

# An Adaptive Star-Delta Starting Method for Induction Motors Based on Real-Time Rotor Speed Measurement

Pranit V. Patil,

Assistant Professor, *Dr. Babasaheb Ambedkar Technological University, Lonere*

**Abstract**— Three-phase induction motors are fundamental to industrial operations, yet their startup is characterized by high inrush currents that can cause voltage instability and stress on electrical infrastructure. While star-delta starters are commonly employed to mitigate this issue, conventional implementations rely on fixed timers for switching, which lack adaptability to varying load conditions. This paper presents the design and implementation of an intelligent, Arduino-based automatic star-delta starter that utilizes real-time speed feedback from an infrared (IR) sensor to determine the optimal transition point from star to delta configuration. The system integrates current and vibration sensors for continuous motor health monitoring, along with a GSM module for remote fault alerting and control. The proposed starter automatically engages the motor in star mode, limiting the starting current to 4.33A (compared to a theoretical 7.5A in delta). Upon detecting that the motor has reached approximately 80% of its rated speed (~1150 RPM) via the IR sensor, the microcontroller seamlessly switches the contactors to delta mode, allowing the motor to attain its full rated speed of 1440 RPM at 7.5A. Experimental results validate the system's reliability in providing a smooth, adaptive transition and its effectiveness in sending real-time SMS alerts during overcurrent or excessive vibration events. This cost-effective and automated solution offers significant improvements in motor protection, energy efficiency, and operational safety over traditional timer-based starters, making it highly suitable for modern industrial automation and IoT-enabled environments.

**Keywords**— *Automatic Star-Delta Starter, Arduino Uno, Three-Phase Induction Motor, Real-Time Speed Feedback, IR Sensor, GSM Module, Fault Detection, Industrial Automation.*

## I. INTRODUCTION

Three-phase induction motors are widely recognized as the workhorses of modern industry, powering essential machinery such as pumps, fans, compressors, conveyor belts, and various industrial drives. Their popularity stems from their robust construction, simple design, high

efficiency, reliability, and relatively low maintenance requirements compared to other motor types [1]. However, despite these advantages, the direct starting of an induction motor presents a significant technical challenge: the high inrush current. When a three-phase induction motor is started Direct-On-Line (DOL), it draws a starting current that can be five to seven times its rated full-load current [2]. This sudden surge can lead to severe voltage dips in the electrical supply network, excessive stress on motor windings, unwanted tripping of protection devices, and mechanical shock to the driven load, ultimately reducing the motor's operational lifespan and efficiency.

To mitigate these adverse effects, various reduced-voltage starting methods have been developed. Among these, the Star-Delta ( $Y-\Delta$ ) starting method is one of the most prevalent for medium-power induction motors, typically in the range of 5 HP to 50 HP [3]. This technique initially connects the motor stator windings in a star configuration, effectively reducing the voltage across each winding by a factor of  $1/\sqrt{3}$  (approximately 58% of the line voltage). This correspondingly reduces the starting current to about one-third of the DOL starting current, thereby minimizing stress on the power system. After the motor accelerates to a speed near its rated value (typically around 75-85% of synchronous speed), the windings are reconnected in a delta configuration, allowing the motor to operate under full voltage and deliver its rated torque.

Conventional Star-Delta starters traditionally employ mechanical timers, time-delay relays, or basic electromechanical control circuits to govern the transition from star to delta. While functional, these conventional methods suffer from a critical limitation: they operate based on a fixed, pre-set time interval rather than the actual operating condition of the motor [4]. This open-loop control approach lacks adaptability to varying

load conditions, supply voltage fluctuations, or changes in motor inertia. If the pre-set time is too short, the motor may switch to delta before it has sufficiently accelerated, resulting in a second current surge almost as severe as a DOL start. Conversely, if the time is too long, the motor runs in star mode for an extended period, leading to inefficient operation, reduced torque output, and unnecessary energy losses [5]. Furthermore, traditional starters offer no means of real-time performance monitoring, fault diagnosis, or remote supervisory control, making proactive maintenance and rapid response to abnormal events difficult in modern industrial environments.

Recent advancements in embedded systems, sensor technology, and wireless communication have opened new avenues for intelligent motor control. Researchers have explored the integration of microcontrollers such as Arduino for automating motor starting sequences [6], the use of various sensors for monitoring parameters like current, vibration, and speed [7], and the application of IoT and GSM technologies for remote monitoring and fault alerting [8]. However, existing literature often addresses these aspects in isolation; there remains a gap in developing a cohesive system that synergistically combines real-time, sensor-based adaptive switching control with comprehensive multi-sensor protection and IoT-enabled remote communication within a single, cost-effective starter framework.

This paper addresses this identified gap by presenting the design and implementation of an Arduino-based automatic star-delta starter for a three-phase induction motor. The primary innovation of this work lies in replacing the conventional fixed-timer with a closed-loop control strategy utilizing an infrared (IR) sensor for real-time rotor speed feedback. This ensures that the transition from star to delta occurs precisely when the motor reaches an optimal speed threshold (approximately 80% of rated speed), dynamically adapting to actual operating conditions. Additionally, the system incorporates current and vibration sensors for continuous motor health monitoring and integrates a GSM module for remote fault alerting and control, enabling operators to receive real-time SMS notifications and respond promptly to anomalies such as overcurrent or excessive vibration.

The main objectives of this work are as follows:

1. To design and develop an automatic star-delta starter circuit controlled by an Arduino microcontroller.
2. To implement real-time speed feedback using an IR sensor to ensure an adaptive and precise star-to-delta transition.
3. To integrate current and vibration sensors for overload and mechanical fault detection.
4. To incorporate a GSM module for remote monitoring and SMS-based fault alerts.
5. To validate the performance of the proposed system through experimental testing on a 5 HP, three-phase squirrel cage induction motor.

## II. PROPOSED SYSTEM ARCHITECTURE

This section presents the detailed design and working principle of the proposed Arduino-based automatic star-delta starter. The system is developed to provide a smooth, adaptive, and remotely monitorable starting mechanism for a three-phase induction motor. The methodology encompasses the overall system architecture, hardware component selection, circuit design, and the control algorithm implemented in the microcontroller.

### 2.1 System Overview

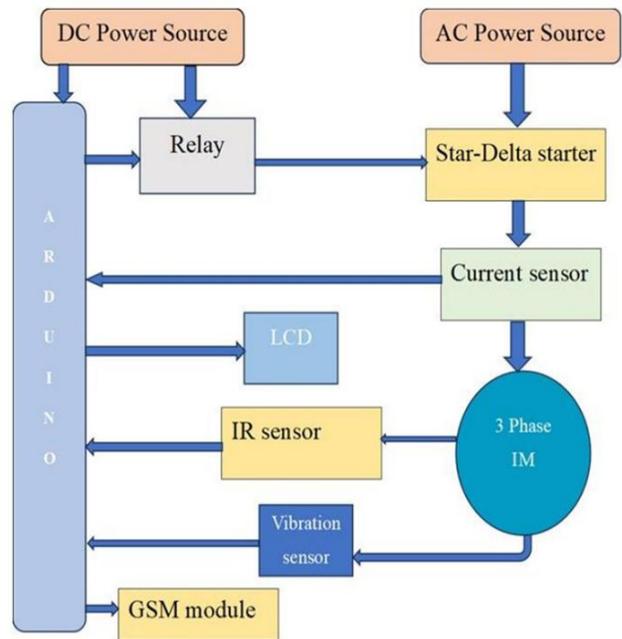


Fig 1. Block Diagram of Automatic star delta starter

The proposed system is designed to automatically start a three-phase induction motor in star configuration to limit the inrush current and subsequently switch to

delta configuration upon reaching an optimal speed. Unlike conventional timer-based starters, this system utilizes real-time speed feedback from an infrared (IR) sensor to determine the precise switching instant. Additionally, current and vibration sensors are integrated for continuous motor health monitoring, and a GSM module enables remote fault alerts and control.

The block diagram of the proposed system is shown in Fig. 1. The system consists of three main sections: the power circuit, the control circuit, and the monitoring/communication section.

## 2.2 Power Circuit Design

The power circuit handles the high-voltage AC supply and motor connections. It comprises the following components:

- **Three-Phase Power Supply:** A 415V, 50Hz AC supply is used as the input.
- **Miniature Circuit Breaker (MCB):** Provides short-circuit and overcurrent protection for the entire system.
- **Contactors:** Three contactors are employed—main contactor (K1), star contactor (K2), and delta contactor (K3). The contactors are rated for 230V AC coil voltage and 30A current-carrying capacity, suitable for a 5 HP motor.
- **The main contactor (K1)** connects the motor to the power supply.
- **The star contactor (K2)** short-circuits the motor terminals (W2, U2, V2) to form a star point.
- **The delta contactor (K3)** connects the motor windings in delta configuration by linking U1-W2, V1-U2, and W1-V2.
- **Overload Relay:** Provides thermal overload protection to the motor.
- **Terminal Blocks:** Used for safe and organized wiring connections.

## 2.3 Control Circuit and Hardware Components

The control circuit operates at low voltage (5V and 12V DC) and is isolated from the power circuit. The key hardware components are as follows:

**Arduino Uno Microcontroller:** The core of the control system, based on the ATmega328P microcontroller. It operates at 5V and features 14 digital I/O pins and 6 analog input pins. It processes sensor data, executes the control algorithm, and drives the relay module.

**Power Supply Unit:** A step-down transformer (230V/12V AC) reduces the mains voltage, which is then rectified using a bridge rectifier, filtered by capacitors, and regulated to 12V DC and 5V DC using voltage regulator ICs (7812 and 7805) to power the relays, sensors, and Arduino, respectively.

**Relay Module (4-Channel):** Acts as an interface between the low-voltage Arduino and the high-voltage contactor coils. The relay module is optically isolated to protect the microcontroller from voltage spikes. Triggering current is 20mA per channel at 12V DC.

**IR Sensor Module:** Used for non-contact speed measurement of the motor shaft. A reflective object (e.g., a piece of white tape) is attached to the shaft, and the IR sensor detects each rotation. The Arduino calculates the RPM (Revolutions Per Minute) by counting the pulses over a fixed time interval (typically one second). The sensor operates at 5V with a detection range of 2cm to 30cm.

**Current Sensor (ACS712):** A Hall-effect-based current sensor capable of measuring AC or DC current up to 30A. It is connected in series with one of the motor phases to monitor the line current. The sensor outputs an analog voltage proportional to the measured current, which is read by the Arduino's analog pin. The sensitivity is 66 mV/A.

**Vibration Sensor (SW-420 or ADXL335):** Detects mechanical abnormalities such as bearing faults, misalignment, or imbalance. In this work, an ADXL335 accelerometer-based vibration sensor is used. It measures acceleration in three axes, and the resultant vector magnitude is computed to quantify vibration intensity in terms of g-force.

**GSM Module (SIM900A):** Enables remote communication. It is interfaced with the Arduino via serial communication (UART). The module is configured to send SMS alerts to a pre-programmed mobile number upon detection of fault conditions. It operates on a 3.4V to 4.5V supply and uses a 2G network for communication.

## 2.4 Circuit Diagram and Working Principle

The complete circuit diagram of the proposed system is shown in Fig. 2. The working principle is described in three distinct phases: starting, transition, and running.

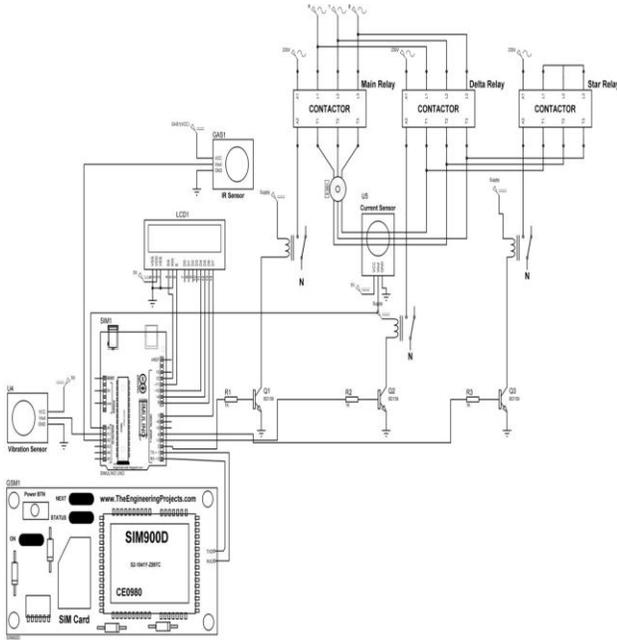


Fig. 2 Circuit Diagram of Automatic star delta starter

Phase 1: Star Mode (Starting)

Upon receiving a start command, the Arduino first activates the main relay, which energizes the main contactor (K1), connecting the motor to the three-phase supply. Simultaneously, the Arduino activates the star relay, energizing the star contactor (K2). With K1 and K2 closed, the motor windings are connected in star configuration. The voltage across each winding is reduced to 58% of the line voltage ( $415V/\sqrt{3} \approx 240V$  per phase). Consequently, the starting current is theoretically reduced to one-third of the DOL starting current. For the 5 HP motor with a rated current of 7.5A, the star-mode starting current is calculated as:

$$I_{star} = \frac{I_{delta}}{\sqrt{3}} = \frac{7.5}{\sqrt{3}} = 4.33A$$

The IR sensor continuously monitors the rotor speed, and the current sensor tracks the line current. The LCD displays "Star Mode" along with real-time RPM and current values.

Phase 2: Speed Monitoring and Adaptive Transition

The Arduino continuously reads the pulse count from the IR sensor to calculate the instantaneous rotor speed using the following logic:

- Each rotation of the shaft generates a pulse detected by the IR sensor.

- The number of pulses is counted over a sampling interval of one second.
- RPM is calculated as:  $RPM = \text{Pulse Count per Second} \times 60$

The system compares the measured RPM with a predefined threshold, set at approximately 80% of the motor's rated speed. For a motor with a synchronous speed of 1500 RPM and a rated speed of 1440 RPM, the threshold is set to 1150 RPM. When the measured RPM reaches or exceeds this threshold, it indicates that the motor has sufficiently accelerated and is ready for full-voltage operation. At this instant, the Arduino deactivates the star relay and, after a brief interlocking delay (typically 50-100 ms to prevent short-circuiting), activates the delta relay.

Phase 3: Delta Mode (Running)

With the delta relay energized, the delta contactor (K3) closes, and the star contactor (K2) opens. The motor windings are now connected in delta configuration, and full line voltage (415V) is applied across each winding. The motor now operates at its rated speed and delivers its full torque. The LCD updates to display "Delta Mode" along with the running parameters. The motor continues to operate in this mode until a stop command is received or a fault is detected.

2.5 Protection and Monitoring Logic

The system incorporates two primary protection mechanisms:

1. Overcurrent Protection: The ACS712 current sensor continuously monitors the line current. If the measured current exceeds a predefined threshold (e.g., 8.0A, slightly above the rated 7.5A) for a sustained period, the Arduino interprets this as an overload condition. It immediately de-energizes all contactors, stopping the motor, and triggers the GSM module to send an SMS alert: "Overload detected. Motor OFF."
2. Vibration-Based Fault Detection: The vibration sensor (ADXL335) measures acceleration along three axes. The resultant vibration magnitude is calculated as:

$$V_{mag} = \sqrt{x^2 + y^2 + z^2}$$

If the vibration magnitude exceeds a predefined threshold (e.g., 2.5g), indicating a mechanical fault

such as bearing damage or misalignment, the system shuts down the motor and sends an SMS alert: "Excessive Vibration. Motor OFF."

### 2.6 GSM-Based Remote Monitoring

The GSM module (SIM900A) is configured for SMS-based communication. The Arduino sends AT commands to the module to initialize it and set it to text mode. Upon system startup or fault occurrence, the Arduino can send alerts to a pre-stored mobile number. Additionally, the system can receive remote commands:

If an SMS containing "OFF" is received, the Arduino shuts down the motor.

If an SMS containing "ON" is received while the motor is off, the Arduino initiates the starting sequence.

This feature enables supervisory control and rapid response to alarms, particularly useful in unattended or remotely located installations.

### III. SIMULATION AND MODELLING

The simulation of the proposed system was carried out using Proteus Design Suite, which is a powerful software tool for schematic capture, circuit simulation, and microcontroller programming. Proteus was chosen for the following reasons:

1. **Microcontroller Simulation:** It supports co-simulation of Arduino microcontroller with embedded C/C++ code.
2. **Component Library:** It provides a comprehensive library of electrical and electronic components including contactors, relays, motors, and sensors.
3. **Real-Time Visualization:** It allows real-time monitoring of voltage, current, and other circuit parameters using virtual instruments such as voltmeters, ammeters, and oscilloscopes.
4. **Cost-Effective Validation:** Simulation enables testing of various fault conditions and control algorithms without risk of damaging actual hardware components.

The Arduino code (sketch) developed for the hardware prototype was first tested in the simulation environment by loading the hex file into the virtual Arduino module within Proteus.

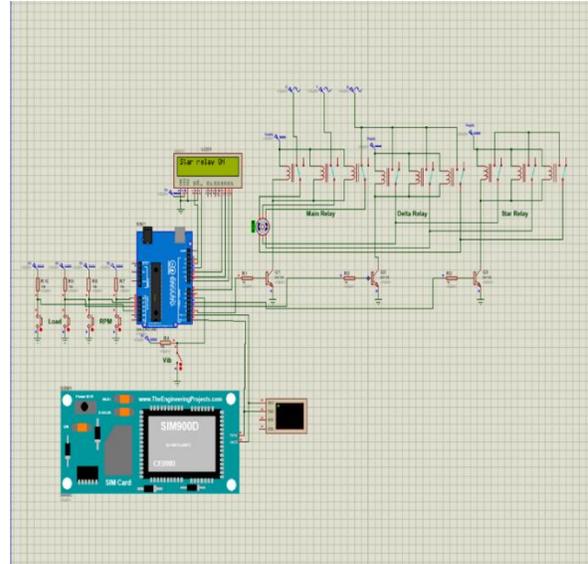


Fig. 3. Simulation of proposed system

The complete simulation circuit developed in Proteus is shown in Fig. 4. The circuit includes the three-phase power supply, contactors, induction motor, Arduino microcontroller, relay module, sensors, and LCD display. The wiring configuration follows the standard star-delta connection scheme with proper interlocking to prevent simultaneous activation of star and delta contactors.

### 3.1. Simulation Results and Observations

The simulation was conducted in three distinct phases to validate the system's performance under different operating conditions.

#### 1. Star Mode Operation

the simulation snapshot when the motor is started in star configuration. The following observations were made:

The main contactor (K1) and star contactor (K2) are energized, while the delta contactor (K3) remains de-energized.

The motor windings are connected in star configuration, resulting in reduced voltage across each winding.

The line current measured by the virtual ammeter is approximately 4.33A, which closely matches the theoretical calculation ( $I_{star} = I_{delta}/\sqrt{3} = 7.5/\sqrt{3} = 4.33A$ ).

The IR sensor generates pulses corresponding to the motor speed, which is displayed on the LCD as approximately 950-1000 RPM during the initial acceleration phase.

The LCD displays "Star Mode" along with the current RPM and current values.

### 3.2 Modelling of the Control Algorithm

The control algorithm for the automatic star-delta starter was modeled using a flowchart as shown in Fig. 4 and subsequently implemented in C/C++ code for the Arduino microcontroller. The key aspects of the software modeling include:

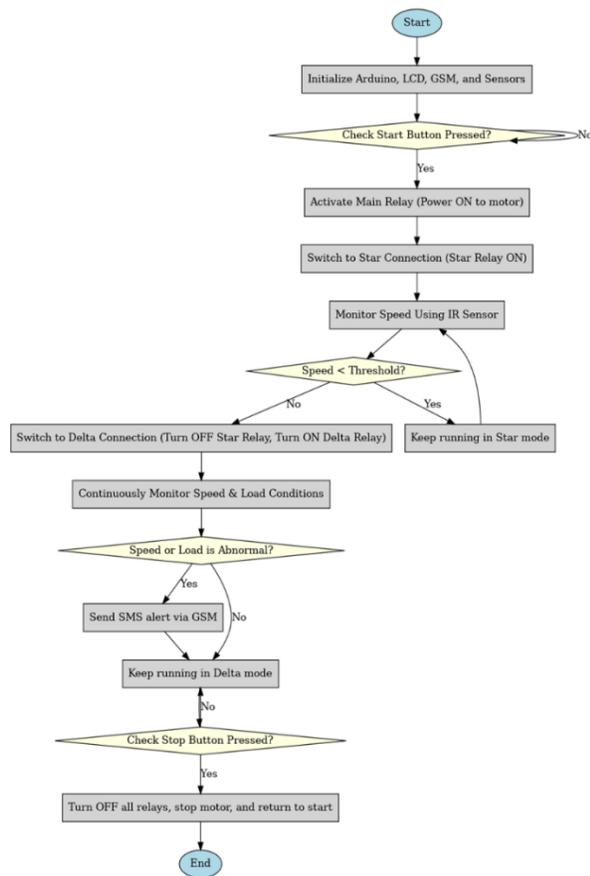


Fig. 4. Flowchart of The Project

#### 1. Speed Measurement Algorithm:

- The IR sensor is connected to an interrupt-enabled digital pin on the Arduino.
- Each falling edge (or rising edge) of the sensor output triggers an interrupt service routine (ISR) that increments a pulse counter.

- Every second, the pulse count is converted to RPM using the formula:

$$RPM = \frac{\text{Pulse Count} \times 60}{\text{Time Interval (seconds)}}$$

- The pulse counter is then reset for the next measurement cycle.

#### 2. Current Measurement Algorithm:

- The analog output of the ACS712 current sensor is read using the Arduino's 10-bit ADC.

- The ADC value is converted to voltage using:

$$V_{out} = \frac{\text{ADC Value} \times 5.0}{1023.0}$$

- The current is calculated using the sensor sensitivity (66 mV/A) and the zero-current offset voltage (2.5V):

$$I = \frac{|V_{out} - 2.5|}{0.066}$$

#### 3. Vibration Measurement Algorithm:

- For the ADXL335 accelerometer, the X, Y, and Z axis outputs are read through analog pins.

- Each axis voltage is converted to acceleration (in g) using the sensitivity (typically 330 mV/g).

- The resultant vibration magnitude is computed as:

$$V_{mag} = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

#### 4. Switching Logic:

- The Arduino continuously compares the measured RPM with the threshold (1150 RPM).

- When  $RPM \geq \text{Threshold}$ , the star relay is turned OFF, and after a delay, the delta relay is turned ON.

- Interlocking is implemented in both software and hardware to ensure that star and delta contactors are never energized simultaneously.

### IV. HARDWARE IMPLEMENTATION

The hardware prototype of the automatic star-delta starter was developed to control a 5 HP, three-phase squirrel cage induction motor. The system was assembled on a wooden mounting board with proper insulation and segregation between the power circuit (415V AC) and the control circuit (5V/12V DC) to ensure safety and minimize electromagnetic interference.

Fig. 5. shows the complete hardware setup of the proposed system.

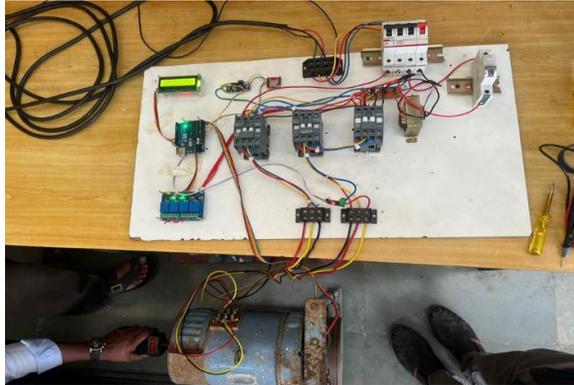


Fig. 5. Photo of Hardware of Automatic star delta starter

The final hardware assembly, with all components properly mounted and wired, is shown in Fig. 6. The system was enclosed in a metal cabinet with proper cable glands, ventilation, and a transparent window for viewing the LCD display

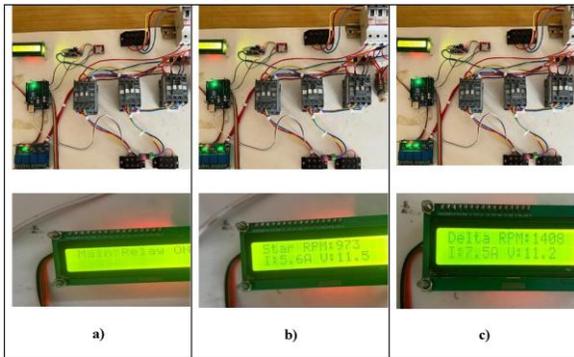


Fig. 6 a) Main Relay ON b) Star Relay ON c) Delta Relay ON

## V. CONCLUSION

This paper presented the design, simulation, and hardware implementation of an Arduino-based automatic star-delta starter for a three-phase induction motor. The system successfully addresses the limitations of conventional timer-based starters by employing real-time speed feedback from an IR sensor to determine the optimal star-to-delta transition point. Additionally, current and vibration sensors provide comprehensive motor protection, while a GSM module enables remote monitoring and control via SMS.

Experimental results on a 5 HP motor demonstrate that the system effectively limits starting current to

4.33A in star mode, automatically switches to delta mode at 1150 RPM (80% of rated speed), and achieves full-load operation at 1440 RPM with 7.5A current. The protection mechanisms reliably detect overload and excessive vibration conditions, triggering motor shutdown and sending SMS alerts. The system successfully responds to remote ON/OFF commands, enabling supervisory control from any location.

The proposed solution offers a cost-effective, adaptable, and intelligent alternative to traditional motor starters, with potential applications in industrial automation, remote installations, and educational settings. Future work may include cloud-based IoT integration, advanced fault diagnosis algorithms, three-phase monitoring, and data logging capabilities for predictive maintenance applications.

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