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A Comparative Study between PI Controller and Fuzzy Controller for Speed Control of Dual Induction Motor

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Abstract: ***A comparative study is made between the PI controller and fuzzy controller demonstrating the speed control of dual induction motor using fuzzy logic controller under unbalanced conditions. The dual induction motor is controlled by weighed vector value and the process of finding the weighed vector value is presented. The simulation is done in the MATLAB platform to study the effectiveness of the control.***

Keywords: Dual Induction Motor, Fuzzy logic controller, P I (Proportional Integral) Controller, Summation torque, Unbalanced condition, Weighed Vector control and Weighed vector value.

1. Introduction

Implementation of coordination control of multiple induction motor is very important in industrial applications and transportation systems. There are two categories in coordination control of multiple induction motor. They are
1) Single inverter driving multiple induction motors.
2) Multiple inverter driving multiple induction motors.

The later control is complex because of the increase in number of IGBTs. The single inverter driving multiple induction motor find more advantages because of low cost, light weight, compact structure and less IGBTs. The single inverter drive system can be further divided as follows
1) Multiple-leg inverter control.
2) Vector control.
Multiple leg inverter control found to have its own disadvantages because of increased in use of IGBTs. In vector control of multiple induction motor, some strategies were proposed to control multiple motor fed by the single inverter.

1.1 Objectives

The objective of the thesis are listed below
1) To improve the control of dual induction motor fed by a single inverter during unbalanced load condition using fuzzy logic controller.
2) To determine the weighed vector value necessary for controlling the dual induction motor.
3) To simulate the speed control of dual induction motor in MATLAB platform.

2. PI Controller

The system involves in the speed control of dual fed induction motor fed by single inverter using weighed vector control. The control process is survived by the PI controller unit which controls the stator current and the rotor flux produced in the motors. The weighed value is calculated under unbalanced load conditions, which possess the further operation of the motors without disturbance. Thus allowing the independent operation of the two induction motors.

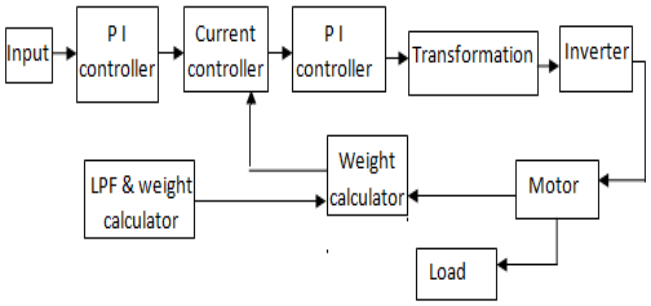

Figure 1.1: Block Diagram of the system with PI controller

2.1 Fuzzy controller

The system involves in the speed control of single inverter dual fed induction motor using fuzzy logic controller. The weighed values are calculated by the fuzzy controllers using the summation torque and stator current of the motors so that the weighed value controls the speed of the induction motor under unbalanced load conditions. The independent operation of the motors depends on the controlled current input from the controller, thus under unbalanced load conditions the weighed value is calculated and the feedback is given to the controller for better operation.

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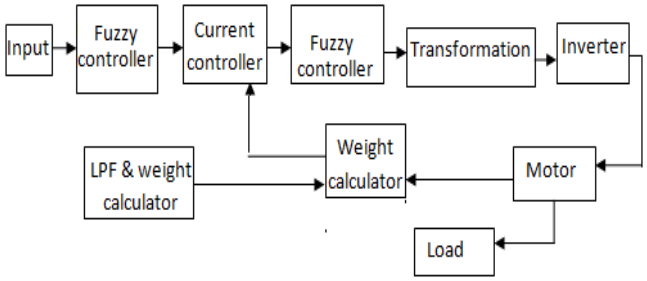

Figure 1.2: Block Diagram of the system with Fuzzy controller

3. Modeling of Induction Motor

3.1 Mathematical descriptions of ac induction motors

There are a number of AC induction motor models. The model used for vector control design can be obtained by using the space vector theory. The 3-phase motor quantities (such as voltages, currents, magnetic flux, etc.) are expressed in terms of complex space vectors [7] .Such a model is valid for any instantaneous variation of voltage and current and adequately describes the performance of the machine under both steady-state and transient operation. Complex space vectors can be described using only two orthogonal axes. The motor can be considered a 2-phase machine. The utilization of the 2-phase motor model reduces the number of equations and simplifies the control design.

3.2 Space vector definition [4]

Assume that i_{sa} , i_{sb} , and i_{sc} are the instantaneous balanced 3-phase stator currents:

$$i_{sa} + i_{sb} + i_{sc} = 0 \quad (3.1)$$

The stator current space vector can then be defined as follows:

$$i_s = k\,(i_{sa} + a i_{sb} + a^2 i_{sc}) \quad (3.2)$$

Where,
a and a2 = The spatial operators (a = ej2π/3, a2 = ej4π/3)
k = the transformation constant (k=2/3)

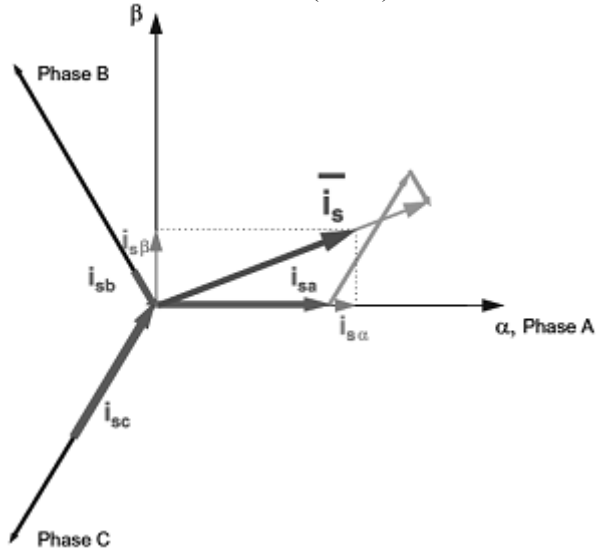

Figure 3.1: Stator Current Space Vector and Its Projection

The space vector defined by equation (3.2) can be expressed utilizing the two-axis theory, the stator current space vector in the stationary reference frame attached to the stator can be expressed as:

$$i_s = i_{s\alpha} + j i_{s\beta} \quad (3.3)$$

The equation (3.4) shows the actual 3-phase stator currents as

$$i_s\alpha = k\left(i_s a - \frac{1}{2} i_s b - \frac{1}{2} i_s c\right) \quad (3.4)$$

$$i_s\beta = \frac{k\sqrt{3}}{2}\left(i_s b - i_s c\right) \quad (3.5)$$

where,
k=2/3 is a transformation constant

The space vectors of other motor quantities (voltages, currents, magnetic fluxes, etc.) can be defined in the similar way as the stator current space vector.

3.3 AC Induction motor model

The AC induction motor model is given by the space vector form of the voltage equations. The system model defined in the stationary α, β-coordinate system attached to the stator is expressed by the following equations. Considering the initial condition of the motor model is symmetrical, with a linear magnetic circuit characteristic.

1) The stator voltage differential equations

$$u_s\alpha = R_s i_s a + \frac{d}{dt}\psi_s\alpha \quad (3.6)$$

$$u_s\beta = R_s i_s\beta + \frac{d}{dt}\psi_s\beta \quad (3.7)$$

2) The rotor voltage differential equations

$$u_r\alpha = R_r i_r\alpha + \frac{d}{dt}\psi_r\alpha + \omega\psi_r\beta = 0 \quad (3.8)$$

$$u_r\beta = R_r i_r\beta + \frac{d}{dt}\psi_r\beta + \omega\psi_r\alpha = 0 \quad (3.9)$$

3) The stator and rotor flux linkages expressed in terms of the stator and rotor current space vector

$$\psi_s\alpha = L_s i_s a + L_m i_r a \quad (3.10)$$

$$\psi_s\beta = L_s i_s\beta + L_m i_r\beta \quad (3.11)$$

$$\psi_r\alpha = L_r i_r a + L_m i_s a \quad (3.12)$$

$$\psi_r\beta = L_r i_r\beta + L_m i_s\beta \quad (3.13)$$

4) Electromagnetic torque expressed by utilizing space vector quantities

$$t_e = \frac{3}{2} n_p\left(\psi_s\alpha i_s\beta - \psi_s\beta i_s a\right) \quad (3.14)$$

4. Controllers

4.1 PI controller

Proportional & Integral Controllers (PI) controllers were developed because of the desirable property that systems with open loop transfer functions of type 1 or above have zero steady state error with respect to a step input [6].

Proportional action: responds quickly to changes in error deviation.
Integral action: is slower but removes offsets between the plant's output and the reference.

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4.1.1 Formulation of PI feedback

Table 4.1: Symbols used

Symbols	*Description*
u	Feedback output
k_p	Proportional gain
k_i	Integral gain
e	Error of the system
τ_1	Integration time in s
τ_N	Rest time in s
i_d	Stator current of d-axis
i_q	Stator current of q-axis

The definition of proportional feedback control is

$$u = K_p e \quad (4.1)$$

The definition of the integral feedback control is

$$u = K_I \int e d_\tau \quad (4.2)$$

In the PI controller we have a combination of P and I control, ie. involving equations (4.1) and (4.2)

$$u = K_p e + K_I \int e d_\tau \quad (4.3)$$

$$u = K_p e + \frac{1}{\tau_I} \int e d_\tau \quad (4.4)$$

$$u = K_p (e + \frac{1}{\tau_I} \int e d_\tau) \quad (4.5)$$

Thus the equation (4.5) gives the combined feedback of P and I controller.

4.1.2 Tuning PI controllers

The general approaches to tuning of PI controllers are listed below.

1) Initially have no integral gain (TI large, I controller is in off condition)
2) Increase KP until get satisfactory response
3) Start to add in integral (decreasing TI) until the steady state error is removed in satisfactory time (may need to reduce KP if the combination becomes oscillatory).

4.1.3 Role of PI controller in the project

The PI controller controls the flow of stator current and regulates the i_d and i_q currents with k_p and k_i values

4.2 Fuzzy controllers

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

4.2.1 Fuzzy rules

Fuzzy rules are used in fuzzy control in order to define the map from the fuzzy input signals (error signals, measured signals, or command signals) of the fuzzy controller to its fuzzy output signals (control signals)[1].

Fuzzy SISO-Rule
Fuzzy AND-Rules

The rules map the fuzzy input variables to the output variables.

4.2.2 Role of fuzzy controller in the project

The Fuzzy controller controls the flow of stator current and regulates the i d-axis and i q axis currents with the fuzzy rules.

5. Weighed Vector Control

5.1 Weighed Vector Control of Induction Motor [2]

The dual induction motors fed by the single inverter has same frequency voltage. The various slip between the two induction motors is caused due to unbalanced load, which results in different speed and stator current of the two induction motors. Generally, the equal vector management is applied to calculate the given excitation current and force current within the existing method [4]. The weighted value k_m is defined to process the vector control strategy. The figure 2 illustrates the rotor flux and the stator current in d–q axis.

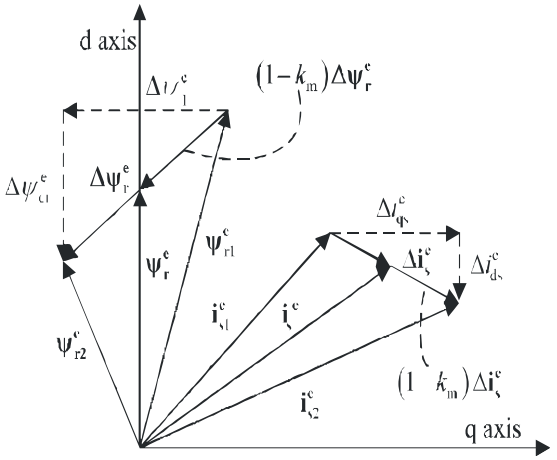

Figure 5.1: Weighted vector model of dual IMs fed by the single inverter

Table 5.1: Symbols used

Symbols	*Description*
i_r	Rotor current
i_s	Stator current
ψ_r	Rotor flux
ψ_s	Stator flux
l_m	Excitation inductance
l_r	Rotor inductance
d_m	Critical slip
d_x	Increment of critical slip
d_p	decrement of critical slip
ω	Angular velocity

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$$\frac{d\psi_{r1}^{e}}{dt} + (S_r + j(w_e - w_{r1}))\psi_{r1}^{e} = L_m S_r i_{s1}^{e} \quad 5.5$$

$$\frac{d\psi_{r1}^{e}}{dt} + (S_r + j(w_e - w_{r2}))\psi_{r2}^{e} = L_m S_r i_{s1}^{e}$$

$$\frac{d(2\psi_r^e + k_w\Delta\psi_r^e}{dt} = S_r L_m (2i_s^e + k_w\Delta i_s^e) - S_r(2\psi_r^e + k_w\Delta\psi_r^e) + j(k_w\Delta w_r\psi_r^e + k_u\Delta w_r\Delta\psi_r^e - (w_e - w_r)(2\psi_r^e + k_w\Delta\psi_r^e)) \quad 5.6$$

$$\frac{d(\Delta\psi_r^e)}{dt} = S_r L_m \Delta i_s^e - S_r\Delta\psi_r^e + jw_e - w_r - k_w\Delta w_r)\Delta\psi_r^e + j\Delta w_r\psi_r^e$$

$$k_w = 2k_m{}^2 - 2k_m + 1 \quad 5.7$$

$$k_u = 2k_m - 1$$

The rotor flux linkage, stator current, and angular velocity necessary for finding the weighed vector are shown in the equations (5.1), (5.2) and (5.3).

$$k_w\frac{d\Delta\psi_{dr}^{e}}{dt} = L_m S_r(2i_{ds}^{e} + k_w\Delta i_{ds}^{e}) - S_r(2\psi_{dr}^{e} + k_w\Delta\psi_{dr}^{e}) + ((w_e - w_r)k_w - k_m\Delta w_r)\Delta\psi_{qr}^{e}$$

$$k_w\frac{d\Delta\psi_{qr}^{e}}{dt} = (k_w\Delta w_r - 2(w_e - w_r))\psi_{dr}^{e} - S_r k_w\Delta\psi_{qr}^{e} + (k_m\Delta w_r - k_w(w_e - w_r))\Delta\psi_{dr}^{e} + L_m S_r(2i_{qs}^{e} + k_w\Delta i_{qs}^{e})$$

$$\frac{d\Delta\psi_{dr}^{e}}{dt} = L_m S_r\,\Delta i_{ds}^{e} - S_r\,\Delta\psi_{dr}^{e} + (w_e - w_r - k_w\Delta w_r)\,\Delta\psi_{qr}^{e}$$

$$\frac{d\Delta\psi_{qr}^{e}}{dt} = L_m S_r\,\Delta i_{qs}^{e} - S_r\,\Delta\psi_{qr}^{e} + \Delta w_r\Delta\psi_{dr}^{e} - k_w(w_e - w_r - k_w\Delta w_r)\,\Delta\psi_{dr}^{e} \quad (5.8)$$

5.2 Calculation of stator current

The equation (5.4) represents the flux linkage and stator current in d and q axis. The rotor flux oriented state equations of the induction motors are given in equation (5.5)

On Substituting equations (5.1), (5.2) and (5.3) in equation (5.3) we obtain equation (5.6)

$$\psi_r^e = k_m\psi_{r1}^e + (1 - k_m)\psi_{r2}^e$$
$$\Delta\psi_r^e = \psi_{r2}^e - \psi_{r1}^e \quad (5.1)$$

$$i_s^e = k_m i_{s1}^e + (1 - k_m)i_{s2}^e \quad (5.2)$$
$$\Delta i_s^e = i_{s2}^e - i_{s1}^e$$

$$w_r = k_m w_{r1} + (1 - k_m)w_{r2} \quad (5.3)$$
$$\Delta w_r = w_{r2} - w_{r1}$$

$$\psi_r^e = \psi_{dr}^e \quad (5.4)$$
$$\Delta\psi_r^e = \Delta\psi_{dr}^e + j\Delta\psi_{qr}^e$$
$$i_s^e = i_{ds}^e + j\,i_{qs}^e$$
$$\Delta i_s^e = \Delta i_{ds}^e + j\Delta i_{qs}^e$$

Now substitute equation (5.4) in equation (5.6) in order to represent it in d-q reference. The rotor flux linkage ψ_{dr}^{e} is constant in the d axis ,so the deferential of this component is zero($\frac{d\psi_{dr}^{e}}{dt}$)=0 .The resulted equations are Now substitute equation (5.4) in equation (5.6) in order to represent it in d-q reference. The rotor flux linkageψ_{dr}^{e} is constant in the d axis, so the deferential of this component is zero ($\frac{d\psi_{dr}^{e}}{dt}$)=0 .

Thus the stator current expression in d-axis attained as follows

$$i_{ds}^{e*} = \frac{\psi_{dr}^{e}}{L_m} + \frac{(k_u\Delta w_r - k_w{}^2 j\,\Delta w_r\Delta\psi_{qr}^{e}}{2L_m S_r} \quad (5.9)$$

5.3 Calculation of Summation torque

In order to find the weigh torque value, the torque of each motor must be determined and summed, they are represented as T_1 and T_2.The summation torque of the dual induction motor is given by T_s

$$T_s = T_1 + T_2$$
$$T_1 = \psi_{r1}^{e} * i_{s1}^{e}$$
$$T_2 = \psi_{r2}^{e} * i_{s2}^{e}$$
$$T_s = T_1 + T_2 = k_x(\psi_{r1}^{e} * i_{s1}^{e} + \psi_{r2}^{e} * i_{s2}^{e}) \quad (5.10)$$

Where,

$$k_x = 1.5n_p\,L_m/L_r \quad (5.11)$$

Now expanding equation (2.10) by Substituting equation (5.1) and (5.2), The summation torque is given in equation (5.12)

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$$T_s = k_x\left(\psi_r^e - (1-k_m)\Delta\psi_r^e\right) * \left(i_s^e - (1-k_m)\Delta i_s^e + k_x\left(\psi_r^e + k_m\Delta\psi_r^e\right) * \left(i_s^e + k_m\Delta i_s^e\right)\right) \quad (5.12)$$

$$\frac{T_s}{k_x} = 2\psi_{dr}^e i_{qs}^e + k_u\left(\Delta\psi_{dr}^e\Delta i_{qs}^e - \Delta i_{ds}^e\Delta\psi_{qr}^e\right) + k_w\left(\psi_{dr}^e\Delta i_{qs}^e + \Delta\psi_{dr}^e\Delta i_{qs}^e - i_{ds}^e\Delta\psi_{qr}^e\right) \quad (5.13)$$

The summing torque in the d-q frame is obtained by substituting equation (5.4) in the equation (5.12)

5.4 Calculation of reference current

The reference stator current expression in q-axis is obtained as follows

$$i_{qs}^{e*} = \frac{\frac{T_s}{k_x} - k_w\left(\psi_{dr}^e\Delta i_{qs}^e - i_{ds}^e\Delta\psi_{qr}^e\right) - k_u\left(\Delta\psi_{dr}^e\Delta i_{qs}^e - \Delta i_{ds}^e\Delta\psi_{qr}^e\right)}{2\psi_{dr}^e + k_w\Delta\psi_{dr}^e} \quad (5.$$

5.5 Weighed Value Calculations

5.5.1 Methods for weighed value calculation

The characteristics of dual induction motors fed by single inverter can be defined in two ways on the basis of the load applied to the machine.

1) Speed relevant system
2) Speed irrelevant system

5.5.1.1 Speed relevant system

In this system the speed of each motor is independent and determined by its own torque. The proportional relation of the components of these two motors will be similar thus it is enough to control the torque difference of the motors.

5.5.1.2 Speed irrelevant system

In this system the speed of each motor varies according to the unbalanced load applied to the motor. The slip with the speed of the motors is influenced by the differential torque of the motors.

5.5.2Calculation of the Weight value

The weight value $k_m$consists of two components say

1) Torque component k_{mt}
2) Speed componentk_{ms}

The components are calculated by the practical torque and speed obtained which are illustrated as

$$k_{mt} = \frac{T_1}{T_1 + T_2} \quad (5.15)$$

$$k_{ms} = k_{ms} + \text{sign}\,(k_{msd})d_p.k_{msd} \geq d_x$$
$$k_{ms} = k_{ms} - \text{sign}\,(k_{msd})d_n.k_{msd} < d_x \quad (5.16)$$

6. Results Using PI Controller

6.1 Simulation of speed control of dual IM using PI controller

The figure 6.1 depicts the simulation of vector speed control of dual induction motor implementing PI controller developed in the MATLAB.

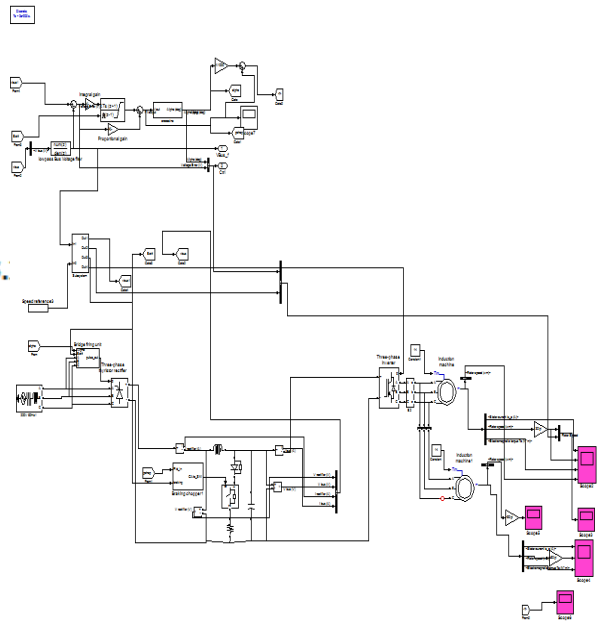

Figure 6.1: Simulation of Speed control of Dual Induction motor using PI controller

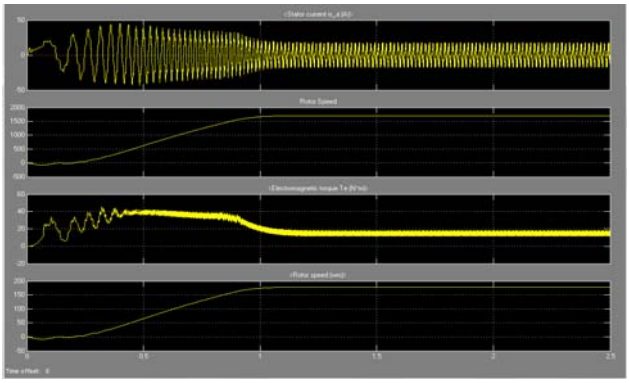

Figure 6.2: output graph obtained for motor 1

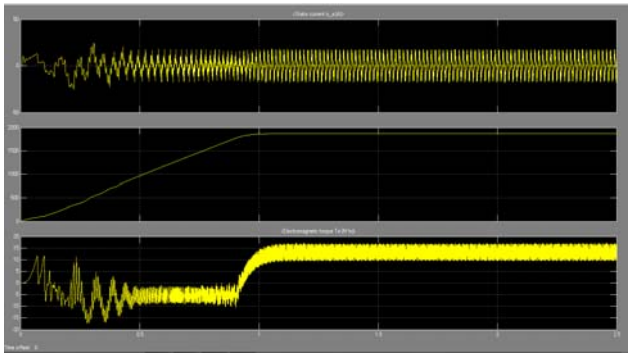

Figure 6.3: output graph obtained for motor 2

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7. Results Using Fuzzy Controller

7.1 Simulation of speed control of dual IM using fuzzy controller

The figure 7.1 depicts the simulation of vector speed control of dual induction motor implementing fuzzy controller developed in the MATLAB.

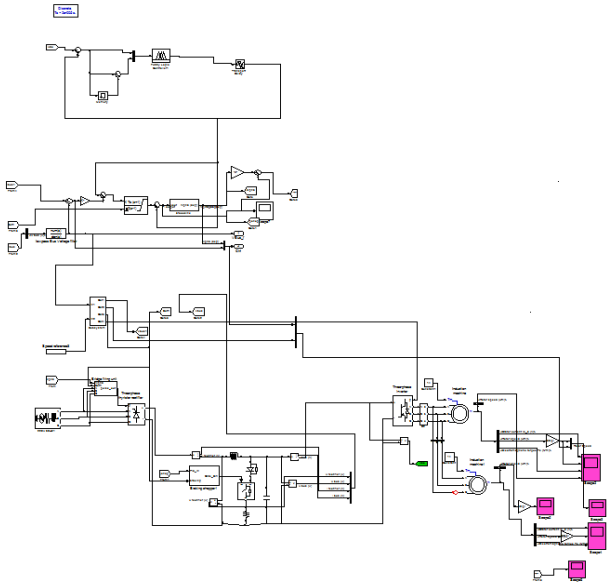

Figure 7.1: Simulation of Speed control of Dual Induction motor using fuzzy Controller

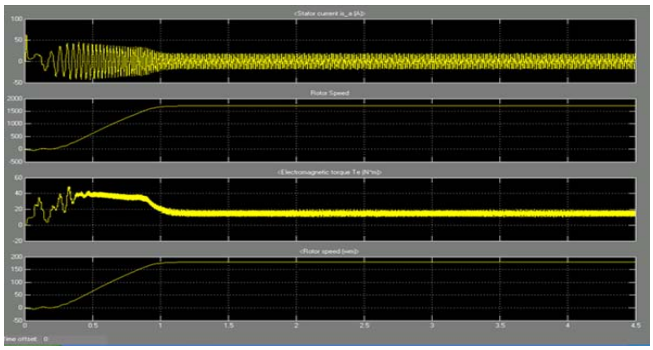

Figure 7.2: output graph obtained for motor 1

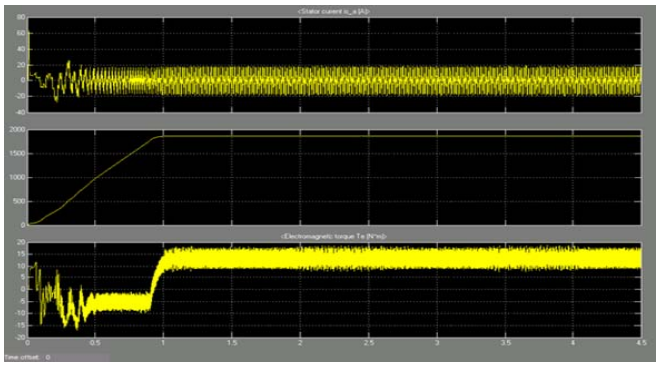

Figure 7.3: output graph obtained for motor 2

8. Inference

From the figure 6.2, 6.3 and figure 7.2, 7.3 it is clear that the starting torque is obtained well while using fuzzy controller and the harmonics is also considerably low.

9. Conclusion

In this project work, the weighed vector speed control of dual induction motor using fuzzy logic controller under unbalanced load condition is demonstrated. A frame work is developed for obtaining the weighed vector value. Modeling of induction motor is also presented.

A simulation is done in MATLAB to accomplish the weighed vector control of dual induction motor. The effectiveness of the system is analyzed through the graph achieved from the simulation. The result shows that the fuzzy logic controller is more effective than PI controller in controlling dual induction motor speed.

10. Future Scope

As a future work, the hardware of the project can be implemented and more advanced controller can be used instead of fuzzy controllers.

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