Virtual Development of Maximum Torque per Ampere by ANFIS with PI-Based Induction Motor Drive

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Abstract: This study established an innovative method for controlling the induction motor drive using a neural network with a fuzzy inference (ANFIS) with the help of the modeling of the machine. The suggested technique best considers dynamic reactions, such as those from electric vehicles. The magnetic flux of the rotor is then evaluated for the maximum torque per ampere to produce the required torque at different overshoots and settling parameters of torque and speed of the motor. After this design, the torque flux controller will be improved due to machine saturation. In a non-dynamic induction motor model with a changing field alignment, it is suggested in this Paper that ANFIS-based torque per ampere may lead to the development of a novel torque-flux controller strategy. This technique can boost the stator current while allowing for individuality and free operation. The innovation in some of the earlier contributions connected to this contribution and the current study related to M.T.C. based on vector control with torque ripple reduction strategies via adaptive ANFIS, FLC, and PI for induction motors is described in this paper. To achieve the maximum torque ripple reduction with the new control technique, an adaptive ANFIS controller coupled to the induction motor system is proposed. Additionally covered are comparison results and comparative tables.

Keywords: Maximum Torque, Induction Motor, Optimization, ANFIS, Fuzzy logic system, flux controller.

Received: May 22, 2022. Revised: October 3, 2023. Accepted: November 2, 2023. Published: December 22, 2023.

1. Introduction

The type of control method used and the degree to which torque and current ripple might be reduced by this strategy under transient and steady-state situations substantially impact the motion control of I.M. and drive operation. With a revolutionary maximal torque control technique with PI and vector modulation, the current study seeks to explore the minor ripple of torque & current of the harmonic stator of the drive. It does this by taking into account the proper gain values aimed at flux controllers & torque. Additionally, for a variety of torque & speed values, fixed switching frequency operation has been used in this contribution to reducing torque ripple and current under steady-state working situations. This method has become standard without innovations and uses adaptive fuzzy maximum torque (AFMT) controllers. This seeks to enhance the performance of a three-phase induction motor drive in terms of torque, speed, and stator current (IMD). Because of its straightforward operation, quick response time, and robustness, IMD's maximum torque control (M.T.C.) is frequently utilized in industry. However, minimum working speed and drawbacks, including unusual noise, bigger torque hormonic, and dynamic switching frequency, provide challenges for the Classical M.T.C. process of employing a P.I. controller. Therefore, it has been determined that maximum torque control has been estimated using an ANN-based controller instead of a traditional FLC controller to determine the speed of an induction motor and simulate it in the MATLAB/ Simulink environment. It is established that the projected arrangement performs better than the conventional one by comparing the performance of both models under various load perturbations. However, even it does not satisfy an industry requirement to control the induction motor. Then finally, ANFIS controllers were implemented for the same and compared. This proposed paper compares Adaptive Neuro-Fuzzy Inference System (ANFIS) and Proportional-Integral-Derivative controllers on a 3-Phase Induction motor. This study's primary objective is to show improved motor speed control utilizing an ANFIS controller, which also helps to sustain motor speed under varying loads. The maximum torque control scheme is one of the most complex fundamental methods for regulating machines' electromagnetic torque and flux. An effective adaptive controller is necessary for the torque and speed management of these drives in high-performance applications.

In this situation, ANFIS, an artificial neural network (ANN) and FLCC combination or hybrid, helps to implement maximum torque control and overcome the difficulties in high-performance drives (Fuzzy Logic Control). In this proposed method, the speed of the induction motor is controlled using ANFIS controllers, and its maximum torque control will be performed based on the output of the ANFIS and the estimated rate of the induction motor. The projected algorithms analyze the capacity of the Induction motor under various operating circumstances. In recent years the usage of Permanent Magnetic Synchronous Machines (PMSM) increased in place of Induction Motors because of their Torque, Efficiency, and high-power applications. However, the PMSM motors are an economic burden, and the magnetic property of the materials will produce inadequate torque at their origin, which causes the cost of the PMSM is increasing consistently. Therefore, these PMSMs have been replaced with induction motors due to their high magnetic induction property. This induction motor will be used for industrial and electrical traction drives [1], which has been evaluated to create research interest in progressive design and control concepts for induction motors. An induction motor can be controlled with the Field-oriented vector control (F.O.C.) method and direct torque control (D.T.C.) as per the Industrial standards to obtain better functional transient performance in all applications. The Induction Motor drive, controlled by the Direct Torque and Vector controlled methods, gives the constant flux magnitude at low values. As a result, an induction motor produces torque, providing an accurate dynamic performance with a standard power factor and higher efficiency.

The focused concept of torque of an Induction Motor is a part of the amplitude of flux and the stator current, which reduces the losses in power conversion. Using various optimization techniques [2], the flux levels are modified as a function of the electromagnetic torque. The regulation of flux limits the dynamic performance of induction motor drives [3]; hence, this methodology will focus on fast response applications like in an electric vehicle. As a result, the motor will operate at rated torque by limiting the time proportionate to each other. Many optimized control methods apply to the control of induction motors [4], which contain the minimization of active power loss and loss of the power factor. However, few research papers have considered determining the performance of the dynamic behavior of the induction motor during transient torque response. This paper proposes that the results are compared with traditional methods to compare the usefulness of the suggested algorithms.

Maximum Torque Control: The motor's overall magneto motive force (MMF) can be derived as

$F_{total} = N_a I_a + N_f I_f$ (1)

N_a is the coil of an armature, N is the armature field, f is the field coil turns, and I_a is the armature R.M.S. current.

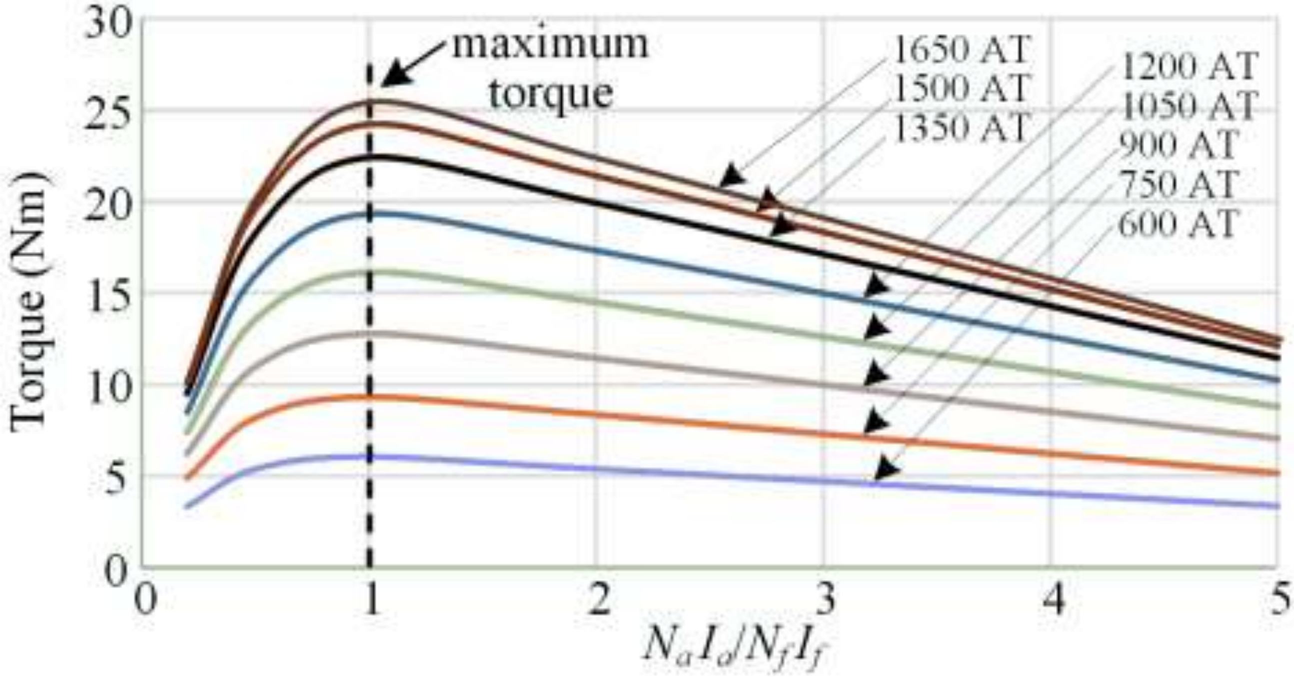

Fig. 1. Torque Vs. MMF ratio of overall magnetic EMF

Note that $2I_a = (ir^2\ qs + ir^2\ ds)1/2$. (1)

Rearrange (1) to the following:

$I_a + N_f\ N_a\ I_f = F_{total}\ N_a$. (2)

$T_e = \frac{3}{2}$ PLf $I_f \sqrt{2} I_a$. (3)

Substituting (2) into (3) and eliminating I_a yield

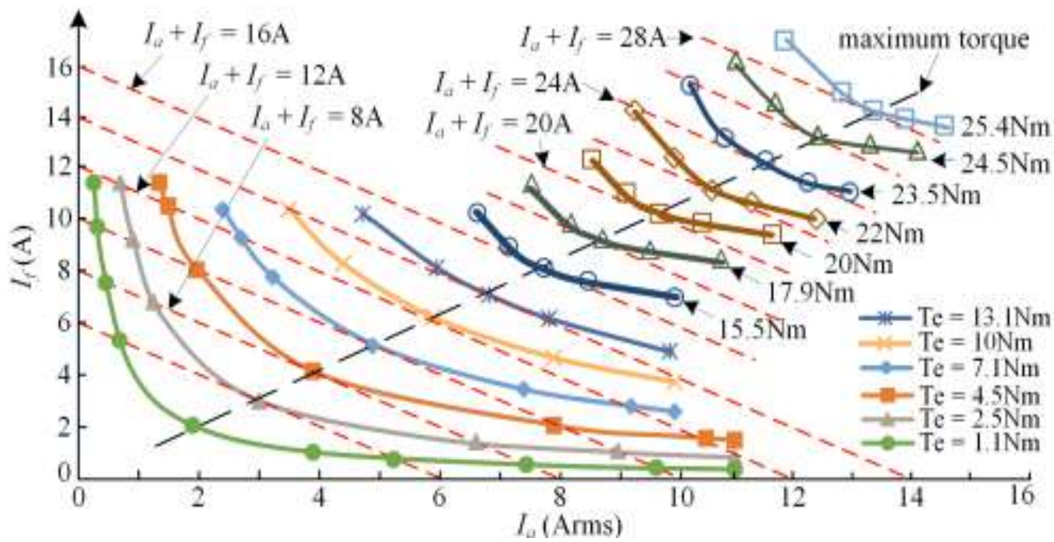

Fig. 2. Dynamic torque lines and steady state total-current lines.

$F_{total} = N_a - N_f N_a I_f$. (4)

By substituting $\partial Te/\partial I_f = 0$ for (4), the using I_a and I_f to determine maximum torque using the equation (5)

$I_f = F_{total} 2N_f$. (5)

Combining (3) and (5) and eliminating F_{total} yield

$I_a = N_f Na I_f$. (6)

When the total MMF is stationary, this MMF consequence will demonstrate that the maximum torque tracks when Na Ia = Nf If. The F.E.A. was utilized to confirm that the characteristics shown in Fig. 1 existed. It delivers the motor's computed torque relative to NaIa/Nf. The ratio if there are various Ftotal values. At Na Ia/Nf If = 1, maximum torque continuously arises for any F_{total}. Be warned that the saturation influence began to affect F_{total} at 1350 AT. The currents continually increase the resulting torque in a short amount of time.

However, the maximum torque arguments remained NaIa/NfIf = 1. Fig. 2 shows the continuous torque when If and Ia are seen as vertical and horizontal axes, respectively.

2. Methodology of the proposed system

A vector controller will be used to implement the maximum torque management strategy for the induction motor. The whole control system is shown in Fig. 3. The mechanical speed of the rotor is denoted by m. The outer loop is where the vector control is supposed to be. The PI control and the armature currents on the q-axis affect velocity accuracy ($i_r q_s$). The default value of the d-axis armature current signal (ir ds) is zero. The internal loops determine the armature current. The synchronous frame current [5], [6] generates the armature current.

Furthermore, the hysteresis current controller maintains a constant field current because i_r ds is by default set to zero and ir qs is equal to $2I_a$. Therefore, to get the most incredible torque, the current field command I_f is considered at ir qs / 2. As shown in Fig. 3, a limiter and an absolute function (abs) were added and applied while evaluating I f to prevent it from returning zero or a negative result.

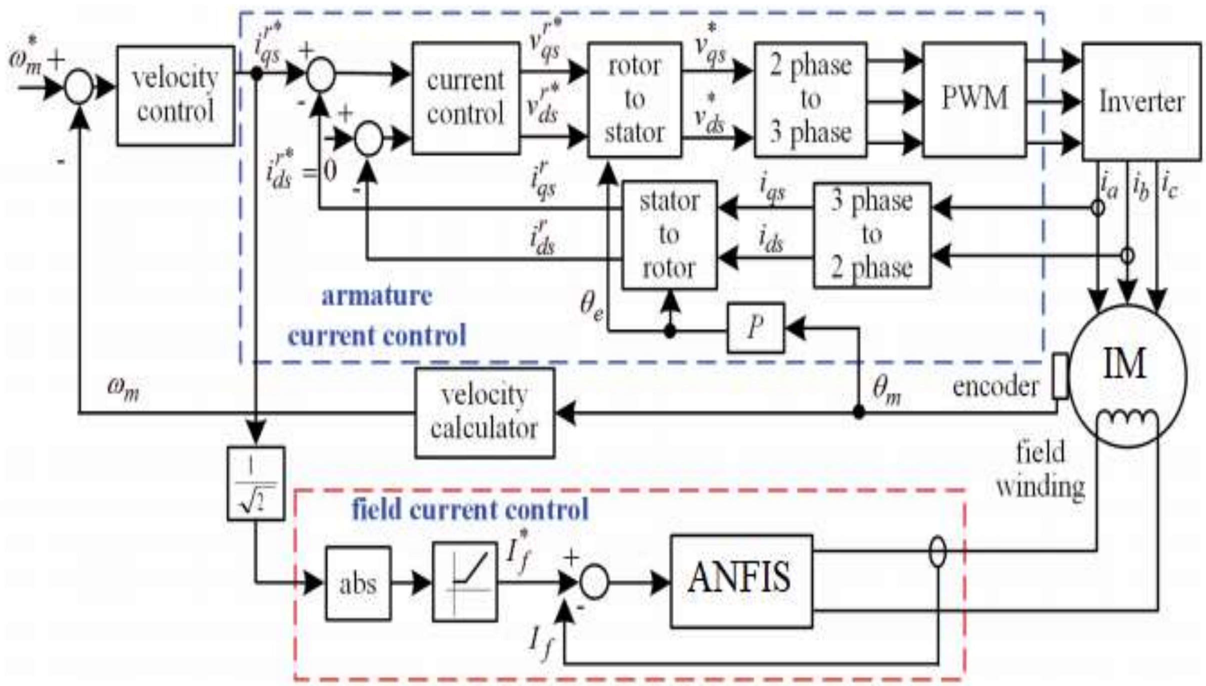

Fig. 3. Block diagram of M.T.C. of Induction Motor.

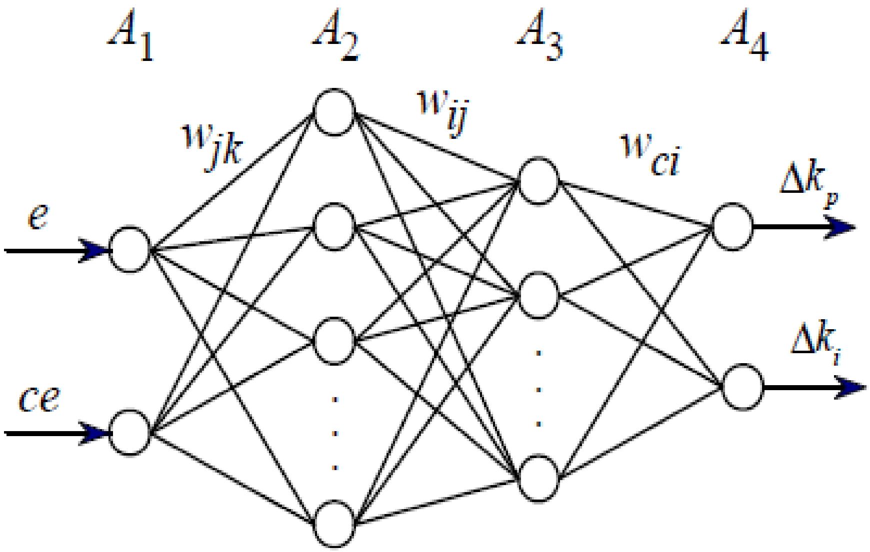

Fig. 4 The construction of ANFIS

When an induction motor operates under load, its basic structure with the fuzzy controller is linked with adaptive neural systems to determine its speed and torque [7]. Initially, a rule base system will be used to construct the fuzzy logic controllers. This system links the input variables to the properties of the output model. Therefore, planning and creating the rule base system to improve K.P. and Ki are taking the relevant factors into account.

A smaller K.P. is required for larger values of e, whereas a lower K.P. is necessary for smaller values of ec. A large K.P. is required for e-e (c>0), but a small K.P. is required for e-e (c0). To prevent the overload, high values of K.T. default to zero. The steady-state error is reduced since K.T. is active for fewer values of 'e' and is more substantial when 'e' is less. So, receiving the tuning rules for K.P. and K.T. as Tables is possible.

TABLE 1: Fuzzy logic rule base membership system

E(pu) / CE(pu)	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	PS
NM	NL	NL	NL	NM	NM	ZE	PS
NS	NL	NL	NM	NS	ZE	PM	PM
ZE	NL	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NS	PS	PS	PL	PL	PL	PL

$$\begin{cases} K_P = K_P^* + \dfrac{\sum_{j=1}^{n} \mu_j\ (e,e_c)\ \Delta K_{Pj}}{\sum_{j=1}^{n} \mu_j(e,e_c)} \\ K_P = K_i^* + \dfrac{\sum_{j=1}^{n} \mu_j\ (e,e_c)\ \Delta K_{Ij}}{\sum_{j=1}^{n} \mu_j(e,e_c)} \end{cases} \qquad (7)$$

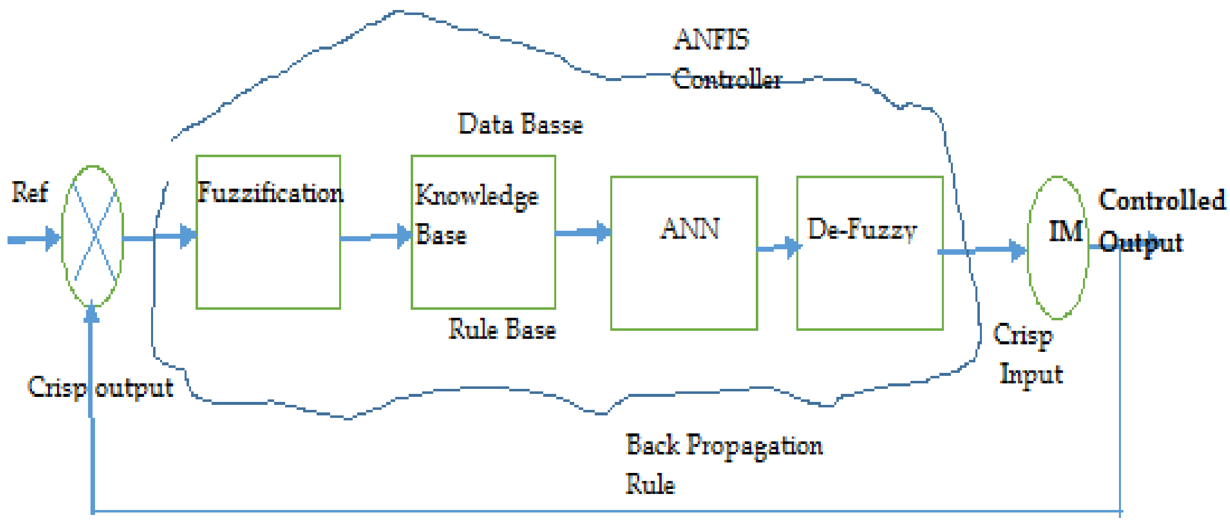

Fig 5. Block diagram of ANFIS Control Scheme

In the MAX-MIN design process, the fuzzy inference system (F.I.S.) [8] has a significant impact. In real-time applications, the inference must transform the vague control achievement into a precise control action. The fuzzy variable is considered to defuzzify using the centre of gravity (C.G.) approach and converted to physical values.

A suitable controller is essential when creating feedback control for a dynamic Induction Machine system because it considers the maintenance of all disturbances and quickly restores the system to its creative condition. The mathematical structure of the induction motor and the mathematical model of the controller are the two stages of design that may be advised in the building of the controller's (ANFIS) scheme [9] through [12]. The simulation method can then simplify it and make it easy to analyze. Eq (3), established in the Simulink model, describes the torque representation in the system mathematically. The induction motor's speed control has been the primary goal of this work's ANFIS controller design. Fig. above displays the block diagram of an induction motor. The error and the change in error are represented using Eqs. (8) and (9) have been recognized as inputs to the ANFIS controller.

$e(k) = \omega ref - \omega r$ ----(8)

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

Here ω_{ref} is the reference speed, ω_r is the actual rotor speed, e(k) is the error, and $\Delta e(k)$ is the change in error.

The fuzzy system transforms the discrete data into linguistic variables, essential for producing the inputs for rule-based membership systems. Based on previously acquired information or comprehension, 49 rules are written. The neural networks are connected to this well-designed rule base membership function [13]. With back-propagation, the neural networks use the method to choose the appropriate rule base. To select a good rule base, the control signal training must be developed and designed [14]. Finally, the control signal is generated to achieve the best outputs once the relevant rules have been chosen and activated.

3. Results & discussions:

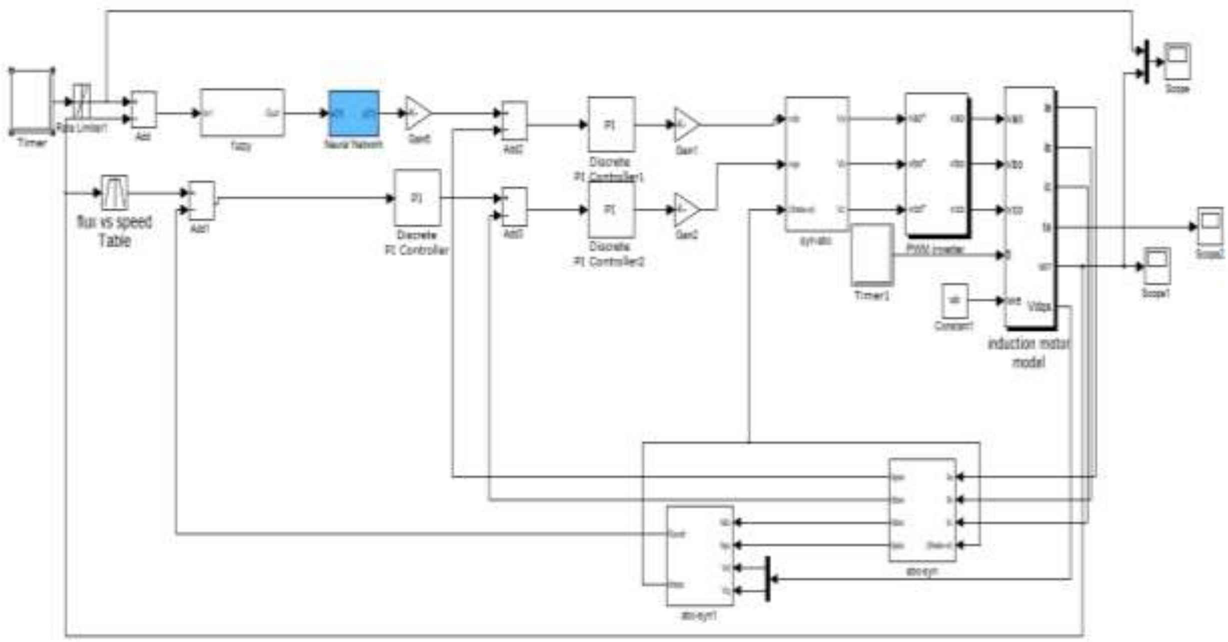

Fig 6 Simulation Diagram of Induction motor with ANFIS

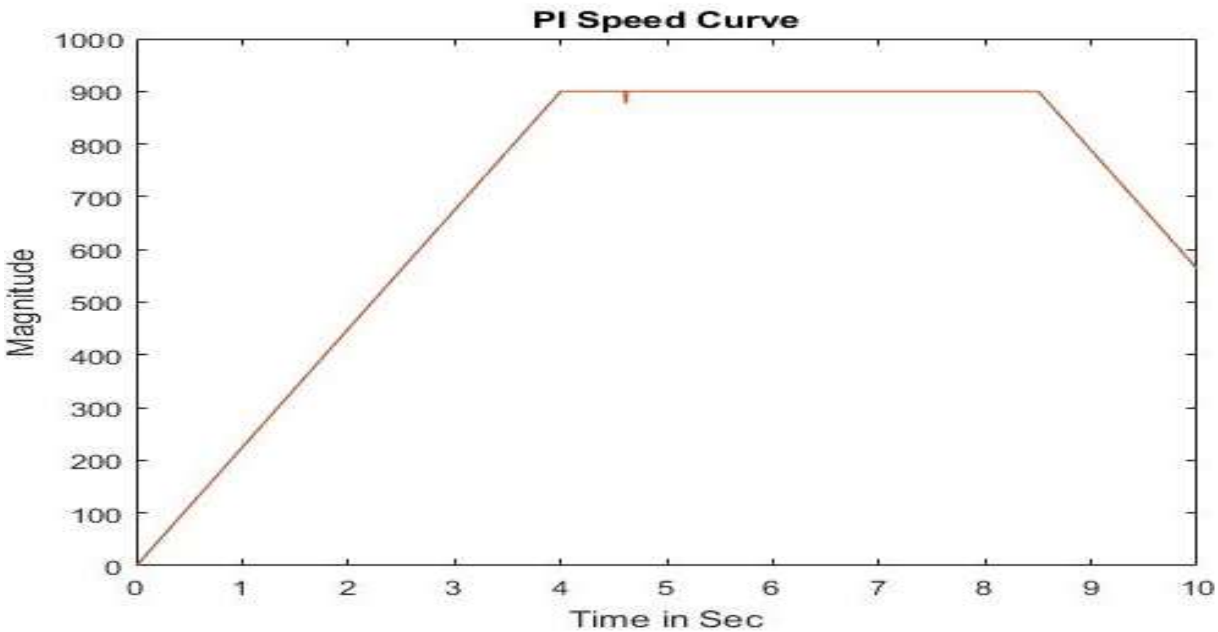

Fig 7 (a) Conventional (PI) based essential reference speed & real speed

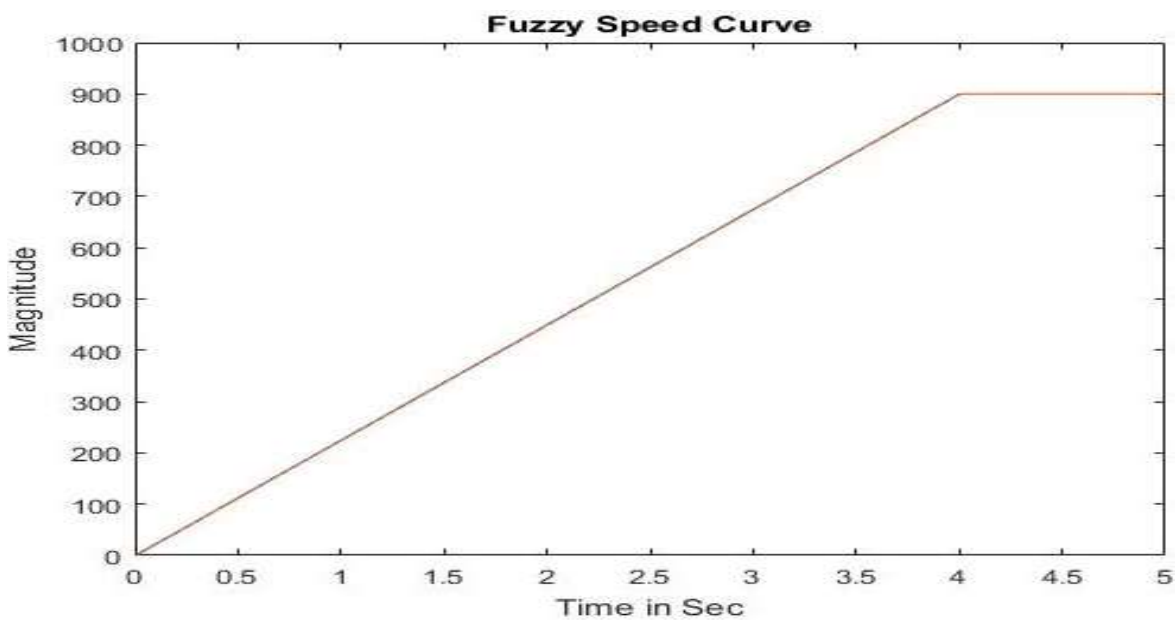

Fig 7 (b) ANFIS-based essential reference speed & actual speed

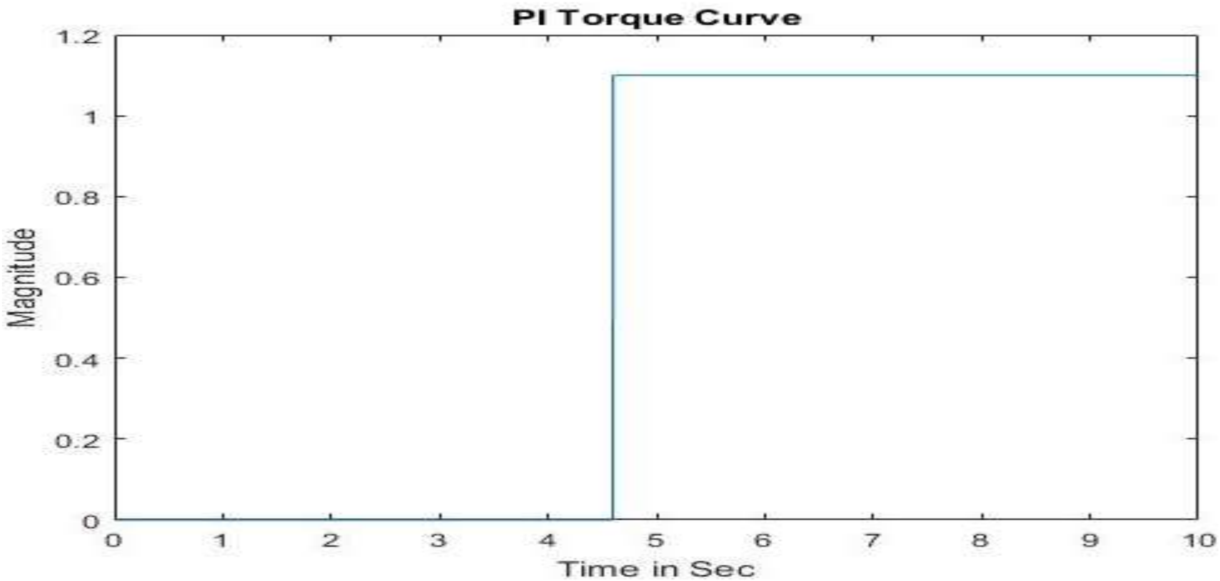

Fig 8 (a) Conventional (PI) controller based torque

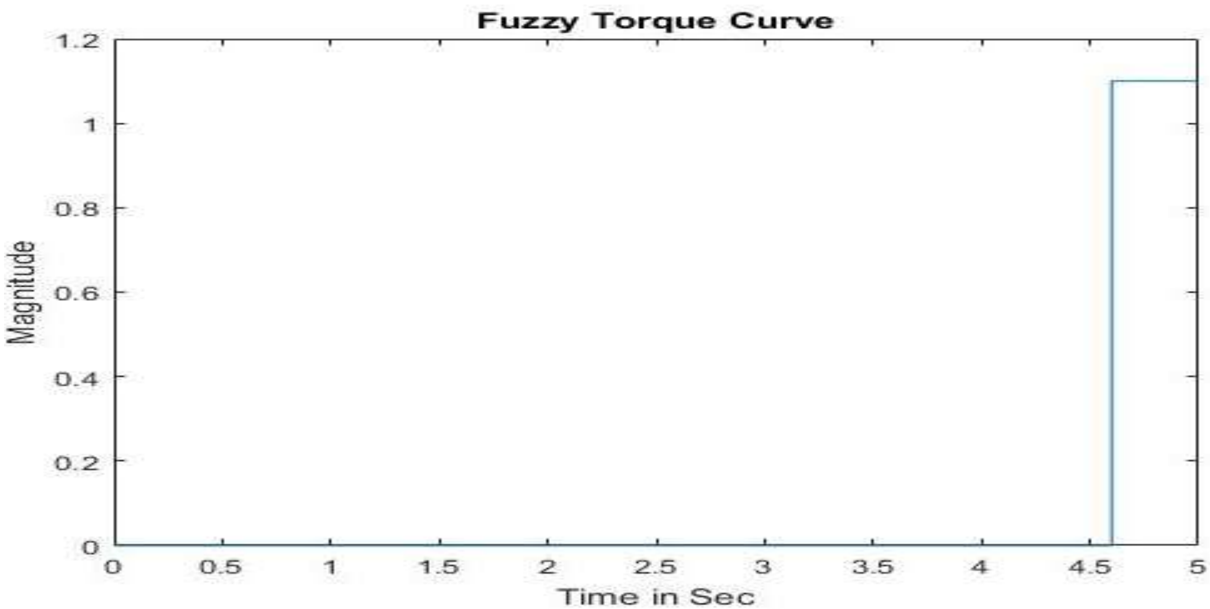

Fig 8 (b) Fuzzy-based torque

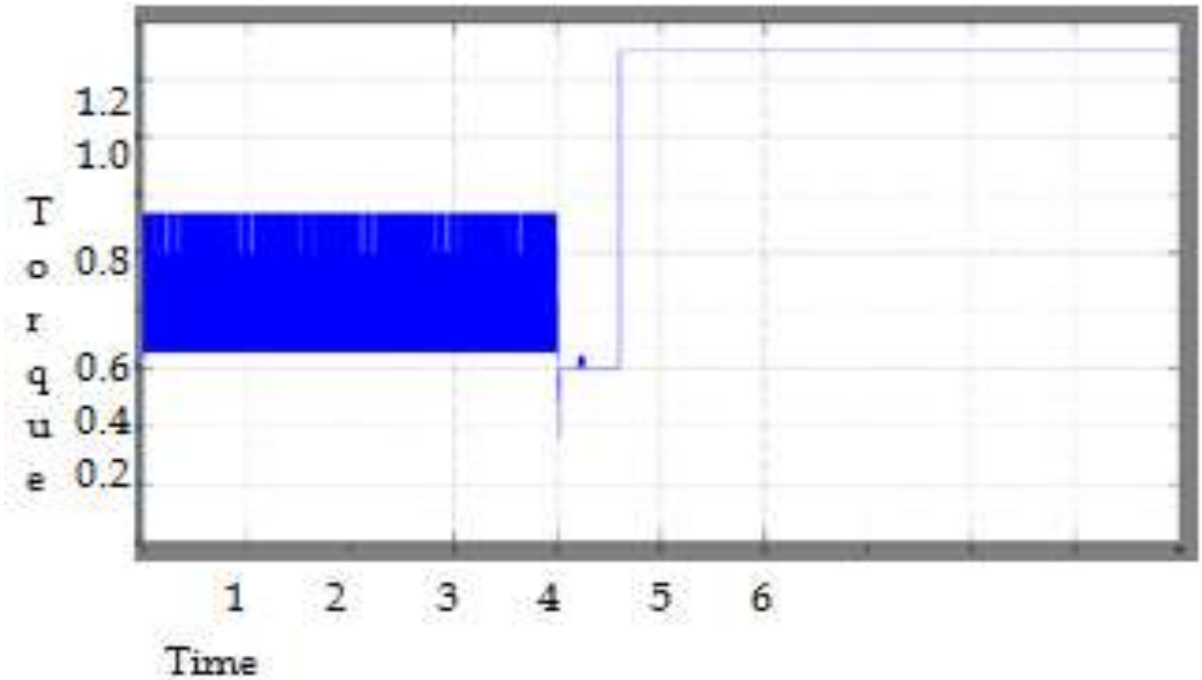

Fig 8 (c) ANFIS-based torque

As seen in figures 7 and 8, the characteristics change as a function of speed and load torque, with a speed of 900 [rpm] at 0.1 [sec] and a load torque of 5 [N.m] varying between 0.6 [sec] and 0.8 [sec]. The information regarding speed estimation compared to the PI ANFIS controller is shown in Fig. 7(a). Torque is created in Fig. 8 (a). The progression of fig. 8(a) to explore is shown in fig. 8(b & c). Figure 8 (a) demonstrates that a portion of the speed is increasing, and Figure 8 (b) demonstrates that the load torque is changing in some way. The typical PI controller has a little overshoot, whereas the proposed ANFIS controller stabilizes speed more quickly in this work. The parameters of maximum torque control in forward and reverse operation are shown in Fig. 8. This study shows that total torque control boosts speed faster and is more accurate and efficient than the conventional method. Fig. 7 displays the response characteristics of the input speed-changing principle. More so than the typical approach, the suggested maximum torque control also demonstrates outstanding qualities.

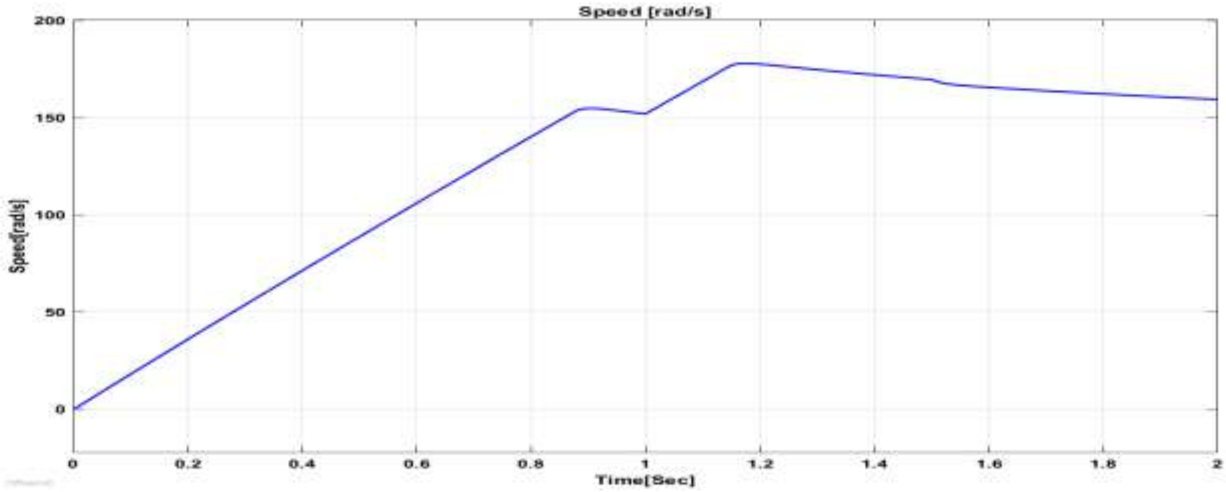

Fig 9: Speed variations of an induction motor with the P.I. controller

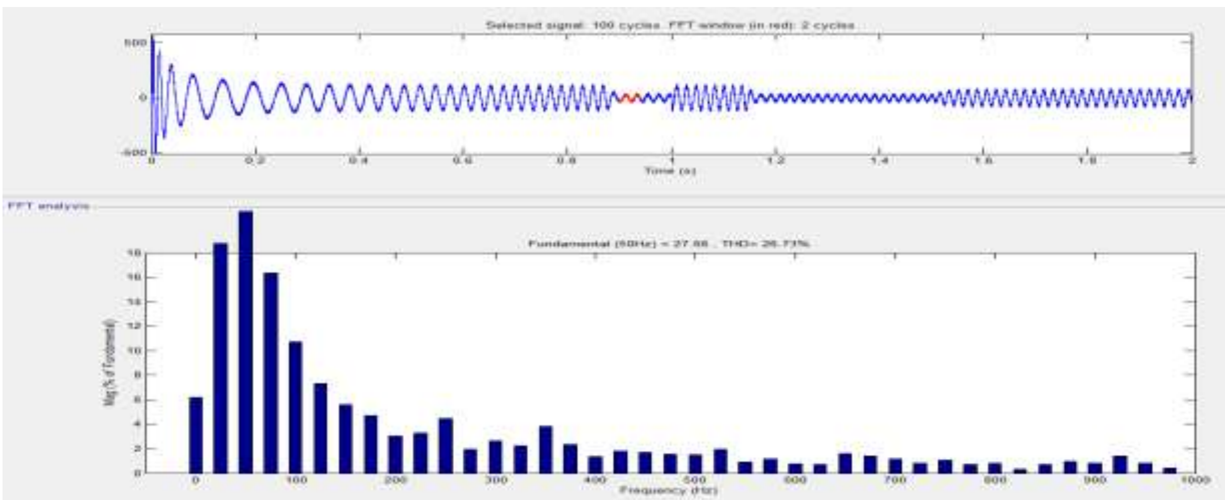

Fig 10: Induction motor THD (26.73%) with PI controller

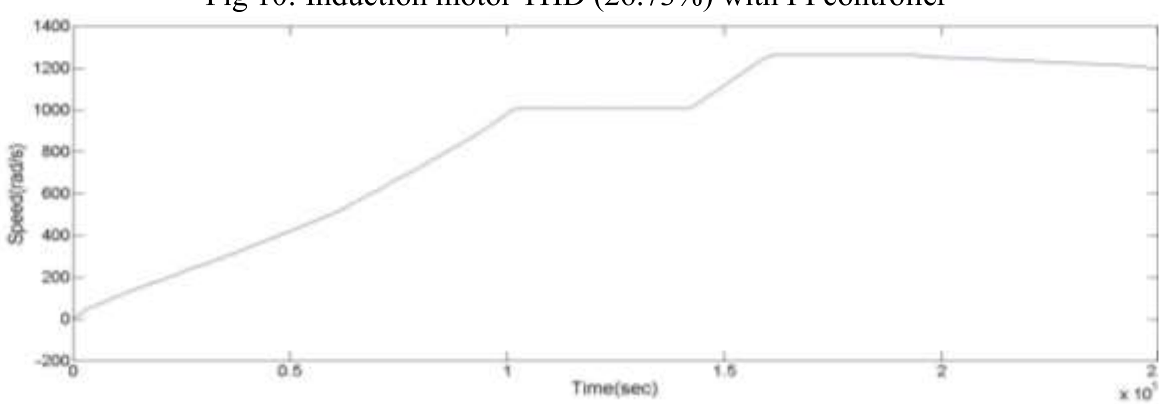

Fig 11: Induction motor speed inaccuracy using FLC controller

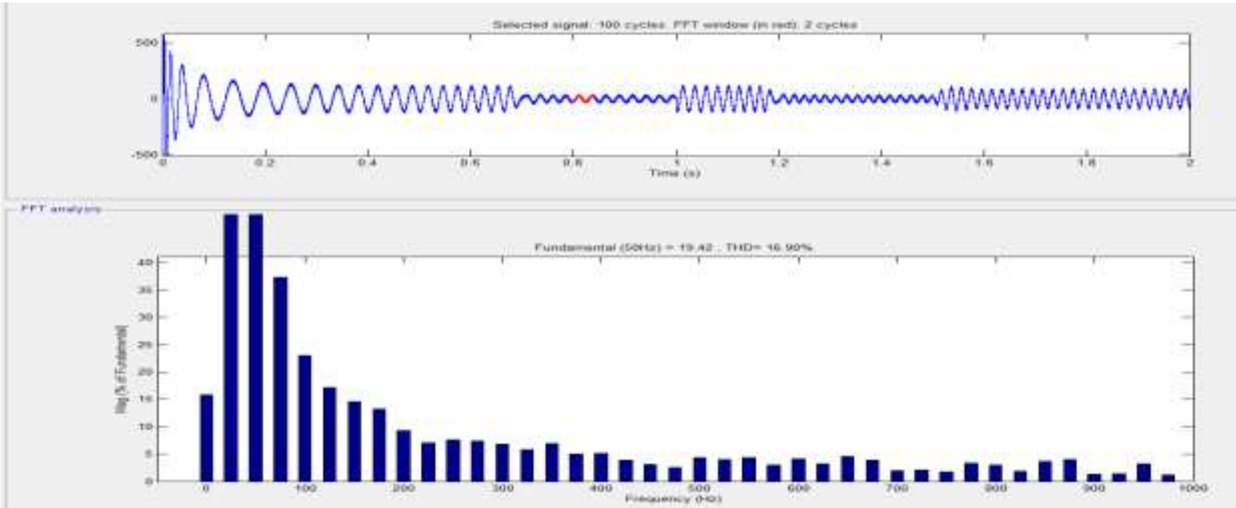

Fig 12: Total harmonic distortions of an induction motor with FLC (T.H.D=16.90%)

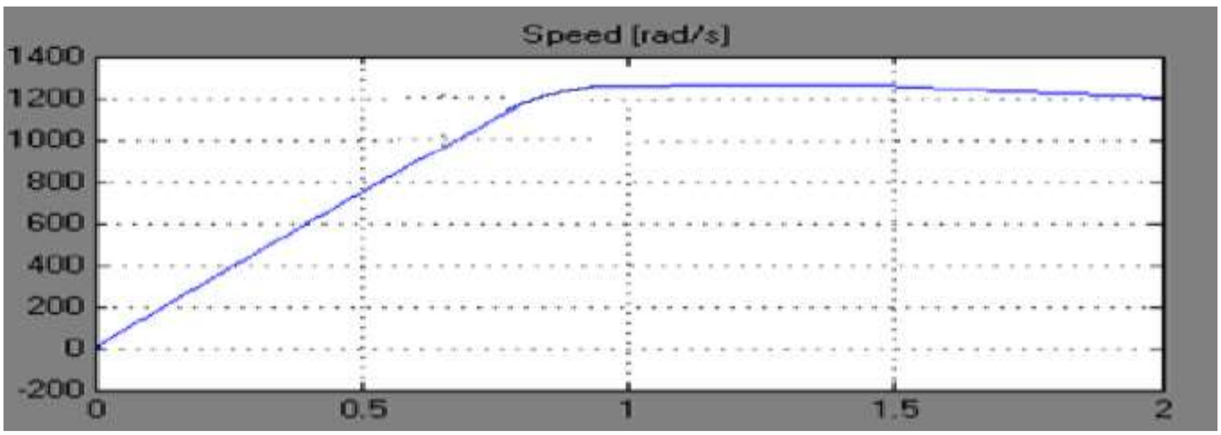

Fig 13: Speed problem with the induction motor's ANFIS controller

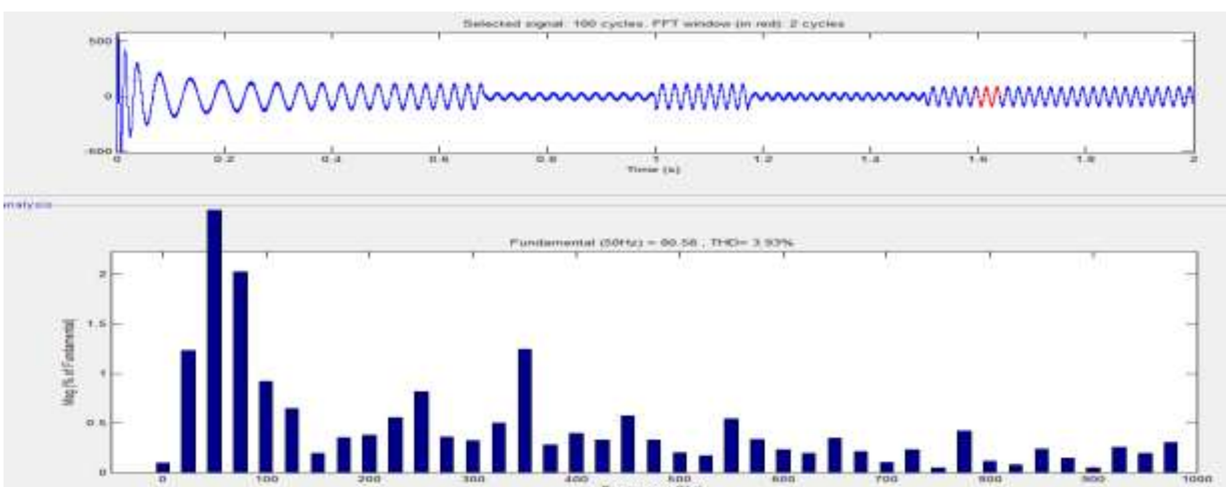

Fig 14: Total harmonic distortions of an induction motor with adaptive ANFIS (T.H.D=3.93%)

Discussions:

Table 2: Comparative Dynamic Speed Analysis of an Induction Motor with Various Artificial Intelligent Controllers at Magnetizing Inductance: 34.7e-3 H

S.No	Type	%Overshoot	Settling Time (Ts)	Total Harmonic Distortion (THD)
1	Zero Controller	20.1	2.13	46.91
2	PI Controller	12.3	1.83	26.72
3	Fuzzy Logic Controller	11.1	1.65	7.92
4	ANFIS	8.9	0.85	3.91

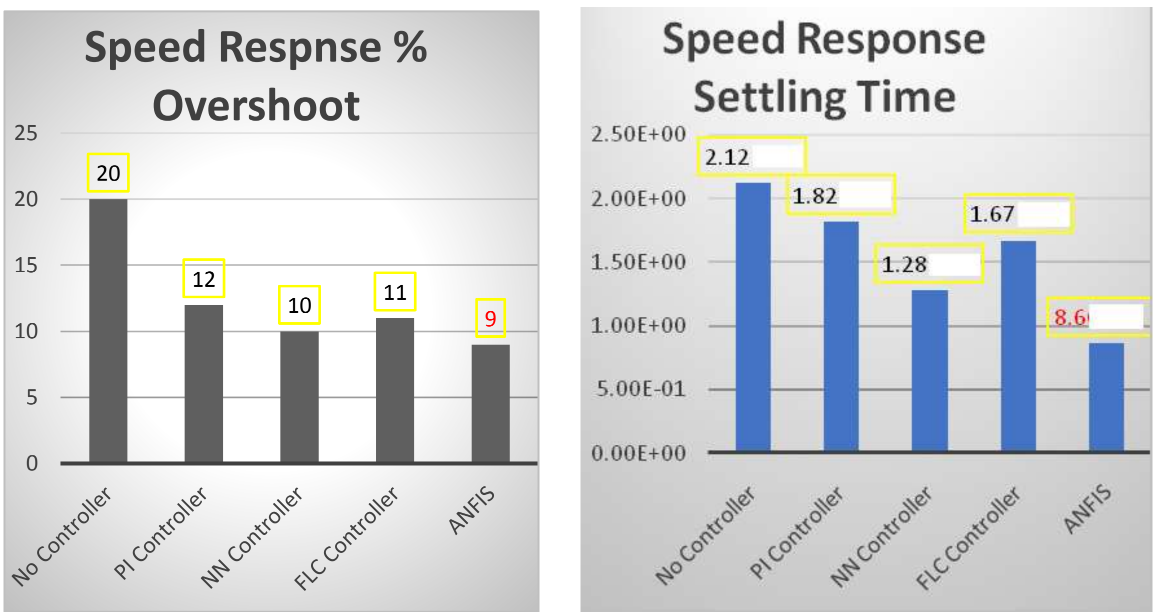

Fig 15: Comparison of the active torque response of an induction motor using several AI controllers at 34.7e-3 H

Study: From comparing the findings, it can be shown that the ANFIS Controller has the least amount of overshoot and settling time compared to other traditional controllers.

Table 3: determining the induction motor's setting time at various load circumstances while using a reference speed of 150 rad/sec

Type of Controller	Different Loads/sec			
	0 Nm (Tm)	2 Nm (Tm)	50 Nm (Tm)	100 Nm (Tm)
PI Controller	2.27	2.32	2.37	2.41
Fuzzy Logic Controller	0.71	0.71	0.83	1.02
ANFIS	0.23	0.25	0.24	0.26

4. Conclusion

This proposed thesis describes the novel design strategy that integrates the linear induction motor drive with the ANFIS controller. In MATLAB software, the entire driving system is created and modeled. The outcomes are then examined. The induction motor drive with ANFIS controllers demonstrates how the robust and quick response considerably lowers the PI controller's speed and torque ripples during startup, load perturbation, and speed reversal. The same criteria must be considered when creating a control strategy to provide the highest possible torque. Furthermore, these operations preserve a relatively steady flux response. The performance index from tables II and III show that the ANFIS torque controller, which can take the place of the traditional PI controller, operates satisfactorily.

Additionally, by varying the gain of the speed-PI controller, experimental evidence is shown for the adaptability and robustness of the ANFIS system. The control strategy created for the lower flux weakening zone ensures that the maximum amount of torque is being used. Additionally, it can withstand changes in parameters, including those brought on by saturation. When the suggested ANFIS controller is utilized, the findings demonstrate perfect decoupling and enhanced flux reactivity. The simulation-based comparative performance analysis was supported under various functional environments, as shown in Tables 2 and 3. The ANFIS controller system outperforms linearized induction motor drives based on PI-torque controllers without sacrificing its decoupling capabilities. The suggested controller is therefore shown to be appropriate for applications demanding high-performance industrial induction motor drives with torque-sensitive loads when employed as a torque regulator. The proposed strategy makes it incredibly simple to think through an induction motor's dynamic response. The linear estimation magnetic system offers the maximum torque per ampere at the desired torque when used in conjunction with the ANFIS.

The suggested design will also improve the torque flux controller per machine saturation. The proposed method offers accurate output side replies from the ANFIS controller. By analyzing the constant flux using field-oriented control, ANFIS controllers have shown that they are superior to traditional controllers.

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