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Predictive Condition Monitoring of Induction Motor Bearing Using Fuzzy Logic

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***Abstract* — Induction motor is critical component in industrial processes and is frequently integrated in commercially available equipment. Safety, reliability, efficiency and performance are the major concerns of induction motor applications. Due to high reliability requirements and cost of breakdown, condition monitoring, diagnosis and Protection increasing importance. Protection of an induction motor (IM) against possible problems, such as stator faults, rotor faults and mechanical faults, occurring in the course of its operation is very important, because it is very popular in industries. Bearing fault is well known mechanical fault of IM.41% faults related to bearing in IM. To avoid break down of IM condition monitoring of motor bearing condition is very important during the normal operation. Various classical and AI techniques like fuzzy logic, neural network, neuro-fuzzy are used for condition monitoring and diagnosis of IM. Among the above mentioned AI techniques, Fuzzy logic is the best technique for condition monitoring and diagnosis of IM bearing condition. Therefore, the present paper focuses on fuzzy logic technique. In this paper Fuzzy logic is design for the condition monitoring and diagnosis of induction motor bearing condition using motor current and speed. After applying Fuzzy logic it has been seen that continuous monitoring of the current and speed values of the motor conditioned monitoring and diagnosis of induction motor bearing condition can be done.**

***Keywords* — Induction Motor (IM), Artificial Intelligence (AI), Fuzzy Logic, Fuzzy logic system (FLS)**

I. Introduction

Due to rugged construction, easy maintenance and cost-effective pricing, More than 90 per cent of all motors used in industry worldwide are AC induction motors. Industrialized countries, induction motors are responsible for the 40% to 50% of energy consumption [10]. Recent studies indicate that 90% of the failures in machines occur due to miss function of the internal components, such as the main motor. Therefore, protection, diagnosis and condition monitoring [1][4] of IMs has received considerable attention in recent years. Classical techniques for three phase IMs are generally provided by some combination of mechanical and electrical equipments such as contactors, timers, electromagnetic switches, thermal relays, over current relays and over/lower voltage relays. These equipments have mechanical parts, and their responses are very slow compared with that of electronic equipment. The mechanical parts of the equipment can cause problems during their operations and reduce the life and efficiency of the system. In terms of economic consideration, the cost of the digital hardware has been decreased and the cost of classical relays has been increased recently. Various techniques have been used for diagnosis and protection Latest methods supported by artificial intelligence [8] [11], microprocessor, Computer and other technique in the protection, diagnosis and condition monitoring [2] [3]. Condition monitoring implies monitoring various parameters of a machine in order to assess the health of the machine.

The fuzzy logic [5],[6] is attractive approach, which can accommodate motor parametric variations and difficulty in obtaining an accurate mathematical model of induction motor due to rotor parametric and load time constant variations. The fuzzy logic is a knowledge-based control that uses fuzzy set theory and fuzzy logic for knowledge representation. Fuzzy logic controller is suitable for diagnosis of induction motor bearing conditions.

II. Classification of Induction Motor Faults

(A) Stator Faults

There are main two types of the stator faults as per the following two categories [9].

1. Faults in Laminations due to core hot spot, core slackening and Faults in frame due to vibration, circulating currents, loss of coolants, earth faults.
2. Stator Windings Faults: The most common faults of stator windings are due to local damage to insulation, fretting of insulation, contamination of insulation by moisture, oil or dirt, damage to connectors, cracking of insulation, discharge erosion of insulation, displacement of conductors, turn-to-turn faults[4]

(B) Rotor Faults

There are two types of types of squirrel-cage rotors exist in induction motors: cast and fabricated. Cast cage rotors are used in motors up to 3000-kW rating. Fabricated cages are used for higher ratings and special application machines where possible failure events occur on bars and end-ring segments. Cast rotors are almost impossible to repair after bar breakage or cracks although they are more durable and rugged than fabricated cages. Typically, they are used in laboratory tests to validate diagnostic procedures for practical reasons. Broken bar and cracked end ring faults share only 5%–10% of induction machine faults but the detection of these events is a key issue [2].

(C) Mechanical Faults

About 40% to 50% of induction motor faults are related to mechanical defects.

1. Bearing Faults

Most electrical machines use either ball or rolling-element bearings which consist of outer or inner rings. Balls or rolling elements rotate in raceways inside the rings. Bearing faults may be reflected in defects of outer

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race, inner race, ball, or train. Even in normal balanced operations with good shaft alignment, fatigue faults can occur. Generally, a fault in the load part of the drive gives rise to a periodic variation of the induction machine load torque. Examples of such faults causing torque oscillations include the following: general fault in the load part of the drive system, load imbalance, shaft misalignment, gearbox faults, or bearing faults. Torque oscillations already exist in a healthy motor owing to space and time harmonics of the air-gap field but the considered fault-related torque oscillations are present at particular frequencies often related to the shaft speed [2].

2. Eccentricity Faults

Eccentricity faults in induction machines have been investigated extensively. The eccentricity of a cylinder rotating around an air-gap can be classified as static, dynamic, or mixed eccentricity. For static eccentricity, the center of rotation is simply displaced from the original center of a certain quantity. Then, for a dynamic eccentricity, the center of rotation is still at its origin while the cylinder is displaced. Finally, for mixed eccentricity, both the cylinder and the center of rotation are displaced from their respective origin. Air-gap eccentricity is one of the commonest failure conditions in an induction machine. It may be static or dynamic in nature or a mixture of both. Usually, there are interactions between the faults. An eccentricity may be caused by many problems such as bad bearing positioning during the motor assembly, worn bearings, bent rotor shaft or operation under a critical speed creating rotor whirl.

III. Proposed Fuzzy Logic System

Following figure shows the block diagram of proposed fuzzy logic system for bearing condition. Proposed system monitors the bearing condition by measuring motor current and motor speed.

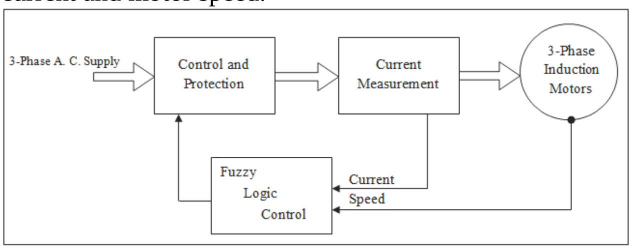

Fig.1. Block Diagram of Proposed Fuzzy Logic System for bearing condition

Fuzzy Set & Rule Formation

From the physical operation principle of the system, a simple control rule can be written in fuzzy logic as:

Speed and Current are the input fuzzy variables, Bearing condition is the output fuzzy variable. SS, NS, LS and VLS are the fuzzy set membership functions for speed. SC, NC, HC and VHC are the fuzzy set membership functions for current. Thus, maximum 4x4 = 16 rules can be formed as tabulated in Table I.

Table 1: Fuzzy Rules for Bearing Fault

If Speed is	And Current is	Then B_c is
SS	SC	G
SS	NC	G
SS	HC	F
SS	VHC	F
NS	SC	G
NS	NC	G
NS	HC	F
NS	VHC	F
LS	SC	F
LS	NC	F
LS	HC	F
LS	VHC	B
VLS	SC	F
VLS	NC	F
VLS	HC	B
VLS	VHC	B

B_c represent the bearing condition **G**=good, **F**=fair, **B**=bad

IV. Design Fuzzy Logic Controller in Simulink/Matlab

A. Fuzzy Interference System Editor

A fuzzy logic controller has been designed with 2 inputs(speed and current) and one output(Bearing condition) as shown in figure (2)

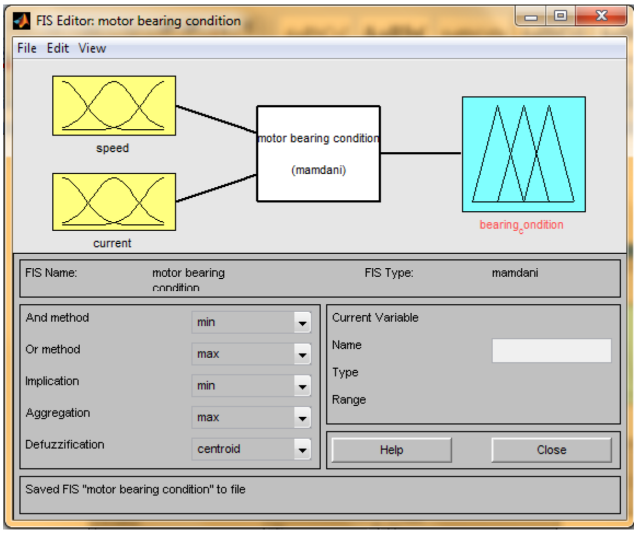

Fig.2. FIS Editor

B. Membership Function Editor

1. Speed Signal

Range for the speed signal (input 1) is taken [1500 rpm to 1350 rpm]. The shape for the speed signal (input 1) is triangular. Figure (3) show the membership function for speed signal.

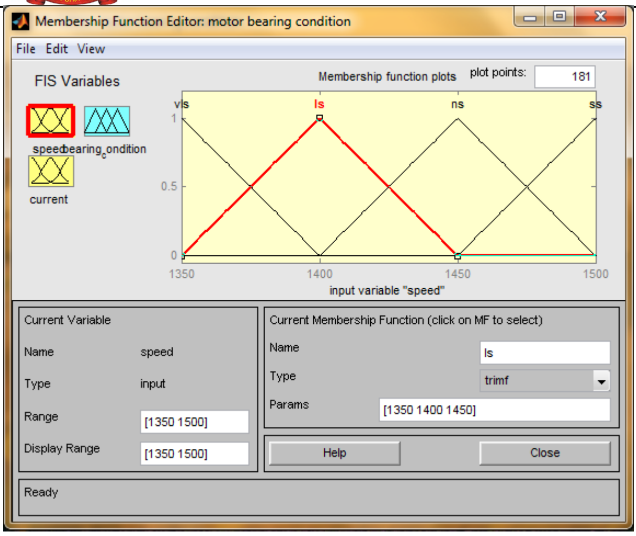

Fig.3. MF Editor (Input 1 speed Signal)

2. Current Signal

Range for the current signal is taken [4 A to 6A]. The shape for the current signal (input 2) is triangular. Figure (4) show the membership function for current signal.

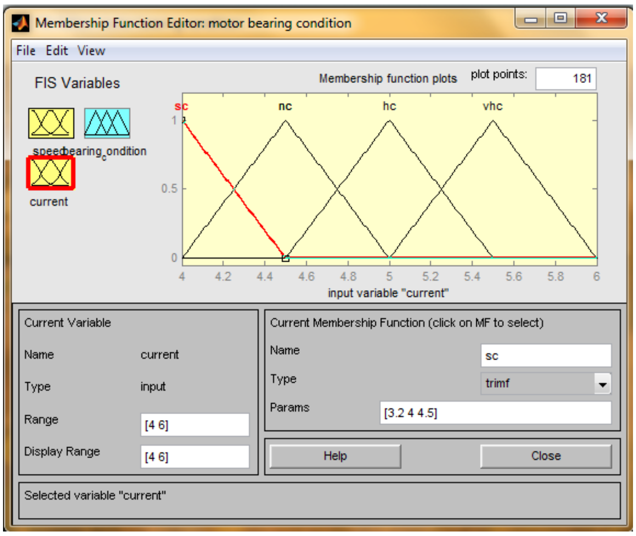

Fig.4. MF Editor (Input 2 current Signal)

3. Output Signal (Bearing condition)

Range for the output signal (bearing condition) is taken [0 to 1]. The shape for the output signal (bearing condition) is triangular. Figure (5) show the membership function for output signal (bearing condition).

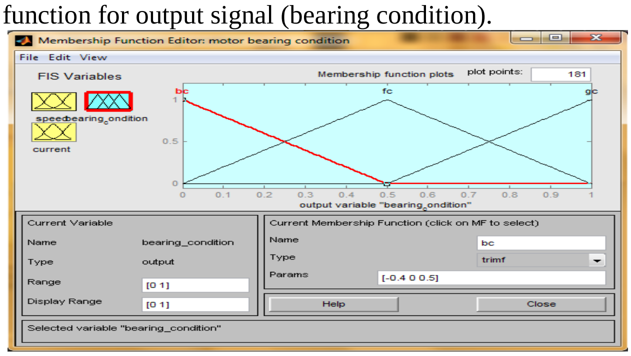

Fig.5. MF Editor (Output Signal Bearing condition)

4. Rule Editor

The logical connectives of rules AND, OR, and NOT are selected using rule editor and 16 rules have been constructed in rule editor. Figure (6) shows rule editor, figure (7) shows the Rule viewer and figure (8) shows surface viewer.

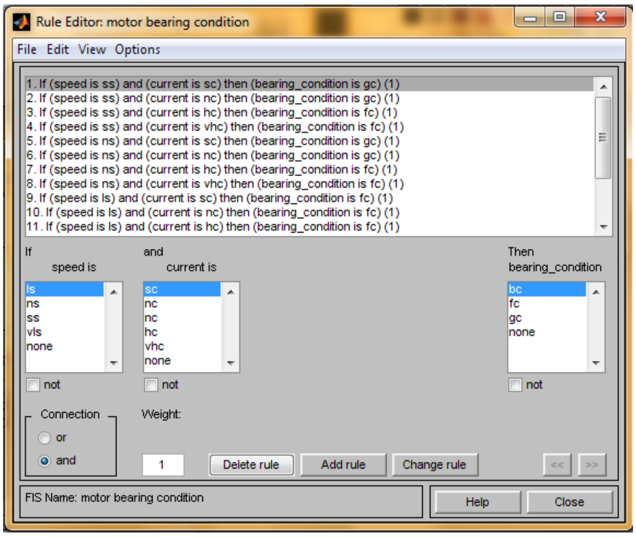

Fig.6. Rule Editor

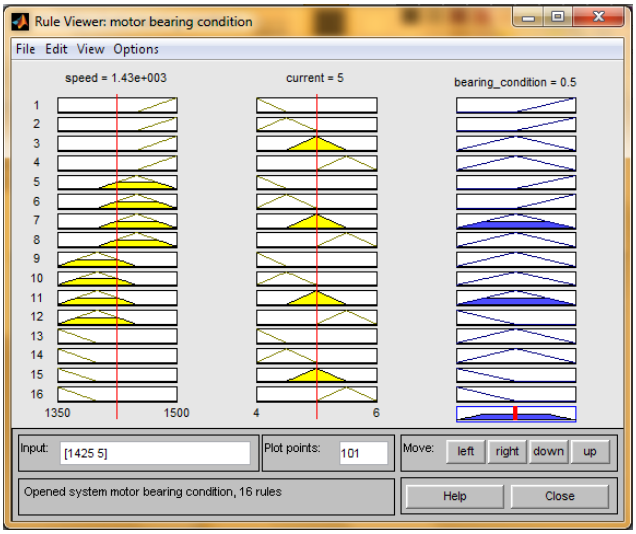

Fig.7. Rule Viewer

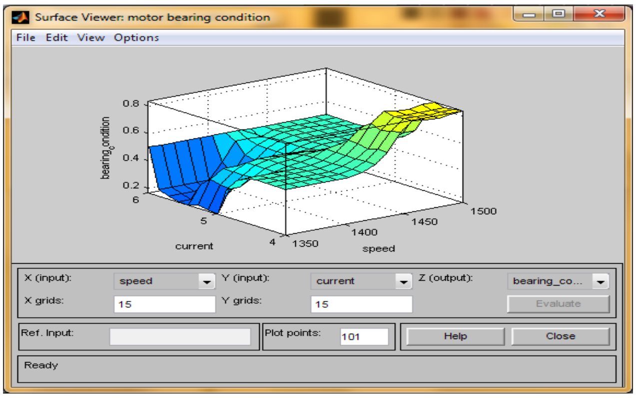

Fig.8 Surface Viewer

V. Conclusion

The fuzzy logic is trained by using current and speed signals of induction motor following various rules of fuzzy logic. After training of the fuzzy logic, it has been seen that by using motor current and speed signals fuzzy logic gives the condition of motor bearing as an output signal. In a general sense, by continuous monitoring of the Current and Speed of the Induction motor, fuzzy logic can be used for condition monitoring and diagnosis of induction motor bearing condition.

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