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Design & Simulation of an Adaptive Neuro-Fuzzy Inference System (ANFIS) for Current Control of AC Drive

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Abstract. Induction motors are largly used in various application in these days. This is the reason they are manufactured in wide numbers. This paper presents the study of Artificial Neural Network (ANN), Fuzzy Control System, Adaptive Neuro-Fuzzy Inference System (ANFIS) and Proportional. These all techniques are applied to AC machine drive to control current transients. While AC induction motor is operating the load and the parameters varies accordingly, but the provision of desirable control both in transient and steady states must be ready. Hence, the control strategy is required as rugged and acceptable . Due to the inability in some regular control methods like PI, PID controllers to work under broad spectrum of operation, the controllers under Artificial Intelligence category like ANN, ANFIS, Fuzzy controller, genetic algorithm and few expert systems are being used widely in the various application. Here, the problem with conventional, fuzzy controller is that the parameters interrelated with membership functions and the rules depend generally on the insight of the experts. The concept of Hybrid technology controllers is growing these days. To sort out this problem, ANFIS, ANN, Fuzzy Logic Control and PI controllers are put forward in this paper and studied..

Keywords: ANFIS, Fuzzy Logic, Membership functions, ANN, Controller, Simulink, Matlab,

1 Introduction

Induction motors play a prime role in the industrial sector especially in the field of electric drives & control. Without proper controlling of the speed, it is virtually impossible to achieve the desired task for a specific application. AC motors, specifically the squirrel-cage induction motors (SCIM), has several inherent advantages like simplicity, reliability, low cost and virtually maintenance-free electrical drives. However, for high dynamic performance industrial applications, their control remains a challenging problem because they exhibit significant nonlinearities and many of the parameters, mainly the rotor resistance, vary with the operating conditions . Vector control of an induction machine gets decoupled torque and flux dynamics leading to separate control of the torque and flux as for a separately excited DC motor. FOC methods are attractive, but suffer from one major disadvantage, viz., they are sensitive to motor parametric variations such as the rotor time constant and an incorrect flux measurement or estimation at low speeds.

In this designed ANFIS model, neural network used to select a proper rule base techniques , which is achieved using the back propagation algorithm. This integrated approach improves the system performance, cost-effectiveness, efficiency, dynamism, reliability of the designed controller. The simulation results presented in this paper show the effectiveness of the model developed & has got much faster response time or settling times.

Space Vector Pulse Width Modulation (SVPWM) method is one of the advanced, computation-intensive PWM method and possibly the best among all the PWM techniques for variable frequency drive applications. Because of its superior performance characteristics, it has been finding widespread applications in recent years. Satean, et.al. Presented a novel control technique of control of the induction motors using space vector pulse width modulation method . They even developed an excellent 3-phase bridge inverter which was used to apply a balanced 3phase voltages to the SCIM. In due course, fuzzy logic concept was introduced by Lotfi Zadeh in 1965. Many researchers used this FLC concept developed by Zadeh to develop controllers for their applications, which had yielded good results. Thus, this FLC concept remained as a popular control scheme in the control world even today. Arulmozhiyal & Baskaran described in brief a number of fuzzy control logic applications on various plants in their paper. They even devised a new control strategy to control the speed of IMs using FLC technique .

Fuzzy Logic control (FLC) has proven effective for complex, nonlinear and imprecisely defined processes for which standard model based control techniques are impractical or impossible. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1. This means that if the reliable data is not available or if the controlled system is too complex to derive the required decision rules, development of a fuzzy logic controller become quite difficult. In this case, the expert knowledge can be made use of for framing the proper rules which can be further used to tune the controller for obtaining better results .Furthermore, an optimal fuzzy logic controller cannot be achieved by trial-and-error. These drawbacks have limited the application of fuzzy logic control.

In the above mentioned papers, there were a lot of drawbacks & disadvantages, one of the parameter being the settling time of the responses & the proper selection of the rule base. The responses had taken a lot of time to reach the final steady state value. In this paper, a sincere attempt is made to reduce the settling time of the responses & make the speed of response very fast by designing an efficient controller using ANFIS control strategy. The proper rule base is selected using an intelligently developed back propagation also. Here, we have formulated this complex control strategy for the speed control of IM, which has yielded excellent results compared to the others mentioned in the literature survey above. The results of our work have showed a very low transient response and a non-oscillating steady state response with excellent stabilization.

The structure of the research work presented in this paper is organized in the following sequence. A brief review of the literature survey of the related work was presented in the previous paragraphs in the introductory section. Section 2 presents the mathematical modeling of the induction motor. Review about the adaptive neuro fuzzy inference scheme used in the design of the controller is presented in section 3. The design of the ANFIS controller is presented in section 4. The section 5 shows the development of the Simulink model. For the current control of the induction motor.
simulation results & the discussion on it are presented in the section 6. This is followed by the conclusions in the concluding section.

2 Mathematical modeling of the induction motor

The mathematical model of the induction machine can be represented by a set of differential equations in the twin –axis (d-q) stationary reference frame.

$$\dot{i}_{ds} = (R_r L_r i_{ds} - \omega_r L^2_m i_{qs} - R_r L_m i_{dr} - \omega_r L_r L_m i_{qr} - L_r v_{ds}) / a_0$$

$$\dot{i}_{qs} = (\omega_r L^2_m i_{ds} + R_s L_r i_{qs} + \omega_r L_r L_m i_{dr} - R_r L_m i_{qr} - L_r v_{qs}) / a_0$$

$$\dot{i}_{dr} = -(R_s L_m i_{ds} - \omega_r L_m L_s i_{qs} - R_r L_s i_{dr} - \omega_r L_r L_m i_{qr} - L_m v_{ds}) / a_0$$

$$\dot{i}_{qr} = -(\omega_r L_m L_s i_{ds} + R_s L_m i_{qs} + \omega_r L_r L_s i_{ds} - R_r L_s i_{qr} - L_m v_{qs}) / a_0$$

$$a_0 = L^2_m - L_r L_s \qquad \text{----(1)}$$

The mathematical model of induction machine can also be rearranged with the stator and rotor currents set as the state variables as in equation (1). In terms of stator and rotor currents, the torque can be written as in (2)

$$T_e = (\frac{3}{2}\frac{p}{2} L_m)(i_{qs} i_{dr} - i_{ds} i_{qr}) \qquad \text{---(2)}$$

For the machine model created, inputs chosen were the stator voltage, the rotor speed, and the rotor resistance. The states chosen were the stator currents and rotor currents using the d-q (twin) axis model in the stationary reference frame. This gives the four electrical states. The outputs chosen were the stator and rotor currents and the "electrical" torque produced magnetic saturation effects were not included.

3 Review about the adaptive neuro fuzzy inference scheme used in the design of the controller

ANN has strong learning capabilities at the numerical level. Fuzzy logic has a good capability of interpretability and can also integrate expert's knowledge. The hybridization of both paradigms yields the capabilities of learning, good interpretation and incorporating prior knowledge. ANN can be used to learn the membership values for fuzzy systems, to construct IF-THEN rules, or to construct decision logic. The true scheme of the two paradigms is a hybrid neural/fuzzy system, which captures the merits of both the systems .This concept is made use of in developing the ANFIS controller in this paper. A neuro-fuzzy system has a neural-network architecture constructed from fuzzy reasoning. Structured knowledge is codified as fuzzy rules, while the adapting and learning capabilities of neural networks are retained. Expert knowledge can increase learning speed and estimation accuracy.

Fuzzy logic is one of the most successful applications in the control engineering field, which can be used to control various parameters of real-time systems. This logic combined with neural networks yields very significant results. This merged technique of the learning power of the NNs with the knowledge representation of FL has created a new hybrid technique, called neuro-fuzzy networks **.** This technique gives a fairly good estimate of the speed and is robust to parameter variation **.**

4 The design of the ANFIS controller

In the modeling and feedback control of any dynamical system, a controller is a must for the plant as it takes care of all the 125 disturbances and brings back the system to its original state in a couple of second.

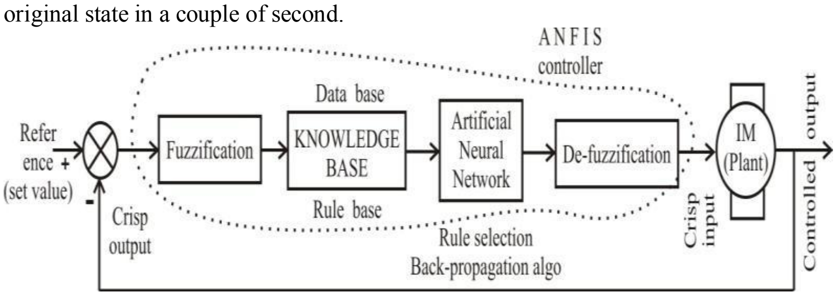

Fig.1 Block diagram of the ANFIS control scheme

To start the design of the controller using the ANFIS scheme, first, a mathematical model of the induction motor plant along with the controller mathematical model is required, which can be further used for simulation purposes. The mathematical model of the plant is given by Eq. (1) and it is a fourth-order mathematical model of size (4 4), which is used here in the Simulink model. The basic structure of the ANFIS coordination controller developed in this study to control the speed of the IM. The block diagram of the developed controller is shown in Fig. Inputs to the ANFIS controller, i.e., the error and the change in error, are modeled using Eqs. (3) and (4) as follows:

$$e(k) = \omega ref - \omega r \text{ ----(3)}$$

$$\Delta e(k) = e(k) - e(k-1) \text{ ---- (4)}$$

where ωref is the reference speed, ωr is the actual rotor speed, e(k) is the error and Δe(k) is the change in error. The fuzzification unit converts the crisp data into linguistic variables, which is given as inputs to the rule-based block. The set of 49 rules is written on the basis of previous knowledge or experiences. The rule-based block is connected to the neural network block. Back-propagation algorithm is used for NN training in order to select the proper set of rule base. For developing the control signal, training is a very important step in the selection of the proper rule base. Once the proper rules are selected and fired, the control signal required to obtain the optimal outputs is generated.

5 Development of the Simulink model

ANFIS controller based system was developed using the various toolboxes in Matlab /Simulink. The various waveforms are observed on the corresponding scopes after running the simulations.

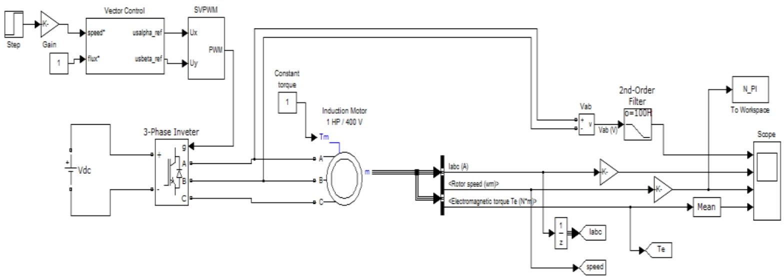

Fig.2 The Simulink model for the ANFIS controller.

6 Simulation results:

The Simulink model of ANFIS controller is as in Fig.2 In order to start the simulations, the 49 fuzzy rule set has to be invoked first from the command window in the Matlab. Initially, the fuzzy file where the rules are written with the ncorporation of the T-S control strategy is opened in the Matlab command window, after which the fuzzy editor (FIS) dialogue box opens. The .fis file (sugenosevenrules2.fis) is imported using the command window from the source and then opened in the fuzzy editor dialog box using the file open command. Once the file is opened, the TS-fuzzy rules file gets activated. Furthermore, the data is exported to the workspace and the simulations are run for a specific period of time (say 3 second). The fuzzy membership function editor is then obtained using the view membership command from the menu bar. The written TS-fuzzy rules also can be viewed from the rule view command. The rule viewer for the 2 inputs and 1 output can be observed pictorially. Now, after performing all the preliminary operations, the simulations are run for a period of 3 second in Matlab . Once, the simulation is run, various parameters such as speed, flux, torque, currents, slip, etc. get stored in the workspace. After running the developed Simulink model, we get the error, change in error and an intermediate parameter.

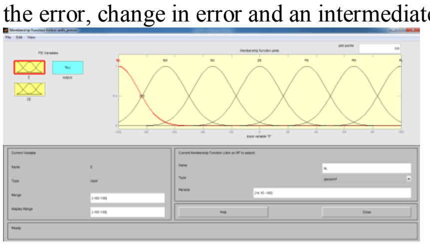

Fig.3 Input Membership Function

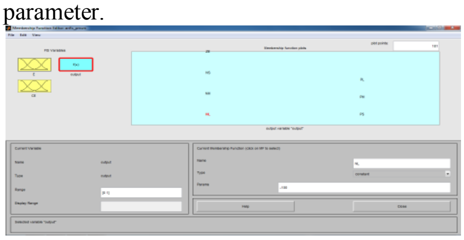

Fig.4 Output Function

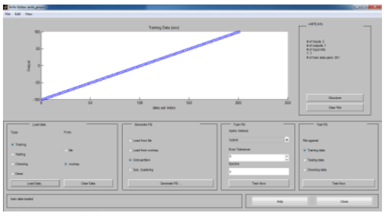

Fig.5 Training Data

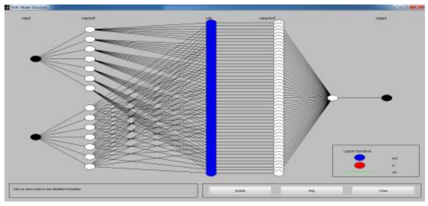

Fig. 6 ANFIS model with 2 inputs and 1 output

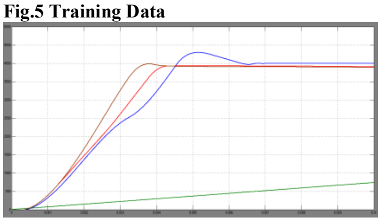

Fig.7 Speed comparison with different controllers
Brown : ANFIS ; Red: Fuzzy ; Blue : Hysteresis ;
Green : Predictive

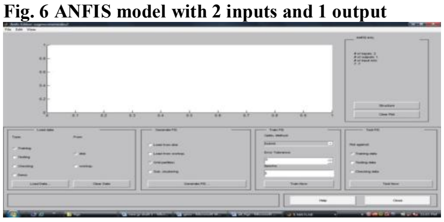

Fig.8 ANFIS editor window

These variables, which are in the form of data in the workspace, are loaded into the 'anfis' editor (Fig. 9). Once the data file is loaded, the 'anfis' has to be trained by selecting a back-propagation algorithm with a suitable number of epochs. In our work, we have used the back-propagation algorithm with a suitable number of epochs being used for training the rules. This is done by selecting these 2 items in the 'train window' of the 'anfis' editor and training the neural network for proper selection of the rule base. The trained data are further exported to the workspace using the file-export command.

The developed ANFIS model structure with 2 input neurons and 1 output neuron along with 4 hidden layers (input membership function, rule base, membership function and aggregated output) is shown in Fig. 7.5. The training of the ANN by using the fuzzy rule base for the selection of the proper and optimal rule is taken care of by the designed ANFIS controller. Note that 7 by 7 rules are used in the hidden layers. Both neuron 1 and neuron 2 are connected to 7 fuzzy rules. The hidden layers contains 49-49 neurons to deal with the problem (for selection of the proper rule base, because the rule base is written randomly in fuzzy, the neural network selects the right optimal rule base to fire). The 2 input neurons, viz., the error and change in error, are given as input to the 1st hidden layer of the ANN as shown in Fig. 6. This 1st hidden layer deals with various input membership functions. In the 2nd and 3rd hidden layers, the set of 49 fuzzy rules is properly identified by training and the sets of optimal rules are selected. These sets of optimum rules are available at the 4th hidden layer. Out of the 49 rules, the optimal rules are fired here and the de-fuzzified output is obtained as the output neuron. The de-fuzzified output is further used to generate the firing pulse to be applied to the inverter bridge, which is further used to control the speed of the IM drive. After the simulation is run, the performance characteristics are observed on the respective scopes.

Conclusion: A novel and systematic method of achieving robust speed control of an IM system using SVPWM technique for voltage source inverter by means of adaptive neuro-fuzzy inference system has been investigated in this chapter. The SVPWM is used to control the firing angle of the inverter. This, in turn, controls the speed of the IM. The Simulink model was developed in Matlab 7. Due to the incorporation of the ANFIS controller, it was observed that the motor reaches the set speed very quickly in a shorter period of time. One of the main advantages of the ANFIS scheme is that, it is computationally efficient, increases the dynamic performance and provides good stabilization when there is a sudden fluctuation in one of the system parameters, say speed of the IM. This shows the excellent response of the proposed control scheme as it has the learning capability using the neural networks. The ANFIS systems handling more complex parameters, which demonstrates the effectiveness of the sudden variation of speed (because of parametric variation) from the normal value and its effects on the various parameters (such as slip, current, torque, etc.) to obtain the stability.

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