# Online Health Monitoring of Induction Motor IOT Based

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**DEPARTMENT OF ELECTRICAL ENGINEERING**

# Certificate

This is certified that the work presented in this project thesis on ***"ONLINE HEALTH MONITORING OF INDUCTION MOTOR IOT BASED"*** is entirely written by the following students themselves under the supervision of ***Dr. Attah Ullah Khidrani.***

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***This project is submitted in partial fulfilment of the requirement for the award of "Degree of Bachelor of Engineering" in Electrical discipline.***

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# DEDICATED TO

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Our Mentors and Advisors,
For their guidance, expertise, and invaluable insights that have shaped my understanding and enriched the quality of my work.

# DECLARATION

It is to certify that this is the original copy our thesis. We have completed all the chapters of this thesis by our own self under the directions of our supervisor, and we are the sole author of the thesis. We hereby declare that this thesis has not been submitted for any degree elsewhere.

**MEMBER's SIGNATURES**

# ABSTRACT

Induction motors, known for their reliability, low cost, and straightforward construction, are instrumental in driving various industrial processes. These motors translate electrical energy into mechanical work with high efficiency, necessitating minimal maintenance. While conventional maintenance methodologies predominantly employ scheduled routines or reactive actions post-unforeseen failures, the need for constant health monitoring is paramount. This stems from the intrinsic role induction motors play in sectors ranging from manufacturing to energy systems and transportation. The current research revolves around the concept of online health monitoring systems for induction motors, which have recently emerged as potential game-changers. By harnessing sensor technologies, advanced data processing algorithms, and connectivity protocols, these systems promise real-time insights into motor health.

This thesis focuses on the development of a cost-effective and reliable system for consistent health monitoring of induction motors to mitigate unplanned downtimes. The methodology encompasses defining the system's scope, sensor selection for vital health parameters, ensuring sensor compatibility, and designing data acquisition protocols. Machine learning algorithms are employed for fault detection and facilitating predictive maintenance. This modern approach is juxtaposed with traditional maintenance practices, evaluating accuracy, reliability, and cost-effectiveness. Anticipated outcomes include enhanced fault detection, predictive maintenance capabilities, and improved motor efficiency. Given the widespread use of induction motors in industries ranging from power distribution to wind turbines, this health monitoring system signifies a stride towards amplified industrial efficiency and productivity.

# TABLE OF ABBREVIATION

| | |
|---|---|
| **IM** | **Induction Motor** |
| **CRIM** | **Cage Rotor Induction Motor** |
| **WRIM** | **Wound Rotor Induction Motor** |
| **FT** | **Fourier Transform** |
| **FFT** | **Fast Fourier Transform** |
| **STFT** | **Short Time Fourier Transform** |
| **GT** | **Gabor Transform** |
| **WVD** | **Winger Ville Distribution** |
| **WT** | **Wavelet Transform** |
| **IR** | **Infra-Red** |
| **MCU** | **Micro Controller Unit** |
| **RTD** | **Resistance Temperature Detector** |
| **RPM** | **Revolution per Minute** |
| **Wi-Fi** | **Wireless Fidelity** |
| **ISR** | **Interrupt Service Routine** |
| **LCD** | **Liquid Crystal Display** |
| **PCB** | **Printed Circuit Board** |
| **RTC** | **Real Time Clock** |
| **GSM** | **Global System for Mobile** |

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## TABLE DETAIL

# CHAPTER No. 1. Introduction

## 1.1. Overview of Induction Motors

From their inception, induction motors have significantly impacted the industrial world. Their fundamental capability to convert electrical energy into mechanical action allows for a wide range of applications. Their origins trace back to the late 19th century when innovators were searching for effective and efficient means of energy conversion. The preference for induction motors in various industries today is attributed to their reliability, cost-effectiveness, and simplicity in construction.

Induction motors (IM) are electro-mechanical energy conversion devices which employed ina large amount of industrial applications for the conversion of electrical energy to mechanical energy. These types of machines are extremely admired throughout the globe as the workhorse in industrial uses. There are several causes as written below behind the recognition of I.M are:

- Uncomplicated in design, tough in construction and in addition they are inherently strong and able to labor in any ecological condition.
- Nonexistence of brushes, commutators and slip rings (in case of cage rotor I.M) compose the I.M comparatively cheap.
- Nonexistence of brushes, commutators and slip rings (in case of cage rotor I.M) they are more or less maintenance free motors and sturdy and therefore these motors can jog for years on the end with comparatively no cost of maintenance.
- IMs are comfy to labor in polluted and hotheaded environments since they do not have brushes which could be the reason of sparks.

- Unlike synchronous motors, 3-ϕ IMs have own starting torque thus no starting methods are needed unlike synchronous motor.

- Existing in large range of power ratings beginning from fractional horsepower to a number of hundreds of horsepower.

With these above mentioned smart advantages in IMs, they are very outstanding in industrial and household applications. Regardless of these benefits, the IM is also undergoing from some of the weaknesses as compared to dc motors and synchronous motors as given here:

- 3-ϕI.Mespecially cage rotor induction motor (CRIM) has the affinity of high incoming starting current but supplied meager starting torque. It constructs the motor mismatched for many industrial purposes like traction. Large incoming starting current can create transitory voltage dip at the starting of the machine. However that current can be restricted by implementing some starting methods in IM.
- IM persistently works at lagging p.f and in particular during light loads IM functions at very bad p.f (0.2 to 0.4 lagging).This low power raises $I^2R$ losses in the system and therefore decreases system efficiency. Thus, a number of power factor correction devices like static capacitor banks have to be connected close to the I.M to reimburse the power factor.
- Excellent speed control of I.M is a complicated mission. On the other hand, in recent days due to the development of the power electronics field, solid state speed control cures the problem up to adequate extend. A variable-frequency power-electronic drive is made use in this case.

In spite of these characteristic limitations approximately 80% of the motors in the industries are IMs. IMs are categorized into two types based on its stator construction. They are (a) Squirrel cage type Induction motor or cage rotor Induction motor (CRIM) and (b) Slip ring Induction motor or Wound rotor Induction motor (WRIM). But the mostly preferred IM for the industry is Cage rotor type IM (CRIM) for its stoutness. In this thesis health monitoring is done on CRIM. A3-$\phi$ CRIM is shown here in the Fig.1.1.

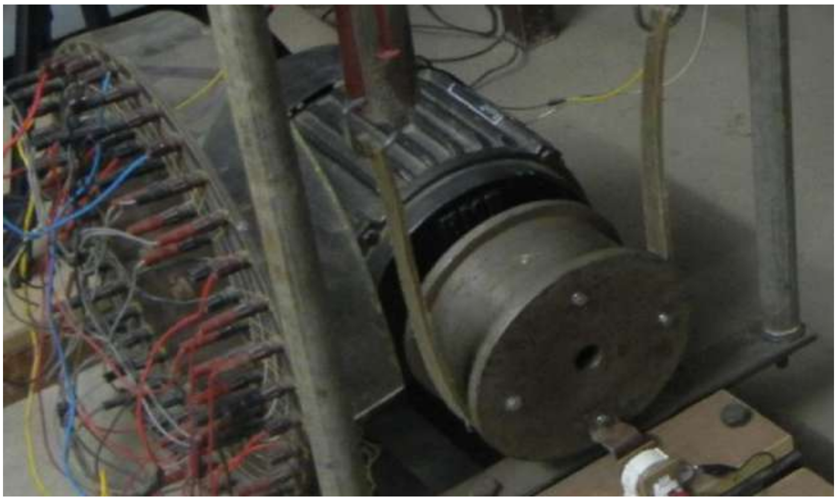

Fig. 1.1: Induction motor

CRIMs are very tough in construction and not only utilized in common uses but also utilized in distinctive environment and dangerous location. IMs are usually used in different distinctive applications like packaging equipment, conveyors, elevators, pumps centrifugal machines, presses and machine tools. On the other hand, applications in hazardous sites contain petrochemical and natural gas plants, whereas severe environment applications for IMs include grain elevators, shredders and apparatus for coal plants. Even though CRIMs are highly trustworthy industrial drive, these motors are frequently exposed to unfriendly environments during working which escorts to early stage deterioration. If there is even a tiny fault in the machine, then that will also work like infection to the machine which will later make total failure of the machine and hence the system related to the machine. This kind of breakdown will kill the time and make the large loss of money .The fault is also reduce the efficiency of the machine and create other disturbances like unexpected temperature rise and even more vibration. The temperature rise and vibration may be the cause of insulation life problem and bearing problem respectively. As a result, health monitoring of CRIM and appropriate analysis of the problem is very necessary to get a suitable action which stop the exclusive maintenance cost. It is more essential to identify the fault as soon as it occurred or tents to occur. An expert diagnosis technique and hence a system for health monitoring of CRIM is to be developed to escape from all above said difficulties.

## 1.2. The Importance of Maintenance

While induction motors are renowned for their resilience, maintenance remains pivotal to ensure their longevity and efficiency. Traditionally, maintenance practices primarily consisted of scheduled routines or reactive interventions following unforeseen failures. Such approaches, though conventional, come with a plethora of drawbacks. Unplanned downtimes, potential efficiency reduction, and sometimes safety hazards can be the consequences of unexpected breakdowns. In a world driving towards maximal operational efficiency, these traditional methodologies often fall short of ensuring optimal motor performance.

There are different faults occurred in the induction motor while it is operating as workhorse in the industry. Some of the very regular and repeatedly occurred IM faults are shown in Fig. 1.2. There will be a detail discussion of induction motor faults in chapter 2 in literature review.

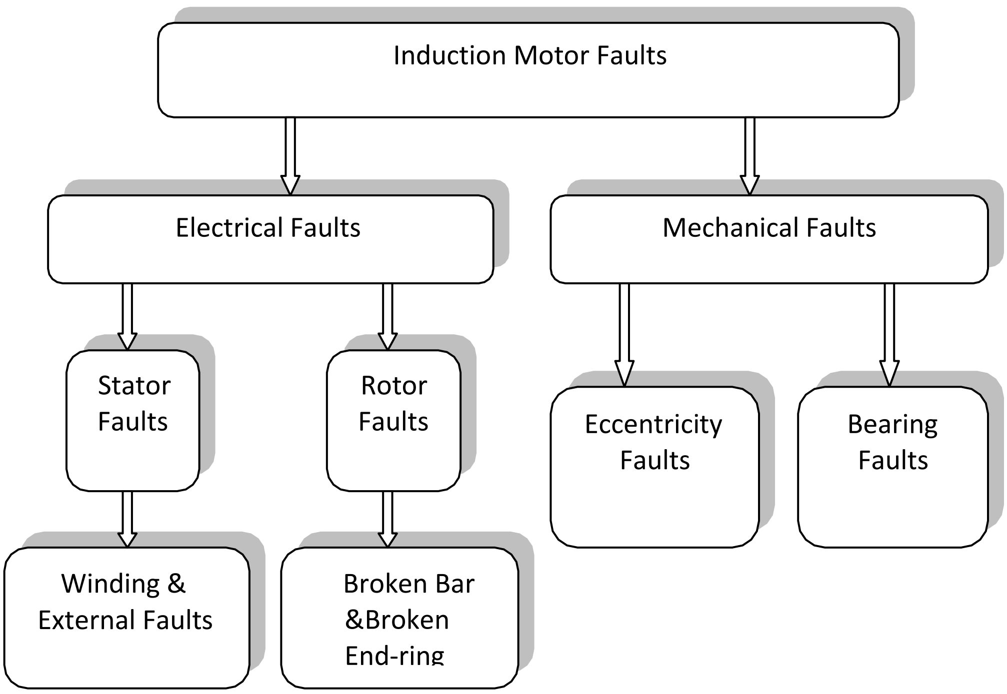


Fig. 1.2: Classification of Induction Motor Faults

Due to the various types of faults occurred in induction motor, it is very challenging for the researchers to develop an efficient health monitoring system for the induction motor. For that reason researchers developed a lot of health monitoring techniques to monitor the health of the induction motor. Various diagnosis techniques are also invented by the researchers to detect the particular faults in the induction motor.

Health monitoring is the process of monitoring the various necessary parameters in the machinery, such that a considerable change is indicative of a developing failure. The use of health monitoring allows maintenance to be scheduled or other action to be taken to avoid the consequences of failure, before the failure occurs. On the other hand, a deviation from a reference value such as temperature and vibration behavior must occur to identify looming damages. Health monitoring system can only measure the deterioration of the machine condition before the failure already commenced. Health monitoring is just a preventive step to protect the machine form a total shutdown. It is typically much more cost effective than allowing the machine to fail.

Today's industrial policy and globalization has made industrial environment very competitive. Therefore, down time for maintenance is of great importance. Significant saving in energy and production cost can be attained by applying health monitoring system in the industry. Machinery used in the industrial purposes is very costly and valuable assets but unfortunately they have to work under extremely unsympathetic condition, where a failure may be disastrous, both in safety and economic features.

There may be two options in operating plant and machinery

- **Breakdown maintenance:** Machine will operate until it requires attention and stripped down.
- **Condition based maintenance:** Failures anticipated and monitored continuously.

Both techniques have their own applications.

### 1.3. The Emergence of Health Monitoring

As technology has advanced, the realm of maintenance has also experienced innovation. Online health monitoring systems, equipped to provide real-time insights into the operational health of machines, have emerged. These systems harness advanced sensor technologies, sophisticated data processing algorithms, and modern connectivity protocols to furnish real-time and accurate data. The underlying promise is two-fold: enhanced operational efficiency through predictive maintenance and an overall reduction in unscheduled downtimes.

Health monitoring plays a very important rule as a preventive maintenance of the important machinery in industry, like induction motor in our case, by detecting problems before they result in a major machine malfunction breakdown.

Here some of the common benefits of health Monitoring are given below:

- Minimization of machinery breakdowns or failure
- Exploring the cause of repetitive failure of machine
- Planned and anticipated maintenance
- Ensuring the safety of the equipment against vibration and shock
- Lower maintenance cost
- Dynamic balancing of rotors and rotating components
- Measurement of natural frequency in static condition
- Less downtime and more productivity
- Reduced inventory for spares
- Better customer relations.
- Enhancing the machine endurance limit
- Greater safety to work force.

Type of Health monitoring of Induction motors are shown in Fig. 1.3.

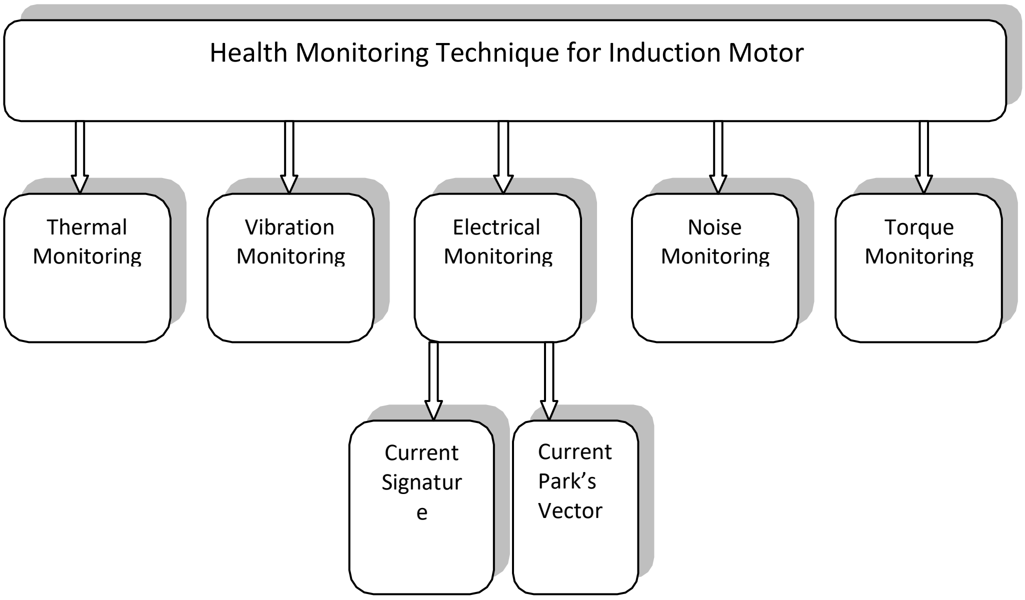


Fig. 1.3: Different Health Monitoring Techniques

Fig. 1.3 has shown some of the parameters which help us to monitor the health of the induction motor. Thermal monitoring can be done by two ways one with the thermal sensor connected physically to the machine and the other with the help of analysis of thermal image of the machine. Thermal image is taken by the infrared thermal image camera. Vibration monitoring can be done by the vibration sensor connected with the induction motor. Electrical monitoring can be done my observing stator current signature. By capturing the sound signature of the CRIM we can develop a noise monitoring technique which helps to monitor the machine health. By measuring the air gap torque of an induction motor also health of the induction motor can be predicted.

The most important health monitoring techniques is diagnostic techniques for induction motor faults. We have used innovative soft computing techniques to identify the faults in CRIM. The whole analysis is done in two ways one is on line method and other is off line method. In on line method, continuously health condition will be declared on the computer screen. If there is any fault occurred, that can be identified and declared by the system and a warning message will be displayed on the computer screen quickly until the fault is corrected. On the other hand, off line method will identify the faults by analyzing the data which are saved in the computer directory during the data acquisition. The whole analysis is done by using the MATLAB and LabVIEW

Software. The process of fault diagnosis is shown in Fig. 1.4

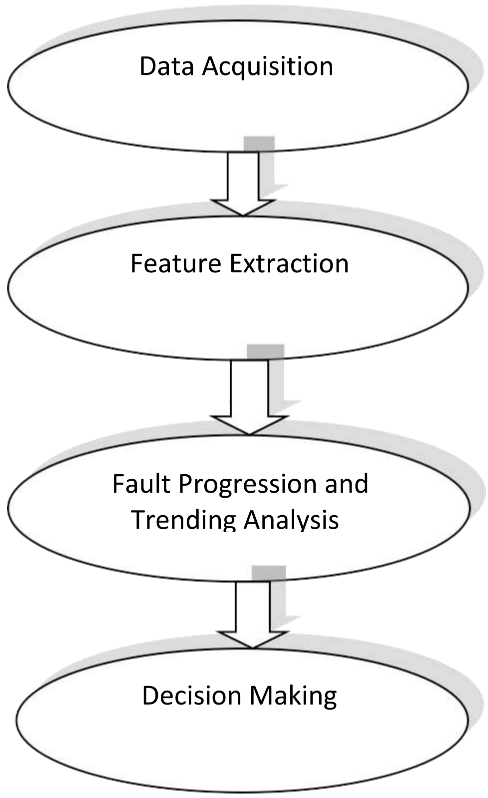


Fig.1. 4 Process for fault diagnosis

Some of the techniques which are used by the research scholars to diagnose the health condition of CRIM are tabulated below:

- Model based techniques
- Signal Processing Techniques

Table: 1.1 Various Signal processing Techniques

| Methods | Mathematical Techniques |
|---|---|
| Spectrum through Frequency Domain Method | Fast Fourier Transform (FFT) |

| | |
|---|---|
| Spectrum Through Time Frequency Domain method | (a) Short Time Fourier Transform (STFT)<br>(b) Gabor Transform (GT)<br>(c) Winger-Ville Distribution (WVD) |
| Wavelet Transform Method (WT) | Wavelet Transform (WT) |

- **Soft computing Techniques**
  a. Fuzzy system
  b. Artificial neural network
  c. Genetic Algorithms
  d. Integration of above techniques
- **Quantum computing**

Among all various techniques available for the health monitoring of IM, soft computing techniques are very fast, intelligent and efficient technique. Due to its intellectual quality, there is an evolution in soft computing in present era which motivates the scholars to grow an evolutionary algorithm for monitoring the health of IM. Quantum computing is also a powerful tool in that area.

### 1.4. Motivation

Induction motors are like the heartbeats of many industries. They help run big machines, produce power, and even keep our factories working smoothly. Just like we visit doctors to check our health and prevent sickness, these motors also need a 'health check'. If they suddenly stop or break, it can cause a lot of problems, like slowing down production or causing accidents.

However, the old ways of checking these motors aren't good enough anymore. We used to wait for a problem to show up or check them only once in a while. Imagine only visiting a doctor when you are very sick or once every few years; it's risky, right?

Today, we have new technology that can watch these motors all the time, making sure they're working well. This thesis is inspired by a simple idea: let's use the latest tools to keep an eye on these motors, catch problems early, and fix them before they get big. In this way, factories can run better, there are fewer breakdowns, and everyone stays safer.

Although induction motors are very robust in construction and highly reliable industrial drive, but they often operate in typical environment and hazardous area due to their wide application in various fields. Hence these types of machines normally work in such a place where situations are unfriendly. This unfriendly situation could take the machine deterioration very fast. As a result motor can get unhealthiness effecting bad performance, loss of time and money and production shutdown. A minute fault in IM even can causes increased losses such as reducing efficiency and increasing temperature which will increase the machine vibration and cause of insulation breakdown. Safety, reliability, efficiency and performance are some of the major concerns of induction motor applications. Early detection of fault can save the machine from large fault and failure and the total shutdown of the system. Failure and total shutdown of the IM will be very costly for the industry. Due to high reliability requirement, and cost of breakdown, the issue of condition monitoring of induction motors and diagnosis is of increasing interest and investigations into the fault detection and diagnosis of induction motors.

Health monitoring of induction motor is that of similar to human health monitoring done by an expert doctor by measuring various parameters of human body with the help of different biomedical instruments as shown in Fig. 1.6. That motivates the researchers to make an expert system by using soft computing techniques like a doctor that can be able to detect the health condition of induction motor.

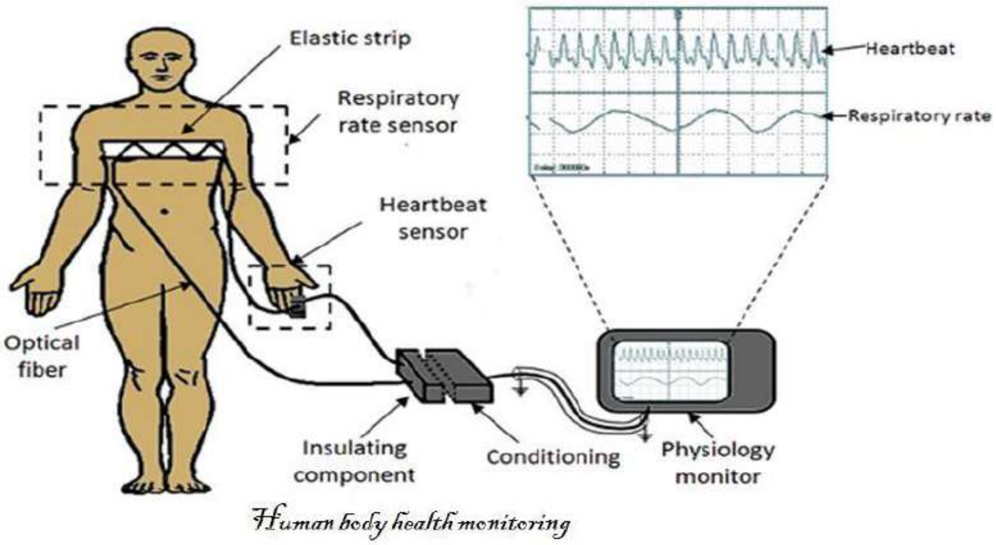


Fig.1.5: Health monitoring of a Human body

Soft computing challenges to solve the category of computationally hard problems that normally classical algorithmic approaches are inefficient to solve them, whereas a human being is mostly skilled at solving them. To reduce that human effort soft computing has taken the charge to solve that of computationally hard problems. Soft computing algorithms are very efficient to monitor the machine restlessly and to make an intelligent decision for any interruption. This effectiveness encourages the researchers to implement and adopt soft computing tools for the health monitoring of induction motor.

## 1.5. Problem Statement

Induction motors, crucial for the efficient functioning of diverse industrial sectors, demand reliable and consistent operation. Their importance is underlined by the numerous processes they drive and sustain. However, the prevalent maintenance practices, which predominantly lean on scheduled routines or reactive measures post-failures, often fall short of ensuring the motor's optimal performance. This results in unforeseen breakdowns, affecting both productivity and operational efficiency.

One of the primary challenges surrounding induction motors is the early detection of potential faults or deteriorations. If not identified promptly, these minor issues can evolve into critical failures, leading to considerable downtime and financial losses. Essential to the motor's health are regular monitoring activities, such as tracking temperature, vibration levels, and assessing current/voltage readings. These parameters, when consistently checked, ensure the motor's longevity and optimal performance. Moreover, regular maintenance, in conjunction with these monitoring activities, plays a vital role in upholding the motor's health.

However, with the technological evolution, there emerges a potential solution to this persisting challenge: online health monitoring systems. These innovative systems offer continuous data acquisition, in-depth analysis, and real-time interpretation. Such capabilities empower industries to detect anomalies, deviations, and patterns that might hint at future faults, allowing for preemptive interventions. The pressing question, and the focal point of this thesis, is how effectively these online health monitoring systems can be integrated and utilized to reshape and enhance motor health strategies across various applications, potentially overhauling the traditional maintenance paradigm.

### 1.6. Objectives

1. **Understanding Induction Motors:** Delve deep into the foundational principles of induction motors to understand their operation, benefits, and challenges.

2. **Assessment of Traditional Maintenance:** Examine the conventional maintenance methodologies, identify their shortcomings, and explore the implications of unexpected motor failures.

3. **Introduction to Modern Monitoring:** Introduce and comprehensively understand the concept, technologies, and advantages of online health monitoring systems for induction motors.

4. **Design and Development:** Aim to create a reliable, cost-effective system for continuous health monitoring of induction motors, ensuring minimal unplanned downtimes and maximized operational efficiency.

5. **Integration of Advanced Technologies:** Incorporate sensor technologies, data processing algorithms, and connectivity protocols, ensuring real-time, accurate data acquisition and interpretation.

6. **Predictive Maintenance:** Develop and fine-tune machine learning algorithms capable of early fault detection, facilitating proactive rather than reactive maintenance strategies.

7. **Comparison and Analysis:** Contrast the newly proposed health monitoring approach with traditional maintenance methods, assessing factors such as accuracy, reliability, and cost-effectiveness.

8. **Operational Implications:** Investigate the potential benefits of the health monitoring system, including extended motor lifespan, improved efficiency, and reduced maintenance costs.

9. **Broadened Applications:** Explore the wider application of the proposed health monitoring system across various industries, considering areas like manufacturing, power distribution, and renewable energy sectors.

10. **Safety and Sustainability:** Highlight the potential safety benefits of early fault detection and consider the environmental and economic benefits of optimized motor operations and reduced energy wastage.

11. **Future Recommendations:** Based on findings, provide recommendations for further research, technological improvements, and industry-wide implementation of induction motor health monitoring systems.

### 1.7. Thesis Structure

The thesis is structured into five main chapters. **Chapter 1: Introduction** provides the background of induction motors, outlining their significance in the industrial realm, and presents the problem statement highlighting the limitations of traditional maintenance. The chapter also delves into the motivation behind the research, laying out the objectives and giving a brief overview of the entire thesis structure. **Chapter 2: Literature Review** offers a comprehensive exploration of historical maintenance practices, traces the evolution of health monitoring systems, evaluates sensor technologies pivotal for monitoring, and assesses the role machine learning has begun to play in predictive maintenance. Gaps in the existing literature are also identified, setting the stage for the research. **Chapter 3: Methodology** elucidates the research design, explaining the strategy for sensor deployment, details the data collection and preprocessing steps, and dives deep into the development of machine learning models tailored for fault detection. **Chapter 4: Results** presents the findings, showcasing the effectiveness of the proposed system in early fault detection, predictive maintenance, and overall motor health monitoring. Finally, **Chapter 5: Conclusion** wraps up the study, summarizing key insights, offering recommendations, and suggesting potential avenues for future research in the domain.

# CHAPTER No. 2. **Literature Review**

In recent years, there is significant progress in the field of the fault analysis and maintenance of induction machines, with the extension of computer techniques, control techniques, and advance intelligence algorithms. Many methods of fault detection are proposed, such as the knowledge based method, the analytical model method and the signal processing method [1-4].

## 2.1. Introduction

An induction motor (IM) is a singly excited machine. The power is supplied only to the stator winding, not to the rotor. An IM is simply an electric transformer whose magnetic circuit is separated by an air gap into two relatively moveable portions, one carrying the primary and the other secondary winding. Alternating current supplied to the primary winding from an electric power system induce an opposing current in the secondary winding, when latter is short- circuited or closed through an external impedance. Relative motion between the primary and secondary structure is produced by the electromagnetic forces corresponding to the power thus transferred across the air gap by induction [5-7].

The essential feature which distinguishes the IM from other types of electric motors is that the secondary currents are created solely by induction, as in a transformer instead of being supplied by a D.C exciter or other external power source, as in synchronous and D .C. machines. IM are used in both the domestic and industrial applications. In industry about 90% of the motors are IMs [8-11].

Some advantages of IM are listed here:

1. Uncomplicated in design, tough in construction and in addition they are inherently strong and able to labor in any ecological condition.
2. Nonexistence of brushes, commutators and slip rings (in case of cage rotor IM) compose the IM comparatively cheap

3. 3-ϕ IMs are most trustworthy and comparatively cheap in price.
4. IM doesn't need any additional motor for starting, whereas simple synchronous motor needs.
5. IM needs very less maintenance cost.

Regardless of these advantages IMs undergo few drawbacks as compared to dc motors and synchronous motors as given here:

1. IM persistently works at lagging p.f and in particular during light loads IM functions at very bad p.f (0.2 to 0.4 lagging). This low power raises I2R losses in the system and therefore decreases system efficiency.
2. 3-ϕ I.M especially cage rotor induction motor (CRIM) has the affinity of high incoming starting current but supplied meager starting torque.
3. These motors run at almost fixed speed, hence fine speed control of I.M is a complicated mission.

## 2.2. Induction Motor Construction

IM can be classified as

1. Squirrel cage or Cage Rotor type Induction motor (CRIM).
2. Slip ring or Wound rotor type Induction motor (WRIM)

The vital parts of the IMs are A. Frame B. stator C. rotor.

Fig.2.1: CRIM stator construction

Explanation of the various parts is given in tabulation form here.

Table: 2.1 Induction motor parts and their description

| **Name of the parts** | **Description** |
|---|---|
| **Frame** | Depending upon the relevance to which they are used for, the different types of frames are made. The main purpose of the frame is to hold the bearing and to defend the other machine parts like coil ends and the core. Usually in the small sized IMs frames are built with cast iron to minimize its cost. In case of big size IM, the frames are prepared by the laminated sheets to minimize losses. |
| **Stator** | It is the immobile part of the I.M. It looks hollow cylinder made up of slotted laminations of sheet steel as shown in Fig. 2.1. The thickness of the lamination is normally between 0.1 to 0.3 mm. Coating of the insulating varnish or an oxide coating is used to insulate the laminations. Thicker laminations are used for the small size I.M as loss is not important and cost is important for a small I.M. Ventilating ducts are kept of an interval of 5 to 7 cm along the length of the core. A rotating magnetic field is generated when stator winding is excited by 3-ϕ ac supply. The stator is having specific number of poles. The speed at which rotating magnetic field rotates is known as synchronous speed. It is denoted by $N_s$. This $N_s$ is inversely proportional to the pole. $N_s=\frac{120f}{P}$ Where P=Total number of poles and f = frequency in Hz. |
| **Rotor** | The moving parts of the IM is called rotor. Rotors are basically two types and the motors are also named by the name of the rotor like (i) Squirrel cage or cage rotor IM and (ii) Slip ring or wound rotor IM. |

**(i) CRIM rotor:** It is made up of stampings which are keyed directly to the shaft as shown in Fig. 2.2. The slots are partially closed and winding consists of embedded copper bars to which the short-circuited rings and brazed. The squirrel cage rotor is so robust that it is almost indestructible.

The great majority of present day IMs are manufactured with squirrel-cage rotors, a common practice being to employ winding of cost aluminum. In this constructions the assembled rotor lamination are placed in a mould after which molten aluminum is forced in, under pressure, to forms bars, end ring and cooling fans as extension of end rings. This is known as die cast rotor and has become very popular as there are no joints and thus there is no possibility of high contact resistance. In this type rotor, it may be noted that slots are not made parallel to the shaft but they are skewed to serve the following purposes [12]:

1. To get more uniform torque and receive less noise.

2. To avoid the magnetic locking probability of the rotor.

Fig.2.2: CRIM rotor

### (ii) WRIM rotor:

Construction of WRIM rotor is shown in Fig. 2.3. The wound rotor has also slotted stampings and the windings are former wound. The wound rotor construction is employed for IMs requiring speed control or extremely high values of starting torque. The wound rotor has completely insulated copper windings very much like the stator winding. The winding can be connected in star or delta and the three ends are brought out at the three slip rings. The current collected from these slip rings with carbon brushes from which it is led to the resistance for starting purposes. When the motor is running, the slip rings are short-circuited by means of a collar, which is pushed along the shaft and connected all the slip rings together on the inside. Usually the brushes are provided with a device for lifting them from the slip rings when the motor has started up, thus reducing the wear and the fractional losses. Advantages of the external variable resistance are listed here [13].

1. To control the starting current and to prove more starting torque.

2. Speed of the motor can be controlled.

The number of slots in the rotor should never be equal to the number of the slots in the stator. If they are there would be a variation of reluctance of the magnetic path from maximum, when teeth are opposite slots, to minimum when teeth are opposite teeth. The resulting flux pulsations would have a high frequency, since the periodic time would be the interval period for a tooth to occupy similar positions opposite to successive teeth. This will not only cause extra iron losses but the rotor will tend to lock with the stator if at the time of starting teeth are opposite teeth. The best plan is to make the number of the stator and the rotor teeth prime to each other [14].

Fig.2.3: WRIM rotor

### 2.3. Working Principle of IM

When the stator or primary winding of a 3-ϕ IM is connected to a 3-ϕ ac supply, a rotating magnetic field is established which rotates at synchronous speed. The direction of revolution of this field will depend upon the phase sequence of the primary currents and therefore will depend upon the order of connection of the primary terminals to the supply. The direction of rotation of the field can be reversed by interchanging the connection to the supply of any two leads of a 3-ϕ IM. The speed at which the field produced by the primary currents will revolve is called the synchronous speed (Ns) of the motor and is given by an expression [15, 16]

$\mathbf{Ns}=\frac{\mathbf{120f}}{\mathbf{p}}$ Where f is the supply frequency and p is the number of the poles on stators

Due to the rotation, the magnetic field itself will be cut by the standstill rotor conductors and emf will be induced in the rotor conductor per the Faraday's law. According to Lenz's low, the direction of induced emf would be in such a direction that it would try to oppose the very cause for which it is due. As a result the rotor will start rotating at the same direction of the rotating magnetic field to minimize the relative motion between rotor and magnetic field. The speed of the rotor (N) always will be slightly less than the synchronous speed, but never at the same speed to maintain the cause of induced emf in the rotor. The difference between the Nsand N is known as slip and it is mostly calculated in %[17, 18].

$$\%Slip(s)= \frac{(Ns-N)}{Ns} x100$$

## 2.4. Induction Motor Faults

### 2.4.1 Introduction

Induction motors is critical components in many power plants & industrial processes and is frequently integrated in commercially available equipment. Safety, reliability, efficiency and performance are some of the major concerns of IM applications. Due to high reliability requirements, and cost of breakdown, the issue of condition monitoring of IMs and diagnosis is of increasing importance. For these reasons, there has been a continually increasing interest and investigations into the fault detection and diagnosis of induction motors [19-23]. Due to all these reason proper knowledge of different fault occurred in IM is very essential. IMs are very robust in construction and almost maintenance free machine compare to all other machine. But they work in unfriendly environment and due to that fault in an IM is a very common fact. Proper knowledge and information about the fault can help to monitor the health condition of the motor. Table 2.1 shows the statistics of IM faults and Failures from the different sources. Fig.2.4: showing the different types of common faults in Induction Motor [24-31].

Table 2.2: Statistics of Induction motor faults and Failures [AKA 12]

| | **IEEE-IAS (%) Electrical Safety Workshop 1985a** | **IEEE-IAS (%) Electrical Safety Workshop 1985b** | **EPRI (%) Electric Power Research Institute 1985c** |
|---|---|---|---|
| Number of faulty motor | 380 | 304 | 1052 |
| Bearing-related | 44 | 50 | 41 |
| Winding-related | 26 | 25 | 36 |
| Rotor-related | 8 | 9 | 9 |
| Other | 22 | 26 | 14 |

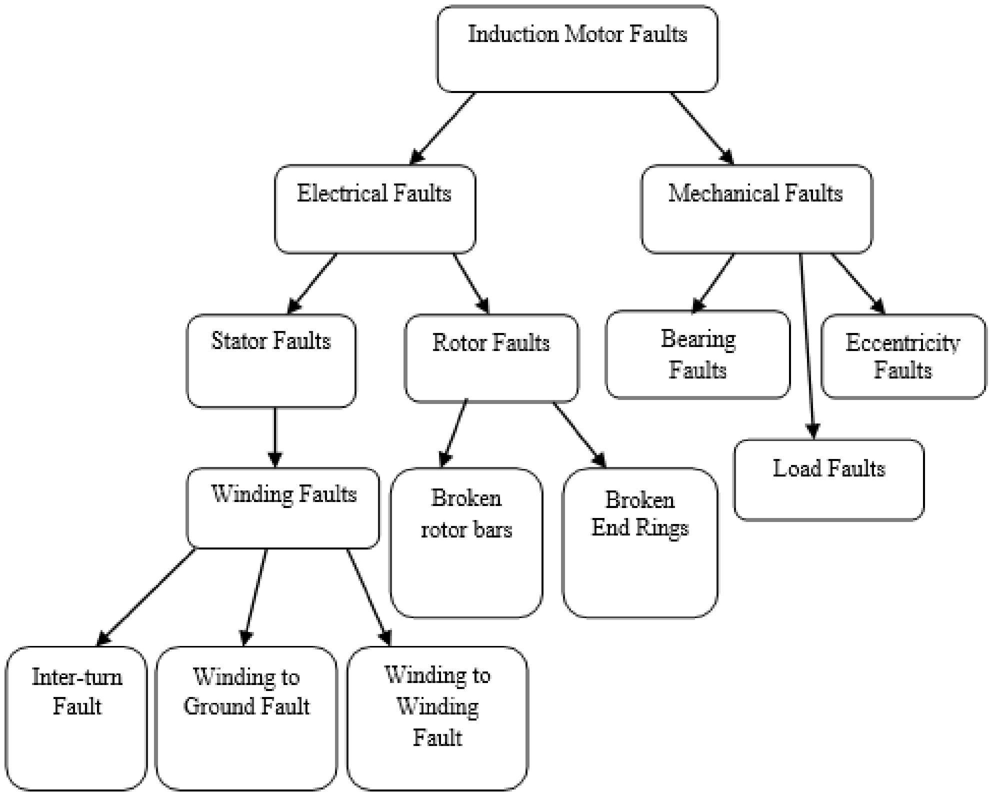


Fig.2.4: Types of common faults in Induction Motor

### 2.4.2 Bearing Fault

The majority of electrical machines use ball or rolling element bearings and these are one of the most common causes of the failure. These bearings consist of an inner and outer ring with a set of balls or rolling elements placed in raceways rotating inside these rings. Faults in the inner raceway, outer raceway or rolling elements will produce unique frequency components in the measured machine vibration and sensor signals [32-34]. These bearing fault frequencies are function of the bearing geometry and running speed [25-40]. Bearing faults can also cause rotor eccentricity and hence it creates more motor vibration and additional noise. As per the statistics the most commonly occurred fault in an IM is bearing faults. It has been found that 41% of the total faults is bearing fault which is high. Bearing faults normally not occurred in very sudden, it occurred gradually except few cases. Therefore, preventive maintenance can help to stop all those severe faults which are occurred due the bearing faults like rotor eccentricity fault, winding fault [41-48].There are two types of bearing faults as listed below:

(I) Single- point-defects bearing fault

(ii) Generalized roughness bearing fault

### 2.4.3 Stator Winding Faults

Almost 40 % of all reported IM failure fall into this category. The stator winding consists of coils of insulated copper wire placed in the stator slots. Stator winding faults are often caused by insulation failure between two adjacent turns in a coil. This is called turn- to- turn fault or shorted turn [49-53]. The resultant induced currents produce extra heating and cause an imbalance in the magnetic field in the machine. If undetected, the local heating will cause further damage to the stator insulation until catastrophic failure occurs [54-59].The unbalanced magnetic field can also result in excessive vibration that can cause premature bearing failure [60-66].There are various type of fault occurred in stator winding with the different combination. Different types of stator winding faults are described in Table 2.3 and different types of short turn faults are shown in Fig. 2.5 [67, 68].

Table: 2.3 Different types of winding faults

| **Name of the winding Faults** | **Explanation** |
|---|---|
| Burning of the insulation | Burning of the insulation of the winding and resulting complete winding short circuits of all phases which are typically caused by blocked rotor, over loadings, sub-rated voltage, and over rated voltage power supplies. This kind of fault may be caused by repeated starts and speed reversals. |
| Inter-turn short circuits | It means short circuit within the same phase, short circuits between stator core and winding, short circuits on the connections and short circuits between phases, are generally occurred by stator voltage transients. |
| Complete short circuits | Complete short circuits of one or multiple phases may take place due to contactor or breaker failure, phase loss which is happened by an open fuse, power supply failure or connection failure. |
| Inter-turn short circuits | Inter-turn short circuits are as well occurred due to voltage transients that may be happened by the successive reflection resulting from cable connection between ac drives and motors. Such kind of drives produce additional voltage stress on the stator windings because of the inherent pulse width modulation of the voltage given to the stator windings. Further, lengthy cable connections between an ac drive and motor may induce motor over voltages. Successive reflections of transient voltage may be the cause of these kind of over voltages. |

| | |
|---|---|
| Short circuits in single phase | Short circuits in single phase are generally because of an unbalanced stator voltage, an unbalanced voltage is caused by wrong connection of the motor terminals, an unbalanced load in the power line or wrong connections in the power circuit. Furthermore, an unbalanced voltage occurred due to the three stator voltages is below or above the value of the other phase voltages. |

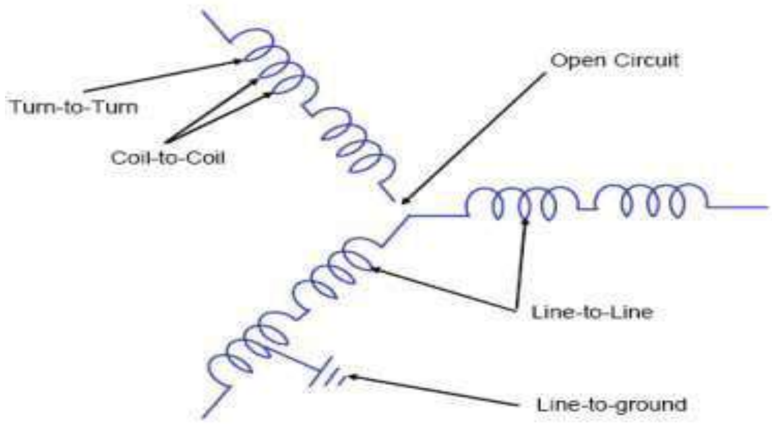


Fig.2.5: Different types of short turn faults

### 2.4.4 Rotor Faults

Rotor bars and end rings of a CRIM are constructed by the copper material due to its excellent conductivity. Rotor bars of the rotor are working as the rotor conductor and they are short circuited by the heavy end rings. Motor's rotor cage faults which includes broken (crack) rotor bars or the end-ring broken (crack) of average size CRIM is approximately five to ten percent of all CRIM failures [69]. Rotor cage fault is even more common for any average size motors compare to little size motors, because of the extensive temperature rise on the rotor. There may be various types of reasons for the CRIM faults. Most of them are listed here. [70]:

(I) A rotor bar may be incapable to extend longitudinally in the slot it occupies at the time of starting of CRIM, when thermal stresses are imposed upon it.

(ii) A large centrifugal force is developed by the heavy end rings of CRIM causing dangerous stresses on the bar [71].

(iii) An uneven metallurgical stresses may be built in to cage assembly at the time of brazing process in manufacture, and that too can lead to breakdown during operation.

There could be two types of breakage in the rotor cage as briefly described here [72]:

**(a) Skewed bars Breakage:** The rotor bars may be partly or totally cracked at the working of CRIM, because of stresses caused by improper rotor geometry design [73]. The rotor bars breakage is the one of the vital fault in the rotor of CRIM. whenever a rotor bar creaks or fractures, the situation of the nearby bars also weakens gradually due to the improved stresses [74]. To protect such type of growing destructive procedure, the fault should be identified timely when the crack is just started [75].

**(b) End-rings Breakage:** The rotor bars of the CRIM are short-circuited by end-rings at the ends. Substandard casting in the case of die-cast aluminum rotors or the poor end-ring connections in the case of fabricated rotor cages at the time of manufacturing are the basis of the end-ring defects [76].The end rigs get heated because of conduction of the heavy current.

Due to some of the over loading or even at the long time running, rings get over heated. The heat spread quickly and due the running centrifugal force the end rings get cracked [77].

If the creak in the end rings are not detected at the beginning, rings will be damaged quickly making the rotor eccentricity fault and hence the bearing fault later [78].

### 2.4.5 Rotor core fault

Rotor core is made of silicon steel. If the rotor core is damaged as shown in Fig.2.7, the current signature of machine, power drawn, power factor all electrical parameters will be similar to the healthy machine, but the mechanical parameters like vibration, sound will be changed. The effect of rotor core fault will be some time the cause of eccentricity effect on the rotor of machine [79].

Fig.2.6: Healthy stator and rotor

Fig.2.7: Healthy stator but Unhealthy rotor (rotor core problem)

### 2.4.6 Rotor Eccentricity Fault

Eccentricity occurs when rotor is not centered within the stator, producing a non - uniform air gap between them. This can be caused by defective bearings or manufacturing faults. The vibration in the air gap disturbs the magnetic field distribution within the motor which produces a net magnetic force on the rotor in direction of the smallest air gap. This so called “unbalanced magnetic pull” can produce more noise and mechanical vibration and later cause of bearing faults [80]. There might be three different categories of the eccentricity as listed here [81, 82]:

(a) Static eccentricity

(b) Dynamic eccentricity

(c) Mixed eccentricity

When rotor bar itself will be inclined with respect to then it is called static eccentricity. I will create uneven magnetic pull causing bearing fault and the more vibration and noise. It may also be responsible for the bending of shaft [83].

When there is an inclination of rotor’s natural axis with its rotational axis, then it is called dynamic eccentricity which will create more vibration and sound of the motor causing less lasting of bearings and over load on shaft.

Mixed eccentricity is the combination of static and dynamic eccentricity. In reality, static and dynamic eccentricities have the tendency to exist together in the machine. Most of the machine contain some of the eccentricity either any of the above said form.

### 2.4.7 Mechanical Load Faults

CRIM are always worked as a prime mover for the other mechanical load. So always it has be coupled with some other machine or load through rotor shaft. Now sometimes coupling and the gear in between the CRIM and the load connected to it creates some problem. It could be the problem of faulty alignment and imperfect gear system [84].

Faulty alignment in the coupling will create the more vibration and noise in the machine. This load fault will be the cause for damage of bearing, mechanical over loading and can create over heating in the machine which tends to motor failure. Loading faults may be the cause of workers unsafely and might be the cause of human injury.

Because of that the motor overload prevention has become an important engineering research topic. Overload fault can create winding overheated resulting insulating life decreased [85]. A huge current flowing through the winding makes the winding over hot. That's why, nowadays motor overload preventions indicates recognition of over current and unnecessary temperature rise and its prevention. Motor can be provided thermal protection by simply monitoring of the body temperature, but it has some of its own inherent disadvantages [86].

## 2.5. Health Monitoring Technique for Induction Motor

### 2.5.1 Introduction

Health monitoring is the process of monitoring the parameter of condition in machinery, such that a significant change is indicative of a developing failure. The use of health monitoring allows maintenance to be scheduled, or other actions to be taken to avoid the consequence of the failure, before the failure occurs. Nevertheless, a deviation from the reference value (e.g. temperature or vibration behavior) must occur to identify the impeding damages. The failure has already commenced and the health monitoring system can only measure the deterioration of the health. It is typically much more cost effective than allowing machinery to fail [87].

Today's industrial policy and globalization has made industrial environment very competitive. Hence, down- time for maintenance is of great importance. Substantial savings in energy and production cost can be achieved by applying condition monitoring in industry.

Plant machineries are invaluable assets and are designed to operate under extremely harsh condition, where a failure may be catastrophic, both in safety and economic aspect.

Two options may be considered in operating plant and machinery:

1. Breakdown maintenance: machine will run until it needs attention and then stripped down.

2. Condition based maintenance: failure anticipated and monitored continuously.

Both techniques have their applications. Condition monitoring plays a vital role in providing higher availability of plant machinery by detecting problems before they result in a major machine malfunction breakdown [88].

### 2.5.2 Type of Monitoring Techniques

#### 2.5.2.1 Thermal Monitoring

Slight temperature variations across a surface can be discovered with visual inspection and nondestructive testing. Heat is indicative of failing components, especially regarding electrical contacts and terminals. Short circuit of the winding will be a major cause of huge generation of heat. Health monitoring can be done by measuring the heat of a particular spot of the machine or the overall heat of the machine. Health monitoring of IM can also be done by the estimation of temperature of IM of various parts.

The problem of this method is that a separate thermal sensor is needed. In spite of that, this method is one of the most popular methods for last many years due to breakdown of the insulation. Different types of relays are prepared time to time as per the requirement based on the thermal monitoring as thermal security is needed for the stator winding insulation and bearing.

Research scholars are more interested to go for the thermal monitoring without sensor as it has some of certain advantages. In that direction different thermal model has been developed. There are mainly two types of thermal model as written here [89]:

(I) Finite element analysis based thermal model of IM

(ii) Lumped parameter thermal model of IM

Thermal model-based method calculates the motor losses and implements thermal models for the estimation of the motor temperature. First order to higher order thermal model of IM has been developed as given:

(I) First-order Thermal Model of IM

(ii) Second-order Thermal Model of IM

(iii) Higher-order Thermal Model of IM

#### 2.5.2.2 Motor Vibration Monitoring

Vibration is a natural phenomenon for any kind of working device. Every device which is working has its own natural vibration. When any device vibrates, it creates a noise from it. A small vibration even can be able to generate a large noise. Mechanical, magnetic, aerodynamic factors are the responsible to create the vibration and hence the noise for any electrical and electronics devices. Radial force is one of the basic reason for vibration of CRIM. Real health monitoring techniques for 3-ϕ IM are normally done by the arrangement of mechanical and electrical monitoring together. Vibration can be categories as the mechanical parameter and one of the vital non electrical exogenous variable through which CRIM health can be monitored.

At the present day advanced signal processing techniques like Wavelet transform has been used along with ANN as a classifier to identify the fault of CRIM based on the extracted feature information of the vibration signature. Any new machine also has some of the vibration which is considered as its natural vibration. Whenever there is any fault in the machine the natural vibration will be changed. For different types fault, the machine will be having different type of vibration. Each fault will have its own vibration. By identifying the pattern of the vibration signature we can easily detect the fault occurred in CRIM. various signal processing techniques like FT, FFT, STFT, WT, WVD are helpful to recognize the signature pattern.

It is one of the method which chosen by the researchers for its effectiveness. Time and frequency both domains are used to analyze the vibration signature. Vibration signature is helpful to detect most of the mechanical faults like bearing fault, eccentricity fault, cooling system fault, rotor fault and unbalances in the driven load. Other electrical faults like single phasing fault, asymmetrical power supply by placing probes can also be identified. In earlier days vibration signature was not much effective due to the lack of soft computing artificial intelligent techniques. With the modern soft computing techniques like ANN, GNN, Fuzzy, Quantum and their integrations, vibration signature analysis has become more popular and move effective in the health monitoring system [90].

#### 2.5.2.3 Motor Torque Monitoring

Induction motor torque is one of the important parameters which decides the characteristics of the CRIM.CRIM torque is related to the other parameters of the motor like slip, rotor winding resistance, rotor reactance, rotor induced emf. That's why CRIM performance can be characterized by the torque developed by it. When there is a defect in the CRIM, it creates the side bandit particular frequencies in the torque. Rotor bar fault of CRIM can be identified easily by identifying the side bands of the supply current. Coil short circuited in the stator can also be identified by this method. Air gap torque can be measured at the working condition of the motor with no time required. This can be economically good for various industries, where an unprepared down time of an IM creates a huge loss in the process of a manufacturing system. Mechanical load, shaft and the rotor are analogous to a spring system. This system has its own frequency. The torque transmitted through that spring system has the different frequency for different condition of the CRIM. Now whenever there is a fault in the CRIM, the torque will be affected due the fault and hence that system frequency will be changed. By studying that changed frequency we can identify the fault in CRIM. Therefore, modern research scholars have taken a keen interest on the motor torque monitoring system for health monitoring of CRIM [91].

#### 2.5.2.4 Motor Sound Signature Monitoring

Sound signature monitoring of an IM can be done by analyzing the acoustic noise spectrum produced by IM. This method is very unpopular as capturing the exact sound track is very difficult nowadays due to the environmental noise pollution. In industry also getting exact sound signature is very difficult due to the noise created by the other neighboring machine. If there is any fault created in the machine, the sound signature will be changed. Sound created by the different faults will be different from each other. After capturing the sound signature from the machine, it's very difficult to under the fault directly. Fast Fourier Transform (FFT), Power Spectrum Density (PSD) and Wavelet Transform (WT) are the signal processing tools which are used to understand the signature of waveform in better way. Either of the tools can be utilized depending on the pattern to understand the faulty condition of the motor. Bearing fault, Air gap eccentricity fault, and single phasing fault can easily be identified by using the sound signature monitoring [92].

#### 2.5.2.5 Electrical Exogenous Variable Monitoring

Electrical signals like voltage, current, instantaneous power and their special components axial flux, air gap torque can be easily utilized for detecting potential failure of IM. There are various types of electrical parameters based monitoring illustrated by the research scholars, such as current signature analysis, Zero sequence and negative sequence current monitoring, and Current Park's vector monitoring etc. [93]. Stator current of the IM is the parameter which is used most as the electrical exogenous variable monitoring. Over current and leakage current can easily be caught by direct stator current monitoring. Many of the electrical faults can be directly identified by monitoring the stator current only. Hence electrical exogenous variable monitoring is the easy way to monitor the health of the IM, as it does not require any extra sensor [94].

##### 2.5.2.5.1 Current Signature Based Analysis

Some of the high rated big sized machines have its own sensor attached with it. They are normally mechanical sensors like vibration sensors and speed sensor. But these kinds of machines are normally large in size and expensive. Basically vibration signature monitoring techniques are used to identify the existence of incipient failure. On the other hand, current signature based analysis is the most popular by the research scholar as it does not require any extra cost of sensors. Spectral study of the input current can help to recognize the fault very quickly. Spectral of the input current will be different for healthy and unhealthy condition of the IM. The stator current waveform of an

IM can be analyzed to spot an existing or the beginning of a failure. It can perform the health monitoring without accessing the rotating parts.

Rotor eccentricity and broken bars in the rotor cage can be identified from the above technique. Even shaft speed oscillation, damaged bearings, unbalanced voltages, single-phasing fault can also be identified utilizing the above methods. Current signature analysis and fractional discharge monitoring together provide commanding health monitoring strategy for IM.

An overview on current signature analysis of medium sized IMs are given for detection the fault by many researchers [95].Study on frequency, time domain phase current and sideband analysis correlates to motor diagnosis. A whole review of different techniques for health monitoring and defending each major component of line connected IM is provided in few papers [96].

#### 2.5.2.5.2 Park's Vector approach

Current Park's vector technique is another significant electrical health monitoring technique. In 3-ϕ IMs, the connection to the mains does not usually use the neutral. Therefore, the mains current has no homo polar component. A two-dimensional representation can be used for describing 3-ϕ phenomenon, a suitable one being based on the current Park's vector [97]. As a function of mains phase variables (ia, ib, ic) the current Park's vector components are:

$id = (2/3)ia - (1/\sqrt{6})ib - (1/\sqrt{6})ic \quad iq = (1/\sqrt{2})ib - (1/\sqrt{2})ic$

Under ideal conditions, three phase currents lead to a Park's vector with the following component:

$id = (\sqrt{6}/2)\, I \sin \omega t$

$iq = (\sqrt{6}/2)\, I \sin (\omega t - \pi/2)$

Where, I is the maximum value of supply phase current, ωs the supply frequency and t the time variable.

A pure sinusoidal signal makes a circular pattern centered at the origin of the coordinates. This is very simple reference figure that allows the detection of abnormal conditions by monitoring the deviations of acquired patterns. In addition this pattern could be learnt by an artificial neural network, and thus the faults could be detected automatically with this method. There are several types of training algorithms like ANN, GNN are suggested in literature for fault detection of IM. Hybrid Park's vector-NA provides a satisfactory level of accuracy, signifying a hopeful industrial application [98].

**2.5.2.6 Thermal Image Monitoring**

Another important noninvasive contactless health monitoring technique is thermal image monitoring technique. Fault detected at the earlier stage at any part without having any contact with the3-ϕ IM may protect the machine from catastrophic failure without producing any noise and loss. So early detection of fault could save the machine and as well as protect the system from the total shutdown. Particularly in 3-ϕ IM, different type of bearing faults occurs because of the unbalance mass on motor shaft [99]. In such cases, a mechanical load distributed asymmetrically over the shaft, causing displacement of the center of mass of the elements coupled to the motor from the rotation center of the machine. This asymmetric distribution generates vibrations and strokes. This unexpected friction produces some of the power loss and that loss is coming out in the form of heat. Similarly, in all the faults in the induction motor produce some of the heat in the particular parts of the machine. Different types of faults in IMs that could be electrical faults or mechanical faults. Electrical faults include different winding faults and rotor faults. Whereas the mechanical faults could be bearing faults and eccentricity faults. In all the above said faults the machine directly or indirectly will gradually produce the heat in the concerned part of the machine. So thermal imaging is one of the pioneer methods to detect the fault at the earlier stage. Now a day, the infrared (IR) thermograph technology has been recognized and accepted as health monitoring method by researchers. Moreover this method is one of the most popular gained more recognized and accepted due to its non-contact and nondestructive features of inspection. It is very quick and trustable monitoring system which can monitor the IM without any interference to the whole system. In IR thermograph based technique, health monitoring is performed by making the analysis of the thermal images captured by infrared camera. It is very well known fact that durability of any electrical equipment is notably reduced as temperature rises. Infrared (IR) thermograph technology offers many advantages over any conventional methods such as prompt response times, ample temperature ranges, highly reliable, harmless, high spatial resolution, and very lucrative approach for the health monitoring of electrical power systems machinery. In this research work health monitoring of an IM by using infrared (IR) thermograph technology has been developed for both real time and off line application. Continuous monitoring of IM gives the real time information, which is useful for health monitoring of running IM. On the other side off line monitoring gives the information of standstill contacts which is useful for the health monitoring of other apparatus like fuse cabinet, inductive heating, corrosion, electrical panel and all those which is stand by

## 2.6. Conclusion

In this chapter it has been basically focused on the exhaustive literature survey on the work done by the previous researchers in the area of Health monitoring of CRIM. Most of the possible related papers of last 4 decades in this area are tried to refer for the vast literature review. The literature is mainly divided in three parts namely (i) Different faults occurred in the CRIM (ii) Different health monitoring techniques and (iii) Diagnostic Techniques for CRIM Faults. This exhaustive literature survey has provided lagging of work in this area and hence scope of the research work to be done. There are huge work has been done on the health monitoring of CRIM. But mostly those are off line analysis. There is a lag of work in online fault detection of CRMI which will be a step ahead in the automation.

# CHAPTER No. 3. **METHODOLOGY**

The crux of this research lies in the design and implementation of a sophisticated health monitoring system for induction motors. This chapter aims to elucidate the meticulous methodology that underpins the entire project, walking the reader through each step, from initial concept to final execution. We hope this step-by-step method makes our system both smart and easy to use. Our main goal is to keep motors healthy and working for a long time.

## 3.1. Defining Scope and Objectives

Before we started, we needed to understand what we wanted our system to do and which motors it would work for. We wanted a system that could watch motors all the time, spot problems early, and give useful information to help fix those problems. There are many types of induction motors out there. Some work in hot places, others in wet areas, and they all have their own special features. We made a list of the main types of motors we wanted our system to work for. We also thought about the conditions they work in and what makes them work well or not so well.

### 3.1.1 Objective Definition

The outset of this journey began with a clear articulation of what the monitoring system aimed to achieve. Detailed objectives were set, which included real-time monitoring, early fault detection, and providing actionable insights for preventive maintenance.

### 3.1.2 Motor Types

Given the varied types of induction motors—from single-phase to three-phase, and from squirrel cage to wound rotor motors—a careful assessment was conducted. This ensured that the monitoring system had the versatility to cater to a diverse range of motors.

### 3.1.3 Operational Conditions

Different motors operate under varying conditions. Some might be exposed to high temperatures, while others might function in humid environments. The system was designed to be resilient, adaptable to different environments, and conditions without compromising on accuracy.

### 3.1.4 Critical Performance Parameters

Performance metrics, crucial for motor health assessment, were delineated. These included efficiency, power factor, slip, and torque among others.

## 3.2. Sensor Identification and Selection

Motors have signs that show how they are doing, like how warm they get, the kind of noises they make, and the electricity they use. To spot these signs, we chose special tools called sensors. These sensors can feel the heat, hear the noises, and measure the electricity. Not all sensors are the same. Some are better at doing certain jobs than others. We tested many sensors to find the best ones for our system. We made sure they could give us clear and correct information about the motors.

### 3.2.1 Health Parameters

Core health parameters that could indicate the motor's condition were identified. These encompassed vibration levels, temperature fluctuations, current flow, and voltage stability.

### 3.2.2 Sensor Selection

Post identification, sensors adept at capturing these parameters with high fidelity were shortlisted. The selection process evaluated the sensitivity, range, and response time of potential sensors.

## 3.3. Sensor Evaluation

We looked closely at what each sensor can do. We wanted to know how fast they work, how clear their information is, and if they can work well with different motors. No sensor is perfect. They can sometimes give wrong information. So, we tested them many times to make sure they are mostly right and only rarely wrong.

### 3.3.1 Sensor Characteristics

Each shortlisted sensor underwent rigorous testing. Aspects such as linearity, hysteresis, repeatability, and drift were scrutinized.

### 3.3.2 Accuracy Assessment

Precision being paramount, the accuracy of each sensor was vetted against benchmark standards.

### 3.3.3 Compatibility Checks

To ensure a seamless integration, sensors were tested for compatibility with different motor types, ensuring no interference with motor operation.

## 3.4. Data Acquisition Design

After picking our sensors, we made a special tool that collects all the information they give. This tool works non-stop while the motors are running. Motors give a lot of information all the time. We made sure all this information was clean and in the right order. This way, it's easier to understand later.

### 3.4.1 Unit Design

A state-of-the-art data acquisition unit was architected, ensuring it could handle continuous data streams from multiple sensors simultaneously.

### 3.4.2 Data Integrity

Provisions were made to safeguard against data corruption or loss during transmission. Error-checking mechanisms were put in place to ensure data integrity.

## 3.5. Data Normalization and Synchronization

We used computer programs that can look at the information from the motors and find problems. These programs can learn from old information to get better at spotting problems. We wanted everyone to understand the motor's health easily. So, we made simple screens that show the information in ways like charts, graphs, and alerts.

### 3.5.1 Normalization Protocols

Given the diverse nature of data, normalization algorithms were developed to bring all data to a consistent scale, facilitating more accurate analyses.

### 3.5.2 Synchronization Techniques

To ensure temporal consistency, sophisticated synchronization techniques were implemented, ensuring that data from various sensors were aligned to the exact same timeframe.

## 3.6. Integration of Machine Learning

### 3.6.1 Algorithm Selection

Post a comprehensive review, specific machine learning algorithms known for their proficiency in time-series data analysis and fault detection were selected.

### 3.6.2 Model Training

Leveraging historical motor data, models were trained to recognize patterns indicative of motor health.

### 3.6.3 Fault Classification

Beyond mere detection, the models were further refined to classify potential faults into categories, allowing for more targeted maintenance actions.

## 3.7. Visualization Interface Development

### 3.7.1 Interface Design

Recognizing the importance of making data easily understandable, intuitive visualization interfaces were crafted. These platforms provided graphical representations of motor health metrics in real-time.

### 3.7.2 Accessibility

Whether it's a desktop dashboard for factory supervisors or a mobile application for on-the-go maintenance staff, the interfaces were designed keeping user convenience in mind.

### 3.8. Alert Implementation

We set up our system to give warnings if something seems wrong. This way, people can check the motor before a small problem becomes a big one. We made sure warnings are easy to see and hear. They can come as a beep, a message on a screen, or even a text message to someone's phone.

#### 3.8.1 Alert Thresholds

Thresholds were set for various health parameters. Any deviation beyond these thresholds would trigger alerts.

#### 3.8.2 Notification Channels

Multi-channel notification systems were integrated. Whether it's an SMS alert, an email, or an in-app notification, stakeholders would be instantly informed of any potential issues.

### 3.9. User-Friendly Interface for Maintenance Personnel

We wanted workers, even if they are not computer experts, to use our system easily. So, we made everything simple to use. Sometimes, looking at old information can help understand a problem. So, we made a way for workers to see both new and old information about the motor.

#### 3.9.1 Design Philosophy

Emphasizing user experience, the interface was designed to be minimalistic yet informative. This ensured that maintenance personnel, even with minimal training, could navigate and make sense of the data.

#### 3.9.2 Historical Data Access

Recognizing the value of historical data in understanding patterns, features were integrated that allowed users to access and analyze past data, aiding in more informed decision-making.

## 3.10. Components and Their Role in the Monitoring System

In order to design a robust health monitoring system for induction motors, several components were meticulously selected for their efficacy and reliability. This chapter will provide insights into each component, explaining its functionality and its contribution to the overall system. The following components are implemented in this system.

- Microcontroller ESP32
- Current Sensor HSTS016L
- RPM Sensor TZT KY-024
- AC Voltage Sensor ZMPT101B
- Temperature Sensor RTD-PT100
- Vibration Sensor TZT 801s
- I2C LCD
- 8 Channel Relay Module
- Connecting Wires and Connectors
- Wi-Fi Module ESP-07
- pole Contactor CTX3 40
- PCB

### 3.10.1 Microcontroller ESP32

This is the brain of our system. The ESP32 microcontroller processes all the information from the sensors and decides the actions to be taken. It's fast, energy-efficient, and can handle multiple tasks, making it ideal for real-time monitoring.

Fig. 3.1 Microcontroller ESP32

### 3.10.2 Current Sensor HSTS016L

This sensor is designed to measure the electric current flowing through the motor. By monitoring the current, we can detect any unusual changes which may indicate a problem with the motor's operation.

Fig. 3.2 Current Sensor HSTS016L

### 3.10.3 RPM Sensor TZT KY-024

To keep an eye on the speed at which the motor is rotating, the RPM (Revolutions Per Minute) sensor is used. It ensures the motor isn't running too fast or too slow, both of which could indicate potential issues.

Fig. 3.3 RPM Sensor TZT KY-024

### 3.10.4 AC Voltage Sensor ZMPT101B

This sensor monitors the voltage level being supplied to the motor. Any sudden spikes or drops in voltage can be harmful, and this sensor helps in detecting such irregularities.

Fig. 3.4 AC Voltage Sensor ZMPT101B

### 3.10.5 Temperature Sensor RTD-PT100

Motors can get hot during operation. The RTD-PT100 tracks the motor's temperature, ensuring it doesn't overheat. Consistent high temperatures can be a sign of wear or malfunction, so this sensor is crucial for motor health.

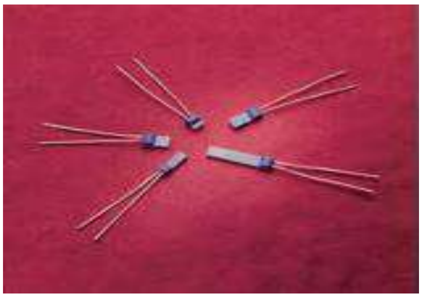

Fig. 3.5 Temperature Sensor RTD-PT100

### 3.10.6 Vibration Sensor TZT 801s

An overly vibrating motor can be a sign of mechanical issues. This sensor detects unusual vibrations, providing early warnings before any significant damage occurs.


Fig. 3.6 Vibration Sensor TZT 801s

### 3.10.7 I2C LCD

This is the display unit of our system. It provides real-time readings from all sensors in an easy-to-read format. It aids maintenance personnel in quickly assessing the motor's health without diving into complex data streams.


Fig. 3.7 I2C LCD

### 3.10.8 8 Channel Relay Module

This component controls the power supply to different parts of the system. It acts like a switchboard, ensuring each component gets power when needed and can be turned off when not in use.

Fig. 3.8 8 Channel Relay Module

### 3.10.9 Connecting Wires and Connectors

These are the veins of our system, ensuring each component is connected and communicating. The quality of these wires and connectors is paramount to ensure consistent data transmission and system reliability.

Fig. 3.9 Connecting Wires and Connectors

### 3.10.10 Wi-Fi Module ESP-07

For remote monitoring capabilities, the ESP-07 Wi-Fi module is integrated. It allows the system to send real-time data to external devices or cloud platforms for further analysis and storage.

Fig. 3.10 Wi-Fi Module ESP-07

### 3.10.11 Pole Contactor CTX3 40

This device controls the flow of electricity to the motor. It acts as a safety mechanism, allowing for quick shut-offs in case of any detected anomalies.

Fig. 3.11 Pole Contactor CTX3 40

### 3.10.12 PCB (Printed Circuit Board)

This is where all components come together. The PCB ensures each component is interconnected in an organized manner, providing a platform for the entire system's operation.

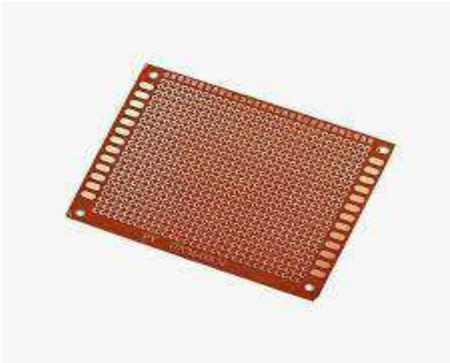

Fig. 3.12 PCB (Printed Circuit Board)

Each component plays a pivotal role in the system's operation. Together, they form a synchronized unit dedicated to ensuring the optimal health of induction motors.

## 3.11. Flowchart

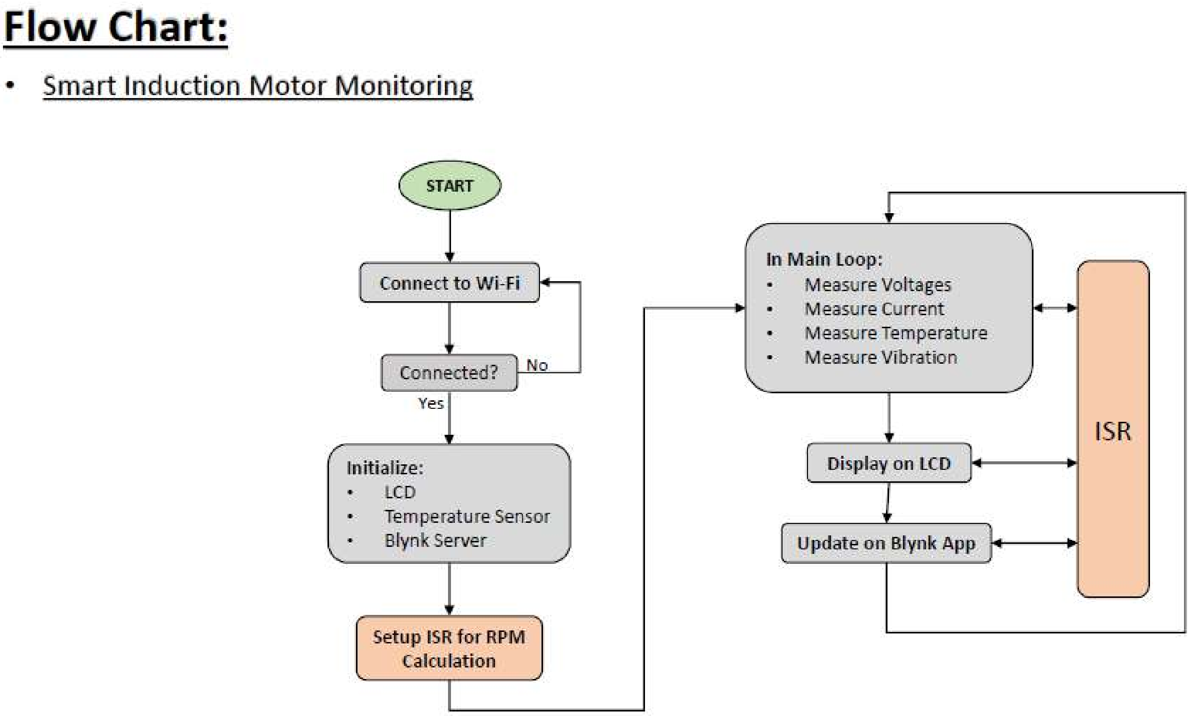


Fig. 3.13 Flowchart of the Proposed Methodology

The flowchart provides a systematic visualization of the operational process of the health monitoring system for induction motors.

1. **Start:** This is the initiation phase, marking the beginning of the system's operational process.
2. **Connect to Wi-Fi:** Once initiated, the system's first task is to establish a connection with the available Wi-Fi network. This connectivity ensures that the system can send and receive data for real-time monitoring.
3. **Connected to Wi-Fi:** Upon successful Wi-Fi connection, the system confirms and acknowledges the successful establishment of the network connection, ensuring that the subsequent steps can proceed without any network-related hindrances.
4. Initialize Essential Components: In this step:
   - **LCD Initialization:** The Liquid Crystal Display (LCD) is activated, preparing it to show real-time data readings and system statuses.
   - **Temperature Sensor Initialization:** The temperature sensor is powered up and calibrated to start collecting temperature data.
   - **Blynk Server Initialization:** The system establishes a connection with the Blynk Server, an essential step for remote monitoring and data visualization on the Blynk app.
5. **Set up ISR for RPM Calculation:** With all components initialized, the Interrupt Service Routine (ISR) is set up to calculate the Revolutions per Minute (RPM) of the motor. This is crucial to monitor the speed and ensure the motor operates within safe limits.
6. **Measurement and Display Phase:** This is the continuous monitoring phase, where:
   - The system measures the motor's voltage, current, temperature, and vibration parameters in real-time.
   - These readings are simultaneously displayed on the LCD for on-site monitoring.

- Concurrently, updates are sent to the Blynk app, allowing remote users to monitor the motor's health and operational status from their devices.

Overall, the flowchart presents a clear sequence of steps that the system follows, ensuring comprehensive monitoring of the induction motor's health both on-site and remotely.

### 3.12. Block Diagram

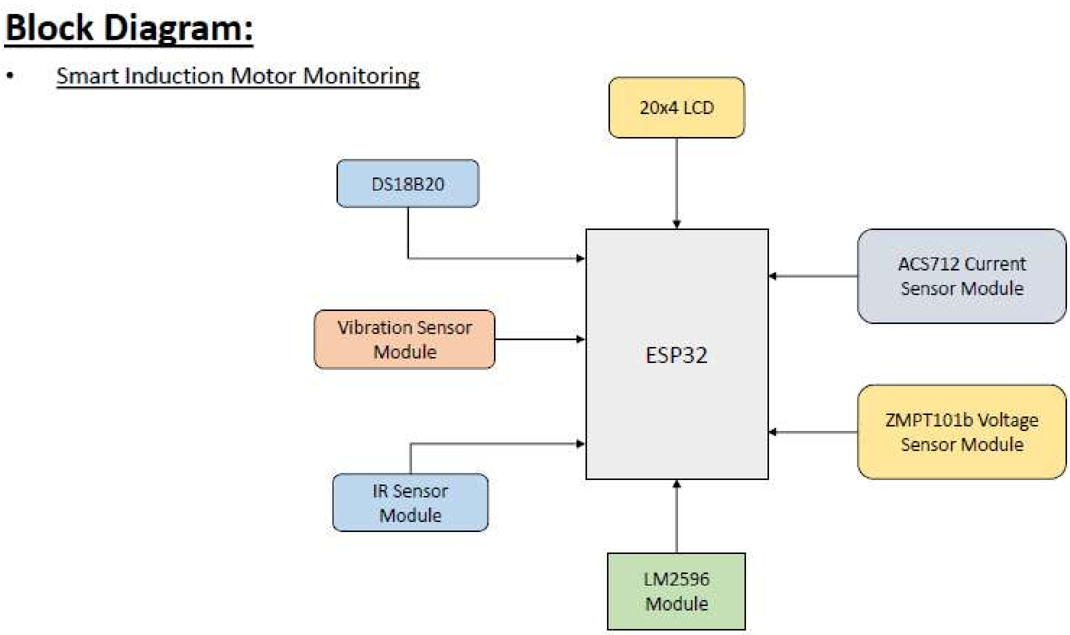


Fig. 3.14 Block Diagram of the Proposed Smart Induction Motor Monitoring System

The block diagram illustrates the central role of the ESP32 microcontroller in interfacing and processing data from various components of the health monitoring system for induction motors.

1. **ESP32 (Center of the Diagram):** Positioned at the core of the block diagram, the ESP32 serves as the main processing unit. It acts as the brain, gathering data from the connected modules, processing the information, and then coordinating actions based on the data.
2. **20x4 LCD:** This component is connected to the ESP32 to display real-time readings and system statuses. Its larger size ensures that multiple metrics or messages can be displayed simultaneously for easy on-site monitoring.

3. **DS18B20:** This is a temperature sensor module. It provides the ESP32 with continuous temperature readings, allowing the system to monitor any overheating or anomalies in the motor's operation.
4. **Vibration Sensor Module:** This module detects any unusual vibrations or oscillations in the motor. Data from this sensor aids the ESP32 in identifying mechanical wear, misalignments, or other issues that might lead to motor failures.
5. **IR Sensor Module:** Infrared sensors typically measure RPM or detect object proximity. In this context, it might be used to monitor the speed of the motor, sending RPM data to the ESP32 for analysis.
6. **LM2956 Module:** While not specified, the LM2956 typically acts as a voltage regulator. It ensures that the ESP32 and other connected modules receive a stable voltage supply, ensuring consistent and safe operations.
7. **ACS712 Current Sensor Module:** This module continuously measures the electric current flowing to the motor. By sending this data to the ESP32, the system can detect any unusual spikes or drops in current which might indicate operational issues.
8. **ZMPT101b Voltage Sensor Module:** This sensor provides real-time voltage readings to the ESP32. By monitoring the voltage supplied to the motor, the system can identify potential electrical anomalies or issues.

In essence, the block diagram succinctly represents the interconnectedness of the components, with the ESP32 acting as the central hub. Each connected module feeds specific data types to the ESP32, allowing for comprehensive monitoring of the induction motor's health and performance.

## 3.13. Schematic Diagram

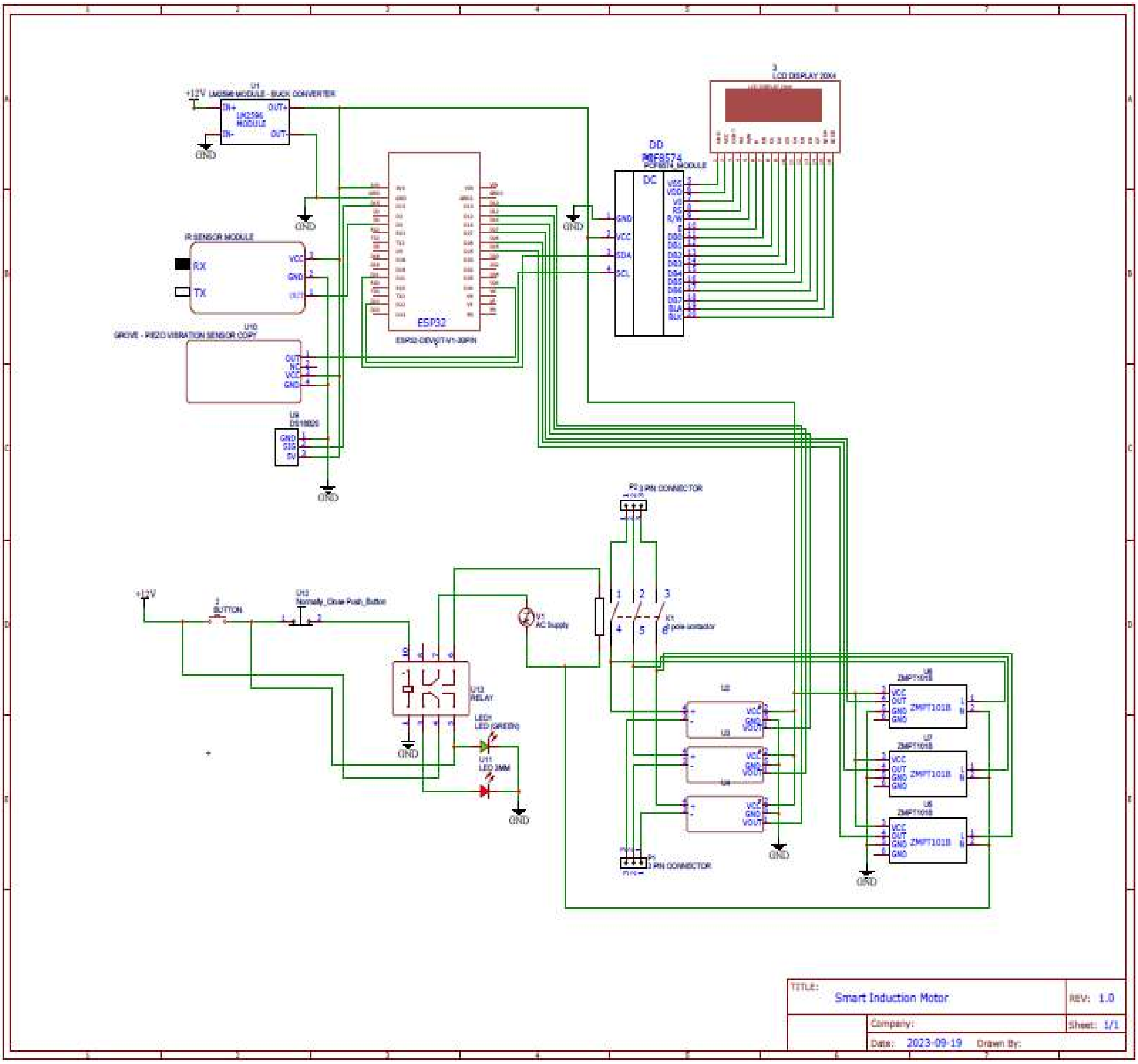


Fig. 3.15 Schematic Diagram of the Proposed System

The schematic diagram illustrates the intricate electronic architecture of the induction motor's health monitoring system. Central to this design is the ESP32 microcontroller, which acts as the main processing unit, interconnecting various components. The 20x4 LCD, directly linked to the ESP32, offers real-time system statuses, while sensors like the DS18B20 provide temperature metrics. The Vibration Sensor Module and the IR Sensor Module feed mechanical and RPM data, respectively, to the ESP32. The LM2956 module, likely a voltage regulator, ensures a stable power supply to all attached modules. The ACS712 Current Sensor and ZMPT101b Voltage Sensor provide essential electric current and voltage readings, respectively. Their data streams flow directly to the ESP32, enabling comprehensive monitoring. In essence, the schematic offers a detailed roadmap of how each component interacts within the system, highlighting the importance of seamless data flow for efficient monitoring.

### 3.14. Technical Specifications and Visual Overview of the Induction Motor

- Power: 370W
- Voltage: 220/380 V Δ/Y
- Current: 1.9/1.1A Δ/Y
- Speed: 2850 rpm, 50 Hz

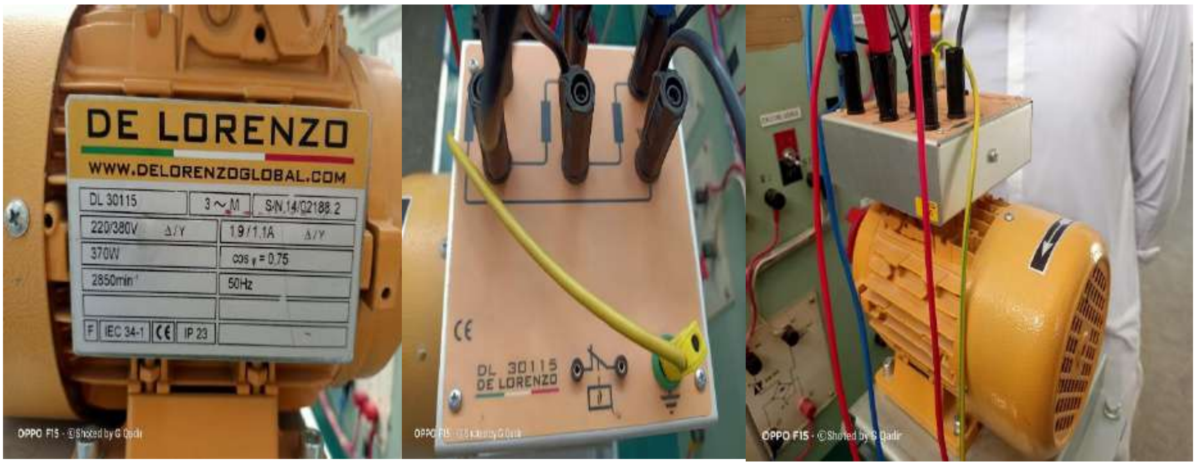


Fig. 3.16 Detailed View of the Induction Motor.

The motor used in the research operates at a power of 370W, with dual voltage capabilities of 220V in Delta configuration and 380V in Star configuration. It draws a current of 1.9A in Delta and 1.1A in Star, running at a speed of 2850 rpm with a frequency of 50 Hz.

## 3.15. Cost Breakdown of Individual Components

Table 3.1 Component-wise Cost Analysis for the Monitoring System

| S.NO | Name of Components | Cost |
|---|---|---|
| 1 | Microcontroller ESP32 | 5000 |
| 2 | AC Voltage Sensor ZMPT101B | 2200 |
| 3 | Current Sensor HSTS016L | 2700 |
| 4 | Temperature Sensor RTD-PT100 | 1800*2= 3600 |
| 5 | RPM Sensor TZT KY-024 | 1150 |
| 6 | Vibration Sensor TZT 801s | 1500 |
| 7 | I2C LCD | 900 |
| 8 | Wi-Fi Module ESP-07 | 3000 |
| 9 | 8 Channel Relay Module | 1350 |
| 10 | 3 pole Contactor CTX3 40 | 4400 |
| 11 | Connecting Wires, PCB and Connectors | 2000 |

# CHAPTER No. 4. **RESULTS AND DISCUSSION**

## 4.1. Real-time Monitoring Performance

## 4.2. Fault Detection and Analysis

## 4.3. Data Visualization and Interpretation

## 4.4. Summary Key Findings

# CHAPTER No. 5. **CONCLUSION**

## 5.1. Recapitulation of the Research Objective and Methodology

The primary objective of this research was to create a sophisticated online health monitoring system for induction motors, aiming to transition from traditional maintenance practices to a real-time, proactive approach. Leveraging components like the ESP32 microcontroller and a suite of sensors, we embarked on a systematic methodology. We integrated sensing, data processing, and real-time visualization, laying the foundation for an innovative monitoring system.

## 5.2. Key Findings and Results

Through meticulous design and integration, the system proved proficient in real-time monitoring and early fault detection. The combination of temperature, vibration, current, and voltage sensors ensured a holistic assessment of the motor's health. Initial tests revealed the system's capability to detect anomalies accurately, underlining its promise in preempting and mitigating potential breakdowns.

## 5.3. Implications and Applications

The research's findings underscore a significant advancement for industries reliant on induction motors. With motors playing pivotal roles in everything from manufacturing and energy to transportation, the system's value is multifold. Industries stand to benefit from reduced maintenance costs, minimized downtime, and potentially extended equipment lifespans. The integrated approach bridges the traditional and modern, fostering a blend of reliability and innovation.

## 5.4. Comparative Analysis

When juxtaposed with conventional maintenance practices, the online health monitoring system showcased notable advantages. While traditional methods often revolve around scheduled checks or reactive solutions post-failure, this system offers continuous monitoring. The potential for predictive maintenance, coupled with the real-time data visualization, places it leagues ahead in terms of efficiency, cost-effectiveness, and reliability.

### 5.5. Future Work and Recommendations

While the current system is promising, there's scope for further optimization. Future endeavors could explore the integration of advanced machine learning algorithms to enhance predictive accuracy. Additionally, expanding the system's applicability to other machinery types could be beneficial. It's recommended that industries, especially those in critical sectors like energy and manufacturing, consider adopting this system to harness its full potential.

### 5.6. Final Thoughts

This research journey underscores the evolving landscape of industrial maintenance. The blend of cutting-edge technology with foundational knowledge paves the way for a future where machinery operates at its peak, and industries flourish with minimized hiccups. The marriage of traditional practices with modern innovations, as showcased in this thesis, heralds a new era of efficient and proactive industrial operations.

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