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# Performance Analysis of Induction Motor Using Artificial Intelligent Techniques

Vivek Dutt and Rohtash Dhiman

***Abstract*– In this paper, we have demonstrated the performance of induction motor (IM) using artificial intelligent techniques: neural networks (NN) and fuzzy logic control. A simulation model using Matlab software is designed to get the performance analysis of induction motor (IM) in the form of speed and stator currents using direct torque control method. This simulink-model consists of induction motor with a switching table on the basis of direct torque control method. All the results are analyzed with the help of simulink-model designed which shows that these intelligent techniques applied on the direct torque control method, give effective and optimized performance of induction motor. It has been found that artificial neural networks and fuzzy logic are best optimization techniques for controlling the performance of induction motor as compared to direct torque control method a-lonely.**

***Index Terms*– ANN, DTC, Fuzzy Logic Control, Induction Motor, Switching Table and Space Vector Modulation (SVM)**

## I. INTRODUCTION

THE three phase induction motor is mostly used as the prime mover in industries, it's due to the induction motor has simple construction, sturdy, easy maintenance and relatively low price, therefore that why the induction motor has start shifting the use of other prime mover in industries. The induction motor has some non linear parameters, especially rotor resistance, which has a wide variation in value for the difference of operation condition. The load change at the induction motor it will create change in motor speed, so that to keep motor speed constant, as it needs some controller which could adapt the change of motors load [1].

Accurate control of electrical machines requires an independent control of magnetic flux and torque. Due to that reason, it should not be surprised that the DC machine has played a huge role in the starting days of high performance electrical drive systems. Induction motor drives controlled by As it is well known that both magnetic flux and torque can be controlled by stator and rotor currents, so due to this fact in the later eighties, a new control method Direct Torque Control (DTC) method has been introduced. This method is characterized by its simple application and a good fast dynamic response [2]. We can remove the following common disadvantages likewise high torque ripple and slow transient response to the step changes in torque during start-up, by applying modern intelligent techniques like artificial neural networks and fuzzy logic. Due to that reason, the application of fuzzy logic control and artificial neural network attracts the attention of many researchers from all over the world [3].

Fuzzy control is a way for controlling a system without the need of knowing the plant mathematic model. It uses the experience of people's knowledge to form its control rule base. There have appeared many applications of fuzzy control on power electronic and motion control in the past few years [4].

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## II. DIRECT TORQUE CONTROL FUNDAMENTALS

In Fig. 1, a possible schematic of Direct Torque Control for ac induction motor is shown. As it can be seen, there are two different loops corresponding to the magnitudes of the stator flux and torque. The reference values for the flux stator modulus and the torque are compared with the actual values, and the resulting error values are fed into the two level and three-level hysteresis blocks respectively. The outputs of the stator flux error and torque error hysteresis blocks, together with the position of the stator flux are used as inputs of the look up table (see Table I). The position of the stator flux is divided into six different sectors.

The basic functional blocks are used to implement the DTC schemes which are represented in Fig. 1 [3], [9]. The basic principle of DTC depends on fact that the stator flux vector is directly manipulated such that the desired torque is produced.

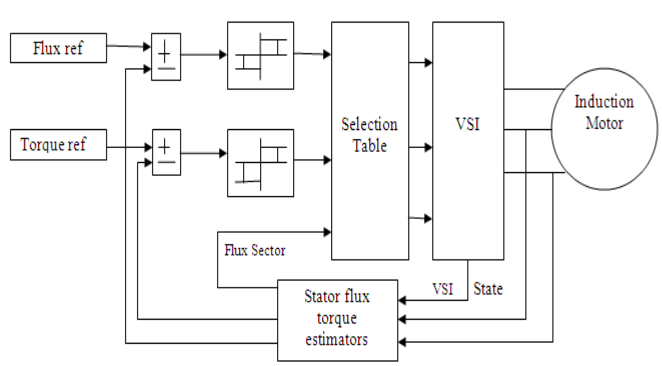


Fig. 1: Basic direct torque control for ac induction motor

This whole process is done by choosing an inverter switch combination which drives the stator flux vector by directly applying the appropriate voltages to the motor windings [5]. Using a closed loop estimator, the instantaneous values of the stator flux and torque are calculated from stator variable. Stator flux and torque are controlled directly and independently by properly selecting the inverter switching configuration. In accordance with the figure 3, the stator flux modulus and torque errors tend to be restricted within its respective hysteresis bands. It can be proved that the flux hysteresis band affects basically to the stator-current distortion in terms of low order harmonics and the torque hysteresis band affects the switching frequency.

The DTC requires the flux and torque estimations, which can be performed as it is proposed in Fig. 3, by means of two different phase currents and the state of the inverter. However, flux and torque estimations can be performed using other magnitudes such as two stator currents and the mechanical speed, or two stator currents again and the shaft position.

The direct torque control method has been derived depending on the basis of the errors between the reference and the estimated values of torque and flux. It is easy to control the inverter states directly for getting the reduced torque and flux errors within the predefined band limits. Direct torque control is a scheme used for the improvement of induction motor speed by variable frequency converter [1]. It controls the torque on the basis of keeping the flux value invariable by choosing voltage space vector.

### *A. Vector Model of Inverter Output Voltage*

The switching commands of each inverter leg are complementary in a voltage fed three phase inverter as shown in Fig. 2.

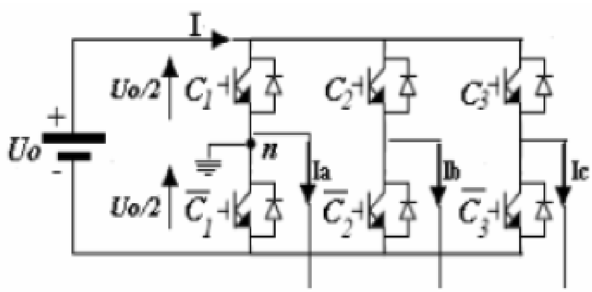


Fig. 2: Three phase voltage inverter [2]

So for each leg a logic state $C_i$ (i=a,b,c) can be defined. $C_i$ is 1 if the upper switch is commanded to be closed while on other hand, it is 0 if the lower one is commanded to be closed first [8]. There will be eight different states, that's why eight different voltages will be possible due to fact that there are three independent legs. The vector transformation can be described as:

$$V_s = \sqrt{\frac{2}{3}}\, U_0 \left[ C_1 + C_2\, e^{j\frac{2\pi}{3}} + C_3\, e^{j\frac{2\pi}{3}} \right] \quad (1)$$

Generally, we can use two methods use for reducing the torque and flux ripple for the DTC drives. One is multi level inverter and the other one **is** space vector modulation (SVM). In the first method, the cost and the complexity will be increased while in the second method, the torque ripple and flux ripple can be decreased; however, the switch frequency still changes.

### *B. Space Vector Modulation (SVM)*

In SVM, the required stator flux can be imposed by choosing the correct inverter state. There are six different sectors obtained by means of dividing the position of stator flux**.** By applying radial or tangential components of stator flux linkage space vector in its locus, decoupling of stator flux modulus and torque is obtained. The components of the same voltage space vector are directly proportional to these two components in the same direction. Fig. 3 has shown the possible dynamic locus of the stator flux and its different variations depending on the VSI states chosen [4]. The possible global locus is divided into six different sectors signaled by discontinuous line.

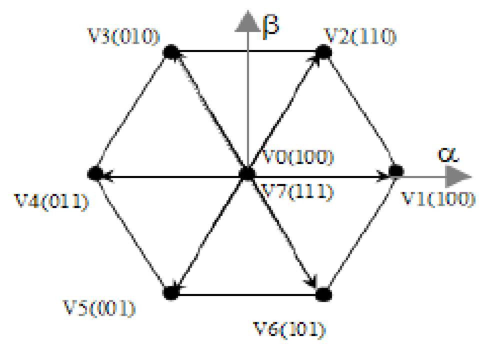


Fig. 3: Partition of the α-β plane into 6 angular sectors [7]

In VSI, there are only 8 distinct states assumed. A non – zero output has been produced by six out of eight states and these states are known as non-zero switching states and zero output has produced by remaining two. Thus, there are six sectors numbered from 1-6 which is shown by $V_1$ to $V_6$ .

As it can be observed in second, there are six non-zero voltage vectors and two zero voltage vectors which are corresponded to ($C_1$, $C_2$, $C_3$) = (111) / (000) as shown by figure 3. [4], [8].

### *C. Stator Flux Control*

When the vector transformation given by equations (2)-(5) is applied, then the components of the current ($I_{s\alpha}$, $I_{s\beta}$), and stator voltage ($V_{s\alpha}$, $V_{s\beta}$) can be obtained as shown below [2]:

$$V_{s\alpha} = \sqrt{\frac{2}{3}}\, U_o \left( C_1 - \frac{1}{2}(C_2 + C_3) \right) \quad (2)$$

$$V_{s\beta} = \sqrt{\frac{1}{2}}\, U_o (C_2 - C_3) \quad (3)$$

$$I_{s\alpha} = \sqrt{\frac{2}{3}}\, I_{sa} \quad (4)$$

$$I_{s\beta} = \sqrt{\frac{1}{2}}\, (I_{sa} - I_{sc}) \quad (5)$$

The components of the stator flux ($\square_{s\alpha}$, $\square_{s\beta}$) given by (7):

$$\begin{cases} \varphi_{s\alpha} = \int_0^t (V_{s\alpha} - R_s I_{s\alpha})\,dt \\ \varphi_{s\beta} = \int_0^t (V_{s\beta} - R_s I_{s\beta})\,dt \end{cases} \qquad (7)$$

The stator flux linkage phase is given by (8):

$$\varphi_s = \sqrt{\varphi^2_{s\alpha} + \varphi^2_{s\beta}} \qquad (8)$$

The electromagnetic coupling can be obtained which starts from the estimated sizes of flux ($\square_{s\alpha}$, $\square_{s\beta}$) and calculated sizes of the current ($I_{s\alpha}$, $I_{s\beta}$).

$$\tau_{em} = p\left(\varphi_{s\alpha} I_{s\beta} - \varphi_{s\beta} I_{s\alpha}\right) \qquad (9)$$

During a large number of converter switching periods $\Gamma_e$, the stator resistance $R_s$ can be assumed constant. The voltage vector applied to the induction motor remains also constant one period $\Gamma_e$. Therefore, first equation of system can be resolved which leads to:

$$\varphi_s = \int_0^t (V_s - R_s I_s)\,dt \qquad (10)$$

$$\varphi_s(t) \approx \varphi_{s0} + V_s \tau_e \qquad (11)$$

In equation (11), the initial stator flux condition is denoted by $\varphi_{s0}$ .

In this equation, it is shown that the term $R_s I_s$ can be neglected, (for example in high speed operating condition) in the extremity of stator flux vector $V_s$. Furthermore, the instantaneous flux speed is only governed by voltage vector amplitude. In fact, we have:

$$\frac{d\varphi_s}{dt} \cong V_s$$

The following figure 4. [4], [9] is established for the case $V_s=V_3$.

In equation (11), it is shown that the end of stator flux vector moves in the direction of the applied voltage vector (as shown in Fig. 4 [5], [9]) by neglecting the stator resistance. Is the initial stator flux linkage at the instant of switching? For answering this question, the voltage vector plane can be divided into six regions for selecting the voltage vectors to control the amplitude of the stator flux linkage as shown in Fig. 3. In each region, two adjacent voltage vectors (which gives the minimum switching frequency) has been selected to increase or decrease the amplitude of respective voltage vector [4]. For instance, vectors are selected to increase and decrease the amplitude when these are in region one and are rotating in a counter-clockwise direction. In this way, stator flux vectors can be controlled at the required value by selecting the proper voltage vectors. Fig. 3 shows how the voltage vectors are selected for keeping within a hysteresis band when these are rotating in the counter-clockwise direction. Therefore, we can increase or decrease the stator flux amplitude and phase for getting the required performances by selecting an adequate voltage vector selection.

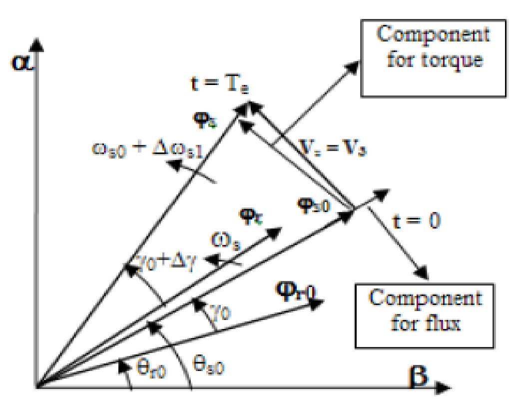


Fig. 4: An example for flux deviation [2]

*D. Stator Flux and Electromagnetic Torque*

The calculated magnitude of stator flux and electric torque are compared with their reference values in their corresponding hysteresis comparators as are shown in Fig. 5. Finally, the outputs of the comparators with the number of sector at which the stator flux space vector is located are fed to a switching table to select an appropriate inverter voltage vector. The selected voltage vector will be applied to the induction motor at the end of the sample time [5].

As shown in Fig. 3, eight switching combinations can be selected in a voltage source inverter, two of which determine zero voltage vectors and the others generate six equally spaced voltage vectors having the same amplitude.

According to the principle of operation of DTC, the selection of a voltage vector is made to maintain the torque and stator flux within the limits of two hysteresis bands. The switching selection table for stator flux vector lying in the first sector of the (α-β) plane is given in table 1. [5], [6].

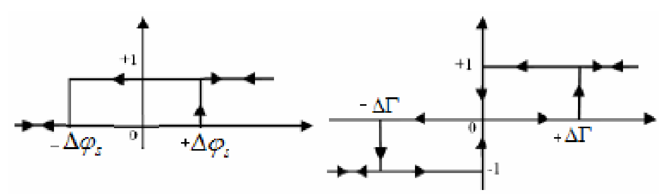


Fig. 5: Stator Flux Hysteresis Comparator and Hysteresis Comparator [2]

TABLE I: DTC BASED SWITCHING TABLE

| Sector | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Flux | Torque | | | | | | |
| $\Delta\varphi = 1$ | $\Delta\tau = 1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_1$ |
| | $\Delta\tau = 0$ | $V_7$ | $V_0$ | $V_7$ | $V_0$ | $V_7$ | $V_0$ |
| | $\Delta\tau = 1$ | $V_6$ | $V_1$ | $V_2$ | $V_3$ | $V_4$ | $V_5$ |
| $\Delta\varphi = 0$ | $\Delta\tau = 1$ | $V_3$ | $V_4$ | $V_5$ | $V_6$ | $V_1$ | $V_2$ |
| | $\Delta\tau = 0$ | $V_0$ | $V_7$ | $V_0$ | $V_7$ | $V_0$ | $V_7$ |
| | $\Delta\tau = 1$ | $V_5$ | $V_6$ | $V_1$ | $V_2$ | $V_3$ | $V_4$ |

## III. FUZZY LOGIC BASED DIRECT TORQUE CONTROL (FLDTC)

In FLDTC, the fuzzy controller is designed with three fuzzy state variables and one control variable to obtain the direct torque control of the induction machine [8], [9]. There are three variables as inputs for fuzzy logic controllers, the stator flux error, electromagnetic torque error, angle of flux stator respectively and the output it is the voltage space vector shown Fig. 6.

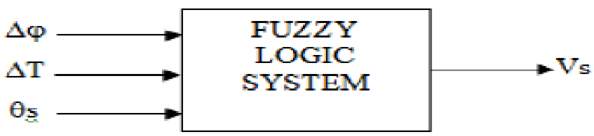


Fig. 6: Switching table in fuzzy logic

- *Flux Linkage Errors*

The value of flux of stator is related to errors of flux linkage and real value of stator's flux □$_s$, they are subject to equation as follows:

$$\Delta\varphi_s = \varphi_{sref} - \varphi_s \qquad (12)$$

- *Electromagnetic Torque Errors*

Error of torque ΔΓ is related to desired torque value $\Delta\Gamma_{ref}$ and real torque value ΔΓ, they are subject to equation as follows:

$$\Delta\tau = \tau_{ref} - \tau \qquad (13)$$

- *The Control Variable*

Inverter switching state (n) denotes the control variable. In a six step inverter, there are seven distinct switching states possible. These switching states are crisp so that they do not need a fuzzy membership distribution. Each control rule can be described using the state variables Δ□, ΔΓ and θs and the control variable (n) (characterizing the inverter switching state). The ith rule Ri can be written as:

Ri : if Δ□, is Ai, ΔΓ is Bi and θs is Ci then n is Ni

These rules can be established using literature and our experience with the help of an intensive simulation stage which is computing the sensitivity factors. The inference method used in this paper is Mamdani's procedure based on min-max decision [10]. The membership functions of variables A, B, C and N are given by μA, μB, μC and μN respectively.

## IV. NEURAL NETWORK BASED DIRECT TORQUE CONTROL (NNDTC)

The use of neural networks is to perform the state selector of a conventional, modified six sector DTC. Each node constitutes a neuron and performs the multiplication of its input signals by constant weights, sums up the results and maps the sum to a nonlinear activation function 'g'; the result is then transferred to its output [17].

A feed forward neural network is organized in layers: an input layer, one or more hidden layers and an output layer. A MLP consists of an input layer, several hidden layers, and an output

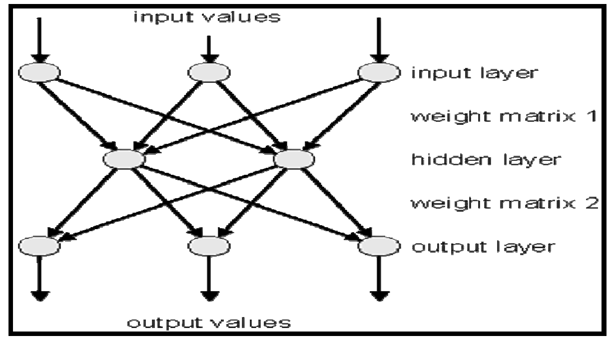


Fig. 7: A multilayer perceptron network with one hidden layer

layer. Node *i*, also called a neuron, in a MLP network is shown in Fig. 7. It includes a summer and a nonlinear activation function 'g' [18].

The inputs $x_k$, k = 1...K to the neuron are multiplied by weights $wk_i$ and summed up together with the constant bias term $\theta_i$. The resulting $i_n$ is the input to the activation function '*g*'. The activation function was originally chosen to be a relay function, but for mathematical convenience a hyperbolic tangent (tanh) or a sigmoid function are most commonly used. The mathematical model of a neuron is given by (14):

$$y_i = g_i = g\left(\sum_{i=1}^{N} w_{ji}\, x_j + \theta_i\right) \qquad (14)$$

### A. Structure of ANN Based DTC Scheme

The ANN is trained by a learning algorithm which performs the adaptation of weights of the network iteratively until the error between target vectors and the output of the ANN is less than an error goal. The most popular learning algorithm for multilayer networks is the back-propagation algorithm and its variants [13], [14]. The latter is implemented by many ANN software packages such as the neural network toolbox from MATLAB.

The switching table required for the simulation using ANN can be created with the following procedure:

1). To create angle of stator flux, we have passed the following program by Matlab:

```
function sys=mdlOutputs(t,x,u)
if(u(1)==0)
    sn=3;
else
    a1=u(1)*(-0.5)+(sqrt(3)/2)*u(2);
    b1=u(1)*(-0.5)-(sqrt(3)/2)*u(2);
    c1=u(1);
    if(a1>0)
        sa1=0;
    else
        sa1=1;
    end
    if (b1>0)
        sb1=0;
    else
        sb1=1;
    end
    if(c1>0)
        sc1=0;
```

```
    else
        sc1=1;
    end
    sn=4*sa1+2*sb1+sc1;
end
sys=[sn];
```

2). To create pulse function, we have passed the following program by Matlab:

```
function sys=mdlOutputs(t,x,u)
    if(u(1)==1)
    a1=1;
    a2=0;
elseif(u(1)==0)
    a1=0;
    a2=1;
end
if(u(2)==1)
    b1=1;
    b2=0;
elseif(u(2)==0)
    b1=0;
    b2=1;
end
if(u(3)==1)
    c1=1;
    c2=0;
elseif(u(3)==0)
    c1=0;
    c2=1;
end
```

3). After making the switching table, we can train the whole procedure for getting the performance of induction motor using ANN Toolbox where performance-plot is shown in Fig. 8:

## V. INTERPRETATION RESULTS

When controlling the induction machine for a DTC system, there are following parameters:
$P_n = 3.760$ Kw, $V_n = 480$ volt, $f_n = 60$ Hz, $R_s = 1.119\ \Omega$, $R_r = 1.089\ \Omega$, $P = 2$, $L_s = L_r = 0.005964$ H, $L_m = 0.2027$H, $J = 0.023$ kgm$^2$ and the sampling period of the system is 50$\mu s$.

To analyze the performance of induction motor with DTC, DTC with Fuzzy Logic and DTC with NN are simulated. In all cases, the dynamic responses of speed and stator currents for the starting process with torque applied and a constant command flux are shown in simulation results.

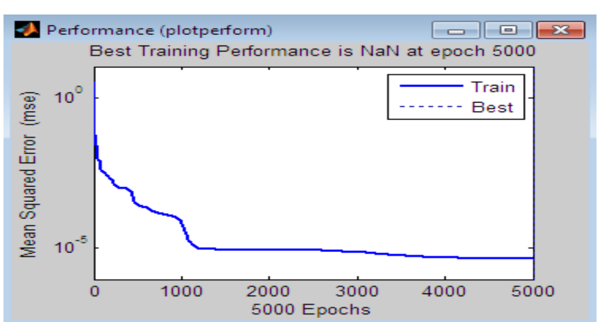


Fig. 8. Performance-plot after training procedure

## VI. SIMULATION RESULTS

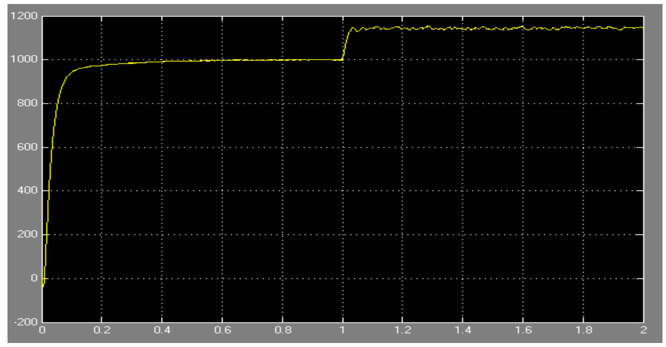

Fig. 9(i): Speed response of IM using DTC

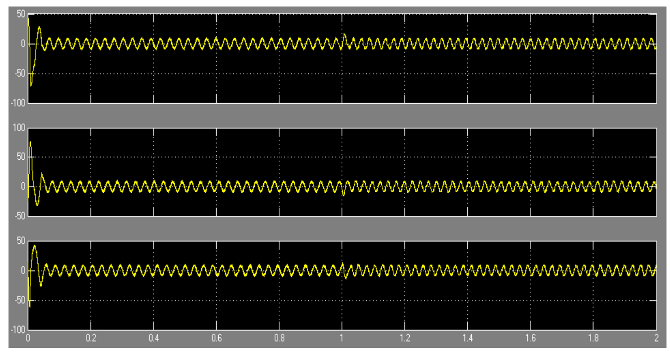

Fig. 9(j): Stator currents response of IM using DTC

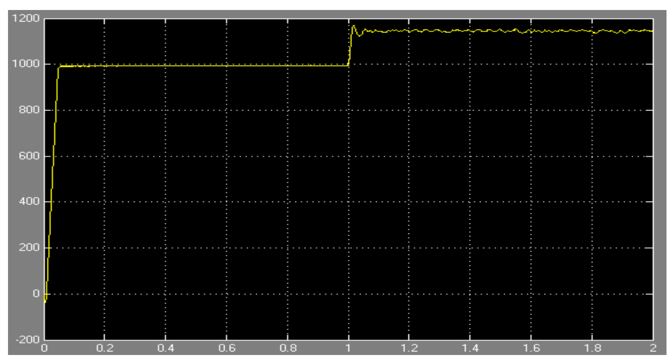

Fig. 10(i): Speed response of IM using DTC with ANN

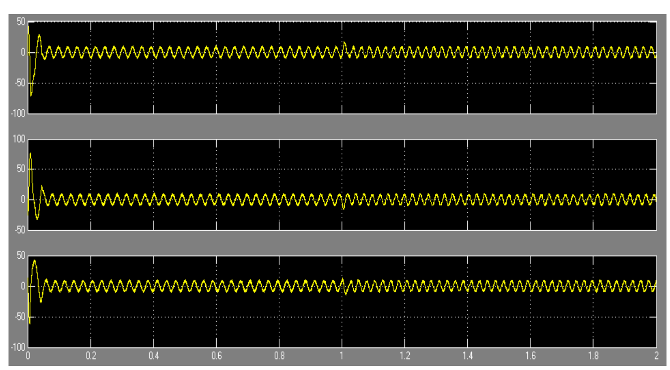

Fig. 10(j): Stator currents response of IM using DTC with ANN

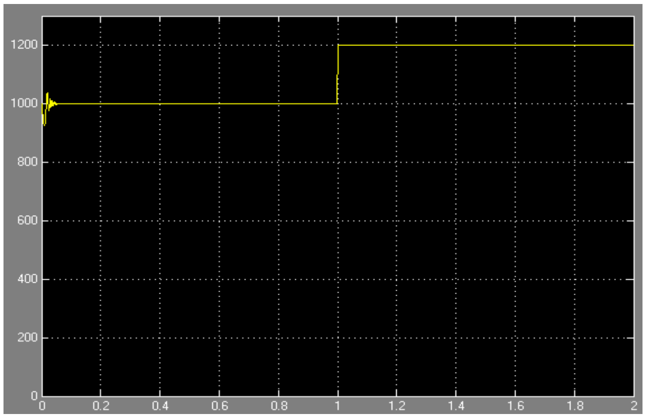


Fig. 11(i): Speed response of IM using DTC with Fuzzy Logic

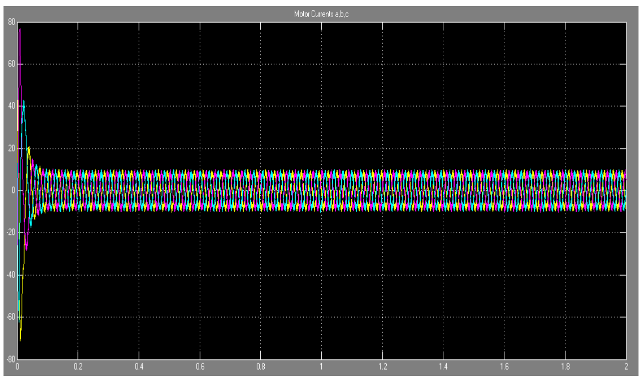

Fig. 11(j): Stator Currents response of IM using DTC with Fuzzy Logic

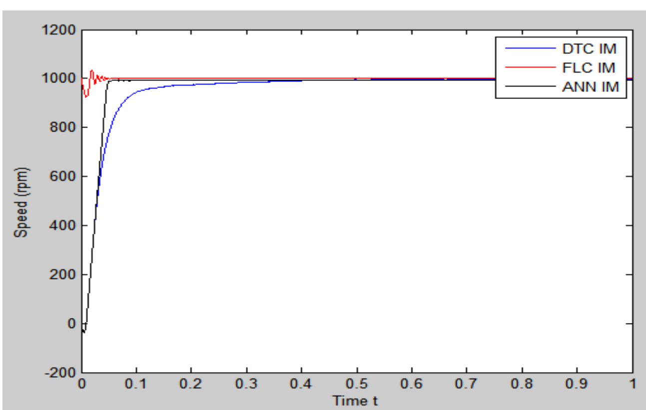


Fig. 12: Performance analysis of IM using intelligent techniques

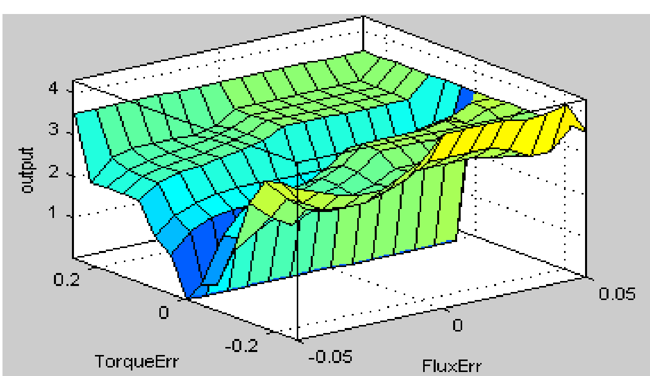


Fig. 13(i). Fuzzy Rule Surface b/w flux error and torque error

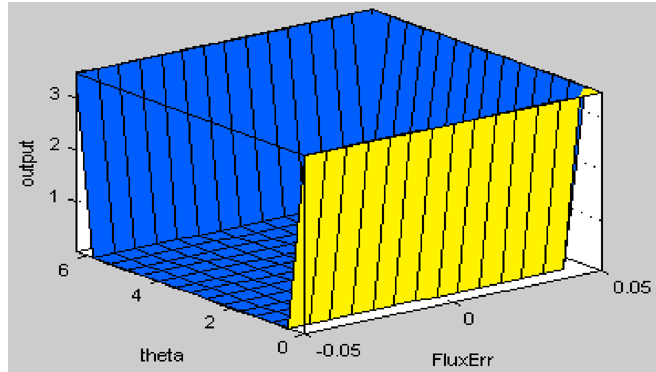


Fig. 13(j): Fuzzy Rule Surface b/w theta (angle of flux) and flux error

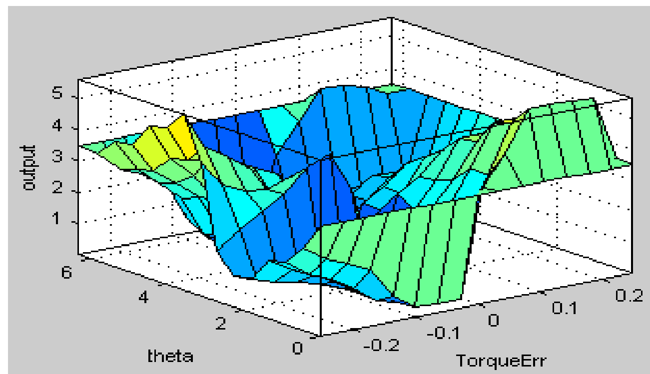


Fig. 13(k): Fuzzy Rule Surface b/w theta (angle of flux) and torque error

Fig. 9(i), 10(i), 11(i) show the speed response of DTC, DTC with ANN, DTC with Fuzzy Logic control respectively, Fig. 9(j), 10(j), 11(j) show stator currents response of DTC, DTC with ANN, DTC with Fuzzy Logic respectively, Fig. 12 shows exact performance analysis of IM using intelligent techniques, Fig. 13(i), (j), (k) represent the corresponding surfaces.

## VII. CONCLUSION AND FUTURE SCOPE

In this paper, performance of induction motor is analyzed using intelligent techniques: ANN and Fuzzy Logic control. Depending on the analysis of diagram of voltage vector, authors acquired whole fuzzy control rule set and training of ANN based upon the switching table for DTC. The performance analysis has been tested with the help of simulations and an optimized speed and stator currents responses are achieved using DTC with ANN and DTC with fuzzy Logic. The simulation results suggest that FLDTC and ANNDTC of induction motor can achieve more precise control of the speed and stator currents.

The main improvements shown are:

- Reduction of torque and current ripples.
- Fast torque response and good maintained speed response.
- Zero-steady-state torque.

Optimization techniques such as Genetic algorithm (GA), Particle Swarm Optimization (PSO) and Advanced PSO can be used for the better performance analysis of induction motor by improving the training algorithm and fuzzy rule set.

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