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Design Machine Condition Monitoring System for ISO 10816-3 Standard using Fuzzy Logic

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***Abstract*—Electrical machines are industry prime movers and industry required machine operates in secure and consistent environment. Due to change in working environment and dynamic loading to machines causes different faults such as stator faults, rotor electrical faults, rotor mechanical faults such as bearing damage, eccentricity, bent shaft, and misalignment etc. If any faults and failure occurs in the machines it can directly lead to unwarranted downtimes, create production losses and increase maintenance cost. This is ample inspiration to study monitoring techniques that can reduce the maintenance costs and excessive downtime. The purpose of this paper is to developed fuzzy logic system with LabVIEW tool in order to classify the condition of the machine by using ISO 10816-3 Standard. This system is able to classify the state of machinery as, 'Newly Commissioned Machinery', 'Unrestricted Operation', 'Restricted Operation' and 'Damaged Occurs'.**

Keywords—Machines, Condition Monitoring System, Fuzzy Logic, LabVIEW.

INTRODUCTION

The electrical machines such as induction motors or generators are used in a wide range of applications. To avoid the failure of machines its strong demands to monitoring the condition of the machines. A wide variety of condition monitoring techniques has been introduced over the last four decades. Nowadays, industry stress to provide more flexible alternatives for maintenance, avoiding waste of time in unforeseen failures, as well as time of scheduled maintenance. This creates the necessity to propose and apply predictive technologies, which ensure that machinery, receive attention only when they present some evidence of their mechanical property deterioration. [1].

The condition monitoring system is moving toward an automated computerized System, trying to remove human experts from the condition monitoring systems, [2] "However, the development of artificial intelligence for electrical machine condition monitoring is still in its infancy and despite the considerable work that has been done in this area, much more is required to bring such techniques into the mainstream of condition monitoring." [3].

Electrical machines and drive systems are subject to many unusual types of faults [4]. These faults include the following:

1) Stator faults which are defined by stator winding open or short circuited
2) Rotor electrical faults such as rotor winding open or short circuited for wound rotor machines and broken bar(s) or cracked end-ring for squirrel-cage machines
3) Rotor mechanical faults such as:
    - Bearing damage
    - Eccentricity
    - Bent shaft
    - Misalignment

4) Failure of one or more power electronic components [4].

Taylor has suggested that, "just as your physician uses a variety of tests and evaluations to assess your state of health, we should do the same for our machinery" [2]. Condition monitoring system of machinery is defined as technique in which the different parameter of the machine are continuous evaluate (Vibration, temperature etc) to define the state of machine either healthy or faulty. It is useful for superfluous damage of machinery and avoids unscheduled maintenance activity.

To increase safety and reduce the maintenance cost of machines, many researchers have been developed various structural health monitoring techniques. Although improved design methodologies have significantly enhanced the reliability and safety of machines, it is still not possible to monitor the health of machines to minute extend.

There are several different techniques for condition monitoring:

1. Vibration Monitoring
2. Noise Monitoring
3. Magnetic Flux Monitoring
4. Partial Discharge Monitoring
5. Infrared Thermography
6. Voltage Monitoring
7. Current Monitoring

Out of the above techniques vibration analysis is one of the oldest and the most successful techniques used for condition monitoring of machines [2]. For vibration monitoring piezoelectric transducer is used, which provide a voltage signal proportional to acceleration. All faults cause a specific alternation of the frequency spectrum, compared to the normal operating condition. Machine vibrations are causes due to Repeating Forces, Looseness and Resonance.

Fault Detection Techniques:-
There are several techniques for fault detection such as:
1. Model Based Approaches
2. Trending
3. Fault Thresholds
4. Multi-Dimension Space Techniques
5. Artificial Intelligent System

Condition monitoring of electrical machines recently have moved from traditional techniques to automated decision making system such as artificial intelligence (AI) techniques because -

- Detailed analysis of the fault mechanism is not required.
- Modeling of the system is not necessary.
- Fault detection can be possible without an expert.
- Several quantities are utilized as input signals: Stator current & voltage, magnetic field and frame vibration.

The main steps of an artificial intelligent diagnostic mechanism are signature extraction, fault identification and fault severity evaluation. The various AI techniques are artificial neural networks (ANNs), Fuzzy Logic, Fuzzy-Neural networks (FNs), genetic algorithms etc [5]. Filippetti et al. successfully diagnosis a broken rotor bar faults in a squirrel cage induction motor using fuzzy logic. He is not only detected the occurrence but also number of broken bars in their system [6].

The International Organization for Standardization (ISO) has defined standard for vibration acceptance limit of machineries name as ISO 10816. Table I shows vibration severity. For example, the machine in group 2 up to 15-300 kw, the vibration level in good condition range from 0.1 to 2.7 mm/sec. Any value of vibration above that range is considered to be at hazard for machine damaged condition. The categories for each class type are labeled as, 'Newly Commissioned Machinery', 'Unrestricted Operation', 'Restricted Operation' and 'Damaged Occurs'.

ISO 10816-3	Machinery Groups 2 and 4	Machinery Groups 1 and 3
Velocity	Rated Power	
CMVP 50 mm/sec RMS	15 kW – 300 kW	Group 1: 300kW–50MW Group 3: Above 15 kW
11.0	Damage Occurs	
7.1		
4.5	RESTRICTED OPERATION	
3.5	UNRESTRICTED OPERATION	
2.8		
2.3		
1.4		
0.7	NEWLY COMMISSIONED MACHINERY	
0.0		

Table I. ISO 10816-3 Standard for vibration severity

III. METHADOLOGY

For Designing of machine condition monitoring system using fuzzy logic in LabVIEW, a set of hypothetical data is used. The system consists of single input and single output. The values that serve as the input data for the system is stored using the Microsoft Excel Program. The excel files vibration data then call into the LabVIEW software. LabVIEW is graphical programming language which is used for automation. It gives fast response and takes less processing time for execution.

In this paper we are mainly focused on Group 2 machinery which includes Medium-size machines and electrical machines with shaft height in between 160 mm and 315 mm. These machines are normally equipped with rolling element bearings and operating speeds above 600 rpm [8].

To design machine condition monitoring system following methodology is applied:

A. Development of Fuzzy Logic System:

Fuzzy logics are multi-valued logics that form a suitable basic for system reasoning under uncertainty or vagueness that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low [9]. For Designing of machine condition monitoring system input is taken from vibration signals .The system has single input and single output .The output of the fuzzy logic is given to the display & motor protection relay. Display shows the machine condition. When machine vibration above the acceptable range protection relay stop the machine which helps to avoid the damage.

B. Membership Functions:

In this system vibration signal is used as input to fuzzy logic system. Triangular and Trapezoidal membership function is used input and output signals. The linguistics terminologies interval for membership function is based on ISO 10816-3 standard shown in Table I.

Figure 1.Shows the input vibration signal membership function graph in which vertical axis shows the degree of certainty between 0 and 1.While the horizontal axis showing the input vibration value that associates with the linguistic terminologies.

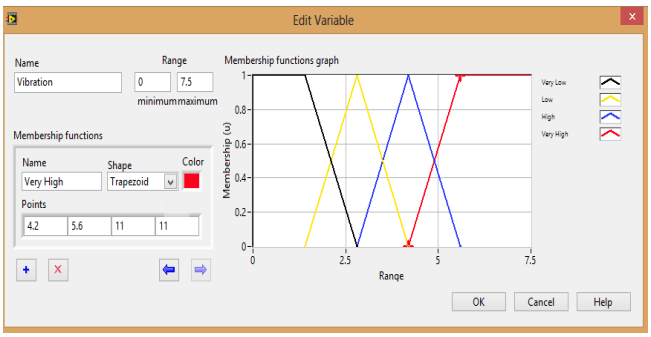

Figure. 1. Membership function for vibration

There are four linguistics terminologies assign vibration input as 'very low',' low', 'high', and 'very high' with numeric value given in Table II.

Categories	Membership Function	
Very Low	$\mu_{VL}(x) = 1$	$\ldots\ldots\ldots 0 \le x < 1.4$
	$= 2.8\text{-}x/1.4$	$\ldots\ldots\ldots 1.4 \le x < 2.8$
Low	$\mu_{L}(x) = 2.8\text{-}x/1.4$	$\ldots\ldots\ldots 1.4 \le x < 2.8$
	$= 4.2\text{-}x/1.4$	$\ldots\ldots\ldots 2.8 \le x < 4.2$
High	$\mu_{H}(x) = 4.2\text{-}x/1.4$	$\ldots\ldots\ldots 2.8 \le x < 4.2$
	$= 5.6\text{-}x/1.4$	$\ldots\ldots\ldots 4.2 \le x < 5.6$
Very High	$\mu_{VH}(x) = 5.6\text{-}x/1.4$	$\ldots\ldots\ldots 4.2 \le x < 5.6$
	$= 1$	$\ldots\ldots\ldots 5.6 \le x$

Table II. Input (Vibration) Membership Function

Similarly four categories had been defined for output. The output membership function available in linguistic forms are 'newly commissioned machinery', 'unrestricted operation', 'restricted operation' and 'damaged occurs'.

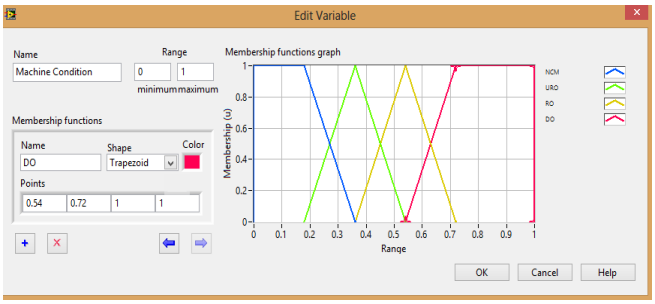

Figure. 2. Membership function for Machine Condition

Table III shows the corresponding membership values for condition of the machine.

Categories	Membership Function	
Newly Commissioned Machinery	$\mu_{NCM}(x) = 1$	$\ldots..0 \le x < 0.18$
	$= 0.36\text{-}x/0.18$	$\ldots.0.18 \le x < 0.36$
Unrestricted Operation	$\mu_{UNO}(x) = 0.36\text{-}x/0.18$	$\ldots. 0.18 \le x < 0.36$
	$= 0.54\text{-}x/0.18$	$\ldots. 0.36 \le x < 0.54$
Restricted Operation	$\mu_{RO}(x) = 0.54\text{-}x/0.18$	$\ldots. 0.36 \le x < 0.54$
	$= 0.72\text{-}x/0.18$	$\ldots. 0.54 \le x < 0.72$
Damaged Occurs	$\mu_{DO}(x) = 0.72\text{-}x/0.18$	$\ldots.0.54 \le x < 0.72$
	$= 1$	$\ldots. 0.72 \le x$

Table III. Output (Machine Condition) Membership Function

C. *Fuzzy Controller/Fuzzy IF-THEN Rule:*

Fuzzy logic controllers are based on the combination of Fuzzy set theory and fuzzy logic. Systems are controlled by fuzzy logic controllers based on rules instead of equations. This collection of rules is known as the rule base usually in the form of IF fact (premise, hypothesis, antecedent)-THEN (consequent) statements [9]. Condition elements in a rule can be connected by different connectives, the most used being AND, OR, NOT. Based on input vibration signal machine condition is classified. For classification of machine condition following rules is used:

SR.NO.	IF(Vibration)	THEN (Machine Condition)
1	Very Low	Newly Commissioned Machinery
2	Low	Unrestricted Operation
3	High	Restricted Operation
4	Very High	Damaged Occurs

Table IV. Fuzzy Rules for Machine Condition Monitoring System

Figure 3 shows the block diagram for the machine condition monitoring system as per the ISO 10816-3 standard for acceptable vibration ranges of machinery. The input to the given system is set of hypothetical data taken in a continuous period of time which is increasing over the time period. The system has single input single output, where vibration signal is a input and machine condition is output. Output is saving in the Microsoft Excel Program from where we can also analysis the fault condition.

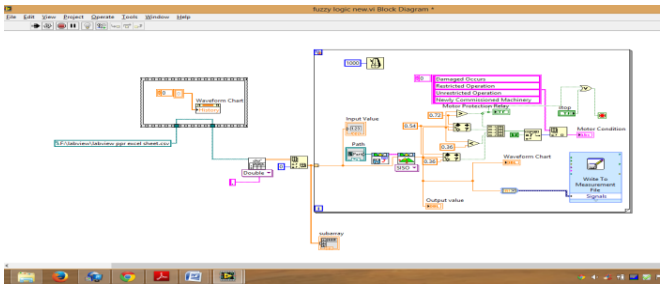

Figure.3. Block Diagram for Machine Condition Monitoring System

IV. RESULT

Figure 4 show the Graphical User Interface (GUI) / Front panel of the machine condition monitoring system. To illustrate the fuzzy inference system, different input vibration signal values were analyzed. When the vibration input value is 'Very Low' with input values of 1.3789mm/sec, the display indicate 'Newly Commissioned' with output value 0.14037. Graph shows the time versus amplitude of the output signal.

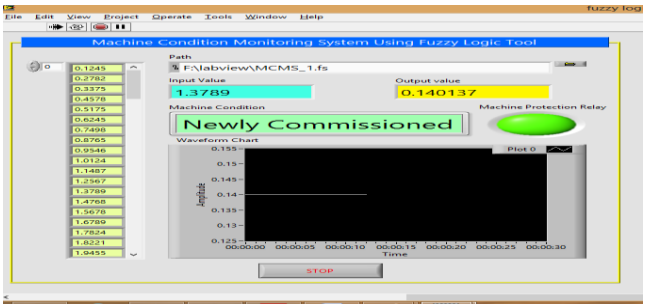

Figure. 4. Front Panel with Input Value 1.37889 mm/sec.

Similarly, Figure 5, shows that when the input vibration is 'Very High 'with a numeric value of vibration signals 5.0744mm/sec, the output indicate 'Damaged Occurs' with a numerical value 0.730178.

Sometimes machines vibrate more than the defined range, for such condition system send a signal to motor protection relay which will immediately stop the motor. So the system also provide machine protection which help to restrict permanent damage of the machines.

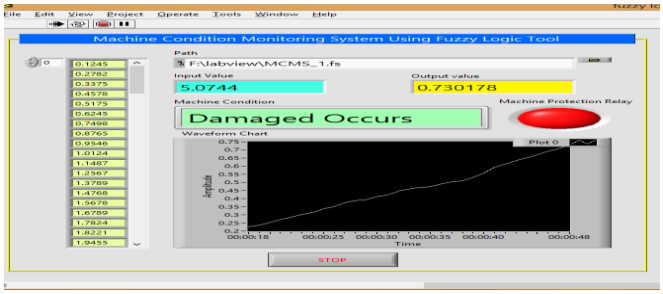

Figure. 5. Front Panel with Input Value 5.0744 mm/sec.

IV. CONCLUSION

By continuous supervision of a dynamic behaviour incipient faults and wear and tear within the machine can be easily detected much before the failure. This does not only prevent the complete failure of the machines, system interruption or bad quality production but also stops the secondary defect that can be induced to other parts of the machine and causes damages to expensive part of the machines. Vibration analysis provides reliable detection of faults in all types of machinery. By using Fuzzy Logic in Lab- VIEW we can easily analyze the condition of electric machines. It's also providing motor protection system for preventing from damage.

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