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FUZZY AND ANFIS BASED SOFT STARTER FED INDUCTION MOTOR DRIVE FOR HIGH PERFORMANCE APPLICATIONS

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ABSTRACT

Soft starters are used with induction motors in blowers, fans, pumps and the crane hoist drives. AC voltage controllers are used as soft starters in induction motors for starting and to adjust its speed. This paper highlights the intelligent controllers such as Fuzzy and Neuro fuzzy based ac voltage controllers to generate the firing pulses for appropriate thyristors for any given operating torque, speed of the motor and the load. FUZZY and ANFIS (Adaptive Neuro Fuzzy Inference System) models have been designed to achieve the proposed algorithm. MATLAB/SIMULINK package was used to simulate the proposed methods. Simulation results presented in this paper explain the advantages of proposed soft starting methods over conventional method. The advantages of intelligent methods proposed in this paper are its simplicity, stability, accuracy and fast response.

Keywords: soft starter, AC voltage controller, FUZZY, ANFIS, thyristor, induction motor.

I. INTRODUCTION

Due to the increased number of induction motors in industry applications and residential appliances especially air conditioners, many utilities and industry firms are affected by the high inrush current that may cause important failures. The problem is more severe in areas where the loads represent a high portion of the power demand. If soft starters are substituted in such applications, reduction of inrush current can be achieved and on the other hand, energy saving can also be possible. Energy savings by voltage control through soft starter is achieved by reducing the applied voltage if the load torque requirement can be met with less than rated flux. This way, core loss and stator copper losses can be reduced [1,2]. In soft starter fed induction motor system, smooth acceleration with reduced stress on the mechanical drive system is achieved. This is due to high starting torque hence increase the life and reliability of belts, gear boxes, chain drives, motor bearings and shafts [3]. Smooth acceleration reduces also stress on the electrical supply due to high starting currents meeting utility requirements for reduced voltage starting and eliminating voltage dip and brown out conditions [4].

Soft starters allow the machine to start, vary its speed and stop with minimum mechanical electric stresses on the equipment. This can be done by appropriate adjustment of the induction motor terminal voltage. However, adjusting the voltage for a given operating condition of speed and torque is not a simple task. To adjust the voltage, the firing angle α of the thyristors shall be calculated for each operating condition. Firing angle is a nonlinear function of motor speed and torque and it is very difficult to find the exact value of α for any motor speed and torque. Some methods of closed loop control technique to achieve this have been developed and presented in [5]. In this method, speed sensor is required to acquire the signal feedback. Some researchers have proposed and developed a method of optimal soft starting without a speed sensor in which sensing of thyristors voltages is very much required [6,7].

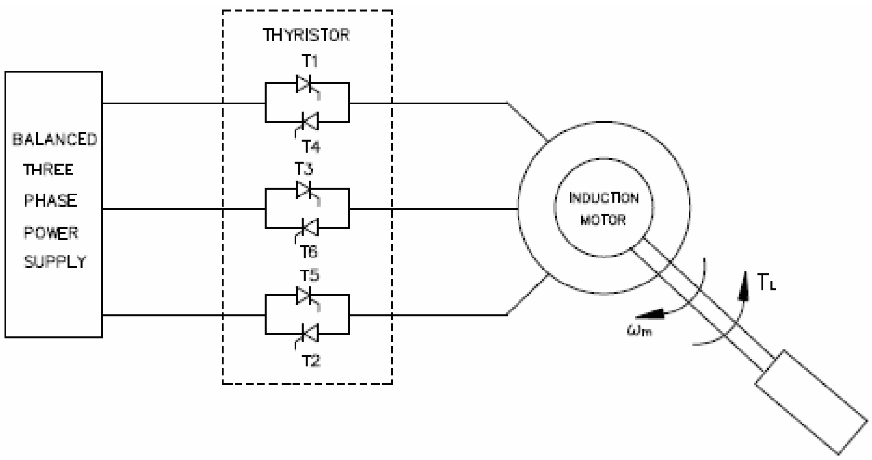

Figure-1. Basic Soft Starter with induction motor.

This paper proposes a new adaptive neuro fuzzy based soft starting strategy for selection of firing angles for thyristors in voltage controlled induction motor drive system. The proposed strategy is mainly operates in open loop and speed and voltage sensors are not required. Moreover, sensing of voltage across thyristors is also not required. In this paper simulation procedures and results have been presented for the proposed method and they have been compared with the conventional soft starter results. The proposed soft starter strategy may be recommended for industrial requirements such as compressors, air blowers, pumps, air conditioners etc.

II. PRINCIPLE OF SOFT STARTER

A soft starter is an ac voltage controller in which the voltage is adjusted through the setting of the thyristor firing angle α. Figure-1 shows the typical schematic of a symmetrical voltage controller or soft starter. Each phase has two thyristors and which are connected in anti-parallel connection. Thyristors in this configuration are fired according the sequence of firing pulses. Figure-2 shows the firing sequence of six thyristors in soft starter circuit. From this Figure, it should be noted that at least two thyristors must conduct simultaneously to allow current to flow through the load and that the firing angle α is measured from the zero crossing of phase A voltage.

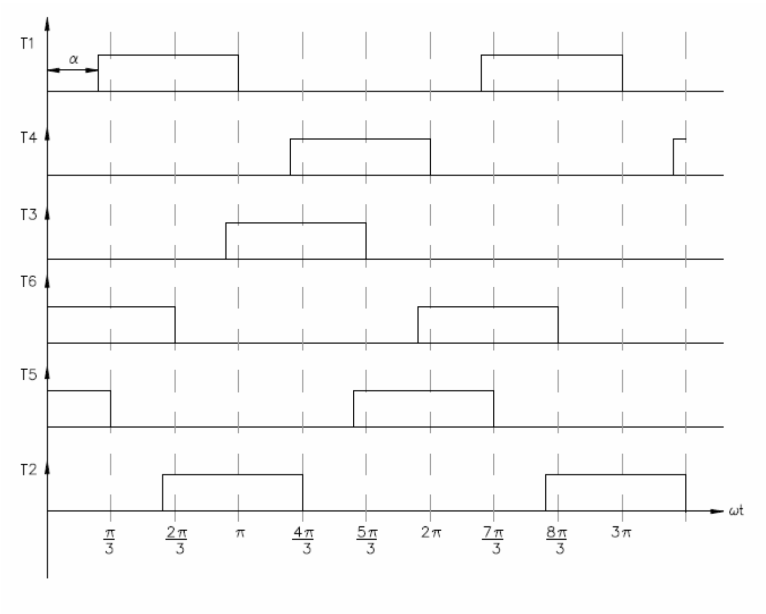

Figure-2. Firing sequence of thyristors.

III. FUZZY MODEL

The proposed fuzzy system is shown in Figure-3. Mamdani model is chosen from SIMULINK to simulate fuzzy based soft starter algorithm. Rules have been written clearly to incorporate two inputs such as torque and speed and output of thyristors firing angle. Membership functions chosen are triangular membership functions. Figures 19 and 20 are triangular membership functions for inputs torque and speed.

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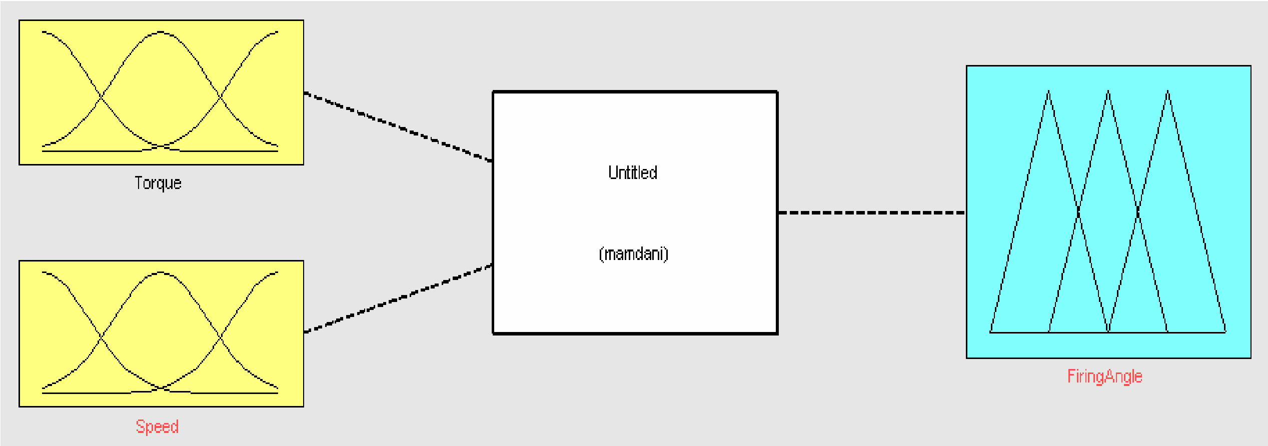

Figure-3. Fuzzy model for thyristors triggering.

IV. ANFIS MODEL

The ANFIS neuro-fuzzy system [8,10,11] was used to implement the proposed model. First, it uses the training data set to build the fuzzy system in which, membership functions are adjusted using the backpropagation algorithm, allowing that the system learns with the data that it is modeling. Figure-4 shows the network structure of the ANFIS that maps the inputs by the membership functions and their associated parameters, and go through the output membership functions and corresponding associated parameters. These will be the synaptic weights and bias, and are associated to the membership functions that are adjusted during the learning process. The computational work to obtain the parameters and their adjustments is helped by the gradient descendent technique.

In this paper, the ANFIS system was used at the MATLAB environment. Its operation can be resumed in two steps:

1. The set of membership functions has to be chosen: their number and corresponding shape.
2. The input-output training data is used by the ANFIS. It starts making a clustering study of the data to obtain a concise and significant representation of the system's behavior.

It is important to note that the system has a good modeling if the training set is enough representative, i.e., it has a good data distribution to make possible to interpolated all necessary values to the system's operation. The clustering technique used was the fuzzy c-means. After setting the number of clusters that are estimated to compose the data, the cluster's centres are searched in an iterative way based on minimizing an objective function. This represents the distance between a data value to the cluster's centre. As we do not know how much clusters exist, or the number of rules composing the neuro-fuzzy compensator, we used the technique of subtractive clustering to estimate the number of clusters.

The ANFIS model which is used for the calculation of firing angle of the appropriate thyristor as a function of the motor speed (ω_m) and torque (T_e), has two input variables (T_e and ω_m) and one output variable (α). Since the angle α is a nonlinear function of the motor speed and torque, then the tansigmoidal function is the most appropriate to model the ANFIS as given in equation (1).

$$f(n) = 2/(1+e^{-2n}) - 1. \qquad (1)$$

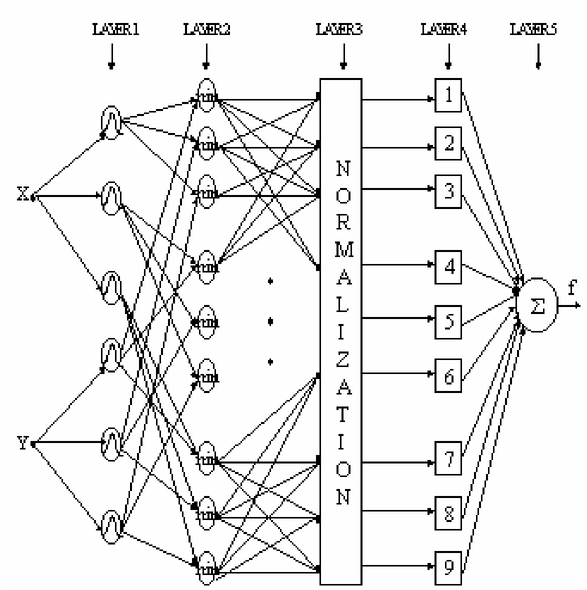

Figure-4. Neuro-fuzzy controller structure.

The layers shown in Figure-4 are defined as follows:

- Layer 1: Every node in this layer contains membership functions.
- Layer 2: This layer chooses the minimum value of two input weights
- Layer 3: Every node of these layers calculates the weight, which is normalized.
- Layer 4: This layer includes linear functions, which are functions of the input signals.
- Layer 5: This layer sums all the incoming signals.

IV. SYSTEM MODELING

Figure-5 shows the proposed system and which is modeled mathematically using software package MATLAB/SIMULINK. 1 H.P., 415 V and 1446 r.p.m. motor was used for simulation and the data output taken from the simulation was used for training in ANFIS. Parameters of motor are given in APPENDIX.

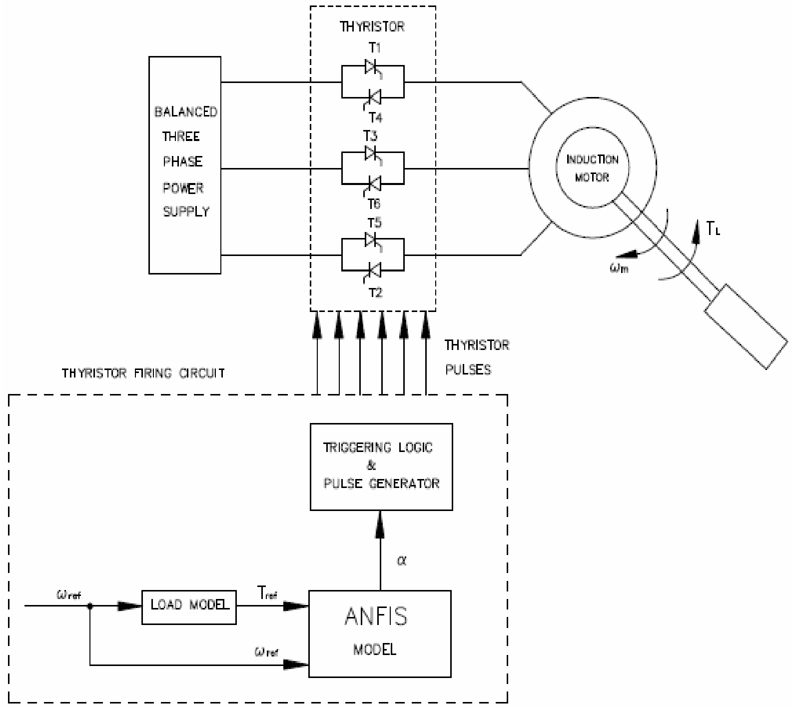

Figure-5. Proposed ANFIS based soft starter strategy.

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It is important to note that the system has a good modeling if the training set is enough representative, i.e. it has a good data distribution to make possible to interpolate all necessary values to the system's operation. After set the number of clusters that are estimated to compose the data, the cluster's centers are searched in an iterative way based on minimizing an objective function. This represents the distance between a data value to the cluster's center. In this paper, the technique of subtractive clustering has been used to estimate the number of clusters.

V. SIMULATION PROCEDURE

The ANFIS model and the drive system have been implemented with MATLAB / SIMULINK package. ANFIS considers two inputs such as torque and speed of the motor and one output namely firing angle of the thyristors. Iterative training of the neuro fuzzy system has been done to achieve the desired output. The presence of this iteration comes from the capability of the training program to simulate the system and, after a pre-defined simulation time, to obtain the simulation results and use them to the training. Training data was obtained from the simulation of complete induction motor drive system. Fig.6 shows the flowchart of training process in which the output of the training block is the compensating signal. The compensated firing angle signal is produced and loaded into the system as shown in the dotted line in flowchart. In this flowchart, N represents the number of iterations and 'i' represents iteration counter. The maximum number of N represents in this paper is stopping criterion. When 'i' reaches N, the training program will be stopped and the results can be taken.

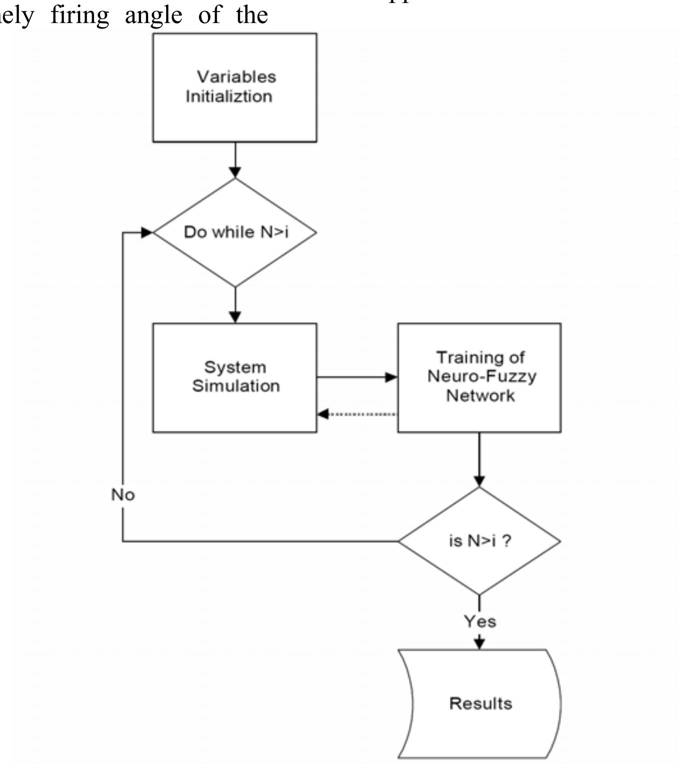

Figure-6. Flow chart for proposed algorithm.

VI. RESULTS AND DISCUSSIONS

Simulation results of the proposed ANFIS system are shown from Figure-7 to Figure-12 and from Figure-14 to Figure-17. Figure-7 shows the actual and ANFIS output of firing angles in which ANFIS output exactly matched with the actual values. Fig. 8 shows the zoomed view of Figure-7 in which the minor difference between the actual an ANFIS data has been shown. Similarly, Figure-9 to Figure-12 shows the ANFIS output and actual data comparison and zoomed view of respected figures for the speed of 0.5 and 0.8 per unit values respectively. Simulation results of direct online starting of induction motor are also produced in this paper to validate the results. They are shown in Figure-13 and Figure-14. Figure-13 shows the torque and speed of induction motor. Figure-14 shows the locus of stator current rms during start up at direct online starting. Figure-15 shows the two axes voltages and currents of motor at the time of starting by using proposed soft starter methodology. Figure-16 and Figure-17 show the surface plots of the Fuzzy and ANFIS models in which two inputs such as torque and speed and one output firing angle are clearly shown. Figure-18 and Figure-21 show the rule formation to develop the proposed models. Figure-19 and Figure-20 are membership functions of motor torque and motor speed used in Fuzzy system. They are triangular shaped membership functions. Similarly Figure-22 and Figure-23 are membership functions of motor torque and motor speed used in ANFIS system. They are Bell shaped membership functions.

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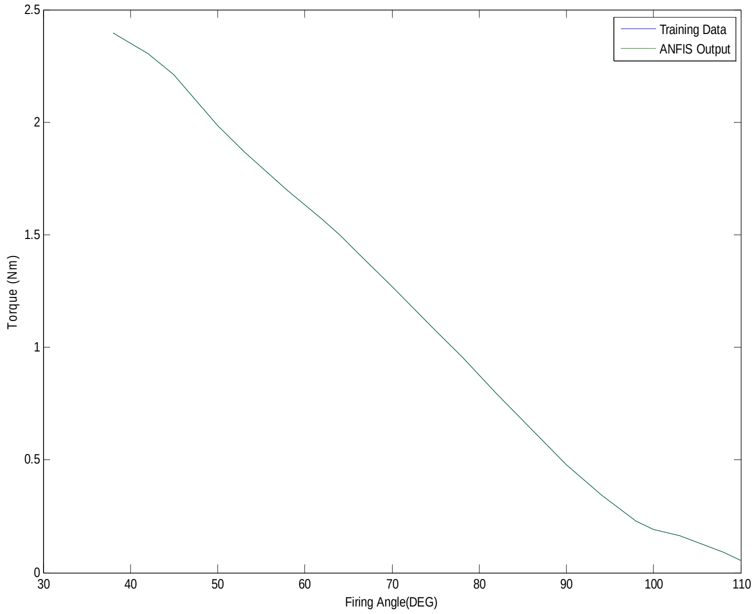

Figure-7. Comparison of actual and ANFIS data at $\omega_m = 0$ (p.u.).

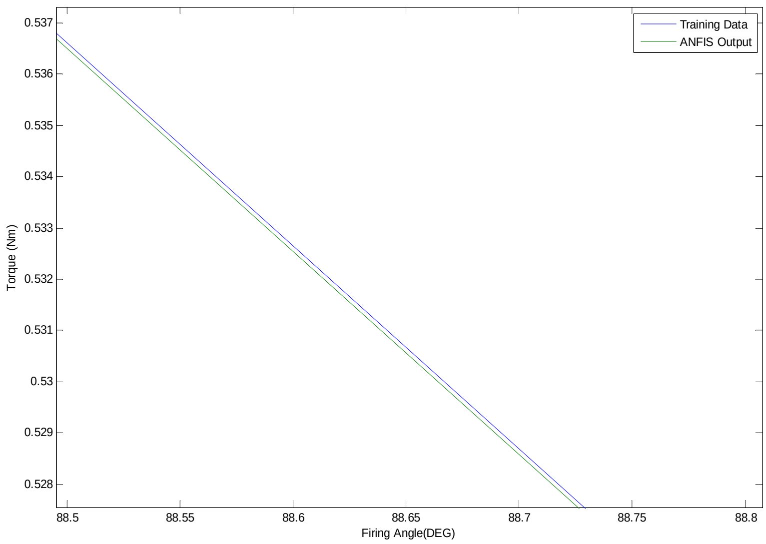

Figure-8. Zoomed view of Figure-4.

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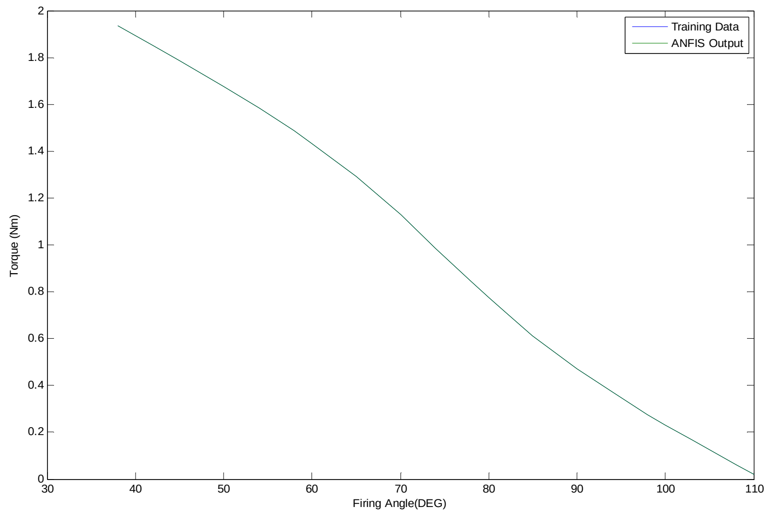

Figure-9. Comparison of actual and ANFIS data at $\omega_m = 0.5$ (p.u.).

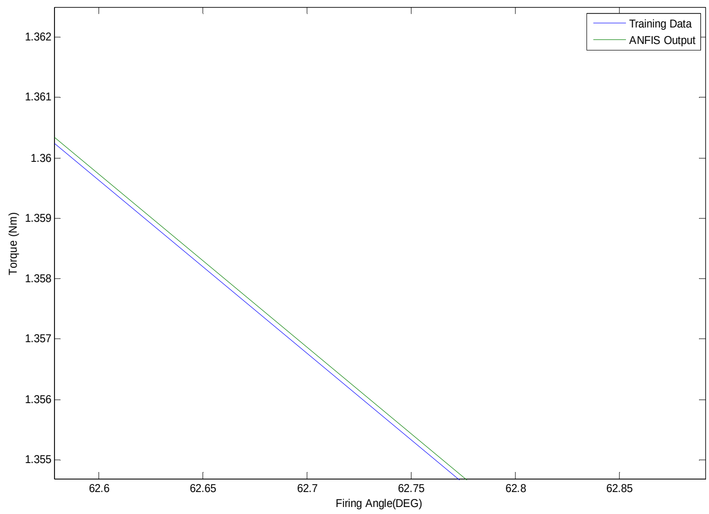

Figure-10. Zoomed view of Figure-3.

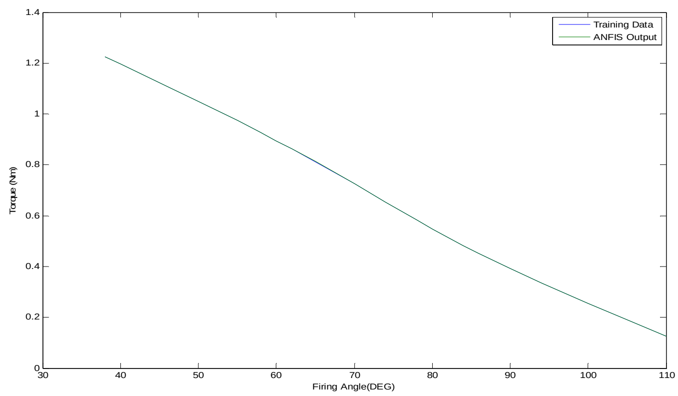

Figure-11. Comparison of actual and ANFIS data at $\omega_m = 0.8$ (p.u.).

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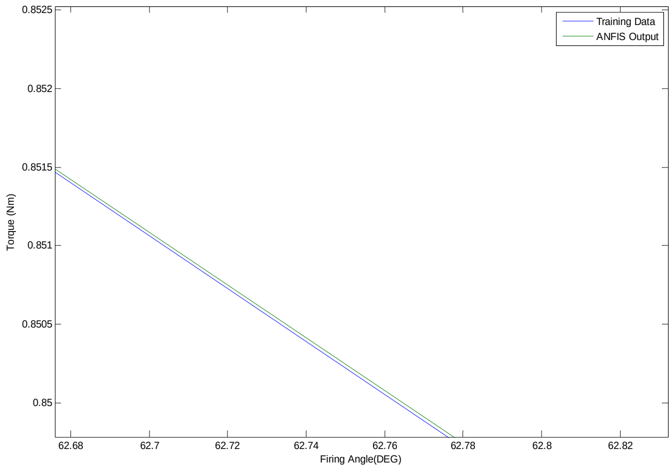

Figure-12. Zoomed view of Figure-5.

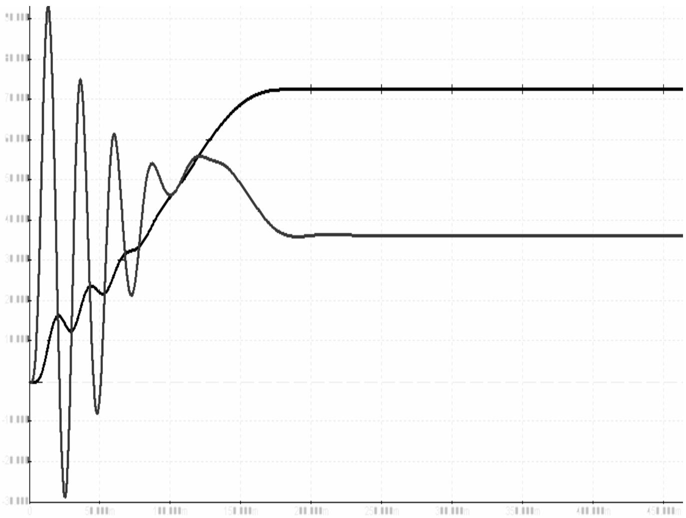

Figure-13. Simulation results of direct on-line motor starting (α=0˚).

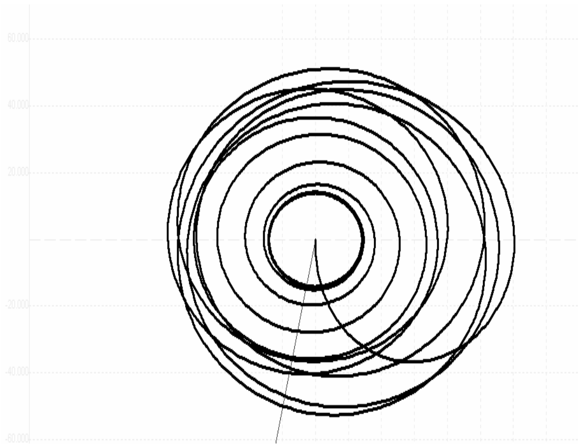

Figure-14. Simulation results of direct on-line motor starting.

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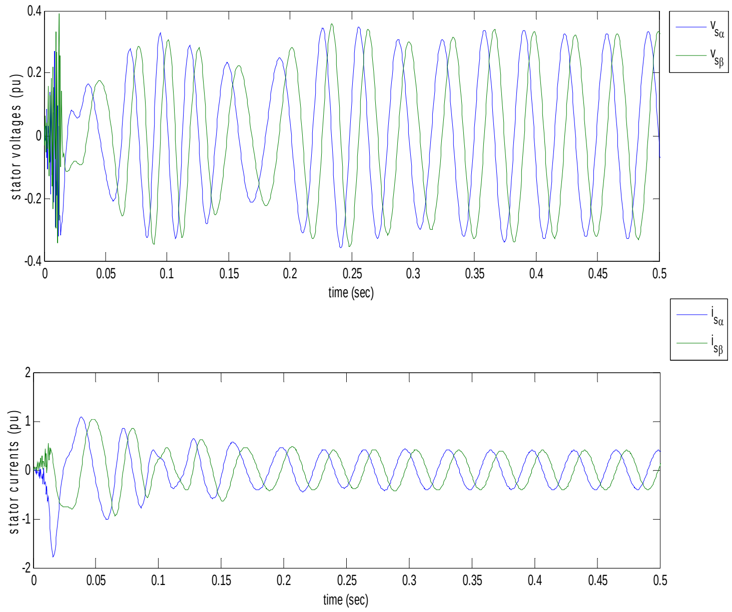

Figure-15. Stator two axes voltages and currents of induction motor.

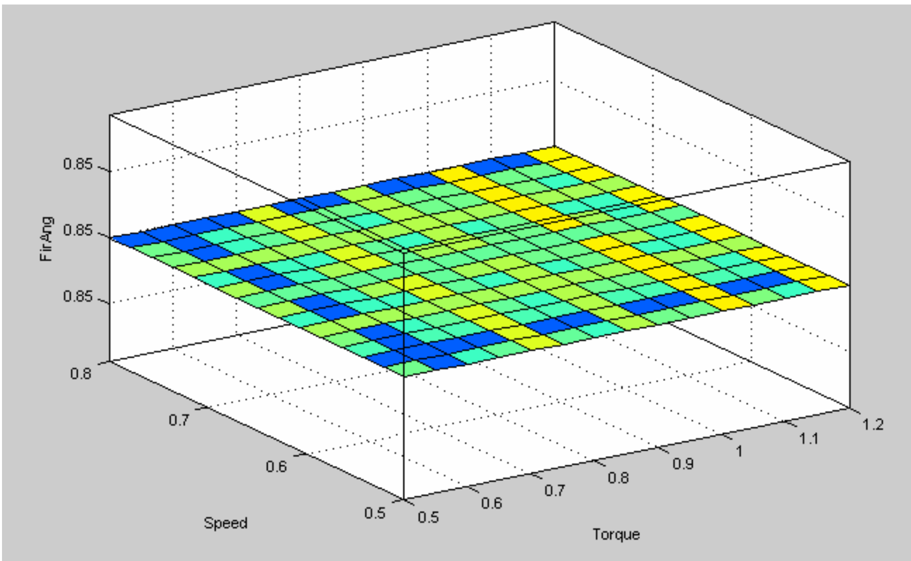

Figure-16. Surface plot of proposed Fuzzy model.

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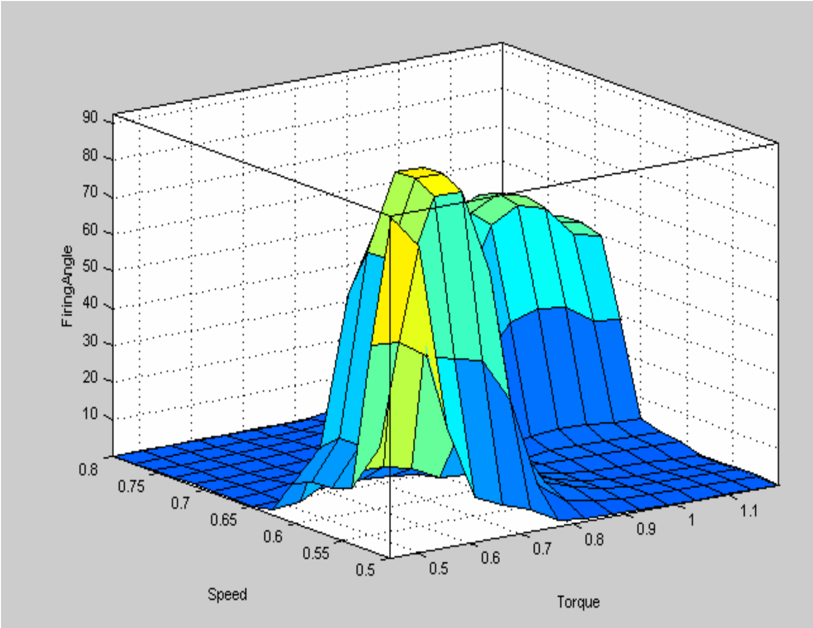

Figure-17. Surface plot of proposed ANFIS model.

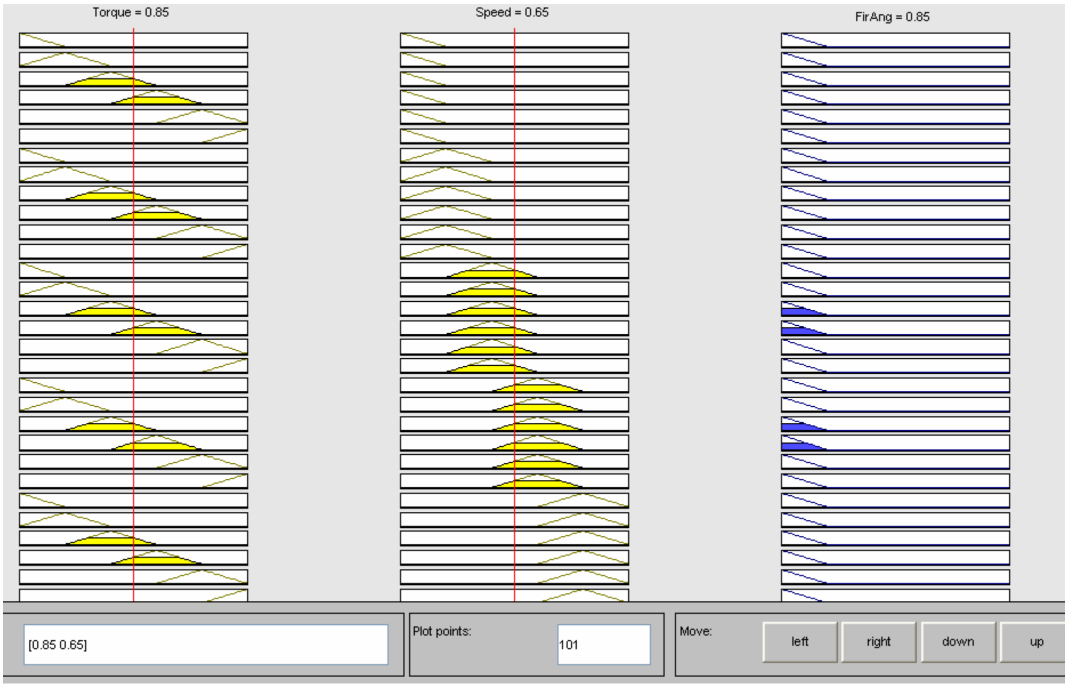

Figure-18. Rule formation for Fuzzy model.

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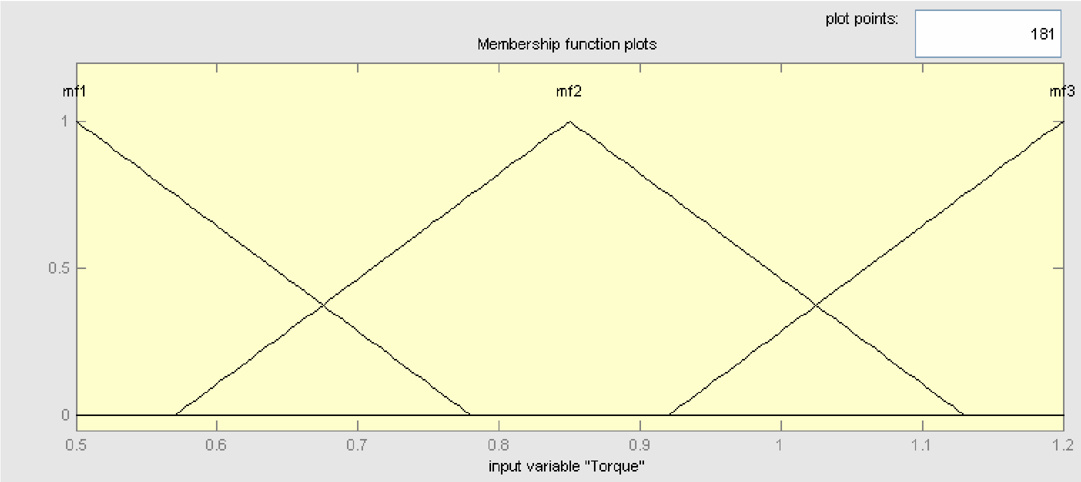

Figure-19. Membership function chosen for torque in Fuzzy model.

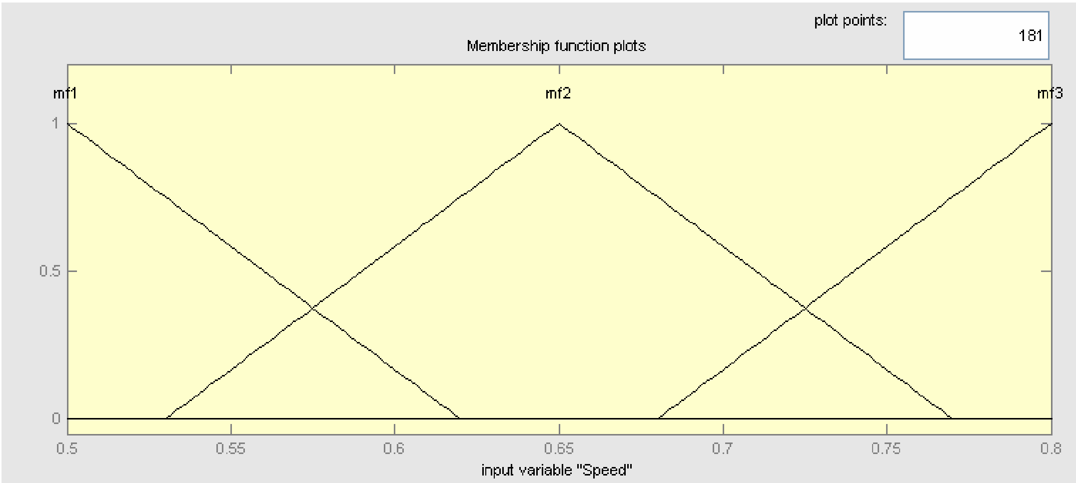

Figure-20. Membership function chosen for speed in Fuzzy model.

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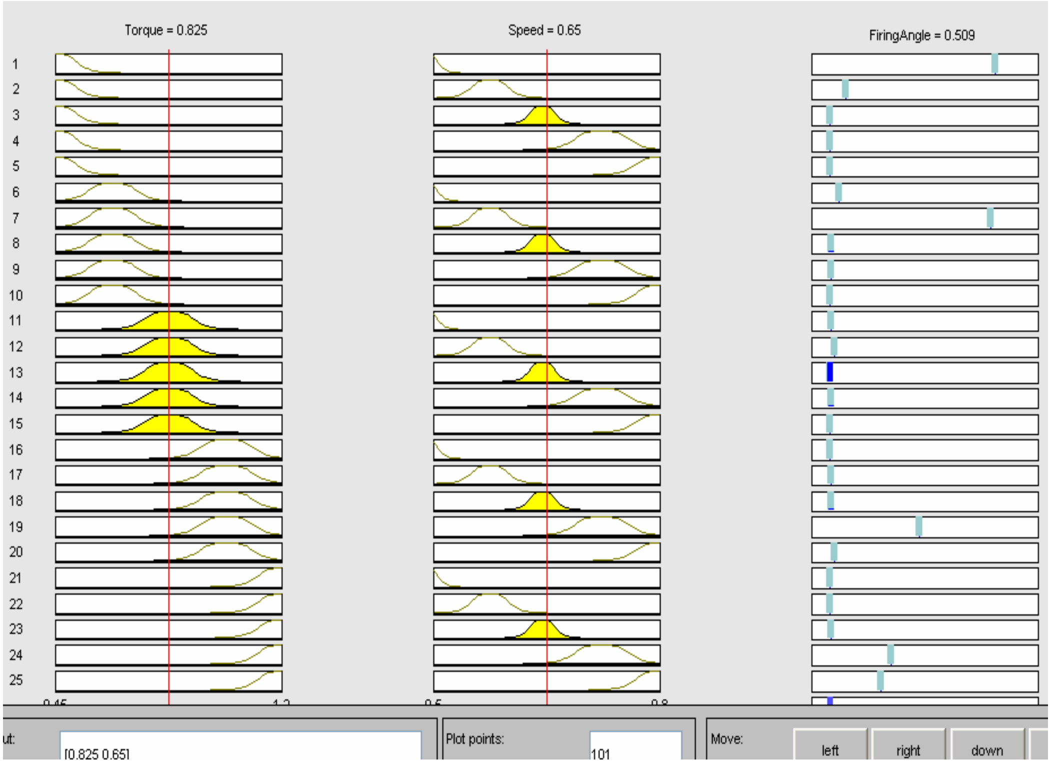

Figure-21. Rule formation for ANFIS model.

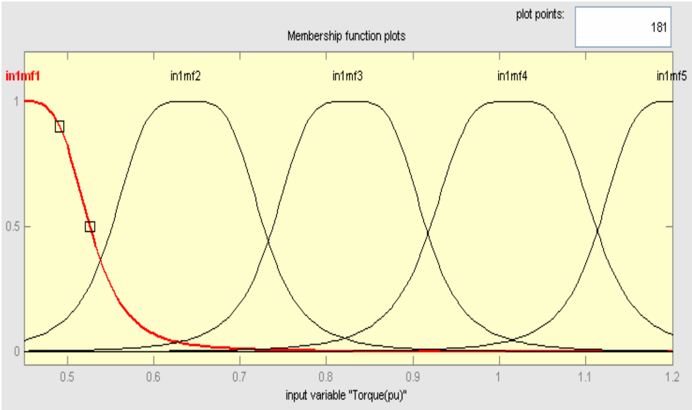

Figure-22. Membership function chosen for torque in ANFIS model.

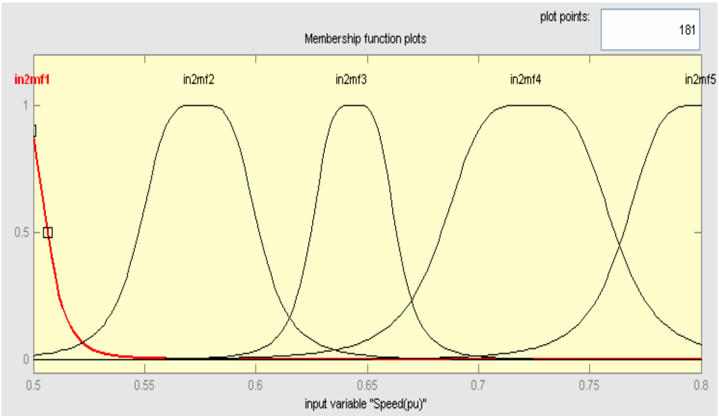

Figure-23. Membership function chosen for speed in ANFIS model.

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VII. CONCLUSIONS

In this paper, a new method of controlling soft-starter fed induction motor drive system using ANFIS has been introduced. This method has a backpropagation based neuro-fuzzy structure with five layers and clusters. This model was simulated using set of data obtained by simulations. The generated data are speed and torque patterns a inputs an their corresponding firing angle patterns as output of the ANFIS model. The results obtained by this ANFIS model shown in this paper are more accurate and this approach has solved the problem of the complexity of the online determination of the appropriate thyristors firing angle for any operating condition. This proposed controller methodology can eliminate the speed or voltage sensors since it is an open loop control.

APPENDIX

Motor	**3 phase, 415V Induction Motor**
Speed	1446 r.p.m
Rated current	2.7A
Stator Resistance	1.723 Ω
Stator inductance	0.1665 H
Rotor resistance	2.011 Ω
Magnetizing inductance	0.1592 H

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