Modelling & Condition Monitoring of 3ϕ Induction Motor using Fuzzy Logic

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Abstract - *3-ϕ Induction motor is commonly used in electrical drive motor in most of industries. During the operation on filed these motors can give various different faults. If these faults occur in 3-ϕInduction motor, then the drive and its application need to be stopped for its repairs. Cost of maintenance and time required can be significant therefore it is desire to improve fault diagnostic techniques. The on-line condition monitoring observes the live working condition of these motor during its working and identifies the faults which will reduce maintenance cost and time lost during maintenance. The paper presents a MATLAB model of 3-ϕInduction Motor is prepared using Fuzzy logic based model to monitor the performance for short circuit, open circuit, overvoltage.*

***Key Words*: 3-ϕ Induction Motor, Condition monitoring, Fuzzy logic, MATLAB.**

1. INTRODUCTION

3ϕInduction motors is widely used as an industrial drive motor which consumes a major part of overall electrical consumption. Fault detection has in it is turned out to be important especially when they are operated in various automated production lines. Industrial operators are continuously intended to reduce the maintenance cost and unexpected downtimes that can lead to financial loss in industry. The current industries are generally utilized condition-based maintenance strategies to reduce failures and downtime. Most of the faults occur in the stator winding of motor, which makes it necessary to identify these faults in time as it can cause failure in the machine.

2. Various type of faults in 3-ϕInduction Motor

3-ϕInduction motor is the most common machine that is used in manufacturing industries. These motors are reliable, highly efficient and can be used to drive almost any kind of load however they are subjected to various types of fault. These faults can be mainly divided into two parts: A) Electrical faults &B) Mechanical faults.

A) Electrical fault

The following electrical faults are very common in three phase 3-ϕInduction motor while operating in industries.

a) Rotor fault

In manufacturing industries low lower rating machines are manufactured by die casting techniques and high rating machines are manufactured with copper rotor bar. Due to technological difficulties motor show some asymmetries in the rotor that can result in the rotor failures.

b) Turn-turn fault

About 40% of faults in 3-ϕInduction motor take place in the stator winding. Large portion of stator related failures are initiated by insulation. This fault results in unbalanced stator current. The different organic insulating materials used in insulations are subjected to aging deterioration from a combination of thermal overloading and cycling, mechanical stresses etc

c) Breakage of stator winding conductor

When this fault occurs, stator current becomes completely unbalanced. This may damage insulation completely. It also results in negative sequence current in both stator and rotor windings.

d) Input voltage unbalance

This fault also results in unbalances stator current. It also results in negative sequence current in both stator and rotor windings.

e) Open phase fault

In this fault one phase is open circuited and winding is supplied with single phasing condition. The motor continues to operate but protection must be provided against such open phase faults.

B) Mechanical Fault

Following are the mechanical faults that are common in three phase 3-**ϕ**Induction motor while operating in industries-

a) Air gap Eccentricity

Air gap eccentricity produces the problem of vibration. When the rotor is not aligned with the stator boar it causes an unbalance magnetic pull. This cause stator and rotor to rub against each other that can damage their winding.

b) Bearing fault

In motor the bearing consist of two rings, inner and the outer rings. A set of rolling elements are placed in between the two rings. A continued stress on the bearings can result in rough running of the bearings which generates vibration and noise.

c) Load fault

3-**ϕ**Induction motor when used in robust environment they undergoes to various conditions like overload, undesirable stressed, etc which put the motors under risk of faults or failures. Hence reliability of motors is need to improve due to significant positions in applications.

3. Fuzzy Control

In the motor fault diagnosis process, time domain current signals are captured from current sensors. The expert system for diagnosis then uses both time domain and frequency domain signals to study condition of motor and locate what faults are present. Experienced engineers are often required to interpret measurement data that are frequently inconclusive. A Fuzzy Logic (FL) approach may help to diagnose IM faults. FL is reminiscent of human thinking process enabling decisions to be judged on vague information. FL allows items to be described with certain membership degree in a set. For fault diagnosis, there are many situations in which a system is not "Good" or "Damaged", but may fall into some internal range. According to the fact that IM condition analysis is a fuzzy concept, the motor condition is described using linguistic variables. Fuzzy subsets and the respective membership functions represent stator current amplitudes. A knowledge base, comprising rule base is built to support the fuzzy inference. The IM condition is diagnosed using a compositional rule of fuzzy inference. The obtained results indicate that the proposed FL approach is capable of highly accurate diagnosis. Humans express knowledge (like an electrical machine referred as "somewhat secure", "little overloaded"). This linguistic input can be represented by a fuzzy system. The internal structure of fuzzy controller is shown in fig 1. Stator current signature contains potential fault information. Fuzzy systems rely on a set of rules.

$$= \{ \mu \ (\ ) \ \Sigma \},= \{ \mu \ () \ \Sigma \}, = \{ \mu \ () \ \Sigma \} \ CM = \{ \mu(c) \ \Sigma \ C \} (1)$$

These rules, with the fuzzy input, i.e. like the natural way that where Iaj, Ibj, Icj and CM are elements of the discrete universe of discourse I_a, I_b, I_c and CM, the optimized rule base has been developed so as to cover all the healthy and the faulty conditions of the motor

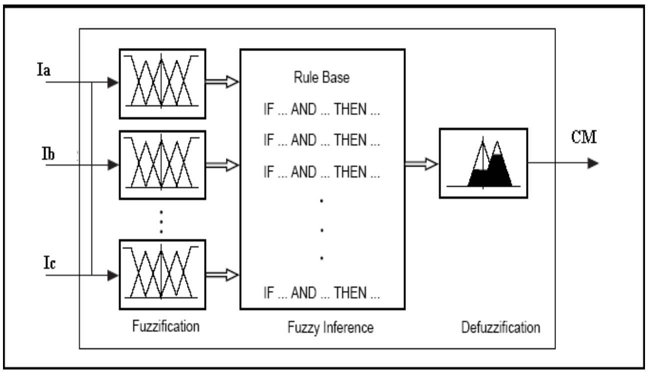

Fig.1. Internal structure of Fuzzy Controller

In this case the I_a, I_b, and I_c are input variables to the fuzzy system. The stator condition, CM is chosen as output variable. All the inputs and outputs are defined by fuzzy set theory. The input variables are interpreted as linguistic variables, with Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Medium (PM). Similarly the output variable stator condition (CM) is interpreted as linguistic variables, with Good, Damaged, and Seriously Damaged.

Membership functions and fuzzy rules are constructed by observing the data set.

There are 31 if-then rules used with the membership function for input and output variables are shown in fig 2 and fig 3 respectively.

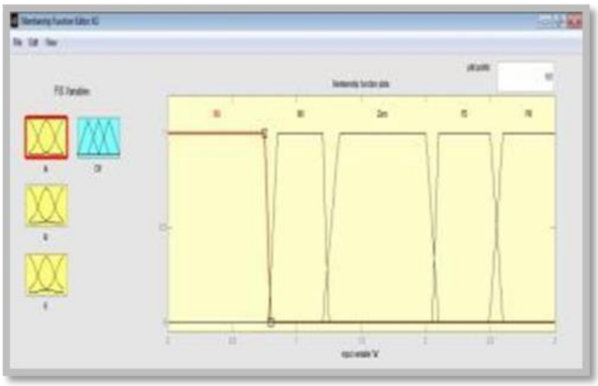

Fig. 2. Fuzzy membership functions for stator currents

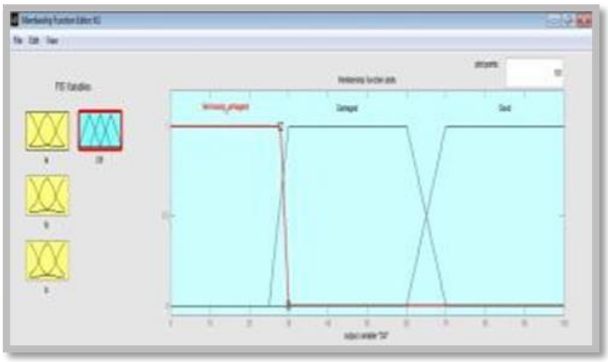

Fig. 3. Fuzzy membership functions for condition of motor Rule Base: SD: Seriously Damaged: Good

Defuzzification is defined as the conversion of fuzzy output to crisp output. There are many types of defuzzification methods available. Here we used Center of Area (COA) method for defuzzification. Despite its complexity it is more popularly used because, if the areas of two or more contributing rules overlap, the overlapping area is counted only once.

Output of FL Controller:

1) Good-70 to100

2) Damaged-30 To 70

3) Seriously Damaged-0 To30

The output of the fuzzy controller is used as the command signal for the closed loop operations. If the fuzzy controller output is good, then the program goes for next set of data to be acquired. Meanwhile if the operator wants, the data like three phase current, three phase voltage, frequency of input voltage, power factor, total harmonic distortion of both the current and voltage and the state of the motor can be stored in a file.

If any incipient faults are slight voltage unbalance occurs, then the output of the fuzzy controller will go Damaged. Immediately the fault data and the current spectrum are stored in a file for analysis purpose with time as long as fault persists. At the same time a warning indication will be given to the operator, and a beep sound will be generated at the central processing unit of the computer to alert the operator at the shop as well as the control room engineer. The front panel of the monitoring system will also display the possible cause for the damaged state of the motor. The instantaneous current and voltage waveforms and the spectrum of the current can be stored as a HTML file to find the root cause of the fault

For the severe faults such as open phase, open coil, single line to ground short and line to line to short, the fuzzy controller output will be seriously damaged. In this state the machine should not be allowed to operate any further. Whenever the fuzzy controller output goes seriously damaged, the machine will be isolated from the supply and the instantaneous fault data are stored, also the front panel of the monitoring system will display the possible cause seriously damaged state of the motor. After performing the above said operations the program will be stopped.

4. Model and Simulation using MATLAB / Simulink

Induction Motor Stator Fault Detection and Health Monitoring Using Fuzzy Logic:

The implementation of the stationary reference abc model of a three-phase IM using Simulink, using the equations listed in the previous section has been given. Fig 4 shows complete simulation block diagram of the IM in the stationary three phase reference frame. The details of the subsystems in the main blocks are also given.

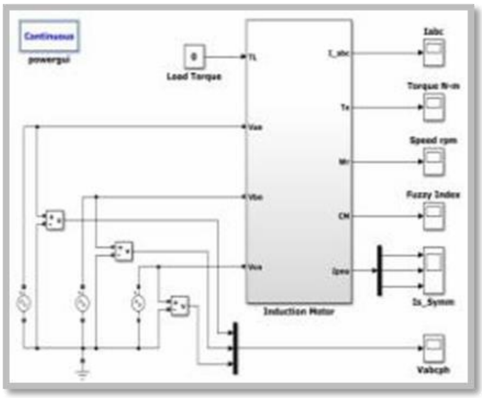

Fig. 4. Simulink model for stator fault detection in Induction Motor using Fuzzy logic

The parameters inside the IM three-phase model and the three phase source can be set by executing an m-file which stores the all parameters used in the model. By running the m-file, parameters value can be accessed by the model from workspace.

The parameters of the machine used for simulation are listed below: Rated Voltage V = 415 V; Supply frequency f = 50Hz; Number of poles, p = 4; Inertia Constant J= 0.023kg-m^2; Stator &Rotor Self Inductances in Henry

LAA=0.585;LBB=0.585;LCC=0.585;Laa=0.585;Lbb=0.58 5; Lcc=0.585;

Mutual Inductance for any two stator or any two rotor windings LAB=-0.275; LAC=-0.275; LBA=-0.275; LBC=- 0.275; LCA=-0.275; LCB=-0.275; Lab=-0.275; Lac=-0.275; Lba=-0.275; Lbc=-0.275; Lca=-0.275; Lcb=-0.275

Mutual Inductance between a stator and a rotor winding in HenryLAa=0.55; LAb=0.55; LAc=0.55; LBa=0.55; LBb=0.55; LBc=0.55; LCa=0.55; LCb=0.55; LCc=0.55; LaA=0.55; LbA=0.55; LcA=0.55; LaB=0.55; LbB=0.55; LcB=0.55; LaC=0.55; LbC=0.55; LcC=0.55

5. Results and Analysis

1) Normal Operation

For the values given, the motor is simulated during starting from rest with rated voltage applied and no mechanical load. Figures shows the stator input voltage, stator current, torque, speed, health of IM, symmetrical components of stator current. From these results it can be concluded that after the transient period is over at 1.2 sec, the health of the motor is good, and there is no negative sequence component in both stator induced voltage and stator current

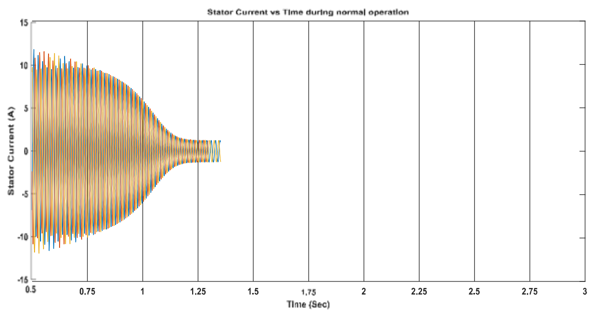

Fig. 5: Three phase stator current of induction motor (Normal Operation)

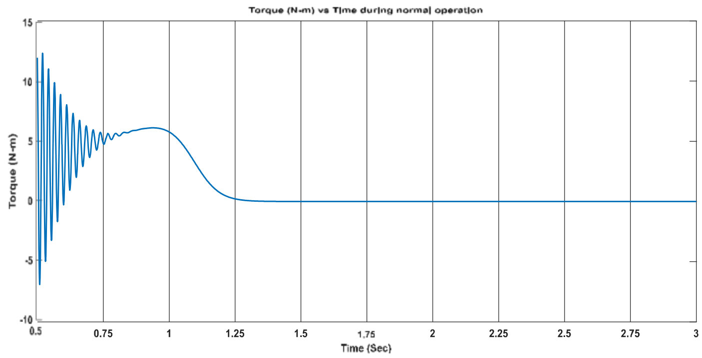

Fig. 6: Developed torque of induction motor (Normal Operation)

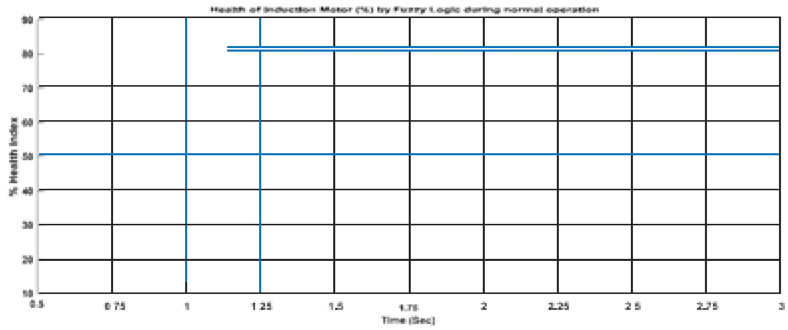

Fig. 7: Percentage health index of induction motor by fuzzy logic (Normal Operation)

2) Turn To Turn short in one phase winding

Simulation for the short circuit in some part of the R phase winding has been carried out. At this condition the value of the stator resistance at short circuit fault is equal to R = 13.1 Ω, we can find the value of the inductance at the fault state by using the ratio between the value of the resistance at both state (normal and fault). Thus the value of the inductance is,

$$\frac{R_{Stator,normal}}{R_{Stator,fault}} = n = \frac{L_{Stator,normal}}{L_{Stator,fault}}$$

$$\frac{15.3}{13.1} = \frac{0.585}{L_{stator,fault}} \Rightarrow \therefore L_{stator,fault} \approx 0.5H$$

Replacing the values of the stator resistance and stator self-inductance in phase R by these values the results can be obtained. Figures shows the stator input voltage, stator current, torque, speed, health of IM, symmetrical components of stator current. The simulation is started up with normal state parameters. After obtaining steady state at 1.2 second the turn fault has been created by changing the above said parameters at 2 sec. From these results it can be concluded that during normal operation (before fault), the motor is in Good health, with no negative sequence component in both statorinduced voltage and stator current. When the fault is created the Istator becomes unbalanced, and the health of the IM goes from Seriously Damaged to Damaged state, and it is found that there is a presence of negative sequence component in stator current and induced voltage variations during fault conditions.

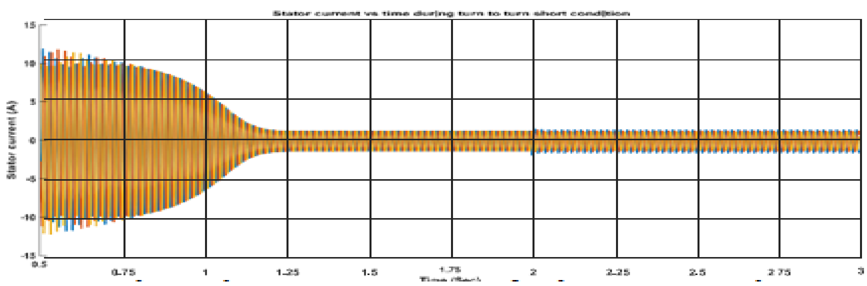

Fig. 8: Three phase stator current of induction motor (Turn to turn short operation)

1 2 2.75

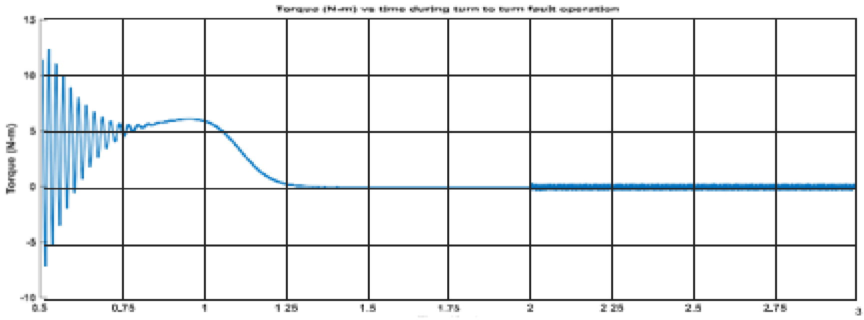

Fig. 9: Developed torque of induction motor (Turn to turn short operation)

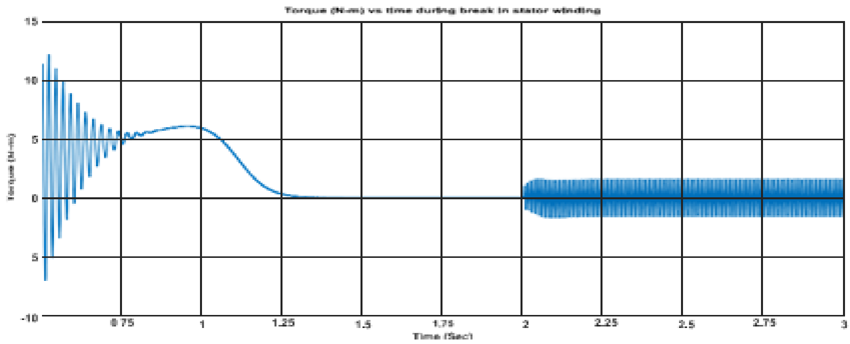

Fig. 10: Percentage health index of induction motor by fuzzy logic (Turn-turn short operation)

3) Break in stator winding

With simulation of a break in the stator winding at R phase, it is not possible to apply a break in the phase with the value of the Rstator and the Lstator to infinity or very high. It is assumed that the value of the Rstator is very high and corresponding to this value we can calculate the value of the inductance by this equation

$$\frac{R_{Stator,normal}}{R_{Stator,fault}} = n = \frac{L_{Stator,normal}}{L_{Stator,fault}}$$

$$\frac{15.3}{10000} = \frac{0.585}{L_{stator,fault}} \Rightarrow \therefore L_{stator,fault} \approx 382.35H$$

Replacing the values of the stator resistance and stator self-inductance in phase R by these values, the fault state results can be obtained. Figures shows the stator input voltage, stator current, torque, speed, health of IM, symmetrical components of stator current. The simulation is using normal state parameters. With steady state obtained at 1.2 second the break in winding fault has been created at 2 sec by changing the above said parameters. From the results it can be observed that during normal operation, the motor has Good health, and there is no negative sequence component in both stator induced voltage and Istator. When the fault is created the Istator becomes unbalanced, and the health of the IM goes to Seriously Damaged and finally settles to the same state, and the presence of negative sequence component in both stator induced voltage and Istator variations during fault conditions can be noticed.

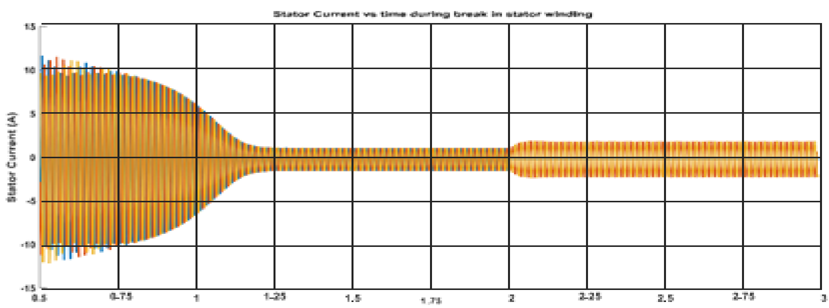

Fig. 11: Three phase stator current of induction motor (Break in stator winding)

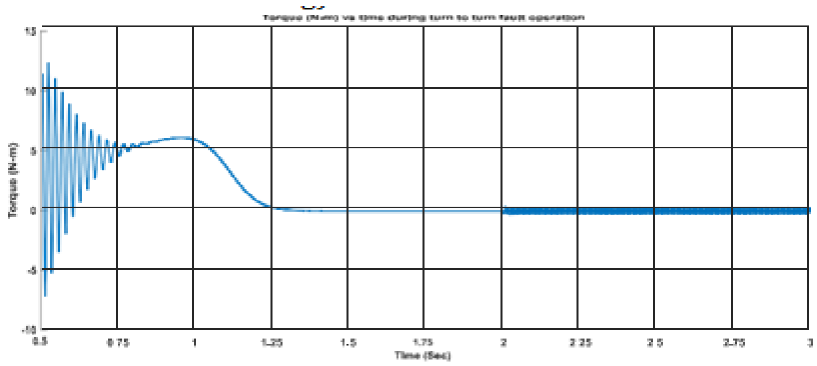

Fig. 12: Developed torque of induction motor (Break in stator winding)

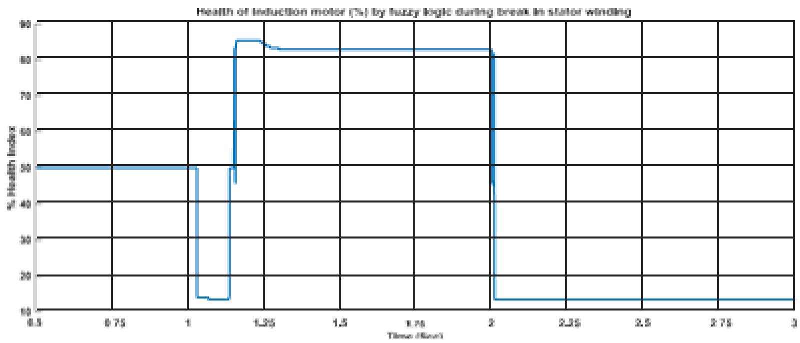

Fig. 13: Percentage health index of induction motor by fuzzy logic (Break in stator winding)

4. Open Phase fault

In this case after normal startup, steady state reached at 1.2 second, then R phase was open circuited at 2 sec and the corresponding results are shown in figures. Motor health is seriously damaged state and shows a presence of negative sequence component of Istator.

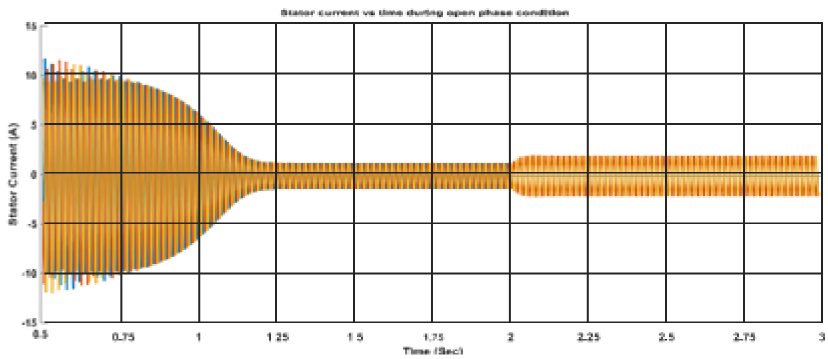

Fig. 14: Three phase stator current of induction motor (One phase open operation)

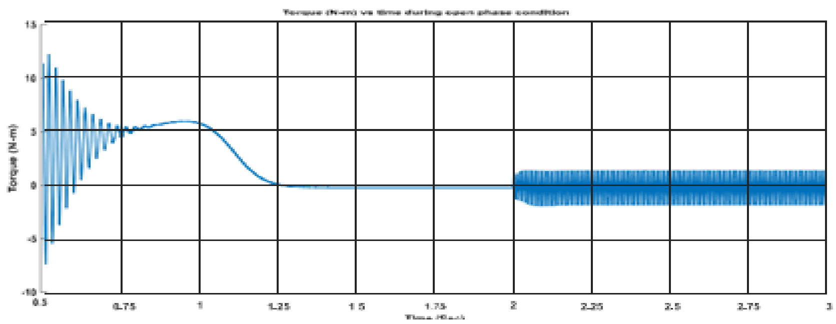

Fig. 15: Developed torque of induction motor (One phase open operation)

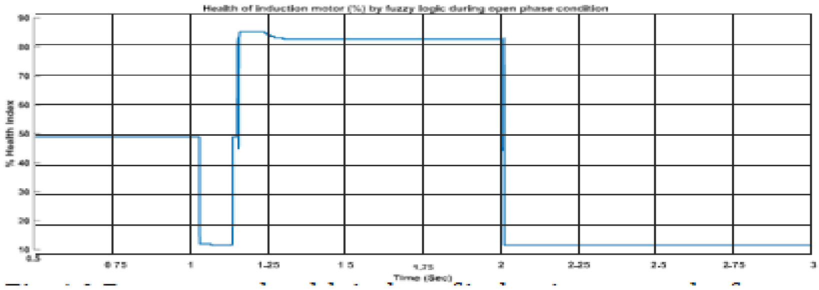

Fig. 16: Percentage health index of induction motor by fuzzy logic (One phase open operation)

6. Conclusion

A Fuzzy logic approach may help to diagnose Induction Motor faults. In fact, Fuzzy Logic is reminiscent of human thinking and natural language enabling vague information based decision making. Therefore, this projects applies Fuzzy logic to Induction Motors fault detection and diagnosis. The motor condition is described using linguistic variables. Fuzzy subset and the respective membership functions describe amplitude of stator current. A knowledge base, comprising of data bases and rules, is built to justify the fuzzy inference. The Induction Motor condition is diagnosed using a compositional rule of fuzzy inference. Fuzzy logic based measurement and health evaluation system has been developed and implemented. This application allows fast failure state estimation for different stator faults on the induction motor. The more detailed analysis to point out the difficult machine conditions under different stator fault conditions of induction motor can be performed. This is a versatile technique for fault analysis and condition monitoring of motors. It solves the shutdown problems and gives safe working environment in continuous industrial processes.

7. Acknowledgment

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