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Direct Torque Neuro Fuzzy Controller (DTNFC) with 3 Level PWM Inverter for Induction Motor

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Abstract - In present days an induction motor is an essential tool of the industries. So controlling of performance of an induction motor is mandatory in many high performance applications. The scalar control method gives good steady state response, but the poor dynamic response. While vector control method gives good steady state as well as dynamic response. But it is complicated in structure so to overcome this difficulty, direct torque control introduced. Performance of Direct Torque Control depends mostly on the accuracy used to measure the stator flux. The measurement of the stator flux is very difficult to achieve. This paper gives an analysis and Simulation of Direct Torque Neuro Fuzzy Controller (DTNFC) with 3-level PWM Inverter for Induction Motor. A Neuro-Fuzzy inference system is applied to achieve high performance stator flux and torque control. Simulation is carried out using MATLAB 2010a.

Keywords – Direct Torque Control, Direct Torque Neuro Fuzzy Controller, Induction Motor, Neuro-Fuzzy inference system, PWM.

I. INTRODUCTION

An induction motor is an asynchronous AC (alternating current) motor. Squirrel cage motor is the least expensive and most widely used induction motor. The importance of sensor less drives of an induction motor (IM) has grown significantly over the past few years due to some of their advantages, such as simple construction, mechanical robustness and a lesser amount of maintenance. These applications include paper and textile mills, pumps and fans, subway and locomotive propulsions, machine tools and robotics, electric and hybrid vehicles, heat pumps, wind generation systems, rolling mills, air conditioners and home appliances etc. Therefore, Induction motors have been used more in the industrial variable speed drive system with the development of the vector control technology. This process needs a speed sensor such as shaft encoder for speed control.

Motion control is required in a large number of industrial and domestic applications like paper mills, rolling mills, textile mills, pumps, fans, machine tools, robots, transportation systems, washing machines etc. The systems employed for motion control are called drives and can employ any one of the prime agents such as, petrol or diesel engines, steam engines, steam or gas turbines, electric motors and hydraulic motors for providing mechanical energy for motion control. Drives employing electric motors are identified as electrical drives.

Illustration of block diagram for electric drive is shown in Figure 1. The load is generally machinery, which is intended to achieve a specified task, e.g. Pumps, fans, washing machines, machine tools, robots, drills and trains. Generally load requirements can be quantified in terms of speed and torque demands. A motor containing speedtorque features and capabilities compatible to the load requirements is chosen.



Figure 1.: Block Diagram of an Electrical Drive

The objective of this paper is to design and simulate speed control system for three phase induction motors using direct torque control method with three level PWM inverter. To introduce direct torque Neuro Fuzzy Control in Three Level PWM Inverter fed DTC induction motor drive; and to prove that the proposed DTNF controller not only has a simple structure but also has all of the features of a high precision speed controller for operating in the whole of the speed

(1)



International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 2, Issue 8, March 2014)

range and for any loading and environmental conditions.

II. DIRECT TORQUE CONTROL OF INDUCTION MOTOR

Direct Torque Control (DTC) is a control technique in AC drive systems to obtain high performance torque control. The conventional DTC drive as shown in Figure 2 contains a pair of hysteresis comparators. The fundamental idea of DTC is to control both the torque and the magnitude of the flux within the associated error bands in real time. In order to realize DTC principle some of the equations of the Induction motor need to be revised. The electromagnetic torque can be articulated as a function of the stator flux and the rotor flux space vectors as follows:

$$T_e = -\frac{3}{2}P \frac{L_m}{L_s L_r - L_m^2} \overline{\Psi}_r \times \overline{\Psi}_s$$

If the modulus of the previous expression is calculated, then it is obtained as:

$$T_e = \frac{3}{2} P \frac{L_m}{L_s L_r - L_m^2} |\overline{\Psi}_r| |\overline{\Psi}_s| \sin(\gamma_s - \gamma_r)$$
(2)
Where,

 L_s , L_r and L_m = stator, rotor and mutual inductances.

 $\overline{\Psi}_s, \overline{\Psi}_r$ = stator flux linkage, and rotor flux linkage vectors,

 γ_s and γ_r = stator and rotor flux angles.





Figure 3: Influence of the Voltage Vector Selected on the Variation of Stator Flux Modulus and Torque

Considering the modulus of rotor and stator fluxes constant, torque can be controlled through varying the relative angle between both flux vectors. Stator flux can be attained through the stator voltage equation in stator fixed coordinates:

$$\bar{V}_s = \bar{R}_s \bar{\iota}_s + \frac{d\Psi_s}{dt}$$

(3)

Where R_s = Stator resistance, i_s = Stator current and Ψ_s = Stator flux linkage.



International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 2, Issue 8, March 2014)

On neglecting the voltage drop in the stator resistance, the variation of the stator flux is directly proportional to the stator voltage applied:

 $\bar{V}_s \alpha \frac{d\Psi_s}{dt}$ (4)

Figure 3 shows the stator flux in the α - β plane, and the effect of the different states of a two level VSI according to torque and stator flux modulus variation.

Space Vector Pulse Width Modulation DTC

In this scheme there are two proportional integral (PI) type controllers; where as conventional DTC uses hysteresis controllers to regulate the torque and the magnitude of flux.

As shown in Fig 4, two proportional integral (PI) type controllers regulate the torque and the flux amplitude, respectively. So, together the torque and the magnitude of flux are incontrol, thus generating the voltage command for inverter control.



Figure 4: Space Vector PWM DTC (SVPWM DTC)

III. DTC SVM with Three Level Inverter

Multilevel inverters are progressively being used in high-power medium voltage applications due to their superior performance compared to two-level inverters, such as lower common-mode voltage, lower dv/dt lower harmonics in output voltage and current and reduced voltage on the power switches.

Among various modulation technique for a multilevel inverter, space vector pulse width modulation (SVPWM) is an attractive method due to the subsequent advantages. It directly uses the control variable given by the control system and identifies each switching vector as a point in complex (α , β) space. It is suitable for digital signal processing (DSP) operation. Switching sequences could be optimized by it.



Figure 5: Space Vector Diagram of Three-Level Inverter

Figure 5 shows the space vector diagram of a three level inverter. There are six sectors (S_1-S_6) , four



International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 2, Issue 8, March 2014)

triangles (Δ_0 - Δ_3) in a sector, and complete 27 switching conditions in this space vector diagram.

IV. METHODOLOGY

Fuzzy logic and neural networks are complementary technologies in the design of intelligent systems. Artificial neural networks (ANN) are low level computational algorithms that offer good performance with sensory data, while fuzzy logic deals with reasoning in a higher level than ANN. The proposed system uses Neuro-fuzzy system combining the third and fourth layer as one single layer of rules. This system has three inputs torque error, flux error and sector information. Triangular membership function (Fig. 6) is used for the antecedent part. The torque and flux errors are getting as the difference between the reference value and actual value. The output of the control is the switching state (0, 1, 2, 3, 4, 5, and 6) for the converter circuit.

The flux errors (F_e) use three linguistic values: positive error (P_E), zero error (Z_E) and negative error (NE) with a universe of discourse [-0.01 0.01]. For the torque error (T_e) the universe of discourse is [-0.1 0.1] with three fuzzy aggregations positive (P), negative (N) and zero (Z). The flux linkage angle θ is divided into six aggregations of 60° each. The Neuro-fuzzy system is formed with the following layers as presented in Fig. 7.

First layer: Comprises of the three inputs F_e , T_e and θ .

$$O_{t1} = I_{t1} = X_t$$
 (5)

Second layer: This is the fuzzy layer that grades the membership function and leads to 12 connections with 1 as the weights between the first and second layer.

$$I_{j2} = w_{ij} O_{i1} (6)$$



Figure 6: Triangular membership function

Third layer: This layer defines the grade of corresponding rules of a fuzzy system with 54 connections combining the rule antecedent and consequent layer. Weights defined are 1 for connections between third and fourth layer.

$$I_{k3} = \prod_j O_{j2} \tag{8}$$

$$O_{k3} = I_{k3} \tag{9}$$

Fourth layer: This fuzzy decision layer sums all the inputs to this layer.

$$I_{i4} = \sum_k O_{k3} \tag{10}$$

Fifth layer: It does defuzzification by adapting to the greatest grade of membership function and gives the single output as the choice of voltage space vector.



International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 2, Issue 8, March 2014)



Figure 7: Neuro - fuzzy controller





Figure 8: Comparison in speed of Induction Motor for 3-level inverter DTC with and without Neuro-Fuzzy controller

The figure above shows the response of induction motor with three level inverter and three level Neuro fuzzy inverter when set point is 100 RPM, 500 RPM and 150 RPM on t = 0, 1 and 1.5 Sec Respectively. The response is almost same.



Figure 9: Comparison in flux of Induction Motor for 3-level inverter DTC with and without Neuro-Fuzzy controller

The figure above shows the flux response of induction motor with three level inverter and three level NF-DTC inverter. It is showing that flux ripple improves with Neuro fuzzy inverter.

International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 2, Issue 8, March 2014)



Figure 10: Comparison in torque of Induction Motor for 3-level inverter DTC with and without Neuro-Fuzzy controller

The figure above shows the flux response of induction motor with three level inverter and three lever Neuro fuzzy inverter. It is showing that torque improvement is almost none.



Figure 11: MATLAB / SIMULINK model of Induction Motor for 3-level inverter DTC

VI. CONCLUSION

Direct torque control (DTC) of induction motor gives optimal performance of drive systems in steady state as well as under transient conditions. DTC achieves precise speed and torque control of induction motor and make it compatible for applications where smooth and fine control of drive is essential. We have implemented Direct Torque Neuro Fuzzy Controller (DTNFC) for Induction Motor with three level inverter. Neural Network means for synthesizing a controller from engineering experiences that can be more robust, have better performance, and reduce cycle times due to the multilayer feed forward network.

It is concluded that despite of their simple control structure the proposed Neuro fuzzy controllers have managed to significantly reduce the torque and flux ripples. As we introduce the Neuro-fuzzy control to conventional DTC, it improves the flux ripple of Induction Motor.

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