

FAULT DETECTION FOR THREE PHASE INDUCTION MOTOR DRIVES USING FUZZY LOGIC

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Abstract: For monitoring the induction motor in industries is essential need and also difficult one. To monitor the Direct Torque Control (DTC) based induction motor condition using artificial intelligence such as fuzzy logic is the proposed work. In this paper, the mathematical modeling of three phase induction motor drives using DTC strategy which is fed by three phase voltage source inverter. In industries, it is necessary to monitor the induction machines all the time and for fault occurring in machine, it is substantial to recognize and analysis of that corresponding fault within the short interval of time. Hence DTC of induction motor is modelled and various fault disputes of induction motor is obtainable by one of the non-linear scheme of fuzzy based detection system using MATLAB/SIMULINK. The soft computing based technique is applied as an identifier for different faults. The fuzzy input is carried over by sensing three phase stator currents and applied as input to the intelligence systems. The fault detection or decision making for suitable corrective action is made by an important parameter according to the fault occurs.

Keywords: Fuzzy Logic, Direct torque control, Induction motor drive, Motor Condition.

1. Introduction

In many industries induction motors are used for the reason that of their features such as low cost and intrinsic roughness. Application similar to speed adjustable drives is used broadly. An induction motors are used in constant speed applications in early days for the reason that the other speed control methods are highly cost and ineffective. These speed control methods are used to avoid the motor failure and to prevent damage quickly. [1] Though Induction motor drives are consistent, they are susceptible to various faults. These faults cause shutdowns of protection, caustic and harmful. Hence these faults are needed to detect as quick as possible to avoid the damage of the machine and to avoid unpredicted production costs. The various fault may occurred in an induction motor where the machine may fail when the fault happens for

a certain period of time. And the smaller faults happens for a certain period of time may also interrupt the machine completely. Consequently to improve the monitoring conditions of the detection system, the time is taken into an account for the extra input. The various faults are occurred in both stator and rotor side of the induction motor which causes

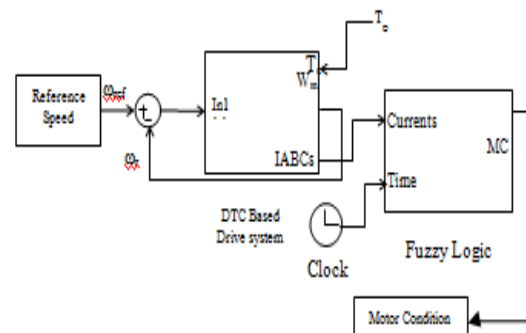


Figure 1. Block Diagram of Fault detection and diagnosis by using fuzzy logic

Noise, vibrations, heating, oscillations which decreases the motor efficiency[2] [3].

The output results of intelligent based DTC induction motor drive is deliberated for both normal and various fault condition such as short circuit, open circuit, under voltage, over voltage, etc. According to the flux and torque estimation from the load, the performance is analyzed by in view of the DTC drives operation and corresponding gate pulses are established. In such case, the direct control is achieved on the given condition below i.e., the corresponding change in flux is directly proportional to the corresponding voltage change where the variations in torque origins the angle variations among the stator and rotor flux.

Perfect fault detecting scheme has low false alarm rates. If the fault detecting probability of the given scheme is poor, then the faults causes the machine failures and breakdown of entire systems. A fault detecting scheme is very much tactful then it is easier

to produces high rates of false alarms which brings out wrong decision made by the system. Hence an intelligent system based fault detecting scheme is obtained in this paper and the inputs are considered as the stator currents and time and motor output condition is considered as outputs for intelligent system fuzzy logic to check the machine and monitoring the arising of fault regularly which is given in Fig.1[4].

2. Direct Torque Control of Induction Motor

The voltage modulation and the current control loops are not necessary for DTC which has a simple structure and there is no coordinate transformation. DTC has good torque and flux performance [5]. This section consists of four blocks such as A) torque and flux estimation B) space vectors C) hysteresis controller for flux and torque D) sector determination. The disadvantages of DTC technique is variations in switching frequency, less operating speed and more ripples in torque. The following methods are calculation of DTC:

A. Torque and Flux Estimation

The mathematical representation of the direct axis flux linkage, quadrature axis flux linkage, phase angle and torque equations as follows [6]

$$F_d = \int (V_d - R_s I_d) dt \quad (1)$$

$$F_q = \int (V_q - R_s I_q) dt \quad (2)$$

$$F = \sqrt{F_d^2 + F_q^2}, \text{ Phase angle} = \tan^{-1} \left(\frac{F_q}{F_d} \right) \quad (3)$$

$$T_e = \frac{3}{2} (F_{ds} i_{qs} - F_{qs} i_{ds}) \quad (4)$$

DTC has two hysteresis comparators in its classical model, one act as a torque controller and second act as a stator flux controller. A classical block of DTC is shown in Fig. 2 [7].

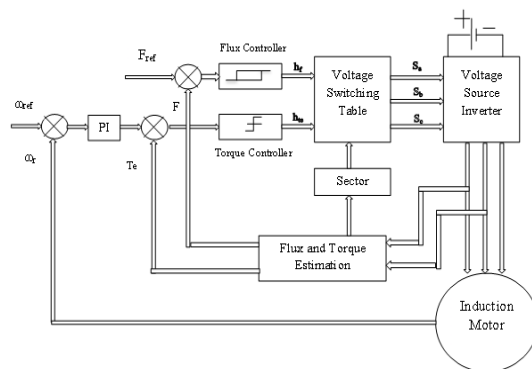


Figure 2. Block diagram of DTC based Induction motor Drive

B. Space Vectors

In reference of stator flux, when the voltage vector is drifted with an angle which is not above 90 degree results to increase in flux[8]. The torque generated is measured within the inverter states between high stator flux to low.

$$V_a = \frac{V_{dc}}{3} (2S_a - S_b - S_c) \quad (5)$$

$$V_b = \frac{V_{dc}}{3} (-S_a + 2S_b - S_c) \quad (6)$$

$$V_c = \frac{V_{dc}}{3} (-S_a - S_b + 2S_c) \quad (7)$$

C. Hysteresis Controller for Torque and Flux

From the estimated value, the reference torque and flux are equated. The reference value of torque is given by h_{Te} and the reference value of flux linkage is given by θ . This controller has maximum and minimum values i.e 0 and 1 which is the digital output. The real output is above the given reference value and it is getting beyond the limit of hysteresis then the output is zero. The real output is below the given reference value and it is getting beyond the limit of hysteresis then the output is one.

The hysteresis band limits for the flux are specified in Eqs. (8) and (9) and the hysteresis bands for the three specified condition is given by Eqs. (10)–(12). [9].

$$h_f = 0 \text{ for } F < F_{ref} + h_f \quad (8)$$

$$h_f = 1 \text{ for } F < F_{ref} - h_f \quad (9)$$

$$h_{Te} = 1 \text{ for } T_e < T_{ref} - h_{Te} \quad (10)$$

$$T_{err} = 0 \text{ for } T_e = T_{ref} \quad (11)$$

$$h_{Te} = -1 \text{ for } T_e < T_{ref} + h_{Te} \quad (12)$$

D. Sector Determination

The vector has separated into six regions and each sector occupies 60 degree. The sector determination is precised in Table I. The diagram of sector determination using MATLAB Simulink is shown in Fig. 3.

Table 1. Sector Determination

sector	1	2	3	4	5	6
θ	$-30 \leq \theta < 30$	$30 \leq \theta < 90$	$90 \leq \theta < 150$	$150 \leq \theta < 210$	$210 \leq \theta < 270$	$270 \leq \theta < 330$

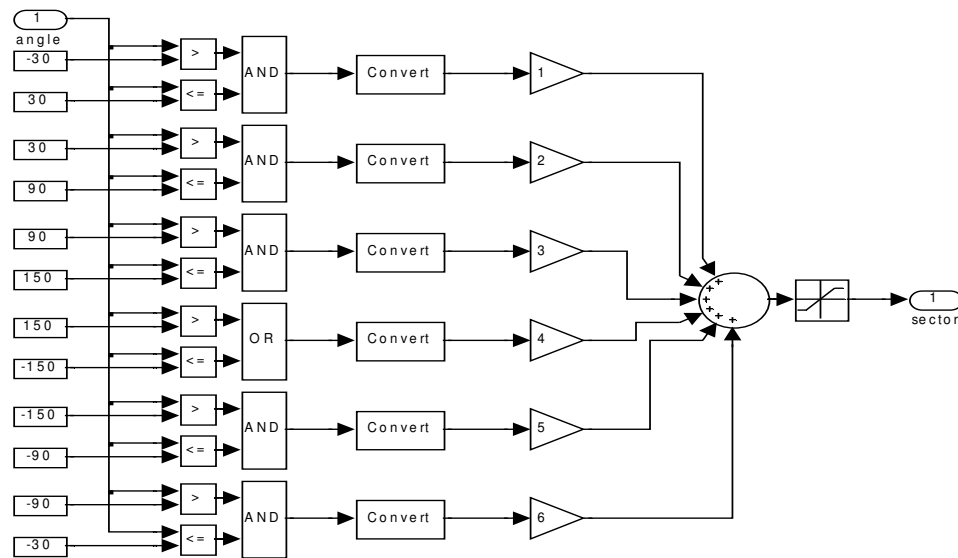


Figure 3. Simulink block diagram of sector determination.

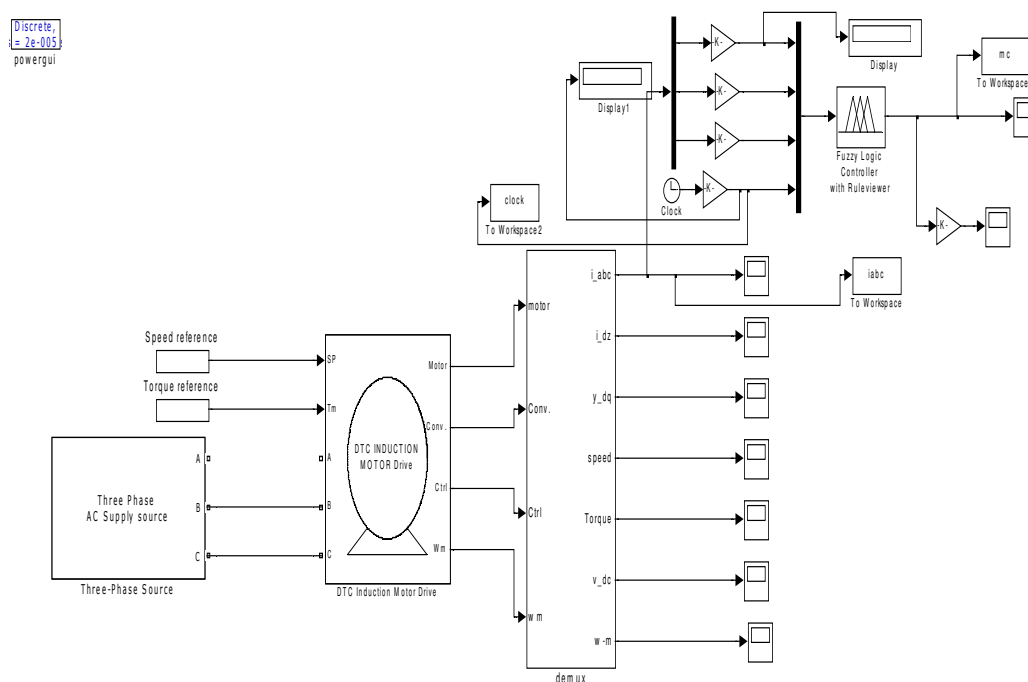


Figure 4. Simulation diagram of fuzzy based fault detection of DTC

3. DTC Drive System Simulation Results

Fig. 4 shows the fault detection of DTC induction motor drive using intelligence technique such as fuzzy logic. Fig. 5 shows stator dq reference frame for the stator currents components. Fig.6 shows stator dq

reference frame for stator flux components which has phase shift of 90 degree. Fig.7. shows flux at 0.4 wb reference value. From the obtained result, Transients has arisen within 0.2 seconds. Fig.8. shows the flux trajectory at the same reference value 0.4 wb.

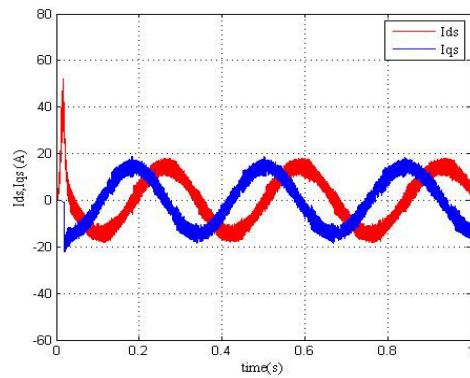


Figure 5. Simulation response Stator current components in stator reference frame.

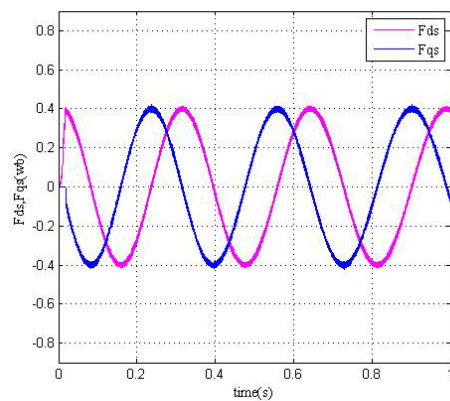


Figure 6. Simulation response Stator Flux Components (F_{ds} and F_{qs})

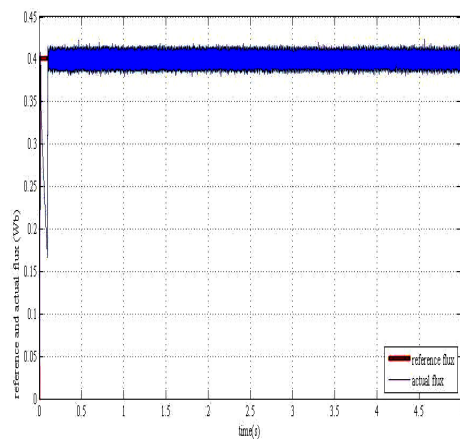


Figure 7. Simulation response Actual flux at reference value = 0.4 Wb

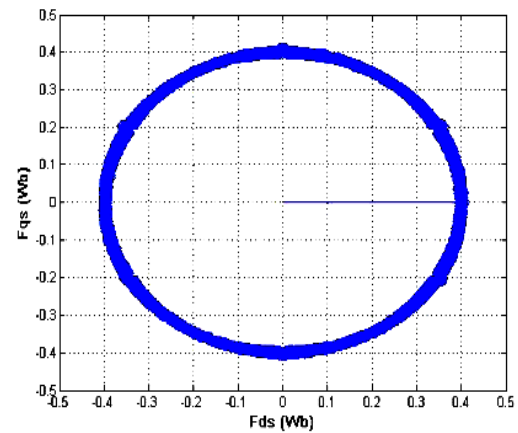


Figure 8. Simulation response Flux trajectory (F_{ds} , F_{qs}) at reference value = 0.4 Wb

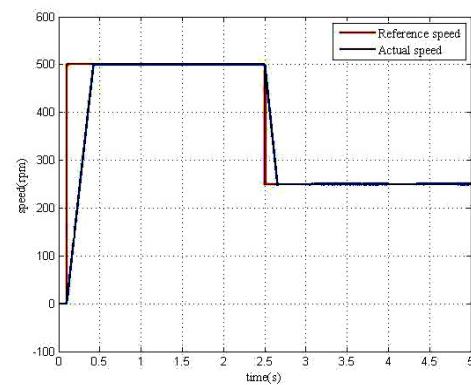


Figure 9. Simulation response speed response for 500 rpm.

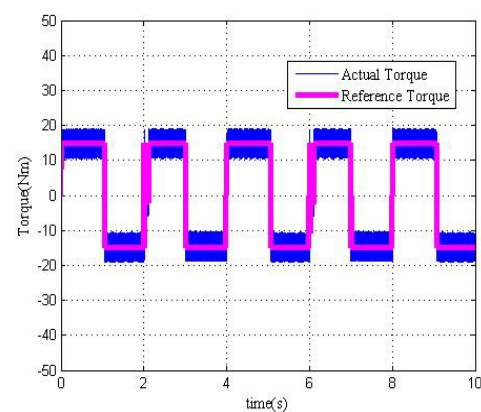


Figure 10. Simulation response Actual torque and reference torque from 15 to -15 N m.

The response for the speed parameter of the DTC Drive system is set in Fig.9. When the reference torque is between 15 to -15 Nm, the actual torque is given in Fig.10.

4. Proposed Fault Detector Fuzzy Modeling System for Induction Motor Drive

An intelligent technique which helps to detect faults in induction motor is fuzzy logic [10]. Fuzzy logic is substantial of human intelligent and decision is made by imprecise evidence which is based upon natural language. The fuzzy has both input and output variables. In this model, the input variables to fuzzy are the stator current (I_a , I_b , I_c) and time. For the fault detection, the motor condition (MC) is considered as output variable. The membership functions of input and output are shown in Fig.11 [11].

The input variable as stator current under normal condition and fault condition are taken from the DTC induction motor drive performance. The fuzzy scheme has the good control for non-linear systems and the induction motor fault is considered as non-linear hence the mamdani method used for the detection. The membership function is formed by the input current is taken as Small, Medium, Big and input time is taken as short duration and long duration and output is framed by motor condition which is able to monitor the faults in induction motor. From the given fuzzy database the Fuzzification is formed and in Fuzzy inference engine, fuzzy IF-THEN rules are enclosed with the minimum operator AND. Based upon these rules, the inputs are processed and generated its actual output based on motor condition membership function. To obtain the motor condition, a suitable defuzzification method is delivered and it is given in Table II. [12].

Table 2. Identification Results Using Fuzzy Logic

Motor Condition	Range
Seriously Damaged	0-30
Damaged	25-75
Good	70-100

To monitor the machine, above 50 rules are enclosed and to decide the motor condition, the few rules are given below which is shown in Fig.12.

- ✓ If (I_a is S) and (I_b is S) and (I_c is M) and (time is Sd) then (MC is G).
- ✓ If (I_a is S) and (I_b is M) and (I_c is M) and (time is Ld) then (MC is D).
- ✓ If (I_a is M) and (I_b is S) and (I_c is M) and (time is Ld) then (MC is D).
- ✓ If (I_a is M) and (I_b is M) and (I_c is M) then (MC is G).
- ✓ If (I_a is S) and (I_b is S) and (I_c is S) then (MC is G).

- ✓ If (I_a is S) and (I_b is M) and (I_c is S) and (time is Ld) then (MC is D).
- ✓ If (I_a is S) and (I_b is S) and (I_c is M) and (time is Sd) then (MC is G).
- ✓ If (I_a is S) and (I_b is M) and (I_c is M) and (time is Ld) then (MC is D).

The faults are categorized based on motor condition is Major Faults like Open Phase, Broken Rotor Bar, Critically Damaged Fault like Over Voltage, Moderate Faults like Unbalanced Voltage, Under Voltage, Ground, Turn-To-Turn, Minor Faults like Over Load, Bearing and Good motor for healthy condition[13].

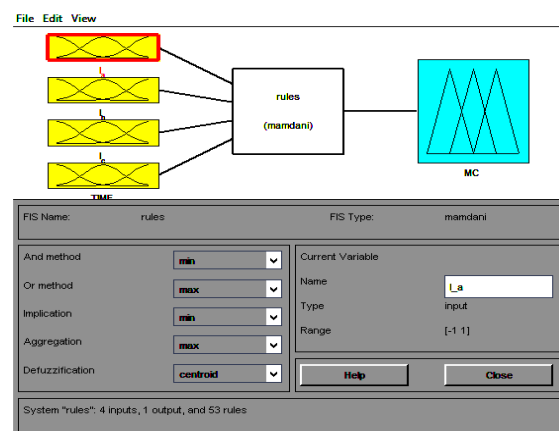


Figure 11. Fuzzy input and output membership functions

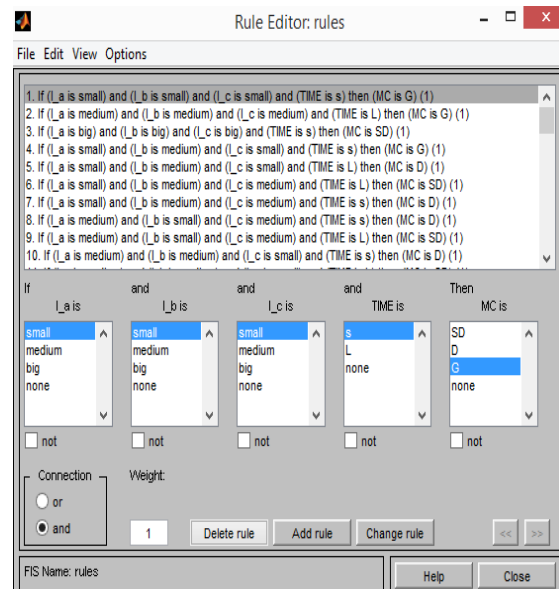


Figure 12. Fuzzy Rules for Fault Detection

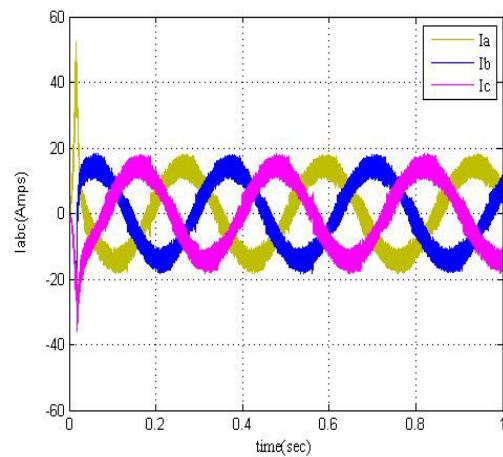


Figure 13. Simulation response Stator current response under normal condition

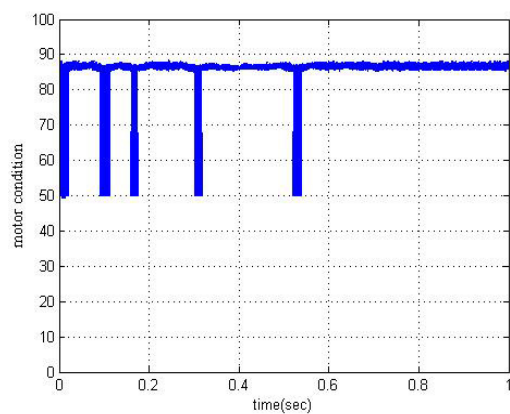


Figure 14. Simulation response Motor condition under normal case

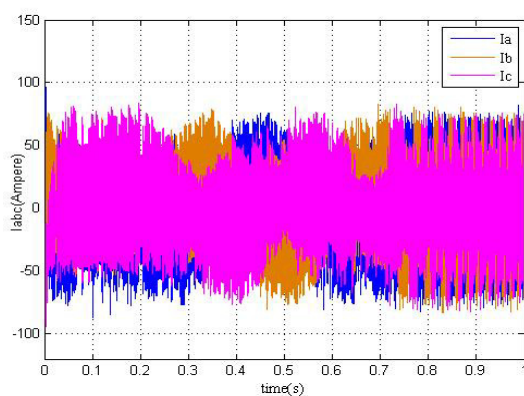


Figure 15. Simulation response Stator current response under overvoltage condition

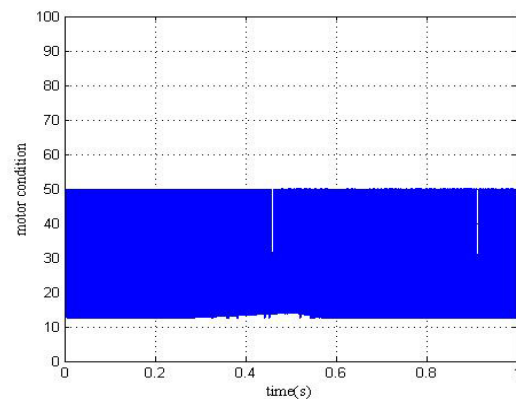


Figure 16. Simulation response Motor condition under over voltage

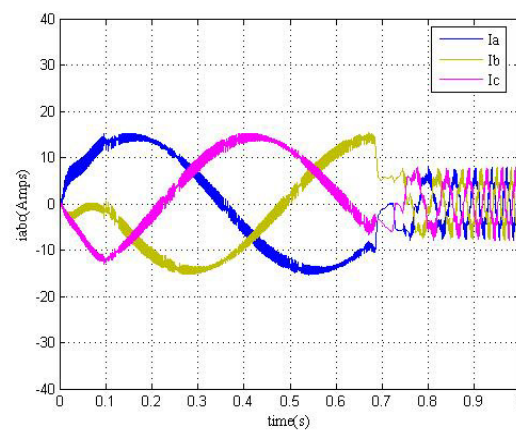


Figure 17. Simulation response Stator current response under voltage condition

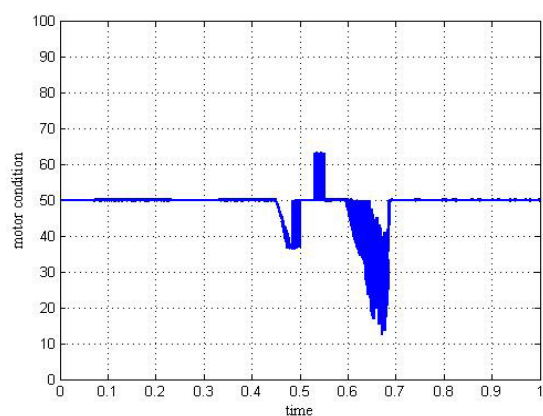


Figure 18. Motor condition during under voltage

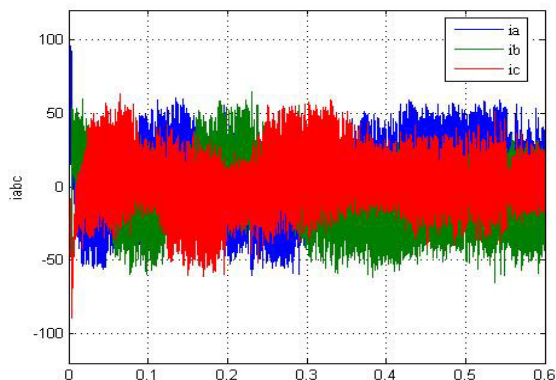


Figure 19. Simulation response Stator current response under open circuit condition

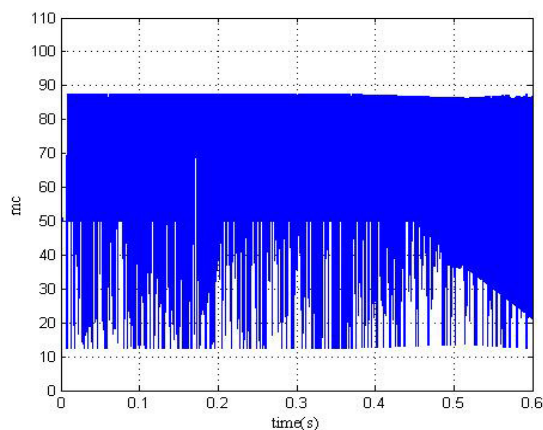


Figure 20. Simulation response Motor condition under open circuit

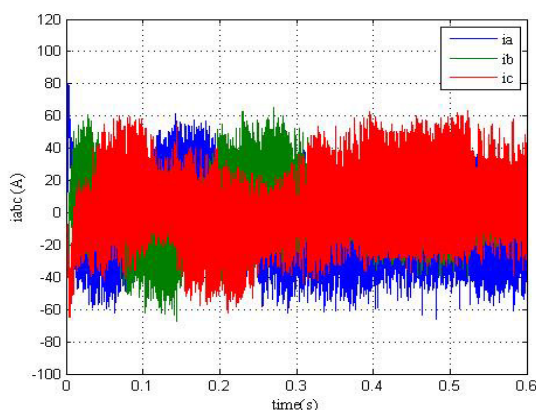


Figure 21. Simulation response Stator current response under short circuit condition

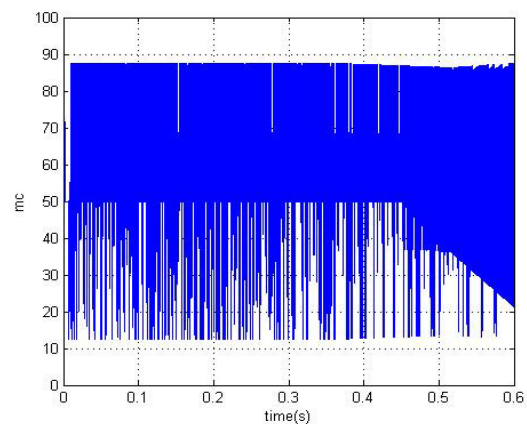


Figure 22. Simulation response Motor condition under short circuit

At initial state, when the DTC drive carries load, it started to rise the current value and under the normal operation it retains its current value to the rated value which is shown in Fig.13. Since the DTC drives controllers are used, transients will occur. Under normal working condition of motor, the actual stator current is shown in Fig.14. The actual obtained current is examined with rated current to describe the motor condition and the duration of the actual current is measured which is related to FIS. After defuzzification, the output found for normal working condition is 87%.

Initially, at the starting stage of the motor when the voltage applied, the current go beyond the rated value which increase its value to 90 amps and causes severe damage to the machine and it is shown in Fig 15. The current go beyond the rated value when occurring of overvoltage fault. If it continues for the certain time long then the motor condition in intelligent system is measured as seriously damaged which has the output as 10-50% as given in Fig.16. When the given voltage is lesser than the rated value, it may origins the damage to the machine because of the decreased current value 10amps delivered to the drive is given in Fig.17. The actual output current is very less than the rated current value when occurring of under voltage fault and it continues for certain time then the motor condition of intelligent system is damaged with output value as 12-50% as given in Fig 18.

The motor runs only in two phases if any one of the phase voltage has detached from the system which go beyond the rated value and origin the value of current is increasing to 90 amps which leads to damage the machine which is plotted in Fig 19. The actual output current goes beyond the rated value for the case of two phase condition and it continues for certain time period then the motor condition is injured with a defuzzified value as 10-80% as plotted in Fig 20. When

short circuit fault occurs, the system goes beyond the rated value which increases the current to 60 amps and causes the damage to the machine is plotted in Fig.21. When the current go beyond the three times rated value for short circuit fault, it continues for certain time period then the motor condition is damaged with a defuzzified value as 10-90% is plotted in Fig 22.

5. Conclusion

The intelligent fault control based DTC of induction motor and many fault issues have been discussed in this paper. A fuzzy signifying frame has been proved as the effective method for both detection and analysis. The fuzzy identifier is familiar as contributions of the stator currents and the time. An important parameter for identify and diagnosis for the various types of faults is Time in seconds. The proposed frame may be associated with, like Electric Vehicle and Sub-Way Metro as a portion of identifying the frame in the driver cabinet. This proposed frame can be linked in some recognition engine drive frame consequent to sustenance the model with the rated streams and drive frame nameplate information. In upcoming diagnosis, various major faults like rotor bar fault and stator current fault will be deliberate using various intelligent technique like artificial neural networks.

References

- [1] Thorsen, O.V., Dalva, M., 1999. Failure identification and analysis for high-voltage induction motors in the petrochemical industry. *IEEE Trans.Ind. Appl.* 35 (4), 810–818.
- [2] Sivakotaiah, S., 2009. Fault detection of induction motor by fuzzy logic algorithm. In: 10th National Conference on Technological Trends (NCTT09), 6–7 November.
- [3] Ali. M. Bazzi, Alejandro Dominguez-Garcia, and Philip T. Krein, "Markov Reliability Modeling for Induction Motor Drives Under Field-Oriented Control," *IEEE Trans. Power Electron.*, Vol, No. 2, feb 2012.
- [4] Shorouk ossama Ibrahim, Khaled Nagdy Faris, Esam abo Elzahab, "Implementation of fuzzy modeling system for fault detection and diagnosis in three phase induction motor drive system", *Journal of Electrical systems and Information technology* 2, PP 27-46, 2015.
- [5] Abdul Wahab, H.F., Sanusi, H., 2008. Simulink model of direct torque control of induction machine. *Am. J. Appl. Sci.* 5 (8), 1083–1090.
- [6] Ansari, A., Deshpande, D., 2010. Mathematical model of asynchronous machine in MATLAB Simulink.
- [7] P. C Krause and C. H Thomas, "Simulation of Symmetrical Induction Machinery" *IEEE Trans., Power Apparatus and Systems* Vol. PAS-84, No. 11, 1965
- [8] Gaeid, K.S., Ping, H.W., Mohamed, H.A.F., 2009. Simulink representation of induction motor reference frames, 1–4.
- [9] Andrzej M. Trzynadlowski, "Control of Induction motor", Academic press publication.
- [10] Sundararaju, K., and R. Senthil Kumar. "Modelling and analysis of relative power system with cascaded multilevel inverter STATCOM using fuzzy controller." *Journal of advances in chemistry* 12.10 (2016).
- [11] Saravana Kumar, R., Ray, K.K., 2009. Fuzzy logic based fault detection in induction machines using Lab view. *Int. J. Comput. Sci. Netw. Secur.* 9(9).
- [12] Chow, M.Y., et al., 1998. Intelligent motor fault detection. In: Jain, L.C. (Ed.), *Intelligent Techniques in Industry*. CRC Press.
- [13] Shuraiji, A.L., 2010. Stator fault diagnosis of single phase induction motors using fuzzy logic system. *Eng. Technol. J.* 28 (21).
- [14] T. Padmapriya and V. Saminadan, "Inter-cell Load Balancing Technique for Multi- class Traffic in MIMO - LTE - A Networks", *International Conference on Advanced Computer Science and Information Technology*, Singapore, vol.3, no.8, July 2015.
- [15] S.V.Manikanthan & K.srividhya "An Android based secure access control using ARM and cloud computing", Published in: *Electronics and Communication Systems (ICECS)*, 2015 2nd International Conference on 26-27 Feb, 2015, Publisher:IEEE, DOI:10.1109/ECS.2015.7124833.

