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Optimization of Torque and Flux ripple for DTC fed Asynchronous Motor Drive Using Hybrid Computing Techniques

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Abstract- This paper presents a comparative study of Space Vector Modulation (SVM)-Direct Torque Control (DTC) of three-phase Induction Motor using conventional PI controller and Hybrid Computing Techniques like Genetic Algorithm tuned PI and Fuzzy Controllers. A dynamic modular model for the three-phase Induction Motor based on Krause's model is developed and the required supply for this system is provided by a Space Vector PWM based three-phase Voltage Source Inverter. The main characteristics of DTC scheme applied to three phase Induction Motor is studied by simulation, emphasizing its advantages and disadvantages for different configurable controllers.Validation of the proposed system is verified and analysed using MATLAB/SIMULINK tool.

Keywords: *Three-phase Induction Motor, Direct Torque Control (DTC), Space Vector PWM, Voltage Source Inverter, PI Controller, Hybrid Computing Techniques .*

1.0 INTRODUCTION

Starting in the middle of the 1960s, every effort was made to develop AC drive systems with variable frequency.Three-phase Induction motor with its relatively simple and rugged constructional feature, is widely accepted by the Industrial community for [1]. New modulation methods such pulse width modulation (PWM) emerged and new control methods such as Vector control and Field-oriented control were introduced [6]. These investigations and developments resulted in a real breakthrough for more efficient variable speed drive systems. High performance electrical drives require decoupled torque and flux control. The Direct Torque Control (DTC), since its introduction in 1985, was most widely used for Induction motor drives with accurate dynamic performance [2,3]. If the torque and flux are correctly estimated, DTC is able to produce very torque and flux control with minimum motor parameter and perturbations. One of the notable demerit of DTC is high torque ripple. The basic DTC scheme operates to control the stator flux and the torque directly by selecting the suitable inverter switching state. A new space vector modulation based DTC (SVM-DTC) based control of Induction motor drive was proposed where an inverter switch position is selected combining with the situation of torque error, current error and the position of stator flux angle [4].

Minimization of flux and torque ripple with constant inverter switching frequency can be achieved using SVM-DTC. Such system preserve DTC transient merits and can compensate the flux and torque errors.These can be minimized by using Predictive Control Scheme [8], SVM technique [5,9,10] and Artificial Intelligence methods [11,12].

In this paper, the performance of the electrical motor drive system is studied using MATLAB/ SIMULINK tool. The simulation results infer

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that the optimization of torque and flux ripples for the proposed system is better with the Hybrid Computing Techniques (Genetic Algorithm tuned PI) than the traditional PI Controller.

2.0 MODULAR MODEL OF THREE-PHASE INDUCTION MOTOR

The d-q dynamic model using Park's ttransformation, Kron's primitive machine model of three-phase Induction motor can be represented in the arbitrary reference frame[13].

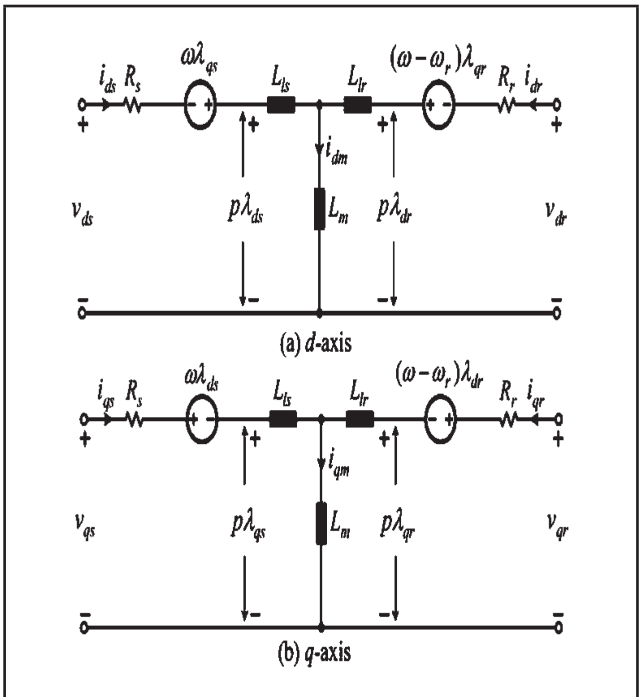

FIG.1. INDUCTION MOTOR DQ-AXIS MODEL IN ARBITRARY REFERENCE FRAME

The stator voltages w.r.t. to d-q axis model can be represented with the following equations.

$$V_{ds} = R_s i_{ds} + \frac{d\lambda_{ds}}{dt} + \omega\lambda_{qs} \quad ...(1)$$

$$V_{qs} = R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega\lambda_{ds} \quad ...(2)$$

$$V_{dr} = R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega - \omega_r\lambda_{qr}) \quad ...(3)$$

$$V_{qr} = R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega - \omega_r)\lambda_{dr} \quad ...(4)$$

Equations (5) to (8) describe the d-q axis flux linkages.

$$\lambda_{qs} = L_s i_{qs} + (i_{qs} + i_{qr})L_m \quad ....(5)$$

$$\lambda_{qs} = L_s i_{qs} + (i_{qs} + i_{qr})L_m \quad ...(6)$$

$$\lambda_{ds} = L_s i_{ds} + (i_{ds} + i_{dr})L_m \quad ...(7)$$

$$\lambda_{dr} = L_r i_{dr} + (i_{ds} + i_{dr})L_m \quad ...(8)$$

3.0 BASIC SYSTEM DESCRIPTION

3.1 Dtc Principle

DTC was introduced by Takahashi in Japan and then in Germany by Depenbrock [5]. Basically DTC is a control philosophy exploiting the torque and flux producing capabilities of AC machines when fed by a Voltage Source Inverter (VSI) that does not require any current control loops.

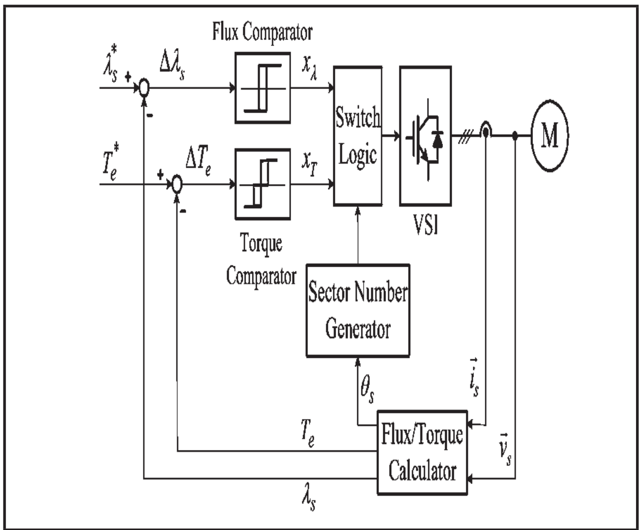

FIG.2. BASIC DTC SCHEME

Both torque and stator flux need to be estimated such that they can be directly controlled in a way that restricts them to a hysteresis band close to the target values.

In the (d,q) reference, the stator flux can be obtained by the following equation:

$$\bar{V}_s = R_s \bar{I}_s + \frac{d}{dt}(\psi_s) \quad ...(9)$$

The electromagnetic torque is proportional to the vector product between the vector of stator and rotor flux according to the following equation:

T_e $T_e = k \, \Psi_s \Psi_r \sin\delta$ **...**(10)

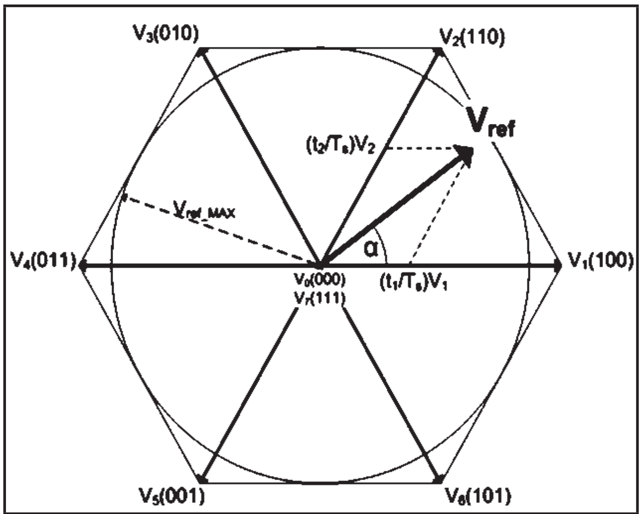

FIG.3. PRINCIPLE OF DTC FOR A TWO-LEVEL VSI FED IM DRIVE

3.2 SVM Fed Voltage Source Inverter Model

The technique of Space Vector Modulation (SVM) is applied to get desired stator flux for which the deviation in the torque and flux be mimimal. Based on the instantaneous current and voltage measurements it is possible to calculate the voltage required to drive the current output torque and stator flux to the demanded values. The calculated voltage is then synthesised using Space Vector Modulation. If the inverter is not capable of generating the required voltage then the voltage vector which will drive the torque and flux towards the demand value is chosen for the required operation The flux equation for each of the three leg can be expressed as

There exists eight states of which two of them have null voltage and hence zero flux states.

$$p\overrightarrow{\lambda_s} = \overrightarrow{v_s} - R_s\overrightarrow{i_s} \quad ...(11)$$

There exists eight states of which two of them have null voltage and hence zero flux states.

The stator flux angle along with the torque and flux hysteresis are used to determine the suitable stator flux sector in order to apply the correct voltage vector to the Induction motor.

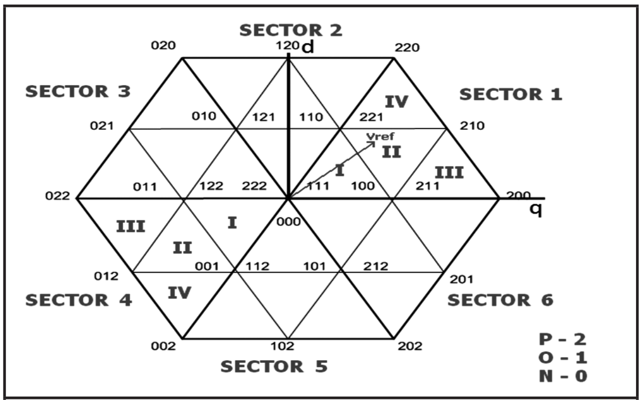

FIG.4. SWITCHING SECTORS OF INVERTER VOLTAGE VECTORS

4.0 CONTROLLER MODEL

4.1 Fuzzy Logic Controller

The design of a Fuzzy Logic Controller requires the choice of Membership Functions. The membership functions should be chosen such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other. This is done in order to avoid any kind of discontinuity with respect to the minor changes in the inputs.To achieve finer control, the membership functions near the zero regions should be made narrow. Wider membership functions away from the zero region provides faster response to the system. Hence, the membership functions should be adjusted accordingly.

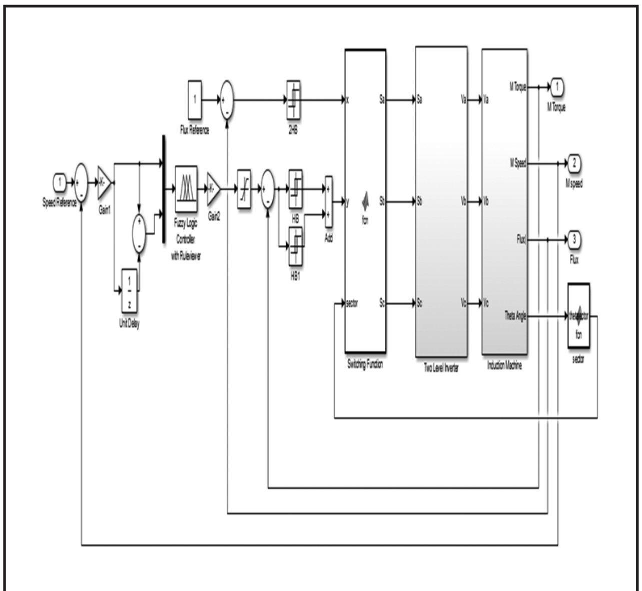

FIG.5 SIMULINK MODEL OF FUZZY LOGIC CONTROLLER BASED SYSTEM

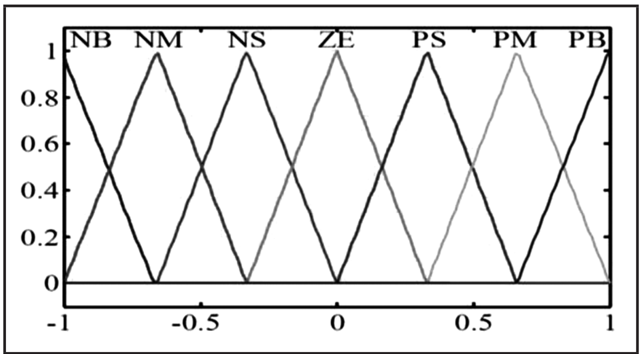

FIG.6 INPUT MEMBERSHIP FUNCTIONS FOR ERROR SPEED (E) AND RATE OF CHANGE OF ERROR SPEED (DE)

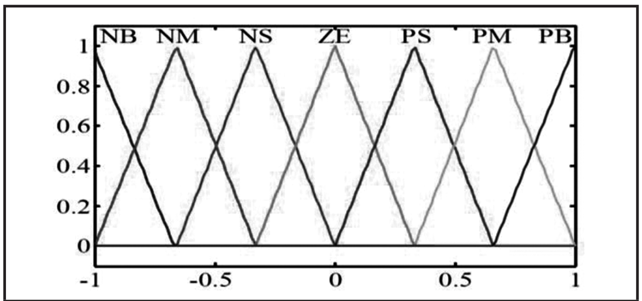

FIG.7 OUTPUT MEMBERSHIP FUNCTION OF FUZZY LOGIC CONTROLLER

TABLE 1

RULE MATRIX FOR FUZZY LOGIC CONTROLLER

e / Ce	NB	NM	NS	ZE	PS	PM	PB
NB	NM	NS	ZE	PS	PM	PB	PS
NM	NS	ZE	PS	PS	PM	PB	PM
NS	ZE	PS	PM	PB	PB	PB	ZE
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PM	PB	PB	PB	PB

After the appropriate membership functions are chosen, a rule base should be created. It consists of a number of Fuzzy If-Then rules that completely define the behaviour of the system. These rules very much resemble the human thought process, there by providing artificial intelligence to the system. In this control design 7x7 rule base are used as shown in Table 1, which consists of 49 if-then rules .

4.2 Genetic Algorithm Tuned Pi Controller (HYBRID COMPUTING TECHNIQUE)

The GA is an optimization procedure based on the mechanics of natural selection and natural genetics. The GA requires only a binary representation of the decision variables to perform the genetic operations i.e. selection, crossover and mutation.

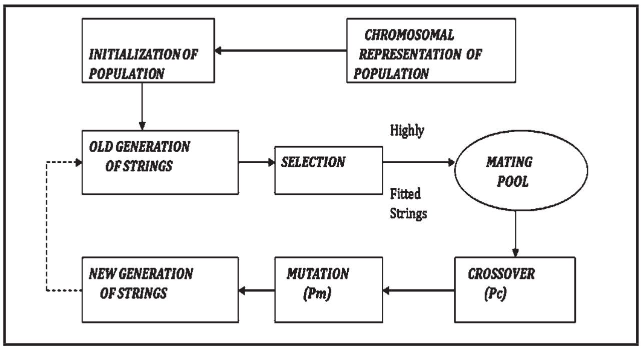

FIG.8. GENERAL SCHEME OF GENETIC ALGORITHM

The block of the objective function is used to estimate the performances of the PI controller by minimizing this function.

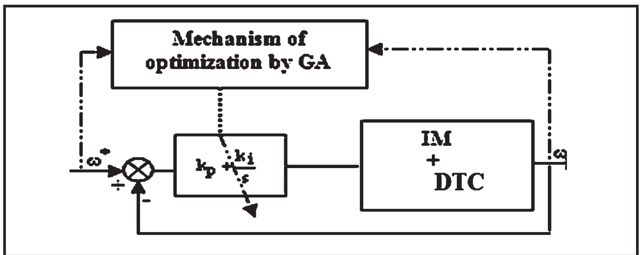

FIG.9. GA TUNED PI METHOD

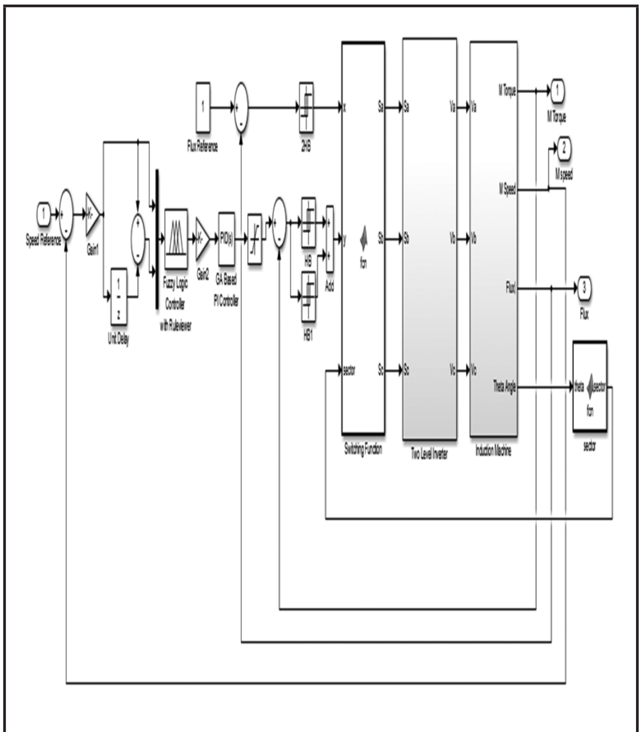

FIG.10 SIMULINK MODEL OF GA TUNED PI CONTROLLER BASED SYSTEM

5.0 RESULTS AND DISCUSSION

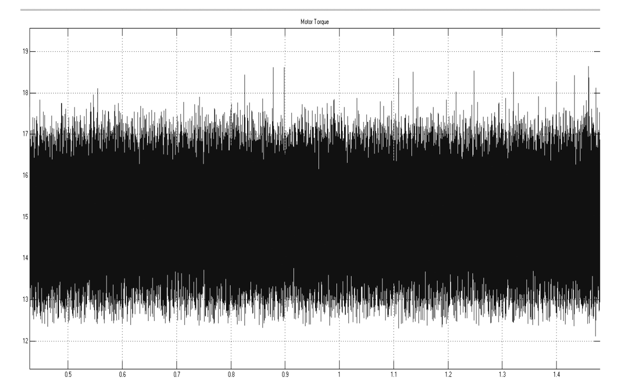

FIG.11 MOTOR TORQUE FOR PI CONTROLLER BASED SYSTEM

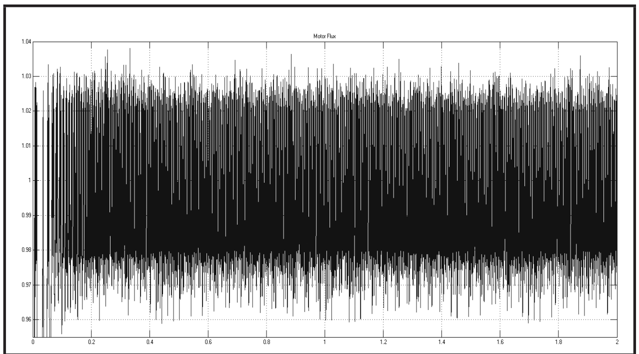

FIG.12 MOTOR FLUX FOR PI CONTROLLER BASED SYSTEM

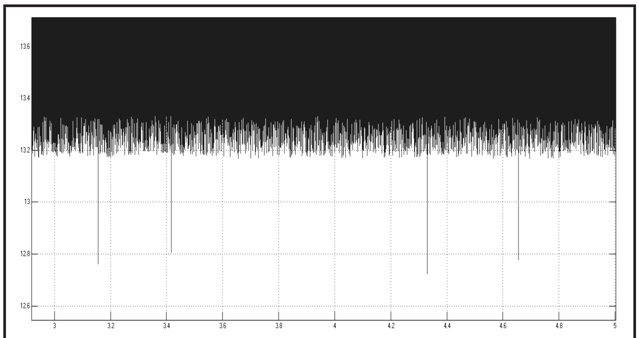

FIG.13 MOTOR TORQUE FOR FUZZY LOGIC CONTROLLER BASED SYSTEM

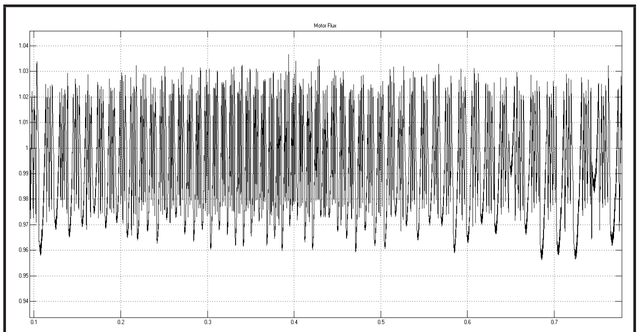

FIG.14 MOTOR FLUX FOR FUZZY LOGIC CONTROLLER BASED SYSTEM

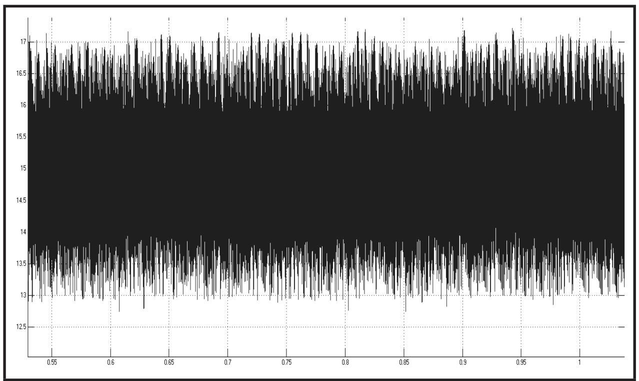

FIG.15 MOTOR TORQUE FOR GA TUNED PI CONTROLLER BASED SYSTEM

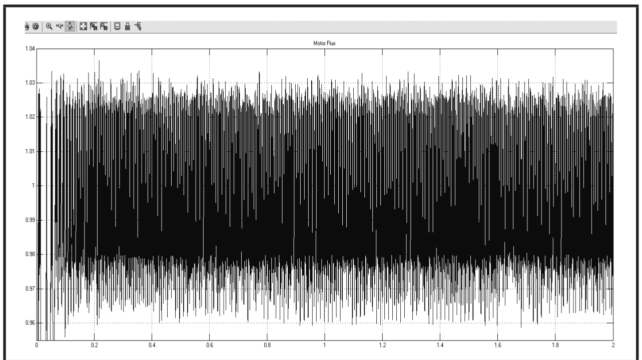

FIG.16 MOTOR FLUX FOR GA TUNED PI CONTROLLER BASED SYSTEM

TABLE 2

COMPARATIVE TABLE

S.No.	Type of Controller	Torque Ripple(%)	Flux Ripple(%)
1	PI	14.86	7.51
2	Fuzzy Logic Controller	7.34	4.67
3	Hybrid Controller (GA Tuned PI)	4.27	3.16

6.0 CONCLUSION

The proposed SVM-DTC scheme driven by two level Voltage Source Inverter was simulated in MATLAB/SIMULINK^{TM} environment. It can be inferred the better performance of Hybrid Computing Techniques compared to Fuzzy and PI controllers. Moreover the percentage ripple content in torque and flux is considerably minimized.

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