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Intelligent Control of Induction Motor

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ABSTRACT

The Direct Torque Control (DTC) is one of the most effective control and modern methods for high performance AC drives in a wide variety of industrial application and conventional DTC technique uses two constant reference values stator flux and torque ripple. In this paper, two approach intelligent techniques such as fuzzy logic (FL) and Artificial Neural Networks (ANN) used to improving the performance of DTC drive in terms of switching frequency and stator flux estimation. In this work a proposed DTC system supported by a Neuro –Fuzzy Controller are constructed to avoid the inherent torque ripples. Simulation studies have been carried out with using MATLAB program. The proposed Direct Torque Control (DTC) system shows a considerable reduction in torque ripples and best starting performance. This improvement leads to an ability to increase the performance at low-load condition torque ripple are greatly reduced with respect to the conventional DTC.

Keywords: *Direct Torque Control (DTC), Field Oriented Control (FOC), Fuzzy Logic (FL), Fuzzy Inference System (FIS) and Artificial Neural Network (ANN).*

1. INTRODUCTION

Nowadays, Asynchronous motor drives with cage type machines have been the work horses in industry for variable speed application in a wide power range that covers from fractional horse power to multi-megawatts. These application include pumps, Fans, Paper textile mills, Subway and locomotive propulsions, electric and hybrid vehicles machine tools & robotics, home appliances, heat pumps, air conditioners, rolling mills, wind generation pumped storage system, etc.[1]

The control and estimation of asynchronous drives in general is considerably more complex than those of dc drives, and this complexity increases substantially if high performances are demanded. The different control techniques of induction motor drives, including Scalar control, Vector or Field Oriented Control (FOC), Direct Torque and Flux Control (DTC (or) DTFC) or Direct Self Control (DSC) and Adaptive control. Scalar control is based on the steady state motor model while Vector control is based on dynamic model of motor. [2]. Scalar control, as the name indicates is due to magnitude variation of the control variables only, and disregards the coupling effect in the machine. For example, the voltage of a machine can be controlled to control the flux, and frequency or slip can be controlled to control the torque. Scalar controls are easy to implement and have been widely used in industry. Scalar control techniques with voltage fed and current –fed inverters etc.,

The invention of Vector control or Field Oriented Control (FOC) in the beginning of 1970s, FOC was first introduced by Blaschke [3]. In vector control and the corresponding feedback signal processing, particularly for modern sensor less vector control are complex and the use of powerful microcomputer or DSP is mandatory. In this method to provide satisfactory steady-state performance, but their dynamic response is poor. In addition to this some drawbacks are separate current loops; Pulse Width Modulation (PWM) and Co-ordinate transformation are required. In the mid-1980s, an advanced Scalar Control technique, known as Direct Torque and Flux Control (DTFC or DTC) or Direct Self-control (DSC) was introduced for voltage-fed PWM inverter drives.

The DTC proposed by Takashi and M. Depenbrock [4] for variable load and speed asynchronous motor drives. It was a good alternative to the other type of vector control which known as FOC due to some well-known advantages, such as simple control structure, robust and fast torque response without co-ordinate transformation PWM pulse generation and current regulators moreover, DTC minimizes the use of motor parameters. Besides these advantages, DTC scheme still had some disadvantages like high torque and current ripples, possible problems during starting and low speed operation, variable switching frequency.

Over the years, many studies have been done to overcome these disadvantages of the DTC and still continue. We want to remove by using and implementing modern resources of Artificial Intelligence (AI) or Intelligent Control methods like Fuzzy Logic (FL), Neural Networks (NN) have been explored by several researchers for its potential to improve the speed regulation of the ac drive system [5-6]. The controller proposed in this paper is neuro-fuzzy based controller which given better performance. The neural network is well known for its learning ability and approximation to any arbitrary continuous function [7]. It has been proposed in the literature that neural networks can be applied to parameter identification and state estimation. The fuzzy logic controller solves the problems of non-linearity's and parameter variations of induction motor drive.

2. MODELING OF INDUCTION MOTOR

The dynamic behavior of asynchronous drive is complex to the coupling effect between the stator and rotor phases. The figure.1 below shows the dynamic d-q equivalent circuits of an asynchronous drive.

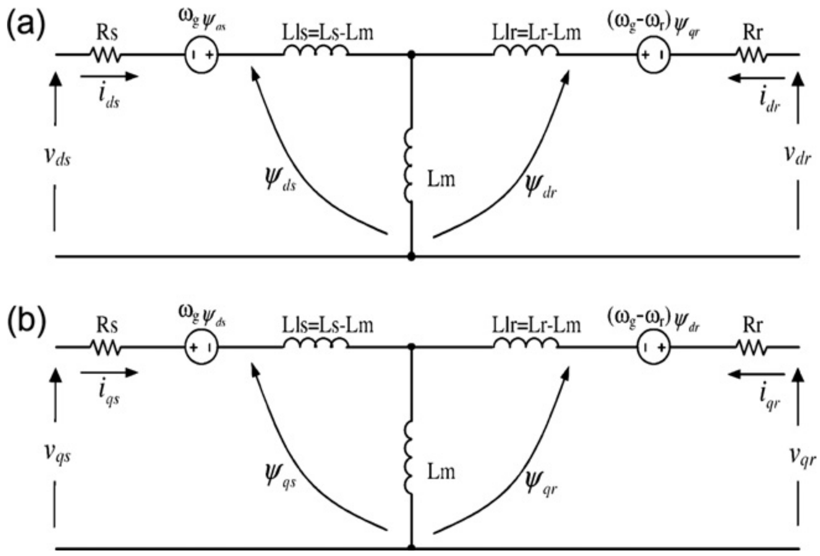

Figure.1 Dynamic d-q equivalent circuits of an asynchronous drive (a) d-axis, (b) q-axis

The flux linkage expressions in terms of the currents can be written from figure as follows:

$\Psi_{qs}=L_{ls}i_{qs}+L_m(i_{qs}+i_{qr})$ (2.1)

$\Psi_{qr}=L_{lr}i_{qs}+L_m(i_{qs}+i_{qr})$ (2.2)

$\Psi_{qm}=L_m(i_{qs}+i_{qr})$ (2.3)

$\Psi_{ds}=L_{ls}i_{ds}+L_m(i_{ds}+i_{dr})$ (2.4)

$\Psi_{dr}=L_{lr}i_{ds}+L_m(i_{ds}+i_{dr})$ (2.5)

$\Psi_{dm}=L_m(i_{ds}+i_{dr})$ (2.6)

The electrical transient model in terms of voltages and currents can be given in matrix forms as

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + SL_s & \omega_e L_s & SL_m & \omega_e L_m \\ -\omega_e L_s & R_s + SL_s & -\omega_e L_m & SL_m \\ SL_m & (\omega_e - \omega_r)L_m & R_r + SL_r & (\omega_e - \omega_r)L_r \\ -(\omega_e - \omega_r)L_m & SL_m & -(\omega_e - \omega_r)L_r & R_r + SL_r \end{bmatrix} \begin{bmatrix} I_{qs} \\ I_{ds} \\ I_{qr} \\ I_{dr} \end{bmatrix}$$

Where S is the Laplace operator, d/d_t. The speed ω_r in the above equations is related to the torque by the following mechanical dynamic equation,

$$T_e = T_L + J\frac{d\omega_m}{dt} = T_L + \frac{2}{P}J\frac{d\omega_r}{dt} \qquad (2.8)$$

Where J = combined rotor and load inertia, and ω_m = mechanical speed. The torque equation in stationary reference frame can be written as:

$$T_e = \frac{3}{2}\frac{P}{2}\bar{\psi}_s \times i_s \qquad (2.9)$$

In terms of stator and rotor currents, the torque can be written as:

$$T_e = \frac{3}{2}\frac{P}{2} L_m \left(i_{rd}\ i_{sq} - i_{rq}\ i_{sd} \right) \qquad (2.10)$$

3. DTC PRINCIPLES

Direct torque control of asynchronous machine presents a good tracking for both electromagnetic torque and stator flux. This control scheme as shown in figure.2 depends only on stator measurement.

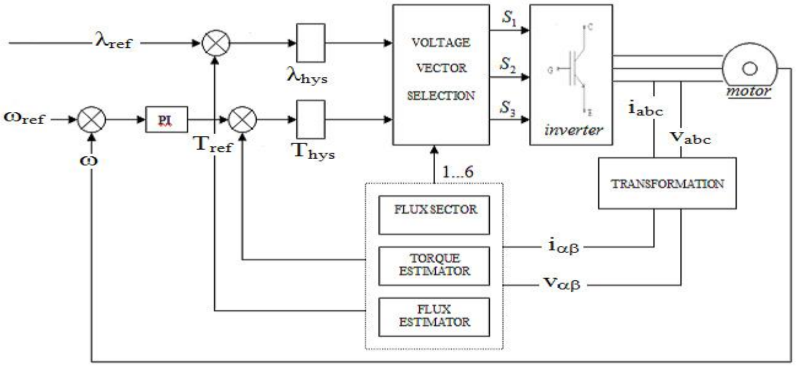

Figure.2 Block diagram of DTC

Here an artificial neural network is used to accomplish tuning of the stator resistance of an asynchronous drive. The parallel recursive prediction error and back propagation training algorithms were used in training the neural network for the simulation and experimental results respectively. The neural network used to tune the stator resistance was trained on-line, making the DTC strategy more robust and accurate. Simulation results are represented for three different neural network configurations [8] showing the efficiency of the tuning process.

3.1 THREE PHASE VOLTAGE SOURCE INVERTER

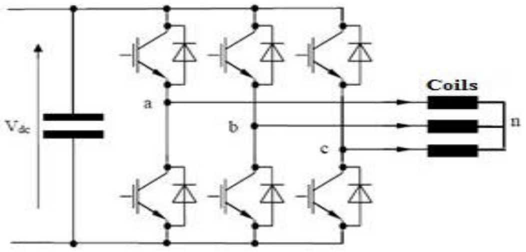

Figure.3 Voltage Source Inverter

In order to get the desired stator flux, the technique of space vector modulation is applied. To describe the concept of space vector modulation, Fig.3 shows a voltage source inverter (VSI) which is feeding a three phase induction motor. The inverter converts the DC to AC through power electronic devices such as an IGBT (Insulated bipolar gate transistor).

3.2 STATOR FLUX CONTROL

This paper describes [9] a Quassi-fuzzy method of online stator resistance estimation of an asynchronous drive, where the resistance value is desired from stator winding temperature estimation as a function of stator current and frequency through an approximate dynamic thermal model of the machine. The estimator has been designed and iterated by simulation study and then implemented by a digital signal processor on a 5 HP stator flux oriented direct vector controlled drive.

3.3 STATOR FLUX & TORQUE CONTROL

In present application of Adaptive Neuro-Fuzzy Inference System (ANFIS) into a cage induction motor towards modeling, control and estimation. [10] This paper contributes [a] development of a simple and more realistic model of the asynchronous drive. Using ANFIS, the parameter sets of the motor model are estimated. The simplified model contains eleven estimated parameters. The identified model can be utilized for ac electric drives.[b] Speed, torque and flux control using DTC algorithm with ANFIS [c] design of estimator through ANFIS which estimates the stator resistance with reference to the temperature when the DTC algorithm is involved. Better estimation of stator resistance results in the improvements in asynchronous drive performance using DTC thereby facilitating torque ripple minimization. The values of stator voltage (V_s), stator current (I_s) and rotor angular velocity (ωr) are taken.

4. DIRECT TORQUE NEURO-FUZZY CONTROLLER

Neuro-fuzzy systems have become popular in several fields and especially in control. In this kind of controllers, fuzzy logic provides a structure within which the learning ability of neural networks is employed. In this field there are a number of possible uses. In fact, for the ANFIS system (Adaptive Network-based Fuzzy Inference System), neural networks are used to implement a fuzzy inference system such as in “Fig.4”.

This technique provides at first a neural network to learn information about a data set, in order to compute the membership function parameters that best allow the associated (FIS) to track the given input/output data.

Figure.4 shows the block diagram of DTC Neuro-Fuzzy Control (DTNFC) of asynchronous drive. Torque and stator flux are estimated mathematically from the motor signals. ANFIS is used as controller to which the torque and flux error along with position inputs and from which inverter switching states are estimated.

A fuzzy logic real time estimator is used as the stator resistance observer, to eliminated the error in rotor resistance estimation. The performance of the asynchronous drive with the above rotor and staotr resistance estimators is investigated for torque and flux responses, to analyze the effects of stator resistance observer on rotor resistance identification for variations in the stator and rotor resistances from their nominal values. Both these resistances are estimated experimetally, in a vector controled induction motor drive and found to give accurate estimates.

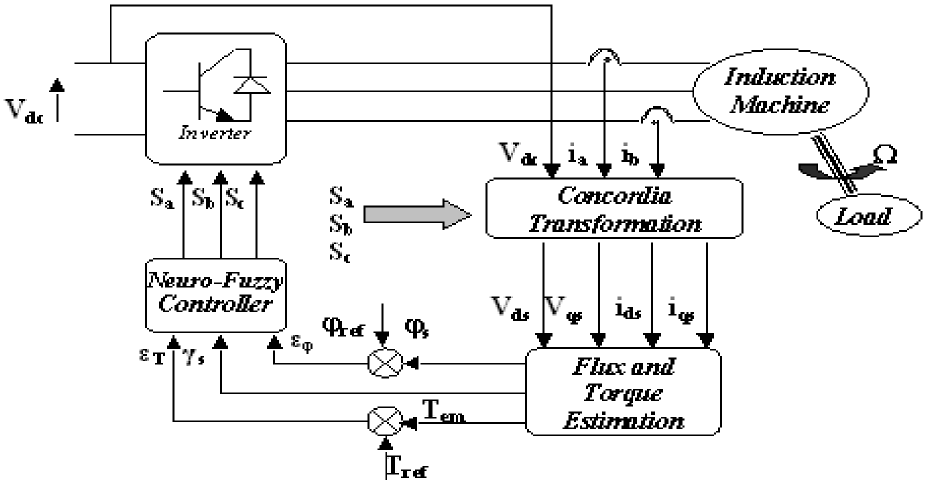

Figure.4 Block diagram of Neuro-Fuzzy Controller

4.1 STRUCTURE OF ANFIS

The ANFIS acts exactly as a classical fuzzy inference system type Sugeno in terms of fuzzification, knowledge base and defuzzification. The neural networks are utilized to model and implement the fuzzy inference system; its structure is as shown in figure.5, in built with five layers.

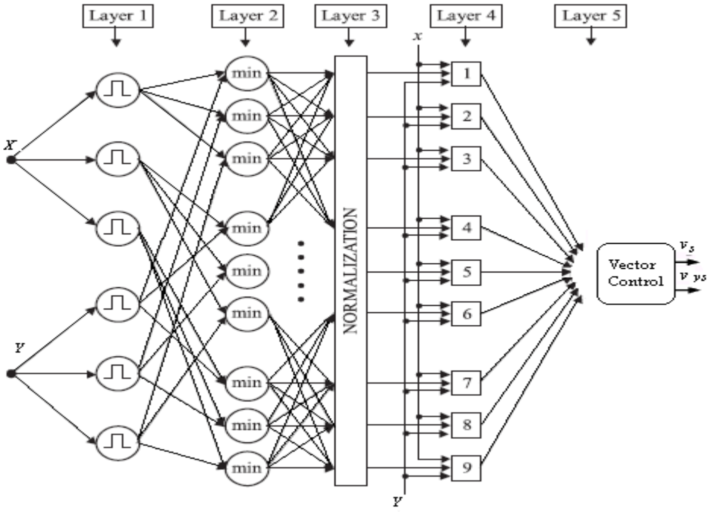

Figure.5 Structure of Adaptive Neuro-Fuzzy Inference System

LAYER 1: This layer is composed of a number of computing nodes whose activation functions are fuzzy logic membership functions (triangular or bell shape).

LAYER 2: This layer chooses the minimum value of the inputs.

LAYER 3: This layer normalizes each input with respect to the others (The i^{th} node output is the i^{th} input divided the sum of all the other inputs).

LAYER 4: This layer's i^{th} node output is a linear function of the third layer's i^{th} node output and the ANFIS input signals.

LAYER 5: This layer sums all the incoming signals.

4.2 A PROPOSED STRUCTURE OF DTC SYSTEM BASED MRAC

The Model Referencing Adaptive control (MRAC) as the name indicates, the plant's response is forced to track the response of a reference model, irrespective of the plant's parameter variation and load disturbance effect. Such a system is defined as a robust system. The reference model may be fixed or adaptive and is stored in the DSP's memory.

Figure shows a model referencing adaptive control using a neural controller. Here, the reference model output (target) is compared with the plant output, which has a parameter variation problem. The ANN controller is trained such that it, along with the plant model, always tracks the reference model. One problem in this direct MRAC control is that the plant lies between the controller and the error and there is no way to propagate the error backward through the controller. To overcome this problem, the indirect MRAC method shown in figure is used. In the beginning, the ANN identification model F(.) is trained to simulate the forward model as shown. The tuning of the ANN controller is now convenient through the neural model F(.) instead of through the plant. The ANN model can be updated periodically if there is plant parameter variation.