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ANFIS BASED VECTOR CONTROLLED INDUCTION MOTOR DRIVE

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Abstract: This paper presents a neuro-fuzzy controller (NFC)-based direct torque control (DTC) scheme for induction motor (IM) drive. The proposed controller results in attractive controlled performance of induction motor using the features of both artificial neural network and fuzzy logic controller. In this scheme, NFC combines fuzzy logic and four layer network of neural network and it is based on the back propagation scheme. DTC is a control technique used in AC drive systems to obtain high performance torque control. The principle is based on simultaneous decoupling of the stator flux and electromagnetic torque.The proposed DTC control of induction proposed are verified both in theoretical and experimental results. The proposed system is implemented in MATLAB/SIMULINK environment
Keywords: Direct Torque Control (DTC), Adaptive Neuro-Fuzzy Inference Scheme (ANFIS), Induction Motor, Field Oriented Control (FOC), Voltage Source Inverter (VSI)

I. INTRODUCTION

Induction Motor plays a important role in industrial applications when compared to other AC motors due to its simple, robust and rugged construction. However, the nonlinear nature and the parameters changes with operating conditions make the control of IM complex. An Induction Motor (IM) is an AC motor based on electromagnetic induction. Here power is supplied to the rotor by means of this induction principle. The efficiency of the motor can be improved by reducing the flux and by balancing the iron and copper losses. The speed control performance will be degraded with the imprecise estimation of electrical parameters of the machine. In general, the estimation of speed is more complex due to the speed of revolving magnetic field and with the change in the mechanical speed [13]. In recent years many studies have been carried out to develop different efficient solutions for the induction motor control. Many vector control techniques were introduced for control of the motor. Field oriented control is one of the techniques. But the complexity of field oriented algorithms forced them to develop a simplified and advanced Direct Torque Control (DTC) technique control. In this the torque and speed of the motor is directly based on the electromagnetic nature of the machine. The name direct torque control is obtained from the fact that on the basis of the errors between the reference and the estimated values of torque and flux, it is possible to control the inverter states directly in order to reduce the torque and flux errors within the permissible limits. The DTC method is a simple and gives fast transient response against the speed variations of the motor; hence most of the industrial drives are equipped with DTC. But the classical controllers adopted for this scheme are highly dependent on the mathematical model of the machine. This results in the inaccuracy of the results. And moreover traditional P, PI and PID controllers are slow with the change in operating conditions of the motor.

So in order to overcome all this hurdles we depend on the soft computing techniques for the control of the machineries. With this advent, the control of large machines in the industries became simpler and easier. In these work, a neuro-fuzzy based DTC control of induction motor is proposed to obtain an efficient control scheme. And the target of this scheme is to minimize torque/flux ripples of the IM drive system thus improving the dynamics. The switching mechanism of the inverter is based on the magnitude of the speed error. The threshold of the switching limit for the flux and torque controllers is based on the sampling frequency .thus a simplified in neuro –fuzzy controller is proposed for the DTC control of induction motor drive where both the advantages of fuzzy and neural networks are introduced [14].the controller used for this neuro-fuzzy algorithm is ANFIS. This system is highly useful for the industrial applications. Another advantage of this is the noise cancellation in the flux. One of the disadvantages of DTC scheme is its torque and flux ripples which can be overcome by space vector modulation technique.

II. CONTROL STRATEGY OF INDUCTION MOTOR DRIVE

The control of induction motor drive can be broadly classified in to scalar control and vector control. The scalar control of IM drives with inverters is widely used in low cost applications and its main advantage is its simplicity. But for the applications which require high dynamics response than v/f control, vector control schemes are preferred. In this vector control, field oriented control and direct torque and flux controls are major classifications. Both of the schemes are having their own advantages and disadvantages. In this paper we are going to discuss only about the DTC scheme of induction motor. This scheme is simplified FOC schemes and this can overcome the disadvantages caused by the FOC. DTC yields high efficiency and quick dynamic and steady-state response. In brief induction motor control methods can be broadly classified as shown in fig. 1

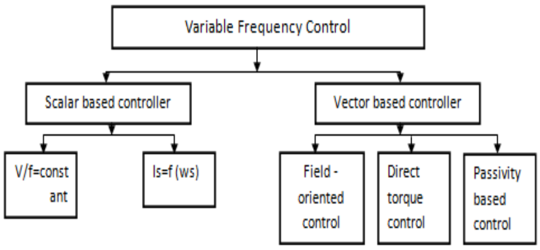

Fig 1 .Classification of control methods of induction motor.

The important features of this scheme are 1) Transformations are not required as in the case FOC. 2) PWM generators and current regulators are not used. 3) Harmonic losses are reduced with the use of space vector technique. DTC can be preferred for high dynamic and steady-state applications, but, on the other side, it shows higher current and torque ripple [10].This drawback can be partially compensated by SVM based DTC scheme. The DTC scheme is simple to implement, requiring a very small computational time when compared to FOC.

A. Principle Operation of DTC

According to the DTC principle, an independent control of torque and flux can be achieved by the application of appropriate voltage vectors. This selection is based on the error between the estimated torque and flux. And their respective reference values should remain within the limits of hysteresis comparators as shown in Fig 2. The locus of stator flux vector from the basic equation governing induction motor operation of stator flux also plays a major role in the selection of desired voltage vectors. In direct torque control method the stator flux and stator torque can directly controlled the selection of the appropriate inverter switching states. In this, based on the measured voltage and current, the motor magnetic flux and torque are calculated. Stator flux linkage is obtained by the integrating the stator voltages. Estimated torque is obtained by the cross product of estimated stator flux linkage vector and measured motor current vector. These estimated values are then compared with their reference values. Depending on the error values obtained voltage vector selection takes place. Thus direct torque control is one form of the hysteresis or bang-bang control.

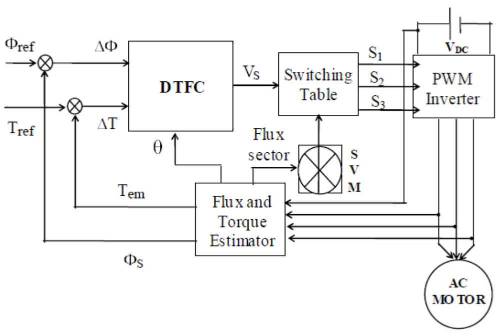

Fig 2.Basic DTC scheme

B. Mathematical Model of DTC of Induction Motor

The dynamic nature of the motor of the induction machine is analyzed with the help of the mathematical equation. With the change in motor parameters such as speed, torque, resistance, flux etc dynamic behavior of motor also changes. So, the dynamic model is essential for analyzing the performance of the induction motor. In order to derive the dynamic model of the induction motor, Clark's transformation is used for the transformation the three phase quantities into two phases direct and quadrature axes quantities. The mathematical modeling for the DTC of the induction motor is given below [6].

Voltage equations:

i)With respect to stator

Vsa(t) = Rsisa**(t) +d/dt(Ψ** sa(t)) (1)
Vsb(t) = Rsisb**(t) +d/dt(Ψ** sb(t)) (2)
Vsc(t) = Rsisc**(t) +d/dt(Ψ** sc(t)) (3)

ii) With respect to rotor

Vra(t) = Rrira**(t)+d/dt (Ψ** ra(t)) (4)
Vrb(t) = Rrirb**(t +d/dt (Ψ** rb(t)) (5)
Vrc(t) = Rrirc**(t +d/dt (Ψ** rc(t)) (6)

Converting to dqo frame

$$\begin{bmatrix} Vsd \\ Vsq \end{bmatrix} = \begin{bmatrix} \cos\emptyset & \cos(\emptyset - \frac{2\pi}{3}) & \cos(\emptyset + \frac{2\pi}{3}) \\ -\sin\emptyset & -\sin(\emptyset - \frac{2\pi}{3}) & -\sin(\emptyset + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix}$$

iii) Flux Equations

Ψ sd = [vsd- isdRs] 1/s (7)
Ψ sq = [vsq - isqRs] 1/s (8)
Ψ rd = [ω **Ψ**rq- irdRr]1/s (9)
Ψ rq = [ω **Ψ** rd - irdRr]1/s (10)

iv) Stator Current Equations

isd = **Ψ**sd(Lr/Lx) -**Ψ**rd(Lm/Lx) (12)
isq = **Ψ**sq(Lr/Lx) -**Ψ**rq(Lm/Lx) (13)

v) Rotor Current Equations

ird = **Ψ**rd(Ls/Lx) - **Ψ**sd(Lm/Lx) (14)
irq = **Ψ** rq(Ls/Lx) - **Ψ** sq(Lm/Lx) (15)

Estimated electromagnetic Torque equations

$T_{em} = 3/2 * P (\emptyset sd\, i_{sq} - \emptyset_{sq}\, i_{sd})$

Inorder to transform the induction motor model in natural coordinates into its equivalent space phasor form, the 120 operator is introduced. The above equations have been rearranged to use the operator 1/s instead of p because simulink deals with the integrator better than with the derivation [3]. In an adjustable speed drive the machine normally constitute an element within the feedback loop, and therefore its transient behavior has to be taken into consideration. High performance speed control such as vector or field oriented control is based on dynamic d-q model of the machine [4].

C. DTC with 2-level inverter

The 3-phase and 2-level VSI is shown in fig.3 it has eight possible voltage vectors, consisting of six active vectors and two zero vectors. There are six switches depending upon the combinations of the switching modes Sa,Sb and Sc.

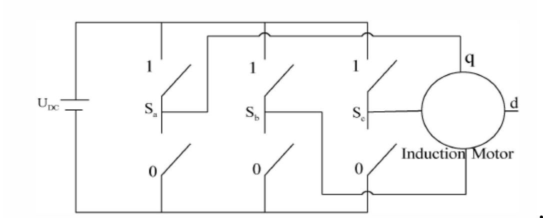

Fig 3.schematic diagram of voltage source inverter

When the upper part of switches is ON, then the switching value is '1' and when the lower switch is ON, then the switching value is '0'.the stator voltage equation can be given as

$U_{s,k}=2/3\ U_{dc}\ [S_a+aS_b+a^2S_c]$

Where Udc is the dc link voltage and a is the coefficient and is given by $e^{j2\pi/3}$

There are eight possible voltage vector switching configuration and is given in the table 1 below.

Table1. Voltage vector selection

Hysteresis controller		Sector selection θ_e(k)					
ψ	T	Sector θ_e(1)	Sector θ_e(2)	Sector θ_e(3)	Sector θ_e(4)	Sector θ_e(5)	Sector θ_e(6)
1	1	U2 110	U3 010	U4 011	U5 001	U6 101	U1 100
	0	U7 111	U8 000	U7 111	U8 000	U7 111	U8 000
	-1	U6 101	U1 100	U2 110	U3 010	U4 011	U5 001
0	1	U3 010	U4 011	U5 001	U6 101	U1 100	U2 110
	0	U8 000	U7 111	U8 000	U7 111	U8 000	U7 111
	-1	U5 001	U6 101	U1 100	U2 110	U3 010	U4 011

III. NEURO-FUZZY CONTROLLER

Fuzzy logic is one of the emerging applications in the electrical engineering field which can be used to control various parameters of the real time systems. This fuzzy logic when combined with neural networks yields very significant results. Neural networks can learn from data. However, understanding the knowledge learned by neural networks has been difficult. To be more specific, it is usually difficult to develop in depth knowledge about the meaning associated with each neuron and each weight. In contrast, fuzzy rule based models are easy to be understood because it uses linguistic terms and the structure of IF-THEN rules [1]. Unlike neural networks, however, fuzzy logic by itself cannot learn. The learning and identification of fuzzy logic systems need to adopt techniques from other areas, such as statistics, system identification. Since neural networks can learn, it is natural to merge these two techniques. This merged technique of the learning power of the neural networks with the knowledge representation of fuzzy logic has created a new hybrid technique, called as the term 'neuro fuzzy networks' [5].Adaptive neuro-fuzzy inference system tunes the membership functions of fuzzy system using either back propagation algorithm or least square type of method. In this fuzzy rules are trained by this controller. Mamdani type is used here inorder to increase its flexibility.

A. Proposed NFC

The proposed NFC incorporates fuzzy logic and a learning algorithm with a four-layer ANN structure, as depicted in Fig. 4.

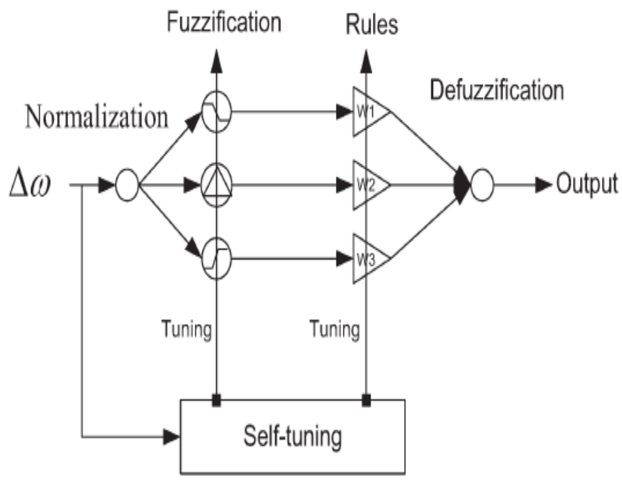

Fig 4.Four layer ANN structure

The learning algorithm adjusts the NFC to match desired system performance [6]. The detailed discussions on different layers of the NFC are given in the following

Input Layer: The input of the proposed NFC is the normalized speed error, which is given by

$$O^{I}=\frac{\omega^{*}-\omega}{\omega^{*}}*100\%$$

Where ω is the measured speed, ω∗ is the command speed, and I denotes the first layer.

Fuzzification Layer: In order to get fuzzy number from input, three membership functions O_1^{II} , O_2^{II} , andO_3^{II} are used, which are shown in Fig 5. The three nodes in fuzzification layer of NFC shown in Fig 4. represent these three membership functions. Here, O stands for output, superscript indicates the layer number, and subscripts indicate the node numbers. The linear triangular and trapezoidal functions are chosen as the membership functions so that the computational burden is low as compared to any exponential functions. where x_i^{II} is the input of the second layer, which is the output of the first layer. It is considered that a2 = 0 so that the member- ship functions become symmetrical and it also further reduces the computational burden.

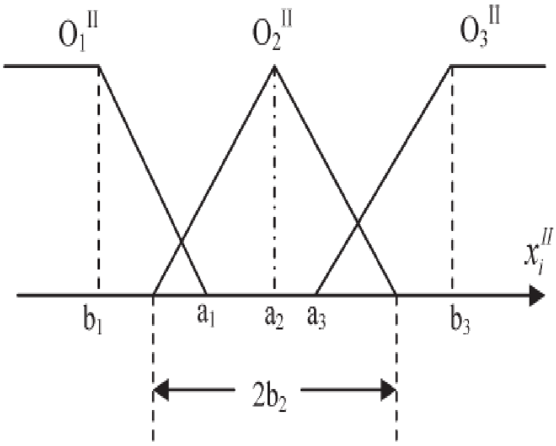

Fig 5.Membership functions for input

Thus, the membership functions O1II, O2II, and O3II represent negative, zero, and positive speed errors, respectively.

Rule Layer: No "AND" logic is needed in the rule layer since there is only one input in the input layer.

IV. SIMULATION RESULTS

The performance of the simplified NFC-based IM drive is explained in simulation using Matlab/Simulink at different operating conditions [7]. The motor performance characteristics under the proposed adaptive neuro-fuzzy interference system are shown in below respectively.

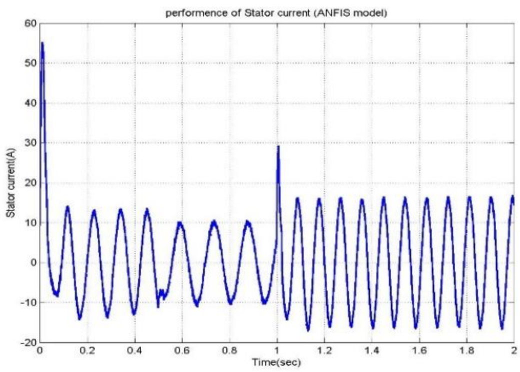

Fig 6 Dynamics of Stator Current.

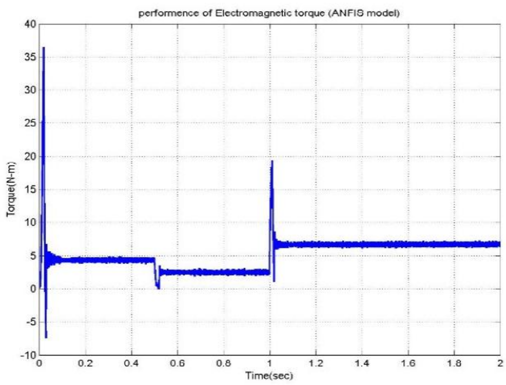

Fig 7 Variations of electromagnetic torque

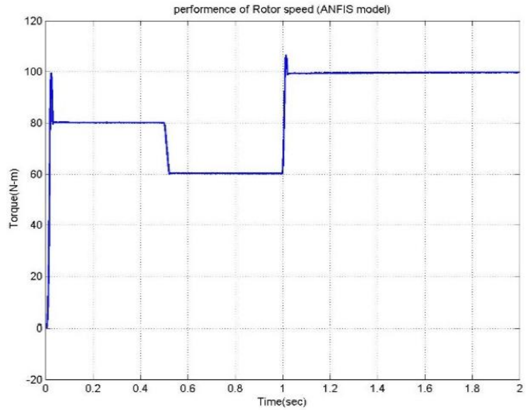

Fig 6 Performance of speed

V. CONCLUSION

The proposed paper has presented a new approach to speed control of induction motor drive with neuro-fuzzy controller. This simplified self-tuned controller determines voltage vector required for the two-level inverter. Also the torque and flux can be directly controlled by controlling the inverter voltage. This proposed scheme results in improved stator flux and torque responses during steady state condition. The main advantage is the improvement of torque and flux ripples, this provides an opportunity for motor operation under minimum switching loss and noise. Thus an efficient controller is obtained for the DTC control of induction motor drive.

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