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Design of Simulink Model with ANFIS Controller for Controlling Parameters of 3Phase Induction Motor Drives

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Abstract— This paper proposed the implementation of adaptive neuro fuzzy inference system i.e. ANFIS for controlling the various parameter of three phase induction motor. The various parameter of induction motor are flux, load, torque, terminal voltage, speed, rotor angle, stator currents, slip, id, iq, rotor currents (3_ abc & d-q) v/s time this shows their performance characteristic on respective scope. The proposed neuro-fuzzy controller incorporates fuzzy logic algorithm with a five-layer artificial neural network (ANN) structure. The performance of the proposed neuro-fuzzy based vector controlled induction motor drive is investigated at different operating conditions. In the designed ANFIS scheme, neural network techniques are used to select a proper rule base, which is achieved using the back propagation algorithm. This integrated approach improves the system performance, cost-effectiveness, efficiency, dynamism, reliability of the designed controller. Fuzzy based controller develop a control signal which yields on the firing of the rule base, which is written on the previous experiences & these rules are fired which is random in nature. This result shows, the outcome of the controller is also random & optimal results may not be obtained. Selection of the proper rule base depending upon the situation can be achieved by the use of an ANFIS controller, which becomes an integrated method of approach for the control purposes & yields excellent results, which is the highlight of this paper. The proposed (ANFIS) controller is designed and showing parameter characteristics curve on scope simulink block through the MATLAB/SIMULINK software.

Keywords— ANFIS Controller, Back Propagation Algorithm, Fuzzy Logic, Induction motor, Matlab, Membership functions, Simulink Model

I. INTRODUCTION

Induction motors play a vital role in the industrial sector especially in the field of electric drives & control. Speed imbalances shows that, it is virtually impossible to achieve the desired task for a specific application. AC motors, particularly the squirrel-cage induction motors (SCIM), make an inherent advantage like simplicity, reliability, low cost and virtually maintenance free electrical drives. Again 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. The Field Orientation Control (FOC) of an induction machine achieves decoupled torque and flux dynamics leading to independent control of the torque and flux as for a separately excited DC motor. The 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.

An induction motors are widely used in various industries as prime work to produce rotational motions and forces. In General, variable speed drives for induction motors require both wide operating range of speed and fast torque response, regardless of load variations. The classical control is always used in majority of the electrical motor drives in [7]. Conventional control makes use of the mathematical model for the controlling of the system. At the time when there are system parametric variations or environmental disturbance i.e. noise, behavior of system is not satisfactory & deviates from the desired performance. In addition, usual computation of system mathematical model is difficult or impossible. For exact mathematic model of the system, then one has to do some identification techniques such as the system identification & obtain the plant model.

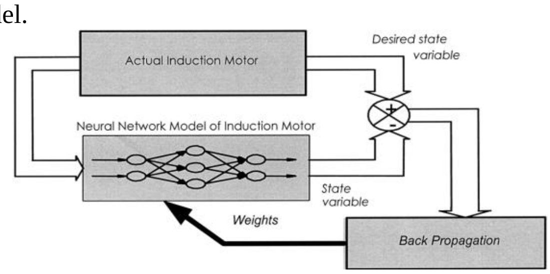


Fig.1: Parameter identification using neural networks

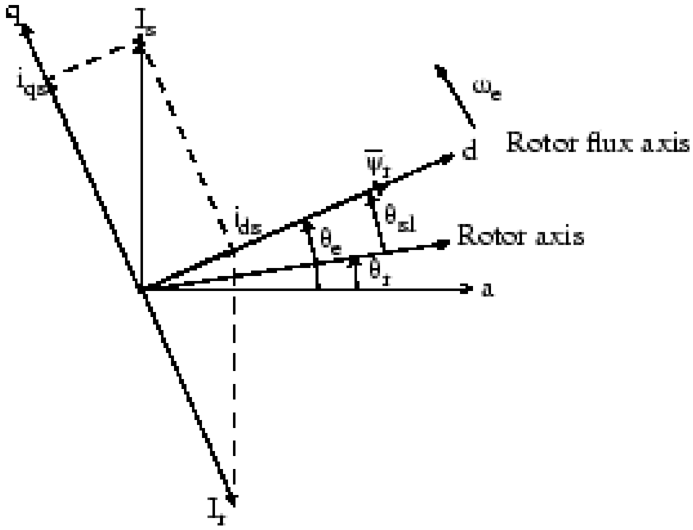
Moreover, the design and tuning of conventional controller increases the implementation cost and adds additional complexity in the control system & thus, may reduce the reliability of the control system. Hence, the fuzzy based techniques are used to overcome this kind of problems. The efficient torque control of induction motor drives in combination with resonant DC-link input filters can lead to a type of stability problem that is known as negative impedance instability. Fuzzy logic based flexible multi bus voltage control of power systems was developed by Ashok in [4]. From last few years, fuzzy logic has create growing interest in many motor control applications due to its non linearities handling features and independence of the plant modeling. The fuzzy controller (FLC) operates in a knowledge based path, and its knowledge relies on a set of linguistic if-then rules, like a human operator. There are a number of significant control methods available for induction motors including scalar control, vector or field oriented control, direct torque and flux control, sliding mode control, and the adaptive control [9]. 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 [5]. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1 [8]. 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 [4]. Furthermore, an optimal fuzzy logic controller cannot be achieved by trial-and-error. These drawbacks have limited the application of fuzzy logic control [10].

II. VECTOR CONTROLLED INDUCTION MOTOR DRIVE

A. Mathematical Model

The induction motor is fed by a current-controlled PWM inverter, which operates as a three-phase sinusoidal current source. The motor speed ω is compared to the reference ω* and the error is processed by the speed controller to produce a torque command Te*. As shown below, the rotor flux and torque can be separately controlled by the stator direct-axis current i_{ds} and quadrature-axis current i_{qs}, respectively.

Field-Oriented Control Principle-



The stator quadrature-axis current reference i_{qs}* is calculated from torque reference Te* as

$$i_{qs}^* = \frac{2}{3}\cdot\frac{2}{p}\cdot\frac{L_r}{L_m}\cdot\frac{T_e^*}{|\psi_r|_{est}}$$

Where, Lr is the rotor inductance, Lm is the mutual inductance, and $|\psi_r|_{est}$ is the estimated rotor flux linkage given by-

$$|\psi_r|_{est} = \frac{L_m i_{ds}}{1+\tau_r s}$$

where τr = Lr / Rr is the rotor time constant.
The stator direct-axis current reference ids* is obtained from rotor flux reference input |ψr|*.

$$i_{ds}^* = \frac{|\psi_r|^*}{L_m}$$

The rotor flux position Θe required for coordinates transformation is generated from the rotor speed ω_m and slip frequency ω_{sl}

$$\theta_e = \int(\omega_m + \omega_{sl})dt$$

The slip frequency is calculated from the stator reference current iqs* and the motor parameters.

$$\omega_{sl} = \frac{L_m}{|\psi_r|_{est}}\cdot\frac{R_r}{L_r}\cdot i_{qs}^*$$

The i_{qs}* and i_{ds}* current references are converted into phase current references ia*, ib*, ic* for the current regulators. The regulators process the measured and reference currents to produce the inverter gating signals.

The role of the speed controller is to keep the motor speed equal to the speed reference input in steady state and to provide a good dynamic during transients. The controller can be a proportional-integral type.

III. CONTROLLER DESIGN

A controller is a device which controls each & every operation in the system making decisions. As per the control system point, it is bringing stability to the system when there is a disturbance, thus safeguarding the equipment from further damages. It may be hardware based controller or a software based controller or a combination of both. In this section, the development of the control strategy for control of various parameters of the induction machine such as the speed, flux, torque, voltage and current is presented using the concepts of ANFIS control scheme, the block diagram of which is shown below in the Fig 2.

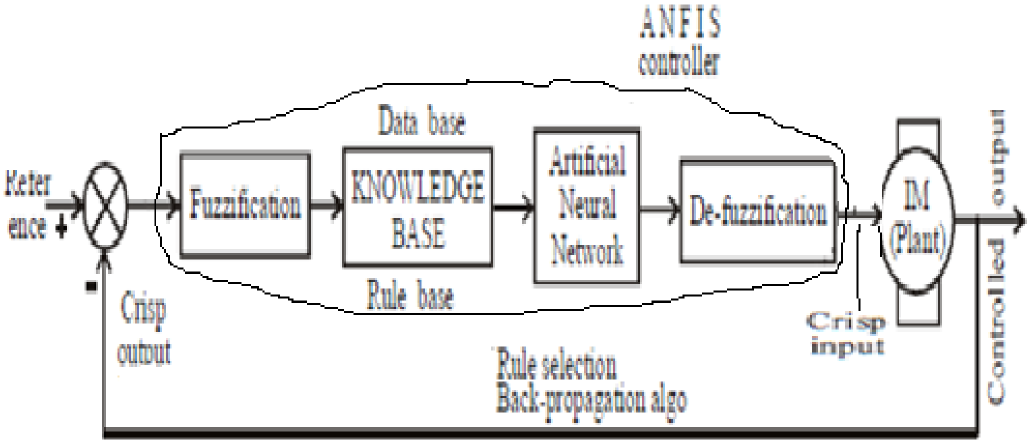


Fig.2: Block diagram of the ANFIS control scheme

Fuzzy logic is one of the successful applications of fuzzy set in which the variables are linguistic rather than the numeric variables. Linguistic variables, defined as variables whose values are sentences in a natural language (such as large or small) it may be represented by the fuzzy sets. Fuzzy set is an extension of a 'crisp' set where an element can only belong to a set (full membership) or not belong at all (no membership). Fuzzy sets allow partial membership, which means that an element may partially belong to more than one set. A fuzzy set A of a universe of discourse X is represented by a collection of ordered pairs of generic element and its membership function $\mu : X \rightarrow \{0\ 1\}$, which associates a number $\mu\ A(x) : X \rightarrow \{\ 0\ 1\}$, to each element x of X. A fuzzy logic controller is based on a set of control rules called as the fuzzy rules among the linguistic variables. These rules are expressed in the form of conditional statements.

Our basic structure of the developed ANFIS coordination controller to control the speed of the Induction Motor consists of 4 important parts viz., fuzzification, knowledge base, neural network and the de-fuzzification blocks.

The inputs to the ANFIS controller, i.e., the error & the change in error is modeled by following equation-

$$e(k) = \omega_{ref} - \omega_r \text{ --------- (1)}$$

$$\Delta e(k) = e(k) - e(k-1) \text{ ------ (2)}$$

Where, 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 fuzzification unit converts the crisp data into linguistic variables, which is given as inputs to the rule based block. The set of 49 rules are written on the basis of previous knowledge and experiences in the rule based block. The rule base block is connected to the neural network block. Back propagation algorithm is used to train the neural network to select the proper set of rule base. The control signal developed due to the trainingand this training is a very important step in the selection of the proper rule base. Once the proper rules are selected & fired, the control signal required to obtain the optimal outputs is generated. The output of the Neural Network unit is given as input to the de-fuzzification unit and the linguistic variables are converted back into the numeric form of data in the crisp form. In the fuzzification process, i.e., in the first stage, the crisp variables, the speed error & the change in error are converted into fuzzy variables or the linguistics variables. The fuzzification maps the two input variables to linguistic labels of the fuzzy sets. The fuzzy coordinated controller uses the linguistic labels. Each fuzzy label has an associated membership function. The membership function of triangular type is used in our work .The inputs are fuzzified using the fuzzy sets & are given as input to ANFIS controller. The rule base for selection of proper rules using the back propagation algorithm is written as shown in the below table.

Table: Rule base for controlling the speed

ΔE \ E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The developed fuzzy rules 7*7=49 included in the ANFIS controller. The control decisions are made based on the fuzzified variables in the above table. The inference involves a set of rules for determining the output decisions. As there are 2 input variables & 7 fuzzified variables, the controller has a set of 49 rules for the ANFIS controller. Out of these 49 rules, the proper rules are selected by the training of the neural network with the help of back propagation algorithm & these selected rules are fired. Further, it has to be converted into numerical output, i.e., they have to be de-fuzzified. This process is called as defuzzification, which is the process of producing a quantifiable result in fuzzy logic.

The defuzzifcation transforms fuzzy set information into numeric data information. There are so many methods to perform the defuzzifcation, viz., centre of gravity method, centre of singleton method, maximum methods, the marginal properties of the centroid methods & so on. In our work, we use the centre of gravity method. The output of the defuzzification unit will generate the control commands which in turn is given as input called as the crisp input, to the plant through the inverter. If here is any deviation in the controlled output which is crisp output, this is fed back & compared with the set value & the error signal is generated which is given as input to the ANFIS controller which in turn brings back the output to the normal value, thus maintaining stability in the system.

IV. **Development of Simulink Model**

Simulink model for the control of various parameters of the induction motor can be developed in Matlab. By using the command window of Matlab it creates the .fis file and it will be helpful in the simulink for controlling the speed of Induction Motor with an important role of ANFIS controller proposed in this paper. This simulink model with the ANFIS controller can be developed using the various toolboxes available in the simulink library such as the power system, power electronics, control system, signal processing toolboxes & from its basic functions. The entire system modeled in Simulink is a closed loop feedback control system consisting of the plants, controllers, samplers, comparators, feedback systems, constants, buses, the mux, de-mux, summers, adders, gain blocks, multipliers, constant blocks, CT & DT blocks, ANFIS editor blocks, clocks, sub-systems, integrators, state-space models, the output sinks (scopes), the input sources, work-space blocks, etc.

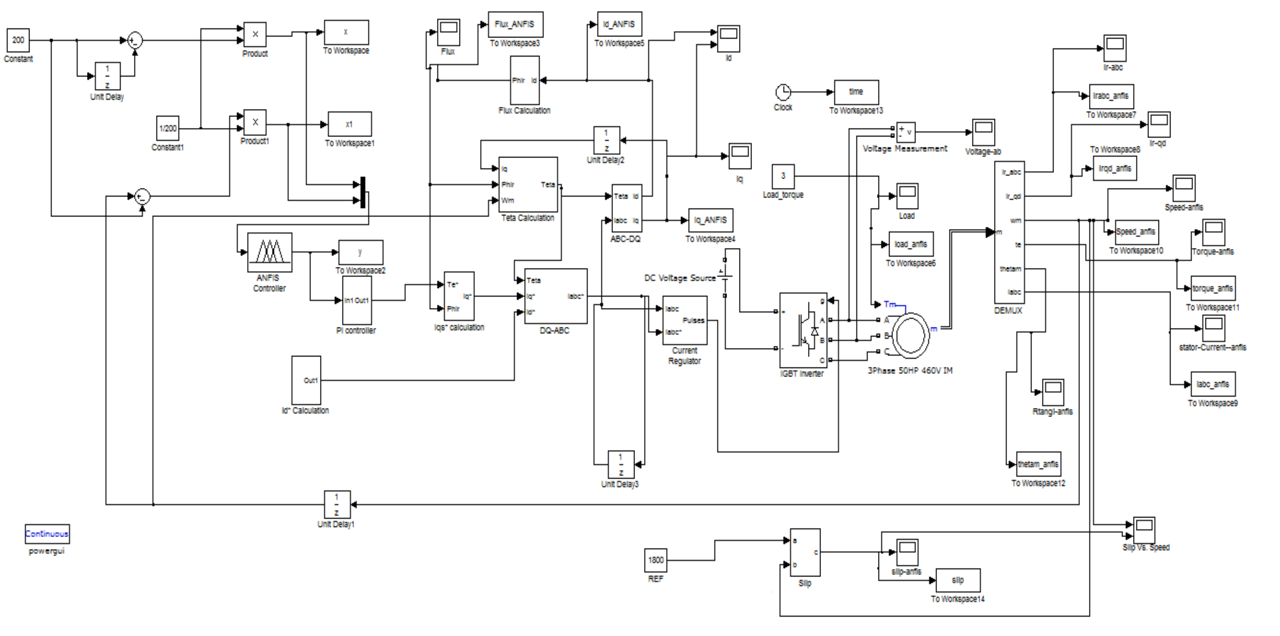


Fig.3: Simulink model for speed control of 3phase Induction Motor

V. Result

Simulink model with the neuro-fuzzy controller for the speed control of IM is developed in Matlab as shown in the Fig.3 above. 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 incorporation of the T-S control strategy is opened in the Matlab command window, after which the fuzzy editor (FIS) dialogue box opens as shown in the Fig. 4. The .fis file (sugenosevenrules2.fis) is imported using the command window from the source & 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. Further, the data is exported to the workspace & the simulations are run for a specific amount of time (say 3 secs). The fuzzy membership function editor is then obtained using the view membership command from the menu bar and this is shown in the Fig.5 . The written TS-fuzzy rules also can be viewed from the rule view command, which is presented in the Fig. 6. The rule viewer for the 2 inputs and 1 output can be observed pictorially in the Fig. 4. Now, after performing all the preliminary operations, the simulations are run for a period of 3 seconds in Matlab with a reference speed of 200 rads / sec & with a load torque of 3 N-m. Once, the simulation is run, the various parameters such as speed, flux, torque, currents, slip, voltage, etc. gets stored in the workspace. After running the Takagi-Sugeno model, we get the error (x), change in error (x1) & an intermediate parameter (y). These 3 parameters, viz., x, x1 & y are stored in a variable in the command window. The 'anfis' editor is opened in the command window (Fig. 7). These variables which are in the form of data in the workspace are loaded into the 'anfis' editor (Fig7). The .fis file is generated next in the 'anfis' editor by loading the data from the workspace. Once the .fis file is generated, the 'anfis' has to be trained properly by selecting a proper algorithm with suitable number of epochs(3). 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 & training the neural network for proper selection of the rule base. The trained data is further exported to the workspace using the file-export command. The surface plot for the error speed & change in error with the output is shown in the Fig.8. Also, the contour plot of the same is depicted.

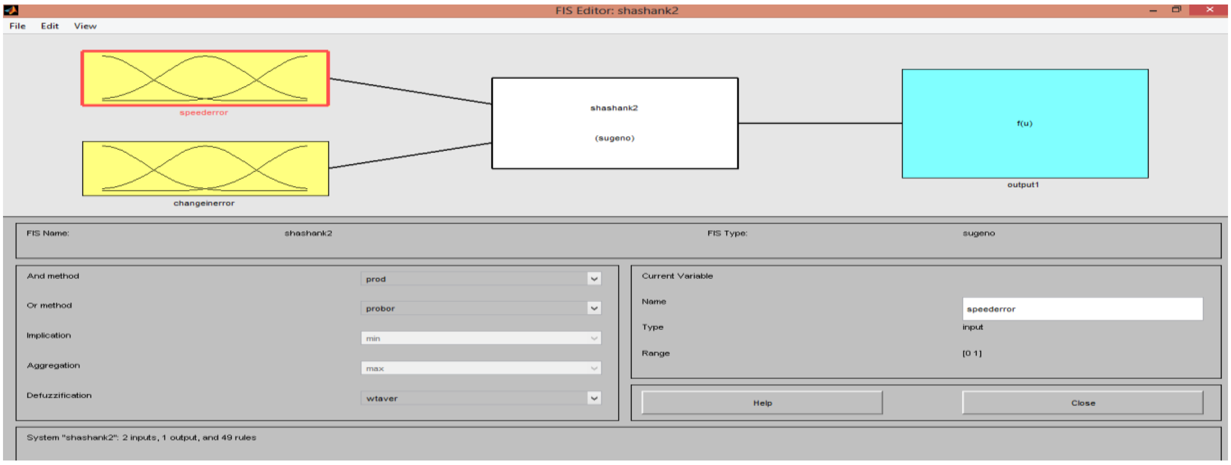


Fig. 4 : FIS editor with 2 inputs & 1 output ; Importing of the .fis file from the source

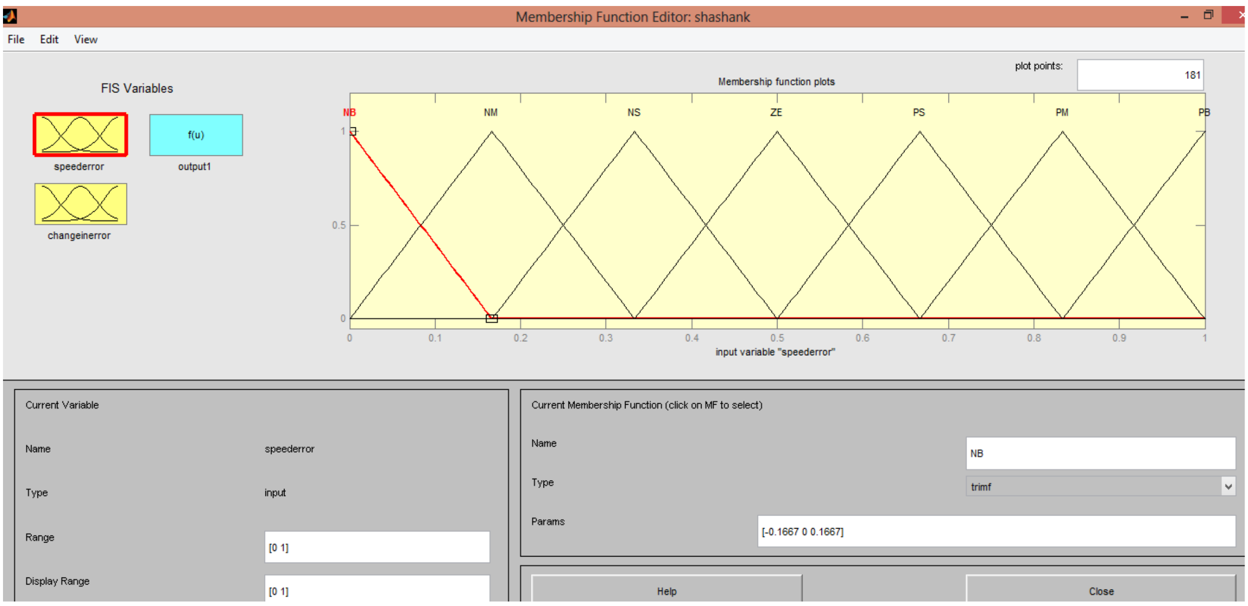


Fig. 5 : Membership function editor

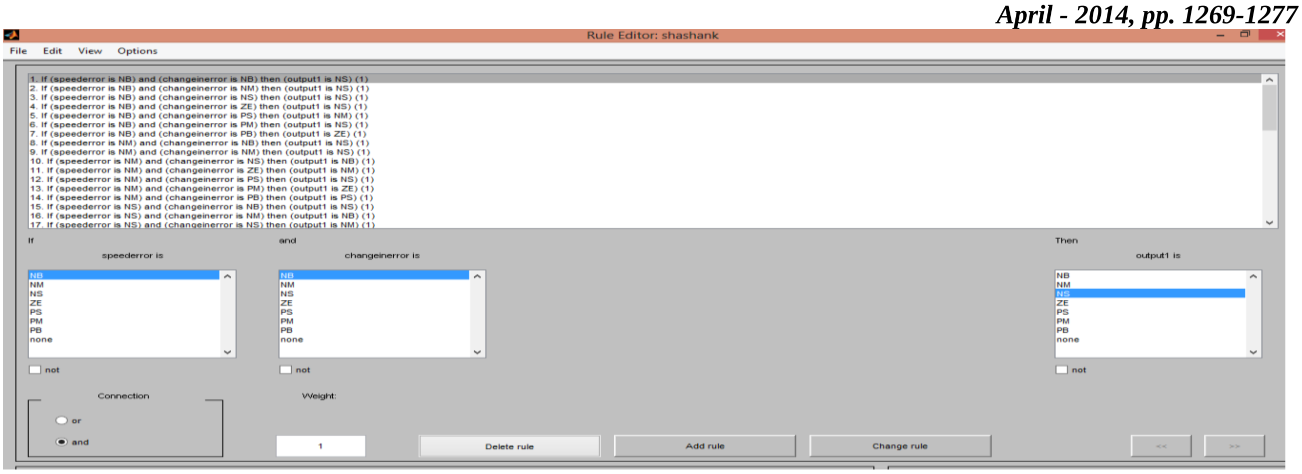


Fig. 6: Rule editor window

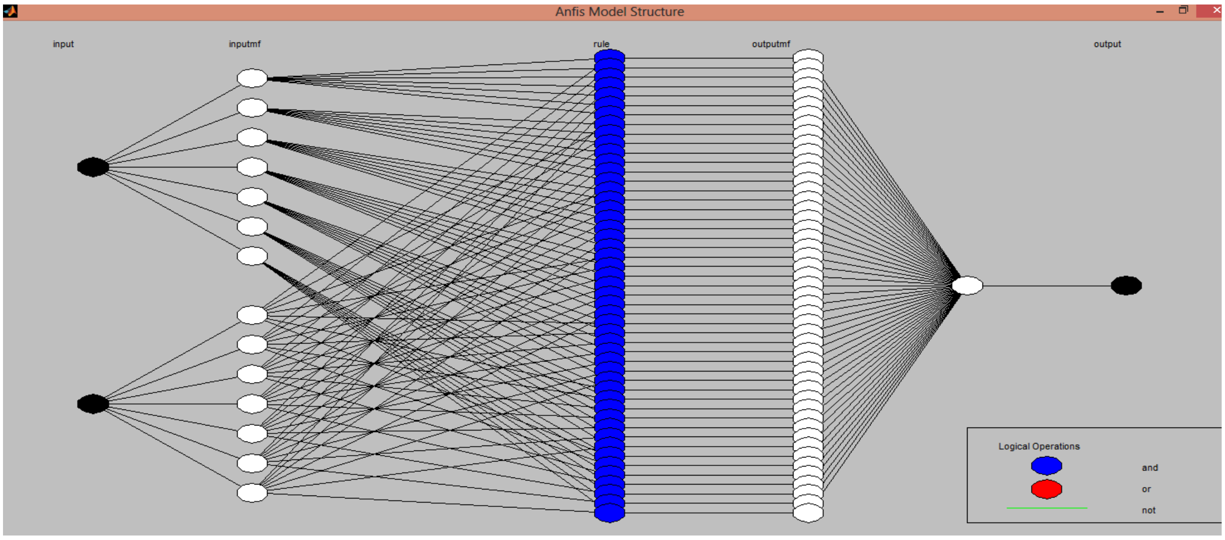


Fig.7: ANFIS model structure with 2 inputs & 1 output showing all the 5 layers in the ANN architecture

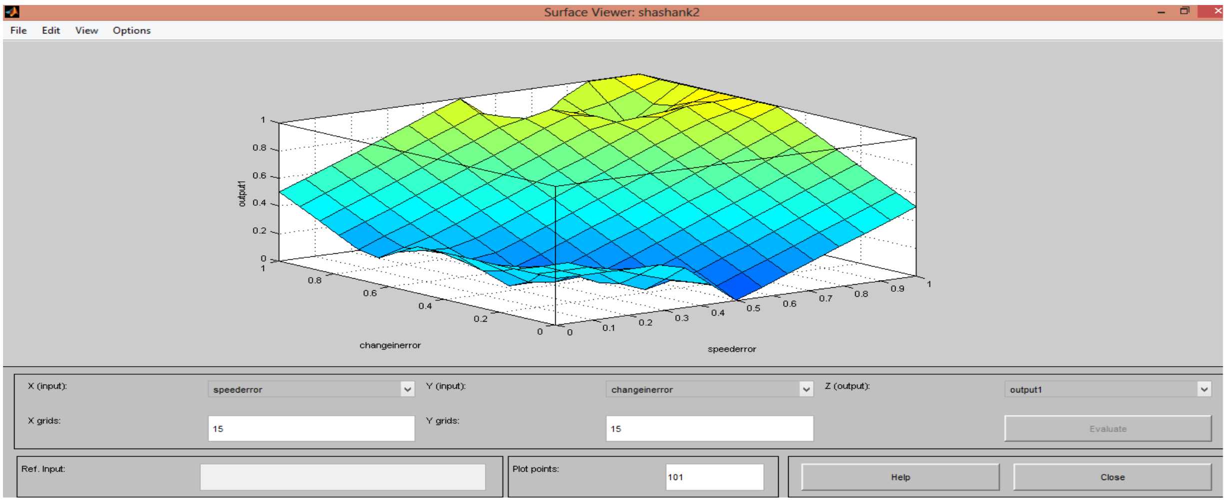


Fig. 8 : Surface plot of the 3 parameters (2 inputs : change in error, speed error & 1 output)

It was observed from the simulation results that by using the neuro-fuzzy (ANFIS) control, for the set speed of 200 r / s & for the 49 rules, the speed reaches its desired set value. This shows the effectiveness of the designed neuro fuzzy controller & the designed neuro-fuzzy controller tries to speed up the performance of the drive, thus showing faster dynamism. It is also observed that with the designed neuro-fuzzy controller, the response characteristics curves take less time to settle & reach the final steady state value.

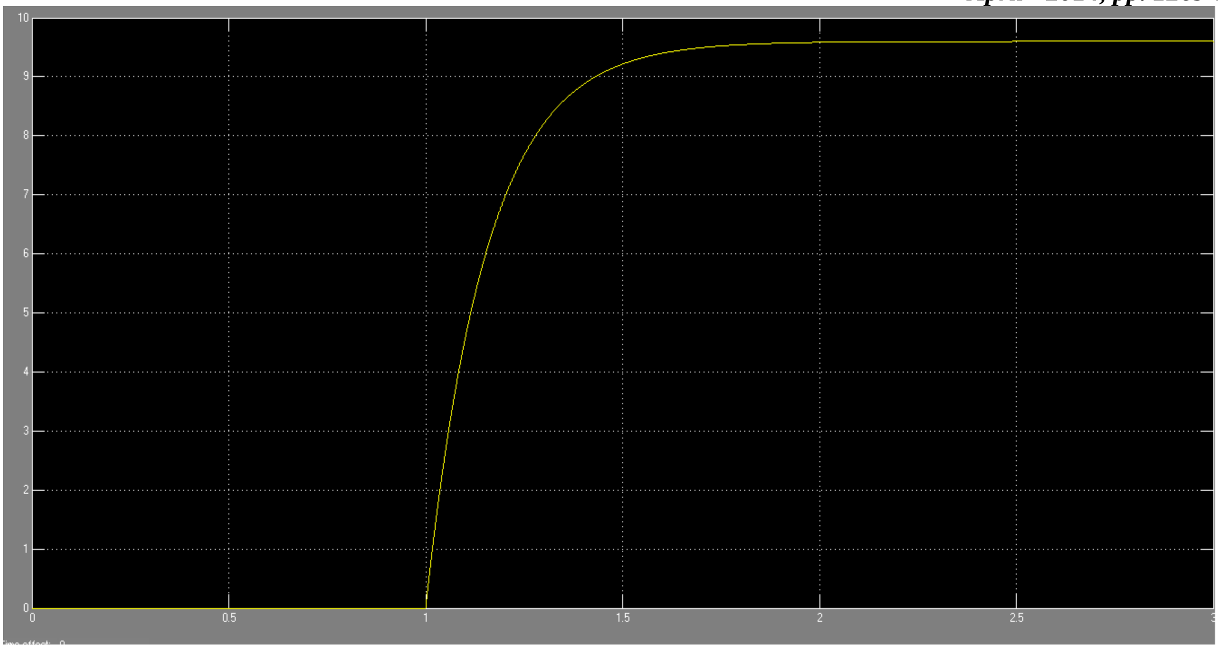


Fig.9 : Plot of flux vs. time

From the variation of flux with time as shown in the Fig. 9, it can be observed that when the motor speed is increasing (during the transient period), more stator current is required to develop the requisite flux in the air gap. Hence, the flux also starts increasing during the transient period (0 to 0.4 sec) exponentially. Once, the motor attains the set rated speed, the flux required to develop the torque almost remains constant after O 0.4 secs. Once, the flux in the air gap remains constant, the variation of the load torque and speed will not disturb the flux curve. Hence, the IM will be operating at a constant flux.

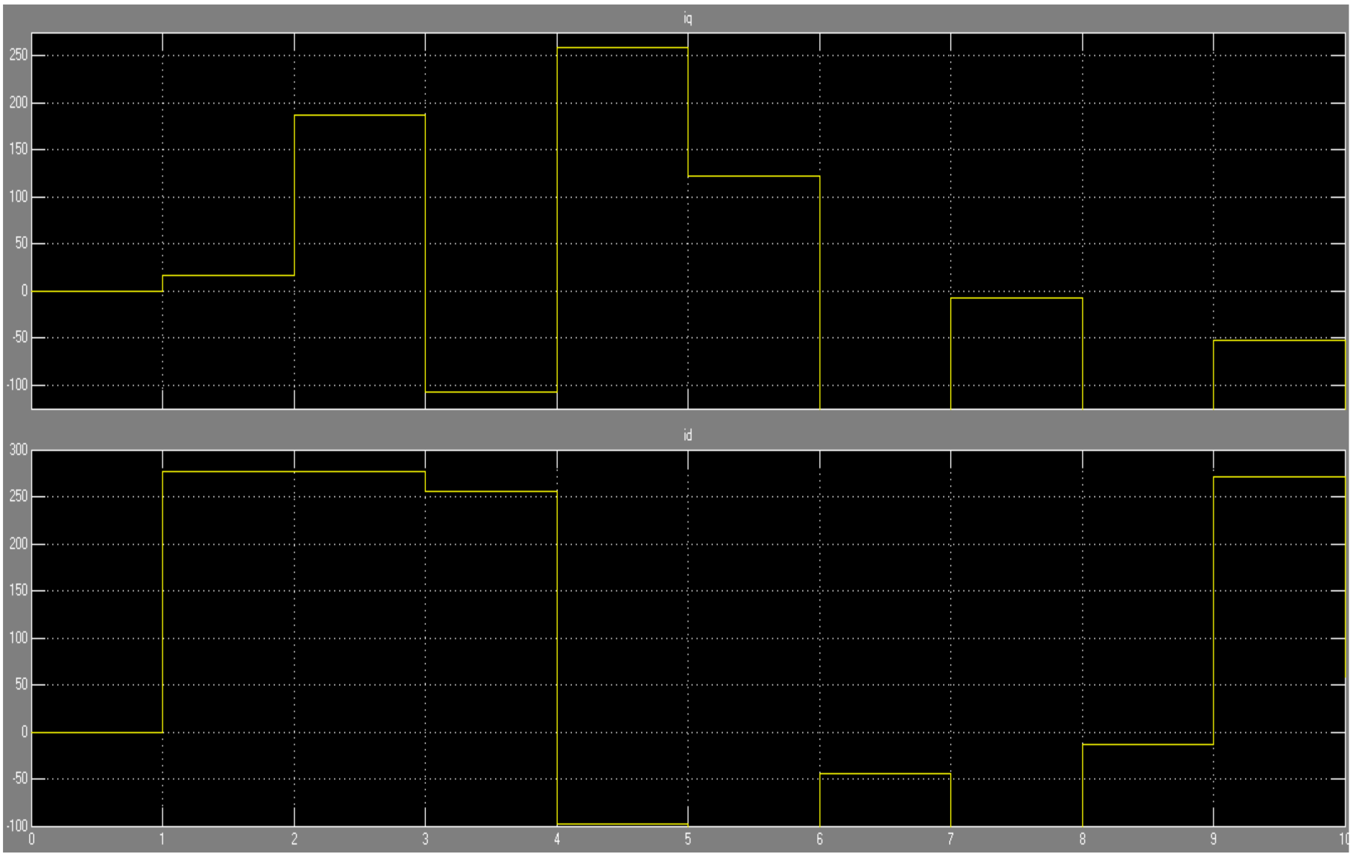


Fig.10 : Plot of i_d & i_q Currents Vs. Time Combine on same scope

The plots of the direct axes (id) & quadrature axes currents (iq) versus time is shown in the Fig.10 combine. From these figures, it can be inferred that the machine reaches the set reference speed of 200 rad/sec.

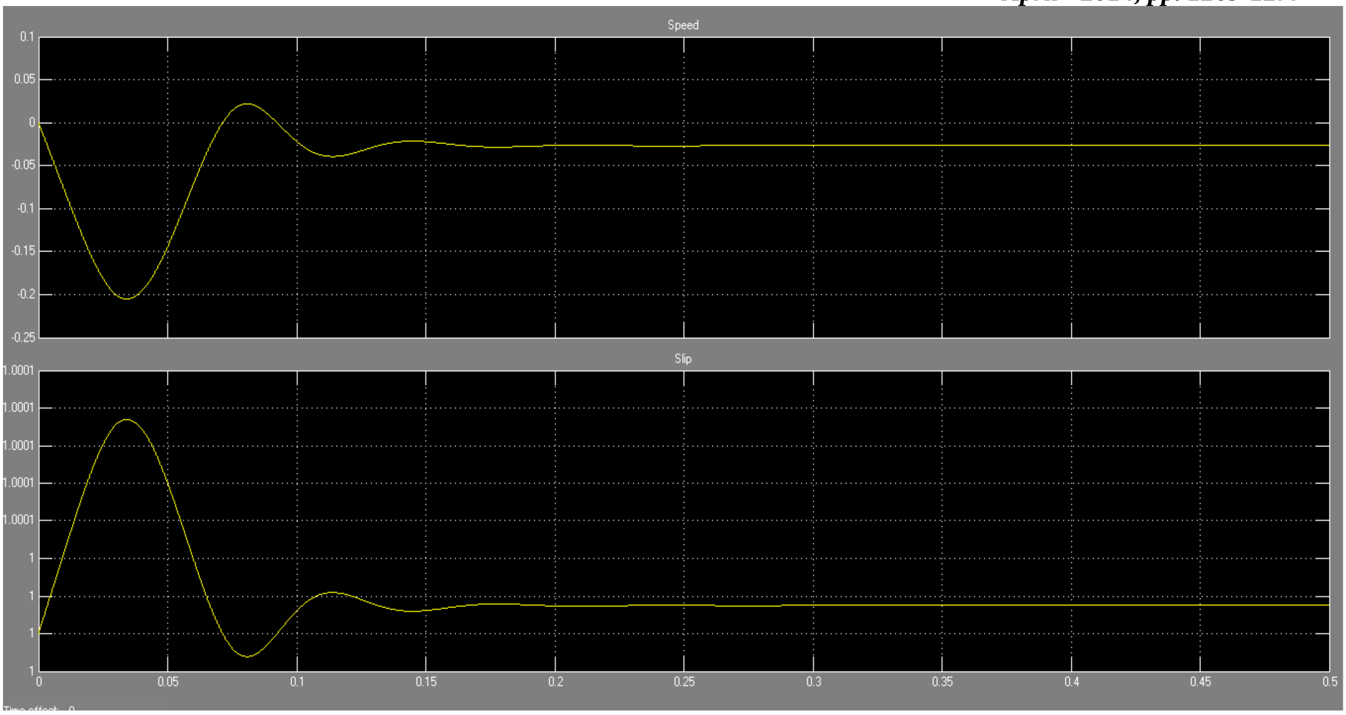


Fig. 11 : Plot of Slip and Speed Vs. Time combine on same Scope

Above plot shows the property of Induction Motor i.e. Slip is inversally proportional to speed of motor. The slip-speed characteristics is shown in the Fig.11. It can be noted that when the speed is varied from 0 to the rated speed, the slip decreases, i.e., the slip is inversely proportional to the speed, which is the property of the IM. When the speed is zero, the slip is 100 %, while the IM is operating at near the rated speed (200 r/s), the slip is very very low.

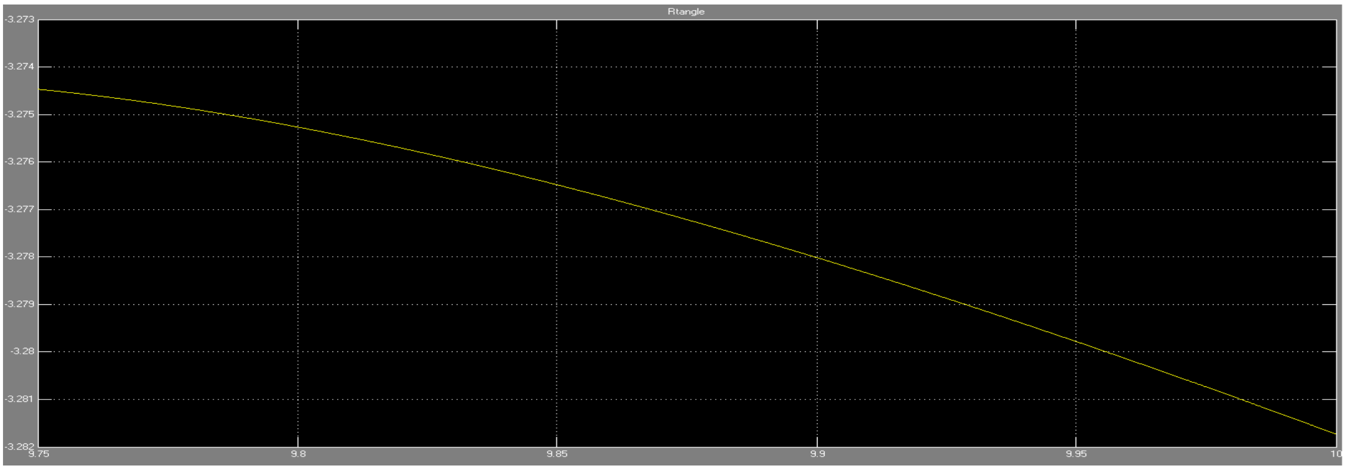


Fig. 12: Plot of Rotor angle Vs. Time

VI. CONCLUSIONS

A systematic approach of achieving the speed control of an induction motor drive by means of adaptive neuro fuzzy inference control strategy has been proposed in this paper. Simulink model can developed in Matlab with the ANFIS controller for the speed control of Induction Motor. The control strategy was also developed by writing a set of 49 fuzzy rules according to the ANFIS control strategy with the back propagation algorithm in the back end. The main advantage of designing the ANFIS coordination scheme is to control the speed of the Induction Motor & to increase the dynamic performance & to provide good stabilization. The characteristic curves of speed, torque, current, flux, slip, load, etc. vs. time we will observed. The outputs can take less time to stabilize, which can be observed from the simulation results. Due to the incorporation of the ANFIS controller in loop with the plant, it will observe that the motor reaches the rated speed very quickly in a lesser time compared to the Mamdani method.

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