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Abstract- **The Type 2 neuro fuzzy controller combines the advantageous of neural networks and fuzzy systems and it has become a popular approach in engineering fields for modelling and controlling of an induction motor. This paper presents torque ripple minimization scheme of an induction motor using type2 neuro fuzzy controller (T2NFC).The performance of the proposed T2NFC based induction motor drive is compared at different operating conditions with conventional proportional integral (PI) controller and it shows that the torque ripple is reduced as compared to the PI controller. The simulated results shows that the T2NFC is more efficient and it is found to be a suitable replacement of the conventional PI current controller for the high performance of induction motor drives.**

Keywords- Induction Motor, Vector control,PI controller and Type 2 Neuro Fuzzy Controller

I. INTRODUCTION

Induction motors are broadly used in various applications like industrial motion control systems and home appliances due its robustness, reliability and ease of control. But the use of induction motors is a challenging task because of its complex mathematical model and non-linear characteristic during saturation [1-2]. The better speed control of induction motor can be obtained by using vector control [3]. Field Oriented Control describes the way in which the control of torque and speed are directly based on the electromagnetic state of the motor, like a DC motor. The field oriented control can be classified as two types: Direct FOC and Indirect FOC. Among both schemes, in high performance industrial applications IFOC is extensively used as it has better torque response, dynamic speed accuracy, reduction in size of motor and short-term overload capability [4-6].

The power converters are operated at low switching frequency as a result, that produces lower order harmonics and higher total hormonic distortion (THD). Hence it is important to minimize the lower order harmonics and THD. A triangular carrier comparison-based synchronized sinusoidal PWM for medium-voltage inverters is used to get dynamic
with wide speed variation for rotor flux-oriented induction motor drive [7-10].

Fixed-gain proportional-integral (PI) and proportional integral-derivative (PID) controllers can handle the control issues in induction motor. The model is very uncertain because of its parameter variations such as saturation, temperature changes, and system disturbances are some the causes of [11]. Therefore, it is often difficult to make a precise mathematical model. Due to uncertainty load changes also the development of induction motor model is difficult task [12].The PI controllers require an accurate mathematical model and the performance of the drive is not satisfactory due to parameters variations [14-16]. To overcome the above draw backs a T2NFC is proposed and it does not require any mathematical model. To test the performance of the drive, a detailed simulation model is developed in MATLAB/Simulink. The performance of the proposed is investigated at all dynamic conditions both in simulation and experimentally. The proposed T2NFC is the replacement of the conventional PI controller for the high performance of the system.

In this paper, an indirect vector control of induction motor is compared with type 2 neuro fuzzy logic controller and PI controller at different operating conditions. In this, Mathematical modelling of induction motor is introduced in the second section. The third section presents the indirect vector control scheme of induction motor. The proposed type 2 neuro fuzzy based indirect vector controlled induction motor drive is presented in fourth section. The simulation results of type 2 neuro fuzzy and PI controller based indirect vector control of induction motor is presented in the fifth section. Finally, concluding remarks are stated in the sixth section.

II. INDUCTION MOTOR MATHEMATICAL MODELLING

The mathematical model of an induction motor with an arbitrary frame rotating at ω_r speed is expressed as follows:

Voltage equations

$$\left\{\begin{aligned} v_{qs} &= R_s i_{qs} + \frac{d}{dt}\psi_{qs} \\ v_{ds} &= R_s i_{ds} + \frac{d}{dt}\psi_{ds} \\ 0 &= R_r i_{qr} + \frac{d}{dt}\psi_{qr} + \omega_r \Psi_{dr} \\ 0 &= R_s i_{dr} + \frac{d}{dt}\psi_{dr} - \omega_r \Psi_{qr} \end{aligned}\right\} \quad (1)$$

The flux linkage equations can be expressed in-terms of the currents

$$\left.\begin{cases}\Psi_{qs} = L_{ls}i_{qs} + L_m(i_{qs} + i_{qr}) \\ \Psi_{qr} = L_{lr}i_{qr} + L_m(i_{qs} + i_{qr}) \\ \Psi_{qm} = L_m(i_{qs} + i_{qr}) \\ \Psi_{ds} = L_{ls}i_{ds} + L_m(i_{ds} + i_{dr}) \\ \Psi_{dr} = L_{lr}i_{dr} + L_m(i_{ds} + i_{dr}\end{cases}\right\} \tag{2}$$

Where V_{dS}, V_{qS}, i_{dS}, i_{qS}, Ψ_s and Ψ_r are stator voltages, stator currents, stator flux linkage and rotor flux linkage respectively. R_s, Rr, L_{ls}, L_{lr} and L_m are the stator resistance, rotor resistance, stator inductance, rotor inductance and mutual inductance, respectively. The equation of the torque expressed in terms of the flux linkages and currents

$$\frac{3}{2}\left(\frac{P}{2}\right)\left(\Psi_{dr}\, i_{qr} - \Psi_{qr}\, i_{dr}\right) \tag{3}$$

III. INDIRECT VECTOR CONTROL

The indirect field oriented control is basically same as that DFOC except the unit vectors are generated in an indirect manner. The indirect vector control technique is explained with the help of the phasor diagram as shown in fig 1

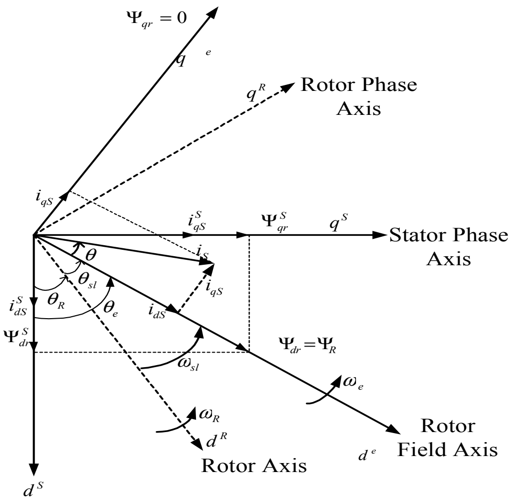


Fig 1 Phasor diagram of indirect vector control

The $d^s - q^s$ axes are fixed on the stator, but the d^r-q^r axes, which are fixed on the rotor, are moving at speed w_r as shown. The d^e-q^e axes are rotating ahead of the d^r-q^r axes by the slip angle θ_{sl} corresponding to the slip frequency w_{sl} .since the rotor pole is directed on the d^e axis and $\omega_e = \omega_r + \omega_{sl}$

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl})dt = \theta_r + \theta_{sl} \tag{4}$$

The equations of the rotor side are

$$\begin{aligned} &\mathrm{P}\Psi_{\mathrm{dr}} + \frac{R_r}{L_r}\Psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \\ &\mathrm{P}\Psi_{qr} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\Psi_{dr} = 0 \end{aligned} \tag{5}$$

For decoupling control, $\Psi_{qr} = 0$, $\mathrm{P}\Psi_{\mathrm{dr}} = 0$ so that the total rotor flux Ψ_r is directed on the d^e axis.

Use the above conditions into equation 4 we get

$$\frac{L_r}{R}\mathrm{P}\Psi_r + \Psi_r = L_m i_{ds} \tag{6}$$

Slip frequency can be calculated as

$$\omega_{sl} = \frac{L_m R_r}{\Psi_r L_r} i_{qs} \tag{7}$$

The block diagram for obtaining rotor angle θ_e in the indirect vector control is shown in Fig. 2

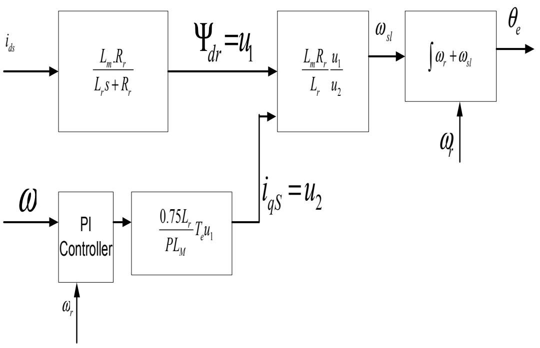


Fig 2 Rotor angle estimation of indirect vector control

IV. TYPE 2 NFC BASED INDIRECT VECTOR CONTROLLED INDUCTION MOTOR DRIVE

The T2NFC is new speed controller for indirect vector controlled of induction motor. T2NFCs are widely known to opponent to changes in parameters and noise which is suitable to cope with uncertainities of induction motor ad load variations.

The proposed T2NFC based induction motor drive is explained in fig 3. The T2NFC architecture design combines fuzzy logic and learning algorithm with a seven-level neural network architecture as shown in fig 4.The inputs of the T2NFC are the error in speed and changes of speed in error, Where ω_r^* is the command speed. In these seven layers architecture, the layer1 represents the inputs, the layer2 represents fuzzification, layer 3 represents firing, layer 4 represents reduction layer, layer 5 represents normalization, layer 6 represents outputs. A T2NFCS are characterized by fuzzy IF-THEN rules,

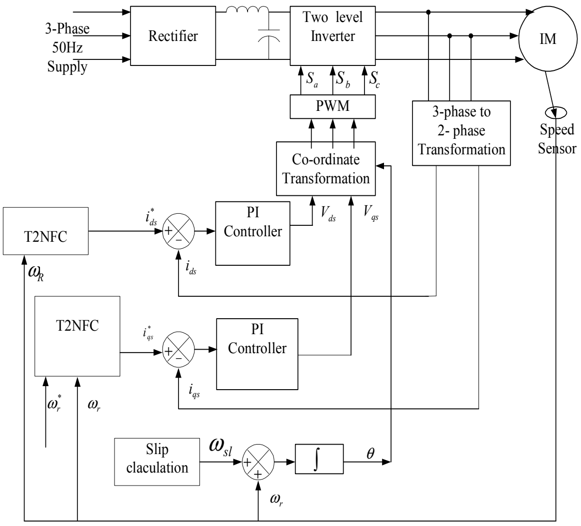


Fig 3 Proposed Type 2 neuro fuzzy controller

$$input^1 = e_\omega = \omega_r^* - \omega_r \quad (8)$$

$$input^2 = \Delta e_\omega = e_\omega(k) - e_\omega(k-1) \quad (9)$$

the parameters in the antecedent and the consequent parts of the rules include type-2 fuzzy values. In Gaussian type-2 fuzzy sets uncertainties can be linked to the mean and the standard deviation (STD). Gaussian type-2 fuzzy sets with uncertain STD and uncertain mean are shown Structure of type-2fuzzy neural system. In the proposed system the rule set with fuzzy can be expressed as :

Rule j (j=1,2--): if e_ω is m_{1j} AND Δe_ω m_{2j} then

$$y_j is \Sigma w_{lk} m_j + b_j$$

where m_{1j} and m_{2j} are antecedent fuzzy sets and x_{1j}, w_{lk} and b_i are the design parameters estimated in training. Here y_i is the output membership function.

Layer 1: input layer consists node member ship functions

$$o_j^1 = A_{mj1}(e_\omega), \text{j=1,2 ...... 7} \quad (10)$$

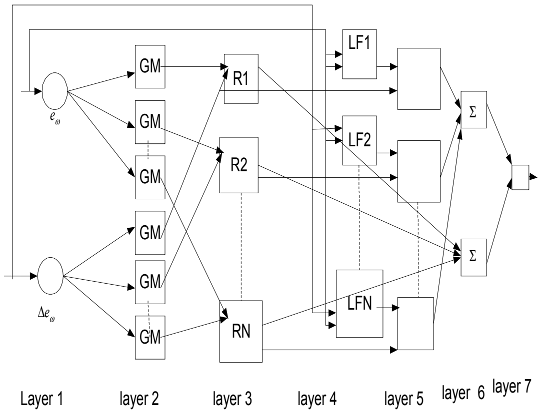


Fig 4 Architecture of type 2 neuro fuzzy system

$$o_j^1 = A_{mj1}(\Delta e_\omega) \text{ j=1,2 ...... 7} \quad (11)$$

Where A_{mj1} and A_{mj2} are triangular membership functions. The mathematical membership function is expressed as

$$A_{mj} = e^{\left(-\frac{1}{2}\left(\frac{(m_j - c)^2}{\sigma^2}\right)\right)} \quad (12)$$

where c and σ are the centre and width of membership functions

Layer2: Firing Layer: In this layer each node calculates the firing strength of a rule with the minimum error or change in error of two input weights

$$o_j^2 = w_i = A_{mj1}(e_\omega).A_{mj1}(\Delta e_\omega)$$
$$= \min\left(A_{mj1}(e_\omega), A_{mj1}(\Delta e_\omega)\right), i = 1,2.....7 \quad (13)$$

Layer 3: In this layer each node calculates the weight, which is normalized firing strengths

$$o_j^3 = \overline{w_j} = \frac{w_j}{w_1 + w_2}, j = 1,2 \quad (14)$$

Layer 4: De fuzzification layer: In this layer, every node with a node function is given by

$$o_j^4 = \overline{w_j} u_j = \overline{w_j}(m_{1j} e_\omega + m_{2j} \Delta e_\omega + r_i), i = 1,2..7 \quad (15)$$

Where $\overline{w_j}$ is the output layer of 3 and m_{1j} is the parameter set.

Layer 5: In this layer each node normalizes the firing strengths of rule that is generated by the type reduction layer

$$o_j^5 = \frac{\Sigma w_j u_j}{\Sigma w_j}, j = 1,2..7 \quad (16)$$

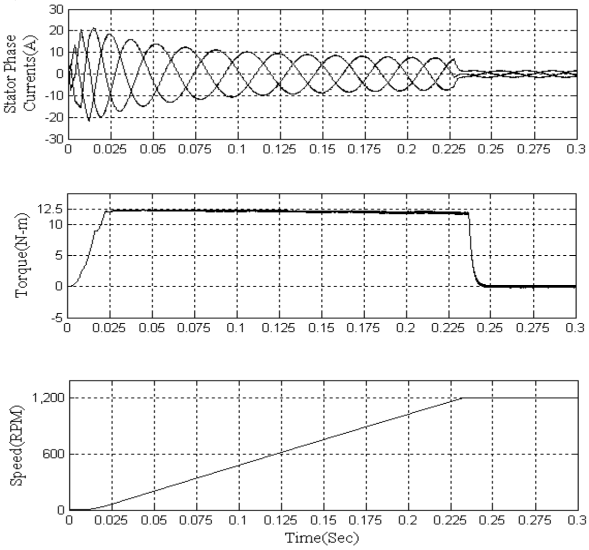
Layer 6: Output layer: In this layer, the output is determined

$$y_j = \sum_{j=1}^{l} m_j w_{lj} + b_i, j = 1....l$$

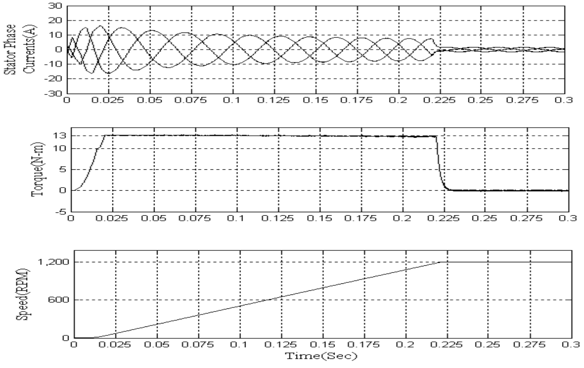
V. RESULTS AND DISCUSSION

a. Performance of induction motor during starting

The performance of the induction motor during stating as shown in fig 5.1(a) and (b). and it shows that the maximum current during the starting is condensed when compared to conventional PI controller based system. The maximum torque obtained with conventional PI controller based system is about 12.5 N-m, but with type 2 Neuro Fuzzy controller is 13 N-m. The speed of the induction motor reaches steady state earlier with type 2 Neuro Fuzzy controller based system



(a) With PI controllers

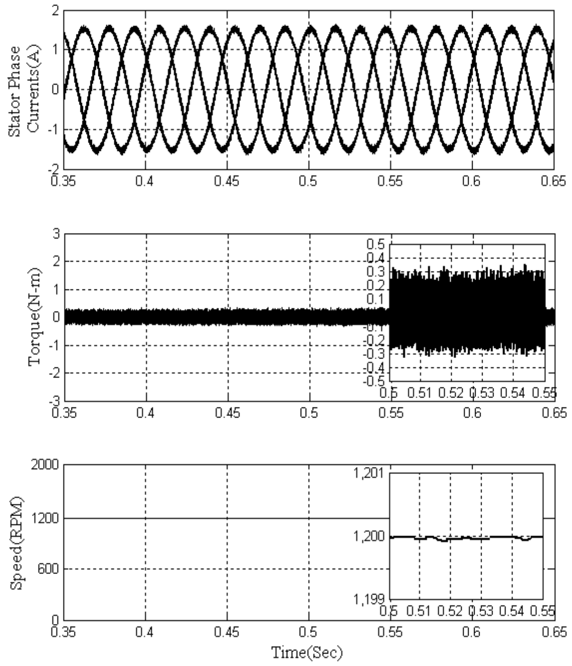


(b) With Type 2 Neuro fuzzy controller

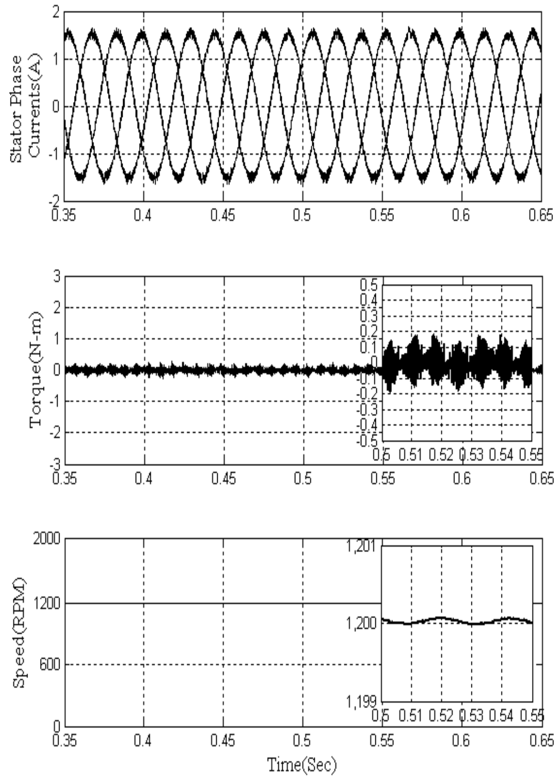
Fig. 5.1: Performance of induction motor during starting with indirect vector control

b. Response during Steady State

The performance of the induction motor during steady state as shown in fig 5.2 (a) and (b). By using PI controller the torque ripple is between +0.35 to -0.35 and with type 2 neuro fuzzy controller is between +0.2 to -0.2. By using type 2 neuro fuzzy controller based system the ripple content in the stator phase current, the speed response oscillations about reference speed 1200 RPM value is less as compared to the PI controller based system.



(a) With PI controllers

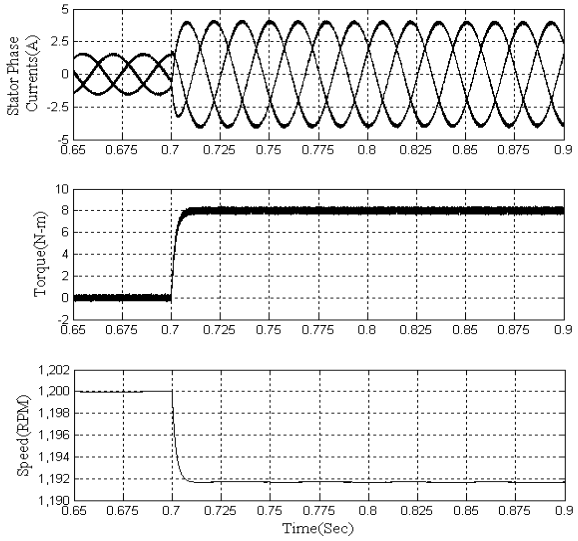


(b) With Type 2 Neuro fuzzy controller

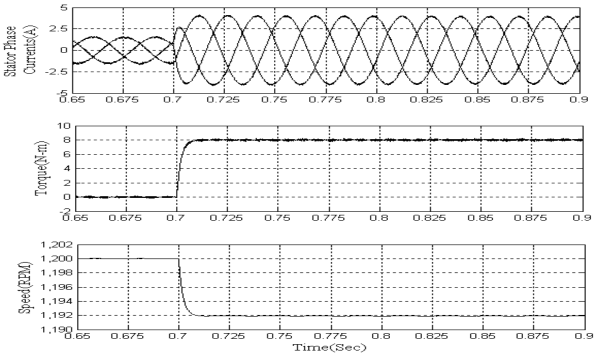
Fig. 5.2: Steady state Performance of induction motor with indirect vector control

*c. **Response during Step Change in Load Torque***

The response of the induction motor during the changes in load torque as shown in the Fig 5.4(a) and 5.4(b) respectively. The ripple content in current waveforms and torque is less with Type 2 Neuro Fuzzy controller based system.



(a) With PI controller



(b) With Type 2 Neuro fuzzy controller

Fig. 5.3: Performance of induction motor during step change in load torque with indirect vector control

VI. CONCLUSION

The performance of indirect vector-controlled induction motor drive with type 2 neuro fuzzy controller is presented in this paper. It is observed that during the starting condition with type 2 neuro fuzzy controller, the maximum current is reduced, the torque is increased by 4% due to that the speed reaches quickly as compared to the PI controller. During steady state condition, the current ripple is less due that the torque ripple is reduced by 33% and speed oscillations is less as compared with conventional PI controller. During the step change load torque, the overall ripple content is reduced as compared to the conventional PI controller. It is observed that there is an improvement in the performance of induction motor compared to the conventional PI controller. To enhance the dynamic performance of the induction motors, the PI controllers in the IVC are replaced with T2NFC. The Simulation model of the proposed drive using T2NFC is developed and compared with using PI controller. The proposed IVC using T2NFC gives better results at various operating conditions.

ACKNOWLEDGMENT

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