Implementation of Embedded based Fuzzy system for Induction motor V/f speed control

Arunapriya.P

Abstract - This paper presents a compact embedded fuzzy system for three-phase induction motor scalar speed control. The control strategy consists of keeping constant the voltage frequency ratio of the induction motor supply source. The control strategy taking the reference speed varies from 500rpm to 1000rpm. The response of the fuzzy controller is taken with varying load and speed. And also the fuzzy control system is built in a PIC Microcontroller, which uses speed error and speed error variation to change both fundamental voltage amplitude and frequency of a sinusoidal pulse-width modulation inverter. The controller performance in relation to reference and load torque variations is evaluated by experimental results.

Index Terms— fuzzy control, induction motors, real time systems, PIC Microcontroller.

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1 INTRODUCTION

Three-phase Induction Motors (TIMs) are widely applied in several industrial sectors. The extensive use of this motor is frequently associated with its simple and rugged structure, adaptation to several load situations and low cost acquisition and maintenance [2]-[6]. Several studies have been carried out in the field of vector control system due to its better dynamic response [7]-[8]. However, scalar control [4]-[10] presents a simple structure characterized by low steady state error. Therefore, the constant voltage-frequency (V/f) scalar control system is considered in this project due to its large application in industrial fields. This work is an attempt to design an Embedded Fuzzy Controller for an induction motor speed control.

PI control methodology is commonly applied in constant V/f control strategy for induction motors [3, 14]. However, in addition to the fact that a mathematic model is desirable for a systematic controller design with conventional methods, the difficulty of identifying the precise parameters for a complex, nonlinear and time-varying behavior of real plants may render, in some cases, its fine-tuning procedure very time consuming even if the empirical methods are used [16].

Conversely, fuzzy-based control methodology has the ability to cope with system nonlinearity and its control performance is less affected by system parameter variations. Moreover, fuzzy techniques utilize a linguistic rule base which is designed by taking advantage of system qualitative aspects and expert knowledge [8, 10,]. These features dispense with the need for a precise mathematical model of the plant, making the system design simpler to implement, even when empirical methodology is applied for fine-tuning procedure.

In [13], a self-tuning neuro fuzzy controller was fully developed in DSP. However, its algorithm was implemented with Matlab/Simulink and a real-time toolbox, whereas the DSP code program was generated by using Control-desk software. Therefore, no code optimization technique was achieved. Another fully embedded fuzzy system was applied in [14] in order to adjust the PI parameters of a Direct Torque Control (DTC) of the induction motor. In [1], a hardware solution for an embedded neural network with a Proportional-Integral-Derivative(PID) ontroller is also presented. Here, the authors combined DSP with FPGA in order to distribute the control algorithm tasks.

This paper therefore proposes an alternative method for simplifying a general-purpose embedded fuzzy logic algorithm, so that it can be built in hardware with reduced memory space and low computational power. The proposed method takes into account the advantages related to the symmetrical feature of the fuzzy membership function in order to store its minimum part in a vector table. From a simple and quick indexation calculus, the entire membership function with all linguistic terms can be restored. This procedure significantly reduces the memory space required for membership function. The proposed method was applied to embed a fuzzy control algorithm in a DSP for real-time V/f induction motor speed control.

Arunapriya.P/Assistant Professor
V.R.S.College of Engineering and Technology,
Arasur,Villupuram, Tamilnadu, India
Email: arunapriyavrs@gmail.com

The fuzzy control algorithm was implemented into PIC microcontroller. The device was responsible for measuring the TIM shaft angular speed with an optical encoder, achieving the fuzzy control algorithm and, finally, generating the sinusoidal-modulated PWM signal in order to turn on six Insulated-Gate Bipolar Transistors (IGBTs) of a three-phase inverter.

This paper is organized as follows. In Section 2 the aspects of the fuzzy control system structure and also the principal elements of the test bench are presented. In Section 3 the proposed simplified embedded fuzzy system is described. In Section 4, the experimental results of the fuzzy speed control performance. Section 5 discuss the summary of the work as conclusion.

2. FUZZY *V/f* SPEED CONTROL SYSTEM STRUCTURE

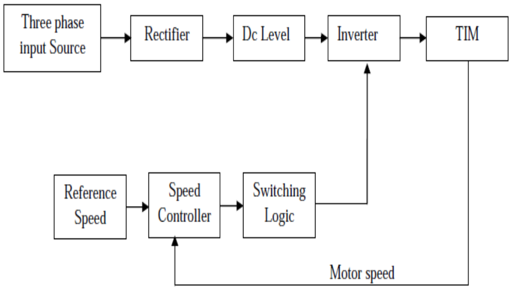


Fig1 Fuzzy control system block diagram.

The speed control of the induction motor was carried out by maintaining constant the voltage-frequency ratio in order to avoid the air-gap flux variations. If the supply voltage is varied without frequency adjustment, the induction motor can operate in the flux saturation region or with a weakened field. The block diagram of the proposed fuzzy control system is illustrated in Fig. 1.

2.1 Three Phase Input Source

It is a common electrical system that is used in commercial and industrial installations. In the US the voltages supplied are three phase, wye connected 480/277 volts. In Canada the voltages supplied are three phase, wye connected 600/347volts. This voltage source is applied to the TIM.

2.2 Rectifier

A nonlinear circuit component that allows more current to flow in one direction than in the other. An ideal rectifier is one that allows current to flow in one (forward) direction unimpeded but allows no current to flow in the other (reverse) direction. Thus, ideal rectification might be thought of as a switching action, with the switch closed for current in one direction and open for current in the other direction. Rectifiers are used primarily for the conversion of alternating current (ac) to direct current (dc).

2.3 Dc Level Switch

The sensor and vessel form the two electrodes of a capacitor. When the level of the medium changes, the electrical capacitance between the electrodes will also change. From this, the sensor electronics deduces when the defined level is reached. This is a robust technology for applications in which heavy buildup makes measurement difficult.

2.4 Inverter

An inverter is simply a DC to AC converter. It uses an SCR or IGBT driven with PWM (Pulse-Width Modulation) followed by a low-pass filter to synthesize simple AC sinusoids or more complex waveforms. A typical application of this is a UPS (Uninterruptible Power Supply). When the AC power fails, the DC batteries are used to form an AC signal very similar to the mains power, and can drive consumer electronics for a finite period of time.

An industrial application is a VFD (variable frequency drive) for induction motors. Induction motors spin at a fixed velocity relative to the incoming AC frequency. To allow for variable-speeds of these motors, a VFD, or inverter is used. In this device, the incoming AC power (single- or three-phase) is rectified to high-voltage DC. Then, an AC output is generated, whose frequency is proportional (more or less) to the desired rotational velocity of the motor.

2.5 Three Phase Induction Motor (TIM)

Three phase induction motor is a device in which the rotor rotates at speed slightly less than the synchronous speed. The difference between the synchronous speed and the rotor speed is called slip which ranges from 2-5%. This TIM's speed is going to be controlled by the fuzzy logic controller.

2.6 Reference Speed

The reference speed here proposed is varies from 500 rpm to 1000 rpm.

2.7 Speed Controller

The Speed Controller block is used find the error voltage between reference Speed and Motor Actual Speed. The speed error controlled is controlled by using PI and fuzzy logic Controller. By using this controller output we can get Torque of the motor. At the same time we calculate the Flux of the motor using flux table.

2.8 Switching Logic

By using the Flux and Torque value calculated by Speed Controller block used here for switching logic. By combining the dc level voltage and flux, torque value could be found by park transformation. Using this value calculate the Switch logic of Inverter. Depending upon the input and actual speed of the motor the switching logic will be decided.

The test bench is basically composed of a three-phase induction motor, a Direct Current (DC) generator, a torque meter and an optical incremental encoder with 2000 pulses per revolution. Fig. 2 illustrates the test bench structure. The proposed fuzzy control system was built into the PIC microcontroller.

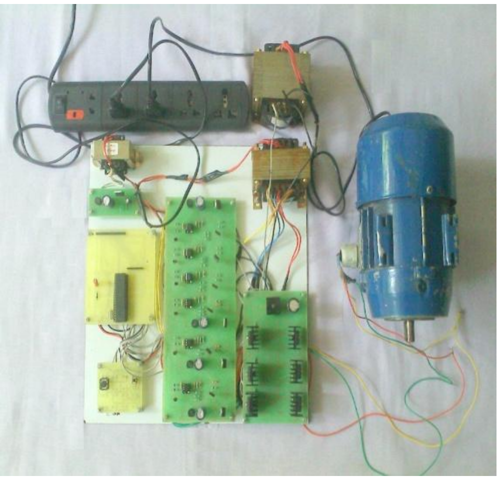


Fig 2 Test bench structure

The encoder used for applications such as speed measuring.

A DC generator of 2 kW was used to impose load torque on the induction motor rotor shaft, which is adjusted by an autotransformer connected to its field winding source voltage supply.

The TIM used in this work was a WEG standard line induction motor with 4 poles, N type, 1.0 hp, 60 Hz, 460 V and 4.1 Nm nominal torque. A Semikron three phase inverter was used to drive the induction motor, which was connected in delta configuration. The switching frequency was set to 10 kHz.

3. FUZZY LOGIC CONTROLLER

Fuzzy logic controller (FLC) is an expert system implementing a part of a human operators or process engineer's expertise which is not incorporated by conventional differential-equation based controllers. It proves to be superior whenever a model of the process is unavailable, it gives the better performance compared to conventional controllers [16].

3.1 Simple fuzzy logic controllers

First generation simple fuzzy logic controllers can generally be depicted by the block diagram such as that shown in figure 3.

The knowledge base module in figure 3 contains knowledge about all input and output fuzzy partitions. It includes the terms set and corresponding membership functions defining the input variables to the fuzzy rule base system and the output variables, or, control actions, to the plant under control.

The steps in designing a simple fuzzy logic control system are as follows:

(i) Identify the variables (input, outputs, and states) of the plant.

(ii) Partition the universe of discourse or the interval spanned by each variables into a number of fuzzy subsets, assigning each a linguistic label (subsets include all the elements in the universe).

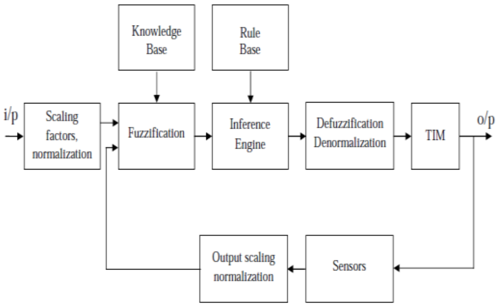


Figure 3 Fuzzy Logic Controller

(iii) Assign or determine a membership function for each fuzzy subset.

(iv) Assign the fuzzy relationships between the inputs or states fuzzy subsets on the one hand and the outputs fuzzy subsets on the other hand, thus forming the rule-base.

(v) Choose appropriate scaling factors for the input and output variables in order to normalize the variables to the [0, 1] or the [-1, 1] interval.

(vi) Fuzzify the inputs to the controller.

(vii) Use fuzzy approximate reasoning to infer the output contributed from each rule.

(viii) Aggregate the fuzzy outputs recommended by each rule.

(ix) Apply defuzzification to form a crisp output.

In a non-adaptive simple fuzzy logic controller, the methodology used and the results of the nine steps mentioned above are fixed, whereas in an adaptive fuzzy logic controller, they are adaptively modified based on some adaptation law in order to optimize the controller.

3.2 Fuzzy variables

Fuzzy variables are also called linguistic variables differ from a numerical variables in that its values are not numbers but words or sentences in a natural or artificial language. Since words, in general, are less precise than numbers, the concept of a linguistic variable serves the purpose of providing a means of approximate characterization of phenomena which are too complex or too ill- defined to be amenable to description in conventional quantitative terms.

More specifically, the fuzzy sets which represent the restrictions associated with the values of a linguistic variable may be viewed as summaries of subclass of elements in a universe of discourse. This of course is analogous to the role played by words and sentences in a natural language.

3.3 Rule-based system

In the field of artificial intelligence (machine intelligence) there are various ways to represents knowledge. Perhaps the most common way to represent human knowledge is to form it into natural language expressions of the type,

IF premise (antecedent), THEN conclusion (consequent)

The form of expression is commonly referred to as the IF-THEN rule based form. It typically expresses an inference such that if we know a fact (premise, hypothesis antecedent), then we can infer or derive, another fact called a conclusion (consequent). This form of knowledge representation characterized as shallow knowledge, is quite appropriate in the context of linguistics because it expresses human empirical and heuristic knowledge in our own language of communication. It does not, however, capture the deeper.

Forms of knowledge usually associated with intuition, structure function, and behavior, of the object around us simply because these latter forms of knowledge are not readily reduced to linguistic phrases or representations. The rule-based system is distinguished from classical expert systems in the sense that the rules comprising a rule-based system might derive from sources other than human experts and, in this context are distinguished from exert systems.

3.4 General fuzzy logic controllers

The principal design elements in a general fuzzy logic control system (i.e., non-simples) are as follows.

1. Fuzzification strategies and interpretation of a fuzzification operator, or fuzzifier.
2. Knowledge base:
    - (i) Discretization/normalization of the universe of discourse
    - (ii) Fuzzy partitions of the input and output spaces
    - (iii) Completeness of the partitions and
    - (iv) Choice of the membership functions of a primary fuzzy set
3. Rule-base:
    - (i) Choice of process state(input) variables and control (output) variables
    - (ii) Source of derivation of fuzzy control rules
    - (iii)Types of fuzzy control rules
    - (iii) Consistency interactivity and completeness of fuzzy control rules
4. Decision-making logic:
    - (i) Definition of a fuzzy implication
    - (ii) Interpretation of the sentence connective and
    - (iii) Interpretation of the sentence connective or
    - (iv) Inference mechanism
5. Defuzzification strategies and the interpretation of a defuzzification operator(de-fuzzifier)

Adaptation or change in any of the five design parameters above creates an adaptive fuzzy logic control system is simple and non-adaptive.

3.5 Membership Function Generation

To subdivide our data set into membership functions some procedures are needed to establish fuzzy thresholds between classes of data. We can determine a threshold line with an entropy minimization screening method, and then start the segmentation process, first into two classes. By partitioning the first two classes one more time, we can have three different classes therefore, a repeated partitioning with threshold value calculations will allow us to describe membership in each set.

Membership function generations based on a partitioning or analog screening concept, which draws a threshold line between two classes of sample data. The main idea behind drawing the threshold line is to classify the sample while minimizing the entropy for an optimum partitioning.

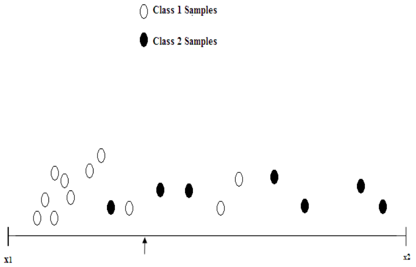


Figure 4 Illustration of threshold value idea

We divide the region [x1, x2] in two. We may say that the left side of the primary threshold is the negative side and the right, positive side; these labels are purely arbitrary but should hold some contextual meaning for the particular problem. We can choose a shape for the two membership functions; one such shape uses two trapezoids, as seen in figure. But the particular choice of shape is arbitrary; we could just as well have chosen to make the threshold crisp and use two rectangles as membership functions. However, we do want to employ some amount of overlap since this develops the power of a membership function. As we get more and more subdivisions of the region;[x1,x2], the choice of shape for the membership function becomes les and less important as long as there is overlap between sets, therefore, selection is judicious. In the next sequence we conduct the segmentation again, on each of the regions shown in figure this process will determine secondary threshold values.

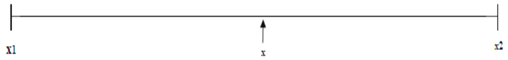


Figure 5 Partitioning range

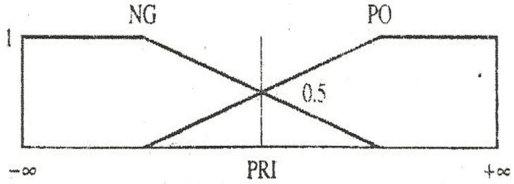


Figure 6 The First partition

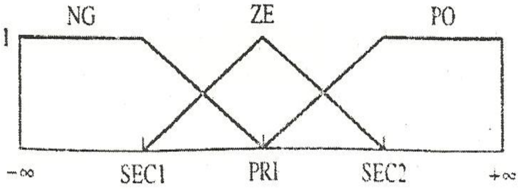
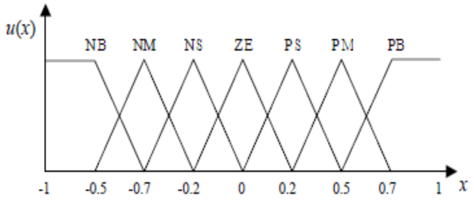


Figure 7 The Second partition



late these secondary threshold values. If we denote a secondary threshold in the negative area as SEC1and the other secondary threshold line in the positive area as SEC2, we now have three threshold lines in the sample space. The thresholds SEC1 and SEC2 are the minimum entropy points that divide the respective areas into two classed. Then we can use three labels of PO (positive), ZE (zero), and NG(negative for each of the classed, their threshold values (PR1,SEC1,SEC2) are used as the toes of the three separate membership shapes shown in figure 4.6. In a fuzzy logic application we often use an odd number of membership functions to partition a region, say five labels or seven. To develop seven portions we would need tertiary threshold values in each of three classes of figure. Each threshold level, in turn, gradually separates the region into more and more classes. We have four tertiary threshold values: TER1, TER2, TER3 and TER4.Two of the tertiary lie between primary and secondary thresholds, and the other two lie between secondary thresholds and the ends of the sample space; this arrangement is shown in figure 4.6. In this figure we use labels such as NB, NM, NS, PS, PM, and PB [15]

4.8 Controller Design And Testing

A fuzzy PI controller is designed taking speed error (e) and change in speed error (de) as input to the fuzzy interference system (FIS) provided by simulink. The two fuzzy variables (universe of discourse), e and de are defined over a range from -1 to +1. Each is split into seven fuzzy sets namely NB,NM,NS,PS,PM, and PB. Triangular membership functions are chosen because they are easy to compute and provide good damping. The sets overlap with adjacent sets so that no rule goes unfired. The output variable is also defined over -1 to +1, split into seven sets with triangular membership functions. Defuzzification is done using centroid method. The fuzzy associative memory table is formed with the intuition of PI control law and the rules are adjusted to give good response and frozen. The rule table is shown in Table 4.1. More details on fuzzy controller design and simulation can be found in simulink user manual.

Table 1 Fuzzy Rule Table

de \ e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	ZE
NM	NB	NM	NM	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PM	PM	PB
PB	ZE	PS	PM	PM	PB	PB	PB

Where,

e – Speed error
de – Speed error variation

4 RESULTS

This chapter resents the simulation response of the Fuzzy controller by varying the peed 500rpm to 1000 rpm and also by varying its torque.

4.1 Controller Response

The controller responses taken for the speed 500rpm with torque10Nm and speed 500rpm with torque 100Nm.Another speed value 1000rpm with 10Nm torque and 1000rpm with 100Nm also taken for analysis. The responses shown.

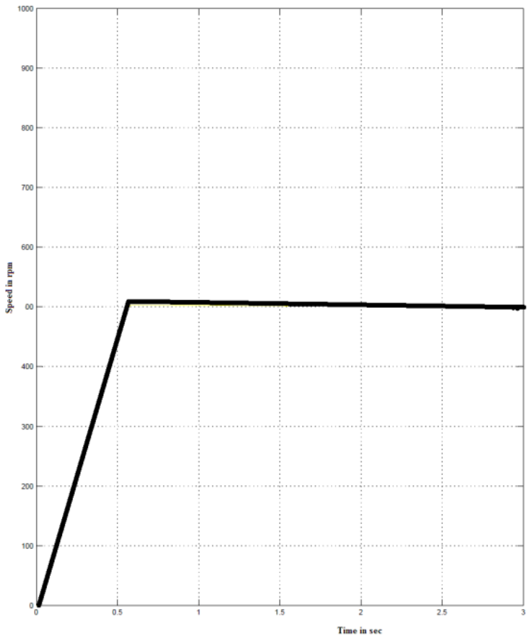


Figure 9. Response of the induction motor with speed of 500rpm and torque of 10Nm

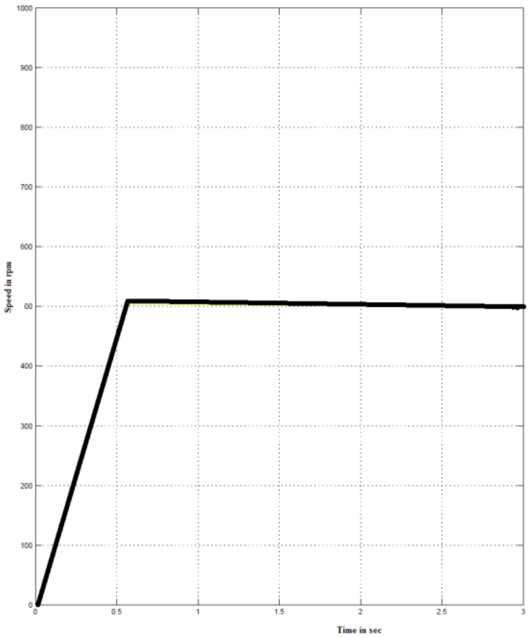


Figure 10. Response of the induction motor with speed of 500rpm and Torque of 100Nm

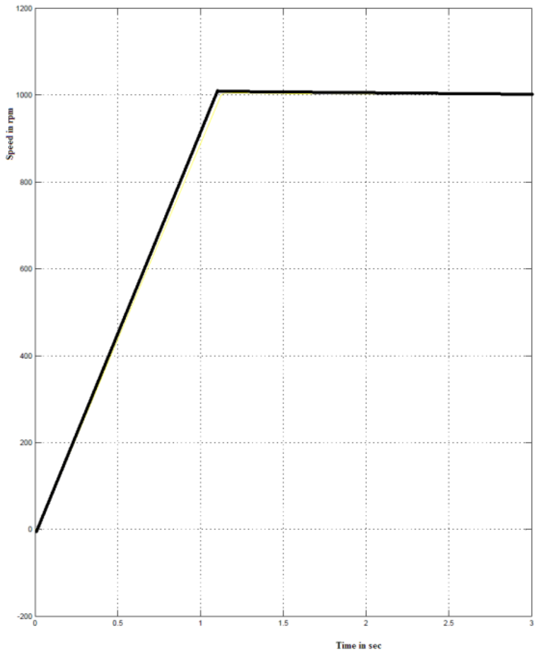


Figure 11. Response of the induction motor with speed of 1000rpm and Torque of 10Nm

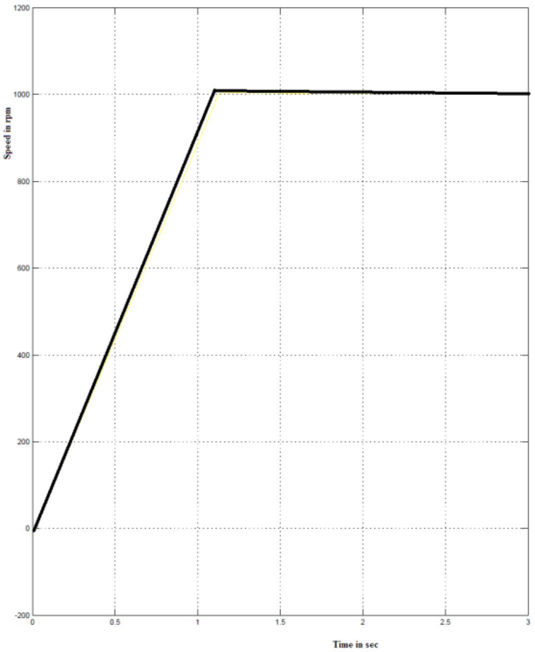


Figure 12. Response of the induction motor with speed of 1000rpm and Torque of 100Nm

5. CONCLUSIONS

From the above simulation responses it concludes that we can control the speed of the Induction motor using fuzzy controller. The fuzzy controller will give the better performance compared to other controllers.

The Future work is real time implementation of this Fuzzy logic controller for induction motor speed control. The speed of the induction motor is controlled using Fuzzy controller. From the result the performance of the fuzzy control system is satisfactory, incrementing the robustness (i.e., less overshoot, less settling time) in relation to load torque variations while achieving the reference speed. The proposed fuzzy control system is thus an acceptable alternative method for V/f common control applications, where a high dynamic and precise is not required.

REFERENCES

[1] Sreenivasa Rao Jalluri, Dr. B. V. Sanker Ram, A neuro fuzzy controller for induction machines drives Journal of Thoretical and Applied Information Technology.

[2] A. Goedtel, I. N. da Silva and P. J. A. Serni, “Load torque identification in induction motor using neural networks technique”, Electric Power Systems Research, vol. 77, no. 1, pp. 35-45, 2007.

[3] A. I. Al-Odienat and A. A. Al-Lawama, “The advantages of PID fuzzy controllers over the conventional types”, American Journal of Applied Sciences, vol. 5, no. 6, pp. 653-658, 2008.

[4] A. Tae-Chon, K. Yang-Won, H. Hyung-Soo and W. Pedricz, “Design of neuro-fuzzy controller on DSP for real-time control of induction motors”, Proceedings of IFSA World ongress and 20th NAFIPS International Conference, vol. 5, pp. 3038-3043, 2001.

[5] B. Karanayil, M. F. Rahman and C. Grantham, “Online stator and rotor resistance estimation scheme using artificial neural networks for vector controlled speed sensorless induction motor drive”, IEEE Transactions on Industrial Electronics, vol. 54, no. 1, pp. 167-176, 2007.

[6] B. Lu, T. G. Habetler and R. G. Harley, “A survey of efficiency estimation methods for in-service induction motors”, IEEE Transactions on Industry Applications, vol. 42, no. 4, pp. 924-933, 2006.

[7] B. Singh, G. Bhuvaneswari and B. Garg, “Harmonic mitigation in ACDC converters for vector controlled induction motor drives”, IEEE Transactions on Energy Conversion, vol. 22, no. 3, pp. 637-646, 2007.

[8] E. Bim, “Fuzzy optimization for rotor constant identification of an indirect FOC induction motor drive”, IEEE Transactions on Industrial Electronics, vol. 48, pp. 1293-1295, 2001.

[9] F. Zidani, D. Diallo, M. E. H. Benbouzid and R. N-. Saïd, “A fuzzy-based approach for the diagnosis of fault modes in a voltage-fed PWM inverter induction motor drive”, IEEE Transactions on Industrial Electronics, vol. 55, no. 2, pp. 586-593, 2008.

[10] G. El-Saady, A. M. Sharaf, A. Makky, M. K. Sherbiny and G. Mohamed, “A high performance induction motor drive system using fuzzy logic controller”, Proceedings of 7th Mediterranean Electrotechnical Conference, vol. 3, pp. 1058-1061, 1994.

[11] M. D. Singh and K. B. Kanchandani, Power electronics, TMH Companies, 7th Wdition, 2010.

[12] M. N. Uddin and W. Hao, “Development of a self-tuned neuro-fuzzy controller for induction motor drives”, IEEE Transactions on Industry Applications, vol. 43, no. 4, pp. 1108-1116, 2007.

[13] M. N. Uddin, Z. R. Huang and M. I. Chy, “A simplified self-tuned neuro fuzzy controller based speed control of an induction motor drive”, IEEE Power Engineering Society – General Meeting, pp. 1-8, 2007.

[14] S. Xiang-Dong, K. Kang-Hoon, Y. Byung-Gyu and M. Matsui, “Fuzzylogic-based V/f control of an induction motor for a DC grid powerleveling system using flywheel energy storage equipment”, IEEE Transactions on Industrial Electronics, vol. 56, no. 8, pp. 3161-3168, 2009.

[15] Timothy J.Ross., Fuzzy logic with Engineering Applications, Mc Graw-Hill, Inc., International Editions, New York, 1997.

[16] W. Dazhi, T. Renyuan, J. Hui and Y. Jie, “Sensorless-speed controlstrategy of induction motor based on artificial neural networks”, FifthWorld Congress on Intelligent Control and Automation (WCICA), vol. 5,pp. 4467-4471, 2004.