APPLICATION OF NEURO-FUZZY CONTROLLER IN TORQUE RIPPLE MINIMIZATION OF VECTOR CONTROLLED VSI INDUCTION MOTOR DRIVE

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ABSTRACT

This paper introduces Neuro-fuzzy based Torque controller for indirect vector controlled VSI fed induction motor drive. Compared to conventional PI controllers the proposed controller significantly reduces the torque ripple without the application of filter. The performance of the vector controlled induction motor drive has been simulated with and without loading conditions using the Neuro-fuzzy controller and the results are compared with PI controller. In addition to it, a SVPWM algorithm in which the calculation of switching times proportional to the instantaneous values of the reference phase voltages is used. Usage of SVPWM eliminates the need for calculation of sector and angle information.

Keywords- Torque ripples minimization, indirect vector control, Neuro-Fuzzy controller, space vector modulation.

I. INTRODUCTION

The functionality of PI controllers is that it works best when tuned at particular operation point and it will not operate satisfactorily when the operating point changes. This drawback can be eliminated using optimized controller in the controlling part. The combination Neuro-fuzzy provides fuzzy logic and neural network which uses the neural network to tune a Fuzzy logic Sugeno type controller which possess the advantages of both fuzzy logic and neural network.
An observer for estimating the rotor flux and the magnetizing current using Lyapunov stability theory and its effect on rotor flux has been discussed [1]. But, this developed control scheme performs well under steady state condition only. A filter based adaptive Neuro-fuzzy speed control coupled with flux regulation scheme of induction motor drive presented [2]. The reference flux is reduced in order to get minimum torque ripple. The performance of PI controllers and fuzzy logic in indirect vector control method has been presented [3]. A fuzzy logic based indirect vector control for induction motor drive presented in [4]. In this, the fuzzy logic controllers gives better results compared to conventional PI controllers under the dynamic operating conditions.

A hybrid PWM based space-vector and a triangle-comparison method has been presented [5]. A space vector modulation technique in-order to reduce the inverter output voltage distortion due to turn-off, turn-on and dead times of power modules, without increasing the harmonic content has been presented [6]. A relationship between space-vector modulation and carrier-based pulse-width modulation for multilevel inverter has been presented [7].

In this paper the error obtained from reference speed to that of the actual speed is fed to the ANFIS controller. Matlab/simulink software is used to develop a complete simulation model of indirect vector control with Neuro fuzzy controller. The induction motor performance using PI and Neuro-fuzzy controllers with and without loading conditions presented. The performance of proposed controller is compared with the conventional PI controller based induction motor drive. Simulation studies are carried out using 3-Phase, 1.3 hp, 400V, 50Hz, and 1480RPM induction machine and parameters are given in Appendix.

II. MODELING OF INDIRECT VECTOR CONTROL

From the mathematical model of a three-phase, squirrel-cage induction motor electromagnetic torque can be described as [8]

\[ T_e = \frac{3}{2} \left( \frac{P}{2} \right) L_m \left( i_{qs} i_{dr} - i_{dq} i_{qr} \right) \]  \hspace{1cm} (1)

Where \( i_{ds}, i_{qs}, i_{dr}, i_{qr} \) are d-q axis stator currents and d-q axis rotor currents respectively; \( L_m \) is mutual inductance respectively; \( P \) is the number of poles.

In the indirect vector control rotor flux is aligned along the d-axis then the q-axis rotor flux \( \psi_{qr} = 0 \). So the electrical torque of the machine can be expressed as

\[ T_e = \frac{3}{2} \left( \frac{P}{2} \right) L_m \lambda_{sd} i_{qs} \]  \hspace{1cm} (2)

Thus torque is proportional to \( i_{qs} \), \( L_q \) is the self inductance

By using the measures rotor speed \( \omega_r \) and slip speed \( \omega_{sl} \) the rotor angle \( \theta_r \) is estimated in the indirect vector control

\[ \theta_r = \int w_r dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \]  \hspace{1cm} (3)
For decoupling control, stator flux component of current \(i_{qs}\) should be aligned on d-axis and the torque component of current \(i_{qs}\) should be aligned on q-axis. This leads to \(\psi_{qr}=0\) and \(\psi_{dr}=\psi_r\), then

\[
\frac{L_r}{R_r} \frac{D\psi_r}{dt} + \psi_r = L_m i_{ds} \tag{4}
\]

The slip frequency can be calculated as

\[
\omega_s = \frac{L_m R_s}{\psi_r L_r} \frac{i_{qs}}{i_{qs}} = \frac{n_t i_{qs}}{L_r i_{ds}} \tag{5}
\]

### III. ADAPTIVE NEURO-FUZZY CONTROLLER

Figure 1 shows a five layered reference model of Neuro-fuzzy based controller. To generate torque the error between the reference speed \(\omega_r^*\) and actual speed \(\omega_r\) is fed to the Neuro-fuzzy controller. The algorithm of Neuro-fuzzy controller is given by the equations (6) to (10).

**Figure 1. Structure of ANFIS**

Layer 1: let denote the output of node i in layer 1, and \(x_i\) is the \(i^{th}\) input of the ANFIS, \(i = 1, 2, ... p\), there is a node function \(A\) associated with every node.

\[
Y_i^1 = A_i(x_i) \tag{6}
\]

The role of the node functions \(A_1, A_2, ..., A_q\) here is equal to that of the membership functions \(\mu(x)\) used in the regular fuzzy systems, and \(q\) is the number of nodes for each input.

The typical choice for membership functions are of Bell shape functions. We refer the premise parameters which are adjustable parameters that determine the positions and shapes of these node functions.

Layer 2: The output of every node in layer 2 is the product of all the incoming signals.

\[
Y_i^2 = A_i(x_i) \text{AND} A_j(x_j) \tag{7}
\]
Layer 3: Each node output represents the firing strength of the reasoning rule. In layer 3, each of these firing strengths of the rules is compared with the sum of all the firing strengths. Therefore, the normalized firing strengths are computed in this layer as

\[ Y_i^3 = \frac{Y_i^2}{\sum_i Y_i^2} \]  

(8)

Layer 4: It implements the Sugeno-type inference system, i.e., a linear combination of the input variables of ANFIS, \( x_1, x_2, \ldots, x_p \) plus a constant term, \( c_1, c_2, \ldots, c_p \), form the output of each IF–THEN rule. The output of the node is a weighted sum of these intermediate outputs.

\[ Y_i^4 = Y_i^3 \sum_j^p O_j X_j + C_j \]  

(9)

Where parameters \( Q_1, Q_2, \ldots, Q_p \) and \( c_1, c_2, \ldots, c_p \), in this layer are referred to as the consequent parameters.

Layer 5: It produces the sum of its inputs, i.e., defuzzification process of fuzzy system (using weighted average method) is obtained.

\[ Y_i^5 = \sum_i Y_i^4 \]  

(10)

IV. SPACE VECTOR PULSE WIDTH MODULATION

In the SVPWM algorithm, the d-axis and q-axis voltages are converted into three-phase instantaneous reference voltages. The imaginary switching time periods proportional to the instantaneous values of the reference phase voltages and can be defined as

\[ T_{RS} = \left( \frac{T_s}{V_{ds}} \right) V_{rs}^*, T_{YS} = \left( \frac{T_s}{V_{ds}} \right) V_{ys}^*, T_{BS} = \left( \frac{T_s}{V_{ds}} \right) V_{bs}^* \]  

(11)

Where \( T_s \) and \( V_{ds} \) are the sampling interval time and dc link voltage respectively. Here, sampling frequency is the twice the carrier frequency.

Then the maximum (MAX), middle (MID) and minimum (MIN) imaginary switching times can be found in each sampling interval by using (10) - (12).

\[ T_{\text{max}} = \text{MAX}(T_{RS}, T_{YS}, T_{BS}) \]  

(12)

\[ T_{\text{min}} = \text{MIN}(T_{RS}, T_{YS}, T_{BS}) \]  

(13)

\[ T_{\text{mid}} = \text{MID}(T_{RS}, T_{YS}, T_{BS}) \]  

(14)
The active voltage vector switching times $T_1$ and $T_2$ are calculated as:

$$T_1 = T_{\text{max}} - T_{\text{mid}} \text{ and } T_2 = T_{\text{mid}} - T_{\text{min}}$$

(15)

The zero voltage vectors switching time is calculated as:

$$T_z - T_s = T_1 - T_2$$

(16)

The zero state time will be shared between two zero states as $T_0$ for $V_0$ and $T_7$ for $V_7$ respectively, and can be expressed as [5].

$$T_0 = K_o T_z$$

(17)

$$T_7 = (1 - K_o)$$

(18)

In this SVPWM algorithm, the zero voltage vector time is distributed equally among $V_0$ and $V_7$. So, here $k_0$ is taken as 0.5 to obtain the SVPWM algorithm.

V. RESULTS AND DISCUSSION

The reference value speed is considered as 1200rpm for Simulation results which are obtained under different operating conditions. The results obtained with the PI controlled and Neuro-fuzzy controlled drive is given in Figures 2-4. The performance of the drive during starting with PI and Neuro-fuzzy controller is shown Figure 2(a) and 2(b). The steady state phase response is shown in Figure 3(a) and 3(b). The response during the step change in load torque command (load torque of 8 N-m is applied at 0.6 sec and removed at 0.8 sec) are shown in Figure 4(a) and 4(b). It is observed that the ripple content in the current wave forms are less, the torque ripple reduced from a value 0.5 to 0.1 with Neuro-fuzzy controller.

(a) With PI controller    (b) With ANFIS controller

Figure 2. Performance of induction motor during starting. (a) With PI controller (b) With ANFIS controller
VI. CONCLUSION

An indirect vector controlled induction motor drive is simulated with Neuro-fuzzy controller and conventional PI controller. The performance of vector controlled drive with Neuro-fuzzy torque controller is improved as compared to the conventional PI torque controller. Vector controlled drive with Neuro-fuzzy torque controller reduces the current ripple, also reduces the maximum current during starting and interestingly torque ripple is reduced from 0.5 to 0.1 value. In large perspective the overall performance of a drive under different operating conditions is improved with Neuro-fuzzy controller compared to conventional PI controller.
APPENDIX

Motor rating = 1.3hp
Stator resistance Rs = 4.1ohm
Stator inductance Ls=0.545H
Rotor inductance Lr=0.542H
Rotor resistance Rr = 2.5ohm
Mutual inductance Lm=0.51H
Moment of inertia J=0.04Kg-m^2.

REFERENCE