

# Smart Fault Detection And Recovery System For Industrial Machinery

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**Abstract—** Industrial motors and rotating machines play a vital role in manufacturing and production environments, where unexpected failures can lead to significant downtime, financial loss and safety risks. Traditional maintenance approaches such as reactive maintenance, performed after a failure and preventive maintenance, based on fixed time intervals are inefficient and often fail to detect early-stage faults. Existing monitoring systems are expensive, complex and mostly suitable only for large-scale industries, making them inaccessible for small and medium enterprises. Hence a low-cost ESP32-based predictive maintenance system for real-time condition monitoring of industrial motors continuously monitors key health parameters such as vibration, temperature and current using multiple sensors. By analyzing these parameters in real time, the system can detect abnormal operating conditions at an early stage. Fault severity is classified into normal, warning and critical levels, which are indicated using visual LED alerts. In addition, the system provides a self-protection mechanism by automatically disconnecting the motor during severe fault conditions, preventing permanent damage.

**Keywords—**Industrial Machinery, Sensor based control, Real time monitoring, Smart devices, Automatic Control.

## I. INTRODUCTION

In manufacturing and production settings, where unplanned failures can result in substantial downtime, monetary loss, and safety hazards, industrial motors and rotating machinery are essential components. Conventional maintenance techniques, like reactive maintenance, which is carried out following a failure, and preventive maintenance, which is based on predetermined time intervals, are ineffective and frequently miss early-stage faults. Due to their high cost, complexity, and limited suitability for large-scale industries, existing monitoring systems are out of reach for small and medium-sized businesses. Therefore, a low-cost predictive maintenance system based on ESP32 continuously monitors important health parameters like vibration, temperature and current using a number of sensors for real-time condition monitoring of industrial motors and other machinery.

The suggested solution is affordable, scalable, simple to implement and appropriate for both industrial and educational applications when compared to current systems. The growing need for productive and accident-free workplaces has made industrial safety and automation top priorities in recent years. Machine vibration, overheating, and unplanned system failures are common issues in industries like manufacturing, mining, construction, and heavy machinery operations. These problems can result in financial loss, decreased operational effectiveness, equipment damage, and—above all—a risk to human safety.

As a result, employing intelligent and automated systems to monitor and regulate these parameters has become crucial. The main goal of the suggested system is to use cutting-edge embedded technology to create an intelligent monitoring and alert system. The purpose of this system is to continuously check the temperature and vibration levels of industrial machinery and use visual alert mechanisms to provide early warning indications. The system assists in preventing machine failures and guarantees smooth operation by identifying anomalous vibrations and temperature changes. The ESP32 microcontroller serves as the system's brain and is primarily used in this setup. The ESP32 was chosen because of its integrated wireless communication capabilities, low power consumption, and high processing power. To gather data in real time from the machine environment, the system is equipped with sensors like temperature, vibration, and current sensors. The controller evaluates the equipment's condition based on the sensor readings and turns on LED indicators, such as green, yellow, and red LEDs in which the Green LED indicates normal operating conditions where vibration, current and temperature levels remain within safe limits.

The Yellow LED represents warning conditions where slight abnormalities are detected and preventive maintenance may be required. The Red LED indicates critical conditions where the machine may be unsafe to operate and immediate action is necessary. Additionally, the system includes a DC cooling fan which automatically activates when temperature levels exceed

the predefined threshold, helping to reduce heat and maintain system stability. The system's goal is to offer an affordable, dependable, and simple industrial monitoring solution. The system is intended to extend machine life, improve operational safety, and decrease manual inspection.

The system supports the idea of Industry 4.0 and is appropriate for contemporary industrial applications thanks to the use of automation and smart sensing technology. The project also emphasizes how crucial it is to combine sensor technology with embedded systems in order to develop real-time monitoring solutions. By using this system, maintenance scheduling can be greatly enhanced, unplanned machine downtime can be decreased and overall productivity can be increased. This system is appropriate for both small- and large-scale industrial settings due to its scalable architecture, low power consumption and compact design.

## II. DESCRIPTION OF BLOCK DIAGRAM

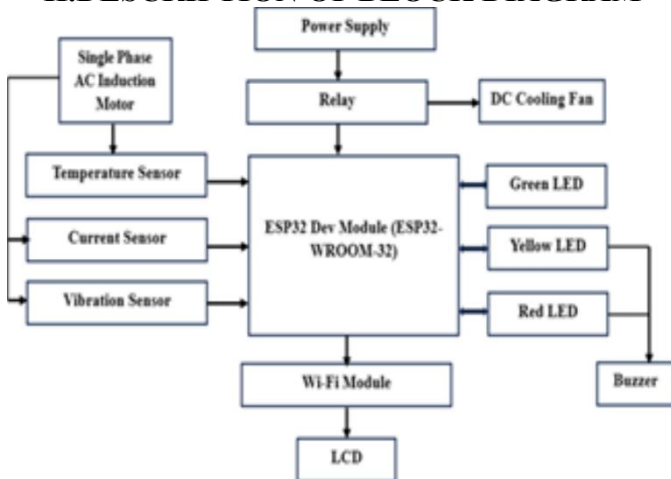


Fig. 1. Block diagram of smart fault detection and recovery system for industrial machinery

### A. ESP32 Microcontroller

The ESP32, serves as the system's brain. The temperature, current and vibration sensors provide it with real-time data. It examines the motor condition based on the program's threshold values. To show the state of the system, it regulates the green, yellow and red LEDs. Additionally, it automatically turns on the DC cooling fan and buzzer under emergency situations.

### B. Temperature Sensor ( LM35)

The AC motor's surface temperature is continuously monitored by the temperature sensor. It aids in the early detection of

overheating situations. The ESP32 receives temperature readings in real time from the sensor. The system switches to warning or critical mode when the temperature rises above acceptable bounds. This extends the life of the motor and avoids thermal damage

### C. Current Sensor (ACS712)

The motor's operating current is measured by the current sensor. It aids in locating anomalous current flow and overload situations. The ESP32 receives the sensor output and analyzes it. The system initiates warning or critical alerts if the current surpasses the predetermined threshold. This shields the motor from short circuits and other electrical issues.

### D. Vibration Sensor (MPU6050).

Unusual mechanical vibrations in the motor are detected by the vibration sensor. Over vibration could be a sign of misalignment, imbalance, or bearing failure. Through I2C communication, the sensor provides the ESP32 with motion data. To ascertain fault levels, the controller analyzes this data. This avoids mechanical failure and aids in predictive maintenance.

### E. Single Phase AC Induction Motor

The primary piece of equipment under observation in our project is the AC motor. In real-time applications, it symbolizes an industrial motor. Temperature, current and vibration are all continuously monitored by the system. Alerts and cooling systems are triggered based on these parameters. This avoids unplanned motor failure and guarantees safe operation. The Following Fig.2. Shows the working of Smart Fault Detection and recovery system for industrial machinery with LED's and connection with AC Motor and the Output is obtained in the Thinkspeak with graph as a Output and their Values in Normal and Abnormal Conditions as shown in the following figures.



Fig. 2. Smart Fault Detection And Recovery System For Industrial Machinery



Fig. 3. Existing system

### III. EXISTING SYSTEMS

The ESP32 board serves as the processor in the current work. The DHT 11, ACS 712, and ADXL 345 sensors are used to gather parameters. The THINGSPEAK platform is used to upload data gathered from multiple sensors to the cloud. IoT platforms that display graphs and widgets allow users to view all of the parameters' real-time data [16, 17].

The results of using assembled hardware with a single-phase induction motor were discussed. The flowchart for the entire process in the proposed work is explained in Figure 1. The ESP32 board connects to the access point when the supply is applied [18, 19]. Sensors attached to motors begin sending signals to the ESP32 board's GPIO pins.

An alert or notification can be sent to the operator if the motor's parameter value rises and exceeds the predetermined limit in any abnormal condition. Such a protocol can be crucial for motor protection [25, 26]. It may also be feasible to predict malfunctions and categorise industrial machinery accordingly. An artificial neural network that has been trained on real-time motor data can produce an output that predicts the type of fault [27]. The machine can be scheduled for maintenance if the problem is still in its early stages. The suggested work can be extended in the future to include fault classification and prediction for different motor types. There are fifteen ADC pins on the ESP32 module.

### IV. PROPOSED SYSTEM

The suggested system is an intelligent Internet of Things (IoT)-based motor monitoring and protection system that is intended to continuously monitor an industrial motor's operational state and provide automated safety measures in unusual circumstances. The block diagram shows how the cooling mechanism, alert system, processing unit, monitoring interface, and sensing units are connected. The ESP32 Dev Module (ESP32-WROOM-32), which serves as the main processing and decision-making unit, manages the entire system's operation.

The industrial machinery that is being observed is represented by the single phase AC induction motor. Mechanical stress, incorrect loading, or environmental factors can cause a number of fault conditions during motor operation, including overheating, overload current, and excessive vibration. Several sensors are incorporated into the system to provide real-time monitoring of these parameters.

To continuously measure the motor's thermal condition, a temperature sensor is positioned close to the motor surface. Long-term motor operation increases heat generation, which, if left unchecked, could harm internal windings and insulation. Thermal energy is transformed by the temperature sensor into electrical signals, which are then sent to the ESP32 for examination.

To determine how much current the motor is drawing, the current sensor is connected in series with the motor supply line. A mechanical blockage, overload, or short circuit conditions are indicated by any unusual increase in current. Early detection of electrical problems is made possible by this real-time current

monitoring. Mechanical anomalies like imbalance, shaft misalignment, loose parts or bearing wear are detected by the vibration sensor. Comprehensive motor health monitoring is possible by combining vibration, temperature, and current data. The ESP32 microcontroller receives all sensor outputs and uses preprogrammed threshold conditions to process the gathered data. The controller classifies the motor condition into three operational states: normal, warning, and critical by comparing sensor readings with predetermined safe limits. Three LEDs are connected as output indicators for visual indication. The Green LED illuminates to show that the motor is operating normally when all parameters stay within safe bounds. The Yellow LED turns on to notify the user that preventive maintenance might be necessary if any parameter gets close to the warning threshold. The Red LED illuminates, signifying a hazardous operating condition, when sensor values surpass critical limits.

The ESP32 simultaneously sounds a buzzer during the critical state, alerting operators to the fault condition instantly. Concurrently, the relay module is activated by the controller, turning on the DC cooling fan. By lowering the excess heat produced in the motor and assisting in the restoration of a safe operating temperature, the cooling fan helps to avoid irreversible motor damage. To guarantee dependable system operation, a regulated power supply unit supplies the ESP32, sensors, relay, LEDs and other electronic components with a steady voltage. Additionally, the ESP32 transmits monitored data wirelessly by utilizing its integrated Wi-Fi capability. An LCD display shows the current system status and parameter values, enabling users to view motor conditions immediately without the need for manual inspection.

So the proposed system puts together a lot of things like sensing and processing and alerting and cooling and wireless monitoring all in one place. This system does a lot, on its own, which means people do not have to get involved much. The industrial motors system is safer to use and it can even tell us when it needs maintenance. This helps the industrial motors last longer and work better.



Fig.4. Normal Operating Conditions Of The System

## V. ANALYSIS OF EXPERIMENTAL GRAPH RESULTS

The ThingSpeak cloud platform is used to create the following graphs. Wi-Fi communication is used to upload real-time sensor data gathered from the ESP32-based smart industrial fault detection system. A particular motor parameter, such as current, temperature, vibration, and overall system status, is represented by each graph. The cloud database is periodically updated by the ESP32, which continuously reads sensor values and processes them using preset threshold logic.

### A. Current Monitoring

The ACS712 current sensor, which is incorporated into the suggested smart fault detection system, is used to monitor the industrial motor's current in real time. When examining the motor's electrical condition and operational stability, this graph is essential. The current sensor can measure the amount of current drawn while the motor is operating because it is connected in series with the motor supply line. The ACS712 sensor converts the magnetic field produced by the flowing current into a proportional voltage signal using the Hall-effect principle. The ESP32 microcontroller uses its analog-to-digital converter (ADC) pins to read this analog signal. Through its integrated WiFi module, the ESP32 uploads the processed data to the ThingSpeak cloud platform after continuously sampling the current values at predetermined intervals.

The program's preset threshold limits are compared with the measured current values by the ESP32. The system considers the situation to be normal if the current stays within the safe operating range. In this scenario, no cooling action is initiated,

the buzzer stays off, and the green LED stays on. The system would turn on the yellow LED, which indicates unusual electrical behavior, if the current rose above the warning limit. Likewise, the red LED and buzzer would turn on to warn operators of a possible electrical failure if the current surpassed the critical threshold. The electrical monitoring subsystem operates precisely and consistently, as this graph illustrates.

Continuous current monitoring aids in the early detection of electrical problems before they cause significant harm, such as wiring problems, motor overload, or insulation failure. The accuracy of the sensor integration and the effectiveness of wireless data transmission via ThingSpeak are further confirmed by the steady graph trend. All things considered, the existing monitoring graph demonstrates that the suggested system effectively maintains electrical safety and avoids unplanned shutdowns.

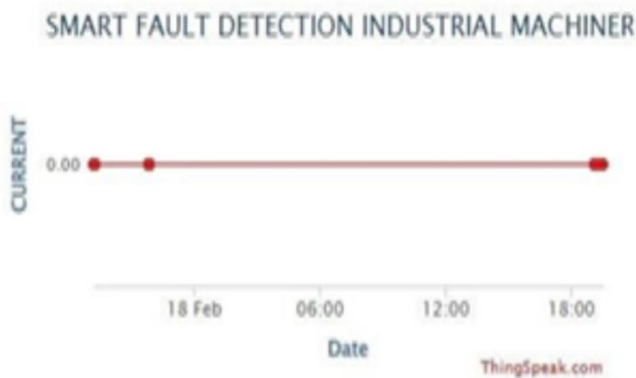


Fig.5. Current Monitoring

**B. Temperature Monitoring**

The temperature changes of the motor that are tracked by the temperature sensor built into the suggested system are shown in the Field 2 chart. Since overheating is a primary cause of motor failure, temperature monitoring is one of the most crucial aspects of industrial motor protection. To precisely measure surface temperature while the motor is operating, a temperature sensor—either the LM35 or the DS18B20—is positioned close to the motor body. The ESP32 microcontroller reads the electrical signals that the sensor produces in proportion to the temperature. After being processed, the gathered data is sent to the ThingSpeak cloud platform for analysis and visualization. The motor's initial idle condition is represented by temperature readings on the graph, which begin at roughly 22 to 25°C. The motor gradually raises its temperature as it starts up because of

heat produced by mechanical friction and electrical losses. The graph shows a consistent rise toward 35–45°C, which is thought to be the typical operating temperature range for small industrial motors. This steady rise attests to realistic motor behavior when running continuously. Later time intervals see temperature peaks get closer to 55–60°C, which suggests a higher operational load or longer running time. Temperature readings are continuously compared to preprogrammed threshold values by the ESP32.

The system alerts the operator that maintenance may be necessary shortly when the temperature rises above the warning level by turning on the yellow LED.

The controller turns on the red LED, buzzer alarm, and relay-controlled DC cooling fan if the temperature rises above the critical threshold. By automatically lowering the motor's temperature, the cooling fan prolongs the motor's life and guards against insulation damage. The graph unequivocally shows how well automatic protection systems and real-time thermal monitoring work. This automated system continuously monitors thermal conditions and reacts immediately to abnormal heating, in contrast to traditional systems that depend on manual inspection. Remote monitoring and historical analysis are also made possible by the cloud's capacity to display temperature trends. This aids businesses in anticipating overheating trends and planning maintenance before a catastrophic failure happens. Therefore, the temperature monitoring graph validates the system's capability to provide intelligent thermal protection and improve operational reliability.



Fig.6. Temperature Monitoring

**C. Vibration Monitoring**

The motor's vibration analysis using the MPU6050 vibration sensor is shown in the Field 3 chart. Early detection of mechanical faults is frequently challenging. An efficient way to find problems like imbalance, bearing wear, loose mounting, or shaft misalignment is through stages and vibration monitoring. The MPU6050 has a gyroscope and accelerometer that can sense motion variations along several axes. Vibration data can be collected in real time thanks to the sensor's I2C protocol communication with the ESP32.

As would be expected when a motor is operating, the graph shows varying vibration values over time. Smoothness and balance are indicated by lower vibration levels. motor rotation, whereas mild fluctuations are indicative of typical operating dynamics brought on by changes in load. Nevertheless, the graph also displays higher peaks that approach maximum values, signifying transient mechanical disruptions. These peaks could be brought on by a small imbalance, an abrupt change in load, or vibrations from the surroundings.

After processing vibration readings, the ESP32 compares them to predetermined limits. The system maintains normal operation and turns on the green LED when vibration levels stay within an acceptable range. The yellow LED illuminates to alert operators to potential mechanical stress when vibration rises above the warning threshold. The system turns on the red LED and buzzer if vibration surpasses critical limits, signaling the need for an urgent inspection to avoid mechanical failure. This graph demonstrates that the system can effectively identify aberrant vibration patterns and capture dynamic mechanical behavior. Operators can better comprehend the evolution of machine health and analyze vibration trends over time with the aid of cloud visualization. Therefore, the vibration graph confirms the system's capacity for intelligent monitoring and early mechanical fault detection.



Fig.7. Vibration Monitoring

**D. System Status Graph**

The ESP32 controller's overall system decision output is shown in the Field 4 chart. This graph displays the processed operational status obtained by combining temperature, current, and vibration parameters, in contrast to other graphs that show raw sensor data. Numerical values that represent various machine conditions are assigned by the controller.

The following is the definition of the status values:

- 0: Normal Situation (Green LED On)
  - 1: warning condition (yellow LED on).
  - 2: Critical Situation (Cooling Fan, Buzzer, and Red LED ON)
- Transitions between these values at various time intervals are depicted on the graph. Safe operating conditions are initially indicated by the status staying at 0.

As When sensor readings marginally rise, the system enters a warning state, or status 1. Early alerts are provided by this stage, enabling preventive action prior to failure. The status changes to 2 when sensor values surpass critical limits, triggering cooling systems and emergency alerts. The ESP32 microcontroller's ability to make intelligent decisions is demonstrated by the dynamic change in status values. The system assesses several sensor inputs at once rather than responding to a single parameter, which improves the accuracy and dependability of the monitoring process.

This integrated decision-making system guarantees proper safety measures and lowers false alarms. The status graph demonstrates that the suggested system automatically interprets machine health conditions in addition to monitoring data. It attests to the effective deployment of automated fault classification, real-time protection mechanisms, and IoT-based smart monitoring. This graph, taken as a whole, demonstrates the automation and intelligence of the suggested industrial fault detection system.

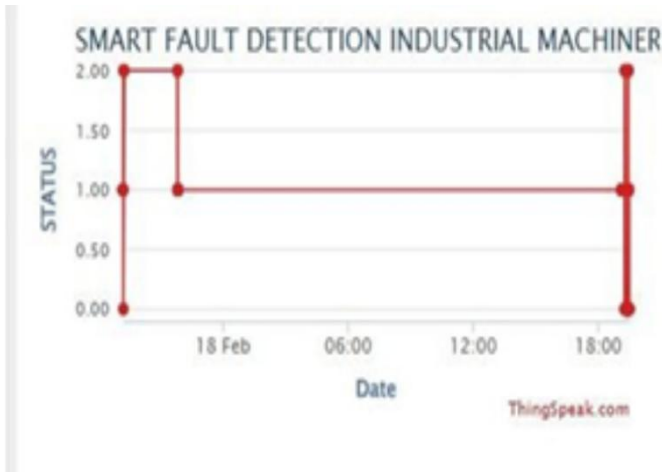


Fig.8. System Status Graph

System Status Graph (Fig. 7) The experimental graphs unequivocally show that real-time industrial motor health monitoring is successfully accomplished by the suggested system. Electrical stability is confirmed by current monitoring, temperature and vibration variations are precisely detected, and automatic status classification guarantees prompt fault alerts. Predictive maintenance and remote supervision are made possible by the integration of IoT cloud visualization.

The operational thresholds utilized in the suggested IoT-based industrial motor monitoring system to assess machine health conditions in real time are represented by the tabulated performance values. Temperature, current consumption, and vibration level are the three main parameters that the system continuously monitors because they are the main markers of motor performance and the occurrence of faults in industrial settings. Three operating regions are assigned to each parameter.

| Parameter          | Normal Value | Warning Value | Critical Value | System Status               |
|--------------------|--------------|---------------|----------------|-----------------------------|
| Temperature (°C)   | 30 – 50°C    | 50 – 70°C     | > 70°C         | Normal / Warning / Critical |
| Current (A)        | 0.2 – 0.6 A  | 0.6 – 0.9 A   | > 0.9 A        | Normal / Overload Alert     |
| Vibration Level    | 0 – 40       | 40 – 70       | > 70           | Stable / Unstable           |
| Motor Health (%)   | 80 – 100%    | 60 – 80%      | < 60%          | Healthy / Attention / Fault |
| Cooling Fan Status | OFF          | Standby       | ON             | Temperature Based           |
| LED Indication     | Green ON     | Yellow ON     | Red ON         | Condition Indicator         |
| Buzzer Status      | OFF          | OFF           | ON             | Fault Alert                 |

Fig.9. Tabulation of Operating Parameters with it's Threshold Values

## VI. PROPOSED SYSTEM WITH METHODOLOGIES

### 1. Real-Time Machine Health Monitoring

The proposed system continuously monitors the industrial motor condition in real time using temperature, current and vibration sensors. The ESP32 controller collects live data without any delay and processes it instantly. This helps in observing machine behaviour during operation rather than checking manually. Continuous monitoring reduces unnoticed failures and improves operational awareness. Industries can track machine performance at every moment. The system ensures accurate detection of abnormal conditions before serious damage occurs. This improves reliability and confidence in machine operation.

### 2. Early Fault Detection Capability

One of the best outputs of the project is its ability to detect faults at an early stage. Abnormal temperature rise, excessive vibration, or unusual current consumption are identified immediately. The system compares sensor values with predefined threshold limits to recognize faults. Early detection prevents sudden machine breakdowns and costly repairs. Maintenance teams can take action before failure happens. This predictive behavior increases equipment lifespan. It also minimizes unexpected downtime in industrial environments recognize faults. Early detection prevents sudden machine breakdowns and costly repairs. Maintenance teams can take action before failure happens. This predictive behavior

increases equipment lifespan. It also minimizes unexpected downtime in industrial environments.

**3. Automatic Cooling and Protection Mechanism**

The system automatically activates a DC cooling fan when overheating is detected. This automatic response protects the motor from thermal damage without human intervention. Immediate

cooling reduces stress on motor windings and components. The automation improves system safety and efficiency. Manual monitoring is not required continuously. The protective action ensures stable motor performance. This feature makes the system suitable for real industrial applications.

**4. Cloud-Based Remote Monitoring (IoT Integration)**

Sensor data is transmitted to the cloud platform using ESP32 Wi-Fi connectivity. The ThingSpeak dashboard displays live graphs for temperature, vibration, and system status. Users can monitor machine health remotely from anywhere. Historical data storage helps in performance analysis and maintenance planning. Engineers can identify trends and predict faults using stored data. Remote monitoring reduces manpower requirements. This improves smart industry implementation aligned with Industry 4.0 concepts

**5. Intelligent Status Indication and Alert System**

The system uses buzzer alerts and LEDs to clearly display machine status. Red denotes a fault condition, yellow a warning, and green a normal condition. Operators can quickly understand the health of the machine thanks to this visual and auditory indication. Alerts speed up reaction times in unusual circumstances. The system increases equipment and operator safety. Operational risks are avoided through prompt identification. It guarantees effective and convenient monitoring.

**6. Low-Cost and Industry-Applicable Smart Solution**

The project achieves industrial fault monitoring using low-cost components like ESP32 and basic sensors. Despite being economical, the system provides advanced monitoring features. Small and medium industries can easily adopt this solution. Installation and maintenance are simple compared to complex industrial systems. The design is scalable for multiple machines. This makes the project practical and economically beneficial. It proves that smart monitoring can be achieved with affordable technology.

The following Fig.9. shows the flow diagram of Smart Recovery System and the working and connection of the each

components and also the work flow from power supply to the various sensors and Single Phase AC motor and the reading are differentiated and the efficiency and state of motor is recognized by comparing it's actual value to the threshold value which is shown here and the output is being noted and utilized for further usage.

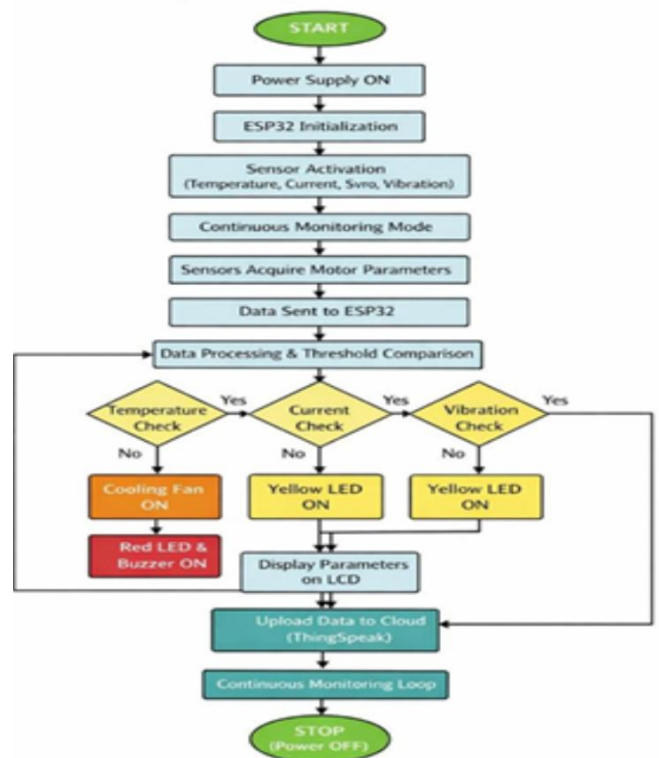


Fig.10.Flow Diagram of Smart Recovery System

**VII. EXPERIMENTAL RESULTS**

A single-phase AC was used to successfully implement and test the Smart Fault Detection and Recovery System for Industrial Machines induction motor in various operational scenarios. The system continuously monitors motor health by integrating ESP32 with temperature, current, and vibration sensors. To examine system performance under warning, fault, and normal operating conditions, experimental testing was done.

The motor was run under typical load conditions during the first testing phase. Safe operating limits are indicated by the temperature sensor's recorded values, which range from 24°C to 40°C. The motor's correct mechanical alignment was confirmed by the vibration sensor's steady readings that fell

within the typical range. The current sensor recorded constant, fluctuation-free current consumption. Accurate baseline monitoring was demonstrated by the system status remaining in normal mode and the absence of any alerts.

In the second stage, artificial stress conditions were introduced by partially restricting airflow around the motor to simulate overheating. The temperature gradually increased beyond the predefined threshold value. The system successfully detected this abnormal rise and automatically activated the cooling fan. The cloud dashboard updated the temperature graph in real time, showing a clear increase followed by stabilization after cooling. This confirms the effectiveness of the automatic protection mechanism.

Further experiments were conducted to simulate mechanical faults by introducing external vibration disturbances. The vibration sensor detected abnormal oscillations immediately and the ESP32 processed the data without delay. The system status changed from normal to warning condition, indicating early fault detection capability. Alert indications such as LEDs and buzzer notifications were activated, demonstrating real-time response performance

## VIII. CONCLUSION

The Industrial Machines Smart Fault Detection and Recovery System effectively illustrates an economical and effective remedy for actual predictive maintenance and real-time tracking of motor health. The system continuously monitors vital industrial motor operating parameters by integrating an ESP32 microcontroller with temperature, current, and vibration sensors. Through the analysis of these parameters, the system successfully detects anomalous circumstances like early-stage overcurrent, excessive vibration, and overheating.

The outcomes of the experiment verify that the system keeps a close eye on machine behavior and reacts right away when threshold limits are crossed. Without human intervention, enhanced equipment protection is ensured by the automatic activation of alert mechanisms, such as buzzer notifications, LED indications, and cooling fan operation. Users can remotely monitor machine performance thanks to real-time cloud monitoring and graphical visualization made possible by the integration of IoT technology.

The suggested system minimizes unplanned machine failures, decreases manual inspection, and enhances operational security. The system is appropriate for small and medium-sized industries where sophisticated monitoring systems are frequently expensive due to its use of reasonably priced

components. All things considered, the project demonstrates that a straightforward, scalable, and energy-efficient design can accomplish intelligent condition monitoring and predictive maintenance.

Thus, the system that has been developed improves machine dependability, prolongs the life of motors, lowers maintenance costs, and facilitates the adoption of intelligent industrial automation that is in line with Industry 4.0 principles.

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