Smart Substation with Automatic Monitoring, Smart Controlling and Overload Protection of transformer using PLC and SCADA

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Abstract - *Electricity plays an indispensable role in modern society as it powers almost every aspect of our lives. However, [6] with the increasing demand for energy, the importance of efficient and reliable power distribution systems has become more apparent. [2][4][6 The traditional power distribution system has several limitations, including inadequate monitoring and control capabilities, which can result in system failures and power outages. The power system comprises generating stations, transmission lines, and distribution systems. Load flows necessitate careful planning, monitoring, and controlling to ensure efficient operation and to minimize production costs. Each process has a distinct mechanism for acquiring data and controlling it. [1][5]Supervisory Control and Data Acquisition (SCADA) is a monitoring system that monitors numerous parameters in a substation. The proposed system's central control room is equipped with SCADA, which provides an intuitive interface for the operator to monitor and control the system. In the event of any abnormalities, the SCADA system displays real-time data and alerts the operator. Furthermore, the operator can remotely control the system using the SCADA system, increasing the system's flexibility and reducing response time in emergencies. This project replaces large control panels with a single PC, making it highly dynamic and cost-effective. The SCADA monitoring system does not experience mechanical wear and tear. The Programmable Logic Controller (PLC) serves as the system's brain. SCADA and PLC work in tandem to operate and control the power system remotely. This automatic network can manage loads, maintain quality, and detect electricity theft. The system also provides the operator with an overall view of the entire network. Pilferage points can be identified, and human errors that cause tripping can be eliminated, increasing reliability and lowering operating costs. Our project integrates network monitoring functions with geographic mapping and fault location to provide a comprehensive power distribution system.*

***Key Words*: PLC, SCADA, Automation, Protection, Load flow, Dynamic, Reliability**

1. INTRODUCTION

A substation is a crucial component of an electrical system that encompasses generation, transmission, and distribution. It serves multiple purposes, such as transforming voltage from high to low, or vice versa, and executing various other vital functions. The electrical utility or significant industrial or commercial customers can own and operate these substations. The term "substation" has its origins in the pre-grid distribution system era. With the growth of central generation stations, smaller generating plants were transformed into distribution stations, which received their energy supply from a larger plant rather than using their own generators. Initially, the first substations were linked to only one power station, which housed the generators, and were regarded as subsidiaries of that power station.

1.1 Substation Automation

Substation automation is a process of using advanced technologies and intelligent devices to automate the monitoring and control of power substations. This results in a more efficient and reliable operation of the power grid. Substation automation systems typically comprise various equipment, such as sensors, controllers, and communication devices. These devices work together to monitor the substation and its components in real-time, and the data is transmitted to a central control system. This allows operators to make informed decisions about the operation of the substation. [1][2][5]Substation automation has several advantages, including improved reliability and reduced downtime. With automated monitoring and control, potential issues can be detected and resolved swiftly, which prevents equipment failures and power outages. Furthermore, it enables the more efficient use of resources like energy and manpower by automating tasks such as switching and fault detection. This, in turn, frees up operators to focus on more complex tasks and decision-making. In summary, substation automation is essential for modern power systems. It allows utilities to operate more efficiently and deliver reliable power to customers, reducing the likelihood of costly outages and failures. During the early stages of electrical substations, the process required manual switching or adjustment of equipment. Additionally, data for load, energy consumption, and abnormal events had to be collected manually. However, as distribution networks became more complex, it became necessary to automate supervision and control of substations. This was done from a centrally attended point to allow overall coordination in case of emergencies and reduce operating costs.

Initially, dedicated communication wires were used for remote control of substations. These wires were usually run alongside power circuits. Over time, different communication technologies such as power-line carrier, microwave radio, fibre optic cables, and dedicated wired remote control circuits were used for Supervisory Control and Data Acquisition (SCADA) systems for substations.

Nowadays, SCADA systems are commonly used in substation automation. These systems allow operators to monitor and control substations from a centralized location. They collect real-time data from various sensors and equipment, enabling operators to make informed decisions and quickly respond to issues. Additionally, SCADA systems support remote monitoring and control, which helps utilities to enhance the reliability of their power distribution networks, reduce downtime and operating costs, and ensure customer satisfaction.

2. SUBSTATION AUTOMATION TASK:

[8]There are 3 main task of automation system:

(1) Data acquisition
(2) Supervision
(3) Control

(1) Data acquisition:

Data acquisition is the process of gathering and recording data from different sources, such as measurement devices, instruments, and sensors. This collected data can then be used in various fields such as engineering, manufacturing, automation, and science for monitoring, decision-making, control, and analysis.

The process of data acquisition involves measuring both analog and digital signals which are then transformed into digital signals that can be easily processed by computers or other devices. The converted signals are then stored in a database or transmitted to other systems for further processing or analysis.[9] The system uses sensors to collect data from various parts of the substation, which is then transmitted to the PLCs for processing and analysis.

There are several components involved in data acquisition which include sensors or measurement devices, signal conditioning equipment, data acquisition hardware, and software. The sensors or measurement devices are used to collect data from the physical environment. The signal conditioning equipment amplifies, filters, and converts the signals into a suitable form for processing. Data acquisition hardware is responsible for converting the analog signals into digital signals that can be processed by a computer. Software is used to control the data acquisition process, store the data, and perform analysis.

Data acquisition is utilized in a broad range of applications such as environmental monitoring, process control, scientific research, and automation. It has become an essential component in various industries that allow organizations to collect and analyze data for informed decision-making and improving their operations.

In accordance to this project it is responsible for collecting the data from various sensors installed in the substation. The collected data is in the form of measured values, such as current or voltage, or the state of contact points (open or closed). This data can be used locally by the device collecting it, sent to other devices within the substation, or transmitted from the substation to one or more databases for use by engineers, operators, administrators, and planners.

(2) Supervision:

Supervision in substation automation refers to the process of monitoring and overseeing automated systems in electrical substations to ensure they are functioning correctly and efficiently. In electrical substations, various types of automated systems are used to control and monitor equipment such as transformers, breakers, and switches. [3]The automation system can be configured to monitor the electrical parameters such as voltage, current, power factor, and frequency in real-time. Additionally, it can detect faults and take appropriate actions such as tripping a circuit breaker to isolate the fault.

The supervision system plays a vital role in monitoring the status of the transformer and substation equipment in real-time. It relies on SCADA software to display the status of the equipment, alarms, and events as they occur in real-time.[10] The data collected from Programmable Logic Controllers (PLCs) is processed and monitored based on the conditions and status of the power system. Engineers and operators can monitor this information remotely on computer displays. [4]The SCADA software provides a user-friendly graphical interface to the operator, which makes it easy to monitor the status of the equipment. The software also generates alarms and events when it detects any abnormalities in the system, and sends them to the operator for further action.

The supervision system is critical for ensuring the safe and reliable operation of the power system. By monitoring the status of the equipment and detecting abnormalities, it can help prevent equipment failures and minimize downtime. Additionally, it enables quick response and resolution of faults, reducing the impact on the power system and customers. In conclusion, the supervision system in substation automation is a critical component that allows engineers and operators to monitor and control the power system effectively. It relies on advanced SCADA software to provide real-time data and a user-friendly interface, making it easier to detect abnormalities and respond quickly to faults.

(3) Control:

The control system is an essential part of substation automation, responsible for regulating the operation of the equipment automatically. [6]Unlike traditional SCADA systems that rely on human supervision, the control system can function independently. One of the primary tasks of the control system is to integrate the power system. This involves consolidating data from the Programmable Logic Controllers (PLCs) into a single point of contact within the substation, streamlining data management and monitoring. Data acquisition, supervision, and control are interconnected in substation automation, and they must function seamlessly. The data acquisition system collects data from sensors and other sources, which the supervision system analyzes. The control system then utilizes this information to regulate equipment operation, ensuring that the substation operates safely and efficiently .The control system also plays a vital role in fault detection and resolution. By automatically detecting abnormalities in the system, the control system can take corrective action, preventing equipment failures and minimizing downtime.

In conclusion, the control system is a critical component of substation automation, enabling the automatic regulation of equipment operation.[7] PLCs also address the importance of cybersecurity measures in the design of smart substation automation systems. The integration of substation data simplifies data management, and the seamless coordination of data acquisition, supervision, and control is crucial for maintaining a reliable and efficient power system. With its ability to detect and correct faults automatically, the control system ensures a safe and stable power supply.

3. PROPOSED SYSTEM

SCADA based systems are essential for the proper functioning and coordination of individual systems. A dedicated Programmable Logic Controller (PLC) is used for data logging and control operations. One of the key benefits of SCADA based systems is that each system can function independently, allowing other systems to be shut off when not in use. This paper provides a comprehensive overview of various protocol implementations in creating a PLC-based unit and the usage of an advanced graphical user interface for process control. The use of this paper replaces the need for large control panels placed in large rooms. All functions are integrated into a single PC, making it highly dynamic and cost-effective. Supervisory Control and Data Acquisition (SCADA) is used to monitor multiple parameters available in a substation, and interlinking provides an easy way to access data and provide control from a common point. This reduces manpower and time delays. In the control room, the plant is monitored, and commands are given through the user. This method is economical and safe for operation. If there are any modifications or future extensions, they can be easily updated in the PLC and SCADA. In the substation, multiple switches are used, and if one switch trips, the particular area can easily be identified.[4][5] Automatic monitoring and control of power system parameters are achieved with the use of virtual instrumentation and a graphical interface unit.

4. IMPLEMENTATION OF SUBSTATION AUTOMATION

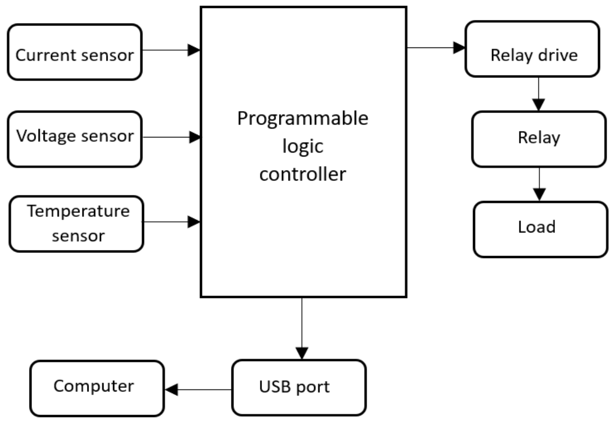

Fig 3: Block diagram

4.1 PLC

A Programmable Logic Controller (PLC) is a digital computer that is specifically designed to automate industrial electromechanical processes. These processes include controlling machinery on assembly lines, amusement rides, and light fixtures. PLCs are commonly used in various industries and machines. PLCs are engineered to handle multiple analog and digital inputs and output arrangements. They can operate in extended temperature ranges and can resist electrical noise, vibration, and impact. Programs that regulate machine operation are typically stored in non-volatile memory or battery-backed-up memory.

PLCs have evolved over time to include various forms of control systems, such as sequential relay control, motion control, process control, distributed control systems, and networking.[7] Some modern PLCs offer data handling, storage, processing power, and communication capabilities that are similar to those of desktop computers. Unlike regular computers, they are designed to be armored for harsh environmental conditions such as dust, moisture, heat, and cold. They also come with extensive input/output (I/O) arrangements, which allow them to interface with different sensors and actuators. [3][4]PLCs are programmed to perform specific tasks such as monitoring equipment status, regulating voltage levels, and switching between different power sources.

In conclusion, PLCs are specialized digital computers that are indispensable in automating industrial electromechanical processes. Their capabilities have evolved to include various control systems and networking, making them a critical component of modern industrial automation.

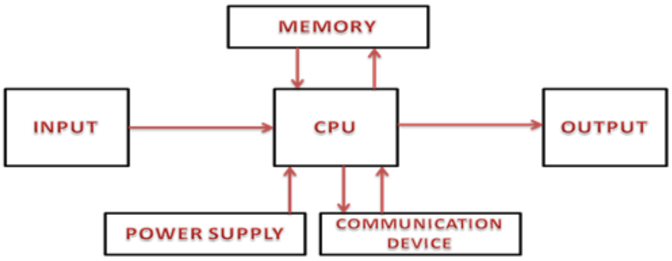

Fig 4.1: PLC

The above figure shows basic block diagram of PLC (Programmable Logic Controller). The CPU of a PLC is typically programmed using a programming terminal, which can be a personal computer or a dedicated Human-Machine Interface (HMI). The CPU consists of basic modules, including external modules and Input/Output (I/O) modules, which can access bit, byte, word, and double-word addressable memory locations. One of the critical features of a PLC is its real-time performance. A Programmable Logic Controller (PLC) is considered a hard real-time system because it requires output responses to be generated within a predetermined timeframe based on input conditions.[4]This real-time capability ensures that the PLC can respond quickly to changes in the input signals and control the output devices accordingly.

4.2 INTERFACING WITH PLC SYSTEM

A system can be controlled using a Programmable Logic Controller. The programming of PLC includes commands to turn on and off outputs as per the input conditions and the internal program of PLC. Once a Programmable Logic Controller (PLC) takes control of the system, it utilizes sensor inputs to make informed decisions and updates outputs to actuate the system. The actuators perform the operation to open and close the circuit breakers. This states that the controller is limited by the sensors available. Thus, if an input of PLC is not available then the controller will not detect conditions. The physical prototype model is interfaced with the Programmable Logic Controller (PLC) using its four outputs and five inputs in this particular model. The figure given below is the image actual working model.

Fig 4.2: Working Model

The inputs are configured as:-

X0 – Voltage Sensor
X1 – Current Sensor
X2– Smoke Sensor
X3 – Temperature Sensor
X4 – Temperature Sensor

The outputs are configured as:-

Y0 – Circuit breaker 1 opened
Y1 – Circuit breaker 1 closed
Y2 – Circuit breaker 2 opened
Y3 – Circuit breaker 2 closed

4.3 SCADA

[2] SCADA (Supervisory Control And Data Acquisition system) is a combination of telemetry and data acquisition. The system collects information through Remote Terminal Units (RTUs), which are then sent back to a central site for analysis and control. The information is displayed on various operating screens or displays. SCADA systems are distributed and used to manage geographically dispersed assets over thousands of square kilometers, where centralized data acquisition and control are crucial to system operation.

SCADA systems are used in distribution systems such as water distribution and waste water collection systems, oil and gas pipelines, electrical power grids, and railway transportation systems. The centralized monitoring and control of remote field sites via long-distance communication networks are carried out by the control center of a SCADA (Supervisory Control and Data Acquisition) system. It monitors alarms and processes status data, based on information received from remote stations.[9] Automated or operator-driven supervisory commands can be pushed to remote station control devices, which are often referred to as field devices.

[1][5] Field devices control local operations such as opening and closing valves and breakers, collecting data from sensor systems, and monitoring the local environment for alarm conditions. A SCADA system gathers data from sensors and instruments located in remote areas, and transmits the data to a central site for process monitoring by controllers. Automation systems are used to increase the efficiency of process control by trading off high personnel costs for low computer system costs.

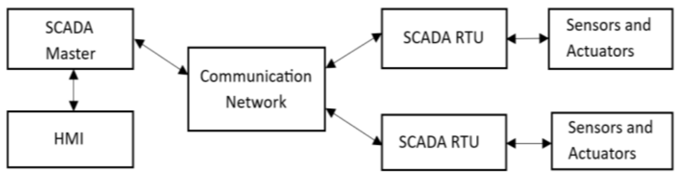

Fig 4.3: SCADA

5. WORKING

We have a setup consisting of two lines represented by two towers. The power supply is regulated by a SMPS, or switch mode power supply, which provides power to our modular Delta-made PLC, the DVP14SS2. A relay card with 24v and 5v relays controls the motor of the actuator, two circuit breakers, and a changeover switch. The PLC sends signals to the relays, and a voltage regulator is attached due to the presence of 5v relays. There are two automated isolators that can be implemented to all isolators. Each isolator has a motor actuator to open and close the contacts. Also two circuit breakers are present- one for each line. Relays are used to symbolize the circuit breakers. Additionally, two transformers and two bulbs are attached to symbolize the two loads.

In operation mode, the SMPS is connected to the power supply and provides power where necessary. To turn on Line 1, we send a signal from SCADA to the isolator actuator, which will connect the circuit for a given amount of time. To turn off Line 1, we simply open the isolator from SCADA, which will disconnect the circuit and stop power from being supplied to the load. All controlling signals are provided by the PLC.

In the event of a problem with one of the lines, we can use the changeover switch to switch the load from one line to the other to provide power.

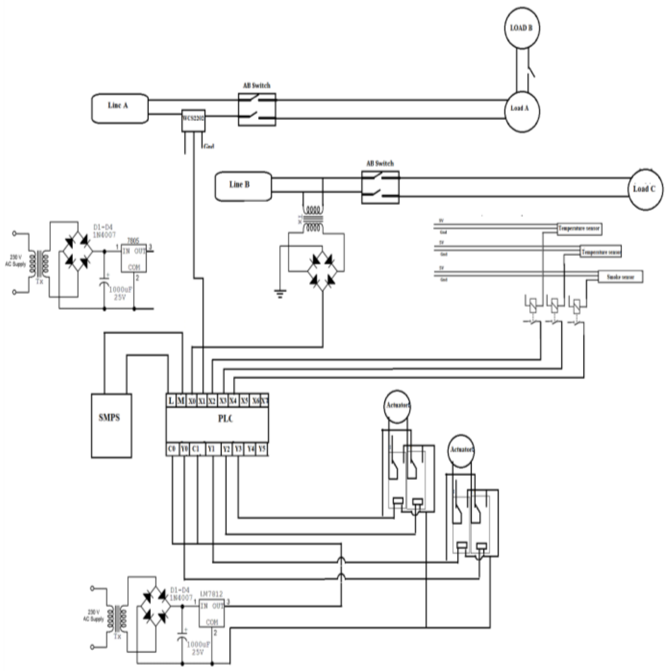

Fig 5: Circuit Diagram

6. RESULTS

This model has ensured the efficient working and substation automation using PLC and SCADA by detecting various faults. The faults include under voltage, over current, increase in temperature limit faults as well as a situation of fire. During normal conditions the SCADA screen shows that all the indicators of the faults are green. At faulty condition the indicator of the particular fault will turn red and the automated system will open the circuit breaker of the particular line immediately .The Fig 6.1 gives the SCADA screen for normal operation, Fig 6.2 gives the SCADA screen for the under voltage fault condition and Fig 6.3 gives the SCADA screen for the over current fault condition.

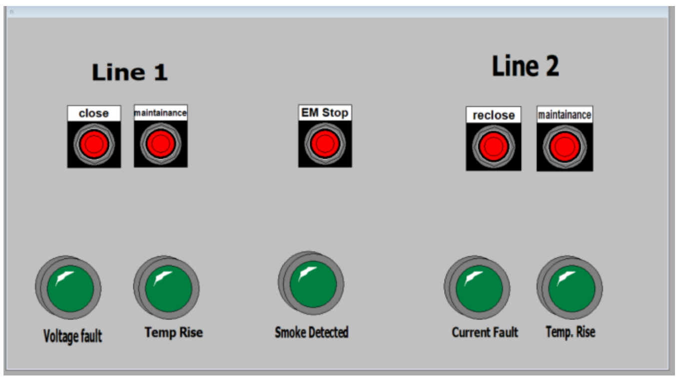

Fig 6.1: SCADA screen for normal operation

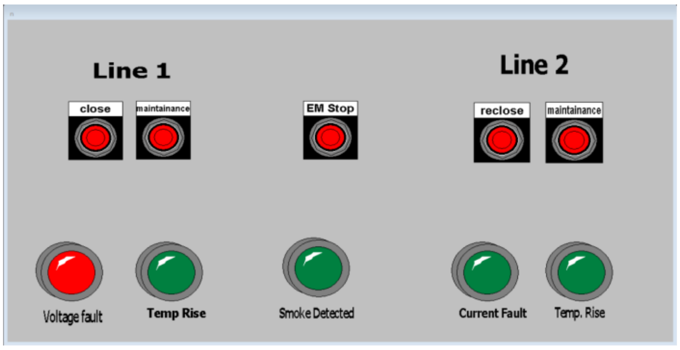

Fig 6.2: SCADA screen for the under voltage fault condition

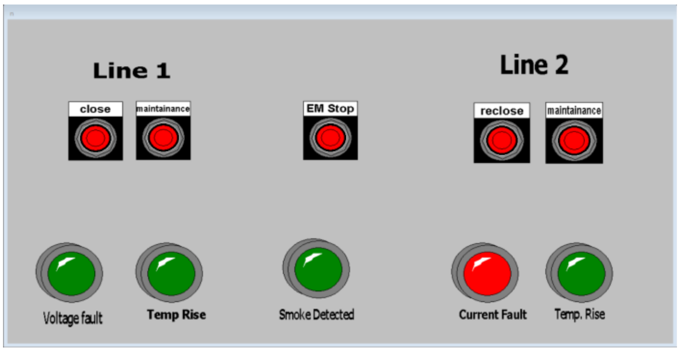

Fig 6.3: SCADA screen for over current fault condition

6. CONCLUSION

In conclusion, the adoption of PLC and SCADA technology for the implementation of a Smart Substation holds numerous advantages for power utilities. These benefits encompass increased operational efficiency, enhanced reliability and security, and improved monitoring and control capabilities. By integrating advanced communication systems and intelligent devices, real-time data and insights can be obtained, enabling power utilities to optimize their operations and overall performance. However, the successful implementation of such a system necessitates meticulous planning, design, execution, as well as ongoing maintenance and upgrades. As the field of Smart Grid technology continues to advance, Smart Substations are poised to play an increasingly vital role in ensuring a dependable and sustainable energy supply. This project aims to replace outdated practices that involve physically visiting sites for fault detection and repair, with modern methods. Moreover, it also offers valuable features such as transformer overload protection, fire hazard detection and prevention, as well as temperature and smoke sensing. These parameters hold significant importance for commercial, industrial, and distribution sectors, making this project highly beneficial for the overall system.

6. ACKNOWLEDGEMENT

It brings me immense pleasure and a profound sense of privilege to present this paper titled "Smart Substation with Automatic Monitoring, Smart Controlling, and Overload Protection of Transformers using PLC and SCADA." As students, we consider preparing a research paper a significant milestone in our academic journey, and we are aware that its successful execution is heavily reliant on the guidance and support of our mentor. Thus, we extend our deepest gratitude to electrical engineering department of Government College of Engineering, Nagpur, for their invaluable assistance throughout the development of this paper.

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