"Automatic Switching Based on Condition Monitoring of Three-Phase Induction Motor"

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Abstract*— Ensuring the uninterrupted operation of three-phase induction motors is critical in numerous industrial applications. However, anomalies such as phase imbalance, voltage sags, and overcurrent conditions can severely compromise motor efficiency, potentially leading to equipment degradation and operational downtime. This paper proposes an automated switching architecture engineered to enhance the fault tolerance of three-phase induction motors by enabling dynamic reconfiguration in response to detected electrical anomalies. A dual-motor framework comprising a primary induction motor and an auxiliary backup motor is central to the design. A microcontroller-based system governs the logic for automatic motor switching. In scenarios where the primary motor encounters operational failure or when thermal thresholds are exceeded (e.g., motor winding temperature reaching 45°C), the control unit initiates a transfer of load to the backup motor. This temperature-based transition mechanism addresses the issue of thermal stress due to prolonged motor operation. The proposed system has been validated through empirical evaluation on a physical prototype. Experimental results confirm the system's capability to maintain operational integrity, reduce unplanned downtime, and enhance overall motor system reliability in industrial environments.

***Keywords*— Three-phase induction Motor Protection System, Fault Detection, Microcontroller-Based Monitoring, Automatic Switching**

I. INTRODUCTION

Three-phase induction motors are essential for industrial systems due to their ruggedness, simplicity, and low maintenance requirements. Despite these advantages, they are vulnerable to various operational faults such as over-voltage, under-voltage, overheating, unbalanced phases, vibrations, and insulation breakdown, leading to catastrophic failures if not detected and addressed promptly [1] – [4]. These faults not only reduce the operational lifespan of motors but also cause unplanned downtimes, reduced productivity, and increased maintenance costs [5]. To ensure reliable and safe operation, condition monitoring systems are employed to assess the real-time health status of induction motors. These systems detect incipient faults by monitoring various parameters such as current, voltage, temperature, vibration, and acoustic emissions [6]– [9]. When a fault is detected, automatic switching mechanisms can isolate the faulty motor and engage a backup system, thus minimizing operational disruption and preventing further equipment damage [10] – [12]. Among the most critical conditions leading to faults are electrical abnormalities such as over-voltage, under-voltage, and phase imbalances. These conditions cause insulation stress, unbalanced currents, and thermal overloads that significantly deteriorate motor performance [13]–[15]. Similarly, thermal faults due to continuous overloading or cooling system failure result in insulation degradation, contributing to winding failures [16]– [18]. Mechanical issues like misalignment, shaft imbalance, and bearing failures are also significant contributors to motor faults. Vibration monitoring and noise analysis have emerged as key techniques to identify such mechanical anomalies early [19]– [21]. Integration of artificial intelligence (AI) and machine learning (ML) into condition monitoring has enabled smarter, real-time diagnostics and fault prediction, allowing proactive switching before complete breakdowns occur [22]– [25].

II. SYSTEM DEVELOPMENT

The system is designed to continuously monitor the electrical parameters of a three-phase induction motor and automatically switch between the default and auxiliary motors to maintain continuous operation and protection. The development involves integrating sensors, a microcontroller, relays, contactors, and display units to realize a comprehensive protective mechanism. Figure 1 shows the block diagram of the developed system.

The system development begins with power preparation, where high-voltage three-phase power lines (R, Y, B) are stepped down to safer, low AC voltages (0- 12V) using specialized transformers. These lower voltages are then rectified and regulated through rectifier circuits to supply stable DC power (typically 5V) needed for the control electronics. The phase voltages are monitored in real-time by ADC modules attached to each phase; these converters measure the analog voltage signals and convert them into digital data that the microcontroller can process. Alongside, sensors such as temperature, vibration, and humidity sensors continuously monitor the operational environment and mechanical condition of the motor, providing additional data inputs.

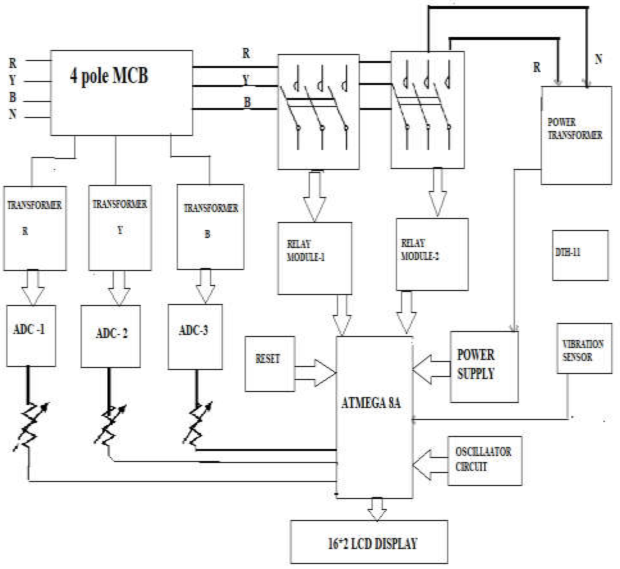

Figure 1: Block diagram of the developed system

The microcontroller (ATmega8A) acts as the brain of the system, reading voltage levels from ADCs and sensor data, then analyzing these inputs against predefined safety thresholds to detect any faults like phase loss, voltage abnormalities, or abnormal temperatures. Upon fault detection, the microcontroller sends control signals to relay modules, which in turn activate contactors to disconnect or switch the motors, ensuring protection and continued operation via an auxiliary motor if necessary. Simultaneously, status indicators such as LEDs and an LCD display provide real-time feedback on system status, fault conditions, and operational parameters. The entire setup is protected by circuit breakers (MCB) and other safety devices to prevent electrical hazards. This integrated process ensures a responsive and reliable system capable of automatically detecting faults, taking protective actions, and maintaining continuous motor operation with minimal manual intervention.

III. Results and Discussion

The design that is being considered aims to achieve two goals; firstly, it will deliver continuous power, and secondly, it will have an auxiliary motor that is programmed using a microcontroller ATMEGA8A to take over if the default motor fails. In addition, a switching algorithm between the motors is designed to control the temperature created in the motor by alternating the default and auxiliary motor functions after reaching 45°C. Automatic switching of a three-phase induction motor during a fault condition is a crucial safety and operational feature in many industrial applications. The primary goal is to quickly isolate the motor from the power supply when an abnormal condition arises, preventing damage to the motor itself, connected equipment, and ensuring the safety of personnel.

A. Fault Detection: Various sensors and protective relays are employed to continuously monitor the electrical parameters of the motor and the power supply. Common fault conditions that are detected include,

- **Overcurrent/Overload:** This occurs when the motor draws more current than its rated capacity, usually due to excessive mechanical load. The temperature sensor is used because the current increases temperature increases, to detect this by monitoring the current over time.
- **Single Phasing:** This happens when one of the three phases of the power supply is lost. Running a three-phase motor on a single phase can cause it to overheat, and drawing excessive current in the remaining phases gives a signal to the microcontroller and displays the fault.
- **Under/Over Voltage**: Deviations from the nominal supply voltage can damage the motor. Undervoltage can cause increased current draw and overheating, while overvoltage can stress the insulation.

- **Temperature Rise:** Excessive operating temperatures, even without overcurrent, can damage the motor's insulation. Thermal sensors DHT 11 are embedded on the motor.

B. Tripping Mechanism: Once a fault is detected, the protective device sends a signal to a switching device, typically a contactor, connected in the motor's power supply circuit.

- **Contactors**: These are electromechanical switches that can be opened or closed remotely. They are commonly used for starting, stopping, and protecting motors. When a fault signal is received, the contactor's coil is de-energized, causing the main contacts to open and interrupt the power supply to the motor.

C. Automatic Switching/Protection:

- **Motor Protection Relays (MPRs):** These are sophisticated digital devices that integrate multiple protection functions (overcurrent, under/over voltage, phase imbalance, ground fault, etc.) into a single unit. They offer more precise and customizable protection characteristics and can provide diagnostic information about the fault. When a fault is detected, the MPR sends a trip signal to the motor's contactor or circuit breaker.
- **Automatic Transfer Schemes:** In critical applications where continuous operation is essential, a backup motor might be automatically switched on if the primary motor fails. This involves a more complex control system that detects the failure of the primary motor and then initiates the starting sequence for the standby motor while disconnecting the faulty one. Microcontrollers are used for such systems.

D. Importance of Automatic Switching:

- **Preventing Motor Damage:** Quickly disconnecting the motor during a fault minimizes the risk of winding burnout, insulation failure, and other forms of damage that can lead to costly repairs or replacements.
- **Ensuring Personnel Safety:** Automatic tripping in case of ground faults or short circuits helps to prevent electrical shocks and other safety hazards.
- **Protecting Connected Equipment**: Motor faults can sometimes affect the power supply or other connected machinery. Automatic isolation helps to prevent the propagation of faults.
- **Minimizing Downtime:** While a fault will still cause a temporary shutdown, automatic protection helps to limit the extent of the damage, facilitating quicker repairs and a faster return to operation.

E. Experimental Setup and Results:

The hardware implementation of the proposed work is done, and the results are presented in the following manner. Figure 2 depicts the experimental setup.

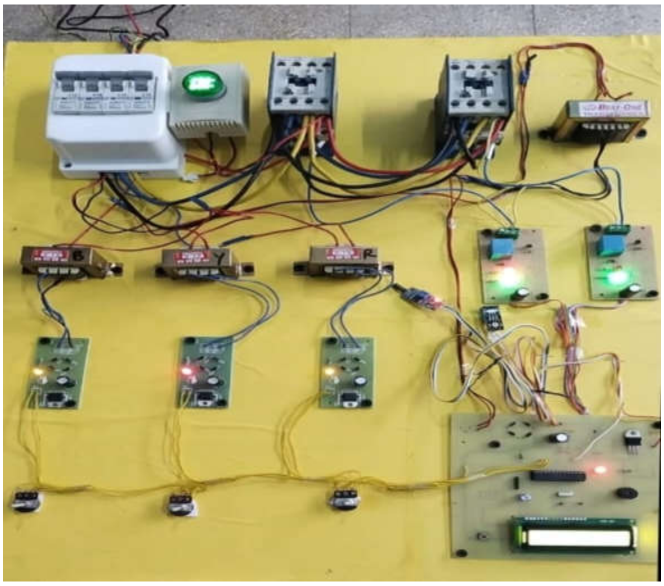

Figure 2: Proposed Experimental Module

Initially, the 230V supply is stepped down with the help of a three (0-12) transformer. These Step-Down Transformers are connected to R, Y, and B phases. Then stepped-down voltage is provided to the three rectifier units. The rectifier unit converts AC 230 V into a DC regulated 5V. Then the 5V supply feeds to microcontroller. The microcontroller used aimed to display the following parameters: 1) R, Y, and B phase, 2) Over voltage fault, 3) Under voltage fault, 4) Temperature, 5) Humidity, 6) Vibration detected. Two relay modules are sensing devices that are used to open the circuit when a fault occurs that any type of fault detected by microcontroller. Then these two relay driving the two contactors are connected to the default and auxiliary motor.
When any fault occurs, the relay senses the fault and contactor one off, and motor one also stops switching the load to motor two. To understand the operation, LED Indicators are fixed to indicate the status of the motor, as indicated in Table 1.

Table 1: states of motors

Sr. No	Working	Operation
1	M1 ON	M2 OFF
2	M1 OFF	M2 ON
3	M2 ON	M1 OFF
4	M2 OFF	M1 ON

The system initially powers on and begins monitoring the phase voltages (R, Y, B).

Figure 3: Phase voltage display

Figure 4.3 shows the reading of the phase voltage display, which indicates the monitored voltages. As per Table 2, the typical phase voltages are approximately 232 V (R: 232 V, Y: 234 V, B: 232 V).

Table 2: Phase Voltage Rating

Sr. No	Phase	Voltage
1	R	232
2	Y	234
3	B	232

These readings are fed into the microcontroller, which continually compares them against nominal values to identify abnormalities such as undervoltage or overvoltage faults.

Figure 4: B-Phase Under Voltage Detected

When an undervoltage fault occurs in the B phase, Figure 4 shows the "B Phase Under Voltage Detected" alert, confirming fault detection.

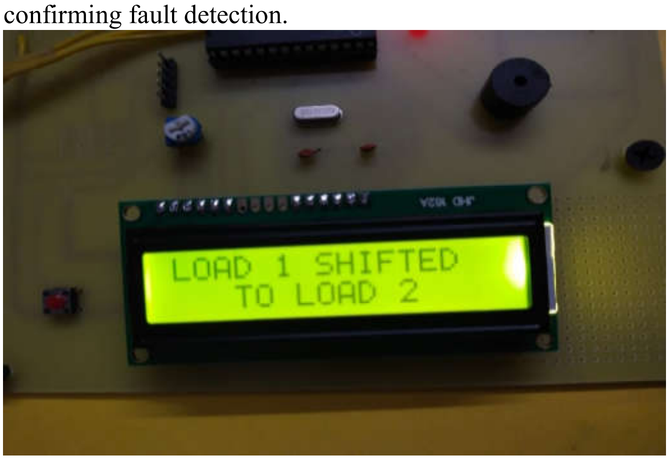

Figure 5: Load 1(Motor 1) Shifted to Load 2 (Motor 2)

Similarly, Figure 5 depicts the load shifting from Motor 1 to Motor 2, highlighting the automatic switching capability when a phase fault is detected.

Table 3: Under-Voltage Result

Sr. No	Phase	Under Voltage	Fault Condition
1	R	232	FAULT NOT DETECTED
2	Y	232	FAULT NOT DETECTED
3	B	123	UNDER VOLTAGE FAULT DETECTED

Table 3 summarizes the under-voltage fault result, indicating that the B phase voltage dropped to 123 V, which the system recognizes as a fault, triggering protective actions.

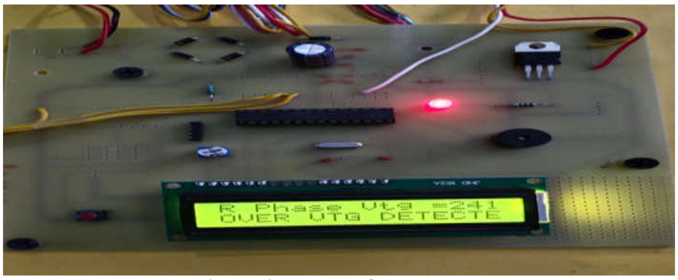

Figure 6: R Phase Over Voltage

The system also monitors over-temperature faults; Figure 6 shows an R-phase over-voltage detection (though it mentions over-voltage, the context here points to temperature monitoring as well). And Table 4 summarizes the over voltage condition.

Table 4: Over-Voltage condition

Sr. No	Phase	Under Voltage	Fault Condition
1	R	241	OVERVOLTAGE DETECTED
2	Y	240	OVERVOLTAGE FAULT DETECTED
3	B	230	FAULT NOT DETECTED

Figure 7: Proposed Experimental Module

Figure 7 displays the over-temperature alert, which triggers when motor temperature exceeds 45°C, as summarized in Table 5. The table indicates that temperatures of 38°C and 40°C do not trigger faults, but at 45°C and 48°C, faults are detected.

Table 5: Temperature Fault Result

Sr. No	Under Voltage	Fault Condition
1	38	FAULT NOT DETECTED
2	40	FAULT NOT DETECTED
3	45	FAULT DETECTED
4	48	FAULT DETECTED

The integration of these sensors and fault detection mechanisms ensures the system's reliability. When faults such as undervoltage, overvoltage, or overheating are detected, the microcontroller activates relays that disconnect or switch the motor, thereby protecting it and ensuring safe operation.

IV. FUTURE SCOPE

Based on the developed system's capabilities and current limitations, the following are the potential future scopes:

- ***Integration of Wireless Monitoring and Control:*** Future systems can incorporate IoT (Internet of Things) technologies to enable remote monitoring, diagnosis, and control of the motor protection system via smartphones or centralized control centers, enhancing accessibility and response times.
- ***Implementation of Advanced Fault Diagnosis Algorithms:*** Incorporating machine learning or predictive analytics can improve fault prediction accuracy, enabling preventive maintenance by analyzing historical data, thus reducing unexpected failures and optimizing maintenance schedules.
- ***Smart ELCB Integration:*** Future systems can incorporate smart ELCBs equipped with microcontrollers and communication modules, diagnostics, and alerts for leakage faults through mobile apps or SCADA systems.
- ***Expansion to Multi-Motor and Networked Systems:*** Developing scalable protection schemes that can simultaneously monitor and protect multiple interconnected motors in industrial setups, facilitating coordinated control and fault management across complex machinery networks.

V. CONCLUSION

It is evident that the developed system effectively monitors and protects a three-phase induction motor against various fault conditions such as undervoltage, overvoltage, overtemperature, and phase faults. Integrating sensors, microcontroller-based control, relay modules, and automatic switching mechanisms ensures continuous operation, safety, and minimal downtime by promptly detecting faults and initiating protective actions like load shifting and motor shutdown. The system's design demonstrates a reliable and efficient approach to industrial motor protection, emphasizing real-time fault detection, automatic response, and user-friendly fault indication through display alerts. Overall, the proposed solution enhances operational safety, reduces equipment damage, and supports uninterrupted industrial processes. We have prepared a system for two motors, which can be used for 'n' number of motors with a smaller number of spare motors, with the required hardware as per the need of the system, to make it more economical. An uninterrupted power supply will be provided

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