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AC Inductor Motor Control Using Neuro-Fuzzy Network

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Abstract

Induction motors have gained wide acceptance with respect to industrial and domestic drives due to their minimal maintenance requirements and low costs. However, speed and position control of an AC induction motors exhibits complex characteristics, various control methods have been adopted for the speed and position control of the motors which have exhibited certain limitations like poor accuracy and high harmonic distortion. A hybrid network which combines the Neural Network and the Fuzzy Logic System known as the neuro-fuzzy networks is developed in this work to control the speed and position of a three phase inductor motor. The stator voltage model was used to generate the data used to train the neuro-fuzzy network for the control of an inductor motor's position while a speed-frequency model was used to generate the data used to train the network for speed control of a typical industrial three phase inductor motor. Developed network for position control was implemented directly in matlab using neuro fuzzy tool box while the developed network for the control of speed implementation was done in the existing state vector pulse width modulation (SVPWM) technique for speed control of inductor motor. The integrated scheme known as neuro-fuzzy state vector pulse width modulation (NFSVPWM) was implemented in Simulink. Results show that neuro-fuzzy network for position control which achieved complete 360 degree detection and also having 50% improvement on the accuracy of the existing methods. The NFSVPWM improved the accuracy of SVPWM by 1.87% while achieving a zero total harmonic distortion (THD). These results can be deployed to industries by implementing them digitally using microcontrollers as target devices.

Keywords: Artificial intelligent, Neuro-Fuzzy Network, Inductor motor, Backpropagation algorithm, Control systems.

INTRODUCTION

Although the techniques behind inductor motor remains unchanged. Artificial intelligent (AI) has a significant influence when controlling an inductor motor and has several advantages over conventional controllers. The main goal of this study us to design a suitable method of controlling an AC inductor motor.

This paper adopts a hybrid technique thereby combining the Neural Network and the Fuzzy Logic control (termed as Neuro-Fuzzy Network) as each individual properties complement each other. In this approach, a neuro-fuzzy controller architecture is proposed which is an improvement on the existing neuro-fuzzy architecture.

Jose' Vieira in his work compared the different neuro-fuzzy architecture and evaluates their performances [1]. His article gave a comparison analysis on the general vision of the area describing the most common hybrid neuro-fuzzy techniques, their advantages and disadvantages. He explained the different types of neuro-fuzzy systems, their structures and application. His work gave great recommendation on the need for the hybrid approach of controlling an inductor motor.

The combination of neural network and fuzzy logic complements each methods by combining their advantages and also avoiding their limitations. Gurpreet S. Sandhu and Kuldip S. Rattan in their research employs a different algorithm which enables Fuzzy logic controller to be interpreted as neural network instead of integrating neural network into certain parts of the FLC [2].

Abolfazi Vahedi in his work formulated a novel sensorless adaptive neuro-fuzzy speed controller for inductor motor drives. Using their individual complementing techniques, the obtained result shows that the adaptive neuro-fuzzy speed controller can gain a very satisfactory performance and a fast response time even though his control strategy was based on bounded rationality [3]. He used the Neural Network in learning data and the Fuzzy Logic for understanding the knowledge learned by the ANN (that is combing the FLC to the tail of the ANN. Its feedback was handled by the critic model. Comparatively, combining neural network and Fuzzy Logic controllers have given significant improvement to the system. Existing Neuro-Fuzzy Systems have been achieved using different combination techniques such as Cooperative neuro-fuzzy system, concurrent neuro-fuzzy network system and hybrid neuro-fuzzy network system [1]. This research wishes to adopt a more effective approach of control.

Mathematical Representation of Position and Speed of a Three Phase Induction Motor

Three phase induction motor adopts the principle of electromagnetic induction [4]. When a three phase sinusoidal voltage is connected across the windings of the stator of an induction motor, varying/rotating magnetic fields are develop around the windings [5]. These magnetic fields have the same frequency as the source voltage, and are 120 degrees apart if the source voltage is balanced [5]. The rotational speed of the magnetic field is known as the synchronous speed w_s of the motor [6][7].

The magnetic fields cuts through the rotor induce electromagnetic force (emf). A secondary magnetic field is

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produced around the rotor circuit by this induced emf. The interaction between the two windings (primary and secondary) produces forces which turns the rotor.

Now the mathematical representation of a balanced three phase voltage source is given by equations 1 to 3 [5].

$V_a = V_m Sin(wt)$ - 1

$V_b = V_m Sin(wt + 120)$ - 2

$V_c = V_m Sin(wt - 120)$ - 3

Where V_a, V_b, V_c are the instantaneous phase voltages of the three source generator while V_m is the amplitude of the source voltage. It is important to observe that the balanced phase voltages are 120 degrees apart.

The relationship between the inductor motor speed, n and the speed, n_s of the rotating magnetic flux is given as

$n = (I - s)n_s$ - 4

Where s is the slip [8].

Given the relationship between the frequency, f and the speed n_s as

$n_s = 120f/P$ - 5

Where P is the number of pole pairs in the stator windings [8].

While examining equations 4 and 5, it is observed that the speed n of induction motor can be controlled when the synchronous speed is controlled which means controlling the source voltage frequency.

Neglecting the induced voltage in the stator winding of the motor, the equation obtained by relating the supply voltage V and the rotating flux ϕ is [8].

$V \, \alpha \, \phi f$ - 6

To obtain an optimal operation, a constant value of the flux ϕ maintained and rated for operation of a specific induction motor. It means that for efficient control of speed of an induction motor to be achieved, the voltage and frequency of the input voltage to the motor must be controlled [8].

Now, the position control of an induction motor means specifying exactly the angle of rotation of the motor per time [6]. In ac domain, it is quite difficult to control the inductor motor's frequency and position. So the next section discussed digital technique for voltage, frequency and position control of ac induction motor.

Digital Techniques for Speed and Position Control of Three Phase Induction Motor

Speed and position of an induction motor can be controlled by employing the ability of a digital switching technique which switches the motor to any desired position or speed. Figure 1 is a high level block diagram for the digital switching technique being used in this work.

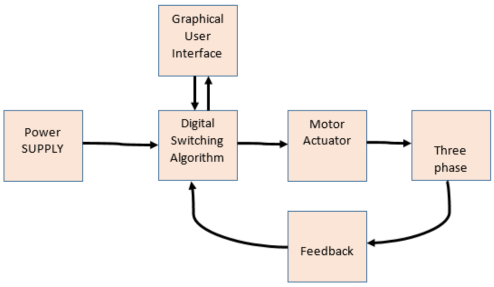

Figure 1: High level description of digital technique for Speed and Position of control three phase induction motor

The digital switching algorithm leverage on neuro-fuzzy technique to control the speed and position of the three phase induction motor through the motor actuator. The graphical user interface (GUI) was used to view the speed and position of the motor while the feedback was used to sense the present state of the motor with respect to the speed.

The Design of the Digital Switching Algorithm for the Speed and Position Control of Three Phase Induction Motor.

Consider the source voltage equations for a balanced three phase induction motor

$V_a = V_m Sin(wt)$ - 7

$V_b = V_m Sin(wt + 120)$ - 8

$V_c = V_m Sin(wt - 120)$ - 9

For w= 2πf where f = 50 Hz, the graphical representation of equations 7 to 9 considering a single cycle is shown in figure 2.

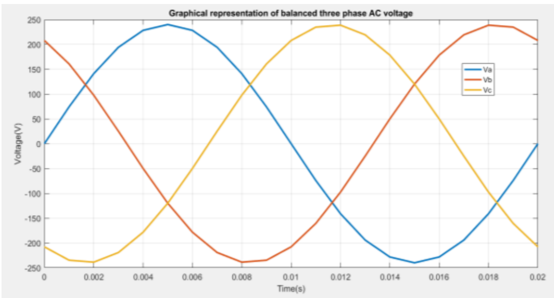

Figure 2. Balanced three phase ac voltage

The angle displacement, θ, of the motor is given by

$\frac{d\theta}{dt} = w$ - 10

$d\theta = wdt$ - 11

This means that integrating the angular speed of the motor gives the position of the motor.

That is,

$\theta = \int wdt$ - 12

The Design of position control Inductor Motor using State matrix method

Table 1 shows the matrix design of how to detect the position of a three phase inductor motor based on the state matrix of the induction motor.

Table 1: State matrix design of position control of three phase induction motor

State	V_a	V_b	V_c	Position θ in degrees	Time T
1	1/3	1/3	-2/3	45	T/8
2	2/3	-1/3	-1/3	90	T/6
3	1/3	-2/3	1/3	135	T/4
4	-1/3	-1/3	2/3	180	T/2
5	-2/3	1/3	1/3	225	T
6	-1/3	2/3	-1/3	270	9T/8
7	1/3	1/3	-2/3	315	10T/8
8	2/3	-1/3	-1/3	360	11T/8

If F is the reference frequency of the source voltage, then T =1/F. Digitally, table 1 can be implemented using neuro-fuzzy logic

Neuro-Fuzzy Network for Position Control of Three Phase Inductor Motor

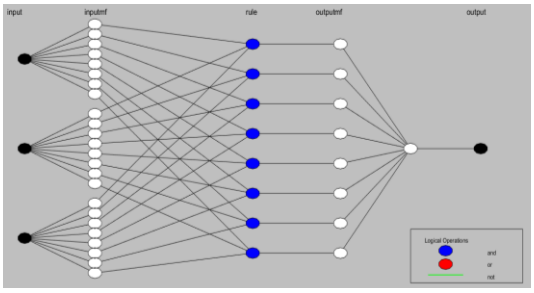

Figure 3. Neuro-Fuzzy network for position control of three phase induction motor

The network of figure 3, is made up of two external layers representing inputs and output. The inputs to the network are V_a, V_b and V_c while the output is the position of the motor. The three hidden layers represent the fuzzification, inference and defuzzification of the network. The characterization of the network was done by training using artificial neural back propagation method leveraging on instantaneous values of the phase voltages for time t = 0 to 11T/8 at a step of 0.0000763889. The data used in the training was generated using equations 7 to 9.

Figure 4: Training result for position control of three phase inductor motor

The figure 4 shows the error goal that was achieved at epochs 1.

Neuro-Fuzzy Network for Speed Control of Inductor Motor

The mathematical relationship between inductor motor speed and the frequency of the supply voltage can be established by substituting equation 14 in equation 15. That is,

$$n = (\mathrm{I} - s)n_s \qquad - \qquad 13$$

$$n_s = 120f/P \qquad - \qquad 14$$

$$n = \frac{120*(1-s)*f}{P} \qquad - \qquad 15$$

Equation 15 shows that the speed of an inductor motor is directly proportional to the frequency supplied.

Given the following specifications for an industrial three phase squirrel cage inductor motor.

Speed: 1501-2000 RPM; No of poles = 2; rated slip = 0.42, Vph = 220 [45].

Equation 15 then becomes

$$\mathrm{n} = \frac{120 * (1 - 0.42) * f}{2}$$

$$\mathrm{n} = 34.8 * f \qquad - \qquad 16$$

Equation 16 gives the specific equation relating the motor speed and the frequency of the supply voltage. The speed of the motor can vary from 1501 to 2000 rpm. For a variation of speed from 1501 to 2000 rpm, the frequency variation is from 43.1322 to 57.4713 Hz. Both the speed and the frequency can be categorized into nine different membership functions as shown in table 2. Figure 5 shows the membership function plot relating to the speed variable while figure 6 shows the fuzzy rule base to be integrated in Neuro-fuzzy network for the motor speed control. Figure 7 shows the neuro-fuzzy network developed from the rule based. It is made up of two external layers and three hidden layers.

Equation 16 was used to generate the data used in training the network. The network was trained to achieve zero error using hybrid propagation algorithm at epoch number of 1 as shown in figure 8.

Table 2: Membership functions for speed control of a typical three phase inductor motor.

Membership Function	Speed Range (RPM)	Frequency Range (Hz)
Extremely Very Low (EVL)	1500-1600	43.00-46.00
Very Low (VL)	1550-1650	44.50-47.50
Relatively Low (RL)	1600-1700	46.00-49.00
Low (L)	1650-1750	47.50-50.50
Normal (N)	1700-1800	49.00-52.00
High (H)	1750-1850	50.50-53.50
Relatively High (RH)	1800-1900	52.00-55.00
Very High (VH)	1850-1950	53.50-56.50
Extremely High (EH)	1900-2000	55.00-58.00

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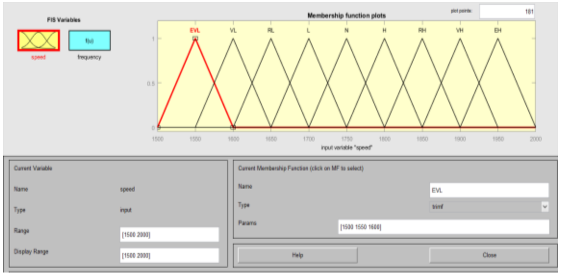

Figure 5. Membership function plots of speed variable

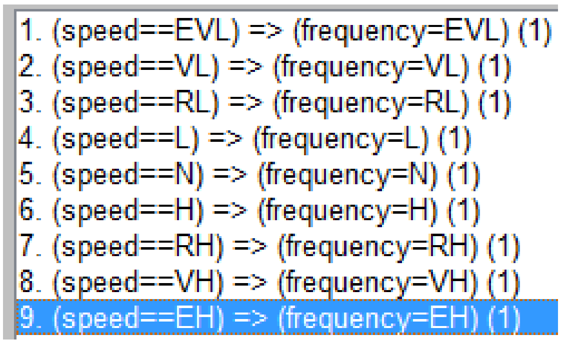
1. (speed==EVL) => (frequency=EVL) (1)
2. (speed==VL) => (frequency=VL) (1)
3. (speed==RL) => (frequency=RL) (1)
4. (speed==L) => (frequency=L) (1)
5. (speed==N) => (frequency=N) (1)
6. (speed==H) => (frequency=H) (1)
7. (speed==RH) => (frequency=RH) (1)
8. (speed==VH) => (frequency=VH) (1)
9. (speed==EH) => (frequency=EH) (1)

Figure 6. Rule base for neuro-fuzzy network for speed control of the inductor motor

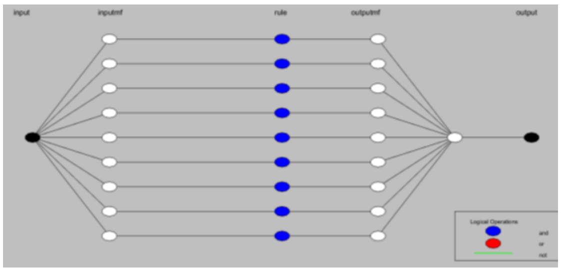

Figure 7. Neuro-fuzzy network for speed control of the three phase inductor motor

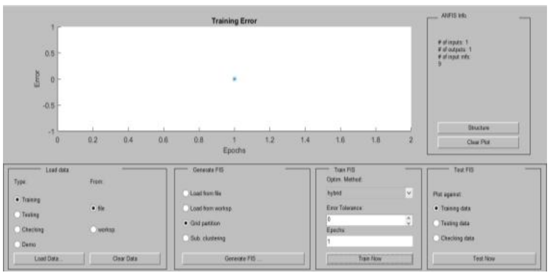

Figure 8. Training result of neuro-fuzzy network for speed control of the inductor motor

Implementation of the Neuro-Fuzzy Network for Speed Control of Three Phase Induction Motor.

In this section, neuro-fuzzy network (NFN) is integrated in the state vector pulse width modulation (SVPWM) scheme leveraging on the NFN for variable selection of the frequency of PWM block for optimized control of the speed of the inductor motor. Figure 9 shows the block diagram of the existing SVPWM scheme while figure 10 is the integrated scheme proposed in this work.

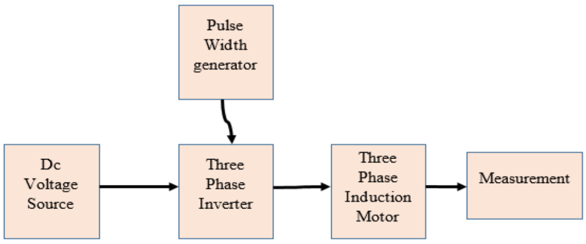

Figure 9. Description of the existing SVPWM scheme

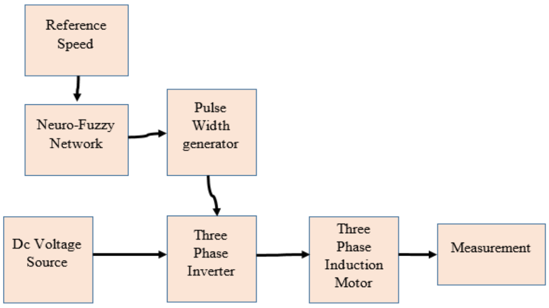

Figure 10. Integrated hybrid scheme for speed control of inductor motor

The integrated hybrid scheme called neuro-fuzzy state vector pulse width modulation (NFSVPWM) was implemented in Simulink using SIM Power tool box. DC source was use as the source voltage. The inverter is implemented using a three arm bridge leveraging on insulated gated bipolar transistor (IGBT) and diodes as power electronic devices. Three squirrel cage inductor motor was used as the motor having a default frequency of 50 Hz and phase voltage of 220 volt. To implement the pulse width generation block, a three phase-six pulse width generator with external reference signal (frequency) was used. The neuro fuzzy network was implemented by importing the trained network into the Simulink environment. Figure 11 shows the complete Simulink model for the implementation of the speed control of three phase inductor motor using NFSVPWM.

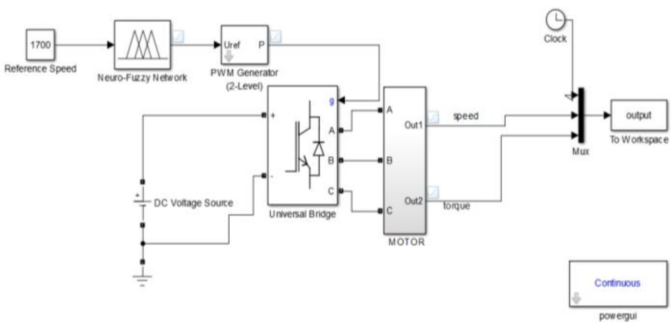

Figure 11. Implementation of NFSVPWM scheme in Simulink

RESULT DISCUSSION

Figure 12. Position of the three phase induction motor at t= 0.00273 second

Figure 13: Position of the three phase induction motor at t= 0.00274 second

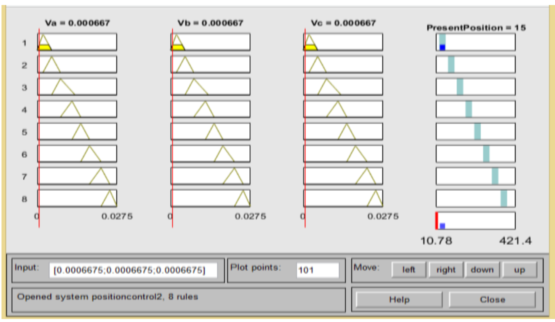

Figure 14. Motor position with all the state variables in state1

Figure 15. Motor position in state 1 at t=0.000342 second

Figure 16. Motor position in state 1 at t=0.000343 second

Figures 12 and 13 show that the angle position of the three phase inductor motor at time t = 0.00273 second is 56.2, and the position at t = 0.00274 is 56.3. It means the resolution of the network is 0.1. Theoretically, the change in position from t = 0.00273 to 0.00274 can be calculated using equation below;

$$d\theta = wdt,$$

$$d\theta = 2 * \pi * 50 * 0.00001$$

$$d\theta = 0.00314.$$

So this means that theoretically a change of 0.00314 in position can be detected. The neuro-fuzzy network was able to detect a change of 0.1 in position of the motor. A deviation of 0.09686 from the ideal value. Figures 14 to 16 shows that the position of the inductor motor is not static within a state.

Discussion on the Results of Speed Control of Three Phase Induction Motor

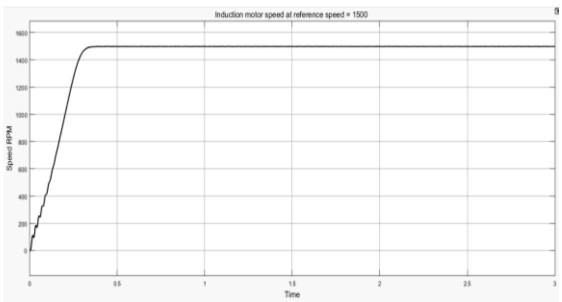

Figure 17. Response of NFSVPWM scheme at reference speed of 1500rpm

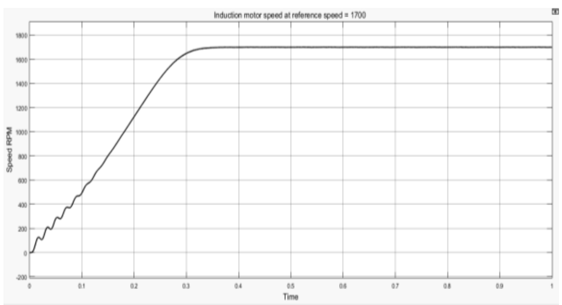

Figure 18. Response of NFSVPWM scheme at reference speed of 1700 rpm

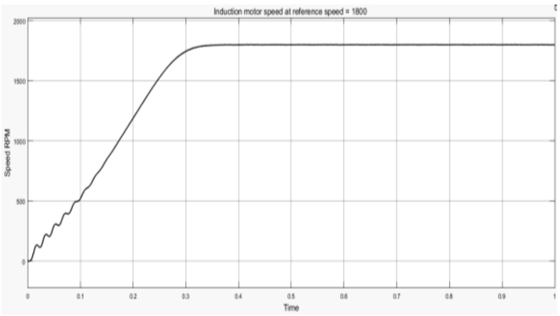

Figure 19. Response of NFSVPWM scheme at reference speed of 1800rpm

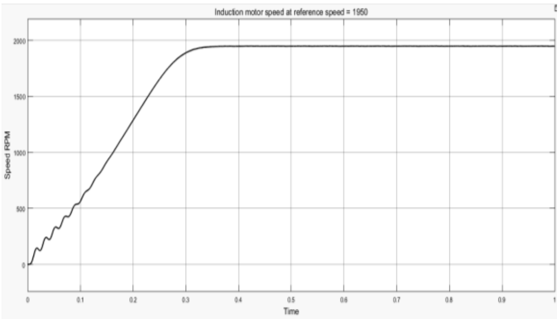

Figure 20. Response of NFSVPWM scheme at reference speed of 1950 rpm

Figures 17 to 20 show that the proposed NFSVPWM scheme is able to achieve control objectives in 0.35 second at various instances tested. At reference speed of 1950 rpm the peak to peak steady state value is 1949 giving a steady state error (SSE) of 1 as shown in figure 21.

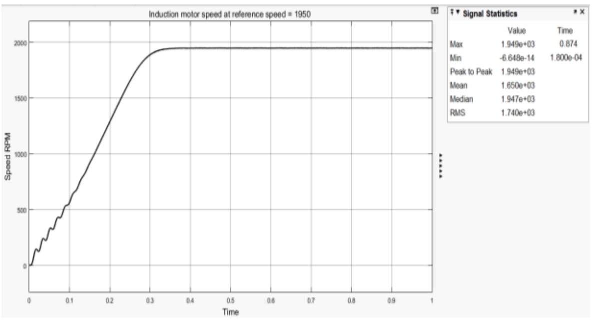

Figure 21. Signal statistics at reference speed of 1950 RPM

Similarly, at reference speed of 1800 rpm the peak to peak steady state value is 1799 giving a steady state error (SSE) of 1 as shown in figure 22.

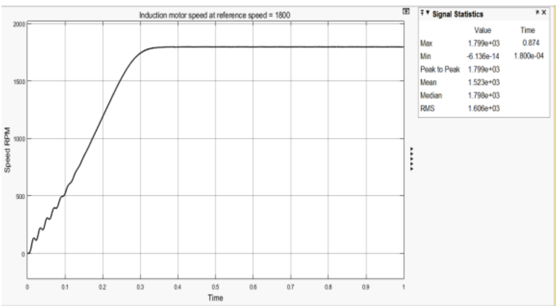

Figure 22. Signal statistics at reference speed of 1800 RPM

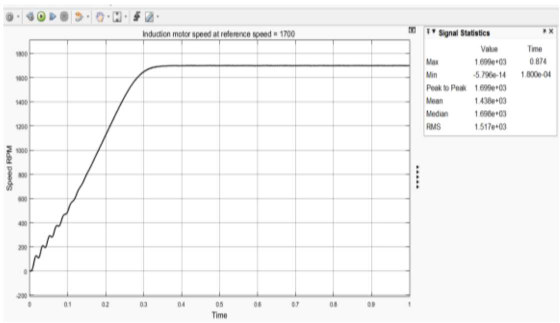

Figure 23. Signal statistics at reference speed of 1700 RPM

It is also shown in figure 23 that the steady state error at reference speed of 1700 rpm is 1. So, average steady state error of the NFSVPWM scheme is 1. This corresponds to accuracy of (1700-1)/1700 = 0.9994. That is 99.94%.

PERFORMANCE ANALYSIS

To show a better improvement of the NFN control method, Fuzzy logic control was analysed (through simulations) for the position control while the existing SVPWM for the speed control.

Comparison of Position Control of Three Phase Inductor Motor Using Neuro-Fuzzy Network and Fuzzy Logic.

Results of position control of three phase inductor motor was achieved using developed fuzzy logic membership functions and fuzzy rule, the results show that the position control of the three phase inductor motor using fuzzy logic approach has a resolution of 0.2 a deviation of 0.19686 from value. So the neuro-fuzzy network brought an improvement of 0.19686 - 0.09686 = 0.1 on the precision of the existing fuzzy logic method of inductor motor position control. This represents 50% improvement on the accuracy of the fuzzy logic method.

The result also revealed shows that with fuzzy logic method, that the position of the motor can only assume eight states as only the increment of 45 degrees will be detected by the logic. The neuro-fuzzy network is able to detect an increment of 0.1 in position even within a state. When approximated to nearest integer, it means the network achieved a position detection 360 states meaning that it improved fuzzy logic method by a factor of 360/8 = 45.

Comparison of Speed Control of Three Phase Induction Motor Using NFSVPWM and SVPWM Methods

Using the existing state vector pulse width modulation (SVPWM) method [9], the simulation achieved responses at different speed, the steady state error (SSE) at reference speed of 1500 rpm is 26. At reference speed of 1700 is 39. Also, when the reference speed is 1800, the SSE is 32 while SSE for reference speed of 1950 is 34. It is clear that the existing SVPWM method or technique exhibits variable SSE at different speeds. The Neuro-fussy state vector pulse width modulation (NFSVPWM) method has constant SSE irrespective of speed of operation. This is an improvement on SVPWM method.

Now, the average SSE of the SVPWM method is 32.75. Using a reference speed of 1700 rpm, it corresponds to accuracy of (1700-32.75)/1700 = 0.9807 which is 98.07%. It means that the NFSVPWM method brought an improvement of 1.87% in the accuracy of SVPWM method.

Performance Evaluation of the NFSVPWM Method

Figure 24 shows the analysis of total harmonic distortion produced in the three phase inductor motor while being controlled using NFSVPWM Method.

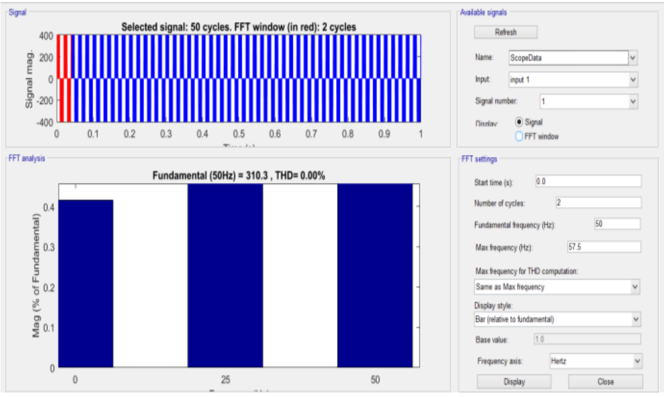

Figure 24: Harmonic analysis of the induction motor

It is observed that within the maximum frequency of operation considered for the motor, there is a zero harmonic distortion! This means that the NFSVPWM method did not only achieve an improved efficiency of the speed control, but also did not distort the stator current of the motor. Distorting the stator current causes an internal heating which affects negatively the efficiency, and ultimately life span of the motor.

From this analysis, the results show that neuro-fuzzy network for position control which exhibits a complete 360 degree detection improved the existing fuzzy technique (FT) by factor of 45 while having 50% improvement on the accuracy of the FT. The NFSVPWM improved the accuracy of SVPWM by 1.87% while achieving a zero total harmonic distortion (THD).

CONCLUSION

This work developed a neuro-fuzzy network for position control of three phase induction motor. The network achieved a position detection of 360 states meaning that it improved fuzzy logic method by a factor 45.

It also developed neuro-fuzzy network for speed control of three phase induction motor. In comparing with the existing control method, it is seen that the proposed NFSVPWM gives an improvement by giving a constant SSE irrespective of the different speed the motor operates.

Recommendations for Further Research

The networks developed in this work were implemented at simulation level. This work can be further validated by implementing the developed concepts practically using digital methods leveraging on micro controllers as target devices.

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