AMSE JOURNALS-AMSE IIETA publication-2017-Series: Modelling D; Vol. 38; N°1; pp 80-88
Submitted April 2017; Revised July 30, 2017, Accepted Nov.15, 2017

Condition Monitoring of Single Phase Induction Motor Using Fuzzy Logic Scheme

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Abstract

In this paper, the authors described a performance based health monitoring technique of the single-phase induction motor. When any internal damage occurs in induction motor, harmonic generates and its severity depends on how much internal damage occurs. Presented technique was based on the analysis of voltage and current signals of induction motor. A Fuzzy logic based algorithm has been made for condition monitoring of Induction motor. The proposed methodology has been tested experimentally on a 100W, 230 V, 50 Hz domestic fan motor to check the accuracy of Fuzzy inference system.

Key words

Single phase induction motor, fast Fourier transform, total harmonic distortion, motor current signature analysis, Labview, fuzzy logic.

1. Introduction

Single-phase induction motors are widely used in many residential, industrial, commercial and utility applications due to its high reliability, low cost etc. Due to the necessity of increasing production, induction motors are required to run continuously without interruption. As every year, the number of operating electric motors increases, so condition monitoring and fault diagnostics is very important because it prevents financial loss and unplanned downtimes causes by faults. During many years, many research efforts are being put forth to develop various methods of fault diagnosis as summarized in [1-5]. Different kinds of faults can occur in induction machine like stator inter turn fault, broken rotor bar fault, eccentric fault, bearing damage etc. The inter-turn fault of stator windings usually occurs due to undetected insulation damage between two adjacent turns. As a result, it slowly develops to a short circuit and finally the winding burns due to excessive heating. In some cases, fault occurs due to an electric arc connecting two points of the winding.

Motor Current Signature Analysis (MCSA) is very important to for condition monitoring of Electric machine. In most of the cases, MCSA relies on the model based diagnostic techniques [3]. But, major drawbacks of model-based techniques are the requirements of precise motor parameters and the need of speed signals additionally with voltage and current signal. The stator voltage and current signals have been usually preferred for condition monitoring and fault diagnosis purpose because sensors for measuring these are usually available in the existing drive system. When stator winding faults occur, it generates harmonics in the line current. But harmonics also created due to distorted supply voltage. So, it is necessary to distinguish the distortion in line current due to motor internal problem and distortion due to distorted supply voltage. However, the distinction between these two phenomena is highly challenging to predict the condition of motor [7,9]. This issue is addressed in this paper. Here, voltage and current signals are used and harmonic distortion has been calculated for both cases. The harmonic distortion has been used as input of Fuzzy logic classifier, which provides the condition of motor.

2. Fault Detection Methodology

2.1 Harmonics Analysis

Due to any abnormal condition of induction motor, the nature of output voltage and current will be non-sinusoidal i.e. distorted. This distortion in any sinusoidal waveform is analyzed using Fourier analysis over a period as follows:

$$X(\omega t) = \sum_{n=2}^{\infty} (A_n \cos n\omega t + B_n \sin n\omega t) \tag{1}$$

where, the coefficients A_n and B_n can be expressed as,

$$A_n = \frac{1}{T} \int_0^T X(\omega t) \cos n\omega t d(\omega t) \tag{2}$$

$$B_n = \frac{1}{T}\int_0^T X(\omega t)\sin n\omega t d(\omega t) \tag{3}$$

where T is the time period of sinusoidal signal and A_n, B_n are the maximum value of sine and cosine components of the harmonics of order n, presents in the output voltage respectively.

The amplitude(C_n) and phase angle (ϴn) of nth harmonic components can be defined as,

$$C_n = \sqrt{A_n{}^2 + B_n{}^2} \tag{4}$$

$$\theta_n = \tan^{-1}\frac{B_n}{A_n} \tag{5}$$

The harmonic components can be evaluated very easily with the help of Fast Fourier Transform (FFT), which is defined by the formula

$$X_K = \sum_{n=1}^{N-1} x_n e^{-j2K\pi n/N} \tag{6}$$

where, K = 0 to N-1

Total Harmonic Distortion (THD) defined as the ratio of the RMS amplitude of a set of harmonic frequencies to the RMS amplitude of the first harmonic, or fundamental, frequency

$$THD = \frac{\sqrt{X_2{}^2 + X_3{}^2 + X_4{}^2 + ----+X_n{}^2}}{X_1} \tag{7}$$

where *Vn* is the RMS voltage of the *n*th harmonic and *n* = 1 is the fundamental frequency.

2.2 Development of Fuzzy Logic Scheme

The Fuzzy logic concept was first introduced by Professor Lofti A. Zadeh to present vagueness in linguistic terms and express human knowledge in a natural process [10]. It deals with uncertain, imprecise or qualitative Decision-making problems in many engineering aspects. It shortens the time for engineering development and in case of highly complex system also it is economical to solve the problem. For this, Fuzzy logic is used in system control and analysis design. In this paper, to describe the motor condition, some linguistic variables have been used. Fuzzy subsets can be assigned to describe the voltage and current distortion by means of corresponding membership functions [6]. For condition monitoring, a knowledge base and data base is required to activate Fuzzy inference. The result of induction motor condition made based on fuzzy inference which is capable of giving high accuracy detection model. The structure of a Fuzzy Inference system is given in Fig.1.

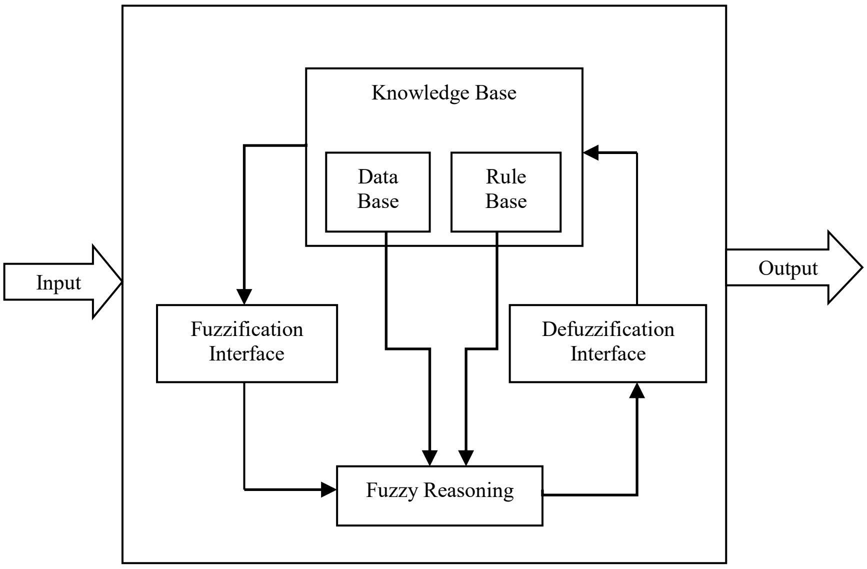


Fig.1. Structure of Fuzzy Inference system

The identification of motor condition requires the interpretation of data and makes decision from the data with the help of rule set. A fuzzy system can store certain knowledge, which allows it to make further decisions with a high percent of accuracy. In the present work, two input variables THD of stator Voltage (THD_V) and THD of stator current (THD_I) have been used. Fuzzy rules and membership functions have been constructed by observing THD inputs. In Fig.2, Fuzzy model for condition monitoring has been given.

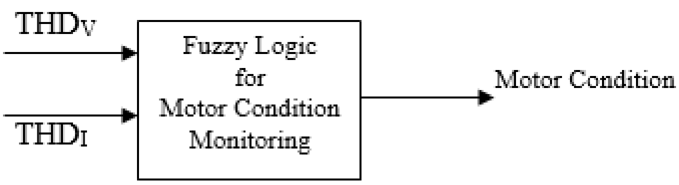


Fig.2. Fuzzy model for motor fault monitoring

For providing accuracy in the system, more insight into the data is needed, so membership functions will be generated for each input variable as Low (L), Medium (M) and High (H). The output variables which result the motor condition are Good (G), Damaged (D) and seriously damaged (SD). Membership functions have been created by observing the data set and the behavior of stator inputs which are likely to cause faults in the motor.

In this study trapezoidal membership functions have been used. The membership functions for input and output variables are shown in Fig.3 and 4 respectively. After determining the initial membership function, the fuzzy if- then" rules have been proposed. These "if-then" rules have been created so as to cover both healthy and faulty cases. In this paper, 6 no. of if-then rules have been proposed.

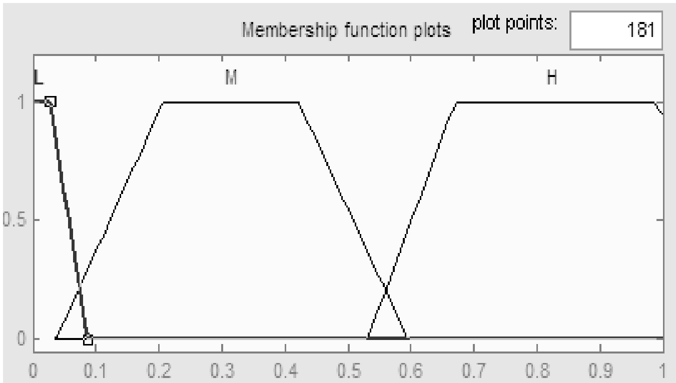


Fig.3. Membership functions of input variable

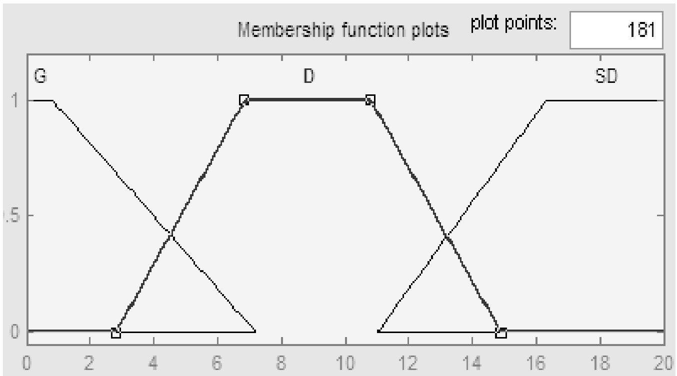
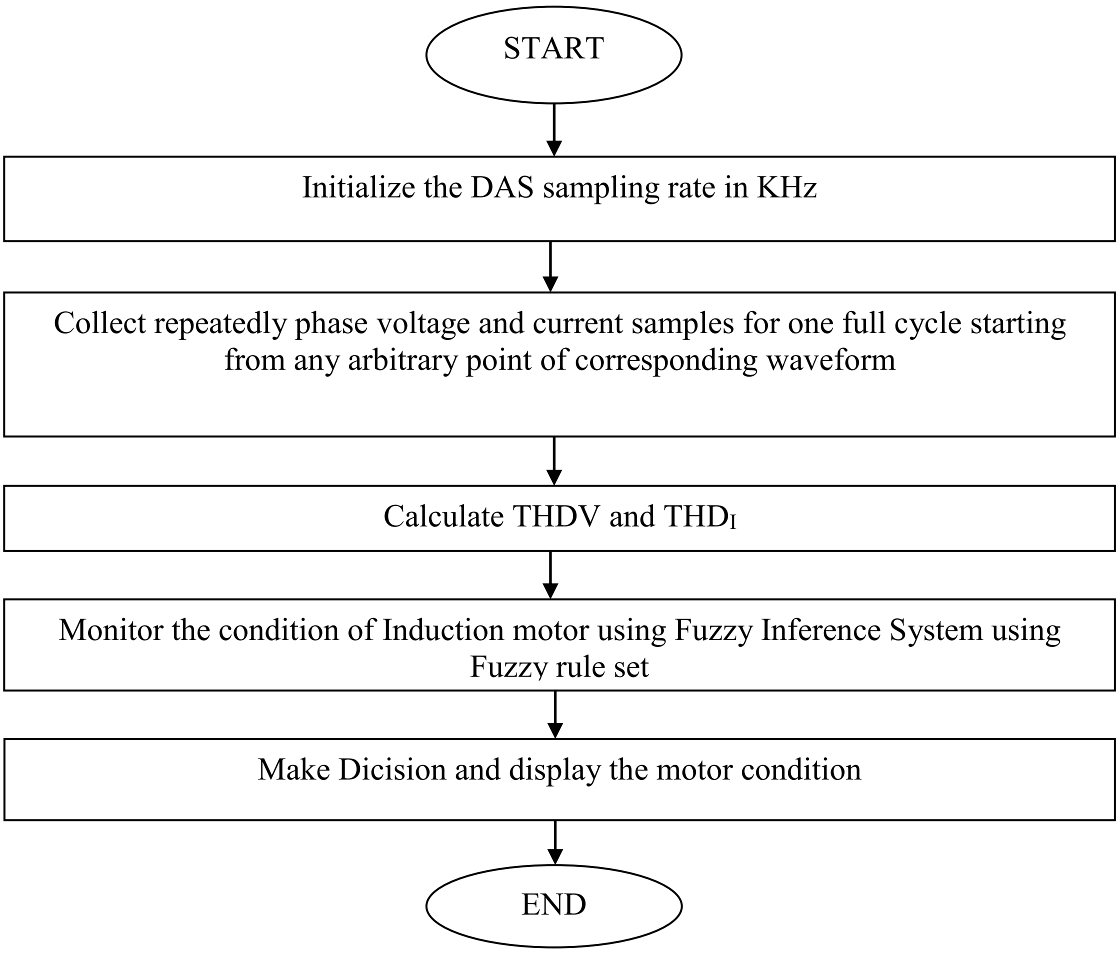


Fig.4. Membership Functions of output variable

Fuzzy rule set:

1. If (THD_V is L) and (THD_I is L) then (OUT is GOOD)
2. If (THD_V is L) and (THD_I is M) then (OUT is DAMAGED)
3. If (THD_V is L) and (THD_I is H) then (OUT is SERIOUSLY DAMAGED)
4. If (THD_V is M) and (THD_I is M) then (OUT is GOOD)
5. If (THD_V is M) and (THD_I is H) then (OUT is DAMAGED)
6. If (THD_V is H) and (THD_I is H) then (OUT is DAMAGED)

By fuzzy inference structure, input conditions of THD are mapped with respective output motor conditions and health monitoring of motor at any instant of time is derived. This is done by the process of Defuzzification for calculating crisp indication of motor condition based on fuzzy output generated by rule weight process of fuzzy inference. Among various methods of Defuzzification, centroid method of Defuzzification has been used. The detailed algorithm of this proposed work has been given below:



3. Hardware Experimentation

To validate the proposed health detection approach, a case-study with 1-phase, 240 V, 50-Hz, 100W fan motor has been performed in the laboratory with loading condition. The analog output of stator voltage and current signal collected with the Labview based data acquisition system (DAS). Labview samples the input voltage and current signals simultaneously to provide the instantaneous data set and from the data set, THD has been calculated, which has been used as input of Fuzzy Inference System. A typical picture of data acquisition system has been given in Fig.5.

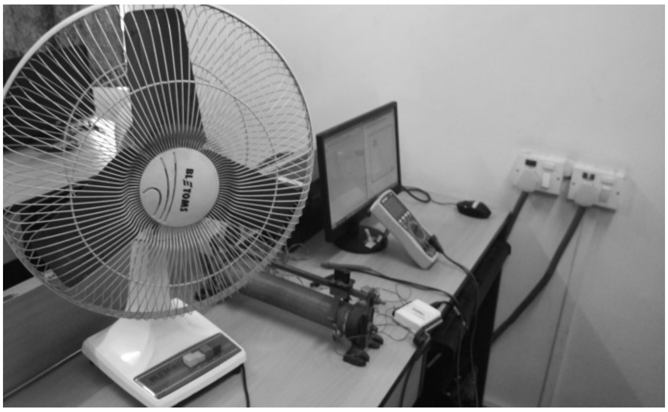


Fig.5. LabVIEW based data acquisition using DAS Card

The obtained voltage and current waveform of motor in LabVIEW Front Panel has been shown in Fig.6. The result of motor condition determination is given in Fig.7.

MATLAB fuzzy tool facilitates the insight to fuzzy inference process vide the rule viewer option on fuzzy inference system Edit menu which helps to make proper design of fuzzy sets, fuzzy rules and overall performance of fuzzy inference system in terms of output targeted for all possible range of inputs.

From the experimental result, it has been observed that fuzzy inference motor condition value comes to 8.85, which indicates the motor is in not in good condition. So, from the experimentation it can be observed that the proposed method has over 99% accuracy in condition monitoring.

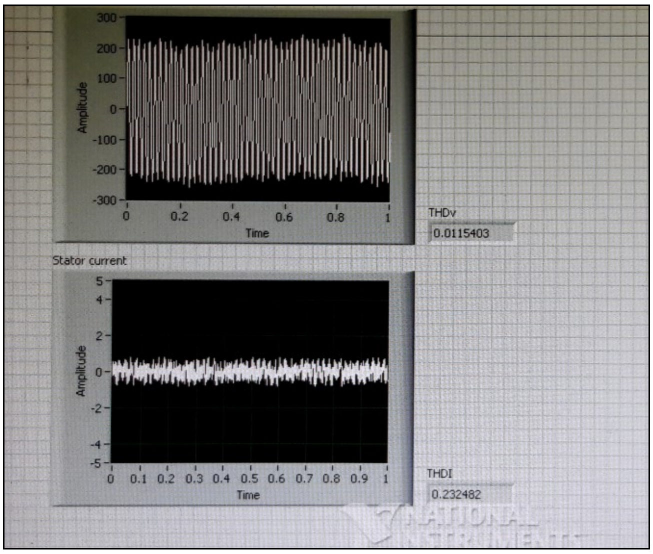


Fig.6. Stator Voltage and Current Waveform in LabVIEW

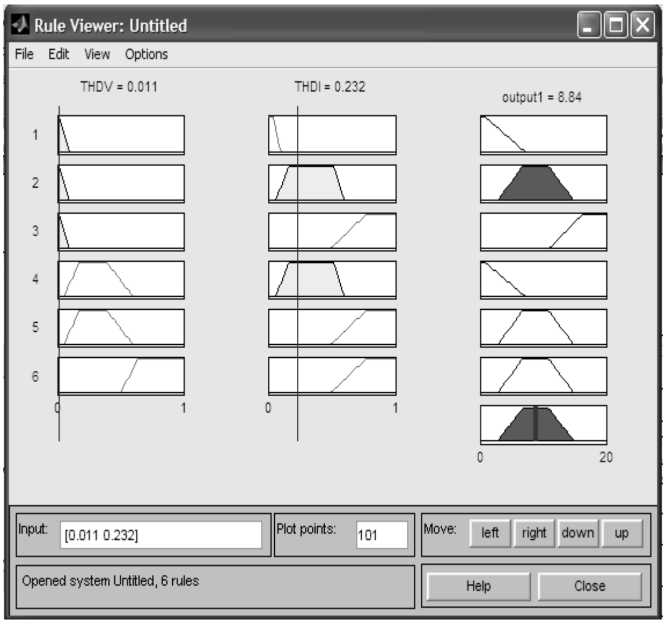


Fig.7. Rule Viewer of Experimental Motor Condition

Conclusions

In this paper, the authors proposed condition monitoring technique of single phase induction motor with the help of Fuzzy logic system. The proposed system is useful for reliability of the single-phase induction motors and other rotating electrical machines such as three-phase induction motors, synchronous motors also. Motor loading condition does not affect upon condition monitoring technique because, loading condition does not generate severe harmonics. In future the authors will try to diagnose type of faults in different types of rotating electrical machines with more reliable fault diagnostic techniques which will be effective for industry.

References

1. H. Henao, G.A. Capolino, M.C. Fernandez, F. Filippetti, C. Bruzzese, Trends in fault diagnosis for electrical machines a review of diagnostic techniques, 2014, IEEE Industrial Electronics Magazine, vol. 8, no. 2, pp. 31-42.
2. R. Islam, S.A. Khan, J.M. Kim, Discriminant feature distribution analysis-based hybrid feature selection for online bearing fault diagnosis in induction motors, 2015, Journal of Sensors, Article Number: 7145715.
3. Z.J. Wang, Z.N. Han, F.S. Gu, J.X. Gu, S.H. Ning, A novel procedure for diagnosing multiple faults in rotating machinery, 2015, ISA Transactions, vol. 55, no. 2, pp. 208-218.

4. M. Irfan, N. Saad, R. Ibrahim, V.S. Asirvadam, An on-line condition monitoring system for induction motors via instantaneous power analysis, 2015, Journal of Mechanical Science and Technology, vol. 29, no. 4, pp. 1483-1492.
5. C.D. Costa, M. Kashiwagi, M.H. Mathias, Rotor failure diagnosis of induction motors by wavelet transform and fourier transform in function of the load, 2015, International Conference on Computer Science and Artificial Intelligence (ICCSAI 2014), vol. 8, pp.109-113.
6. D. Valis, K.U. Pietrucha, Utilization of diffusion processes and fuzzy logic for vulnerability Assessment, 2014, Journal of Eksploatacja i Niezawodnosc–Maintenance and Reliability, vol. 16, no. 1, pp. 48-55,
7. Y.L. Ching, B.K. Chen, L.W. Jen, Y. Fenghsu, Effects of various unbalanced voltages on the operation of an induction motor under the same voltage unbalance factor condition, 1997, IEEE Transaction Digital Library, pp. 51-59.
8. B.P. Cummings, J.R. Jacobs, H. Robert, Protection of induction motor against unbalanced voltage operation, 1985, IEEE Transactions on Industry Applications, vol. IA-21, no. 4, pp. 778-792.
9. P. Zhang, Y. Du, T.G. Habetler, B. Lu, A servey of condition monitoring & protection methods for medium-voltage induction motor, 2011, IEEE Transactions on Industry Applications, vol. 47, no. 1, pp. 34-46.
10. V.P. Mini, S. Ushakumari, Incipient fault detectionand diagnosis of induction motor using fuzzy logic, 2011, IEEE Transaction on Industry Application, vol. 47, no. 1, pp. 675-681.

NOMENCLATURE

MCSA	Motor Current Signature Analysis
THD	Total Harmonic Distortion
FFT	Fast Fourier Transform
DAS	Data Acquisition System