International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 599-607 www.ijaem.net ISSN: 2395-5252

Predictive Maintenance Practices of Induction Motor

V Venkatesh[1], D Vamsi Krishna[2], KV Kalyani[3], D K Panda[4]
Centre for Mining, Environment, Plant Engineering and Operations (CME)
National Council for Cement and Building Materials, Hyderabad, INDIA

Submitted: 05-08-2022 Revised: 11-08-2022 Accepted: 15-08-2022

ABSTRACT
This paper proposes various approaches for the predictive maintenance of motors. Manufacturing industries spent a huge amount of money on rotating equipment. To keep the machine capable of performing the desired task without breakdown, regular maintenance is to be practiced. Predictive maintenance is an essential technique to predict possible shortcomings in the early stage. The electrical signature analysis technique is a precise analysis technique which is performed by using current and voltage signatures from the motor feeder. It predicts possible fault occurrence in different parts of the motor. Vibration analysis using acoustic monitoring devices deals to solve problem identification in motor positioning, soft foot case. Crucial power parameters like harmonics, swells, transients, efficiency, etc. can easily be understood using the latest power and motor analyzer. Computers are connected with machines to take decisions without human intervention in Industry 4.0 which improves asset life, ease of operation, and monitoring the equipment at a remote location is possible. Predictive maintenance approaches using IOT technology are explained.

KEYWORDS: Induction motor, Predictive maintenance methods, mechanical & mechanical faults, Electrical signature analysis, Partial discharge, IOT

I. INTRODUCTION

Electric motor is an important rotating power source in the industry. Among which Induction motor represent almost 90% of electrical motors in production process. In its total life, a motor goes through many faults, which effects the output efficiency and performance of the plant. The significance of predictive maintenance is to obtain knowledge about the operating conditions of equipment and to predict the possible fault. Industries are always working on newer tech reduce the downtime in handling faults and to increase the efficiency/reliability of motors. In this context predictive maintenance performs an important role to achieve reliability in the process.

Since the Induction motor shares a vast majority in industrial applications, conditional analysis is to be followed on various parts of the motor to improve its efficiency. Conditional monitoring avoids unplanned downtime by detecting and diagnosing impending machine failures. This not only helps plant personals from reducing the catastrophic failure but also allows companies to order parts in advance, schedule personnel and plan other repairs during the downtime. Various conditional monitoring methods of predictive maintenance of Induction motor based on electrical and mechanical parameters along with the latest technologies are explained in this paper.

[1]. Predictive maintenance by Electrical Signature analysis to Induction motor. Research gate October, 2012 **Eric Leonardo Bonaldi, Levy ely de lecarda de Olivera, Jonas Guedes Borges da Silva, Germano Lambert-Torresm and Luiz Eduardo Borges da Silva**This paper portrays various predictive maintenance methods by using signature analysis techniques. Here current, voltage signal is considered as a frequency signature spectrum. The signature spectrum is transferred to a spectrum analyzer after passing through a signal conditioner which removes irregular frequencies. Fast Fourier Transfer tool is used in analyzing the spectrum. After analyzing the obtained spectrum various possibilities of faults in the motor are obtained.

[2]. Detection of Induction Motor Coupling Unbalance and Misalignment via Advanced Transient Current Signature Analysis Universitat Politècnica de Valencia, Research gate September 2018, **JA Antonio-Daviu, Peter Popaleny.** This paper analyzes mechanical faults in an induction motor. Bearing failures, shaft misalignment, and incorrect assembly type mechanical problems are

assessed using vibration and thermography techniques. The author had conducted experiments on a test bench with 1.1 kW 4 pole induction motor coupled with a DC machine enabled to set different load conditions for fault analysis. The experimental results are showcased in graphs differentiating healthy motor and faulty motor.

[3]. Fluke 438-II Motor and Power analyzer displays various electrical and mechanical measuring parameters without any sensors and transducers. The handheld instrument can measure different parameters of motor drive in a loaded condition. The obtained parameters are displayed as bar graphs for ease of understanding.

[4]. Acoustic monitoring and background noise in industrial environment, Research Gate Conference paper June 2013, 286273695, **Maciej Orman and Cajetan T. Pinto.** This paper showcases monitoring and predictive maintenance technique for induction motors using acoustic technology. By analyzing the sound emitted from the motor, faults can be predicted. In an experimental study, the author used an acoustic microphone and camera for analyzing the sound of a healthy motor and a faulty motor. Motor foot case arrangement had been altered to vary the fault level of the motor. Graphical representation differentiates the amplitude, and frequency variation of both motors.

[5]. Predictive maintenance using IOT: IOT based predictive maintenance techniques enables the user to maintain, monitor, optimize, and utilize the assets in an effective approach. The real-time monitoring feature allows better visibility of assets and predict possible faults, identify faulty components, and track maintenance schedule. The latest IOT-enabled applications are explained in this paper.

[6]. IR Thermography technology does thermal information analysis from non-contact thermal imaging devices. The emitted radiation in the infrared range of the electromagnetic spectrum is detected. Heat development on the surface or any part of the motor is one of the symptoms of the occurrence of a fault. Possible reasons for the progress of heat in equipment are, bearing fault, shot circuited winding, stator, rotor alignment problems, etc. As a predictive maintenance activity, all such problems can be analyzed from the thermal condition on the equipment surface. Nowadays IR cameras are mounted on drones for thermography measurement of motors or loads installed away from plants.

[7]. Detection of Partial Discharge Activity in H.V Rotating Equipment, IJSRSET, Volume-3, Issue-1, ISSN: 2394-4099, 2017, **Hitesh B. Renuka.** This paper explains the continuous monitoring of partial discharge activity using different PD sensors. Sensors like High voltage coupling capacitor (HVCC), High-frequency current transformer (HFCT), Transient earth voltage (TEV), and Rogowski coil are explained. Partial discharge activity is a key technique in conditional monitoring of HV motor. It provides actual data related to the insulation condition of the motor. From the obtained data the condition of the motor can be assessed without interrupting the running of the machine. A shutdown or other preventive actions can be planned which helps the plant from unplanned breakdowns.

II. PREDICTIVE MAINTENANCE METHODS OF INDUCTION MOTOR

Like all the rotating machines induction motors are exposed to many different electrical, mechanical, thermal, and environmental stress which require thorough attention to make the machine work efficiently.

The most common electrical predictive maintenance methods applied to detect faults in an induction motor are Electrical signature analysis (ESA), partial discharge detection, Motor current signature analysis (MCSA), Extended park's vector approach (EPVA), and Instantaneous power signature analysis (IPSA). Similarly, mechanical predictive methods are vibration analysis, acoustic analysis, and speed oscillations. By applying the right maintenance practices, the service life of equipment, plant productivity and efficiency can be increased. The above-mentioned analysis is performed as predictive maintenance methods of induction motor.

III. FAILURES IN INDUCTION MOTOR

Any rotating part of the motor like bearing, shaft, and rotor is most frequently prone to failure. Along with the rotating part, stator is also affected through faults due to overheating and other possible reasons. The figure shows the layout of induction motor with its input obtained from electric supply and output delivered to a mechanical load. During this transaction many losses occur which are explained below:

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 599-607 www.ijaem.net ISSN: 2395-5252

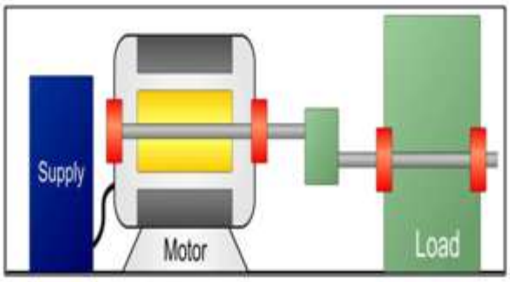

Figure 1: Drive train of Induction Motor

Bearing faults: Bearing is solely responsible for the rotation of shaft and rotor of the motor. Most of the bearings do not achieve their useful life. Its life is impacted by many reasons related to improper maintenance and poor monitoring practices. Incorrect lubrication, mechanical stress, incorrect assembly, miss alignment, coupling system problems etc. are the frequent cause of bearing failure. All other bearing parts like inner and outer races, cage, and balls are also affected by these faults.

Rotor faults: The rotor of the induction motor is subjected to high temperature as compared to the stator winding. Most common reasons for faults are broken bars, broken end rings, rotor misalignment, and imbalance.

Stator winding faults: Due to the consequence of overheating, misalignment, poor quality of construction and materials possible causes for shorted coils of same phase, shorted turns, phase to phase, open circuit, coil to ground, and single phasing. Such failures cause stator current imbalance as well as variation in harmonic current. Mechanical problems in stator are like loosen edges but the possibility of occurrence of such faults is comparatively less.

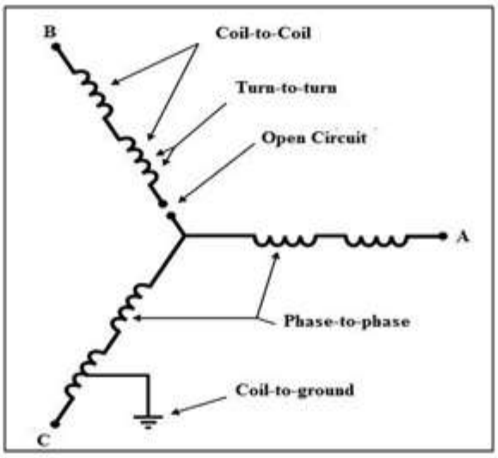

Figure 2: Possible Electrical faults occur in Stator

Faults in the coupling: Coupling accessories like a pulley, and belt which are attached to the load are affected with faults. In most cases load is placed at a place far away from the motor, which is connected using a belt or chain. Several environmental factors come into consideration as in most of the places these belts are exposed to the atmosphere. Failure in these accessories is directly responsible for the requirement of high starting torque, higher inrush current, etc. which contribute possible occurrence of rotor and stator faults.

Improper foundation support causes misalignment of the motor foot, which is also termed as soft foot. "Soft foot" is explained as improper contact between the machine cage and the baseplate used to support it. This is a major cause of problems in shaft alignment measurements. It also causes mechanical vibrations, reduce the life of electric motors and cause internal clearance problem in gearboxes and pumps. Possible causes of soft foot in the motor are dents in the base plate, dirt, trash unwanted materials under machine feet. These problems can be minimized by taking care during the casting of foundation and foundation bolts and using laser guiding equipment for positioning foundation bolts.

A graphical representation of faults in three phase induction motor along with weightage of stator, rotor and electrical, mechanical faults in stator and rotor are displayed below:

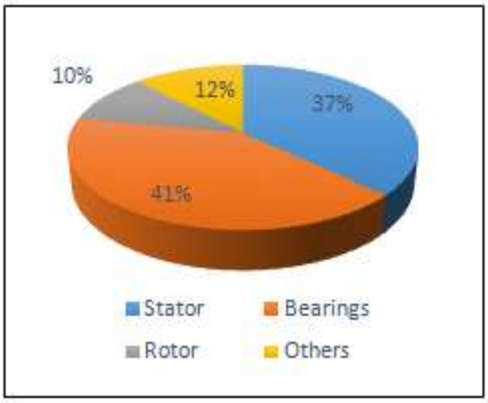

Figure 3: Problems in Induction Motor

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 599-607 www.ijaem.net ISSN: 2395-5252

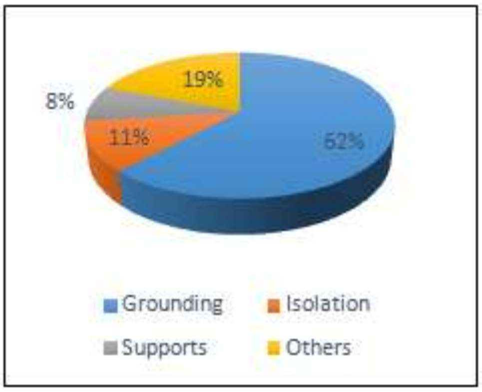

Figure 4: Problems in Stator

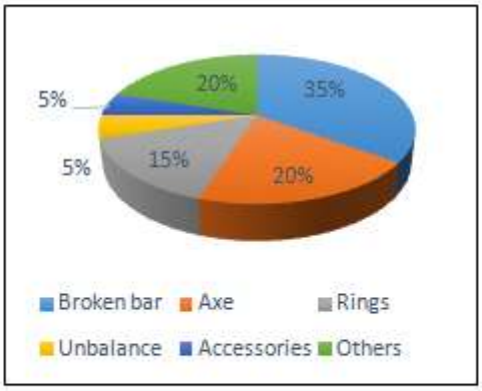

Figure 5: Problems in Rotor

IV. PREDICTIVE MAINTENANCE USING VARIOUS ANALYSIS TECHNIQUES.

Objective of predictive maintenance is to ensure correct maintenance practice at the right time and to reduce the maintenance costs by detecting the faults at an early stage. In order to carry out the analysisdifferent tests of motor current, voltage, vibration and partial discharge are conducted. The results of the tests helps to predict when the motor needs to be replaced. Various methods as mentioned above in (SL.3) are applied on different parts of the motorare shown below:

Drive Train	Analysis
Mechanical imbalance in Motor frame	MCSA
Power Supply	Power Quality
Bearing faults	Vibration
Insulation faults in Motor frame	Partial discharge
Stator Electrical imbalance	EPVA

Table1: Fault analysis technique of motor components.

4.1 Electrical signature analysis

Here the electrical current is taken as a signature which is further analyzed. ESA is a non-intrusive analysis where there is no need to attach any sensors to the rotating part of the motor. From motor control center(MCC) the readings can be taken. Other signature analysis which is obtained using signals of current and voltage are Motor Current signature analysis (MCSA), Voltage signature analysis (VSA), and Extended Park's vector approach (EPVA). In all these above analyses electrical motor acts as a transducer where variations in voltage and current signals are analyzed concerning failure patterns. Working principle of motor current signature analysis is explained in this paper.

Motor current signature analysis (MCSA):

The operating conditions of induction motor are analyzed with this technique without interrupting the production. Electrical signal is sensed in this analysis which contains current components. MCSA detects the faults at an initial period and avoids the damage and complete failure of the motor. Here the acquired current signal from one phase of the motor supply is processed further to obtain a frequency spectrum which is usually termed as "current signature". MCSA uses this current signature of the machine for locating fault frequencies of the machine by comparing with the frequencies of individual components. The frequency spectrum of faulty motor and the healthy motor is found different when a fault is present.
MCSA results assists in identifying following faults:

a. Misalignment/unbalance
b. Winding health
c. Rotor bar damage
d. Foundation issues
e. Eccentricity
f. Load faults
g. Stator mechanical/electrical faults
h. Defective bearings
i. Coupling health

In this technique, an induction motor is used as a transducer which allows the user to evaluate the electrical and mechanical parameters from the panel and consists primarily of one of the three phases of the supply current of the motor. The obtained current signature is further processed using Fast Fourier Transform (FFT) tool. As the main motto of this analysis is to perform testing when the motor is running, so the expert knowledge and data history of the behavior of the set (motor, transmission, and load) are considered.

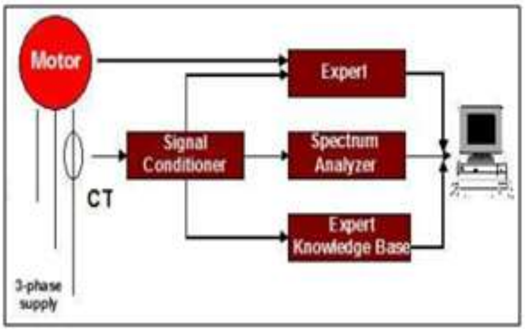

Figure 6: Block diagram of Motor current signature analysis process

4.2Power quality Analysis of Motor

Fluke motor and power analyzer monitor, record, and analyze the electrical and mechanical parameters of the motor feeder. It offers a full range of power quality features that helps the facility managers and engineers to understand where and when dangerous and destructive transients, harmonics, sags, and swells arise. Along with power quality and power parameters the analyzer also measures mechanical parameters like rated speed, torque and calculates motor efficiency of the loaded motor without any torque sensor and tachometer. The analyzer measures various parameters by connecting rated CT's and voltage terminals to the power terminals of the motor feeder following all safety precautions.As a predictive maintenance practice the analyzer diagnoses potential problems and minimize the down time of equipment maintenance.

Figure 7: Power and motor analyzer connecting to a motor feeder circuit.

4.3Vibration Analysis using Acoustic Monitoring of Motor

Monitoring and diagnosing of motors is very crucial in industries to prevent unpredictable shutdowns of electric machinery. One of the possibilities of predicting the fault of motor is by the sound emitted by the machine which is termed as acoustic monitoring but background noise is one of the disrupting factor. Diagnosing by noticing the abnormal sound "by ear" since many years with the existence of background noise. It requires judgmental skill and experience to detect such faults.

As a modern solution, acoustic cameras can solve the problem by identifying the sound source and quantifying it. It produces an image of the acoustic environment through the processing of the multidimensional acoustic signals received via microphone array to overlay that acoustic picture on the display screen.

The acoustic holography technique is used to estimate the sound field near a source by measuring the acoustic parameters by microphone array. A vibration and acoustic study is conducted on two induction motors for condition monitoring in a noisy environment. One motor is healthy and the other has static eccentricity with soft foot case.

The distortion caused by one or more foot of a machine's height differs from others is termed as soft foot. As a part of the study, vibration sensors and an acoustic microphone are positioned near the machine and the output graphs of two machines are plotted. The plotted graphs show the visible variation between its amplitude and frequency. The machine with static eccentricity and soft foot case shows a rise in the amplitude with the same frequency as applied to the healthy motor.

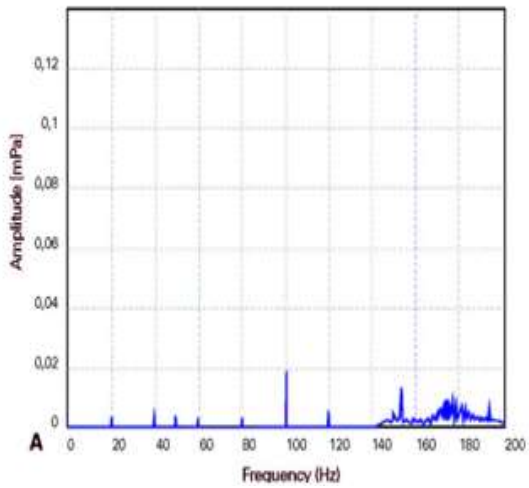

Figure 8(A): Vibration spectrum of healthy motor

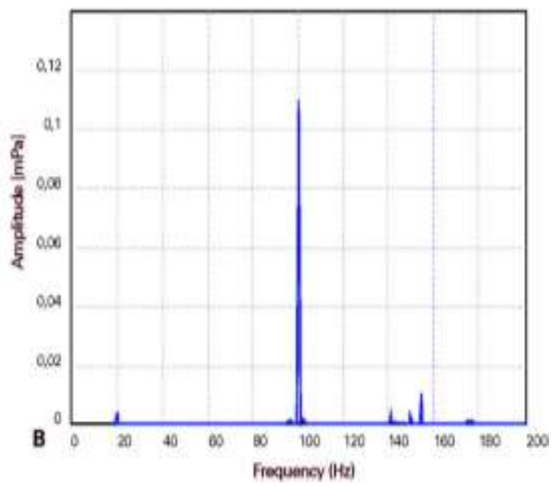

Figure 8(B): Vibration spectrum of motor with static eccentricity and soft foot case

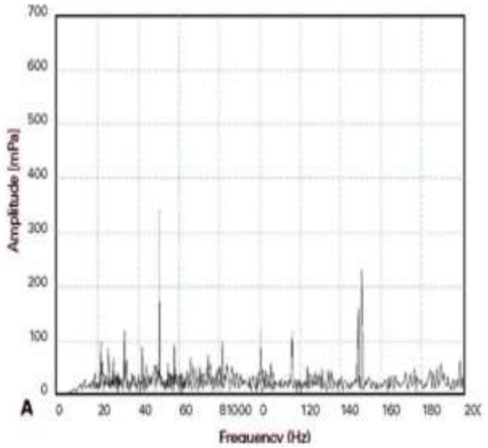

Figure 9(A): Acoustic spectrum of healthy motor

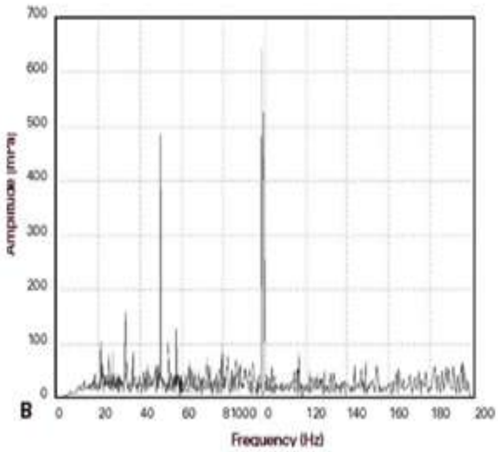

Figure 9(B): Acoustic spectrum of motor with static eccentricity and soft foot case

4.4 Partial Discharge Detection using sensors.

Partial discharge (PD) occurs in high voltage (HV) electric equipment like motors, generators, transformers, and cables. The spark occurs inside the equipment due to damaged or poor insulation levels. In industrial high voltage devices, PD occurs due to poor insulation either inside the equipment called internal PD, or on the surface of the equipment called external PD. Microscopic air-filled voids which remain in the insulation during the manufacturing process, and improper handling act as a possible causes of internal PD. When the local electric field stress exceeds the breakdown strength of air it is termed external PD. Environmental factors like poor air clearance, and contamination on the end-windings act as possible causes of external PD. External PD can easily be detectable, as a deposit of white powder is observed on the insulation.

PD generates a short duration temperature spike and emits UV light which stresses the insulation. Assessment of the condition of electrical insulation can be done by detection and monitoring of partial discharge activity. PD occurs in stator winding of the motor can be measured by HFCT, HVCC sensor at the switchgear end of the supply cable. Various sensors are used for monitoring PD in rotating equipment depending on the attachment of the sensor and features of PD pulses. High voltage coupling capacitor (HVCC), High-frequency current transformer (HFCT), are some of the sensors having high relative sensitivity for online monitoring of PD.

HFCT stands popular among other sensors due to its flexibility and easy installation. Mutual inductance of coil and rate of change of PD current are the deciding factors for measuring PD. It detects PD signal with higher frequency (>10 MHz). With High-frequency sensing, the CT can be placed with a cable connecting motor from a remote location. The output of the CT is passed to measuring equipment to study thelevel of PD.

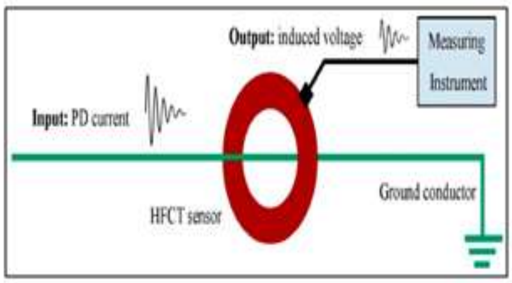

Figure 10: HFCT sensor schematic diagram

HVCC sensor is designed for testing and monitoring PD. The sensors are installed permanently on each phase of the machine MCC panel, for periodic spot testing or connection to a continuous online PD monitoring system. It is available up to 30 kV of operating voltage. Single coupler and twin coupler installations are two modes of sensor connections. Coaxial signal connection cables are taken out to an external sensor connection box on the side of the machine allowing PD measurements to be made at any time without the need for any outage.

4.5Predictive maintenance using IOT

Industry 4.0 stands for fourth industrial revolution which is defined as new level of dominance over the entire value chain of life cycle the products. It revolutionizes the application of new technologies like Internet of Things (IOT), Artificial intelligence, cloud computing, and machine learning in manufacturing industries to improve manufacturing productivity and maintenance activities. The introduction of IOT and other technologies transforms conventional factories into smart factories which are equipped with smart sensors, embedded software, and robotics. This practice involves collection of machine data such as operating temperature, supply voltage, current and vibration through sensors. Wireless transmission of the collected data is transferred to a cloud based centralized data storage platform in real time. Collected data is analyzed by using predictive analytics programs and machine learning algorithms to derive actionable insights and helps to detect errors immediately rather than at later stages when repair work becomes more expensive.

"SIMOTICS CONNECT" is a sensor and communication module, integrated with sensors that digitally monitor the condition of the motor to make it transparent. It facilitates application and process optimizations of low voltage motors. The major monitoring application is to visualize the motor health status and data analytics of the observed parameters using its proprietary software. Measured parameters of the motor are temperature, radial/tangential/axial vibration, electrical stator frequency, and slip frequency. It has a temperature measuring range of -40°C to +85°C with a resolution of 0.03°C and a vibration measurement range of 0.02 to 180mm/s. Along with this calculated motor parameters are motor (on/off), rotation, speed, torque, electrical power, energy consumption, number of starts, and hours of operation.

Figure 11: Simotics Connect linked to a motor

Other predictive maintenance parameters like maintenance, and motor overhauling period forecast are displayed. Any fin cooled three-phase asynchronous motor in line operation with DOL or VFD converter operation. The device is made of galvanized stainless steel material which is IP 54 protected and is externally mounted on the motor's cooling fan with a glued mounting bracket. It has a shock resistance of max. 100m/s2. It is powered with a battery pack with AA type of batteries. The collected data is stored in its cloud storage. Wireless networks like WLAN and Bluetooth are used for data transmission.

Figure 12: Cloud data storage architecture of Simotics Connect

"Machine Monitor" technology application developed by SIEMENS keeps track of maintenance needs for any machine based on its real usage. It allows the user to create customizable maintenance rules for each machine type and activates them for continuous monitoring of the machine. It generates an advance notification for maintenance work that is due soon. Each service line can be analyzed through its trend prediction also required instructions are available in quick access.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 599-607 www.ijaem.net ISSN: 2395-5252

"Energy Manager" technology application developed by SIEMENS creates more transparency about energy consumption in manufacturing industries. Its consumption analysis algorithm helps the user to reduce energy costs. It gives an overview of the information of machines used at a global level which allows to benchmark energy consumers and visualize optimization potential. The analysis tool helps to visualize costs, energy consumption, and CO_2 equivalents from its dashboards. This tool creates a Sankey diagram for energy supply which gives a holistic overview of the production.

4.6 Predictive maintenance using Infrared thermography

As per NFPA (National fire protection association) report, 10% of the fires occurring are associated with electrical system failures like failure of terminals, electrical insulation, and associated components. The infrared thermography technique is gaining importance as an efficient analysis technique. Performing infrared testing on Motors, electrical panels, transformers, power cables, etc. using the latest Thermographic equipment highlights the possible problems with electrical infrastructure under load during the testing process. This is one of the best technologies for predictive maintenance of electrical installations and frontline troubleshooting. This test can be performed as a standard practice at regular intervals of time. The results of the test showcase the abnormal temperature patterns of the electrical equipment. The output of the thermograph can be examined by various color patterns, blue color represents cold, green color is approximately room temperature and darker color like red indicates the hotness of the equipment hotspot.

Figure 13: Thermography imager

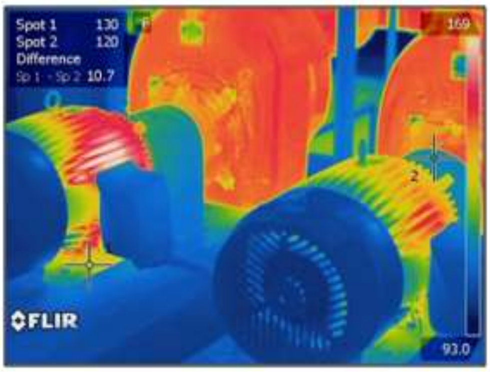

Figure 14: Thermography output of motor

As a non-destructive testing method, it provides valuable information about surface temperature, surface moisture, air leakages, equipment physical status, etc. With this information, an expert engineer can easily examine the condition of equipment from a remote location. A radiometric thermal camera is mounted on a drone, it gathers non-contact temperature measurements from an aerial perspective. Internal insulation faults, stator, and rotor faults lead to a rise in the external temperature of a motor, negligence in attending to the issue may burn the motor windings. In most industrial applications, motors are installed away from the load centers. Continuous monitoring of such motors is difficult for the maintenance team. Drone technology will solve this problem as a periodic maintenance assessment tool.

It is also beneficiary for inspection, hotspot detection, survey, and progress monitoring of solar PV panels, electrical transmission, and distribution lines, street lights, buildings, etc. Machine learning (ML) and artificial intelligence (AI) technologies with drones transform the gathered aerial data into instantly actionable insights, the data also integrates with other enterprise systems to generate reports.

V. CONCLUSION

This paper concludes with various predictive maintenance techniques for conditional monitoring of induction motors in industries. The objective of the context is to disseminate important concepts of maintenance to guide industrial users to have their predictive maintenance group or want to hire external specialized consultants which deliver good results through predictive maintenance practices. Latest technological advances like IOT, thermal cameras, etc. are explained here and are to be utilized for efficient conditional monitoring of machines.

REFERENCES

[1]. **Eric Leonardo Bonaldi, Levy ely de lecarda de Olivera, Jonas Guedes Borges da Silva, Germano Lambert-Torresm and Luiz Eduardo Borges da Silva**- Predictive maintenance by Electrical Signature analysis to Induction motor. Research gate October, 2012.

[2]. **JA Antonio-Daviu, Peter Popaleny**- Detection of Induction Motor Coupling Unbalance and Misalignment via Advanced Transient Current Signature Analysis, UniversitatPolitècnica de València. Research Gate September 2018.

[3]. Fluke 438-II Motor and Power analyzer operational manual

[4]. **Maciej Orman and Cajetan T. Pinto** Acoustic monitoring and background noise in industrial environment, Research Gate Conference paper June 2013, 286273695

[5]. "**SIMOTICS CONNECT 400**" Technical data sheet.

[6]. Fluke Thermal Imagers datasheet

[7]. **Hitesh B. Renuka**, Detection of Partial Discharge Activity in H.V Rotating Equipment, IJSRSET, Volume-3,Issue-1,Online ISSN:2394-4099, 2017