Performance of Three Phase Induction Motor of Direct Torque Control using Fuzzy Logic Controller

Ranjit Kumar Bindala 1 and Inderpreet Kaur 2
1PhD., Scholar Department of Electrical Engineering, Chandigarh University, Ghrauan Mohali, Punjab, India.
ranjit19782002@gmail.com
2Professor, Department of Electrical Engineering, Chandigarh University, Ghrauan Mohali, Punjab, India
inder_preet74@yahoo.com
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Abstract

Fuzzy logic controller is now days are becoming more popular in soft computing applications for improving the control technique in induction motor drives. Direct Torque control (DTC) method uses hexagonal path only when rated voltage is required at high speed. In this paper three phase Induction motor model is used with DTC and Fuzzy logic controller to control the speed and fluctuations in the torque of induction motor. The fuzzy logic controller is used to reduce the flux and torque ripples and improves the performance of DTC method at very low speed of induction motor. The simulated model is made in Matlab/Simulink software to check to the performance of the three phase induction motor model.

Key Words : Three phase Induction Motor model, Direct Torque Control, Voltage Source Inverter, Fuzzy logic controller.
1 Introduction

The three phase squirrel cage induction motors are almost world-wide extensively utilized in industrial applications [1-2]. There are some difficulties during its torque, flux or speed control of it. Now a day’s three phase squirrel cage induction motors are becoming more popular because of economical in cost, rugged construction, and easy to use, reliable and small size [3-4]. The three phase squirrel cage induction motors are available from few watts to megawatts as per the requirement.

In previous system the speed, torque or flux control of three phase squirrel cage induction motors are very complicated and difficult. In these techniques to control the above mentioned parameters the supply voltage is to vary by using auto transformer, supply frequency is varied with the help of cyclo converts and numbers of poles of the motor [5]. by utilizing these schemes speed, torque and flux control is available but upto certain limits for precise control these equipments becomes more costly, to overcome these drawbacks the new direct torque control schemes are proposed [6]. The direct torque control scheme was suggested by TAKAHASHI Depenbrock for the speed control of three phase squirrel cage induction motor [7-8]. Direct torque control scheme is popular because of the following points [6]:

• Fast dynamic torque response
• Robustness with respect to parameter variations
• Feedback system is not required
• Simple construction and low cost
• No need of external excitation

Despite benefits there are some causes like a highly slower response during start up and during a step change in torque and stator flux.
2 Material and Method

2.1 Voltage vector model for three phase squirrel-cage voltage source inverter output

The voltage source inverter consists of three phase supply with three parallel legs each leg consists of two switches which are able to work as eight possible stator voltage vectors. The torque and flux of three phase induction motor model is controlled by using hysteresis band within limits [1-2].

\[ V(t) = \frac{2}{3}[V_a(t) + ZV_b(t) + Z^2V_c(t)] \] (1)

Where
\[ Z = e^{j2/3\pi} \] (2)

\( V_a, V_b \) and \( V_c \) are the per phase instantaneous voltages. The equation (1) and (2) shows that equation (1) has 6 non-zero states and equation (2) has 2 null states. The phasor diagram of equation (1) and (2) shown in Figure 2.1 [9-10].

![Fig. 2.1: DTC with Space Vector](image)

The voltage space phasor using equation (1) along D-axis is \( V_d \).

\[ V(t) = \frac{2}{3}V_d[S_a(t) + ZS_b(t) + Z^2S_d(t)] \] (3)
2.2 Mathematical model of three phase induction motor model

The mathematical model of three phase induction motor when it is operated in both the states i.e. transient state as well as steady state [11-13]. The equilateral circuit is used to calculate torque flux, stator voltage, stator and rotor current etc. The stator voltage and stator current and flux equation are [12]:

Stator voltages equations are:

\[ V_{sa}(t) = R_s i_{sa}(t) + \frac{d}{dt}(\Psi_{sa}(t)) \] (4)
\[ V_{sc}(t) = R_s i_{sc}(t) + \frac{d}{dt}(\Psi_{sc}(t)) \] (5)
\[ V_{sc}(t) = R_s i_{sc}(t) + \frac{d}{dt}(\Psi_{sc}(t)) \] (6)

Rotor voltages equations are:

\[ V_{ra}(t) = R_r i_{ra}(t) + \frac{d}{dt}(\Psi_{ra}(t)) \] (7)
\[ V_{rb}(t) = R_r i_{rb}(t) + \frac{d}{dt}(\Psi_{rb}(t)) \] (8)
\[ V_{re}(t) = R_r i_{re}(t) + \frac{d}{dt}(\Psi_{rc}(t)) \] (9)

Converting to \(dq\) frame: The three-phase supply voltage is converted into two phases by using the given equations. Where \(V_{sa}, V_{sb}, V_{sc}\) are the three-phase stator voltages and \(V_{sd}\) is stator voltage direct axis and \(V_{sq}\) is stator voltage of quardature axis. \(i_{sa}, i_{sb}, i_{sc}\) and \(i_{sd}, i_{sq}\) are three stator and rotor currents respectively, while \(i_{sd}, i_{sq}\) and \(i_{rd}, i_{rq}\) are two phase stator currents and rotor currents respectively [14].

Flux equations are

\[ \Psi_{sd} = [V_{sd} - i_{sd} R_s]^\frac{1}{2} \] (10)
\[ \Psi_{sq} = [V_{sq} - i_{sq} R_s]^\frac{1}{2} \] (11)
\[ \Psi_{rd} = [\omega \Psi_{rq} - i_{rd} R_r]^\frac{1}{2} \] (12)
\[ \Psi_{rq} = [\omega \Psi_{rd} - i_{rd} R_r]^\frac{1}{2} \] (13)
Stator current equations are
\[ i_{sd} = \Psi_{sd} \frac{L_c}{L_X} - \Psi_{rd} \frac{L_m}{L_X} \] (14)
\[ i_{sq} = \Psi_{sq} \frac{L_c}{L_X} - \Psi_{rq} \frac{L_m}{L_X} \] (15)

Rotor Current Equations
\[ i_{rd} = \Psi_{rd} \frac{L_s}{L_X} - \Psi_{sd} \frac{L_m}{L_X} \] (16)
\[ i_{rq} = \Psi_{rq} \frac{L_s}{L_X} - \Psi_{sq} \frac{L_m}{L_X} \] (17)
\[ L_X = L_s L_r - L_m^2 \] (18)

3 Results and Discussion

3.1 Modeling of Three phase induction machine

The three phase induction machine consists of two main parts stator and rotor. Stator is the stationary part and rotor is the rotating part. The parameters of three phase induction motors are stator resistance, rotor resistance, stator reactance, rotor reactance, mutual and self inductance of the motor [15-16]. The equivalent circuit diagram with rating is shown in Figure 3.1.

Fig. 3.1: Equivalent circuit diagram of three phase induction motor

3.2 Principle Model of DTC

The DTC scheme consists of Voltage source inverter, six voltage phasors and two zero phasors to keep in sequence order, the stator
flux and torque with in limit of hysteresis band near the command is shown in figure 2.1. In fig. 1 the DTC space vector the switching positions of the voltage source inverter are shown out with similar voltage vectors based on the model of voltage source inverter shown in figure 3.2 [17,19]. In figure 3.2 the upper switches are shown by 1,3 and 5 and the lower switches are shown by 4,6 and 2.

![Switching model of voltage source inverter](image)

**Fig. 3.2: Switching model of voltage source inverter**

The basic block diagram of direct torque control scheme consist of supply voltage, voltage source inverter, switching table, hysteresis controller, flux and torque estimator, input flux, input torque and three phase induction motor with feedback arrangement as shown in Figure 3.3[18,20].
The block diagram of conventional DTC scheme that reference value of stator flux and stator torque is compared with actual values of three phase induction motor scheme and calculated errors are obtained [21].

### 3.3 Fuzzy Logic Controller with DTC

Fuzzy logic controller consist of three error input variables such as stator flux, electromagnetic torque and stator flux and one output known as voltage space vector. In this Fuzzy logic error is measured which shows the dissimilarity between stator flux with real value of stator flux. Fuzzy logic errors are measured in terms of negative, zero and positive [22, 26].

Electromagnetic torque error is comparison between actual torque and desired torque. Electromagnetic torque error is measured in term of gigantic positive, compact positive, gigantic negative, and compact negative. Flux linkage angle is the between stator flux with reference axis [23, 25]. Fuzzy logic controller using with DTC is shown in Figure 3.4[24].
The DTC using with Fuzzy logic consist of three input variables i.e. flux, electromagnetic torque and stator flux and one output known as voltage space vector. Fuzzy logic errors are measured in terms of negative, zero and positive. Electromagnetic torque error is difference between desired torque and real torque. Electromagnetic torque error is measured in terms of large positive, small positive and large [27, 28].

3.3.1 Working model of Fuzzy logic Controller with DTC

The fuzzy logic model consists of Fuzzy controller, Parks transformation, Inverter, Induction machine model and wind Turbine. In this model wind turbine is used as electrical power source to induction motor model, load angle and pitch is used to control the speed of the wind generator [29, 30]. The output of the wind generator is connected to induction motor machine model through gain. The speed and torque of the induction motor model is controlled when we compare the reference speed with actual speed. The fuzzy controller is used is of mamdani type. It consists of seven membership function. The proposed rules are different from others. To handle these rules I used NVB and PVS system [31-32].
Table 3.1: Fuzzy Rules [32]

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\[ e(k) = \omega_{ref} - \omega_r \] \hspace{1cm} (19)

\[ i = \frac{2}{3} P \frac{L_s}{L_m} \frac{1}{3} \frac{1}{\Psi_r} \] \hspace{1cm} (20)

\[ |\Psi_r| = \text{rotor flux} \]

\[ \Psi_{s\alpha} = \int (V_s - R_s I_{s\alpha})dt \] \hspace{1cm} (21)

\[ \Psi_{s\beta} = \int (V_s - R_s I_{s\beta})dt \] \hspace{1cm} (22)

\[ T_e = \frac{2}{3} P \frac{L_s}{L_m} (\Psi_{s\alpha} I_{s\beta} - \Psi_{s\beta} I_{s\alpha}) \] \hspace{1cm} (23)

\[ T = T_e - T_L = \frac{P}{2} (J \frac{d\omega_r}{dt} + B\omega_r) \] \hspace{1cm} (24)

Fig. 3.5: Membership functions of inputs variables
As proposed model speed, rise time, settling time, transient time and torque ripples has been controlled using Fuzzy logic controller.

4 Simulation Analysis

Fig. 3.6: Membership functions of output variables

As proposed model speed, rise time, settling time, transient time and torque ripples has been controlled using Fuzzy logic controller.

4 Simulation Analysis

Fig. 3.7: Simulink model of DTC with Fuzzy Logic controller

Fig. 4.1: Stator flux trajectory path response DTC with FLC
The Parameters of three phase induction motor model is as under
- Resistance of Rotor in Ohm is 0.39.
- Resistance of Stator in Ohm is 0.19.
- Inductance of Stator in Henry is 0.00021.
- Inductance of Rotor in Henry is 0.0006.
- Mutual inductance in Henry is 0.0004.
- Numbers of Poles = 4
- Moment of inertia (Kgm$^2$) = 0.0226
- Base speed =1400rpm

5 Conclusion

In this paper propose the DTC technique for the control of speed and fluctuations of an induction motor. we offered the direct torque control technique integration with fuzzy logic controller. Moreover, this technique is used to control the speed and torque fluctuations of induction motor by reducing the torque ripples. Furthermore, the simulation results justify that by using Fuzzy logic controller coordination with DTC the speed, fluctuations are controlled and torque ripples are also reduced. The simulation and experimental results have been verified by using MATLAB software.

Appendix:

List of Symbols
- a, b, c: for A, B, C phase sequence components respectively
ac: alternating current
d: for direct axis components
q: for quadrature axis components
em: for electromagnetic (e.g. Tem = electromagnetic torque)
Hz: hertz
I: current in Amperes
J: moment of inertia
Kgm²: kilogram per meter square
L: inductance in Henry
Ls: leakage inductance of stator
Lr: leakage inductance of rotor
Lm: mutual leakage inductance
H: hennery
N: speed in rpm
0: for zero sequence components
Ψ: flux in Weber
P: number of poles
q: for quadrature axis components
r: for rotor quantities
R: resistance in ohms
Rr: rotor resistance
Rs: stator resistance
s: for stator quantities
t: time in seconds
T: torque in Newton meter
Tm: maximum torque
V: voltage in Volts
ω: angular speed in radians/seconds
X: reactance in ohms
Z: impedance in Ohms
θ: phase angle in radians
ψ: phase
∆: little change
P: positive function
N: negative function
M: membership function
Z: zero function
References


