

Article info

Received on: 28.02.2023

Accepted on: 29.03.2023

Published on: 31.03.2023

doi: <https://doi.org/10.52688/ASP24501>

Research Article

Design and Implementation of a Real-Time Monitoring and Protection System

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ABSTRACT

The monitoring of electric parameters directly affects energy efficiency. So, this paper presents the design and practical implementation of a real-time remote monitoring system for the load current values of a three-phase power system. The system will protect against overload and give the status of any phase that is overloaded; in addition, it will display the state of the load (normal load or overload) and the status of the circuit breaker (on or off). Three current transformers (CTs), three precision rectifier circuits, shunt resistors, a Siemens LOGO! 0A8 PLC, and a circuit breaker make up the proposed system. The functional diagram language is employed for the implementation of the proposed software controller for the protection system. A simulation is made for the proposed controller via the LOGO! Soft Comfort V. 8.3.0 software program for virtual implantation of the program before downloading to the PLC via an Ethernet cable. The proposed system has the property of canceling the trip signal of the circuit breaker during a definite time of the inrush and stating the load current. In addition, an automatic reclosure system returns the circuit breaker to its work when the overcurrent is released. PLC-based protection methods are cheaper and provide greater precision with a safe method of operation when compared with other protection controller systems. The key elements that make up this system are a current sensor interfaced to a PLC, which contains Ethernet properties, and a WiFi router for transmission of data wirelessly to the server. The hosting of a web server page facilitates operators' viewing and monitoring of the load current of the power system.

Keywords: PLC, CT, Precision rectifier, Protection System, Monitoring System, Circuit Breaker, and Signal Conditioning Circuit

INTRODUCTION

Industrial monitoring is a very important part of the industrial world today, as it is used to keep an eye on and control industrial applications or equipment. Industrial monitoring is used to know the dynamic condition of industrial devices or machines, accomplish fast processing, minimize power consumption, improve quality, reduce expensive systems, and manage industry globally [1]. Protection of equipment in a power system is a very important aspect, as it is valuable and important for the smooth operation of the power system network [2]. Timers, contactors, and voltage and current relays are used to protect against current. The classical method [3, 4] is a widely used method that involves mechanical dynamics. Many mechanical components have been replaced by computer and programmable integrated circuit (PIC)-based protection methods. The computer-based protection method necessitates the use of an analog-to-digital conversion (ADC) card, whereas the PIC-based protection method does not visualize the measured electrical parameters. In this study, a new protection method based on a programmable logic controller (PLC) has been introduced. All contactors, timers, relays, and the conversion card are removed in this method. Furthermore, the PLC displays all of the system's data, including current values, circuit breaker status, and load status (normal or overload).

To ensure the safe operation of a power system, a superior current protection strategy with greater dependability, functional qualities, and cost effectiveness is required [5-9]. Traditional three-phase current protection devices use electromagnetic relays, which have clear limitations such as low dependability, difficult wiring, huge device size, and limited service life [10-15]. Single-chip microcomputers have been widely used in current protection and reclosing systems, thanks to rapid advancements in protection technology, and microcomputer protection devices have quickly become the mainstream of current protection and reclosing devices.

This study presented a new current protection and reclosing implementation strategy based on PLC to construct a three-stage current protection and automatic reclosing system that addresses the shortcomings of the previous two protection methods. The PLC system combines strong microprocessor control operations with traditional electromagnetic relay protection's simple and easy-to-understand parts. As a result, it can better meet the present protection and control needs of the line [16-17]. Traditional

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tools like computers and PIC-microcontrollers are less accurate than PLC-based protection. It's also less expensive, safer, and easier to use than traditional equipment like PCs and PIC microcontrollers. The PLC exhibits robust construction and operational features such as sequential control, ease of programming, timers and counters, easy-to-use hardware, and reliable control capabilities, which are essential in monitoring application .

SYSTEM RELIZATION AND EXPRIMENTATION

Figure 1 depicts the proposed system's block diagram. A three-phase power source, a three-phase CT, three signal conditioning circuits that transform the current signal from the CT into a voltage signal that can be used by the PLC unit, a circuit breaker, and the three-phase load, which is the last section, are the six essential components of the system [18].

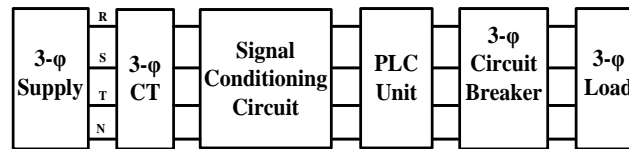


Figure 1: Proposed protection and monitoring system layout

The proposed system is made up of three current transformers that scale large values of load current to small values and three precision rectifier circuits with shunt resistors that are used to condition the CT signals to make a DC voltage signal that is proportional to the load current. The Siemens LOGO! 0A8 PLC is used to get these signals of the load current and see if there has been an overcurrent in each phase of the load. Besides that, make a decision to isolate the fault by sending an output signal to trip the coil of the circuit breaker [19][20]. The load currents are measured using a three-phase CT. As a result, when the current in the circuit becomes too large to directly apply to the measurement instruments, it is reduced. CT generates a lower current that is proportional to the circuit's current. The CT is utilized for each of the three phases of the power line, with a turn ratio of 60:5.

In fact, the PLC is unable to detect the current signal. As a result, a shunt resistor (R_{sh}) is installed across the CT's secondary windings. Not only will this resistor complete the closed loop, but it will also transform the CT's current signal into a voltage signal [21]. As a result, the voltage signal is equal to the primary load current divided by the turn's ratio and multiplied by the resistance value. With the help of three signal conditioning circuits, the voltage signal from the CT is changed into a range that the PLC can read. Each phase's signal conditioning circuit consists of a precision rectifier circuit with operational amplifiers [22]. The first operational amplifier rectifies the AC voltage before the second operational amplifier amplifies it. Creating a DC signal from an AC source has a number of drawbacks, including diode voltage dips. As a result, this circuit provides a precise method of generating this DC signal. The Siemens LOGO! BM 24CE PLC (Version: 0BA8 [18-29]) is used in the project and is known as "LOGO! Basic." It has a 12/24 V DC input voltage, eight digital inputs, and four relays (10 A) as digital outputs.

DEVELOPED SOFTWARE

Figure 2 shows how the functional diagram method for PLC software is used to make the proposed control program with LOGO! Soft Comfort V8.3.

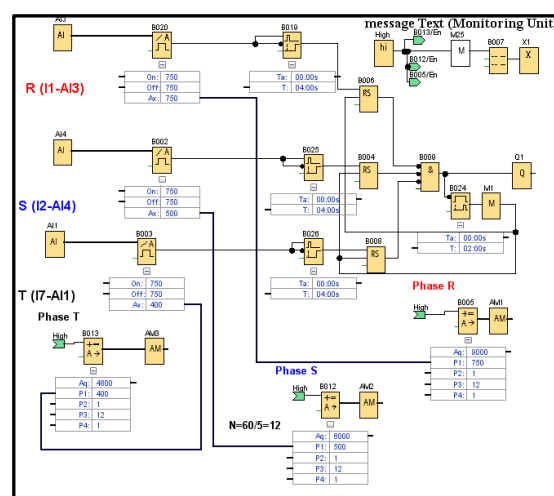


Figure 2: Functional PLC program of the proposed system

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The following steps present the work of the proposed function block diagram program as:

The calibrated signal from the CTs is sent to the PLC through three of its "Analog Inputs" (AI1, AI3, and AI4).

The B020, B002, and B003 "Analog Threshold Trigger Modules" are employed. If the overload current is set as the threshold value, logic 1 is activated on these modules.

When overload occurs, RS "Latching Relays" (B006, B004, and B008) are employed to latch the threshold trigger module's signal.

An "AND gate" (B009) with backwards inputs is used to turn on the PLC's output modules (Q1), which trigger the main circuit breaker's trip coil when any phase is overloaded.

According to the following equation, the load current of each phase is calculated using three "Analog Mathematical Instruction" function blocks: B005, B0012, and B013.

$$\text{Load Current} = \frac{\text{Analog signal value}}{100} * R_{sh} * N \quad (1)$$

Where N is the turn ratio of the CT in use.

Three "Retentive On-delay Timers" (B019, B025, and B026) are used to keep the circuit breaker from tripping when the loads start up. They do this by delaying by 4 seconds the over-current signals sent from the analog threshold trigger modules to the latching relays.

The "On-delay Timer" (B024) is used to reclose the circuit breaker after a specified time by resetting the latching relays (i.e. On-delay timer (B024) whose output is not switched on until a configured delay time has expired, and it is used to reclose the circuit breaker's trip coil after 10 cycles (2 msec.) if the load current is returned to a value less than the threshold value or after the fault.

The "Message Text Unit" (B007) is used to show the following system parameters in real time: Displaying the values of each phase's load current, which are calculated using the analog mathematic instruction function block in accordance with equation (1). Displaying the status of each phase: normal-loaded with message (NL) or over-loaded with message (OL) for each phase Displaying the status of the circuit breaker: on-state (on-live) with message (CB ON) when all phases are at normal load, and message (CB OFF) when any phase, two phases, or three phases are overloaded. Simulation and Experimental Results

In Figure 3, the proposed functional diagram of the control program is tested using the LOGO! Soft Comfort Simulation property. With the Ethernet interface, it don't need any extra cables to program the PLC. It just need to connect the PLC to the router. A functional PLC program is developed and loaded into PLC memory through the Ethernet interface.

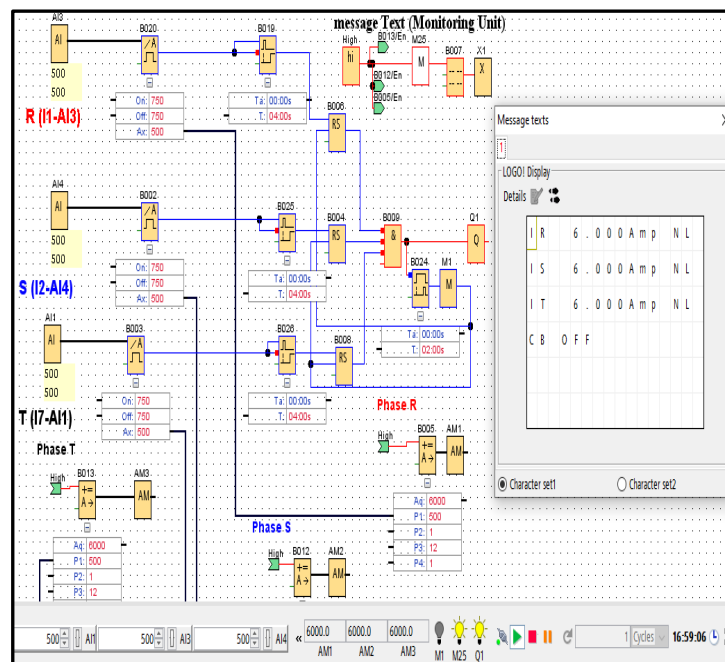


Figure 3: Simulation circuit of the proposed functional diagram program

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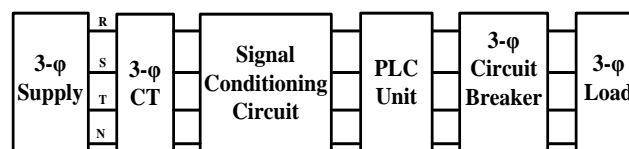


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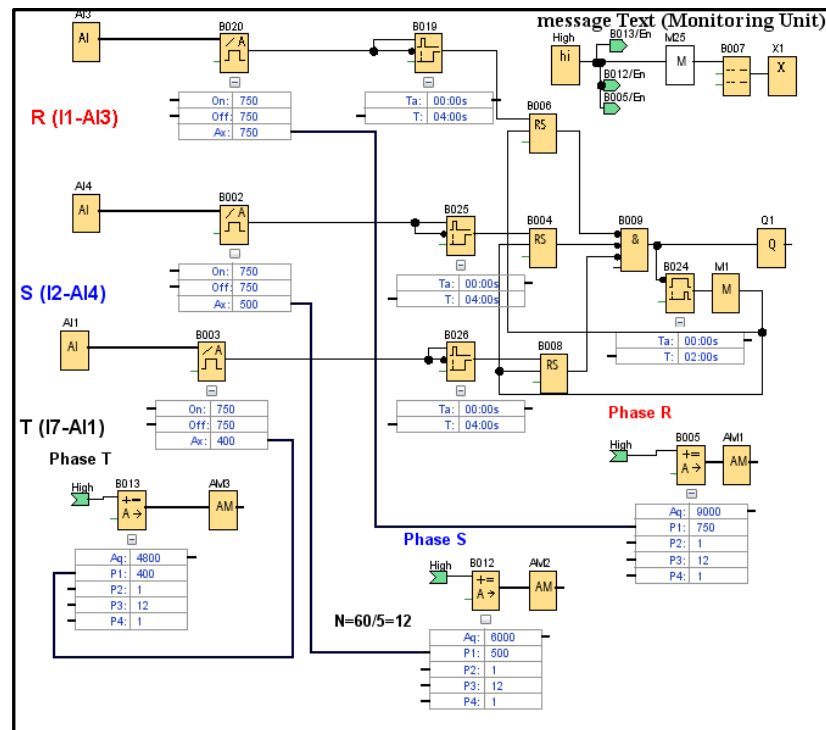


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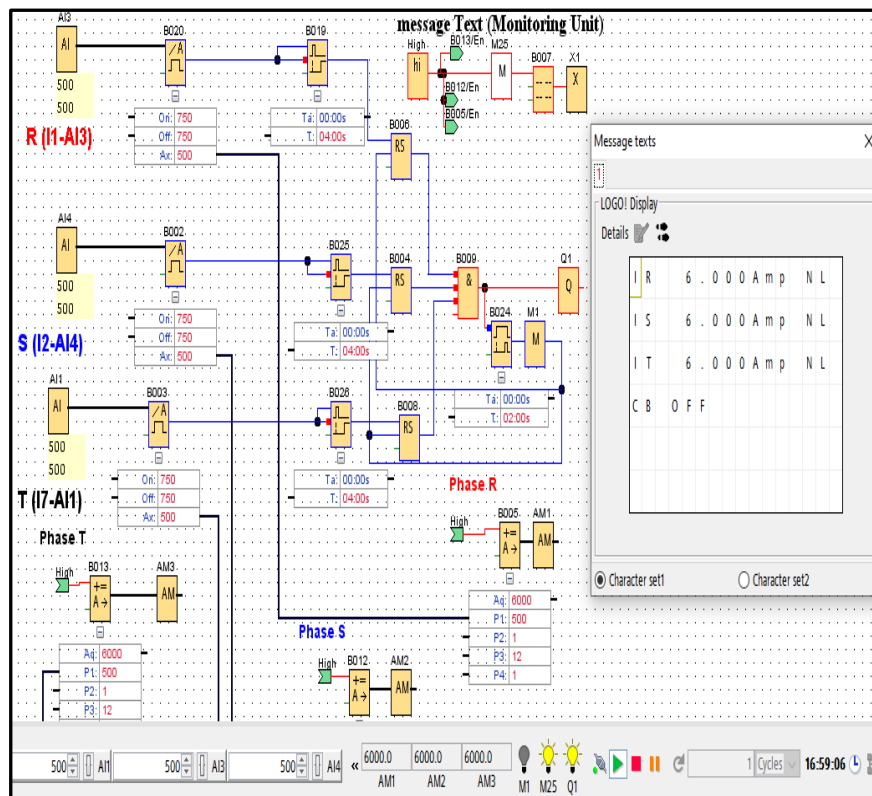


Figure 3: Simulation circuit of the proposed functional diagram program

The message text unit shows the load current values of all phases, the status of each phase: normal load (NL) or over load (OL) (i.e., less than the threshold value of 9 A or above), and the state of the circuit breaker: OFF (CB OFF) or ON (CB ON).

Figure 4 shows the message text unit (simulation results) with the load current values of all phases, and the state of the circuit breaker is ON (CB ON). As Phase R is overloaded (OL) (i.e., more than threshold values of 9 A) as shown in figure 4: a, Phases R-S are overloaded, as shown in figure 4: b, and all Phases R-S-T are overloaded, as shown in figure 4: c.

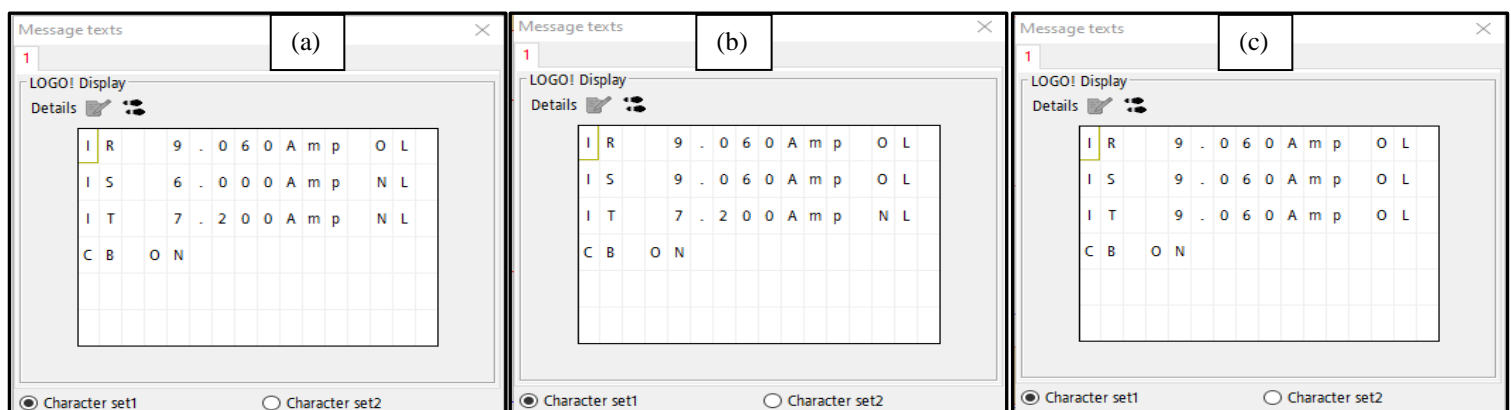


Figure 4: Message text (a): Phase R is overloaded, (b): Phases R&S are overloaded, (c): phases R,S & T are overloaded

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Figure 5 shows the message text in the PLC display unit (experimental results). Figure 5: a shows the load current values of all phases, the state of all phases (which are normal load (NL) as it is lower than 9 A), and so the state of the circuit breaker is OFF (CB OFF). While figure 5: b also shows the current values of all phases, the state of the circuit breaker is ON (CB ON) as all phases are loaded with an overload (OL) greater than 9 A.



(a)



(b)

Figure 5: Message text on the PLC display unit

CONCLUSIONS

Experiments show that the proposed system based on PLC costs less, is more durable, and has a safe and visually appealing environment that is similar to that of the classic. The proposed system checks the amplitude of the load current in a three-phase power system to see if it's too high, then gives the circuit breaker control signals when it's too low. During the inrush, the proposed overcurrent protection system can cancel the circuit breaker's trip signal and state the load current, as well as close the circuit breaker when the overload state is over, so the circuit breaker doesn't trip any more. In the proposed system, it can easily change the time setting of the timers so that they work the way it want. The utilization of the used PLC resources (as function blocks, digital inputs and outputs, and others) for this work is very low. In the future, it could change this work and add other sensors like voltage and implement other protection systems for power systems, like distance and differential protection systems, to make it even safer. There are web server applications that work with the 0BA8 PLC that can be used in the future. These applications can be used to monitor and control the PLC wirelessly from a smartphone, tablet, or PC. The on-line monitoring system based on PLC has good resistance to interference from electricity and magnetic fields and good stability. It allows the operator to optimize the load that can be carried without undue risk and allows for the detection of developing faults in the power system's operation.

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