus the motor currents kept near their reference currents and flows. The correct computations of reference torque rely upon the precise scientific model of IM and additionally its parameters which are truly not consistent amid the motor operation. The impact of motor parameters varieties is just observable at low speed of operation which is considered as a major test for precise computation of the reference torque, and additionally correct operation of IM under vector control procedure. The astute controllers, particularly FLC are utilized with IM drive to pulse the parameters variety at low speed operation. FLC has many highlights, for example, no requirement for correct scientific model of IM, and its activity relying upon phonetic tenets with "IF", "AND", and "At that point" administrators. This idea depends on human logic. The primary downside of FLC, it needs high figuring trouble for reproduction and trial executions. In this manner, the present paper defeats this issue by plan FLC with low numerical weight. Numerous enrollment capacities (MFs) shapes can be picked in light of the creator inclination and experience. These MFs are described by Gaussian participation. The human discernment and experience can be executed through the MF and fuzzy guidelines.

C. Design of Simplified FLC for IM Drive

The dynamic model of IM expressed as follow;

$$T_e = J\frac{d\omega_r}{dt} + B\omega_r + T_L \qquad (2)$$

$$T_e - T_L = J\frac{d\omega_r}{dt} + B\omega_r \qquad (3)$$

$$\frac{d\theta_r}{dt} = \omega_r \qquad (4)$$

where, *J* is the rotor inertia, T_e is the electrical torque, T_L is the load torque, *B* is the frication damping coefficient, and ω_r is the motor speed. Employing small signal model of IM, it can be see that small change of electrical torque ΔT_e resulting in small change of the rotor speed $\Delta\omega_r$. The electrical motor torque equation rewritten as

$$\Delta T_e = J\frac{d\Delta\omega_r}{dt} + B\Delta\omega_r + \Delta T_L \qquad (5)$$

The model of small signal in discrete time for the simplified IM model with applying constant load expressed as

$$\Delta T_e(n) = J\Delta e(n) + B\Delta\omega_r(n) + \Delta T_L \qquad (6)$$

This equation describing the developed electrical torque as a function of motor speed error and change of error described as follow:

$$T_e(n) = \sum_{n=1}^{N} \Delta T_e(n) = f(\Delta e(n, \Delta\omega_r(n)) \qquad (7)$$

Where, *N* is the total number of rules.

$\Delta\omega_r(n) = \omega_r^*(n) - \omega_r(n)$ is the speed error, $\Delta e(n) = \Delta\omega_r(n) - \Delta\omega_r(n-1)$ is the change of error,

$\Delta\omega_r(n-1)$ is the previous sample of speed error, $\Delta\omega_r(n)$ Is the current value of speed error, $\omega_r(n)$ is the current value of motor speed, and $\omega_r^*(n)$ is the present sample of reference motor speed. A Matlab/Simulink implementation of FLC controller is illustrated in Fig. 4. The FLC algorithm of speed controller employed in the IM drive is based on estimation of two inputs, speed error and its change as illustrated in Fig. 3. These two linguistic variables are considered as contribution to the arrangement of as needs be interconnected FL square, and the output is the electrical torque order. The subsidiary piece can be supplanted by time postpone square, which is another approach to get the required info. This time postpone piece would permit abbreviate the figuring load, in the meantime likewise secure the controller shape vulnerabilities as spikes in the output, which are the disadvantage of time subsidiary square, if the handled flag change unexpectedly. The time defer square would give a speedier and adequate strong reaction and also decisively exact following of reference speed. It additionally permits raising the speed sensor testing rate fundamentally.

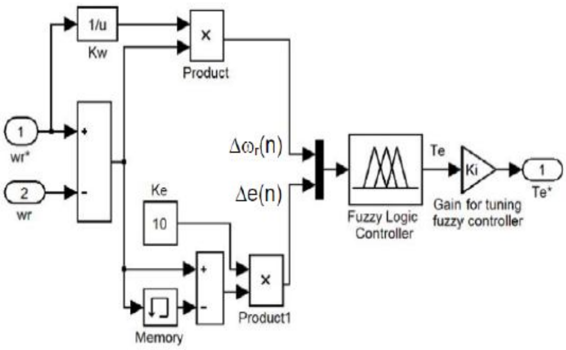

Fig. 4 Block diagram of FLC controller using memory block instead of derivative block.

1) Fuzzification Process

To designe the proposed FLC, the initial step is to pick the scaling parameters Kw, Ke, and Ki which are resolved for fuzzification process and accepting the appropriate estimations of the reference torque. The parameters Kw and Ke are resolved so that the standardized estimation of speed blunder and its change, and separately, remains in satisfactory cutoff points ± 1. The parameter for the output flag Ki is resolved so that the appraised torque is the output of the FLC at all evaluated operations. For usage, the accompanying esteems are resolved Kw= 1/ω_r^* (charge speed), Ke = 10, and Ki = 10 keeping in mind the end goal to acquire the ideal drive recreations and continuous execution. These parameters can be constants or factors and has a noteworthy part for FLC configuration with a specific end goal to get a decent reaction amid every single working condition. In current paper, these parameters are considered constants and are choosed by exploratory experimentation to accomplish the most ideal drive execution. The MF's of $\Delta\omega_r(n)$, $\Delta e(n)$and $T_e(n)$ are picked subsequent to choosing scaling parameters. MF's are vital components of the FLC. Figure 5 demonstrates the MFs utilized for the information and output fuzzy arrangements of FLC for creating the reference torque. The triangular MF's are used for all the fuzzy arrangements of the info and output vectors on account of their simplicity of numerical portrayal. Therefore it makes the conceivable to disentangle the execution of FL deduction motor and to lessen the computational weight for constant operation.

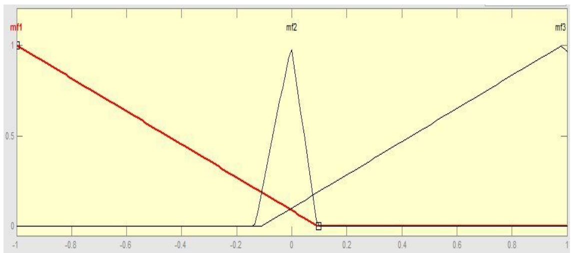

Fig 5: Membership functions for input 1

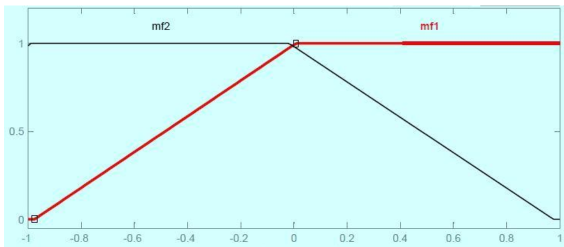

Fig 6: Membership functions for input 2

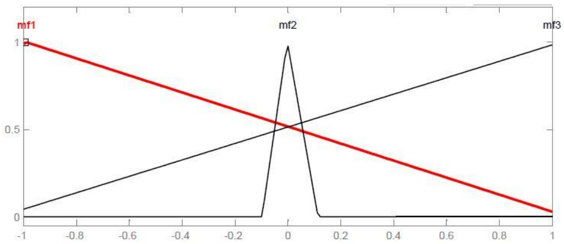

Fig 7: Membership functions for output

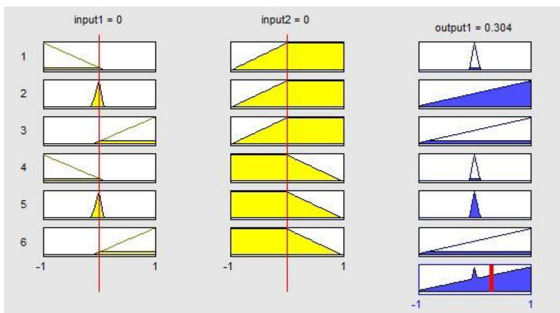

Fig 8 **.**Product sum gravity method.

2) Inference and Defuzzification

Fuzzy derivation is the entire procedure of planning the mapping of the capacity from offered contribution to a output utilizing fuzzy logic administrators. The Mamdani and Sugeno are the two fundamental sorts of fuzzy deduction techniques. The primary contrast between these sorts is the method for characterizing the output. This paper utilizes the usually utilized technique for fuzzy deduction and defuzzification process which is Mamdani max-min (or total item) synthesis with focus of gravity strategy . This technique is connected for defuzzification to get *Te(n).*

IV. AN ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

A adaptive neuro-fuzzy derivation framework or versatile system based fuzzy deduction framework (ANFIS) is a sort of counterfeit neural system that depends on Takagi–Sugeno fuzzy induction framework. The strategy was produced in the mid 1990s. Since it coordinates both neural systems and fuzzy rationale standards, it can possibly catch the advantages of both in a solitary structure. Its induction framework compares to an arrangement of fuzzy IF–THEN decides that have learning capacity to inexact nonlinear capacities. Thus, ANFIS is thought to be an all inclusive estimator. For utilizing the ANFIS as a part of a more productive and ideal way, one can utilize the best parameters acquired by hereditary calculation ANFIS: Artificial Neuro-Fuzzy Inference Systems

- ANFIS are a class of adaptive networks that are functionally equivalent to fuzzy inference systems.
- ANFIS represent Sugeno e Tsukamoto fuzzy models.
- ANFIS uses a hybrid learning algorithm.
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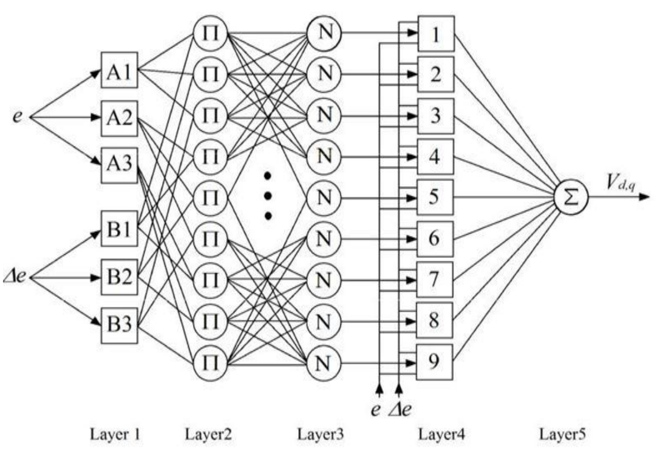


Fig. 9 ANFIS structure

$$e = i_{d\text{-}q}^{*} - i_{d\text{-}q} \quad (8)$$

$$\Delta e = e(k) - e(k-1) \quad (9)$$

$$X = e(t) \quad (10)$$

$$Y = \Delta e(t) \quad (11)$$

$$O_i^1 = \mu_{Ai}(x) = \frac{1}{1+[\frac{x-c_i}{a_i}]^{b_i}} \quad i = 1,2,3 \ldots \quad (12)$$

$$O_{i+2}^1 = \mu_{Bi}(y) = \frac{1}{1+[\frac{y-c_{i+2}}{a_{i+2}}]^{b_{i+2}}} \quad i = 1,2,3.. \quad (13)$$

Where, $\{a_i, b_i, c_i\}$ is the parameter set and A is the linguistic term. Bell-shaped MF's is selected for each node.
Layer 2: This layer is rule inference layer. Every node in this layer is a fixed node label as $\prod$ which multiplies the incoming signals and sends the product out. Each node output corresponds to the firing strength of a fuzzy rule.

$$O_i^2 = w_i = \mu_{Ai}(x)\mu_{Bi}(y) \quad i = 1,2,3 \ldots \quad (14)$$

Layer 3: This is a normalization layer. Every node in this layer is a circle node labelled N. The *i-th* node calculates the ratio of the rule's firing strength to the sum of all rules' firing strength.

$$O_i^3 = \varpi_i = \frac{w_i}{\sum_i w_i} \quad i = 1,2,3 \ldots \quad (15)$$

Layer 4: This is a consequent layer. All nodes are an adaptive mode with node function:

$$O_i^4 = \varpi_i f_i = w_i(p_i x + q_i y + r_i) \quad i = 1,2,3 \ldots \quad (16)$$

Where ANFIS is a normalized firing strength from layer 3, and $\{p_i, q_i, r_i\}$ is the parameter set of this node.

Layer 5: This is output layer. The single node in this layer is a fixed and node is labelled as $\sum$ that computes the overall output as the summing up of all incoming signals:

$$O_i^5 = \sum_i \varpi_i f_i \quad i = 1,2,3 \ldots \quad (17)$$

The parameters of ANFIS are updated using the back propagation error term as follow

$$\frac{\partial E}{\partial O^5} = K_1 e + K_2 \Delta e \quad (18)$$

The error (e) and the change of error (Δe) multiplied by the constants k_1 and k_2.

$$\alpha_{K+1} = \alpha_K - \eta \frac{\partial E}{\partial \alpha_K} \quad (19)$$

Where α is any of the parameters of ANFIS and η is learning rate. The error will be reduced next training iteration.

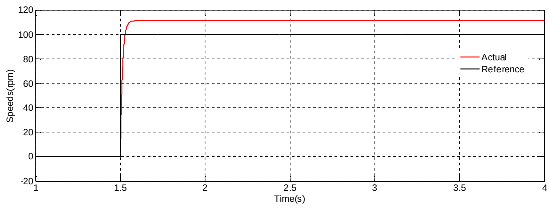
The advantage of using ANFIS over a FLC controller is the output MF's is automatically tuned and it can provide better performance than FLC.

The quality of neuro-fuzzy frameworks includes two conflicting necessities in fuzzy displaying: interpretability versus exactness. Practically speaking, one of the two properties wins. The neuro-fuzzy in fuzzy demonstrating research field is separated into two zones: semantic fuzzy displaying that is centered on interpretability, for the most part the Mamdani model; and exact fuzzy demonstrating that is centered around exactness, primarily the Takagi-Sugeno-Kang (TSK) model.

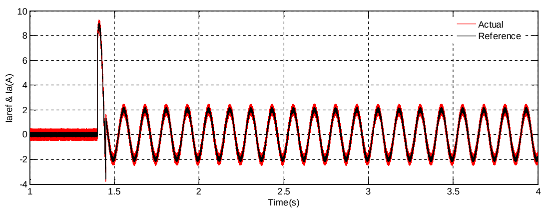
Representing fuzzification, fuzzy inference and defuzzification through multi-layers feed-forward connectionist networks. It must be pointed out that interpretability of the Mamdani-type neuro-fuzzy systems can be lost. To improve the interpretability of neuro-fuzzy systems, certain measures must be taken, wherein important aspects of interpretability of neuro-fuzzy systems are also discussed.

A recent research line addresses the data stream mining case, where neuro-fuzzy systems are sequentially updated with new incoming samples on demand and on-the-fly. Thereby, system updates do not only include a recursive adaptation of model parameters, but also a dynamic evolution and pruning of model in order to handle concept drift and dynamically changing system behavior adequately and to keep the systems/models "up-to-date" anytime.

V. SIMULATION RESULTS

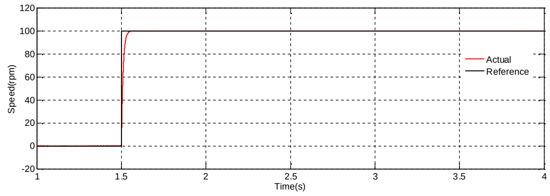


Speed.

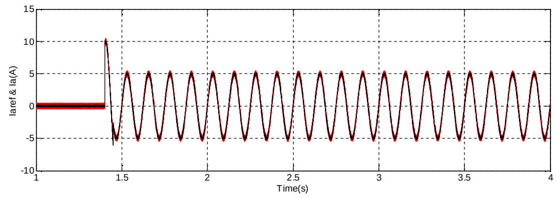


I_a, I_{aref}

(a)

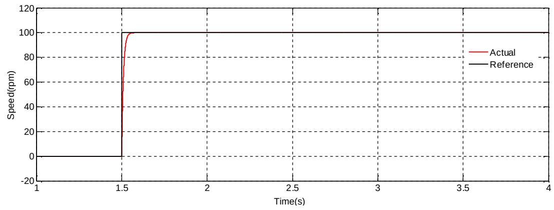


Speed.

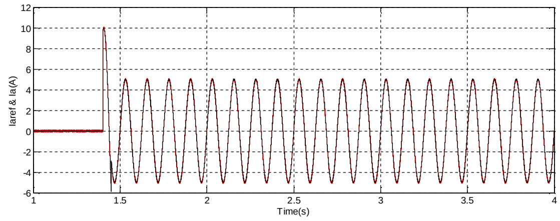


$I_{a,} I_{aref}$

(b)



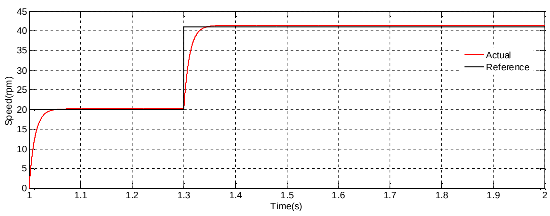
Speed.



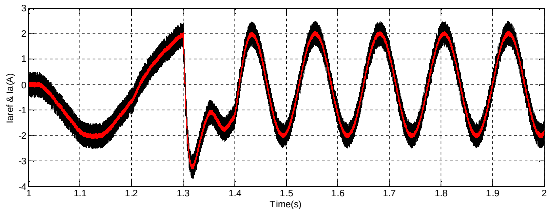
$I_{a,} I_{aref}$

(c)

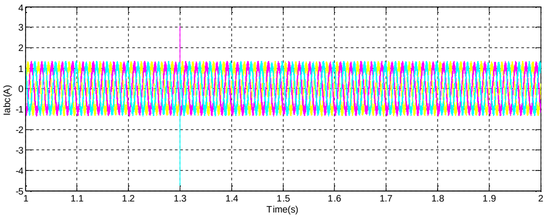
Fig. 10 Simulated speed and stator currents responses of a FSTP inverter fed IM drive for a starting operation at low speed with a step change of a speed reference from 0 to 100 rpm using, (a) Traditional PI controller, (b) FLC, and (c) ANFIS controller



Speed.

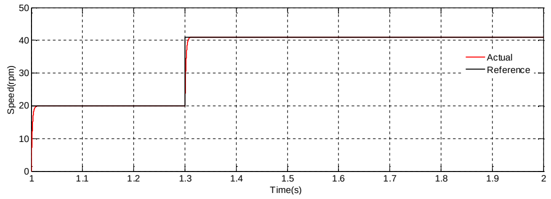


I_a ,I_{aref}

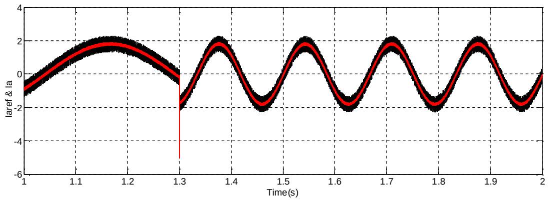


I_{abc}

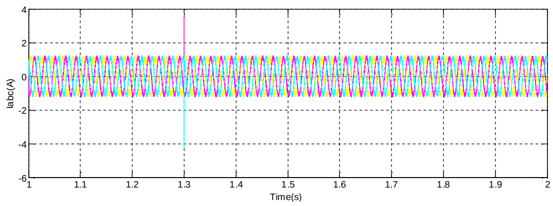
(a)



Speed.

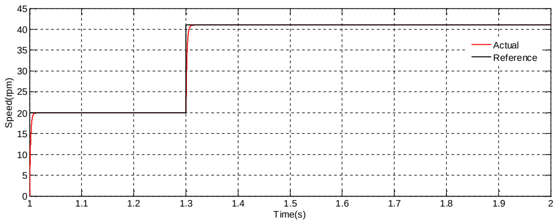


I_a ,I_{aref}

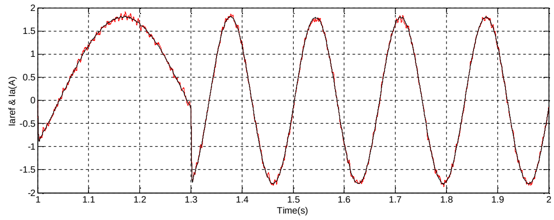


I_{abc}

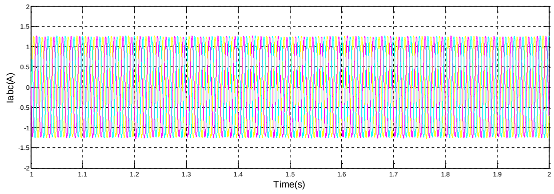
(b)



Speed.



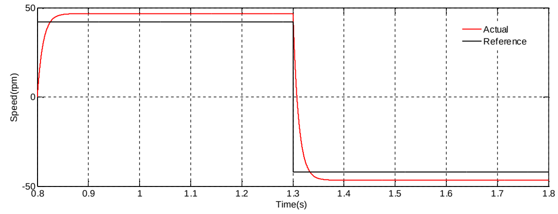
I_a ,I_{aref}



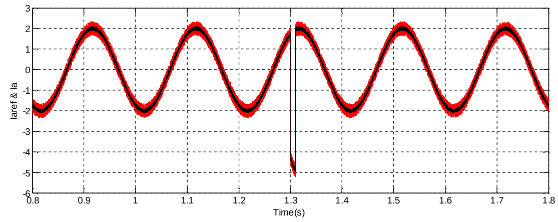
I_{abc}

(c)

Fig. 11 Simulated speed and stator currents responses of a FSTP inverter fed IM drive for a step change of a speed reference from 20 to 40 rpm using, (a) Traditional PI controller, (b) FLC and (c) ANFIS controller.

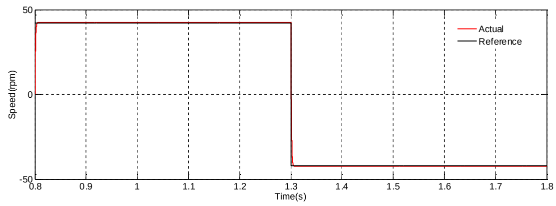


Speed.

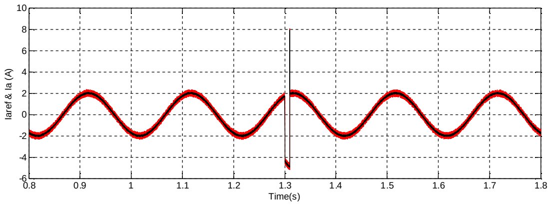


I_a ,I_{aref}

(a)

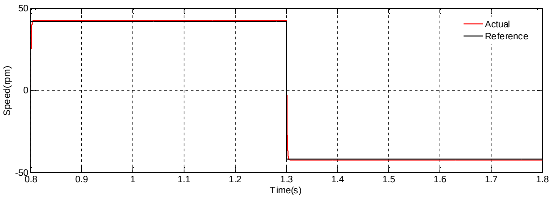


Speed.

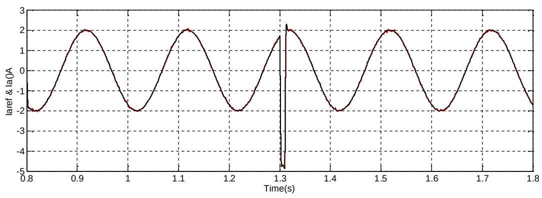


I_a, I_{aref}

(b)



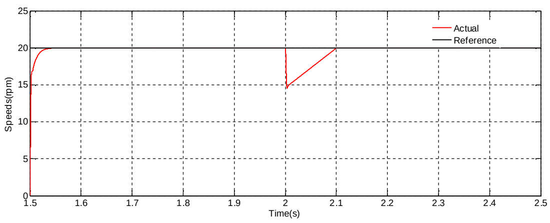
Speed.



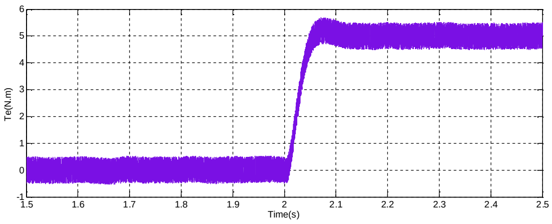
I_a, I_{aref}

(c)

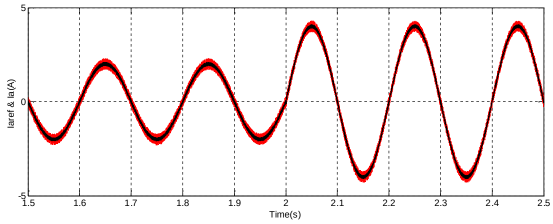
Fig. 12.Simulated speed and stator currents responses of a FSTP inverter fed IM drive for a speed reversal from 40 to □40 rpm using, (a) Traditional PI controller,(b)FLC and (c)ANFIS controller.



Speed.

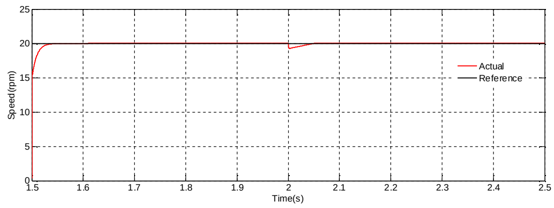


Torque

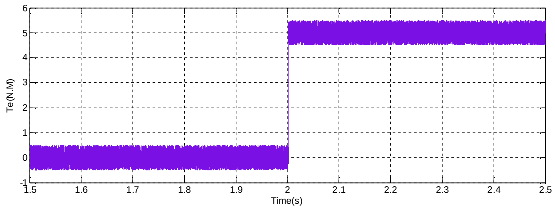


I_a, I_{aref}

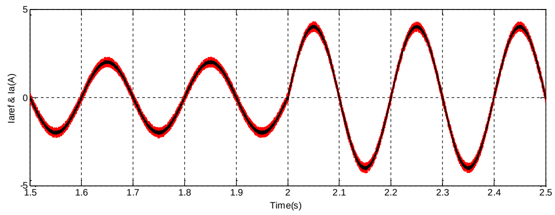
(a)



Speed.

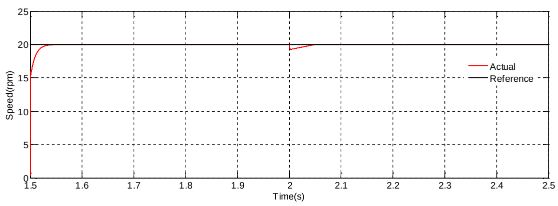


Torque

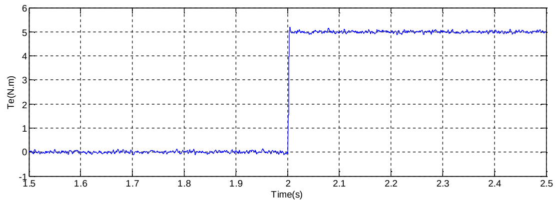


I_a, I_{aref}

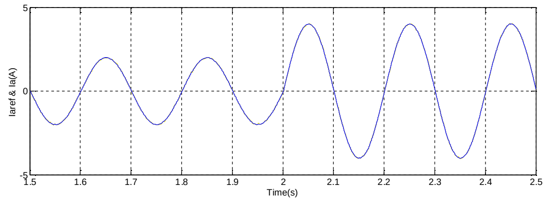
(b)



Speed.



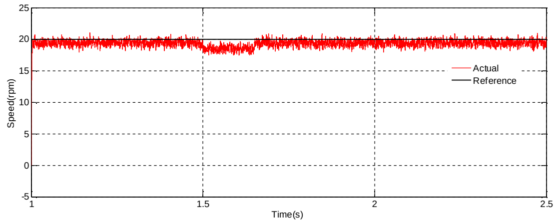
Torque



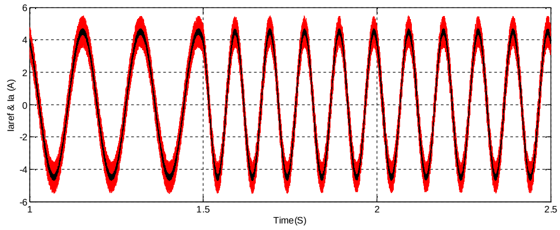
I_a ,I_{aref}

(c)

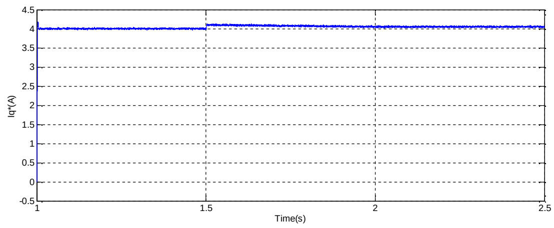
Fig. 13 Simulated speed and stator currents responses of a FSTP inverter fed IM drive for a sudden increase in load of 7 N.m at a speed reference 20 rpm using, (a) Traditional PI controller, (b) FLC, and (c)ANFIS controller.



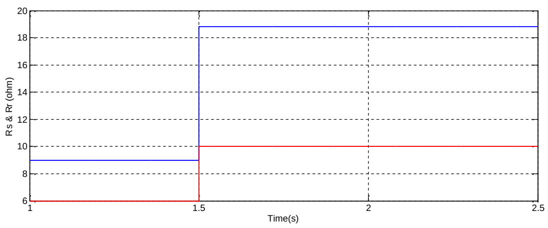
Speed.



I_a ,I_{aref}

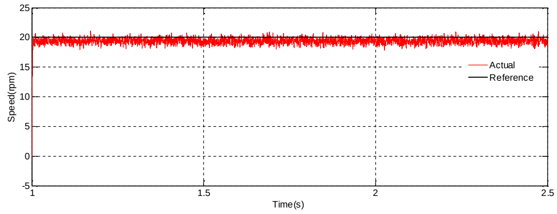


$I_{q\ ref}$

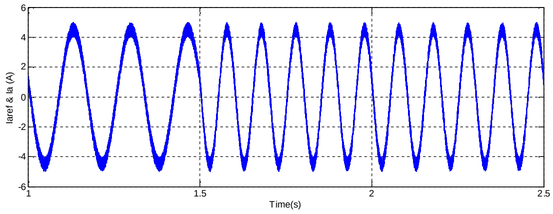


R_s &R_r

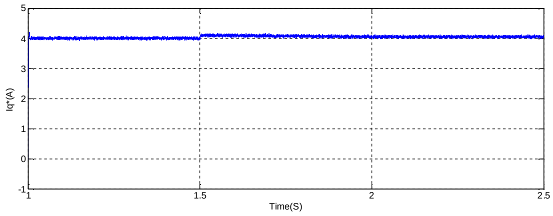
(a)



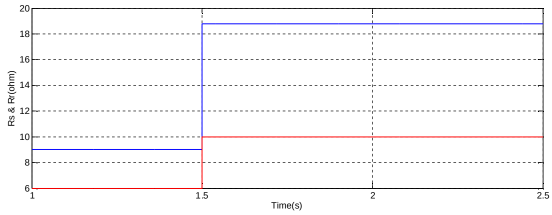
Speed.



I_a ,I_{aref}

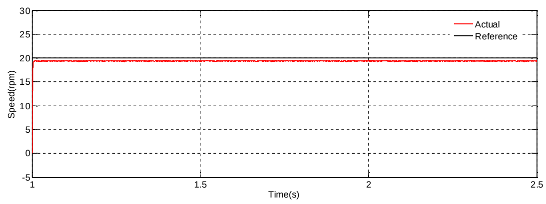


$I_{q\ ref}$

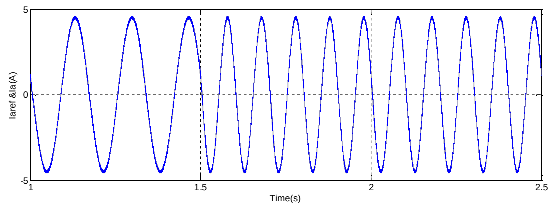


R_s &R_r

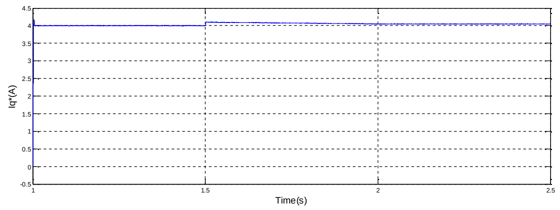
(b)



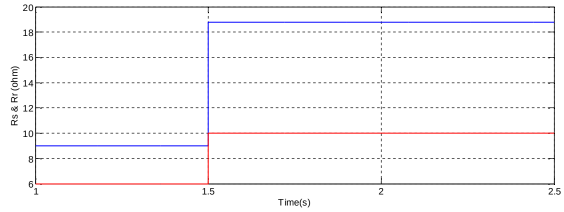
Speed.



I_a ,I_{aref}



I_{qref}



R_s &R_r

(c)

Fig..14.Simulated speed, stator currents, and quadrature current responses of a FSTP inverter fed IM drive for a sudden increase in stator and rotor resistances at a speed reference 20 rpm using, (a) Traditional PI controller, (b) FLC and (c) ANFIS Controller.

VI. CONCLUSION

In this paper, ANFIS-based IFOC for an IM drive fed by FSTP inverter has been effectively implemented by a matlab simulation. The dynamic speed response of the IM drive at low speeds is enhanced utilizing the ANFIS controller. And also The validity of the ANFIS has been analyzed in simulation at different speed reference following and load torque disturbances, especially at low speeds. Comparative simulation results shows that the ANFIS controller of a FSTP inverter fed IM drive is better than the FLC and PI controller under speed following, stack disturbances and parameters variations.

This demonstrates the great ability of ANFIS controller has the better transient and steady state responses under speed following performances, disturbances, and parameters variations rather than PI controller and FLC controller. The proposed IM drive system is likewise reasonable for cost effective low power industrial applications.

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