

PLC based Fault Detection and Protection of a Three Phase Induction Motor

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Abstract—Induction motors are widely used in industries as well as some home appliances. It is therefore necessary to provide protection from likely sources of faults such as overcurrent, overvoltage, under voltage and high temperature. The continuous and intensive use of squirrel cage induction motors in modern industry has in some cases caused a serious deterioration of the electrical insulation in the windings of the machine, generating internal short-circuit failures. Early detection of the fault is essential due to technical and economic issues. The classical method of protecting induction motors from faults involves the use of timers, contactors, and voltage and current relays. Simulation of fault detection is observed using DVP-SS2 series PLC with the ISP Soft and DOP Soft software. The results are validated using the hardware experimental setup including voltage, current relays with contactors and auxiliary relays. The method is highly reliable in protection of motor for various conditions.

Index Terms— Programmable Logic Controller, fault detection, overload ,three phase induction motor.

I. INTRODUCTION

The squirrel cage induction motor is today's one of the most versatile electric machines, due to technical characteristics such as low maintenance cost, high reliability, high starting torque and high efficiency, being implemented in about 70 % of the global industry, consuming approximately 50% of the energy produced on the planet. However, the continuous use of these machines can lead to premature wear in the electrical insulation of their windings, generating short circuit failures, causing their definitive exit from service. These are expensive in terms of maintenance costs, long production times and wasted materials. Motor signature analysis is one of the fault detection techniques in practical applications which is based on the fundamental theory. The detection of various faults such as bearing faults, broken rotor bar identification, stator inter turn fault etc., [1]. Load unbalance, shaft misalignment and bearing faults which are common mechanical faults are treated experimentally using motor current and vibration signal analysis [2]. An induction motor can therefore be made without electrical connections to the rotor.

Although induction motors are usually reliable, they are often subjected to undesirable stress which causes faults and failure. A motor failure that is not identified during its initial stages may become disastrous and the motor may suffer serious damage and result in production shutdowns. Local heating due to inter-turn short-circuiting between adjacent turns in stator winding leads to insulation failure. Such faults are generally insignificant in their

early stage but if they are not traced, it may lead to catastrophic failure and ultimate shut down of the machine [3-4]. In order to protect the induction motor, a diagnostic strategy is included which provides, operational load condition at the time of diagnosis, mechanical load/drive train characteristics, duty cycle, motor design, and rating of the motor, etc. Combination of a front-end signal conditioner, a spectrum analyser, and a PC are part of existing MCSA systems[5]. Other methods such as conventional vibration spectrum analysis, signal and data processing tools-based approach employing wavelet techniques, fuzzy logic, and artificial neural network are a few popular and widespread techniques for fault detection methods used nowadays [6-15]

II. PROPOSED SYSTEM

Due to recent development in Programmable Logic control (PLC), it can be used for fault diagnosis of induction motor.

A. Existing System

The current methods of protection of induction motor includes various components such as timers, mechanical relays, contactors, etc. This is known as the classical method of protection and involves many risks. These risks are due to moving mechanical parts, which may lead to energy losses due to friction and may also require high maintenance. Hence, by using the proposed system of fault protection, we eliminate these risks.

B. Programmable Logic Controller

A programmable logic controller (PLC) is an industrial computer that has been adapted for the control of manufacturing processes, such as assembly lines, robotic devices, machines, or high reliable activity that requires easy programming and process fault diagnosis.

PLCs can range with various inputs and outputs (I/O) from small modular devices, integrated with the processor and housed into large rack-mounted modular devices with thousands of I/O, and which are often networked to other PLC and SCADA systems.

A real-time system referred as PLC in which output results must be produced in response to input conditions within a limited time which results in intended operation.

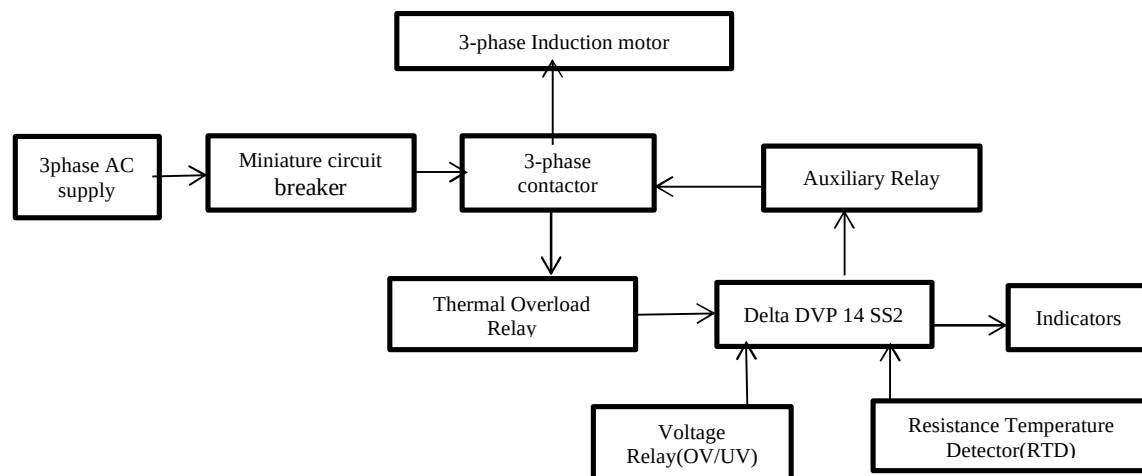


Fig 1: Block diagram of fault detection

Programmable logic controllers (PLCs) are widely used in industry for automation on account of their quick response times, flexibility, reliability, and integration with various sensors, actuators and other devices commonly found in industrial automation systems. PLCs can continuously monitor input signals from various sensors throughout the system. When the PLC detects a fault condition or abnormality, it can generate alarms or notifications. These alarms can be displayed on operator panels, sent as notifications to relevant personnel, or even integrated with a SCADA (Supervisory Control and Data Acquisition) system.

The possible detection methods to identify the motor faults by using PLC are listed as follows:

- Overvoltage and under voltage detection – using an overvoltage/under voltage (OV/UV) relay
- Overcurrent detection – using an overload relay (OLR)

- Temperature measurement – using a resistance temperature detector (RTD).

The following components were used in conducting the experiment.

Induction Motor

An induction motor or also referred as asynchronous motor is an AC electric motor which produces torque due to induced current in the rotor which is obtained by electromagnetic induction from the magnetic field of the stator currents. An induction motor can therefore be made without electrical connections to the rotor. An induction motor's rotor can be either wound type or squirrel-cage type.



Fig 2: Three phase Induction motor & Potential Transformer

Fig 3 : Current transformer & RTD

Potential transformers, also known as voltage transformers (VTs), are electrical devices used to step down high voltages to lower, manageable levels for measurement, monitoring, and protection purposes. The voltage ratios of PTs define the relationship between the primary voltage and the secondary voltage. For example, a PT with a voltage ratio of 100:1 means that for every 100 volts on the primary side, the PT will provide 1 volt on the secondary side.

Current transformers (CTs) are essential components in power systems used for precise measurement and monitoring of electrical currents. The turns ratio of the CT determines the relationship between the primary current and the secondary current, allowing for precise scaling of the primary current to a lower, proportional current suitable for measurement.

Temperature measurement using an RTD:

RTD stands for Resistance Temperature Detector, which is a type of temperature sensor commonly used in various industrial and scientific applications. Platinum RTDs are preferred due to their excellent stability, linearity, and wide temperature range.

Thermal overload relay:

The thermal overload relay working principle is based on the amount of current that flows in the motor or circuit it's connected to. A thermal relay is composed of several different parts, some of which are moving components. The main parts of a thermal overload relay that are involved in temperature sensing and the tripping action include temperature sensing element, tripping mechanism, contacts.



Fig 4: Thermal overload relay (OLR) & Auxiliary relay.

Fig 5: Over/under voltage relay & 3-phase AC contactor

An overvoltage/under voltage relay, also known as a voltage relay or a voltage monitoring relay, is an electrical device used to protect equipment from damage caused by excessive or insufficient voltage levels. It is commonly used in electrical systems to monitor the voltage supply and trigger appropriate actions when abnormal voltage conditions occur. The primary function of an overvoltage/under voltage relay is to detect and respond to voltage deviations beyond predefined thresholds. These relays are typically set to specific voltage limits, and when the monitored voltage exceeds or falls below these limits, the relay initiates a control action to mitigate the potential risks associated with overvoltage or under voltage conditions.

An auxiliary relay is an additional relay used in electrical systems to provide additional control functions, signalling, or interlocking capabilities. It works in conjunction with primary relays or other control devices to enhance the functionality and performance of the system. Auxiliary relays can be utilized to control or switch different voltage levels within a system. They can step-up or step-down voltages, switch between multiple power sources, or isolate circuits for maintenance or troubleshooting purposes. PLC operates using a 24 V DC supply,

while the AC contactor requires a 230 V signal to control it, the auxiliary relay is used to switch between the power sources of these two devices.

A 3-phase contactor is an electrical device used for switching and controlling three-phase power circuits. It is commonly used in industrial and commercial applications where three-phase motors or loads need to be controlled. The contactor consists of a coil, which is energized by a control voltage, and a set of contacts that make or break the electrical connection to the load. When the control voltage is applied to the coil, it generates a magnetic field that attracts the contacts, causing them to close and complete the circuit. This allows the power to flow from the source to the load.

Delta DVP-14SS2 PLC:

The Delta DVP-14SS2 is a model of programmable logic controller (PLC) manufactured by Delta Electronics. PLCs are industrial control devices used to automate and control various processes in manufacturing, industrial automation, and other applications.

The DVP-14SS2 PLC is part of the Delta DVP-S series, which is a compact and cost-effective PLC series designed for small to medium-sized control applications. Here are some key features and specifications of the *Delta DVP-14SS2 PLC*:

CPU: The DVP-14SS2 PLC is equipped with a 32-bit RISC-based CPU, offering fast processing capabilities for efficient control operations.

I/O Points: It supports a maximum of 8 digital inputs and 6 digital outputs. The digital inputs can handle both sinking and sourcing types, while the digital outputs are transistor outputs.

Communication Ports: The PLC features one RS-232 communication port and one RS-485 communication port. These ports enable communication with other devices, such as human-machine interfaces (HMIs), computers, or other PLCs.

Programming: The DVP-14SS2 PLC can be programmed using Delta's proprietary programming software called ISP Soft. ISP Soft provides a user-friendly ladder logic programming environment for creating and editing PLC programs.

Memory Capacity: It has a built-in program memory capacity of 8K steps, allowing for the creation of moderately complex control programs.

Expansion: The DVP-14SS2 PLC supports expansion modules, allowing for the addition of analog I/O, temperature measurement, high-speed counting, and other specialized modules to meet specific application requirements.

Power Supply: The PLC operates on a 24V DC power supply, which is a common voltage in industrial control systems.



Fig 6: DVP-14SS2 PLC

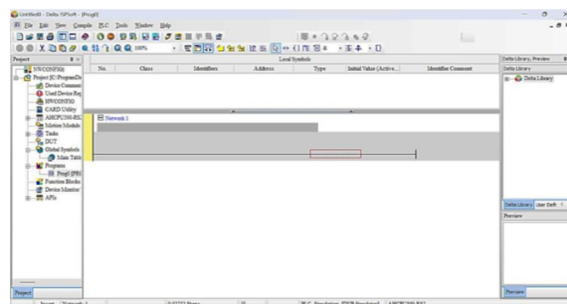


Fig 7: ISP Soft UI

III. SIMULATION RESULTS

In order to properly understand the working of a PLC, we decided to simulate a DVP-SS2 series PLC with the ISP Soft and DOP Soft software.

ISP Soft is a software application developed by Delta Electronics for programming and configuring Delta programmable logic controllers (PLCs). It is a user-friendly programming environment that allows engineers and programmers to create, edit, and debug ladder logic programs for Delta PLCs.

ISP Soft provides a comprehensive set of tools and features for PLC programming. It supports various programming languages such as ladder logic, function block diagram (FBD), structured text (ST), and instruction list (IL). Users can choose the programming language that best suits their application requirements and

programming preferences. The software offers a graphical interface where users can design and organize their ladder logic programs using drag-and-drop functionality. It provides a rich set of function blocks and instructions that can be easily integrated into the program logic.

DOP Soft is a software application developed by Delta Electronics specifically for configuring and programming Delta human-machine interface (HMI) devices. It provides a user-friendly environment for designing, editing, and configuring graphical user interfaces (GUI) for Delta's HMI panels.

DOP Soft offers a range of features and tools to create visually appealing and functional HMIs. It supports drag-and-drop functionality, allowing users to easily place and arrange various elements such as buttons, indicators, text, and graphics on the HMI screen. Users can customize the appearance and behavior of these elements to create intuitive and interactive interfaces.

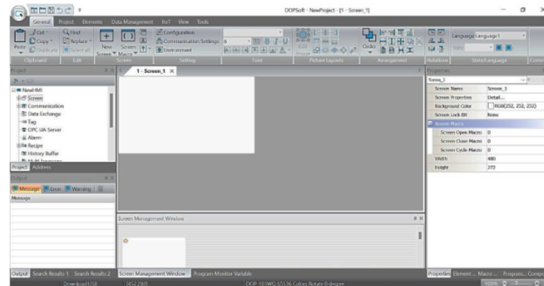


Fig 8:DOP Soft UI

Ladder program:

Ladder programming is a graphical programming language primarily used in the field of industrial automation and control systems. It is commonly used for programming programmable logic controllers (PLCs) and designing ladder logic diagrams. Ladder logic diagrams are visual representations of the electrical circuits and relay logic used in industrial control systems. Diagram resemble a ladder with horizontal rungs and vertical rails. Each rung represents a specific operation or condition that must be satisfied for the control system to perform a certain action. In ladder programming, you use ladder logic symbols to represent different functions and actions. Some of these symbols include:

Contacts: They represent inputs to the system, such as switches or sensors. Contacts can be normally open (NO) or normally closed (NC).

Coils: They represent outputs or actions performed by the system, such as turning on a motor or activating a valve.

Timers: They are used to introduce time delays in the ladder logic program. Timers can be used to control the timing of events and actions.

Counters: They are used to keep track of the number of times an event occurs. Counters are often used to monitor the number of items produced on an assembly line.

Comparators: They are used to compare values, such as comparing a sensor reading to a setpoint or threshold.

Network 1:

The first network consists of a normally open (NO) contact for the input labelled X0 connected to the start button, and four normally closed (NC) contacts for the inputs labelled X1, X2, X3, and X4 connected to the stop button, overload relay (OLR), overvoltage/under voltage (OV/UV) relay, and the temperature sensor respectively.

When the start button is pushed, the circuit is complete and the coil for the output bit Y0, which is connected to the contactor, is energized. This results in the motor turning on.

When the motor is running, the output coil Y1 energizes, hence turning on the 'ON' indicator.

When the motor is turned off, the output coil Y2 energizes, hence turning on the 'OFF' indicator.

Similarly few more combinations of input & output selections are used in detection of overload, under voltage, overvoltage and temperature rise of the motor.

Human Machine Interface(HMI): An HMI typically consists of a display screen, input devices (such as buttons, touchscreens, or keyboards), and output devices (such as indicators or alarms). Its primary function is to provide a visual representation of the system or process, allowing operators to monitor its status, receive real-time data, and control its operation.

All the experimental conditions were tested using simulation by creating HMI interface.



Fig 9a: Ladder program of fault detection

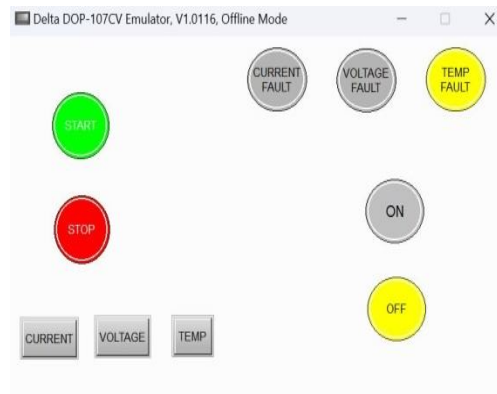


Fig 9b 1: HMI for temperature detection

IV. HARDWARE IMPLEMENTATION

A 3- Φ , 400V, 0.5HP, 4pole induction motor has been used for the experiment. Fault conditions are created with the experimental setup for the following three conditions with the experimental setup.

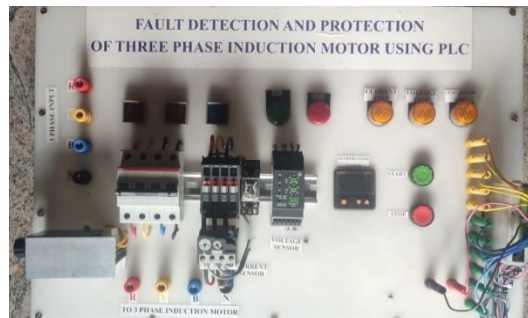


Fig 10: Hardware implementation

Case1 : Under voltage fault condition

Firstly, an under voltage was applied using a dimmer circuit connected to one of the phases of the 3-phase supply. The under voltage relay setting was set to 90% of the phase voltage. This means that if the phase voltage is decreased to 90% of the normal operating voltage, the relay will trip. Once the voltage value reaches around 215V, the OV/UV relay trips and sends a signal to the PLC input. The PLC then sends a control signal to the 3-phase contactor, which disconnects the motor from the supply.



Fig 11: Kit normal running state



Fig 12 2: Kit after under voltage fault occurs

Case 2: Overload condition

An overcurrent condition was observed by overloading the motor using a belt pulley. Due to the increased load, the motor draws more current from this supply. The overload relay setting was set to 1.3 times the normal rated phase current. This means that if the current drawn exceeds this value, the relay will trip. Once the line current

value reaches about 4.5A of line current, the overload relay trips and sends a signal to the PLC input. The PLC then sends a control signal to the 3-phase contactor, which disconnects the motor from the supply.



Fig 13: Kit normal running state



Fig 14: Kit after overcurrent fault occurs

Case 3: Temperature Detection

A temperature fault was created by bringing the temperature sensor (RTD) close to the motor shaft. As the motor runs at high load for a certain period of time, the shaft of the motor heats up. The temperature sensor setting was pre-set to 36°. This means that if the temperature of the motor crosses this value, the temperature sensor sends a signal to the PLC input. The PLC then sends a control signal to the 3-phase contactor, which disconnects the motor from the supply.



Fig 15: Kit normal running state



Figure 163: Kit after temperature fault occurs

V. CONCLUSIONS

A PLC-based system for induction motor fault detection offers significant advantages over traditional methods. By continuously monitoring critical parameters such as current, voltage, speed, and temperature, PLCs can quickly detect and respond to faults, minimizing downtime and preventing further damage. PLCs provide real-time fault detection with high accuracy, allowing for prompt identification and mitigation of issues. Additionally, PLC-based fault detection systems offer advanced diagnostic features, enabling detailed fault analysis and troubleshooting. They provide data logging and reporting capabilities that assist maintenance personnel in identifying and resolving issues efficiently.

By integrating with a personal computer (PC), these systems can provide comprehensive monitoring, analysis, and alarm messaging during fault occurrences. The combination of PLC and PC allows for centralized control, remote monitoring, and easy integration with other devices and systems in an industrial automation environment. PLC-based fault detection for induction motors provides a cost-effective, accurate, and reliable method of safeguarding motor systems. It enhances operational safety, reduces maintenance efforts, and improves overall system performance, making it a preferred choice for industrial applications.

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