FAULT DETECTION & PROTECTION OF 3-PH INDUCTION MOTOR

[Integration of PLC and HMI for Optimal Motor Protection]

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Fault Detection & Protection of 3-ph Induction Motor Using PLC & HMI

Abstract:

3-ph AC induction motors are susceptible to malfunctions if not properly maintained. To prevent costly breakdowns and potential hazards, a robust protection system is essential. Traditional protection methods, relying on mechanical components like relays and timers, have limitations.

This paper proposes a PLC-based protection system as a superior alternative. By continuously monitoring motor voltage, current, and speed, this system can detect anomalies such as stator, rotor, bearing, or eccentricity issues. If a fault is identified, the PLC can either adjust motor parameters to restore normal operation or safely shut down the motor.

Compared to conventional, computer-based, and PIC-based systems, the PLC-based approach offers several advantages. It eliminates the need for physical components, simplifies the system, and provides a more accurate, efficient, and visually informative monitoring solution. This enhanced protection safeguards both the motor and personnel while minimizing downtime and unexpected costs.

Keywords: **Over Current, Over Voltage, Under Speed.**

Key Components:

- ***Nameplate Data:*** Provides initial parameter values.
- ***Sensors:*** Capture real-time speed, current, and voltage.
- ***PLC:*** Monitors parameters, detects faults, and triggers shutdown.
- ***HMI:*** Displays machine status and fault information.

System Functionality:

- **Continuously monitors machine parameters.**
- **Compares monitored values with rated values.**
- **Identifies faults based on parameter deviations.**
- **Initiates machine shutdown upon fault detection.**
- **Provides clear fault information on the HMI.**

Introduction:

What are induction motors?

- Electromechanical devices that convert electrical energy into mechanical power.
- Widely used in industrial and mechanical systems like pumps, conveyors, and machine tools.
- Popular due to their reliability, low maintenance, high efficiency, and wide power range.

Applications of induction motors:

- Used in various industries including coal plants, grain elevators, and chemical plants.
- Offer flexibility for many industrial processes.

Challenges of induction motors:

- Prone to failures in harsh industrial environments.
- Unnoticed failures can lead to production disruptions and resource waste.

Causes of induction motor failures:

- ***Mechanical:*** Bearing failures, rotor bar breakage (caused by overload or sudden load changes).
- ***Electrical:*** Power supply issues, problems with variable speed AC drives (common issues include induced bearing currents, high-frequency currents, and voltage/current imbalance).
- ***Long cable connections***: Can lead to motor overvoltage and transient voltages, causing short circuits and total motor failure.

Most common types of induction motor failures:

- ***Bearing failures:*** Around 40% of all faults.
- ***Inter-turn short-circuits in stator windings:*** Around 33% of all faults.
- ***Broken rotor bars and end ring faults***: Around 10% of all faults.

Overall, the passage highlights the importance of induction motors in industry while also emphasizing the need for proper maintenance and monitoring to prevent failures and ensure smooth operation.

Problem Definition:

Induction motors are susceptible to various faults during operation, and if left undetected, these faults can result in motor failures. These faults can be categorized into two primary groups: electrical faults and mechanical faults. Several conditions can lead to induction motor failure, including:

- ***Power Supply Issues:*** Voltage or current imbalances in the power supply affecting motor performance.
- ***Overload and Under Voltage:*** Excessive load or insufficient voltage straining the motor.
- ***Under Frequency/Under Speed:*** Low frequency or speed affecting motor operation.

This project focuses on simulating and addressing faults due to **Over Current, Over Voltage** and **Under Speed** using a PLC & HMI based protection system.

PLC and HMI:

PLC (Programmable Logic Controller):

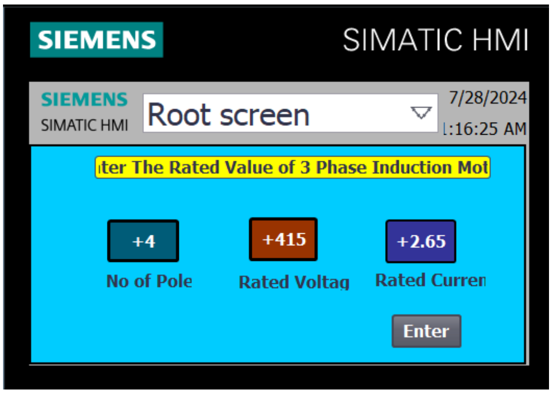
Think of a PLC as the "brain" of an industrial automation system. It's a computer-based control system that's designed to be rugged and reliable enough for factory floor environments.

- ***Function:*** It receives input signals from sensors (like temperature, pressure, or position), processes them according to a programmed logic, and sends output signals to control devices (like motors, valves, or conveyors).
- ***Key Features:*** Robustness, real-time processing, ability to handle digital and analog signals, and compatibility with various communication protocols.

HMI (Human-Machine Interface):

The HMI is the "face" of the automation system. It provides a user-friendly interface for operators to interact with the PLC and monitor the process.

- ***Function:*** Displays process data in a clear and understandable format, allows operators to control the process, and provides alarms and notifications.
- ***Key Features:*** Touchscreens, graphical displays, alarms, data logging, and remote access capabilities.



How They Work Together:

The PLC and HMI work together to create a seamless automation system. The PLC handles the control logic, while the HMI provides a user-friendly way to interact with the system.

- ***Data Exchange:*** The PLC sends data to the HMI about the process status, and the HMI displays this information to the operator.
- ***Operator Input:*** The operator can use the HMI to change setpoints, start and stop processes, and adjust parameters. These commands are then sent to the PLC for execution.

In essence, the PLC is the powerhouse behind the scenes, making decisions and controlling the process, while the HMI is the user-friendly interface that allows humans to interact with the automation system.

Ladder Programming:

Ladder logic, also known as ladder diagram or LD, is a graphical programming language specifically designed for programming Programmable Logic Controllers (PLCs). It utilizes symbolic notations to represent logic operations, with rungs of logic resembling a ladder, hence the name 'Ladder Logic'. This visual representation effectively displays the logical connection between inputs and outputs, akin to contacts and coils in a hardwired electromechanical relay circuit.

Proximity Sensor:

A proximity sensor is a non-contact device that detects nearby objects without physical contact, primarily used in industrial and automation applications for distance and motion detection

Induction Motors:

Induction motors are electric motors that convert electrical energy into mechanical energy. They're widely used in industries, homes, and HVAC systems.

These motors consist of two main parts:

- ***Stator:*** The stationary outer part with windings that create a rotating magnetic field when powered by AC electricity.
- ***Rotor:*** The rotating inner part, often with a squirrel-cage or wound-rotor design.

Here's how it works:

1. AC power creates a rotating magnetic field in the stator.
2. This field induces a voltage in the rotor conductors.
3. Induced current in the rotor interacts with the magnetic field, producing torque.
4. The rotor spins, but slightly slower than the magnetic field.

Key advantages of induction motors:

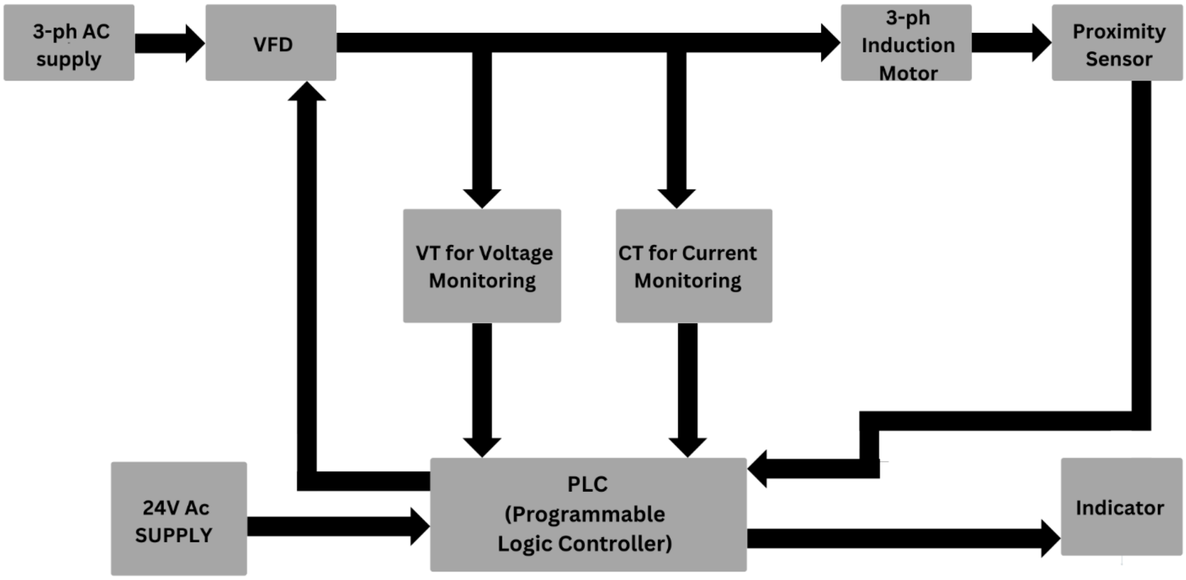
- Simple and robust design
- High efficiency
- Low maintenance
- Wide power range

While they are versatile, induction motors have limitations like speed dependency on power supply frequency and potential low power factor.

Methodology:

The proposed fault detection system comprises hardware for data acquisition, a measurement unit for processing raw data into meaningful parameters like voltage, current and rotor speed, and software for analyzing these parameters, detecting anomalies, and initiating appropriate actions to safeguard the induction motor.

Block Diagram:



Block diagram of the purposed project

Measurement:

Various methods can be employed for identifying motor faults using a PLC. These include:

Speed Measurement using a Proximity Sensor:

A proximity sensor, which detects nearby objects using electromagnetic fields, is employed to measure the induction motor's speed. By monitoring changes in the electromagnetic field as a metal object (like a gear tooth) passes by, the sensor generates pulses. The PLC counts these pulses over a specific time period to calculate the motor's rotational speed.

Potential Transformer (PT):

A potential transformer (PT) is employed to safely measure high voltage levels within a power system. By reducing the voltage to a manageable level, it facilitates accurate monitoring and protection of three-phase equipment. The PT, with a 100:1 ratio, effectively divides the input voltage by 100. This scaled-down voltage is then converted into an electrical signal for the PLC. An overvoltage threshold of 400V is established, corresponding to a 4V output from the PT. The PLC processes this analog signal, multiplying it by 1000 to obtain a digital value. When this digital value surpasses 4000, indicating an overvoltage condition, the system is designed to automatically shut down the motor and activate a fault indicator.

To simulate this process without an actual PT, a potentiometer can be used to manually input voltage values. This allows for testing and calibration of the overvoltage protection logic within the PLC

Current Transformer (CT):

A current transformer (CT) is a vital component in electrical systems that enables safe and accurate measurement of high currents.

By passing the primary conductor through its core, a CT induces a proportional lower current in its secondary winding. This scaled-down current can be easily measured and monitored. CTs are indispensable for protecting electrical equipment by detecting overcurrent, which can lead to motor damage or system failures.

In this specific application, a CT with a 1000:1 ratio is used, meaning the secondary current is one-thousandth of the primary current. The system is designed to trip if the primary current exceeds 1.8 amps, equivalent to a secondary current of 1.8 milliamps. The PLC monitors this value and activates protective measures when the threshold is breached.

Software Used for Simulation:

- ***TIA Portal for PLC and HMI:***

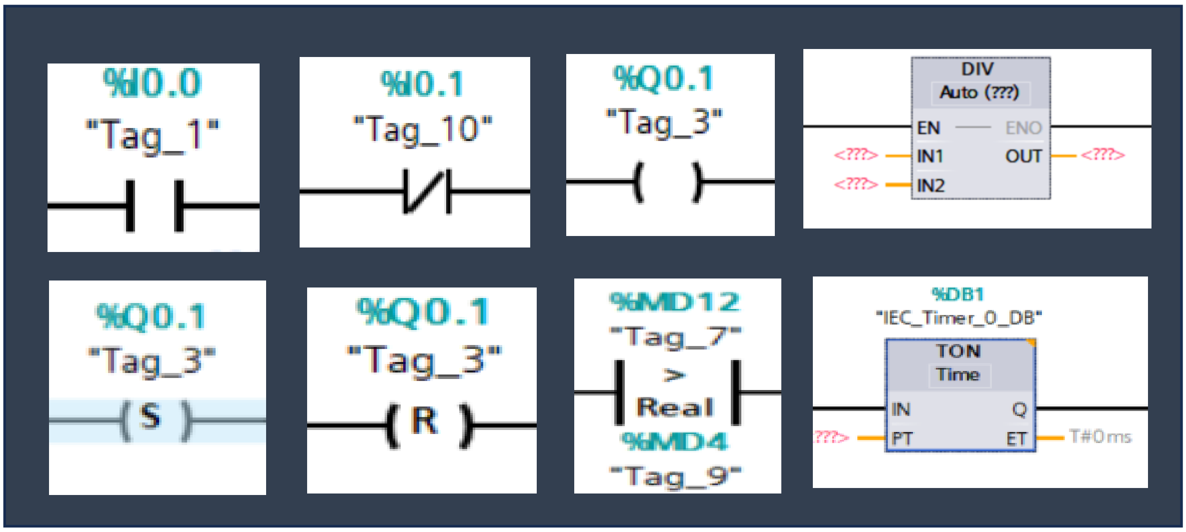
  TIA Portal is Siemens' integrated software environment designed for configuring and programming automation systems. It's a single platform that brings together PLC programming, HMI development, and other automation functions.

- ***Canva:***

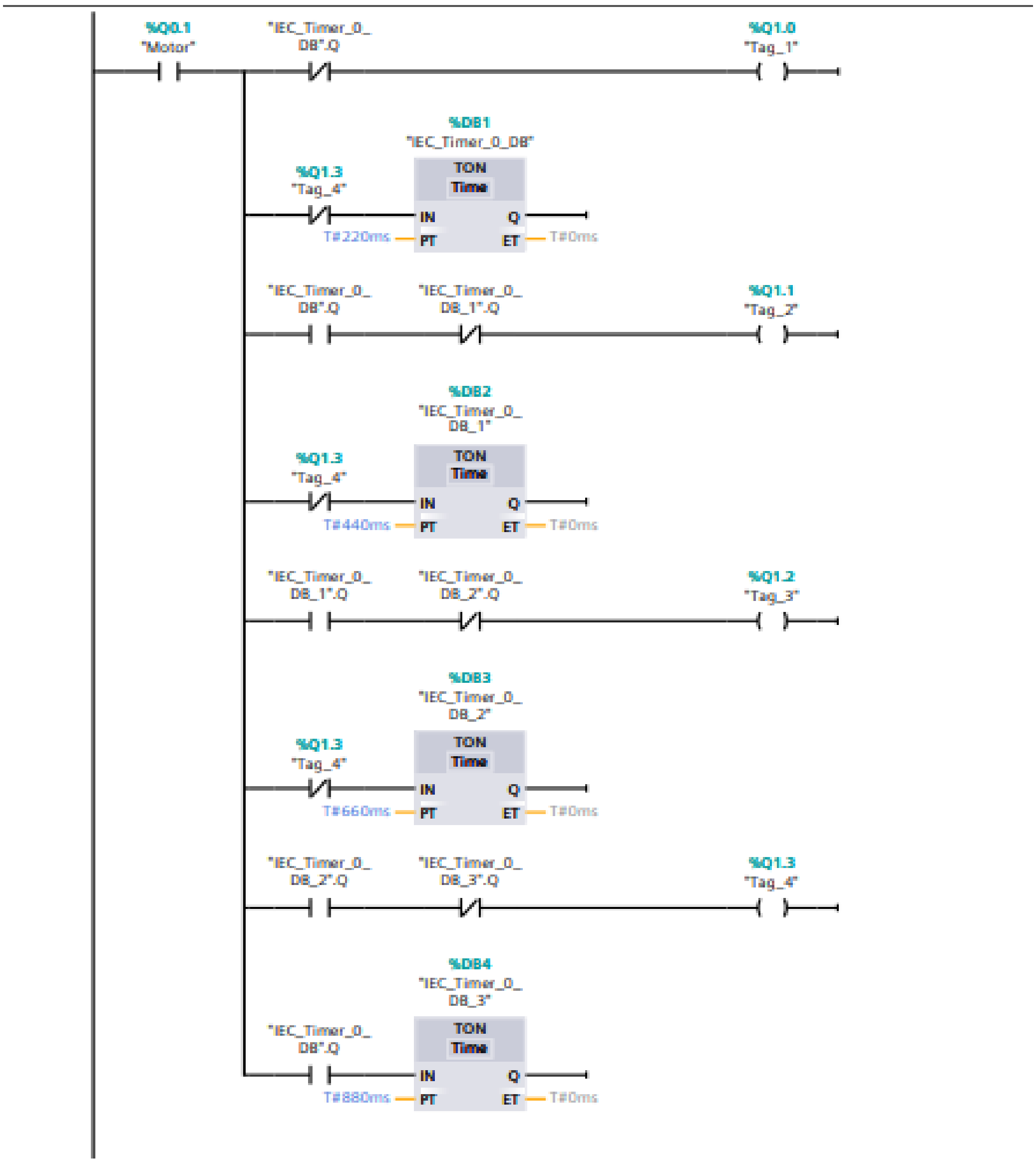
Canva is a user-friendly graphic design platform that empowers individuals and businesses to create stunning visuals without requiring advanced design skills. We have used it for block diagram.

Ladder Logic:

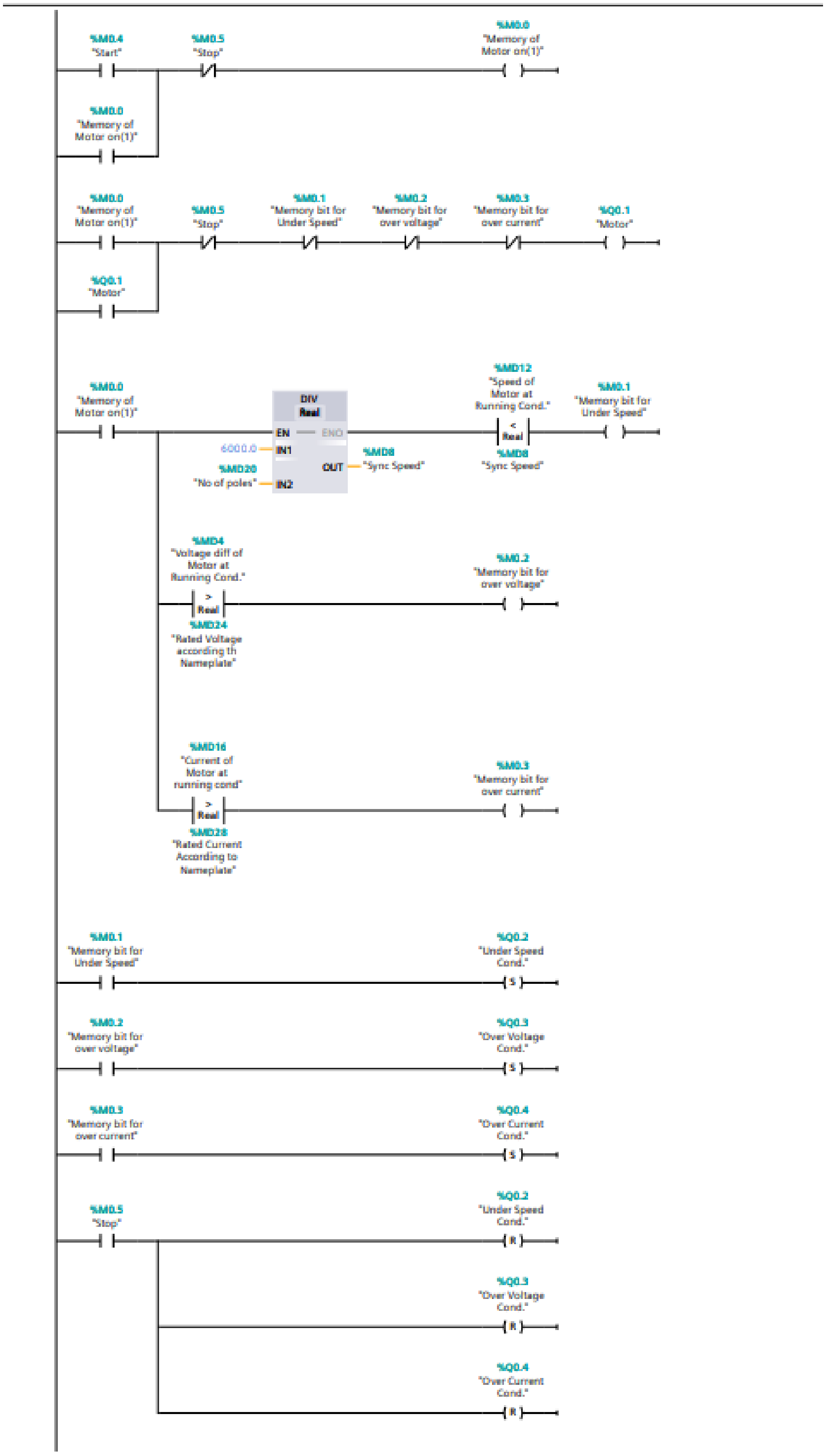
Using Component:



1. Motor Simulation:



2. Under-Speed Fault, Overcurrent & Overvoltage Faults:



Fault Generation:

We've implemented a PLC-based monitoring system for a machine to detect faults based on parameters like speed, current, and voltage. The system simulates real-world conditions by manually inputting values to test its functionality.

Key Points:

- ***Parameter Acquisition:***

  We're using the nameplate for initial values and sensors for real-time data.

- ***Fault Detection:***

  The PLC monitors parameters and triggers a shutdown with an HMI alert.

- ***Simulation:***

  Manual input of values allows for testing different scenarios.

Key Points about Your Simulation:

- ***Manual Parameter Input:***

  We directly modify values in the PLC or HMI to simulate sensor readings.

- ***Fault Testing:***

  We're intentionally introducing abnormal values to trigger fault conditions.

- ***System Evaluation:***

  We're assessing the PLC's response and HMI display for accuracy.

Result & Discussion:

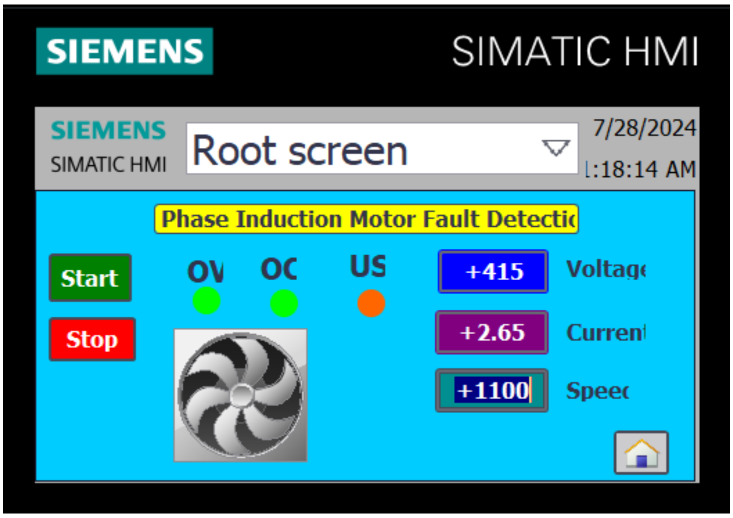
This project seeks to enhance industrial safety and productivity by preventing unforeseen motor failures and their associated disruptions. A PLC-based protection system will be implemented to continuously monitor motor performance, collect real-time data, and initiate appropriate responses. By integrating with a central computer, the system will provide comprehensive insights through graphical and textual displays, enabling informed decision-making and proactive maintenance.

1. Under-speed Fault Detection:

- ***Fault Detection:***
  The system continuously monitors the motor's rotational speed. If this speed drops below the predetermined threshold of rated speed, an under-speed fault is registered.

- ***Motor Shutdown:***
  To prevent potential damage, the system initiates a motor shutdown upon detecting the under-speed condition.

- ***Fault Indication:***
  The **'US'**(Under-speed) indicator on the HMI interface provides clear visual feedback to operators, informing them of the under-speed fault and subsequent motor shutdown.

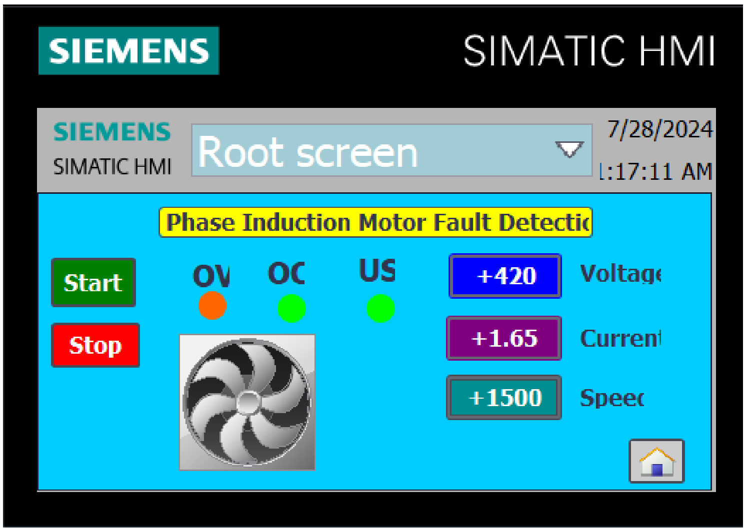


2. Overvoltage Detection:

- ***Fault Detection:***
  The system continuously monitors the voltage level. When the measured voltage surpasses the predefined rated voltage, the protection system registers an overvoltage fault.

- ***Motor Shutdown:***
  Upon detecting the overvoltage fault, the system initiates a motor shutdown sequence. This involves de-energizing the motor to prevent damage.

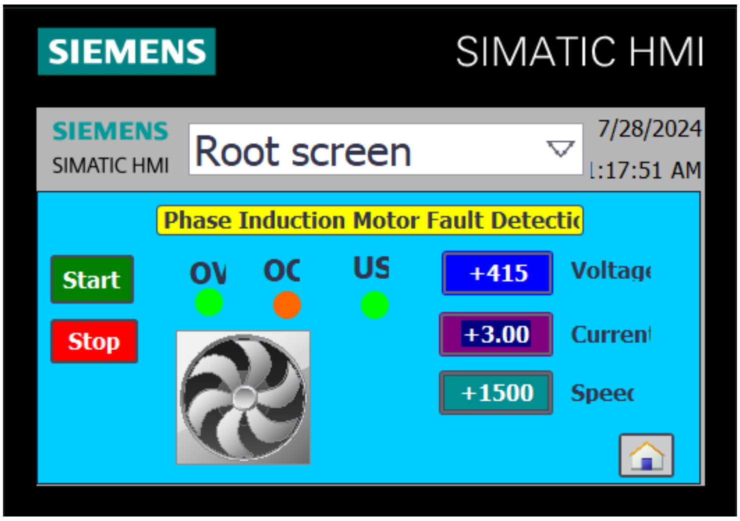
- ***Fault Indication:***
  Simultaneously, an 'OV'(Overvoltage) indicator is activated on the HMI interface. This visual alert informs operators of the overvoltage condition and the subsequent motor shutdown.



3. Overcurrent Detection:

- ***Continuous Monitoring:***
  The system constantly measures the motor current.

- ***Threshold Comparison***:
  The measured current is compared to the rated current.
- ***Fault Indication:***
  If the current exceeds the threshold, an overcurrent fault is declared.
- ***Protective Action:***
  The motor is immediately turned off to prevent further damage.
- ***HMI Notification***:
  An 'OC'(Overcurrent) indicator is displayed on the HMI interface to alert operators of the overcurrent condition.



Conclusions:

The implementation of a PLC-based protection system for induction motors has proven to be a significant advancement in motor control and protection. By integrating sensors for real-time monitoring of critical parameters and utilizing the PLC's computational capabilities, the system effectively detects and responds to faults, preventing equipment damage and minimizing downtime. Compared to traditional methods, this approach offers superior performance, reliability, and diagnostic capabilities. The system's ability to provide early warning of potential issues, coupled with its user-friendly interface, enhances overall system efficiency and operator safety. Future enhancements may include advanced fault analysis, predictive maintenance strategies, and remote monitoring capabilities to further optimize system performance and contribute to overall operational excellence.

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