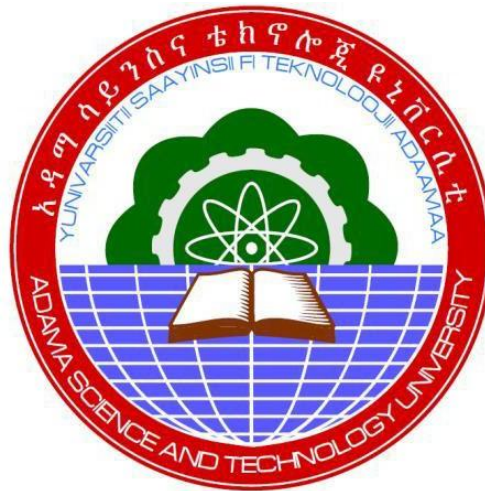


**DESIGN, MODELING AND SIMULATION OF SUBSTATION
FOR ENERGY MANAGEMENT USING PLC BASED SCADA
SYSTEM:
A CASE STUDY: - ADAMA SUBSTATION**

By Kedir Ali



A thesis submitted to Adama Science and Technology University, School of Electrical Engineering and Computing, Electrical Power and Control Engineering Department in Partial fulfillment of the requirement for the degree of Master of Science in Electrical Power Engineering

Office of Graduate Studies
Adama Science and Technology University

Adama, Ethiopia
May, 2019

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TABLE OF CONTENTS

Contents	Page
ACKNOWLEDGEMENTS	I
LIST OF FIGURES	V
LIST OF TABLES.....	viii
LISTS OF ACRONYMS.....	ix
ABSTRACT	1
CHAPTER ONE	2
1. Introduction.....	2
1.1. Background	2
1.2. Statement of the Problem.....	4
1.3. Objective the thesis	4
1.3.1. General objective	4
1.3.2. Specific objectives	4
1.4. Scope of the thesis	5
1.5. Significance of the Study	5
CHAPTER TWO	6
2. Literature Review.....	6
2.1. Computer Control of Power Systems.....	6
2.2. Supervisory Control and Data Acquisition (SCADA).....	7
2.2.1. SCADA Evolution.....	8
2.2.2. SCADA System Architecture	9
2.2.3. SCADA Systems Concepts.....	12
2.2.4. STRUCTURE OF SCADA	13
2.2.5. Fundamental Principles of Modern SCADA Systems.....	13
2.2.6. Modem Use in SCADA System.....	14
2.3. Principles Operation of Modern SCADA System.....	15
2.4. General System Operation of Substation Automation Using SCADA	18
2.5. SCADA Systems for Electrical Distribution.....	19
2.5.1. Automation of Electrical Distribution System.....	19
2.6. Introduction to Programmable Logic Controllers	20
2.6.1. Brief History of PLC	20
2.6.2. PLC Configurations	22
2.6.3. Principles of operation	24

2.7. Smart Grid Energy Management System.....	27
2.7.1. Smart Grid Conceptual Model.....	28
2.8 SUBSTATIONS	30
2.8.1 Introduction.....	30
2.9 Types of substations.....	32
2.9.1 Transmission substation.....	32
2.9.2 Distribution substation.....	33
2.10 Classification of Substation.....	34
2.11 Main Equipments Used in A Distribution Substation	36
2.12 Substation Automation.....	40
2.12.1 Need for Substation Automation.....	40
2.13 Power Reliability through SCADA System.....	41
2.13.1 Reliability of Electrical Distribution system	42
2.13 Empirical Review	44
CHAPTER THREE.....	48
3. METHDOLOGY.....	48
3.1 Substation Automation and Data Collection.....	48
3.2. Data Collection.....	61
3.3 Current Adama Distribution Substation SCADA Application Gaps	57
3.4Substation Control Using SCADA	63
3.5Feeder Control Using SCADA.....	63
3.6. End user load control automation by SCADA.....	66
3.7. Introduction to Simulating Software	67
3.7.1 WinCC System Overview.....	67
3.7.2. The SCADA System Inside TIA Portal.....	67
3.7.4. The interfaces of Win CC.....	69
3.7.5. Step 7 Professional and PLC SIM Soft wares	70
CHAPTER FOUR	71
4. Results And Discussion.....	71
4.1. SCADA SIMULATION RESULT USING WIN CC SOFTWARE.....	73

4.2. Result and Discussion of the system Before SCADA.....	104
4.3. Result and Discussion of the system After SCADA	106
CHAPTER FIVE	108
5. Conclusion and Recommendation	108
5.1. Conclusion	108
5.2. Recommendation	109
REFERENCES	110
Appendix A Substation status	113
Appendix B: Simulation Result of Feeder Four.....	117

LIST OF FIGURES

Figure2. 1 Monitoring and controlling of electrical power system	7
Figure2. 2 Typical local control system [3,26].....	9
Figure2. 3 Open Control SCADA System Architecture [4]	12
Figure2. 4 Common SCADA Installation utilizing Remote Terminals (PLC/DCS, Sensors)[8]	13
Figure2. 5 PC to RTU Using a Modem Specialized SCADA Protocols [7].....	15
Figure2. 6 SCADA Block Diagram	Error! Bookmark not defined.
Figure 2. 7 SCADA System Configuration Diagram of Adama Substation.....	19
Figure 2. 8 Automation of Electrical Distribution System [9]	20
Figure 2. 9 open frame PLC [12]	22
Figure2. 10 Shoe box style PLC [12]	23
Figure2. 11 Modularized PLC [12]	23
Figure2. 12 PLC conceptual application diagram [10]	24
Figure2. 13 Programmable controller block diagrams [10]	24
Figure2. 14 Block diagram of major CPU components [10].....	25
Figure2. 15 Illustration of a scan.....	26
Figure 2. 16 Input/output interface.....	26
Figure2. 17 Smart Grids [26].....	29
Figure2. 18 Traditional Power system [17]	29
Figure2. 19 Future Smart Grid [17].....	30
Figure2. 20 Typical power system elements [24]	32
Figure2. 21 Adama Distribution Substation	34
Figure2. 22 Power Transformer	37
Figure 2. 23 Isolators in a substation	39
Figure3. 1 Model of Adama Substation	49
Figure 3. 2 Annual SAIFI per Feeder	60
Figure 3. 3 Annual SAIDI per Feeder.....	62
Figure 3. 4 Proposed SCADA system for Distribution Substation Automation of Different Feeders	64
Figure 3. 5 Proposed Substation Design	65
Figure 3. 6 Win CC conceptual diagram [34,35]	69

Figure 3. 7 Win CC conceptual diagram [34],[35].....	70
Figure 4. 1 Feeder1 Emergency Switch, Circuit Breaker and PLC Ladder Diagram Simulation.....	73
Figure 4. 2 Feeder 1 PLC Memory Ladder Diagram Simulation	74
Figure 4. 3 Feeder 1 Line Voltages PLC Ladder Diagram Simulation Results	75
Figure 4. 4 Feeder 1 Line Currents PLC Ladder Diagram Simulation Results	76
Figure 4. 5 Feeder 1 Line Power Factor and Line Active power PLC Ladder Diagram	77
Figure 4. 6 Feeder 1 Line Reactive Power and Line Frequency PLC Ladder Diagram Simulation.....	78
Figure 4. 7 Feeder 1 Alarm Circuit PLC Ladder Diagram Simulation Results	79
Figure 4. 8 Feeder 1 Alarm Circuit PLC Ladder Diagram Simulation Results	80
Figure 4. 9 Feeder 1 Alarm Circuit PLC Ladder Diagram Simulation.....	81
Figure 4. 10 Feeder 1 Alarm and Timer Circuit PLC Ladder Diagram Simulation Results.....	82
Figure 4. 11 Feeder 1 Alarm and Timer Circuit PLC Ladder Diagram Simulation Results.....	83
Figure 4. 12 HMI screen to monitor and control the real time substation status.....	84
Figure 4. 13 Trends of feeder 1.....	85
Figure 4. 14 Alarm texts.....	86
Figure 4. 15 Feeder 2 Emergency Switch, Circuit Breaker and PLC Memory Ladder Diagram Simulation Results	87
Figure 4. 16 Feeder 2 PLC Memory Ladder Diagram Simulation Results.....	88
Figure 4. 17 Feeder 2 PLC Memory Ladder Diagram Simulation Results.....	89
Figure 4. 18 Feeder 2 Line Voltages PLC Ladder Diagram Simulation Results.	90
Figure 4. 19 Feeder 2 Line Currents PLC Ladder Diagram Simulation Results.	91
Figure 4. 20 Feeder 2 Line Power Factor and Line Active Power PLC Ladder Diagram	92
Figure 4. 21 Feeder 2 Line Reactive Power and Line Frequency PLC Ladder Diagram.	93
Figure 4. 22 Feeder 2 Alarm Circuit PLC Ladder Diagram Simulation Results.	94
Figure 4. 23 Feeder 2 Alarm Circuits PLC Ladder Diagram Simulation Results.....	95
Figure 4. 24 Feeder 2 Alarm Circuits PLC Ladder Diagram Simulation Results.	96

Figure 4. 25 Feeder 2 Alarm and Timer Circuit PLC Ladder Diagram Simulation

Results.....97

Figure 4. 26 Alarm and Timer Circuit PLC Ladder Diagram Simulation Results.....98

Figure 4. 27 HMI screen.....99

Figure 4. 28 Trends.....100

Figure 4. 29 Alarm text abnormal conditions 101

Figure 4. 30 proposed design of Substation to improve reliability.....103

LIST OF TABLES

Table3. 1 Daily substation data status of 08/11/2009 E. 51

Table3. 2 Daily substation data status of 11/11/2009 E.C 52

Table3. 3 Daily substation data status of 15/11/2009 E.C 53

Table3. 4 Daily substation data status of 08/01/2010 E.C 54

Table3. 5 Daily substation data status of 13/01/2010 E.C 55

Table3. 6 Daily substation data status of 08/02/2010 E.C 56

Table3. 7 Annual SAIFI per Feeder 59

Table3. 8 Annual SAIDI per Feeder.....61

Table 4. 1 comparison result before and after SCADA.....72

Table 4. 2 SUMMARY of reliability before SCADA.....104

Table 4. 3 SUMMARY of reliability after SCADA.....106

LISTS OF ACRONYMS

AMR	Automatic Meter Reading
ANSI	American National Standards of Institute
CDS	Command and Data Subsystem
CM	Conceptual Model
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
DCE	Device and Communication Equipment
DDE	Dynamic Data Exchange,
DNP	Distributed Network Protocol
DTE	Data Terminal Equipment
EMS	Energy Management System
HDLC	High Level Data Link Control
HMI	Human Machine Interface
IEC	International Electro Technical Commission
IED	Intelligent Electronics Device
IEEE	Institute of Electrical and Electronics Engineers
LAN	Local Area Network
MTP	Message Transport Protocol
MTU	Master Terminal Unit
NFR	Near Filed Recording
ODBC	Open Database Connectivity
OLE	Object Linking & Embedding
OPC	Open Protocol Control
PLC	Programmable Logic Controller
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition

SGIP	Smart Grid Interoperability Panel
SQL	Sequential Query Language
TCP	Transmission Control Protocol
UCA	Utility Communications Architecture
VNP	Virtual Network Protocol
WAN	Wide Area Network
Win CC	Window Control Center

ABSTRACT

*Energy Management System (EMS) and Supervisory Control and Data Acquisition (SCADA) are a strongly linked and associated with each other. SCADA system combines power data and process data (both analogue and digital) to enable a real-time analysis of the impact of process changes and energy consumption. In distribution systems certain measures are taken for supervision, control, operation, measurement and protection and highly onerous works that take lot of man power. So the need of advanced automatic control system to reach the required destination becoming mandatory, to supersede antiquated ways that are persisting in the present destination system. This thesis emphasizes mainly on the SCADA (Supervisory Control and Date Acquisition) system, the most sophisticated automatic control system, being used in distribution for quality of power. The SCADA systems remote terminal unit (RTU or PLC) will be installed in switching substation (15KV) which will constantly monitor electrical parameters (Pf, P, Q, V, I and F) and send the data to MTU (Master Terminal Unit). Power which is fed to **Adama** substation comes from two main sources, from **Koka** hydro Electric power station and **Adama wind farm 1** wind station. Despite the existence of these sources there is always power interruption problems in the distribution substation. This is due to the antiquated ways of distribution network and the lack of automatic monitoring and controlling systems in the substation. The research result depicts the reliability of Adama substation does not meet the requirements set by IEEE standards. The system average interruption frequency index (SAIFI) of the substation is 312.0614 interruptions per customer per year with system average interruption duration index (SAIDI) of 428.8393 hours per customer per year at the base case. Based on the research result, the application of PLC based SCADA system on each feeder lines or switching substations, resulted in the improvement of SAFI by 65.31% and SAIDI by 66.26%. The simulation result also shows that this system increases the performance of the distribution substation by using SCAD/EMS to monitor and control the operation of the field devices so as to achieve data acquisition, device control, parameter adjustment, measurement and various signal alarms.*

Key Words: SCADA, PLC, EMS, SAIFI, SAIDI, Win CC

CHAPTER ONE

1. Introduction

1.1. Background

SCADA (supervisory control and data acquisition system) refers to the combination of telemetry and data acquisition. SCADA encompasses the collecting of the information via a RTU (remote terminal unit), transferring it back to the central site, carrying out any necessary analysis and control then displaying that information on a number of operator screens or displays. A SCADA system gathers data from sensors and instruments located to remote sides. Then, it transmits data at a central site for controller monitoring process. SCADA system consists of one or more field data interface devices (RTUs or PLCs). A communication system such as radio, telephone, cable, satellite. A central host computer server or servers (also called a SCADA center, or Master Terminal Unit (MTU)). A collection of standard and/or custom software (Human Machine Interface(HMI)). Critical infrastructure systems include critical physical processes. These processes are controlled by automation systems which combine humans, computers, communications, and procedures. A automation systems are used to increase the efficiency of process control by trading off high personnel costs for low computer system costs. They also contribute to improve performance by taking advantage of faster computer control instead of human reaction times. These automation systems are often referred to as process control system (PCS) or Supervisory Control and Data Acquisition (SCADA) systems, and the widespread use of such systems makes them critical to the safe, reliable, and efficient operation of many physical processes [1].

Efficient energy consumption is a key factor to Ethiopia's ambitious goals for sustainable development and activities. However, for some period of time in a day, the complete electricity distribution network in the country is working under extremely high loads. In order to tackle the increasing electricity demand, a number of solutions for efficient energy consumption, generation of energy from renewable sources and new power distribution business models for active energy control have been considered, and some of them have been pushed via regulations at international level [2].

It is evident that EMS can effectively assist grid operators to optimize the performance of the electric utilities, power plants and the power grid transmission & distribution networks.

However, with the widespread installation of large renewable energy systems, such as wind farms and solar farms, the power grid is facing new challenges in balancing the demand and supply due to the intermittent nature of renewable energy. At the same time, the wide adoption of DERs (e.g. Roof PV system, Energy Storage Systems and Electric Vehicles) also increases the difficulties for the Distributed Network Operators (DNOs) in managing the power flow through the aging electricity assets [3].

Management of energy has been complex and imperative since various sources are to be integrated to a single management system. Therefore, Smart Grid is being invented. Typical electrical grid is made up of four parts: generation, transmission, distribution and customers. Smart Grid is supposed to make everything better by establishing necessary two-way data communications among components within the electrical grid. The term "smart grid" is a term used to name an electrical energy delivering system merging both digital technologies and long transmission networks to optimize energy consumption, as well as to open up new processes for energy production and distribution [4].

The smart grid needs to be complemented with smart (programmable) appliances at the customer sites to efficiently re-distribute the power to provide the benefits satisfying demands for customers and operational efficiencies for suppliers. Smart Energy Management System need to integrate with Smart grid & Smart Appliances to analyze end to end complex power system data which leads to the reduce power consumption and increase smart grid reliability and efficiency. Therefore, the management of energy is becoming more interactive. The possible benefits of smart grid are reported to be reduced finance costs, fewer environmental damages and possibly eliminating power outages.

In conclusion, there is not yet a prominent and economical method in optimization of the Energy Management System, especially for end consumer. This thesis is concentrated in addressing the Energy Management System such improving energy efficiency, profiling demand, maximizing utility, and reducing cost operations. In addition, improvement of the grid on avoiding possible overload and minimizing the frequency and duration of power interruption is another great concern in this research.

1.2. Statement of the Problem

Even though, Ethiopia has been developed various electrical energy generation plants, there is massive shortage of supply of energy throughout the country. These problems have been initiated from electrical equipment malfunction and due to weak system controlling mechanism to do their duty regularly and correctly. Although now a day there are several controlling systems being installed for different substations, while they are very sophisticated and hard to implement.

Despite of the abundant availability of energy resources in Ethiopia, many communities still suffered from power interruption from the utility grid. This is due to poor energy management system and old infrastructures (old substation and transmission lines) that deliver power to end users.

To mitigate the above problems, the utility has to use substation automation method to modernize the system and can satisfy power demands of the customers. Even though the utility had tried to apply SCADA system to the old existing system without modified design it cannot reduce the power interruption that is expected from the SCADA system. This cannot improve the reliability and performance the substation. This thesis proposed substation automation using PLC based SCADA system with modifying the distribution system design. SCADA is a powerful technology to modernize the substation in power system operation if we use correctly and efficiently. It is a powerful tool for substation automation. SCADA is a technique for supervise, monitor and protect the power system status in a real time operation. By using SCADA, we can supervise, monitor, control and protect the power system (substation status) in real – time operation to improve the reliability and performance of the power distribution system.

1.3. Objective the thesis

1.3.1. General objective

The main objective of this thesis is to Design, model and simulate the substation energy management using PLC based SCADA system.

1.3.2. Specific objectives

To achieve aforesaid goal, the following specific objectives will be accomplished.

- To investigate the power distribution problems that arise from both the consumer side and the Electric Utility side of Adama distribution substation.
- To collect and analyze the power system reliability data of the currently existing system.
- To develop a suitable model, the distribution substation for simulation and investigation purpose as well as its impact on energy management system.
- To identify possible solutions for the reliability problems.
- Draw relevant conclusions and recommendations from the result of the investigation on how Energy Management of the grid is improved.

1.4. Scope of the thesis

The main scope of this thesis is to investigate the application of substation automation to the existing distribution system for effective Energy Management to improve the reliability and performance of power distribution system using PLC based SCADA system to Adama distribution substation.

1.5. Significance of the Study

Nowadays in developed countries, the focus is shifting the power sector from creation of additional capacity to better capacity utilization through effective Energy Management and efficient technology. This applies equally to developing countries like Ethiopia, where this focus will result in reduction in need for capacity addition. SCADA based Energy Management System is very important for both the utility and consumer as it has a great significant for improving the reliability and performance of the power distribution system.

CHAPTER TWO

2. Literature Review

2.1. Computer Control of Power Systems

In developed countries, the focus is shifting in the power sector from the creation of additional capacity to better capacity utilization through more effective management & efficient technology. This applies equally to developing countries where this focus will result in reduction in need for capacity addition.

The priorities are: - Better plant management, Higher availability, Improved load management, Reduced transmission losses, Revamps (renovations) of distribution systems, Improved billing & collection, Energy efficiency, Energy audit and energy management. All this would enable an electric power system to generate, transmit and distribute electrical energy at the lowest possible economic and ecological cost.

In distribution network, Computerization can help manage load, maintain quality, detect theft and tampering and thus reduce system losses. Computerization also helps in centralization of data collection. At a central load dispatch center, data such as current, voltage, power factor and breaker status are telemetered and displayed. This gives an operator an overall view of the entire distribution network. This enables him to have to necessary action for its smooth operation. All these functions can be carried smoothly using computer control [4], [5].

Computer control brings in powerful algorithms with the following advantages

- (i) Increase in capacity utilization in generators
- (ii) Savings in energy and so raw materials due to increased operational efficiency
- (iii) Flexibility and modifiability
- (iv) Reduction in human drudgery (labor or work) and
- (v) Improved operator effectiveness.

Intelligent database processors will become more common in power system since the search, retrieval and updating activity can be speed up [5].

Personal computers (PCs) are being used in a wide range of power system operations including power station control, load management, SCADA systems, protection, operator training, maintenance functions, administrative data processing, generator excitation control and control

of distribution networks. IT enabled systems thus not only monitor and control the grid but also improve operational efficiencies and play key part in maintaining the security of power systems. The above objectives can only be met by use of information technology (IT) enabled services in power systems management and control. Emphasis is therefore on computer control, information transmission and exchange. [5]

The operations involved in power systems require geographically dispersed and functionally complex monitoring and control system. The monitoring and supervisory control that is constantly developing and undergoing improvement in its control capability is schematically represented in the figure 2.1 shown below. It can be seen that it is distributed in nature.

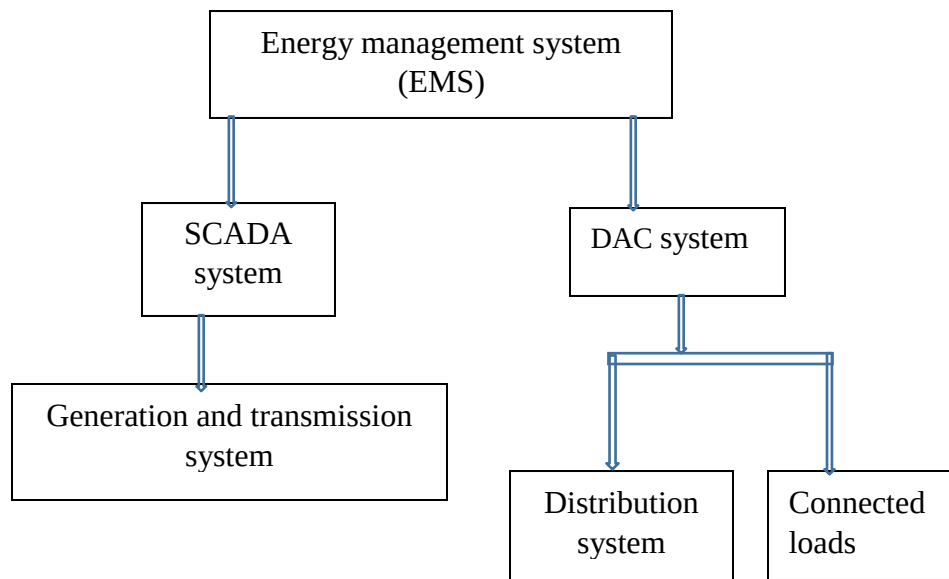


Figure 2. 1 Monitoring and controlling of electrical power system [5].

Automation, monitoring and real-time control have always been part of SCADA system. With enhanced emphasis on IT in power systems, SCADA has been receiving a lot of attention recently.

2.2. Supervisory Control and Data Acquisition (SCADA)

The early SCADA systems were built on replicating the existing system remote controls, lamps, and analog indications at the functional equivalent of pushbuttons, often placed on a mimic board for easy operator interface. The SCADA masters simply replicated point for-point, control circuits connected to the remote, or slave, unit. At the same time as SCADA systems were

developing, a parallel technology on remote tele printing, or Teletype" was taking shape. The invention of the "modem" (Modulator/ Demodulator) allowed digital information to be sent over wire pairs which had been engineered to only carry the electronic equivalent of human voice communication. The introduction of digital electronics made it possible use of faster data streams to provide remote indication and control of system parameters. The integration of Teletype technology and the digital electronics gave birth to "Remote Terminal Units" (RTU 's) which were built with solid state electronics which could provide the remote indication and control of both discrete events and analog voltage and current quantities of the electric power system.

The development of Microprocessors gave the required impetus to SCADA industry craving for increased functionality & faster speeds. The 1970s and early 1980s saw the coming age of integrated microprocessor-based devices which came to be known as "Intelligent Electronic Devices", or IED's. The IED's are being used increasingly to convert data into engineering unit values in the field and to participate in field-based local control algorithms. Many IED's are being built with programmable logic controller (PLC) capability and, communication.

Supervisory Control and Data Acquisition (SCADA) systems are vital components of most nations' critical infrastructures. They control pipelines, water and transportation systems, utilities, refineries, chemical plants, and a wide variety of manufacturing operations. SCADA provides management with real-time data on production operations, implements more Efficient control paradigms, improves plant and personnel safety, and reduces costs of operation. These benefits are made possible by the use of standard hardware and software in SCADA systems combined with improved communication protocols and increased connectivity to outside networks, including the Internet [6], [7].

This chapter explores the evolution of SCADA systems, their characteristics, functions, typical applications, and general security issues.

2.2.1. SCADA Evolution

The scope of SCADA has evolved from its beginnings in the 1960s. The advent of low-cost minicomputers such as the Digital Equipment Corporation PDP-8 and PDP-11 made computer control of process and manufacturing operations feasible. Programmable logic controllers (PLCs) progressed simultaneously. These latter devices implemented traditional *relay ladder*

logic to control industrial processes. PLCs appealed to traditional control engineers who were accustomed to programming relay logic and who did not want to learn programming languages and operating systems. When microcomputers were developed, they were programmed and packaged to emulate PLCs in function, programming, and operation. In fact, competition developed between the two approaches and continues to this day.

Initially, control systems were confined to a particular plant. The associated control devices were local to the plant and not connected to an external network. The early control systems consisted of a central minicomputer or PLC that communicated with local controllers that interfaced with motors, pumps, valves, switches, sensors, and so on. Figure 2.2 illustrates this architecture.

This architecture is sometimes referred to as a distributed control system. Such systems are generally confined to locations close to each other, normally use a high-speed local network, and usually involve closed loop control. As a necessary requirement for the operation of these systems, companies and vendors developed their own communication protocols, many of which were proprietary.

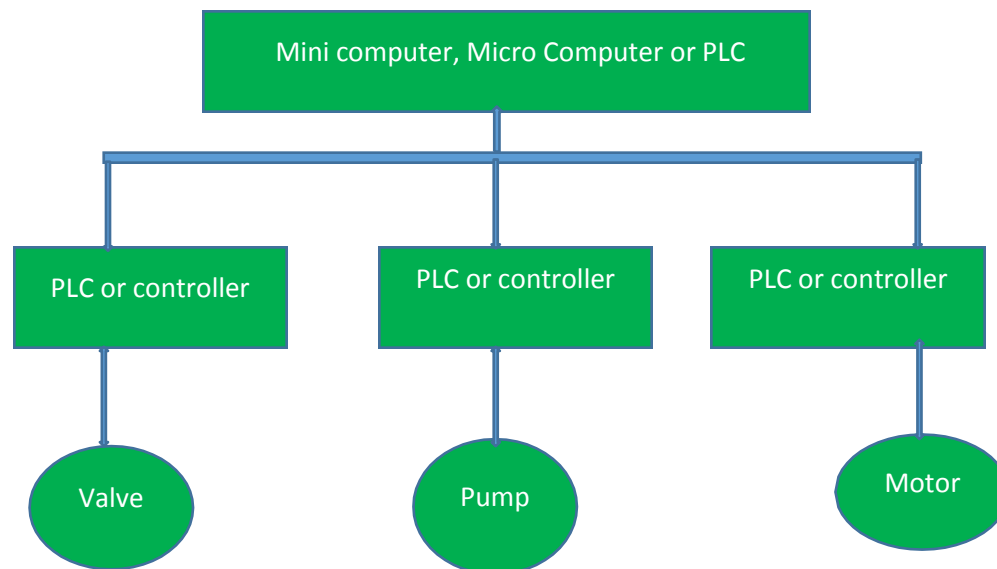


Figure2. 2 Typical local control system [6]

2.2.2. SCADA System Architecture

Specific terminology is associated with the components of SCADA systems. These SCADA elements are defined as follows.

Operator: These are the computer terminals consisting of standard HMI (Human Machine Interface) software and networked with central host computer. These workstations are operator terminals that request and send the information to client computer in order to monitor and control the remote field parameters.

Human operator who monitors the SCADA system and performs supervisory control functions for the remote plant operations.

Human Machine Interface (HMI): Presents data to the operator and provides for control inputs in a variety of formats, including graphics, schematics, windows, pull-down menus, touch screens, and so on. It allows communications equipment from different manufacturers to be connected together. The RS 232 or RS-485 interface is designed for the connection of two devices. Two devices called: DTE (Data Terminal Equipment) communicates with a DCE device and transmits data and receives data and DCE (Device and Communications Equipment) transmits data between the DTE and a physical data communications link.

SCADA system includes a user interface which is usually called Human Machine Interface (HMI). The HMI of a SCADA system is where data is processed and presented to be viewed and monitored by a human operator. This interface usually includes controls where the individual can interface with the SCADA system. HMI's are an easy way to standardize the facilitation of monitoring multiple RTU's or PLC's (programmable logic controllers). Usually RTU's or PLC's will run a preprogrammed process, but monitoring each of them individually can be difficult, usually because they are spread out over the system. Because RTU's and PLC's historically had no standardized method to display or present data to an operator, the SCADA system communicates with PLC's throughout the system network and processes information that is easily disseminated by the HMI. HMI's can also be linked to a database, which can use data gathered from PLC's or RTU's to provide graphs on trends, logistic info, schematics for a specific sensor or machine or even make troubleshooting guides accessible. In the last decade, practically all SCADA systems include an integrated HMI and PLC device making it extremely easy to run and monitor a SCADA system.

Master Terminal Unit (MTU): A central host servers or server is called Master Terminal Unit, sometimes it is also called as SCADA center. It communicates with several RTUs by performing reading and writing operations during scheduled scanning. In addition, it performs

control, alarming, networking with other nodes etc. It allows operators to view the state of any part of the plant equipment and drives most operator interaction with by alarms. It provides displays of process status information, including alarms and other means. Equivalent to a master unit in a master/ slave architecture. The MTU presents data to the operator through the HMI, gathers data from the distant site, and transmits control signals to the remote site. The transmission rate of data between the MTU and the remote site is relatively low and the control method is usually open loop because of possible time delays or data flow interruptions.

Communications Means: The communication network transfers data among central host computers and the field data interface devices and control units. The medium of transfer can be cables, radios, telephone, satellite etc. or any combination of these. Communication can be through the Internet, wireless or wired networks, or the switched public telephone network.

Remote Terminal Unit (RTU)- RTU is the main components in SCADA systems that has a direct connection with various sensors, meters and actuators associated with a control environment. These RTUs are nothing but real- time Programmable Logic Controllers (PLCs) which are responsible for properly converting remote station information to digital form for modem to transmit the data and also converts the received signal from master unit in order to control the process equipment through actuators and switchboxes. It means a microprocessor to connect data input streams to data output streams. RTU should include a battery or charger circuitry. It is accomplished by using an isolated voltage or current source. In SCADA system, RTU is a device that collects data, codes the data into a format that is from the master device and implements processes that are directly by the master. RTUs are equipped with input channels for sensing or metering, output channels for control [7].

Functions as a slave in the master/slave architecture sends control signals to the device under control, acquires data from these devices, and transmits the data to the MTU. An RTU may be a PLC. The data rate between the RTU and controlled device is relatively high and the control method is usually closed loop.

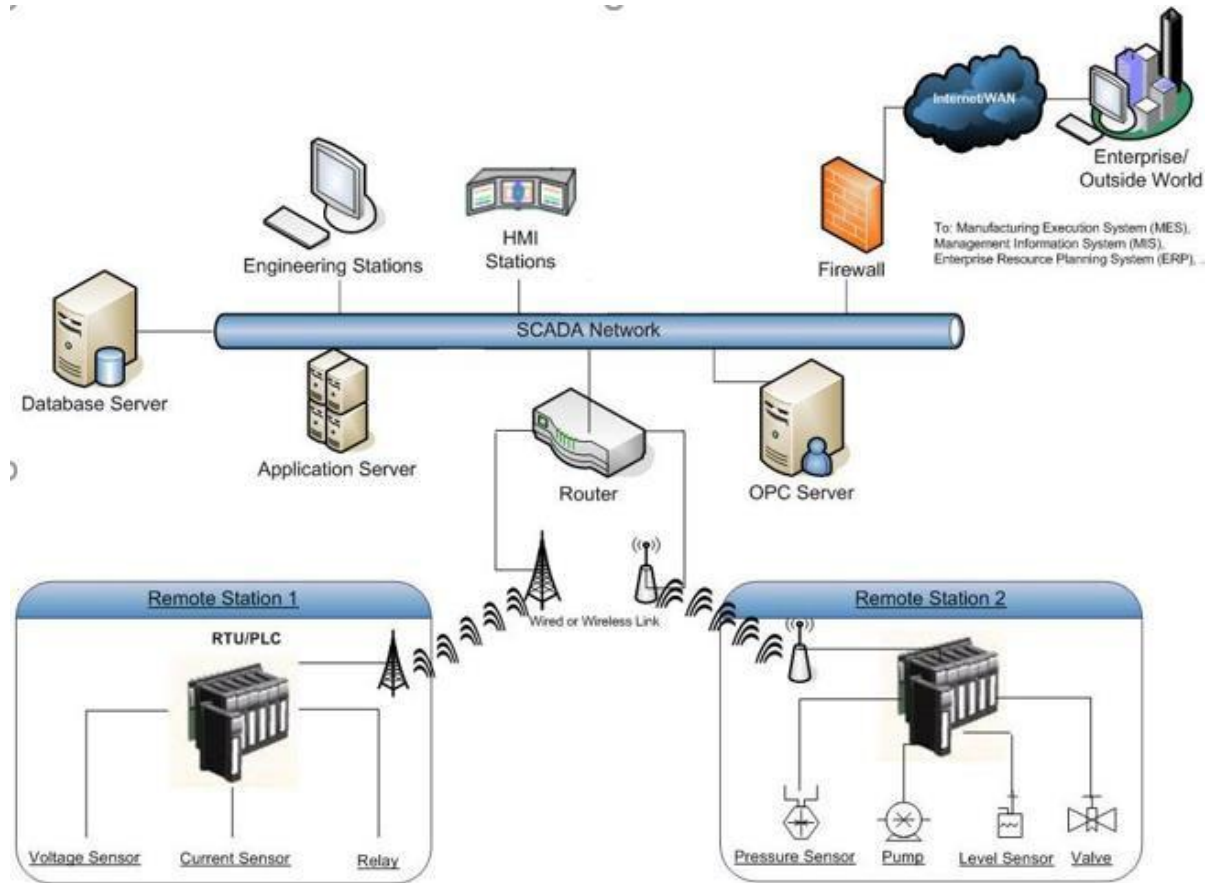


Figure2. 3 Open Control SCADA System Architecture [7]

2.2.3. SCADA Systems Concepts

The term SCADA usually refers to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas (anything from an industrial plant to a nation). Most control actions are performed automatically by RTUs or by PLCs.

Host control functions are usually restricted to basic overriding or supervisory level intervention. For example, a PLC may control the flow of cooling water through part of an industrial process, but the SCADA system may allow operators to change the set points for the flow, and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded. The feedback control loop passes through the RTU or PLC, while the SCADA system monitors the overall performance of the loop

2.2.4. STRUCTURE OF SCADA

Control Center – Main computer, Router, Data Historian, HMI and Engineering workstation

- Collect data, analyze trends and events, generates action

Communication Link – any long-distance communication system: Fiber, Cable and RF

- Serial communication protocol

Filed sites – Remote Terminal Unit (RTU) or Programmable Logic Control (PLC)

- Local control of actuators

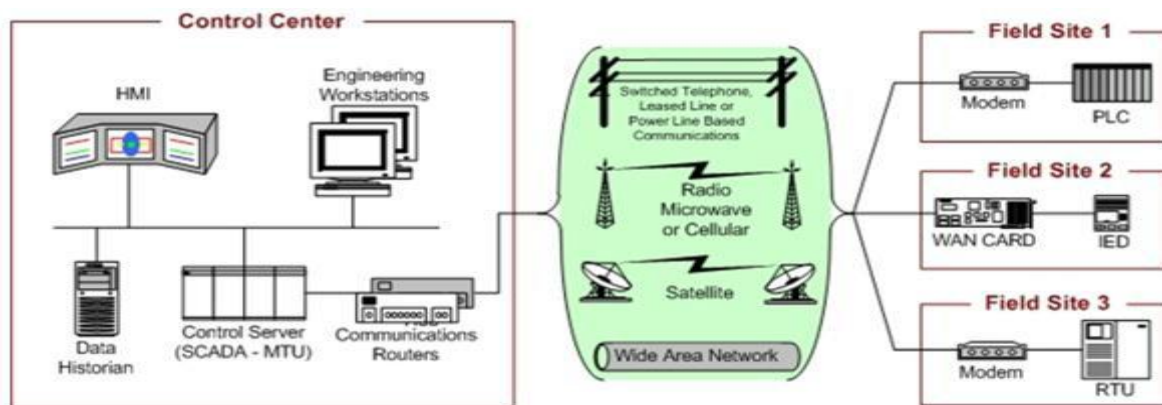


Figure2. 4 Common SCADA Installation utilizing Remote Terminals (PLC/DCS, Sensors) [8]

Data Acquisition begins at the RTU or PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to an Historian, often built on a commodity Database Management System, to allow trending and other analytical auditing [8]

2.2.5. Fundamental Principles of Modern SCADA Systems

SCADA refers to the combination of **Telemetry** and **Data acquisition**. SCADA encompasses the collecting of information, transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on a number of operator screens or displays. The required control actions are then conveyed back to the process.

a) SCADA Hardware

A SCADA System consists of a number of Remote Terminal Units (or RTUs) collecting field data and sending that data back to a master station via a communications system. The master station displays the acquired data and also allows the operator to perform remote control tasks.

b) SCADA Software

SCADA Software can be divided into two types, Proprietary or Open. Companies develop **proprietary software** to communicate to their hardware. These systems are sold as turnkey solutions. **Open software** systems have gained popularity because of the Interoperability they bring to the system.

c) SCADA and Local Area Networks

To enable all the nodes on the SCADA network to share information, they must be connected by some transmission medium. The method of connection is known as the **network topology**. Nodes need to share this transmission medium in such a way as to allow all nodes access to the medium without disturbing an established sender.

Ethernet is the most widely used LAN today because it is cheap and easy to use. Connection of the SCADA network to the LAN allows anyone within the company, with the right software and permission, to access the system. Since the data is held in a database the user can be limited to reading the information.

2.2.6. Modem Use in SCADA System

By using computer technology and taking computer protection device, network instrument, and breaker as the core, the control, signal, measurement, billing and other circuits can be included in the computer system so as to replace the traditional control protection screen and improve the reliability of system. The SCADA system can monitor and control equipments operated on the site so as to achieve functions, such as data acquisition, measurement, parameter adjustment, and various signal alarms [9].

Often in SCADA systems the RTU (Remote Terminal Unit (PLC, DCS or IED) is located at a remote location. This distance can vary from tens of meters to thousands of Kilometers. One of the most cost-effective ways of communicating with the RTU over long distances can be by dialup telephone connection. With this system the devices needed are a PC, two dialup modems

and the RTU (assuming that the RTU has a built in COM port). The modems are put in the auto-answer mode and the RTU can dial into the PC or the PC can dial the RTU.

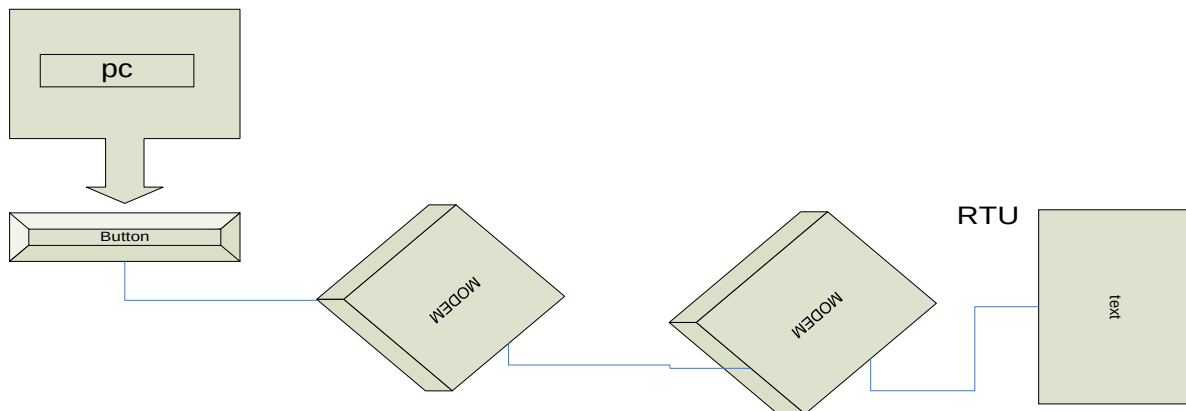


Figure 2. 5 PC to RTU Using a Modem Specialized SCADA Protocols [9]

A Protocol controls the message arrangement common to all devices on a network. Common protocols used in radio communications and telemetry systems include the High-Level Data Link Control (HDLC) Protocol, MPT1317 and Modbus protocols. The CSMA/CD protocol format and Distributed Network Protocol also used. Other protocols are Device net, Control net, TCP, Profibus, field Bus, Ethernet etc....

2.3. Principles Operation of Modern SCADA System

The transmission of information (both directions) between the master station and RTUs using time division multiplexing techniques requires the use of serial digital messages. These messages must be efficient, secure, flexible, and easily implemented in hardware and software. Nowadays the electricity problems are affecting the productivity and efficiency of the industry. This can be eliminated by automating the industrial substation. Through substation automation reliability and performance of electrical protection is increased, advanced disturbance and event recording capabilities are gained. This system can monitor and control the circuit-breakers operated on the site, to achieve data acquisition, measurement, parameter adjustment, and various signal alarms. The SCADA monitoring system uses monitoring hosts to call and monitor the load status, load distribution curve, accident statistics, important alarm, working status, and other electricity monitoring data of various substations. In RTU automated substation, the power equipment, their communication and computers are interdependent. The data from substation equipment is communicated with the SCADA systems using RTU. The main

advantage of using SCADA system is that monitoring and controlling can be done easily and reduce the human labor.

The monitoring system and real-time supervision system of the field devices and the real-time status of the substation like, currents, voltages, power factor, active power, reactive power, frequency and contacts are monitored and controlled by the SCADA system. This supervision is made through digital equipment and special sensors that are installed in the field devices of the substation. The data are collected and processed in a data acquisition and control unit (**UAC**), to thereafter through a communication network, using desirably a protocol standardized international sent to a central computer located at the control building of the substation and later to the operation centers and so allowing a remote supervision. Measured values reflect different time varying quantities, such as voltage, current, power factor, frequency and tap changer positions, which are collected from the power system. They fall into two basic type analogue and digital. All analogue signals are transformed via an A/D converter to binary format because treated as momentary-value that they have to be normalized before storing. The substation automation system in a given substation had to exchange enormous information to deliver the desired performance [10].

The power distribution monitoring system uses two monitoring hosts (one main host, and one standby host) to call and monitor the load status, load distribution curve, important alarm, accident statistics, working status, and other electricity monitoring data of various substations. SCADA is an acronym for Supervisory Control and Data Acquisition. SCADA systems are used to monitor and control a plant or equipment in industries. These systems encompass the transfer of data between a SCADA central host computer and a number of Remote Terminal Units (RTUs).

A SCADA system gathers information (such as where the fault in transmission line has occurred), transfers the information back to a central site, then alerts the home station that a fault has occurred, carrying out necessary analysis and control, such as determining if the fault is critical, and displaying the information in a logical and organized fashion. SCADA systems have made use of the infrastructure of the corporate Local Area Network (LAN)/Wide Area Network (WAN), Wireless technologies for monitoring purpose.

The combination of telemetry and data acquisition is referred as SCADA (Supervisory Control and Data Acquisition system). The SCADA encompasses the collecting of information via RTU (Remote Terminal Unit) relocating it back to central site carrying out decisive rehash and control and then displaying that information on a number of operating screens or displays. SCADA systems are highly distributed systems used to control geographically dispersed assets, often scattered over thousands of square kilometers, where centralized data acquisition and control are critical to system operation. They are used in distribution systems such as water distribution and wastewater collection systems, oil and gas pipelines, electrical power grids, and railway transportation systems [11].

A SCADA control center performs centralized monitoring and control for field sites over long-distance communications networks, including monitoring alarms and processing status data. Based on information received from remote stations, automated or operator-driven supervisory commands can be pushed to remote station control devices, which are often referred to as field devices. 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 to remote sides. Then, it transmits data at a central site for control and monitoring process.

Automation systems are used to increase the efficiency of process control by trading off high personnel costs for low computer system costs. These automation systems are often referred to as Process Control System (PCS) or Supervisory Control and Data Acquisition (SCADA) systems, and the widespread use of such systems makes them critical to the safe, reliable, and efficient operation of many physical processes.

The broad architecture of a SCADA involves physical equipment such as switches, pumps, and other devices able to be controlled by a Remote Telemetry Unit (RTU). The dual roles of the master computers are to provide the information such as meter readings and equipment status to human operators in a digestible form and to allow the operators to control the field equipment, and interface with the system using operator consoles which communicate with the master computers over a network [12].

2.4. General System Operation of Substation Automation Using SCADA

SCADA refers to the combination of telemetry and data acquisition. SCADA encompasses the collection of information (Data), transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on a number of operator screens or displays. The required control action is then conveyed back to the process.

SCADA system consists of a number of remote terminal units (RTUs) or (PLCs) collecting field data (eg- current, voltage, frequency) and sending that data to the master station through communications system. The master station displays the acquired data (electrical parameters) and also allows the operator to perform remote control tasks. Hence the operator, supervise, monitors, controls and finally protect the power system in a real- time condition.

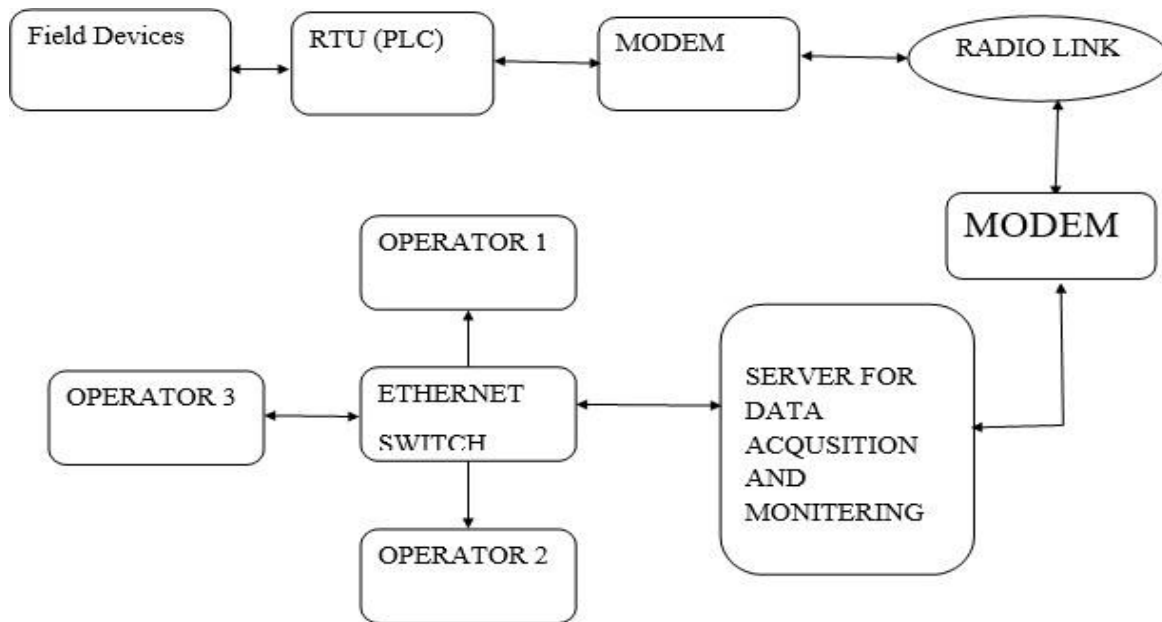


Figure2. 6 SCADA Block Diagram

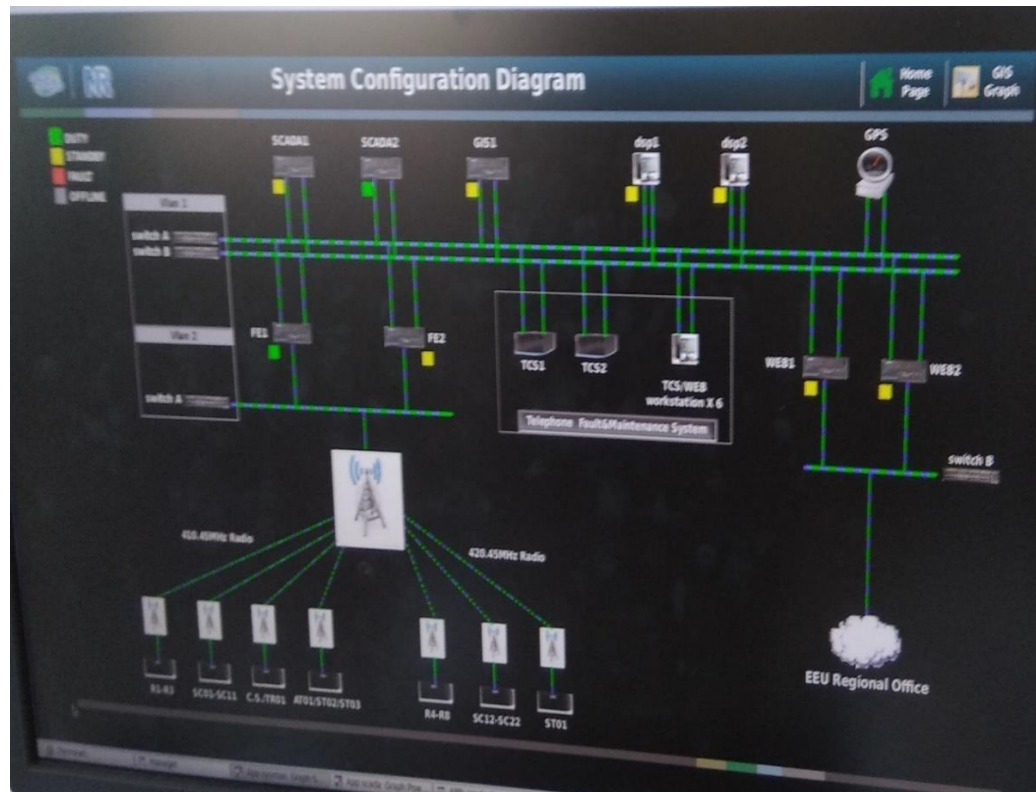


Figure 2. 7 SCADA System Configuration Diagram of Adama Substation

2.5. SCADA Systems for Electrical Distribution

Nowadays computer control is one of the most cost-effective solution for improving reliability, optimum operation, intelligent control and protection of a power system network. Having advanced data collection capabilities SCADA system play a significant role in power system operation. Typically, at distribution side SCADA does more than simply collecting data by automating entire distribution network and facilitating remote monitoring. Coordinate, control and operating distribution components just like in Smart Grid system.

2.5.1. Automation of Electrical Distribution System

Modern SCADA systems replace manual labor to perform electrical distribution tasks and manual processes in distribution systems with automated equipment. SCADA maximizes the efficiency of the power distribution system by providing the features like real time view in to the operations, data trending and logging, maintaining desire voltages, currents, and power factors, generating alarms etc.

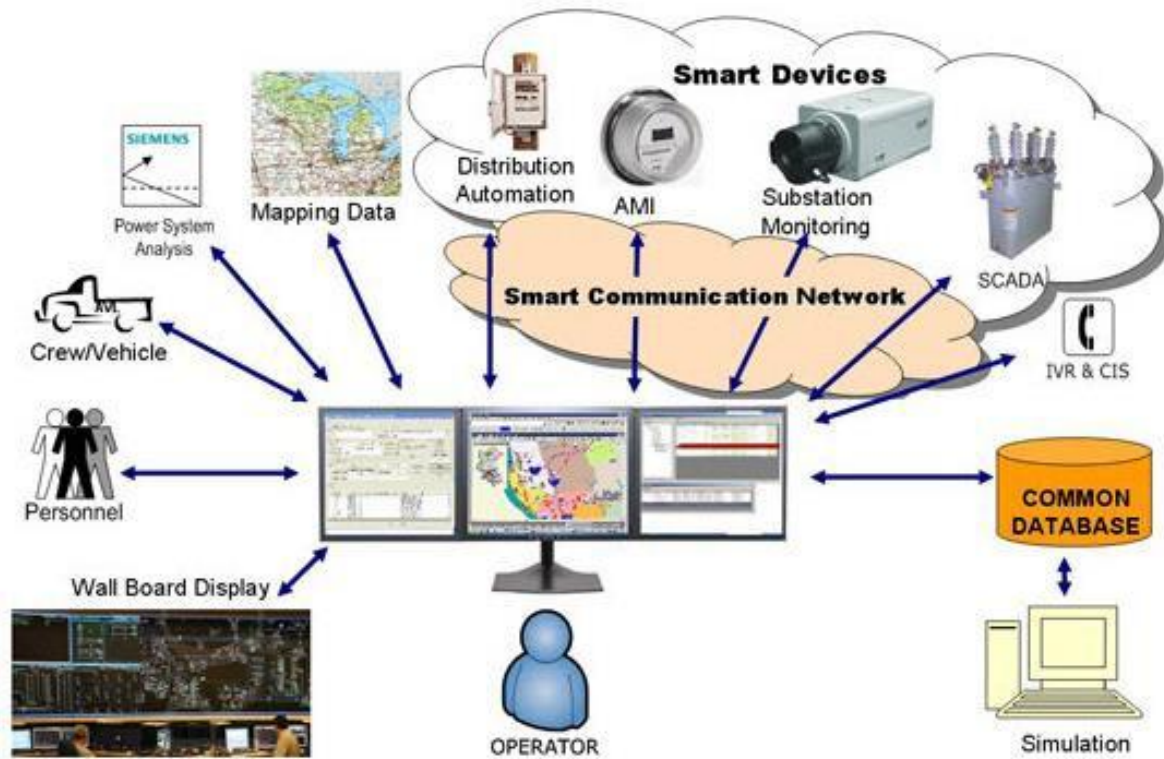


Figure 2. 8 Automation of Electrical Distribution System [13]

SCADA performs automatic monitoring, protecting and controlling of various equipments in distribution systems with the use of intelligent electronics devices (or RTUs). It restores the power service during fault condition and maintains the desire operating conditions. SCADA improve the reliability of the supply by reducing the frequency and duration of outages and also gives the cost-effective operation of distribution system. Therefore, distribution SCADA supervise the entire electrical distribution system to achieve energy management [13].

2.6. Introduction to Programmable Logic Controllers

2.6.1. Brief History of PLC

Early machines were controlled by mechanical means using cams, gears, levers and other basic mechanical devices. As the complexity grew, so did the need for a more sophisticated control system. This system contained wired relay and switch control elements. These elements were wired as required to provide the control logic necessary for the particular type of machine operation. This was acceptable for a machine that never needed to be changed or modified, but as manufacturing techniques improved and plant changeover to new products became more desirable and necessary, a more versatile means of controlling this equipment had to be

developed. Hardwired relay and switch logic was cumbersome and time consuming to modify. Wiring had to be removed and replaced to provide for the new control scheme required. This modification was difficult and time consuming to design and install and any small "bug" in the design could be a major problem to correct since that also required rewiring of the system. A new means to modify control circuitry was needed. The development and testing ground for this new means was the U.S. auto industry. The time period was the late 1960's and early 1970's and the result was the Programmable Logic Controller, or PLC. Automotive plants were confronted with a change in manufacturing techniques every time a model changed and, in some cases, for changes on the same model if improvements had to be made during the model year. The PLC provided an easy way to *reprogram* the wiring rather than actually rewiring the control system [14]

The PLC that was developed during this time was not very easy to program. The language was cumbersome to write and required highly trained programmers. These early devices were merely relay replacements and could do very little else. The PLC has at first gradually, and in recent years rapidly developed into a sophisticated and highly versatile control system component. Units today are capable of performing complex math functions including numerical integration and differentiation and operate at the fast microprocessor speeds now available. Older PLCs were capable of only handling discrete inputs and outputs (that is, on-off type signals), while today's systems can accept and generate analog voltages and currents as well as a wide range of voltage levels and pulsed signals. PLCs are also designed to be rugged. Unlike their personal computer cousin, they can typically withstand vibration, shock, elevated temperatures, and electrical noise to which manufacturing equipment is exposed.

As more manufacturers become involved in PLC production and development, and PLC capabilities expand, the programming language is also expanding. This is necessary to allow the programming of these advanced capabilities. Also, manufacturers tend to develop their own versions of ladder logic language (the language used to program PLCs). This complicates learning to program PLC's in general since one language cannot be learned that is applicable to all types. However, as with other computer languages, once the basics of PLC operation and programming in ladder logic are learned, adapting to the various manufacturers' devices are not a complicated process. Most system designers eventually settle on one particular manufacturer

that produces a PLC that is personally comfortable to program and has the capabilities suited to his or her area of applications [15].

2.6.2. PLC Configurations

Programmable controllers (the shortened name used for programmable logic controllers) are much like personal computers in that the user can be overwhelmed by the vast array of options and configurations available. Also, like personal computers, the best teacher of which one to select is experience. As one gains experience with the various options and configurations available, it becomes less confusing to be able to select the unit that will best perform in a particular application.

Basic PLCs are available on a single printed circuit board as shown in Figure 2.9. They are sometimes called **single board PLCs** or **open frame PLCs**. These are totally self-contained (with the exception of a power supply) and, when installed in a system, they are simply mounted inside a controls cabinet on threaded standoffs.

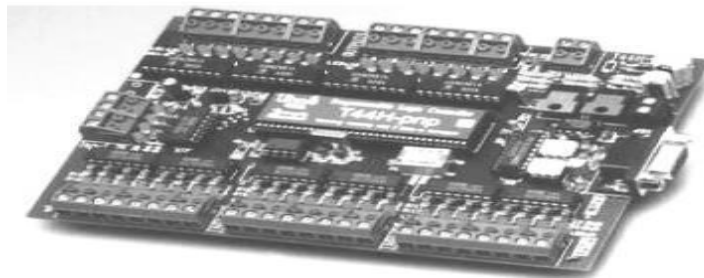


Figure 2. 9 open frame PLC [15]

PLCs are also available housed in a single case (sometimes referred to as a **shoe box**) with all input and output, power and control connection points located on the single unit, as shown in Figure 2.10. These are generally chosen according to available program memory and required number and voltage of inputs and outputs to suit the application.



Figure2. 10 Shoe box style PLC [15]

More sophisticated units, with a wider array of options, are **modularized**. An example of a modularized PLC is shown in Figure 2.11.

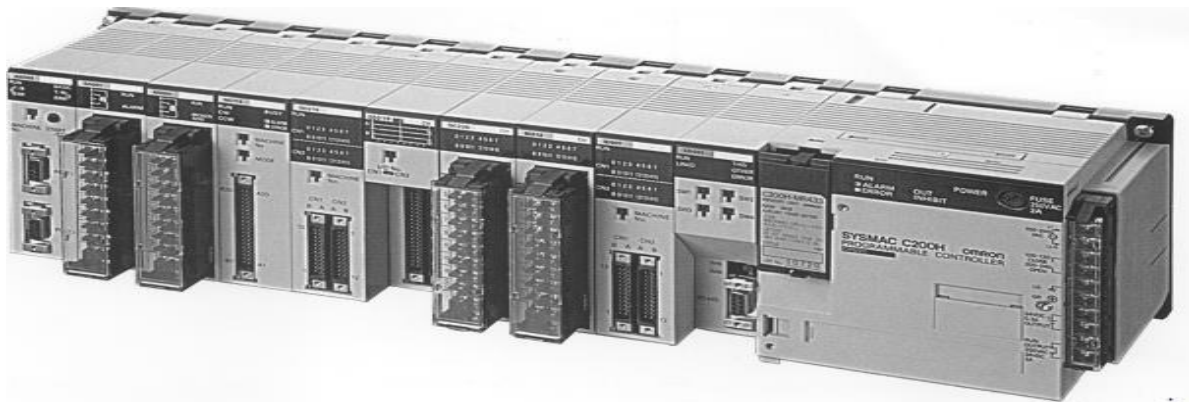


Figure2. 11 Modularized PLC [15]

Programmable Logic Controllers, also called programmable controllers or PLCs, are **solid-state** members of the computer family, using integrated circuits instead of electromechanical devices to implement control functions. They are capable of storing instructions, such as sequencing, timing, counting, arithmetic, data manipulation, and communication, to control industrial machines and processes. Figure 2.9 illustrates a conceptual diagram of a PLC application.

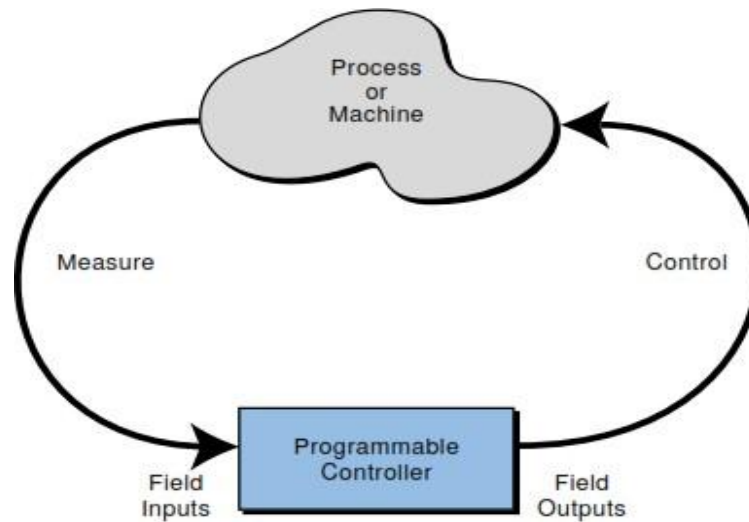


Figure2. 12 PLC conceptual application diagram [16]

Programmable controllers have many definitions. However, PLCs can be thought of in simple terms as industrial computers with specially designed architecture in both their central units (the PLC itself) and their interfacing circuitry to field devices (input/output connections to the real world).

2.6.3. Principles of operation

A programmable controller, as illustrated in Figure 2.10 consists of two basic sections:

- ✓ The central processing unit
- ✓ The input/output interface system

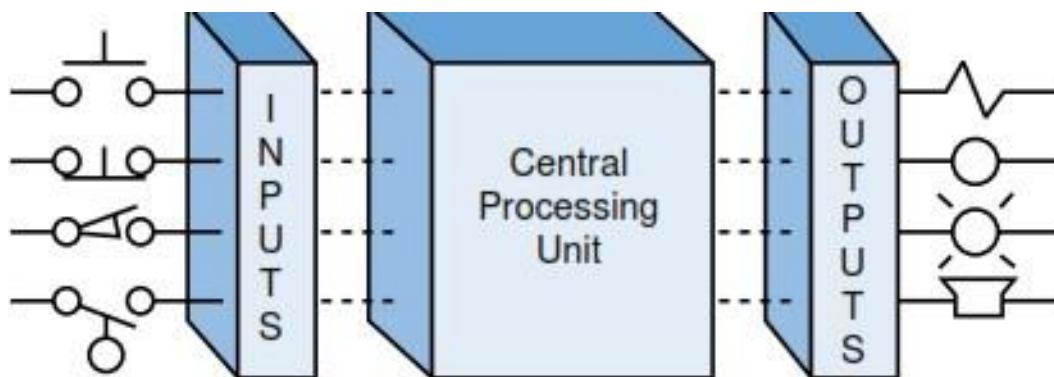


Figure2. 13 Programmable controller block diagrams [16]

The central processing unit (CPU) governs all PLC activities. The following three components, shown in Figure 2.14, form the CPU:

- ✓ The processor
- ✓ The memory system
- ✓ The system power supply

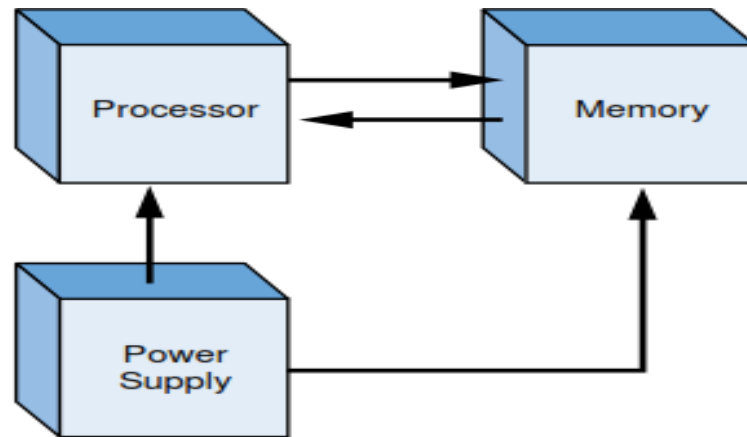


Figure2. 14 Block diagram of major CPU components [16]

The operation of a programmable controller is relatively simple. The **input/output (I/O) system** is physically connected to the field devices that are encountered in the machine or that are used in the control of a process. These field devices may be discrete or analog input/output devices, such as limits switches, pressure transducers, push buttons, motor starters, solenoids, etc. The I/O interfaces provide the connection between the CPU and the information providers (inputs) and controllable devices (outputs) [16].

During its operation, the CPU completes three processes: (1) It **reads**, or accepts, the input data from the field devices via the input interfaces, (2) It **executes**, or performs, the control program stored in the memory system, and (3) It **writes**, or updates, the output devices via the output interfaces. This process of sequentially reading the inputs, executing the program in memory, and updating the outputs is known as **scanning**. Figure 2.12 illustrates a graphic representation of a scan.

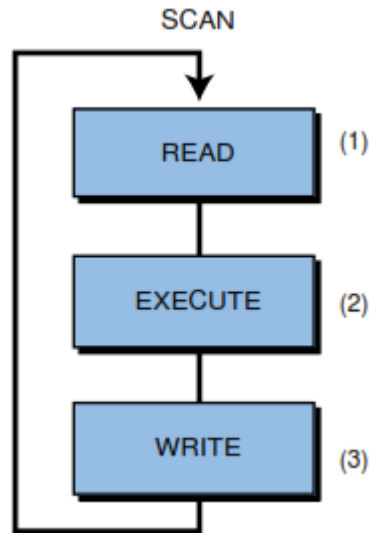


Figure2. 15 Illustration of a scan

The input/output system forms the **interface** by which field devices are connected to the controller (see Figure 2.16). The main purpose of the interface is to condition the various signals received from or sent to external field devices. Incoming signals from sensors (e.g., push buttons, limit switches, analog sensors, selector switches, and thumbwheel switches) are wired to terminals on the input interfaces. Devices that will be controlled, like motor starters, solenoid valves, pilot lights, and position valves, are connected to the terminals of the output interfaces. The system **power supply** provides all the voltages required for the proper operation of the various central processing unit sections.

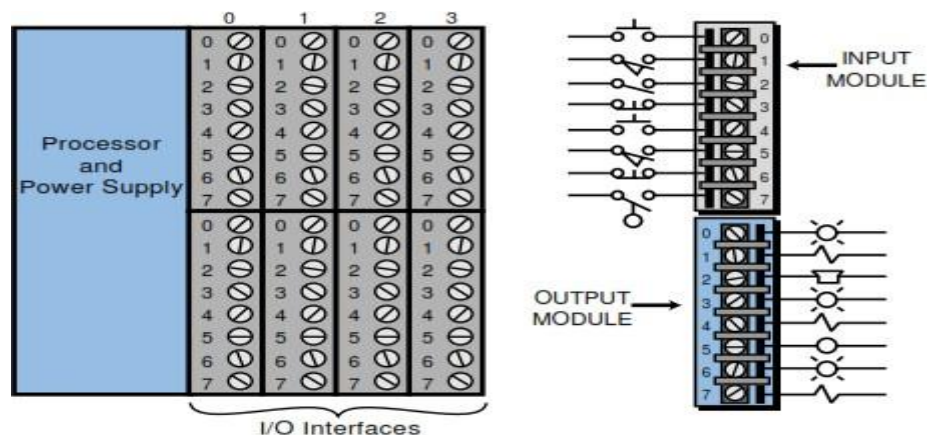


Figure 2. 16 Input/output interface

2.7. Smart Grid Energy Management System

The present revolution in communication systems, particularly stimulated by the internet, offers the possibility of much greater monitoring and control throughout the power system and hence more effective, flexible and lower cost operation. The Smart Grid is an opportunity to use new ICTs (Information and Communication Technologies) to revolutionize the electrical power system. However, due to the huge size of the power system and the scale of investment that has been made in it over the years, any significant change will be expensive and requires careful justification. A smart grid is an umbrella term that covers modernization of both the transmission and distribution grids. The concept of a smart grid is that of a “digital upgrade” of distribution and long-distance transmission grids to both optimize current operations by reducing the losses, as well as open up new markets for alternative energy production [17].

Smart grid means adding computer and communications technology to the existing electricity grid. It refers to an improved electricity supply chain that runs from a major power plant all the way inside your home. In short, there are thousands of power plants throughout the United States that generate electricity using wind energy, nuclear energy, coal, hydro, natural gas, and a variety of other resources. These generating stations produce electricity at a certain electrical voltage. Smart Grid was built when energy was relatively inexpensive. While minor upgrades have been made to meet increasing demand, the grid still operates the way it did almost 100 years ago energy flows over the grid from central power plants to consumers, and reliability is ensured by maintaining excess capacity. Infrastructures like electricity which is controlled by SCADA can play a big role on Smart Grids [18].

The term "smart grid" is a term used to name an electrical energy delivering system merging both digital technologies and long transmission networks to optimize energy consumption, as well as to open up new processes for energy production and distribution.

Power outages and electricity blackouts and brownouts are very costly for energy providers and very uncomfortable for users. Therefore, it is advantageous for both end-users, as well as for energy suppliers to decrease the number and the duration of high demand periods because grid maintenance costs, energy losses and the need for stand-by generators would be strongly reduced, and a better quality and reliable service would be offered to end-users.

Furthermore, real-time information transmitted over communication networks will allow power outage anticipation, as well as service perturbation detection. By rapidly detecting and analyzing data coming from the distribution network, the smart grid will be in a position to take corrective actions, so as to restore power stability when needed. Harmonizing local distribution at the house level with energy distribution at a larger level can also reduce grid congestion.

Existing implementations of Smart Grid offer a wide range of features. These features include load adjustment, demand response support, decentralization of power generation and price signaling to end consumers. These functions are fulfilled through integrated communications, sensing and measurement, Smart Meters and phasor measurement unit etc.

The Energy Management System is the brain unit inside the Smart Grid. It is responsible for directing proper power supply to end consumers. In addition, it helps harmonized usage of household appliances through an energy efficient way. In application level, it is a series of computer-aided tools operating manually or automatically to monitor, control, and optimize the performance of generation, transmission and distribution grid [19].

2.7.1. Smart Grid Conceptual Model

The Smart Grid Conceptual Model (SGIP CM, 2010) which describes the seven (7) primary domains that comprise Smart Grid: Bulk Generation, Transmission, Distribution, Customer, Markets, Operations and Service Provider. (See Figure 2.17) “The Smart Grid Conceptual Model is a set of views (diagrams) and descriptions that are the basis for discussing the characteristics, uses, behavior, interfaces, requirements and standards of the Smart Grid (SGIP CM, 2010). The two domains with the greatest direct impact on the electrical supply chain are the customer (See Figure 2.18) and bulk generation (See Figure 2.19) domains as they form the core drivers for change in the electrical system. The other domains will, in general, need to adapt to the changes in these two domains but all domains are interconnected and therefore affect each other. Changes occurring in the wholesale and retail markets will directly impact other domains. New services and service providers will enable new capabilities which will be consumed by other domains. The operations domain integrates and balances network resources with the objective of achieving safe, secure and reliable real-time operations of the power system [20].

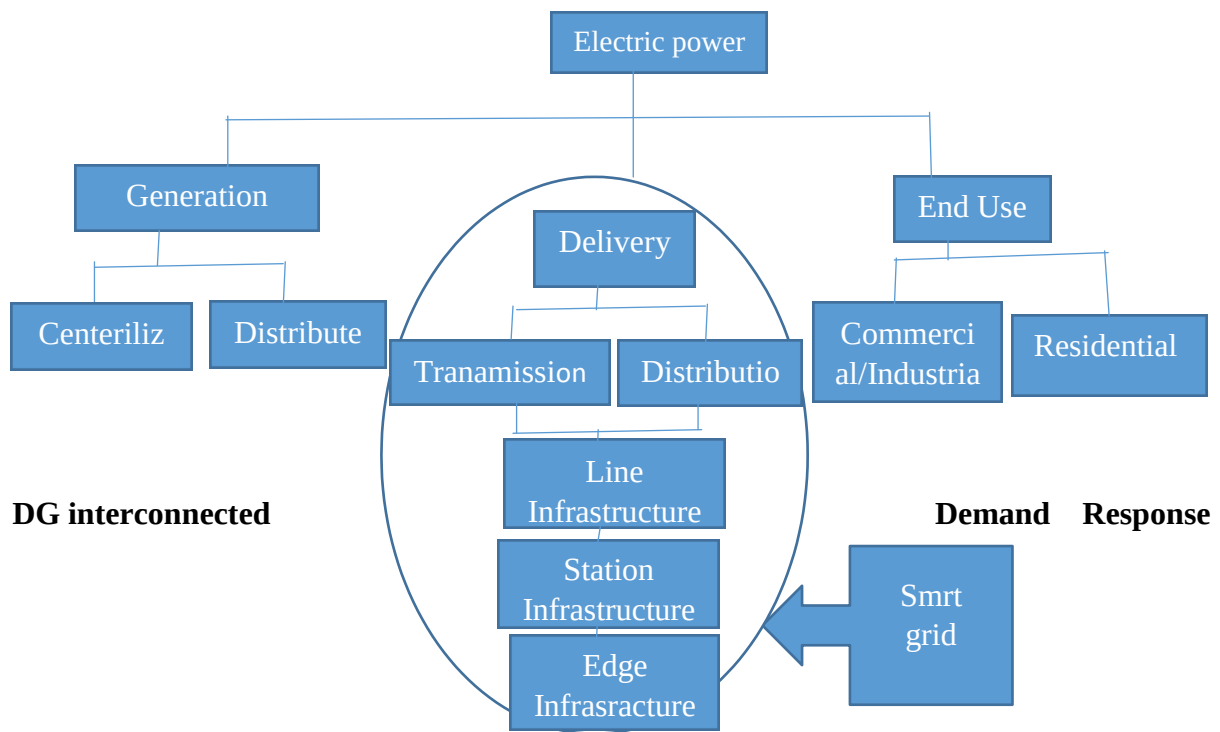


Figure 2. 17 Smart Grids [20]

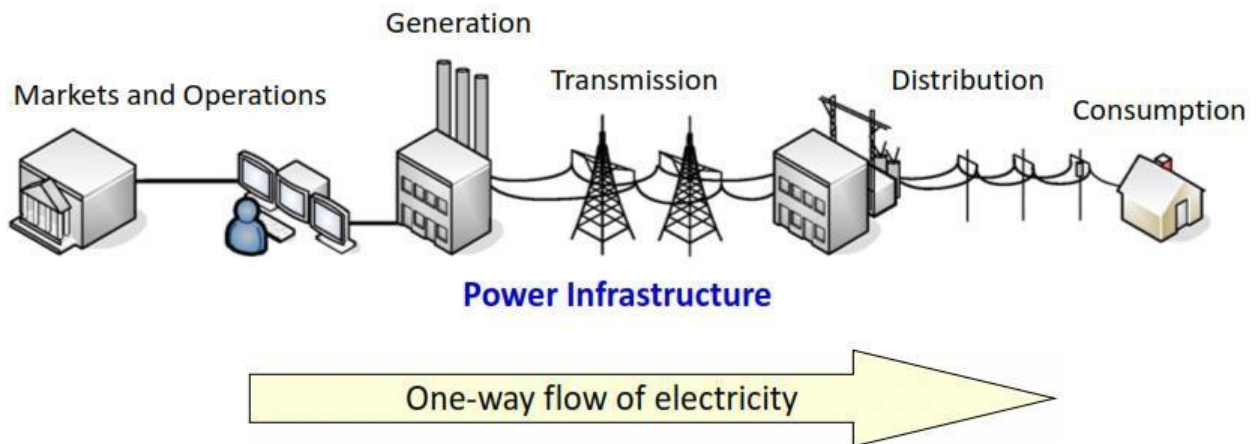


Figure 2. 18 Traditional Power system [17]

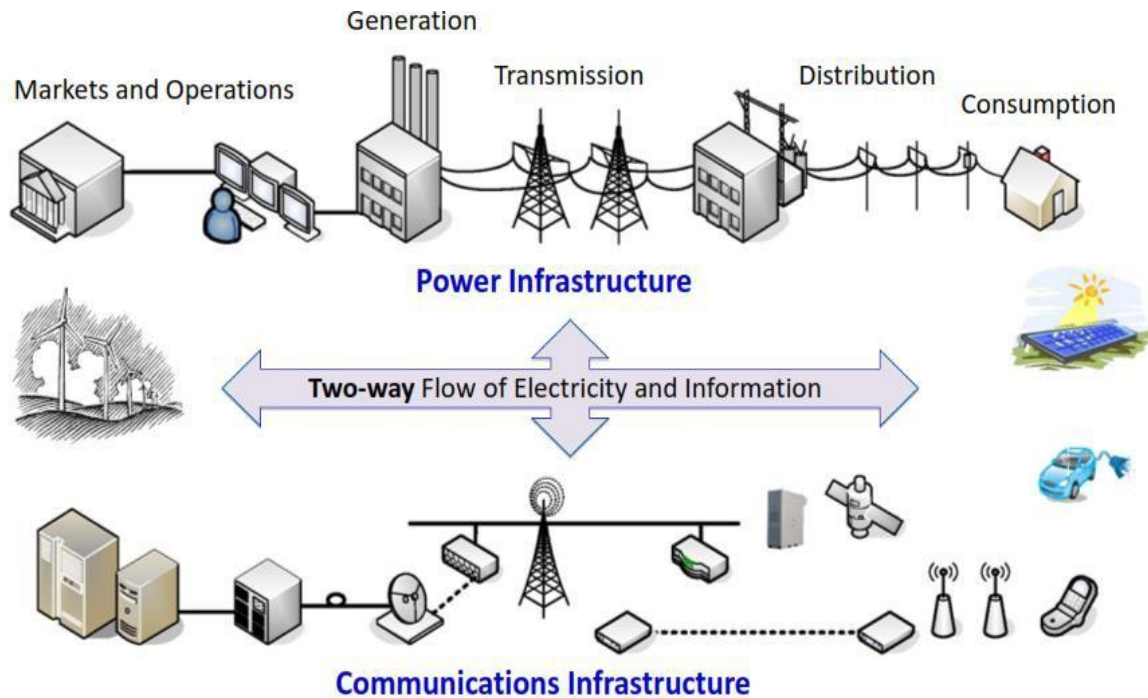


Figure 2. 19 Future Smart Grid [17]

2.8. SUBSTATIONS

2.8.1. Introduction

A substation is the part of an electricity transmission and distribution system where voltage is transformed from low to high and vice versa using transformers. Transformation may take place in several stages and at several substations in sequence, starting at the generating plant substation where the voltage is increased for transmission purposes and is then progressively reduced to the voltage required for household use. The word substation comes from the days before the distribution system became a grid. The first substations were connected to only one power station, where there was the generator, and were entirely dependent on it, hence the name. A substation that has a step-up transformer increases the voltage whilst decreasing the current, while a step-down transformer will decrease the voltage while increasing the current for domestic and commercial distribution. It is more efficient to transmit electricity over long distances at very high voltages; the function of the substation is to reduce the voltage from transmission level to values suitable for local distribution.

Substations may be on the surface in fenced enclosures, underground, located in special purpose buildings, located on power poles (aerial substations) or located in the service areas of the buildings they service. Substations located within the buildings they serve are particularly a feature of high-rise buildings.

Modern electric power systems are supplied by large central generators that feed power into high voltage interconnected transmission network. The power, often transmitted over long distances, is then passed down through a series of distribution transformers to final circuits for delivery to customer depicts in the figure 2.17.

Operation of the generation and transmission systems is monitored and controlled by Supervisory Control and Data Acquisition (SCADA) systems. These link the various elements through communication networks (for example, microwave and fiber optic circuits) and connect the transmission substations and generators to a manned control center that maintains system security and facilitates integrated operation. In larger power systems, regional control centers serve an area, with communication links to adjacent area control centers. In addition to this central control, all the generators use automatic local governor and excitation control [21].

Local controllers are also used in some transmission circuits for voltage control and power flow control, for example, using phase shifters (sometimes known as quadrature boosters). Traditionally, the distribution network has been passive with limited communication between elements. Some local automation functions are used such as on-load tap changers and shunt capacitors for voltage control and circuit breakers or auto-reclosers for fault management.

These controllers operate with only local measurements and wide-area coordinated control is not used. Over the past decade, automation of the distribution system has increased in order to improve the quality of supply and allow the connection of more distributed generation. The connection and management of distributed generation are accelerating the shift from passive to active management of the distribution network. Network voltage changes and fault levels are increasing due to the connection of distributed generation. Without active management of the network, the costs of connection of distributed generation will rise and the connection of additional distributed generation may be limited [22].

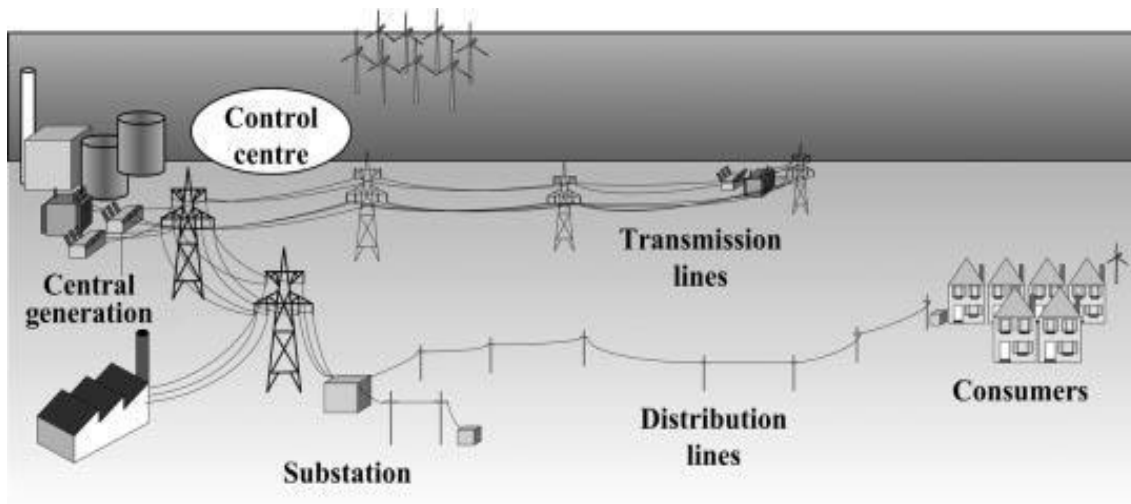


Figure 2. 20 Typical power system elements [22]

Indoor substations are usually found in urban areas to reduce the noise from the transformers, for reasons of appearance, or to protect switchgear from extreme climate or pollution conditions. Where a substation has a metallic fence, it must be properly grounded to protect people from high voltages that may occur during a fault in the network. Earth faults at a substation can cause a ground potential rise. Currents flowing in the Earth's surface during a fault can cause metal objects to have a significantly different voltage than the ground under a person's feet; this touch potential presents a hazard of electrocution.

2.9. Types of substations

2.9.1. Transmission substation

A transmission substation connects two or more transmission lines. The simplest case is where all transmission lines have the same voltage. In such cases, the substation contains high-voltage switches that allow lines to be connected or isolated for fault clearance or maintenance. A transmission station may have transformers to convert between two transmission voltages, voltage control devices such as capacitors, reactors or static VAR compensator and equipment such as phase shifting transformers to control power flow between two adjacent power systems. Transmission substations can range from simple to complex. A small "switching station" may be little more than a bus plus some circuit breakers. The largest transmission substations can cover a large area (several acres/hectares) with multiple voltage levels, many circuit breakers

and a large amount of protection and control equipment (voltage and current transformers, relays and SCADA systems).

2.9.2. Distribution substation

A distribution substation transfers power from the transmission system to the distribution system of an area. It is uneconomical to directly connect electricity consumers to the high-voltage main transmission network, unless they use large amounts of power, so the distribution station reduces voltage to a value suitable for local distribution.

The input for a distribution substation is typically at least two transmission or sub transmission lines. Input voltage may be, for example, 66 KV, or whatever is common in the area. The output is a number of feeders. Distribution voltages are typically medium voltage, between 11 and 66 KV depending on the size of the area served and the practices of the local utility.

The feeders will then run overhead, along streets (or under streets, in a city) and eventually power the distribution transformers at or near the customer premises. Besides changing the voltage, the job of the distribution substation is to isolate faults in either the transmission or distribution systems. In a large substation, circuit breakers are used to interrupt any short or overload currents that may occur on the network. Distribution substations may also be the points of voltage regulation, although on long distribution circuits (several km/miles), voltage regulation equipment may also be installed along the line.

Complicated distribution substations can be found in the downtown areas of large cities, with high-voltage switching and backup systems on the low-voltage side.



Figure 2. 21 Adama Distribution Substation

2.10. Classification of Substation

a) According to service requirement

- i. Transformer sub-station: Those sub-station which change the voltage level of electrical supply is called Transformer sub-station.
- ii. Switching sub-station: This sub-station simply performs the switching operation of power line.
- iii. Power factor correction Substation: This sub-station which improves the pf. of the system are called pf. correction substation. These are generally located at receiving end of substation.
- iv. Frequency changer substation: Those sub-stations, which change the supply frequency, are known as frequency changer substation. Such substation may be required for industrial utilization

- v. Converting sub-station: That sub-station which change A.C power into D.C. power are called converting substation. Ignition is used to convert AC to DC power for traction, electro plating, electrical welding etc.
- vi. Industrial sub-station: Those sub-stations, which supply power to individual industrial concerns, are known as industrial sub-station.

b) According to constructional features

- i. Outdoor Sub-Station: For voltage beyond 66KV, equipment is invariably installed outdoor. It is because for such Voltage the clearances between conductor and the space required for switches, Circuit Breakers and other equipment becomes so great that it is not economical to install the equipment indoor.
- ii. Indoor Sub-Station: For voltage up to 11KV, the equipment of the substation is installed indoor because of economic consideration. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltage up to 66KV
- iii. Underground Sub-Station: In thickly populated areas, the space available for equipment and building is limited and the cost of the land is high. Under such situations, the substation is created underground. The design of underground substation requires more careful consideration.

c) According to nature of duties

- Step-up or Primary Substations- Where from power is transmitted to various load centers in the system network and are generally associated with generating stations.
- Step-up and Step-down or Secondary Substations- may be located at generating points where from power is fed directly to the loads and balance power generated is transmitted to the network for transmission to other load centers.
- Step-down or Distribution Substations- receives power from secondary substations at medium high voltage (above 66 kV) and step down its voltage for secondary distribution.

d) According to operating voltage

- ✓ Medium Voltage Substations (MV Substations) - Involving voltages between 11 KV and 66 KV.

- ✓ High voltage substations (HV Substations) - Involving voltages between 66KV and 132 KV
- ✓ Extra High voltage substations (EHV Substations) - Involving voltages between 132 KV and 400 KV
- ✓ Ultra-high voltage substations (UHV Substations)- Operating on voltage above 400 KV

e) According to Importance

- Grid Substations- These are the substations from where bulk power is transmitted from one point to another point in the grid. These are important because any disturbance in these substations may cause the failure of the grid.
- Town Substations- These substations are EHV substations which step down the voltages at 33/11 KV for further distribution in the towns and any failure in such substations results in the failure of supply for whole of the town.

2.11. Main Equipments Used in A Distribution Substation

It can be performed as a transmission substation and, also as a distribution substation. As a distribution substation, the sub-transmission voltage is reduced for general distribution throughout the area. A substation needs devices such as the following intelligent electronic devices:

- ✓ Potential transformers (PT)
- ✓ Current transformers (CT)
- ✓ Main transformers
- ✓ Disconnecting switches (DS)
- ✓ Circuit breakers (CB)

2.11.1. Power Transformers (Main Transformer)

A transformer is a device that transfers electrical energy from one circuit to another through inductively coupled conductors—the transformer's coils. A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core, and thus a varying magnetic field through the secondary winding. It is the costliest equipment in a substation and important from the view of station layout.

One of the governing factors affecting the layout of a substation is that whether the transformer is a 3-phase transformer or a bank of 3 single phase transformers. The space requirement with bank of 3 single phase transformers is much more than a single 3 phase transformer. In case of a 3-single phase unit it is normal to provide one spare single-phase transformer to be used in case of a fault or if one of the single-phase transformers is under maintenance. On account of large dimensions, it is very difficult to accommodate two transformers in adjacent bays. In order to reduce the risk of spread of fire, large transformers are provided with stone pebble filled soaking pits and oil collecting pits.

With transformers, however, the high cost of repair or replacement, and the possibility of a violent failure or fire involving adjacent equipment, may make limiting the damage a major objective. The protection aspects of relays should be considered carefully when protecting transformers. Faults internal to the transformer quite often involve a few turns. While the currents in the shorted turns are large in magnitude, the changes of the currents at the terminals of the transformer are low compared to the rating of the transformer.



Figure 2. 22 Power Transformer

2.11.2. Instrument Transformer

They are devices used to transform voltage and current in the primary system to values suitable for measuring instruments, meters, protective relays etc.

They are basically the current transformers and voltage transformers.

a) **Current Transformers:** It may be of bushing or wound type. The bushing types are normally accommodated within the transformer bushing and the wound types are separately mounted. When current in a circuit is too high to directly apply to measuring instruments, a

current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. The CT is typically described by its current ratio from primary to secondary [23].

The normal load current of transmission and distribution circuits varies up to hundreds or even thousands of amperes. When a short circuit fault occurs, the current may increase to more than 20 times the normal load current. Current transformers (CTs) are used to transform the primary current to a lower value (typically 1 or 5 A maximum) suitable for use by the IEDs or interfacing units.

The majority of CTs, which are now in service, are iron cored with a secondary winding on the core. The primary is often the main circuit conductor forming a single turn. The iron core of these transformers introduces inaccuracies in the measurements due to the presence of magnetizing current (which only appears on the primary), flux leakage, magnetic saturation and eddy current heating. In order to minimize their measurement errors, the design is optimized for the specific application. Measurement CTs are used to drive ammeters, power and energy meters. They provide accurate measurements up to 120 per cent of their rated current. In contrast, protection CTs provide measurement of the much greater fault current and their accuracy for load current is generally, less important [24].

b) **Voltage Transformers:** It is necessary to transform the power system primary voltage down to a lower voltage to be transferred through process bus to IEDs, bay controller and station computer. The secondary voltage used is usually 110 V. At primary voltages up to 66 KV, electromagnetic voltage transformers (similar to a power transformer with much lower output rating) are used but at 132 KV and above, it is common to use a Capacitor Voltage Transformers (CVT).

2.11.3. Isolator

In electrical systems, an isolator switch is used to make sure that an electrical circuit is completely de-energized for service or maintenance. Such switches are often found in electrical distribution and industrial applications where machinery must have its source of driving power removed for adjustment or repair. High-voltage isolation switches are used in electrical substations to allow isolation of apparatus such as circuit breakers and transformers, and transmission lines, for maintenance.

An isolator can open or close the circuit when either a negligible current has to be broken or made or when no significant voltage change across the terminals of each pole of isolator occurs. It can carry current under normal conditions and can carry short circuit current for a specified time. They can transfer load from one bus to another and also isolate equipments for maintenance. Isolators guarantee safety for the people working on the high voltage network, providing visible and reliable air gap isolation of line sections and equipment. They are basically motorized i.e. motor does the closing and opening of the isolator. Isolators are distinguished as “off load” and “on load” isolator



Figure 2. 23 Isolators in a substation

2.11.4. Circuit Breaker

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgear designed to protect high voltage circuits feeding an entire city.

2.12. Substation Automation

It has been known for a long time how substation automation would fit the applications that are presently implemented using standard substation solutions. The substation automation system is a computational system that integrates several subsystems that normally operate in independent form such as SCADA, communications, protections, control, measurement, alarms announcers to obtain a unique system of substation data acquisition, monitoring and control [29].

The substation automation process looks for to obtain the data stored in the IED's in an agile and safe way. The use of IED's has become general for several reasons and among them: to diminish costs of automation and integration, to improve the operation and to improve the service. These intelligent devices have the capacity to make one or several functions like the measurement, protection, control and communication with the RTU or Substation Data Concentrator. Examples of the functions performed by IED's, are the following ones [30]:

Measurement: Information acquisition of the most important electrical variables like phase currents, voltages, phase-neutral, residual voltage, frequency, power factor, overvoltage, undervoltage, active and reactive power, energy, etc.

Protection: They present a very ample range of protection functions, distance protection, directional and non-directional overcurrent protection, earth faults protection, over and under voltage, control of synchronism and autoreclosure.

Control: Local and remote control functions of several equipment like disconnecting switches, with the state indication.

Condition monitoring: Monitoring functions to check the circuit breakers condition and programming the circuit breaker maintenance.

Communications: For SCADA integration is important to have a standard open interface and standard communication protocols like IEC 870-5-103, DNP 3.0 or new IEC 61850 based on UCA 2.0.

2.12.1. Need for Substation Automation

Substation automation is very important to have high quality of energy management in order to improve any power system operation. Some of the basic needs are the following.

- ✓ Substation automation is required to increase reliability and performance of electrical protection of circuits in a substation which will affect the efficiency of power distribution.
- ✓ Advanced disturbance of the power and event recording capabilities can be achieved by using RTU (PLCs).
- ✓ Display of real time substation information is possible by using multifunction meter and SCADA, which is required for getting open access from switching substation.
- ✓ Remote switching advanced supervisory control can be done easily by the output module of RTU (PLC) which is connected to the coil relay for more efficiency.
- ✓ Advanced automation functions like intelligent load shedding can be done for easier, faster and safer during the power transmission time or at any short circuit problem.
- ✓ The main circuit breaker can be controlled by using internet instead of manual control which is possible by the use of RTU and the communication unit with SCADA.
- ✓ Any fault can be identified and detected by sending alarm text.

2.13. Power Reliability through SCADA System

Through the data provided by SCADA systems, utilities have been able to improve power reliability, proactive detect and resolve problems, meet power quality requirements and support strategic decisions. Utilities have taken advantage of SCADA systems to build an adaptable, secure and responsive infrastructure by continuously monitoring status and measurement data from substation feeders and pole-mounted equipment. SCADA systems in power utility applications provide critical functionality to reduce electrical outage duration and frequency of interruption and enhance personal safety.

The implementation of SCADA for power distribution not only reduce the manual labor operation and its cost but also facilitates automatic operations with minimizing disruptions.

The PLC/RTU in substations continuously monitor the substation components and correspondingly transmit the data to centralized PC based SCADA system.

In the event of any outage of power this SCADA allows the exact location of fault and identifying the fault type, therefore, without waiting for the calls from customers SCADA gives an alarm system to the operator for identifying and preventing it.

And also in distribution substations, SCADA automatically controls isolator Switches and Circuit breakers for violating limits, there by continuous inspection of parameters are performed without any line worker. Generally, SCADA system improves the reliability and efficiency of power system by performing the following functions.

- ❖ Improving power system efficiency by maintain and acceptable range of power factor.
- ❖ Limiting peak power demand.
- ❖ Continuous monitoring and controlling of various electrical parameters in both normal and abnormal conditions.
- ❖ Trending and alarming to enable operators by addressing the problems spot.
- ❖ Historical data and viewing that from remote locations.
- ❖ Quick response to customer service interruptions.

2.13.2. Reliability of Electrical Distribution system

The reliability of electrical power distribution system plays an important role in the comfort and security for both the utility and the customers. The reliability index is a method of evaluating the reliability parameters of a power distribution equipment on the reliability of the quality of service to the customers. These indices include SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index), CAIDI (Customer Average Interruption Duration Index) and CAIFI (Customer Average Interruption Frequency Index). According to the IEEE standard 1366-2003 standard the definitions for these indices are as follows.

A. System Average Interruption Duration Index (SAIDI)

The most often used performance measurement for the sustained interruption is the system Average interruption duration index (SAIDI). This index measures the total duration of an interruption for the average customer during a given time period, SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other time period.

To calculate SAIDI, each interruption during the period is multiplied by the duration of interruption to find the customers-hour of interruption. The customer- hours of all interruption are them summed to determine the total customer-hours.

It is given by

$$SAIDI = \frac{\sum (r_i \times N_i)}{NT} \quad (4.1)$$

where

SAIDI = System Average Interruption Duration Index

$\sum$ = Summation function

r_i = Restoration time, hours

N_i = Total number of customers interrupted

NT = Total number of customers served.

B. System Average Interruption Frequency Index (SAIFI)

The System Average Interruption Frequency Index (SAIFI) is the average number of times that a system customer experiences an outage during the year (or time period under study). The SAIFI is found by divided the total number of customers interrupted by the total numbers of customers served. SAIFI is a dimensionless number.

$$SAIFI = \frac{\sum(N_i)}{NT} \quad (4.2)$$

Where

SAIFI = System Average Interruption Frequency Index

$\sum$ = Summation Function

N_i = Total number of customers interrupted

NT = Total number of customers served.

C. Customer Average Interruption Duration Index (CAIDI)

Once an outage occurs the average time to restore service is found from the Customers Average Interruption Duration Index (CAIDI). CAIDI is calculated similar to SAIDI except that the denominator is the number of customers interrupted versus the total numbers of utility customers.

$$CAIDI = \frac{\sum (r_i \times N_i)}{N_i} \quad (4.3)$$

where

CAIDI = customer average interruption duration index

$\sum$ = Summation Function

r_i = Restoration time, hours

N_i = Total number of customers interrupted

D. Customer average interruption duration index (CAIFI)

Similar to SAIFI is CAIFI, which is the Customer Average Interruption Frequency Index. The CAIFI measures the average number of interruptions per customer interrupted per year. It is simply the number of interruptions that occurred divided by the number of customers affected by the interruptions.

$$CAIFI = \frac{\sum (N_o)}{\sum (N_i)} \quad (4.4)$$

Where

CAIFI = Customer Average Interruption Duration Index

$\sum$ = Summation Function

N_o = Number of interruptions

N_i = Total number of customers interrupted.

2.14. Empirical Review

Today the rapid growth of Information Technology (IT) tools has promoted many PDC to bring up to date their fault diagnosis as well as troubleshooting systems. Among new technologies used for this purpose, SCADA systems are considered as the widely appropriate tool used for such processes. Moreover, they proved the importance on using computer-based system for sustainable development in the automation of the power distribution network to improve the customers 'service and the reliability of the network. Also, the paper outlines the general concepts and required equipment for the automation of such power networks. The author improves the reliability of the network by 30% [18].

The paper proposed by [19] is based on SCADA provides management with real-time Data on production operations, an implement more efficient control paradigms, improves plant and

personnel safety, and reduces costs of operation. The proposed model that illuminates the categories of data, functionality, and interdependencies present in a SCADA. The model serves as a foundation for further research on how to best apply technical controls in substation and domestic distribution areas. This paper has technical limitations.

Main concept of the paper is data acquisition & controlling by using SCADA software PLC. Here PLC is a medium between electrical system & Personal Computer for SCADA to take input and output bits. By using the parameters, we can easily control any load in our system to improve system operation, system reliability, etc. alternatively, SCADA and PLC communication system make it possible to integrate protection control and monitoring electrical parameter together for maximum benefit [20].

This paper has proposed a model that illuminates the categories of data, functionality, and interdependencies present in [21]. This automated distribution system is analyzed to develop a secure, reliable and convenient management tool which can use remote terminal units (RTUs). SCADA provides management with real-time data on production operations; implements more efficient control paradigms, improve plant and personnel safety, and reduces costs of operation. The security of SCADA systems depends on the effective application of security principles and technology to the SCADA system.

In this paper they used different methods for generation of electricity like wind, PV (photovoltaic), hydro, biogas & distributed using PLC & controlling using SCADA. Due to Energy Management System using PLC & SCADA operational cost decreases & also easy to handle. Online monitoring & distribution of energy is possible due to this developed Energy Management System [22]. The research work is focused on methods of generation of electricity from renewable energies and how to distribute and control them. It does not talk about how energy is distributed from distribution substation.

This novel automated fault isolation system has been developed and integrated into a new customer side distribution system. The main contribution of the work in this research project is to develop and design a distribution automation system aimed at the low voltage (LV) distribution system. This research work does not consider the (HV) and (MV) system [23].

The research studied by [26] is outlines information about the SCADA techniques used by the author in the hardware models of a dynamic system developed by him. This includes the construction of a master unit for data acquisition and software to view the data of the Multi

Function Meters from AC Network Analyzer—a dynamic model developed by him for the practical training to the engineers from the industry and engineering institutions for their laboratory. A critical literature review has been also presented covering a period of more than 15 years. The review indicates current application of SCADA to energy management systems, security and other aspects including the SCADA models as teaching aid. This research work is limited on practical training only.

The paper has done by [27] entitle Efficient Design of SCADA Systems Using Minimum Spanning Trees and the NFR Framework. The paper states proper design of SCADA systems is an important issue for developers of SCADA systems and their users. Current practice seems to center around purchasing a best-of-breed solution and configuring it to meet the expected system goals. In this paper they proposed an efficient design approach based on minimum spanning trees and the NFR Framework wherein SCADA designs are captured in spanning trees and minimum spanning trees indicate the optimally weighted designs, and the most suitable among these weighted designs is chosen by employing the NFR Framework, which is a goal-oriented framework for analyzing competing alternatives and choosing the best one based on the goals for the SCADA system. This work does not include PLC system and limited to Local area network (LAN).

The study in [29] about Local and wide area computer networks have provided the means for utility SCADA and SCADA/Energy Management Systems to distribute functions over many interconnected processors. This has enabled users to avoid obstacles historically encountered when expanding capabilities in local control systems and when maintaining geographically dispersed data bases at remote control centers. These features also lead to improvements in processing performance, fault tolerance, maintenance and programming simplification and life cycle cost reduction. The authors review the improvements which are being, or have been, incorporated into recent utility installations. Specification suggestions are offered for achieving a truly distributed local area network (LAN) system. This paper mainly focusses on power generation rather than distribution substation.

The paper conducted in [32] discusses some of currently the most challenging problems of SCADA system design, and presents a possible architecture of a general purpose SCADA intended for high-end applications. The paper gives proposal of a new architecture, which relies

on basic principles from the old implementation, adapted and perfected to fulfill the needs of the modern market. Some of the basic requirements for implemented SCADA system includes scalability, distributed and reliable networked operation, high capacity/performance in real time, and support to future extensibility of the solution and implemented data model. The paper focus mainly on improvement of SCADA system design rather than its application.

CHAPTER THREE

3. METHODOLOGY

3.1. Substation Automation and Data Collection

Adama substation is located in west of Adama city and is an outdoor type substation. The expansion work of this substation was done in 1999 E.C. After expansion the substation has two incoming lines, one from Koka hydro power station and the other from Adama wind farm one station. Each incoming line carries 50MW power and 132KV system voltage.

Adama substation has eight feeders to distribute power to the whole city. It has also two outgoing lines one to Modjo town for traction purpose and the other one goes directly to Awash 7killo. Each feeder lines carry distribution voltage of 15 KV. The substation has two permanent transformers and one mobile transformer. The two permanent transformers have 50MVA apparent power (25MVA each) and the mobile one has 50 MVA apparent power alone. Therefore, the total power supplied to the whole city is 100MVA (90MW) at present time.

In addition, there are eight switching substations in the city which are located at some kilometers away from the distribution substation to improve the distribution level. These switching substations are mentioned as follows:

1. Wonji. Mazoria Switching Substation
2. Tractor factory Switching Substation
3. Medihanealem Switching Substation
4. Abageda (kidanemihret) Switching Substation
5. Post Office Switching Substation
6. ASTU (Musina Hintsu) Switching Substation
7. Amede Switching Substation
8. Boku Michael Switching Substation

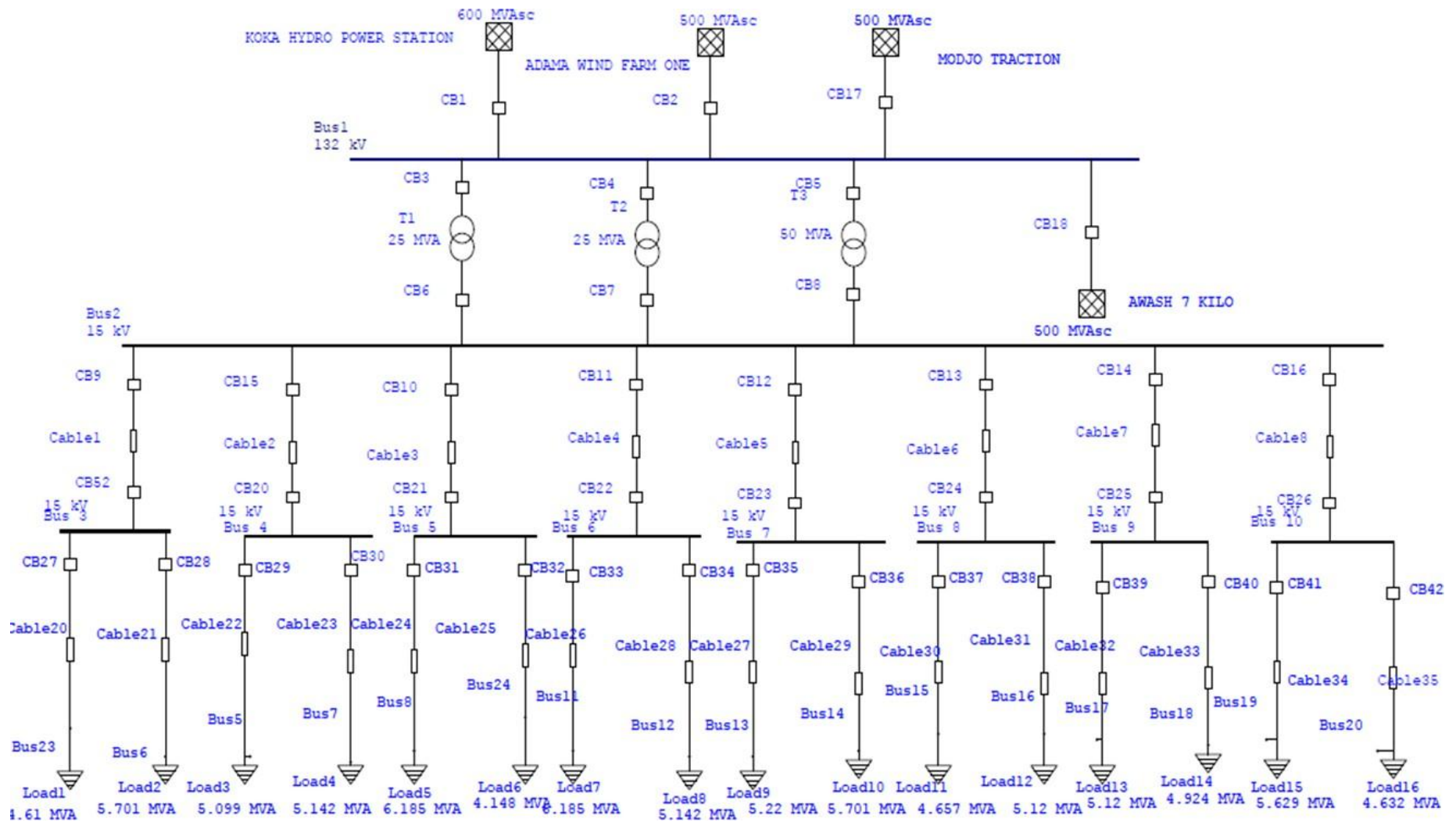


Figure3. 1 Model of Adama Substation

Adama distribution substation has enough power to supply the whole city. However, there is always power interruption and power outage in the city. This is due to lack of high-quality energy management system and non-modernized distribution system. Due to the traditional manual operating system and old infrastructure, especially the old distribution lines the substation has suffered from power interruption (power outages). This problem has a great impact on both the utility side and the consumer side. This leads unnecessary frequent arguments between the utility and the customers.

Due to the above reasons the substation has faced the following problem.

- ✓ Poor reliability of the power system operation
- ✓ Poor efficiency of the power system distribution
- ✓ Higher maintenance cost (economic problem)
- ✓ Frequent power interruption/ power outage/
- ✓ Unable to satisfy consumer demands.
- ✓ Unnecessary arguments between the utility and the customers.
- ✓ Longer time to restore power (takes longer time to restore power)
- ✓ Poor quality of service.

3.2. Data Collection

The following consecutive tables show the daily substation data status of Adama distribution substation which are recorded at different times.

Table3. 1 Daily substation data status of 08/11/2009 E.

Substation Status																				
Feeder Lines	7:00Hour					9:00 Hour					11:00 Hour					19:00 Hour				
	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15	319	8			15	308	7.7			15	302	7.4			15	38	1.1		
L2	15.1	280	7.2			15	260	6.8			15	290	7.4			15	285	7		
L3	15.1	300	7.2			15	260	6.5			15	300	7.5			15	300	7.8		
L4	15.2	265	6.5			15	240	6.2			15	245	6.4			15	280	7.2		
L5	15.1	160	4			15	170	4.4			15	45	1.2			15	160	4.1		
L6	15.1	50	1.2			15	90	2.2			15	100	2.4			15	110	2.3		
L7	15.1	270	6.8			15	250	6.4			15	240	6.3			15	200	5		
TRI	15.1	810	20	7		15	740	18.2	6		15	750	18.2	7		15	800	20.2	7	
TRII	15.1	810	20	7		15	740	18.2	6		15	750	18.2	7		15	800	20.2	7	

V=Voltage (KV) I = Current (A) P= Active Power (MW) PF = Power factor Q = Reactive Power (MVAR)

From table 4.1 above, the nominal current of each feeder is 300A, based on this power is interrupted three times a day due to over load and fault conditions and one over loading condition. That is; L1 (I OL) is opened at 19:00Hr due to over load, L6 (I EF) is opened at 7:00Hr due to over load, L5 (I SC) is opened at 11:00Hr due to short circuit, and L1 (I=319 A) at 7:00Hr is over loaded.

Table 3. 2 Daily substation data status of 11/11/2009 E.C

Substation Status																				
Feeder Lines	7:00Hour					9:00 Hour					11:00 Hour					19:00 Hour				
	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15	226	5.6			15	320	8.1			15	315	8			15	318	8		
L2	15	210	5.2			15	280	7.2			15	270	7			15	280	7.2		
L3	15	260	6			15	320	8.2			15	300	8			15	290	7.8		
L4	15	240	5.6			15	250	5.8			15	260	6.1			15	280	7		
L5	15	200	5.1			15	240	5.6			15	260	6			15	240	5.6		
L6	15	100	2.4			15	110	2.5			15	90	2.2			15	100	2.4		
L7	15	235	5.8			15	220	5.4			15	240	6			15	250	6.2		
TRI	15	650	17	6		15	640	16.8	6		15	780	20	7		15	800	20.5	7	
TRII	15	650	17	6		15	640	16.8	6		15	780	20	7		15	800	20.5	7	

V = Voltage (KV) **I** = Current (A) **P** = Active Power (MW) **PF** = Power factor **Q** = Reactive Power (MVAR)

Since the nominal current of each feeder is 300A the above table shows us over loading conditions of the substation at peak-load hours of the day. The feeders L1 (I=320 A) at 9:00Hr is over loaded, L1 (I=318 A) at 19:00Hr is over loaded, L1 (I=315 A) at 11:00Hr is over loaded and L3 (I=320 A) at 11:00Hr is over loaded.

Table 3. 3 Daily substation data status of 15/11/2009 E.C

Substation Status																				
Feeder Lines	7:00Hour					9:00 Hour					11:00 Hour					19:00 Hour				
	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15.1	240	6.4			15	260	6.6			15	250	6.8			15	320	8.2		
L2	15	280	7			15	270	6.8			15	275	6.8			15	270	6.5		
L3	15	290	7.6			15	290	7.6			15	280	7.4			15	270	7.4		
L4	15	180	5			15	260	6			15	270	6.6			15	290	7.6		
L5	15	160	4			15	200	5			15	240	5.4			15	180	5		
L6	15	80	1.8			15	60	1.6			15	40	0.5			15	40	0.5		
L7	15	200	5.1			15	280	7.6			15	280	7.6			15	240	6		
TRI	15	618	15	6		15	700	17	7		15	770	19	8		15	750	20	8	
TRII	15	618	15	6		15	700	17	7		15	770	19	8		15	750	20	8	

V = Voltage (KV) **I** = Current (A) **P** = Active Power (MW) **PF** = Power factor **Q** = Reactive Power (MVAR)

Table 4.3 above shows L6 is interrupted three times a day due to over load and fault condition. There is also an over loading condition on L1. That is; L1(I=320A) is overloaded at 19:00Hr, L6(I OL) is opened at 11:00hr due to over loaded, L6(I OL) is opened at 9:00hr due to overloaded and L6(I_{EF}) is opened at 19:00 due to ground fault.

Table 3. 4 Daily substation data status of 08/01/2010 E.C

Substation Status																				
Feeder Lines	7:00Hour					9:00 Hour					11:00 Hour					19:00 Hour				
	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15.1	320	8.1			15.1	176	4.5			15.1	200	5			15.1	280	7.5		
L2	15.1	216	5.2			15.1	290	7.2			15.1	275	7.4			15.1	320	8		
L3	15.1	220	5.4			15.1	250	6.1			15.1	270	6.8			15.1	290	7.5		
L4	15.1	200	5			15	220	5.6			15	225	5.6			15	210	5.2		
L5	15.1	170	4.2			15	270	6.5			15	260	6.7			15	220	5.3		
L6	15.1	62	1.4			15	65	1.2			15	210	2.6			15	170	4.2		
L7	15.1	150	3.6			15	220	2.8			15	160	4			15	170	4.4		
TRI	15.1	650	17	5.4		15	670	17.5	5.8		15	700	18	6		15	710	18.2	5.8	
TRII	15.1	650	17	5.4		15	670	17.5	5.8		15	700	18	6		15	710	18.2	5.8	

V = Voltage (KV) **I** = Current (A) **P**= Active Power (MW) **PF** = Power factor **Q** = Reactive Power (MVAR)

From the above table, it can be seen that L1 and L2 are over loaded where as L6 is interrupted two times in a day. This can be displayed on the Multi-Function meter in this manner; L1 (I =320 A) at 7:00Hr is over loaded, L6(IEF) is opened at 7:00 due to ground fault, L2 (I= 320 A) at 19:00Hr is over loaded and L6(I OL) is opened at 9:00 due to over load.

Table 3. 5 Daily substation data status of 13/01/2010 E.C

Substation Status																				
Feeder Lines	7:00Hour					9:00 Hour					11:00 Hour					19:00 Hour				
	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15	198	5.1			15	180	4.6			15	180	4.5			15	270	6.4		
L2	15	230	5.6			15	280	7			15	290	7.4			15	320	8		
L3	15	280	6.8			15	275	7			15	275	6.6			15	290	7.6		
L4	15	200	5			15	180	4.6			15	180	4.4			15	250	6.2		
L5	15	45	1.2			15	270	6.6			15	270	6.8			15	240	5.6		
L6	15	35	1.0			15	160	4			15	200	4.9			15	180	4.6		
L7	15	110	2.4			15	150	3.5			15	180	4.2			15	50	1.3		
TRI	15	660	17.1	5.1		15	675	17.7	5.6		15	710	18	6.6		15	760	19	6.8	
TRII	15	670	17.2	5.1		15	690	18	6.1		15	710	18	6.6		15	760	19	6.8	

V = Voltage (KV) **I** = Current (A) **P**= Active Power (MW) **PF** = Power factor **Q** = Reactive Power (MVAR)

From the above table, it can be seen that L5, L6 and L7 are interrupted where as L2 is over loaded at peak load hours. The recorded data can be interpreted in this manner; L5 (I SC) is opened at 7:00Hr due to short circuit, L7 (IEF) is open at 19:00Hr due to ground fault, L6 (I OL) is opened at 7:00Hr due to over load and L2 (I=320 A) at 19:00Hr is over loaded.

Table 3. 6 Daily substation data status of 08/02/2010 E.C

Substation Status																				
Feeder Lines	7:00Hour					9:00 Hour					11:00 Hour					19:00 Hour				
	V	I	P	Q	P.E	V	I	P	Q	P.E	V	I	P	Q	P.E	V	I	P	Q	P.E
L1	15	227	5.2			15	220	5.1			15	198	5			15	210	5.2		
L2	15	280	6.6			15	290	7.2			15	305	7.8			15	322	8.2		
L3	15	290	7			15	35	1.1			15	250	6.2			15	280	6.8		
L4	15	40	0.9			15	240	6.2			15	315	8.1			15	230	5.8		
L5	15	150	3.4			15	250	6.4			15	260	6.6			15	200	5		
L6	15	130	3			15	160	3.6			15	180	4.6			15	190	4.4		
L7	15	150	3.2			15	130	3			15	130	3			15	150	3.6		
TRI	15	655	17	9		15	600	15	7		15	645	16	8		15	760	19	10	
TRII	15	655	17	9		15	600	15	7		15	645	16	8		15	760	19	10	

V = Voltage (KV) I = Current (A) P= Active Power (MW) PF = Power factor Q = Reactive Power (MVAR)

From the above table, we can see that L3 and L4 are interrupted and also L2 and L4 are over loaded at peak load hours. That is; L2 (I =322 A) at 19:00Hr is over loaded, L4 (I =315 A) at 11:00Hr is over loaded, L4 (I OL) is opened at 7:00 Hr due to over load, I3 (I OL) is opened at 7:00Hr due to over loaded.

To mitigate the above power interruption and over loading problems, the utility has to use substation automation method to have automatic monitoring, supervising, controlling and protect the power system network in real- time operation. Substation automation can reduce the frequency and duration of power interruption and improve the reliability and performance of the power distribution network so that it is very important for both the utility and the customers. This thesis proposed Substation Automation Energy Management using PLC based SCADA system.

SCADA is a powerful technology to modernize the substation in power system operation. It is a powerful tool for substation automation. PLC based SCADA is a technique used to supervise, monitor and protect the power system status in a real time operation. By using SCADA, we can supervise, monitor, control and protect the power system (substation status) in real – time operation and hence Energy Management can be achieved.

3.3 Current Adama Distribution Substation SCADA Application Gaps

Even though the substation had tried apply the SCADA system it has the following main problems or gaps of the current SCADA application in the distribution substation.

- SCADA implementation is not completed so that frequency and duration of interruption did not reduce.
- The system does not show the fault type (eg, over current, over voltage, under voltage etc.).
- SCADA system does not indicate the fault location.
- Alarm texts are displayed on the operator screen after 25 minutes that means the system is so weak and slow.
- SCADA is applied on the existing system without modified substation design this does not improve the reliability of the substation.
- The current SCADA system does not reduce the power interruption as expected from the SCADA system.

This research work fills the above gaps by performing the following functions

- The SCADA system indicated in the research work show the fault type.
- The new proposed SCADA system indicate the fault location.
- Alarm texts are displayed on the operator screen after 10-20 seconds so that power is restored in a short period of time.
- New substation Design is proposed to reduce the frequency and duration of power interruption.
- The system improves the reliability and performance of the distribution substation

One of the main advantage of substation automation is the improvement of reliability and performance of a power distribution network. In order to calculate the reliability of a given substation another data has to be collected which shows the frequency and duration of power interruption. The following tables show, the data collected from Adama substation from July 2009 - June 2010 E.C to calculate the reliability indices (SAIFI and SAIDI) before and after the application of SCADA system. From these data it will be known how long the duration of outages and the frequency of outages on each feeder. In calculation of duration will be known in time units of hours, while the failure rate will only calculate the total numbers of trips or turns off each feeder in the given period.

Table 3. 7 Annual SAIFI per Feeder

Adama Substation Power interruption report										
ANNUAL SAIFI REPORT FROM July, 2009 - June, 2010										
Before SCADA						After SCADA				
No	Feeder Name	Total Frequency of interruption	No of customers	Total Customers Interrupted/year	SAIFI	Total Freq. of Interruption	No of Customers	Total No of Customers interrupted	SAIFI	EEA Standard Value
1	L1	375	2682	1,005,750	375	125	2682	335250	125	20 tim/Cust/year
2	L2	415	2700	1,120,500	415	138	2700	372,600	138	
3	L3	427	2725	1,163,575	427	142	2725	386,950.00	142	
4	L4	298	2600	751,400	298	99	2600	257,400	99	
5	L5	169	2475	418,275	169	56	2475	138,600	56	
6	L6	271	2563	694,573	271	90	2563	230,670	90	
7	L7	322	2650	853,300	322	107	2650	283,550	107	

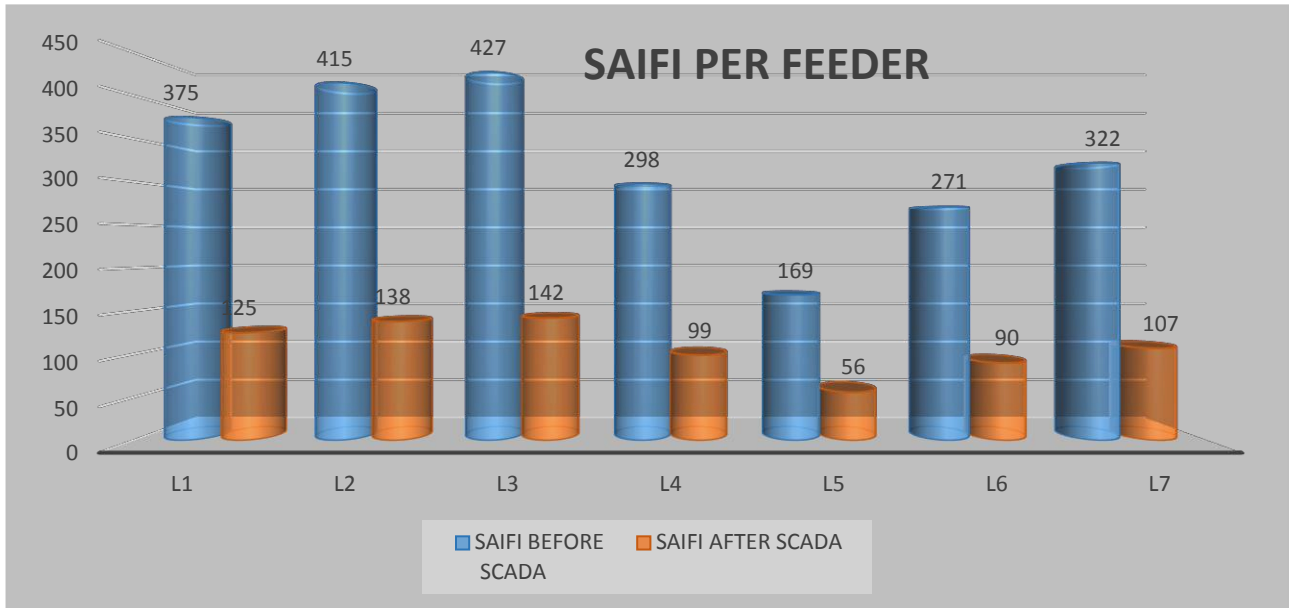


Figure 3. 2 Annual SAIFI per Feeder

From the above bar graph, SAIFI values of the feeders L1, L2, L3, L4, L5, L6 and L7 are 375 int/customer/year, 415 int/customer/year, 427 int/customer/year, 298 int/customer/year, 169 int/customer/year, 271 int/customer/year and 322 int/customer/year respectively. But as per the Ethiopian Electric Agency's (EEA) standard, SAIFI value should not exceed 20 int/customer/year. Since the current calculated value of SAIFI is above the acceptable benchmark by large margin, there is a serious reliability problem in the current Adama distribution substation.

However, after the application of SCADA the reliabilities of each feeder found to be 125 int/customer/year, 138 int/customer/year, 142 int/customer/year, 99 int/customer/year, 56 int/customer/year, 90 int/customer/year and 107 int/customer/year. This shows the reliabilities of each feeder has been improved.

Table 3. 8 Annual SAIDI per Feeder

Adama Substation Power interruption report										
ANNUAL SAIDI REPORT FROM July, 2009 - June, 2010										
Before SCADA						After SCADA				
No	Feeder Name	Total Duration of interruption (hr)	No of customers	Total Customers Hours (hr) /year	SAIDI	Total Duration of Interruption (hr)	No of Customers	Total No of Customers Hours (hr)/year	SAIDI	EEA Standard Value
1	L1	411.9	2682	1,104,715.80	411.90	137.3	2682	386,238.60	144.20	25 hr/cus/year
2	L2	480.4	2700	1,297,080	480.4	160.1	2700	432,270	160.10	
3	L3	473.1	2725	1,289,197.50	473.4	157.7	2725	429,732.50	157.70	
4	L4	244	2600	634,400	244	81.3	2600	211,380	81.30	
5	L5	390.7	2475	966,982.50	390.7	130.2	2475	322,245	130.20	
6	L6	631.3	2563	926,011.90	361.3	120.4	2563	308,585	120.40	
7	L7	428.7	2650	1,136,055	428.7	142.8	2650	378,420	142.80	

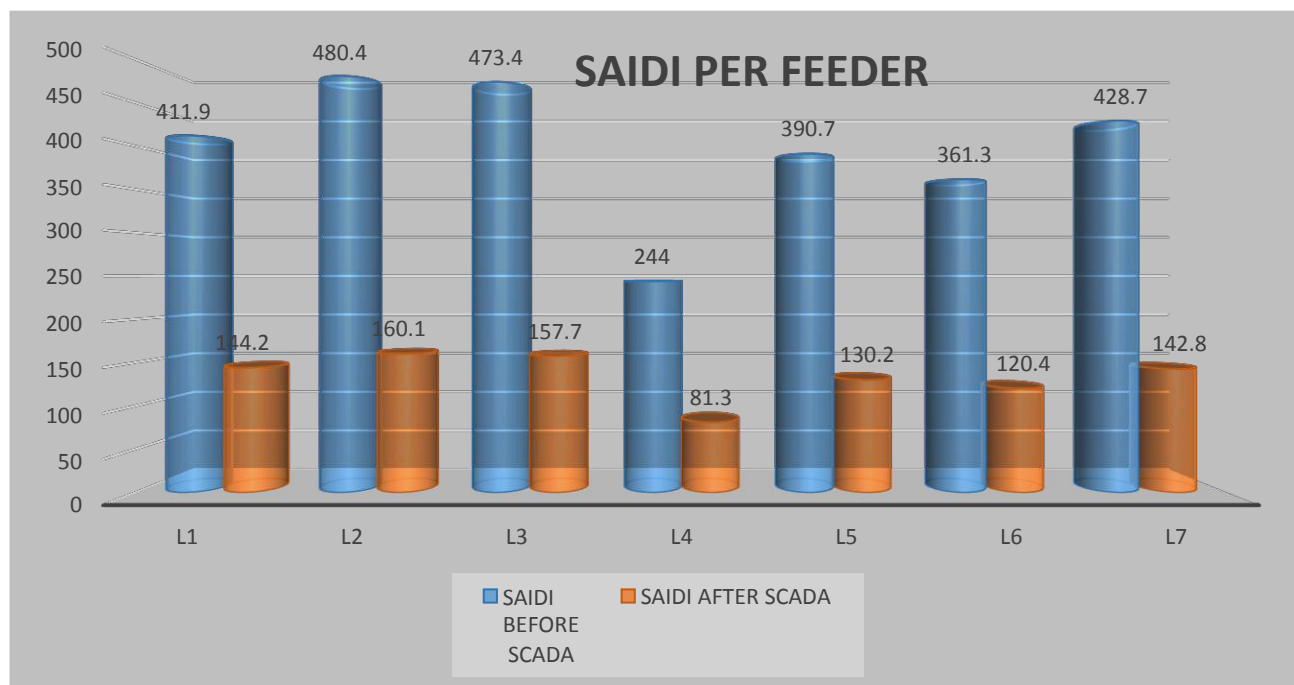


Figure 3. 3 Annual SAIDI per Feeder

From the above graph, we can also see that the SAIDI values of the feeders L1, L2, L3, L4, L5, L6 and L7 are 411.9 hrs/customer/year, 480.8 hrs/customer/year, 437.1 hrs/customer/year, 244 hrs/customer/year, 390.7 hrs/customer/year, 631.3 hrs/customer/year and 428.7 hrs/customer/year respectively. But as per the Ethiopian Electric Agency's (EEA) standard, SAIDI should not exceed 25 hrs/customer/year. This clearly shows that the current calculated value of SAIDI is above the acceptable benchmark by a large margin, there is a serious reliability problem in the current Adama distribution substation.

The graph also shows that after the application of SCADA on each feeder the reliabilities of each feeder has been improved to be 137.3 hrs/customer/year, 160.1 hrs/customer/year, 157.7 hrs/customer/year, 81.3 hrs/customer/year, 130.2 hrs/customer/year, 120.4 hrs/customer/year and 142.8 hrs/customer/year. Thus reliabilities of each feeder has been improved.

3.4. Substation Control Using SCADA

In substations automation system, SCADA performs the operations like bus voltage control, bus load control, circulating current control, over load control, transformer fault protection, bus fault protection etc. SCADA system continuously monitors the status of various equipments in substation and accordingly sends control signals to the remote control equipments. Also, it collects the historical data of the substation and generate the alarms in the events of electrical accidents of faults.

In SCADA based substation control system, Various input/output (I/O) modules connected to the substation equipment gathers the field parameters data, includes status of switches, circuit breakers, transformers, capacitors and batteries, voltage and current magnitudes, etc. RTUs (PLCs) collect I/O data and transfer to remote master unit via network interface modules. The central control or master unit receives and logs the information, displays on HMI and operates the control actions based on the received data. This controller also responsible for generating trend analysis, centralized alarming and reporting.

The data historian, workstations, master terminal unit and communications servers are connected by LAN at the control center. Wide area network (WAN) connections with standard protocol communication is used to transfer the information between fields sites and central controller. Thus, by implementation of SCADA for substation control eventually improves the reliability of the network and minimizes the downtime with high speed transfer of measurement and control commands.

3.5. Feeder Control Using SCADA

This automation includes feeder voltage of VAR control and feeder automatic switching. Feeder voltage control performs voltage regulation and capacitor placement operations while feeder switching deals with remote switching of various feeder, detection faults, identifying fault location, isolating operation and restoration of service. In this system SCADAs architecture continuously checks the faults and their locations by using wireless fault detector unit deployed at various feeding station. It facilities the remote circuit switching and historical data collection of feeder parameters and their status. The system continuously monitors the status of every feeder by measuring field data parameters like voltage, current, active power, reactive power,

power factor and frequency of the power system and display on the Operator screens so that either the system or the operator take automatic control if there is any fault on the system.

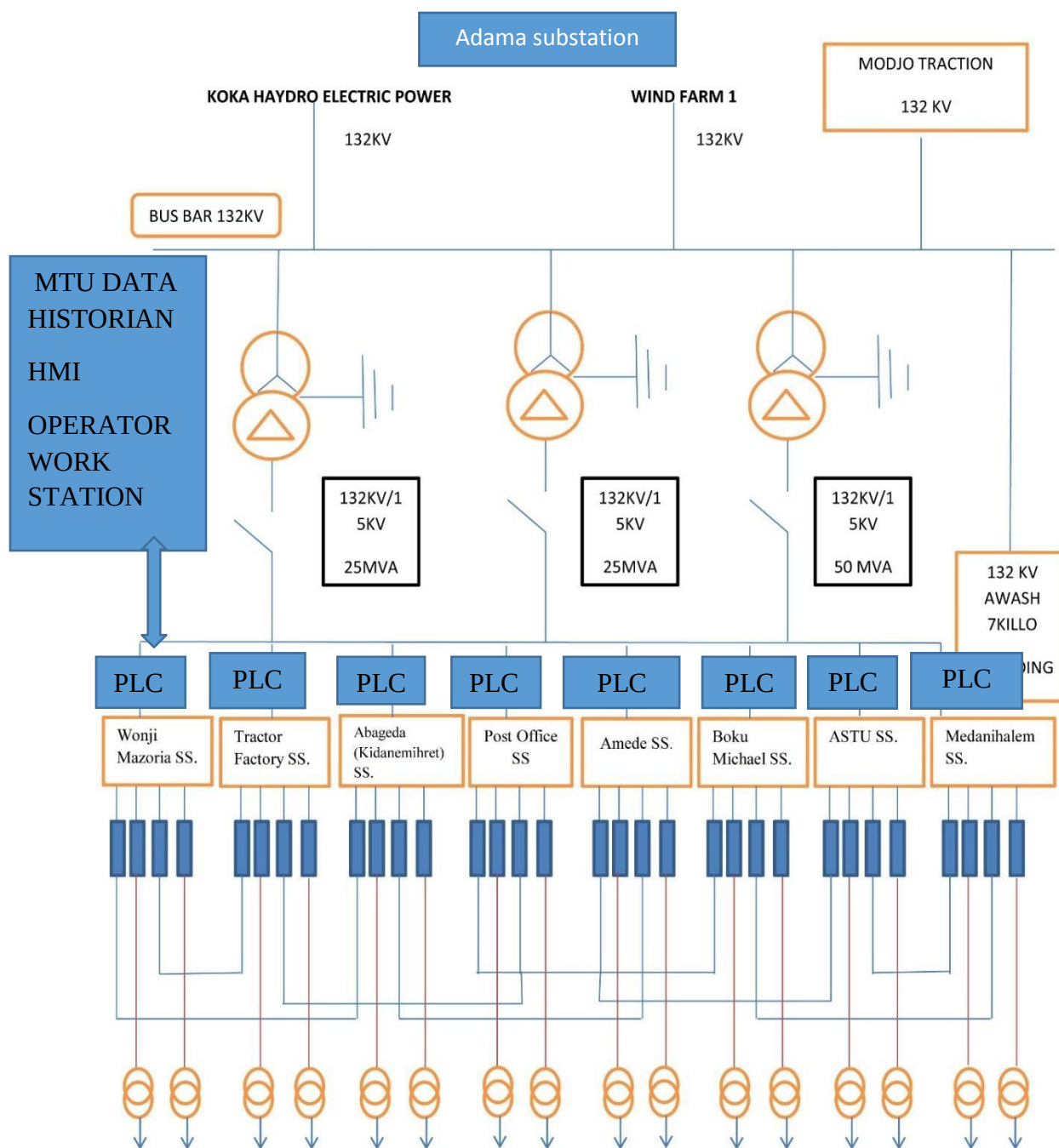


Figure 3. 4 Proposed SCADA system for Distribution Substation Automation of Different Feeders

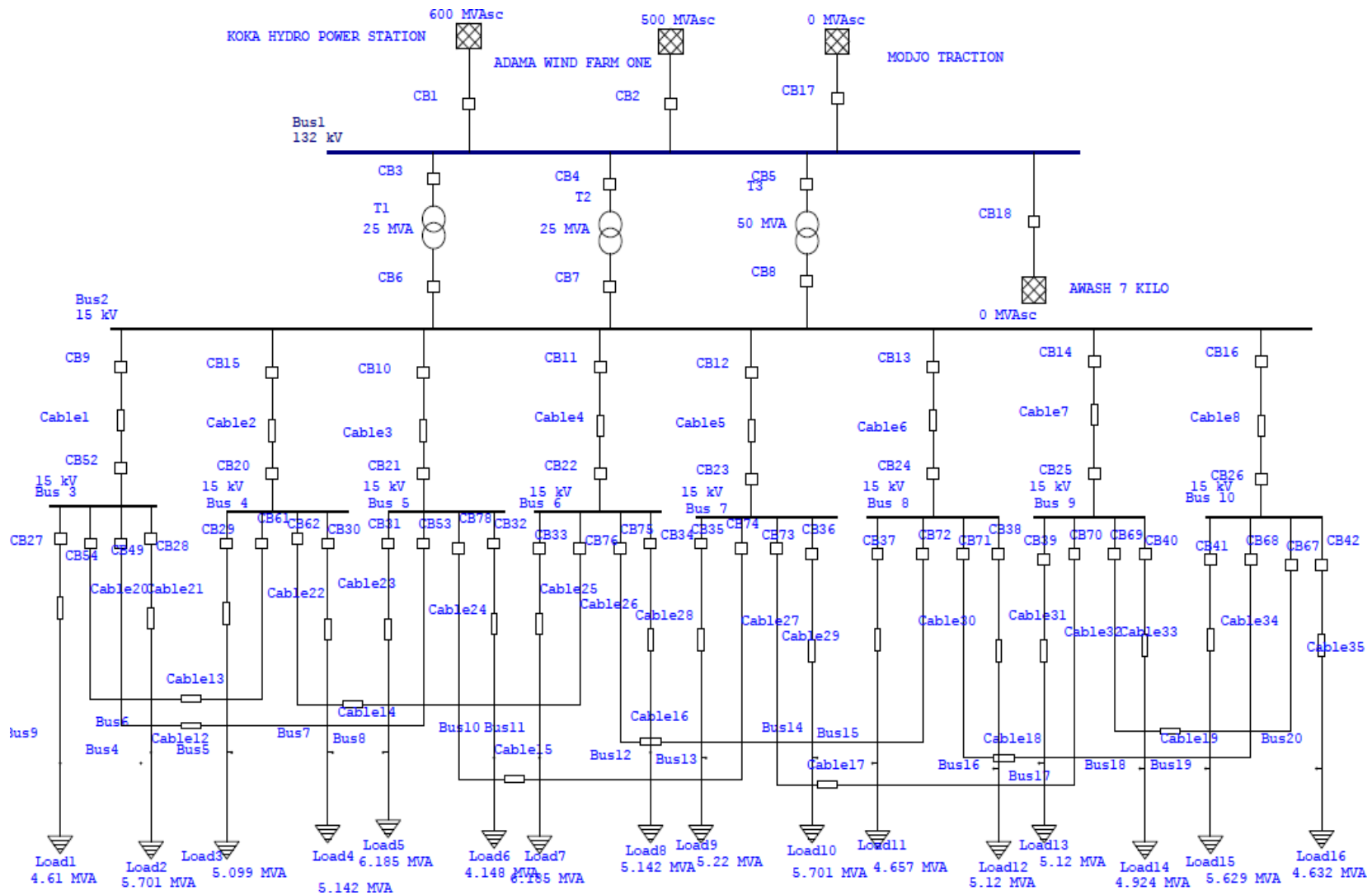


Figure 3. 5 Proposed Substation Design

In the above figure switching substation of different feeders (underground as well as overhead network) are automated with modular and integrated devices in order to decrease the number and duration of outages. Under ground and overhead fault detection devices provide accurate information about transient and permanent faults so that at the remote side preventive and corrective measures can be performed in order to reduce the fault repeatability.

Ring main unit and remote-control units (RTUs) of underground and overhead network responsible for maintenance and operational duties such as remote load switching, capacitor bank insertion and voltage regulation. The entire network is connected with a communication medium in order to facilitate remote energy management at the monitoring station. This is the main objective of this study.

In this SCADA system each switching substation is inter-connected with neighboring switching substations. This system improves the reliability of the substation by reducing the frequency and duration power interruption caused by overload and fault conditions.

3.6. End user load control automation by SCADA

This type of automation at user end side implements function like remote load control, automatic meter reading and billing generation etc. It provides the energy consumption by the large consumers and appropriate pricing on demand or time slots wise. Also detects energy meter tampering and theft and accordingly disconnects the remote service. Once the problem is resolved, it connects the service.

A centralized smart meter data management system using SCADA is an easy and cost-effective solution for automation the energy meter data for billing.

In this smart meter with a communication unit extract the energy consumption information and made it available to central control room as well as local storage unit. At the central control room AMR control unit automatically retrieves, stores and converts all meter data. Modems or communication devices at each meter provide secure two way communication between central control and monitoring room and remote sites.

3.7. Introduction to Simulating Software

3.7.1 SIMATIC Win CC System Overview

SIMATIC Win CC is a Supervisory Control and Data Acquisition (SCADA) and Human-Machine Interface (HMI) system from Siemens. SCADA systems are used to monitor and control physical processes involved in industry and infrastructure on a large scale and over long distances. SIMATIC Win CC can be used in combination with Siemens controllers. Win CC is written for the Microsoft Windows operating system [33].

This provides with general information about procedures for realizing HMI projects (Human Machine Interface). Only a few years ago, HMI systems were referred to as operations and monitoring systems.

Win CC (TIA Portal) is the software for all HMI applications ranging from the simplest operation solutions with basic panels to SCADA applications on PC –based multi-user system. SIMATIC Win CC (TIA Portal) comprises Engineering software in the variants Win CC Basic, Win CC Comfort, Win CC Advanced and Win CC Professional. Win CC Advanced and Win CC Professional are also available as Runtime software packages, which can be expanded options.

Win CC (TIA Portal) Runtime software offers more transparency, whether preinstalled on SIMATIC HMI devices or as independent products with scalable functionality for PC platforms.

3.7.2. The SCADA System Inside TIA Portal

With SIMATIC Win CC Professional Siemens offers a SCADA system which is perfectly integrated in the TIA Portal and with which we are optimally prepared today for the requirements of the increasing digitalization of production processes.

SIMATIC Win CC Runtime professional is a PC- based operator control and monitoring system for visualization and operator control of processes, production flows, machines and plants in all sectors- from simple single- user systems to distributed multi-user systems and cross-location solutions.

In the last few years, the requirements for a system that monitors and controls production processes, as well as archives and processes production data, have increased dramatically. To

One of these new systems is Win CC. Win CC certainly is unique, considering its functionality, openness, and up-to-datedness of software technology. Older generation HMI systems often provided only one way to solve a task. Win CC, on the other hand, almost always gives you multiple solution options. This configuration manual has been written to illustrate the best solution approaches taking into account performance and extent of configuration work.

This system overview(description) is an extremely compact version of the technical documentation for Win CC. The system description is intended for decision-makers and configuring engineers who want an overview of all functions, the look and feel, and the compatibility of Win CC. This document speaks your language. Your requirements for an automation system are defined in the "Introduction "section and condensed into customer-oriented keywords in the "Highlights" section. The rest of the document is then structured according to these keywords [35].

By customizing the Win CC wizards to suit your individual needs, you can automate your configuration. This is particularly useful for wiring the interfaces of any faceplates you have developed yourself. You can then expand the functionality of these faceplates for object-oriented application. This will automatically update thousands of places where objects are used. Linking function, faceplates, libraries, picture levels, dynamic display, mass configuration, online configuration, tag simulator, global script: This is state-of-the-art configuration in Tag Management, in the message system, in the Archive system, etc. [36].

3.7.3. Win CC concept

In general, Win CC offers three solution approaches for a configuration:

- ✓ using Win CC standard tools
- ✓ using existing Windows applications with Win CC via DDE, OLE, ODBC, and ActiveX
- ✓ using Visual C++ or Visual basic to develop your own applications embedded into Win CC

For some, Win CC is the HMI system for fast and cost-effective configurations, for others it is an infinitely expandable system platform. The modularity and flexibility of WinCC gives completely new possibilities for planning and implementing automation tasks.

Modular structure of Win CC

Win CC offers system modules for the visualization, messaging, acquisition, and archiving of process data, as well as for the coordinated integration of user defined application routines.

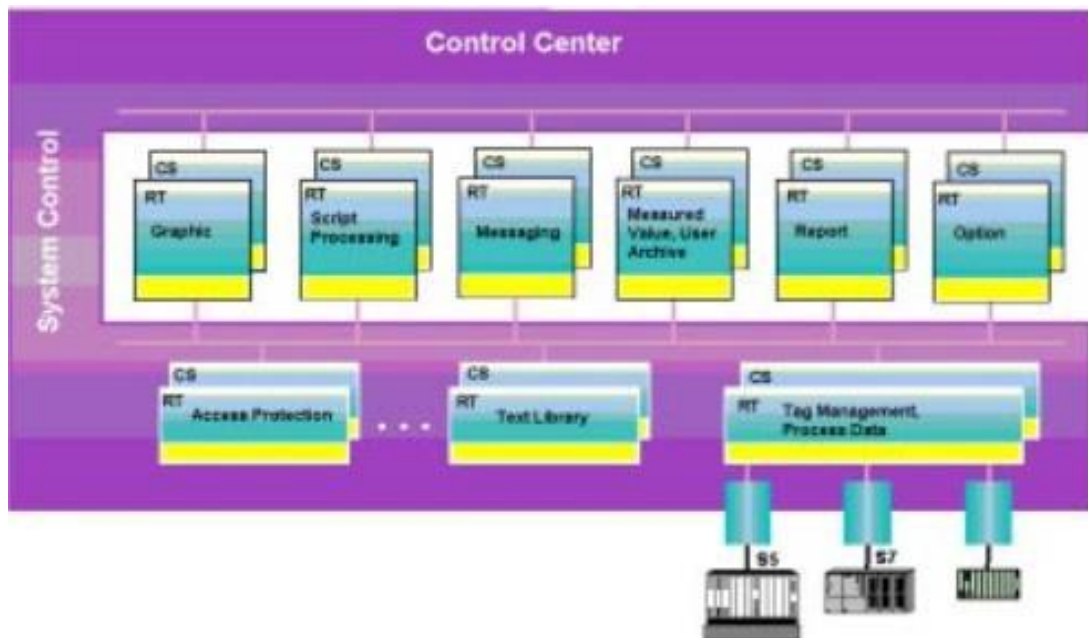


Figure 3. 6 Win CC conceptual diagram [34]

3.7.4. The interfaces of Win CC

Win CC is completely open to any user add-on. This openness is accomplished through Win CC's modular structure and its powerful programming interface. The following picture illustrates the connection possibilities of various applications.

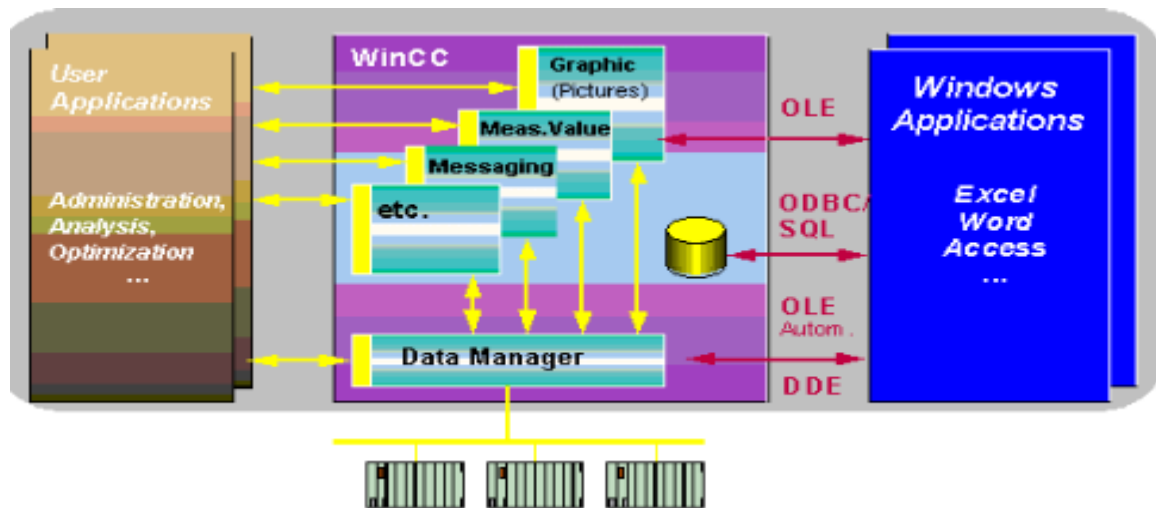


Figure 3. 7 Win CC conceptual diagram [35]

3.7.5. Step 7 Professional and PLC SIM Soft wares

Step 7 professional is the most comprehensive engineering software for demanding control tasks. It is the ultimate engineering tool for configuration and programming for all SIMATIC controllers.

Step 7 (TIA Portal) helps us to solve our engineering tasks intuitively and efficiently. Due to its integration in to the TIA Portal Step 7 offers impressive performance in every works and programming step thanks to its transparency, intelligent user navigation and straightforward work flows.

Functions such as drag and drop, copy and paste and Auto completion make work much quicker and easier. PLC SIM software are also used for the simulation purpose.

CHAPTER FOUR

4. Results and Discussion

Energy management is an important constraint in the design of substation automation. So, if energy consumption increases then the substation monitoring is very important for the purpose of controlling the hardware and software optimization with the help of PLC ladder logic system and SCADA were used. This technique is used in order to reach strong conclusion about their actual impact on the energy monitoring and control without manpower.

In substation many relays and circuit breakers are used. When any one breaker is trip because of the problems, it can be monitor and control through SCADA windows. In energy management, the computer is used for assigning the priority for various over loads and faulty conditions. The signals are given to the computer of the electricity board where there is the electronic control unit which controls the sequence of disconnecting the load. On basis of controls from the computer the breakers are managed and in computer the SCADA system is installed which is used for monitoring and control. If there is any problem that occurs in a plant, one can easily identify which part is trip off. After that we can troubleshoot the problem through man power and monitor the substation.

In this chapter the simulation result of PLC integrated with SCADA will be discussed in detail. The following table shows the comparison of results of a distribution substation before and after using SCADA.

Table 4. 1 comparison result before and after SCADA

N ^o .	Before SCADA	N ^o .	After SCADA
1.	Poor reliability of the power system distribution	1.	Increases the reliability of the power system due to online monitoring and timely recognition of faults and load sharing system
2.	Poor efficiency of the power system distribution	2.	Maximizes the efficiency and performance of the power system distribution by continuous monitoring and control of distribution network from remote location
3.	Higher maintenance and labor cost.	3.	Save labor cost by elimination manual operation of distribution equipment /cost effective/
4.	Frequent power interruption/ power outage/	4.	Reduce the outage time by system - wide monitoring and generating alarms so as to address problems quickly
5.	Unable to satisfy consumer demands	5.	Improves the continuity of service by restoring service after the occurrence of faults (temporary)
6.	Unnecessary argument between the utility and the customer	6.	The system avoids the unnecessary argument between the utility and the customer by improving the service quality
7.	The system takes longer time to restore power	7.	Facilitates the view of historical data in various ways
8.	Poor quality of service	8.	Reduces the labor cost by reducing the staff required for field work
9.	The system cannot indicate the real - time states of the power system	9.	SCADA system can indicate the real - time of the power system every time, so that we can monitor and protect the power system.
10.	Online monitoring is impossible	10.	The operator can monitor, control and takes the necessary action from remote location
11.	The system is much exposed to equipment damage	11.	Due to timely recognition of faults equipment damage can be avoided
12.	No warning and alarming system before faults	12.	SCADA system warns the operator before the fault by sending alarm signals

4.1. SCADA SIMULATION RESULT USING WIN CC SOFTWARE

The following Simulation results show how PLC based SCADA system supervise, monitor, control and protect the power distribution system in real-time operation so as to achieve Energy Management System. By achieving EMS can improve the reliability and performance of the power supply distribution system.

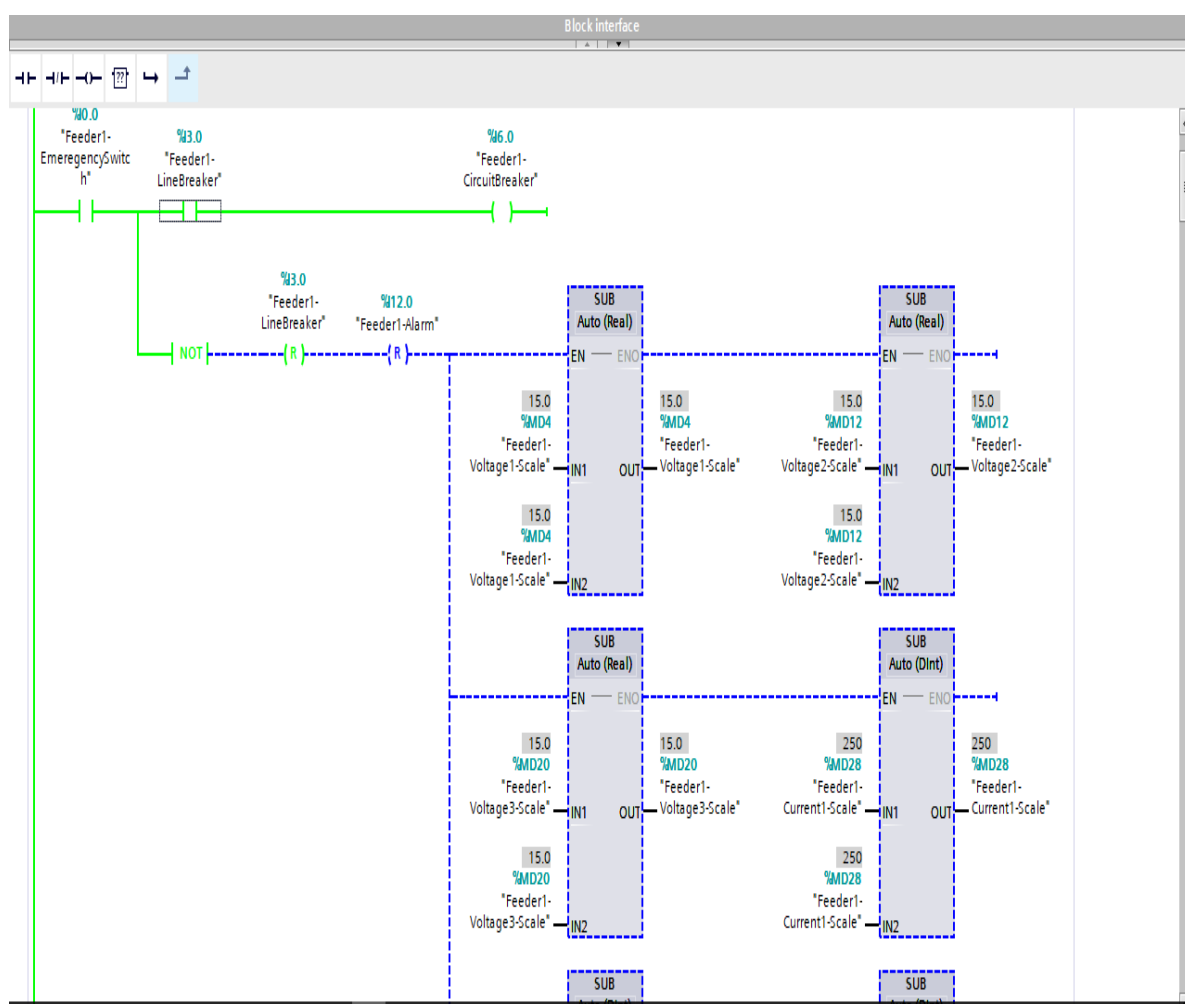


Figure 4. 1 Feeder1 Emergency Switch, Circuit Breaker and PLC Ladder Diagram Simulation

Remote switching substation can be controlled by remote switching operation of Circuit Breakers. This remote switching operation of the system (i.e. the opening and closing operation) of switch and Circuit Breakers of the switching substation can be done after monitoring PLC program.

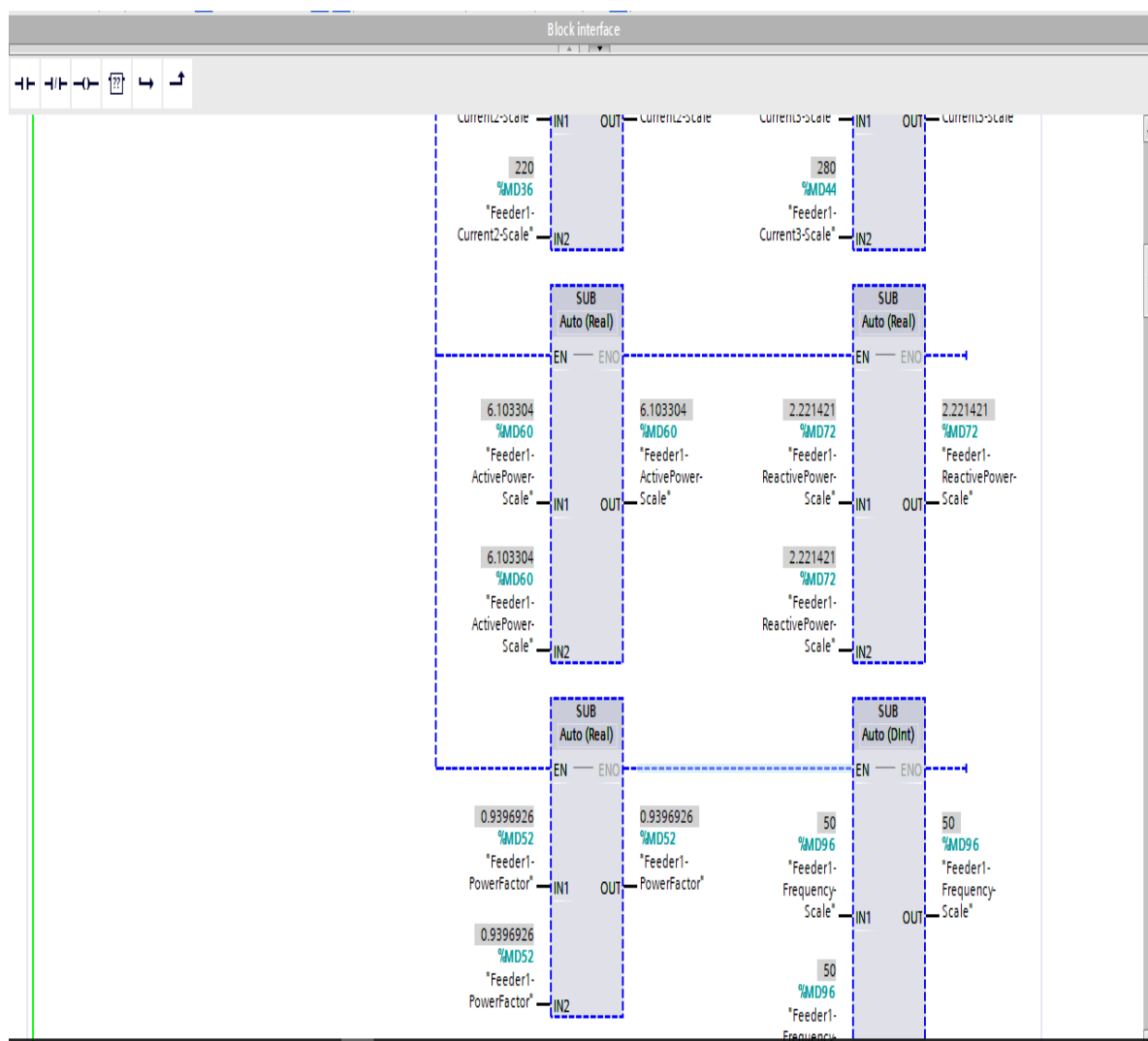


Figure 4. 2 Feeder 1 PLC Memory Ladder Diagram Simulation

The above figure shows us each block in the memory of the PLC, the CPU completes three processes during its operation;

1. It reads, or accepts the input data from the field devices via the input interface.
2. It executes, or performs the control program stored in the memory system.
3. It writes, or updates the output devices via the output interface.

This processes of sequentially reading the inputs, executing the program in the memory and updating the output is known as scanning.

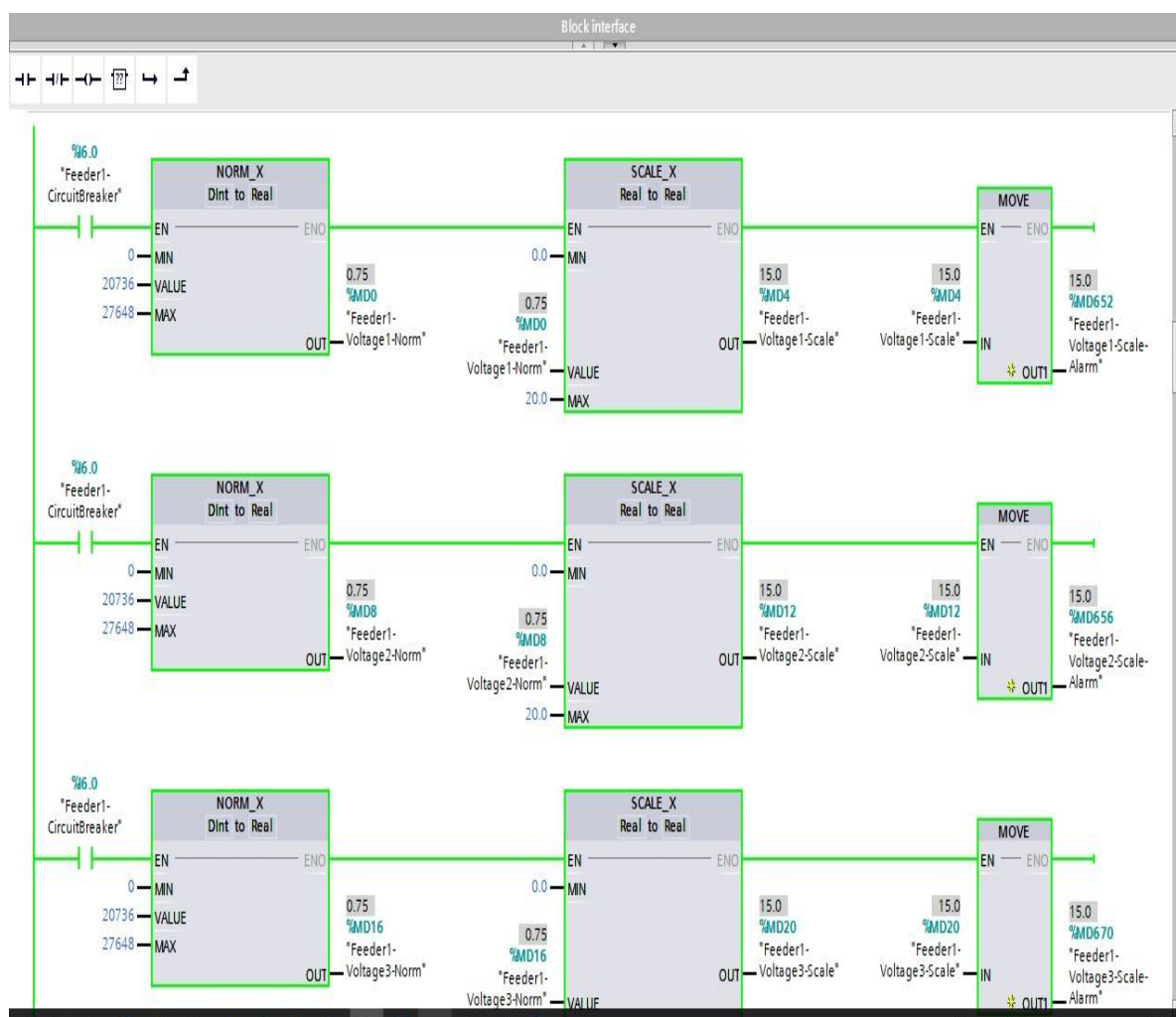


Figure 4. 3 Feeder 1 Line Voltages PLC Ladder Diagram Simulation Results

In the above figure each block in the first column is a normalizer block. This one of the Siemen's standard block with the indicated input range values. This normalizer block normalizes and scales the given inputs with the given range and give the required output voltage ratio scale. The second blocks in the second column are the voltage scale blocks which give the require amount voltages, in this case 15KV. The third blocks in the third column are the move blocks. The output of each block is connected to the respective alarm circuits for the purpose of getting alarm texts during fault conditions.

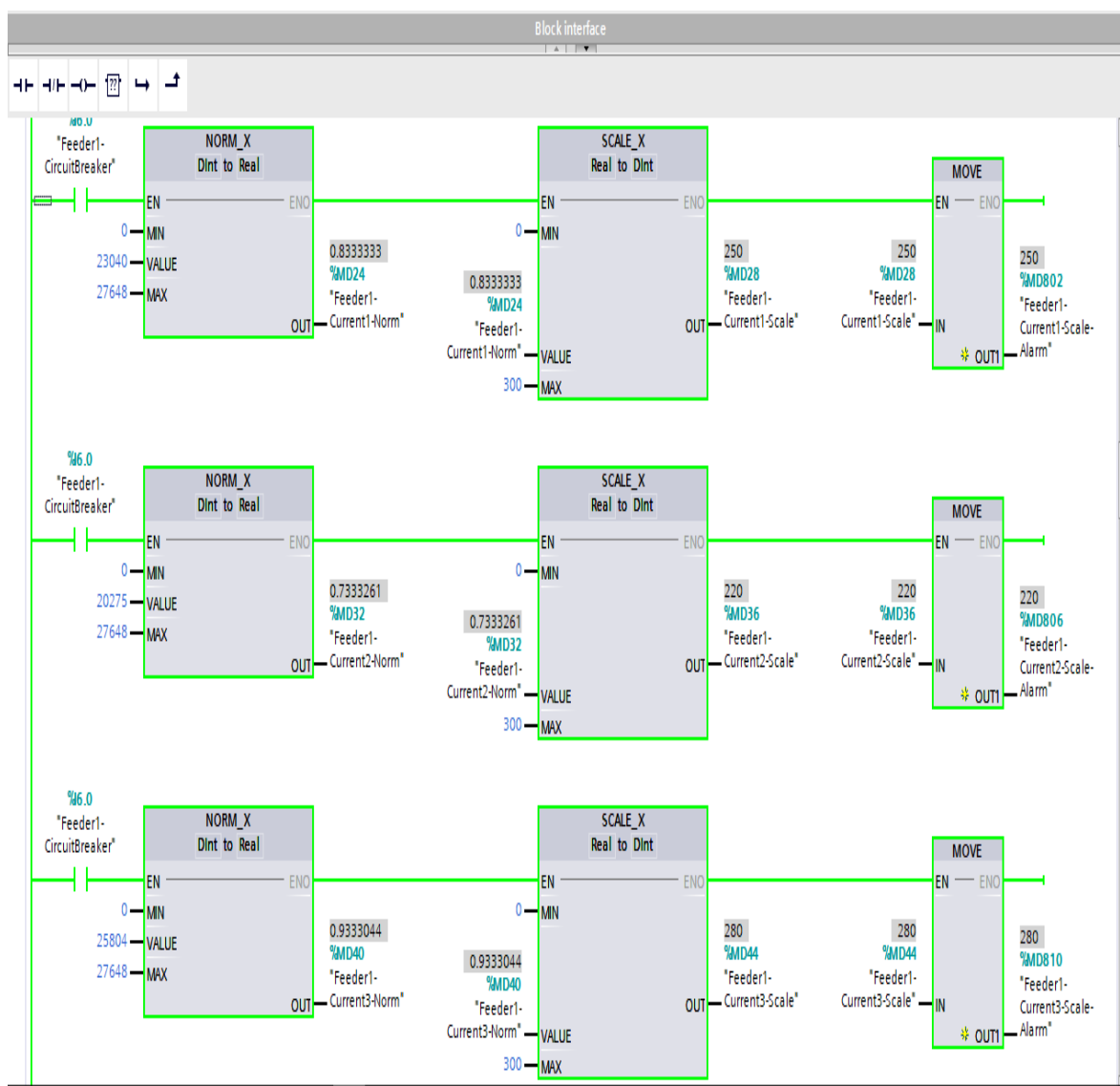


Figure 4. 4 Feeder 1 Line Currents PLC Ladder Diagram Simulation Results

Referring to the above figure the first down ward blocks are also the normalizer blocks with the given input ranges. These blocks normalize and scale the input currents with the given range and give the output required current scale ratios. The second blocks are the current scale blocks which give the required amount of currents as an output. The output of each block is connected to the respective move blocks. Each move block is connected to their respective alarm circuits to get the access of alarm texts when a fault happens.

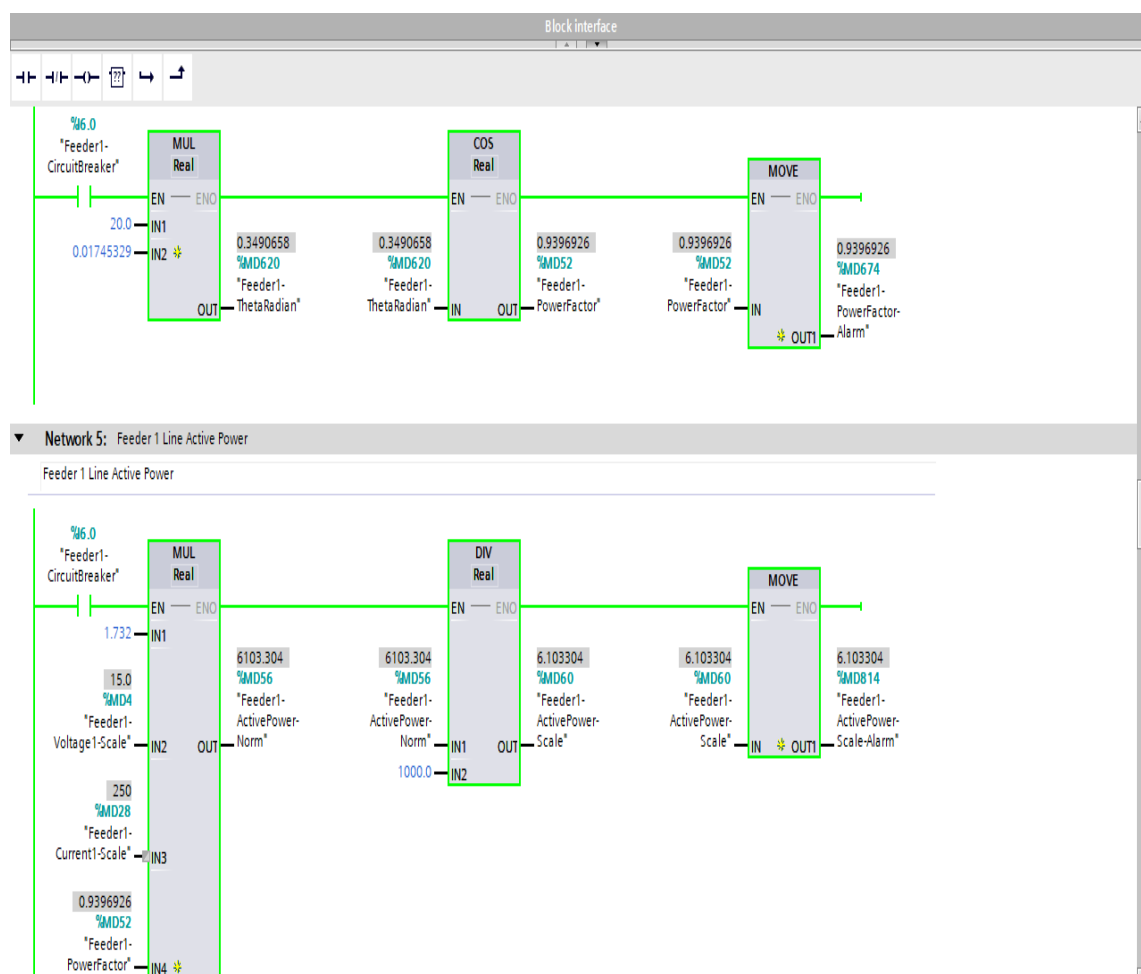


Figure 4. 5 Feeder 1 Line Power Factor and Line Active power PLC Ladder Diagram

Referring to the power factor block, the first block is the multiplication or conversion block that converts the given input degree in to electrical radian degree to have electrical parameter. Since power factor is the cos theta of the given degree in radian, the second block, the cosine block gives the cosine value of the given degree. As indicated above, this is the power factor of the present system. The last block that is the move block is connected to the alarm circuit for the purpose of obtaining alarm texts during fault.

For the active power block, the multiplication block calculates the three-phase active power. The second block is the division block which converts the three-phase power in Mega Watts. The move block is then connected to the alarm circuit to get an access of alarm texts during fault.

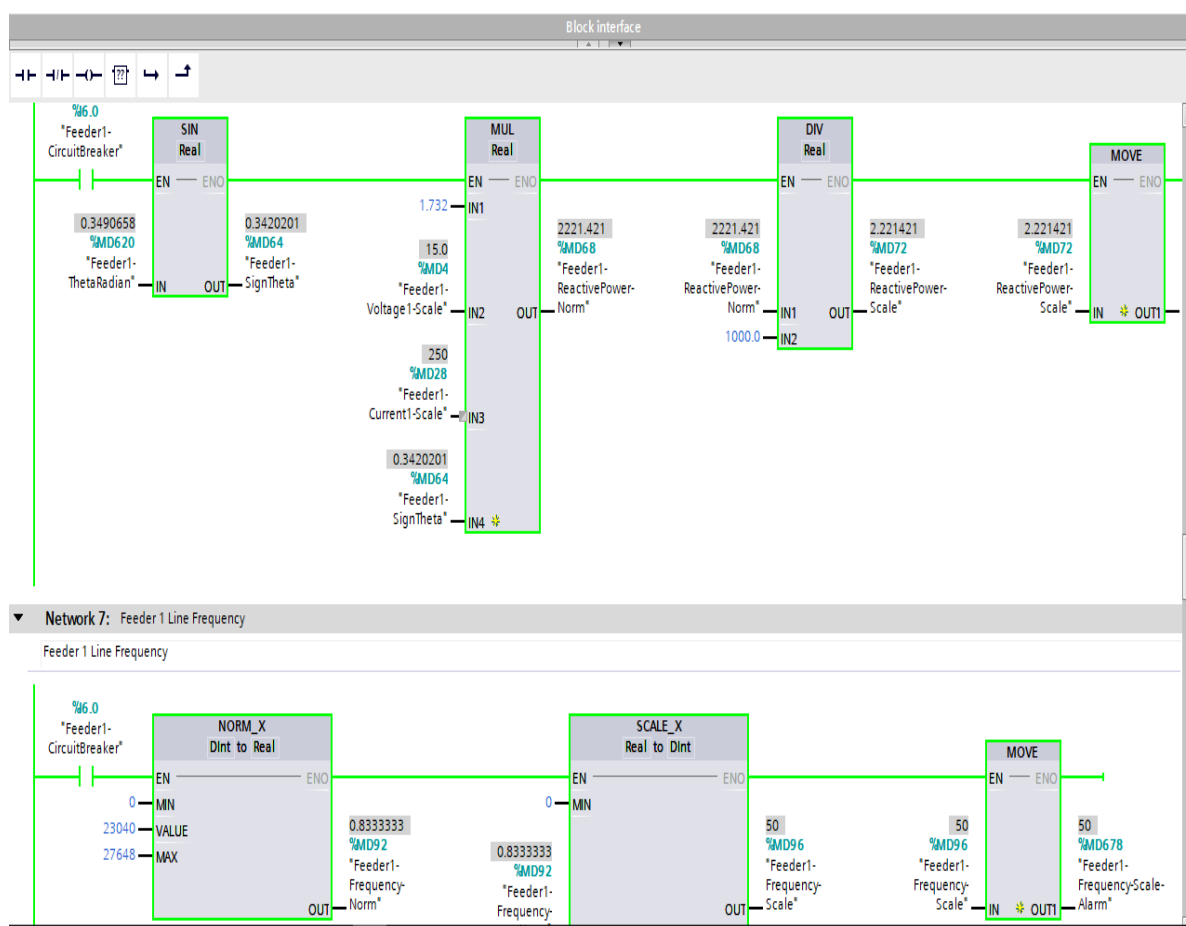


Figure 4. 6 Feeder 1 Line Reactive Power and Line Frequency PLC Ladder Diagram Simulation

Referring to the above figures, For the Reactive power block the first block the sine block that converts the radian value the given degree in to its sine value. The multiplication block calculates the total three phase reactive power of the system. The division block converts the total reactive power of the system in to equivalent unit, that is MVAR. To obtain alarm texts during fault condition the move block should be connected to the alarm circuits.

The operating principle of all the blocks in the line frequency is the same as the operating principles of all the respective block of the line voltage blocks and line current blocks except that the frequency blocks process the frequency of the system.

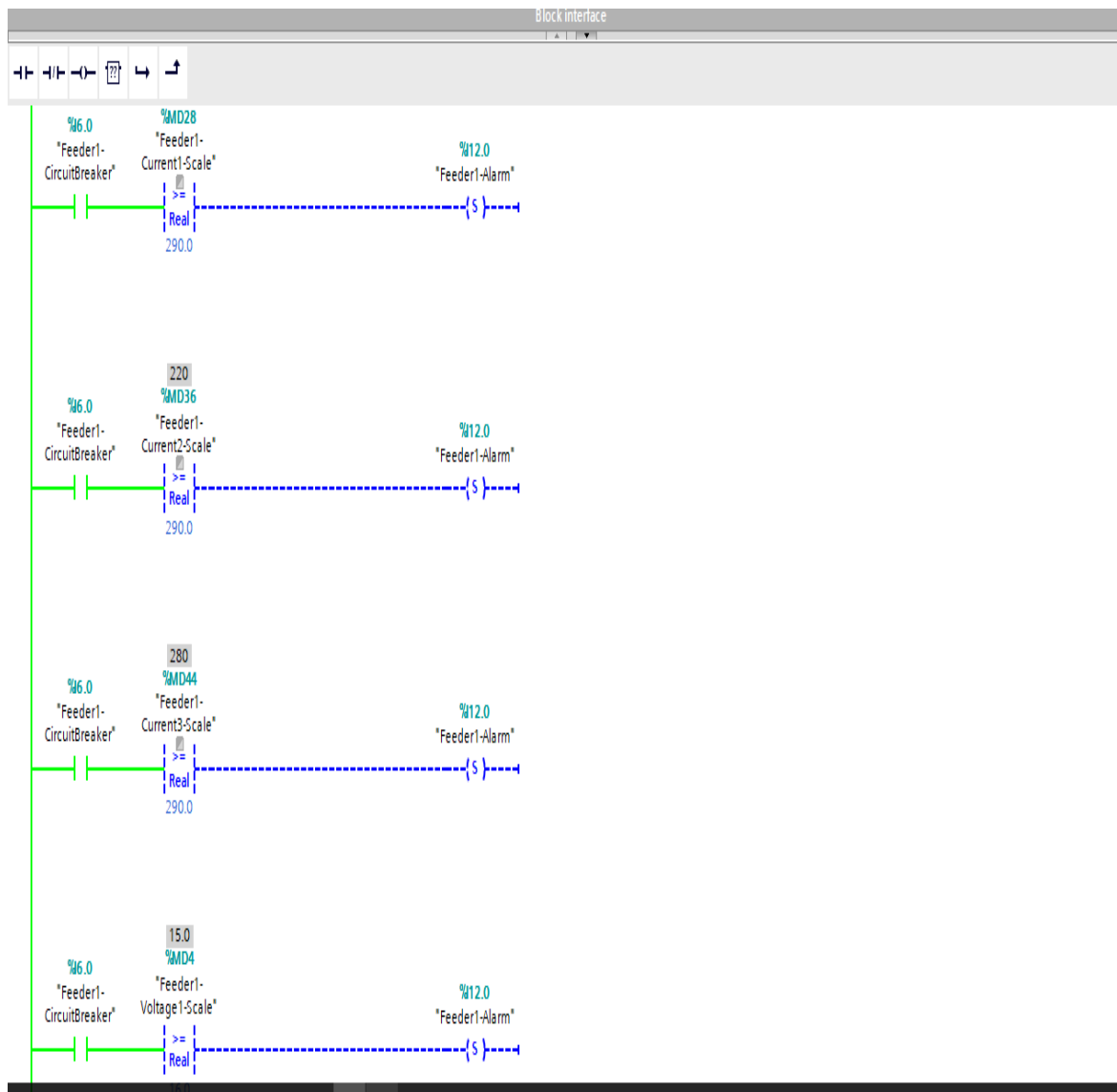


Figure 4. 7 Feeder 1 Alarm Circuit PLC Ladder Diagram Simulation Results

Figure 4.7 in the above depicts us the three-line currents (I1, I2, I3) and the line voltages (V1) all are within the predetermined values. At this time the real status of the system is said to be at normal condition. Each circuit is connected to its respective alarm circuits to activate the circuit breakers to be operated to protect the system from damage under fault conditions.

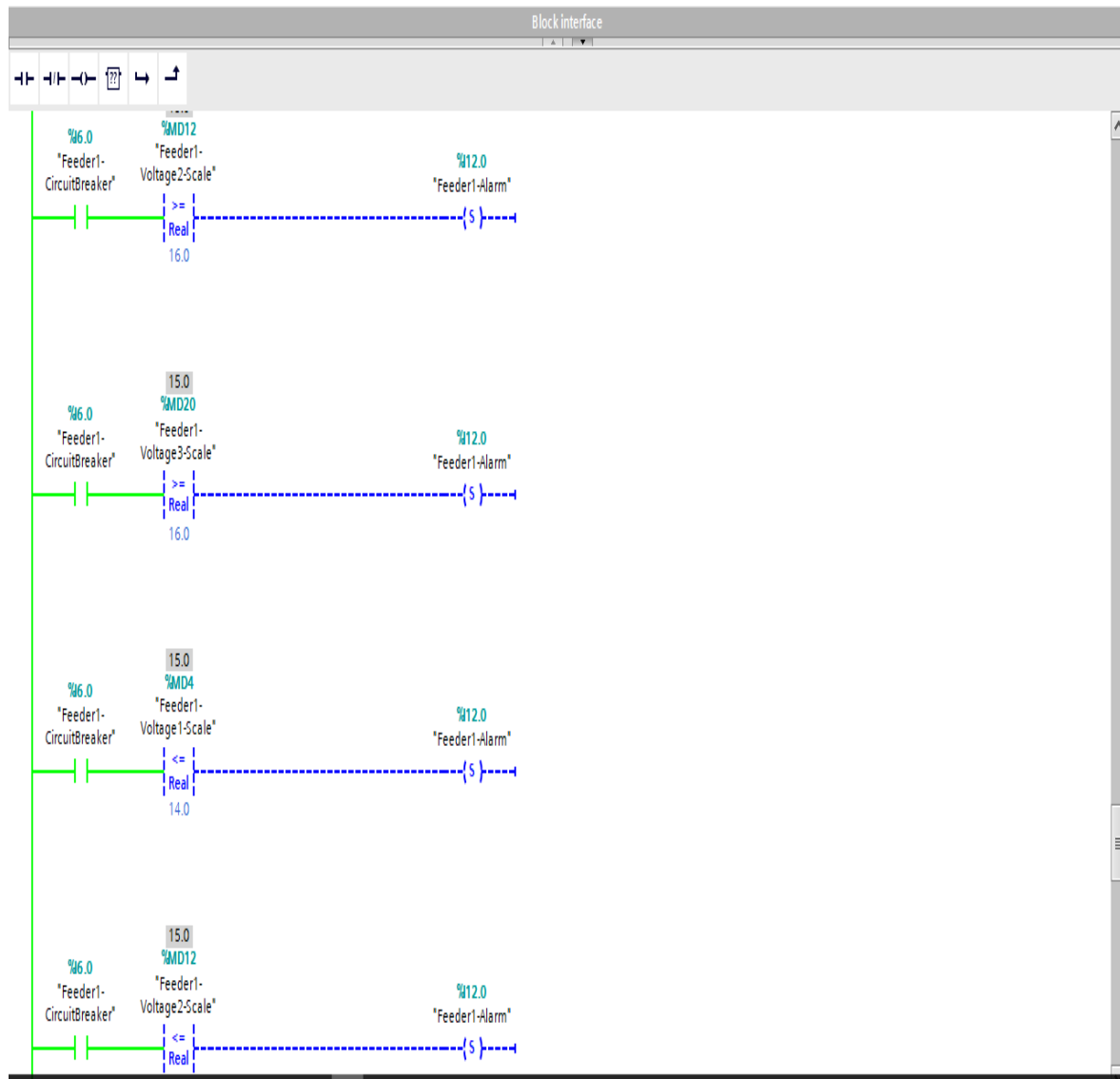


Figure 4. 8 Feeder 1 Alarm Circuit PLC Ladder Diagram Simulation Results

In the above figure, the simulation result shows there is no voltage problems in the power system. That means there is no under voltage or over voltage problems in the system. All parameters are within the predetermined values. Hence the system is in normal condition. Each circuit is connected to the alarm circuit to activate the circuit breakers to be operated when they get a control signals from the alarm circuit to protect any device under control.

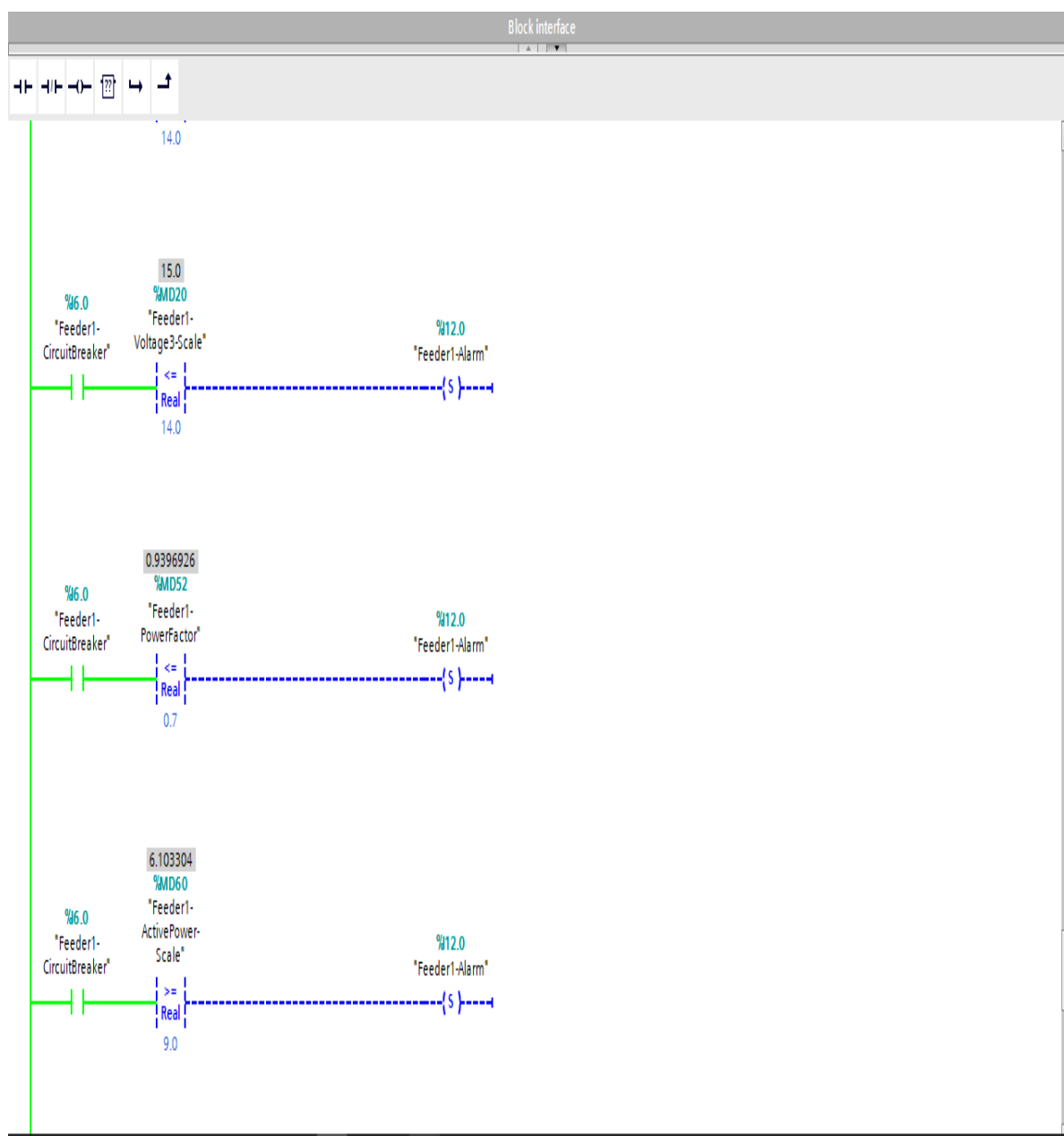


Figure 4. 9 Feeder 1 Alarm Circuit PLC Ladder Diagram Simulation

Referring to figure 4.9, the simulation result shows us all the three electrical parameters (i.e. voltage, power factor, Active power) are all within the predetermined values. If any one of the parameters is out of the predetermined values, the alarm circuit cross-ponding to it will be green to initiate the circuit breaker to be operated. After some seconds this breaker takes an action (opens) to protect the system from damage.

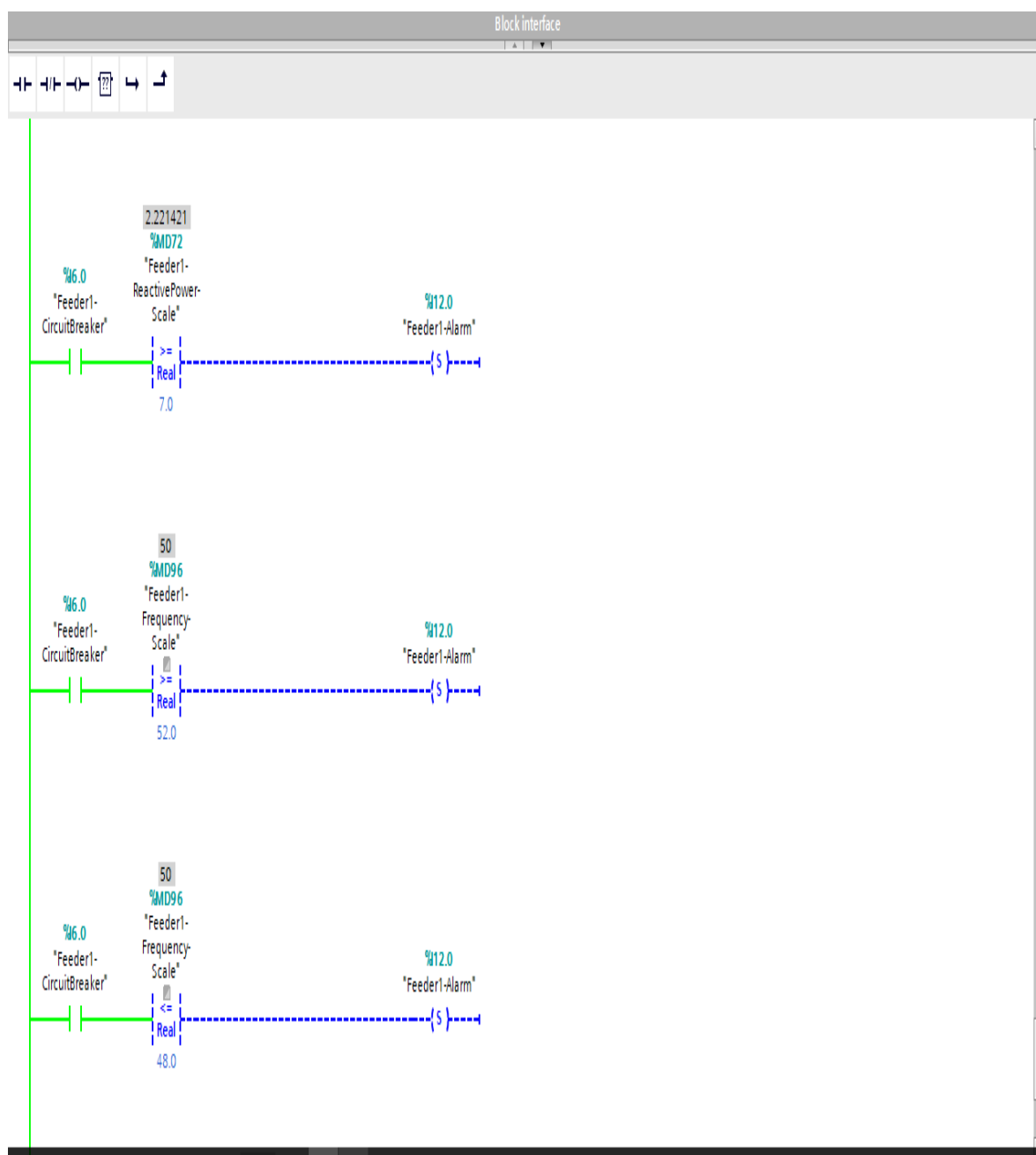


Figure 4. 10 Feeder 1 Alarm and Timer Circuit PLC Ladder Diagram Simulation Results

From the above figure, the simulation result shows us the real time status of the system is under normal condition. Because all the parameters are within the preset values. If any fault occurs in the system, , the alarm circuit cross- ponding to it will be green to initiate the circuit breaker to be operated.

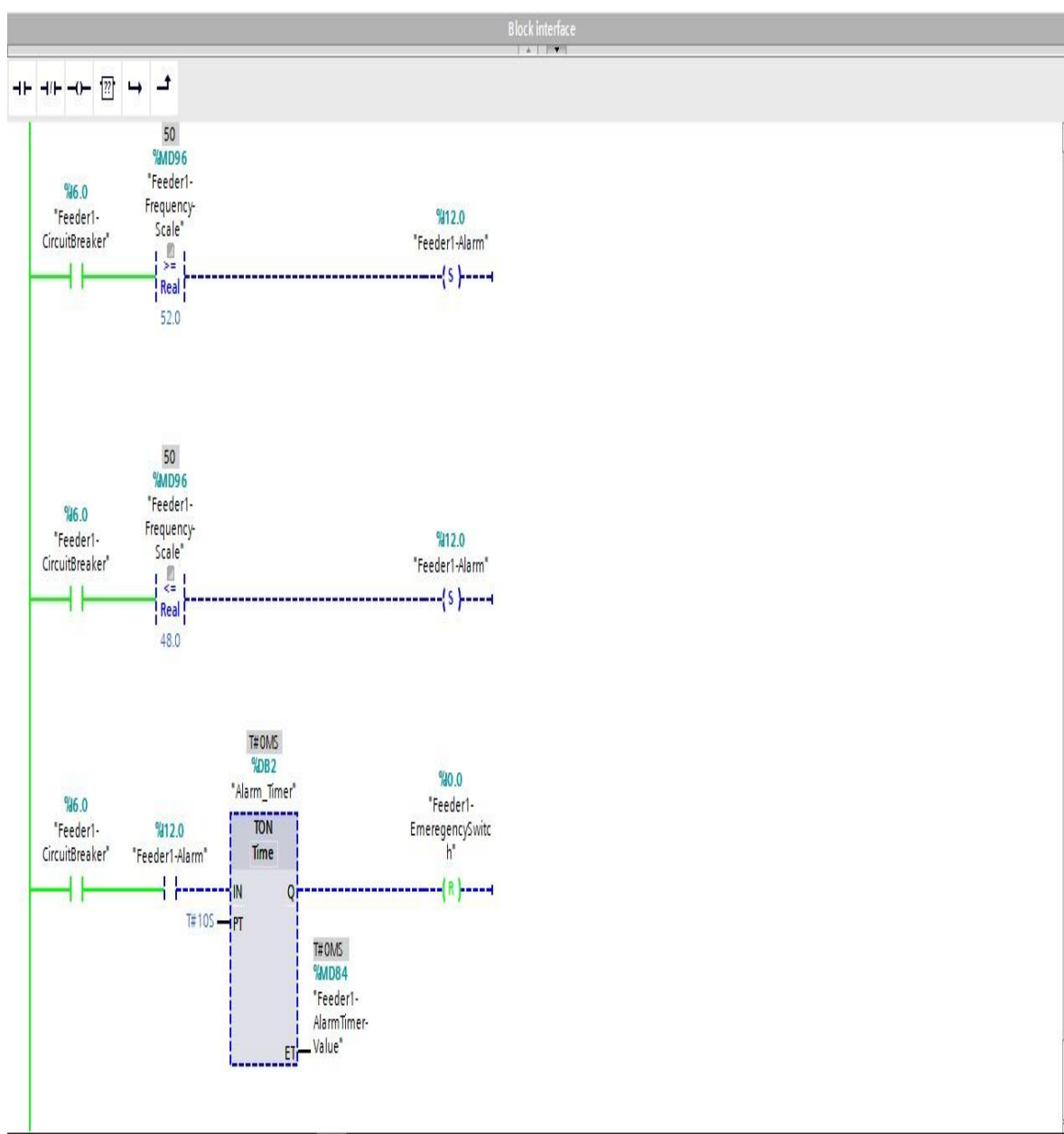


Figure 4. 11 Feeder 1 Alarm and Timer Circuit PLC Ladder Diagram Simulation Results

The above figure depicts that; the simulation result shows us the real time status of the system is under normal condition. Because all the parameters are within the preset values. If any fault occurs in the system, the timer circuit sends an alarm signal to the circuit breaker after 10 seconds to open and protect the system from damage.



Figure 4. 12 HMI screen to monitor and control the real time substation status

The above figure 4.12 depicted normal operation of the substation. Every parameter is within the predetermined values. So, the system is operated with the acceptable range

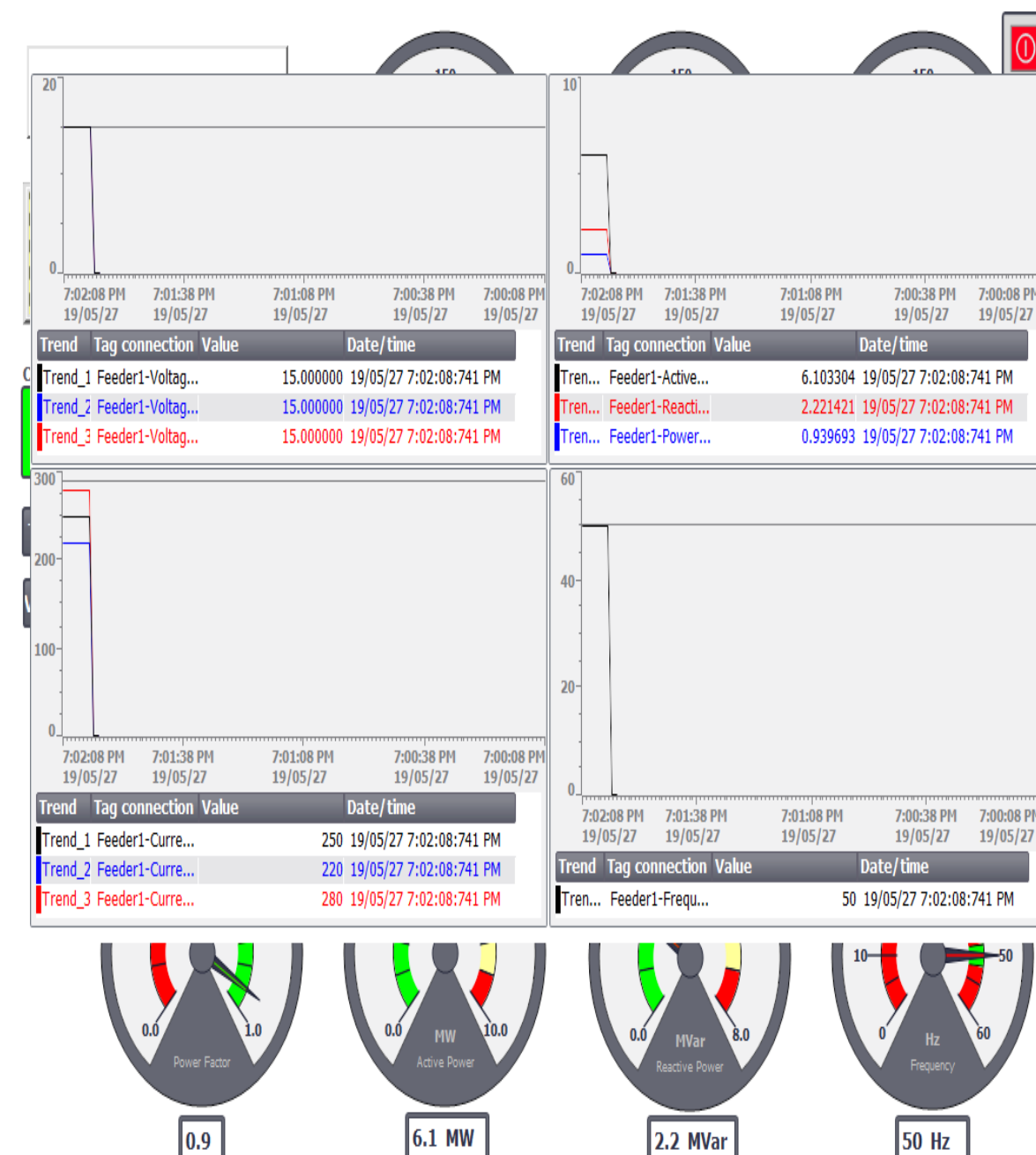


Figure 4. 13 Trends of feeder 1

The above figure 4. 13 described different trends: Line voltages trends, Line currents trends, Active power trend, Reactive power trend, Power factor trend and Frequency trend.

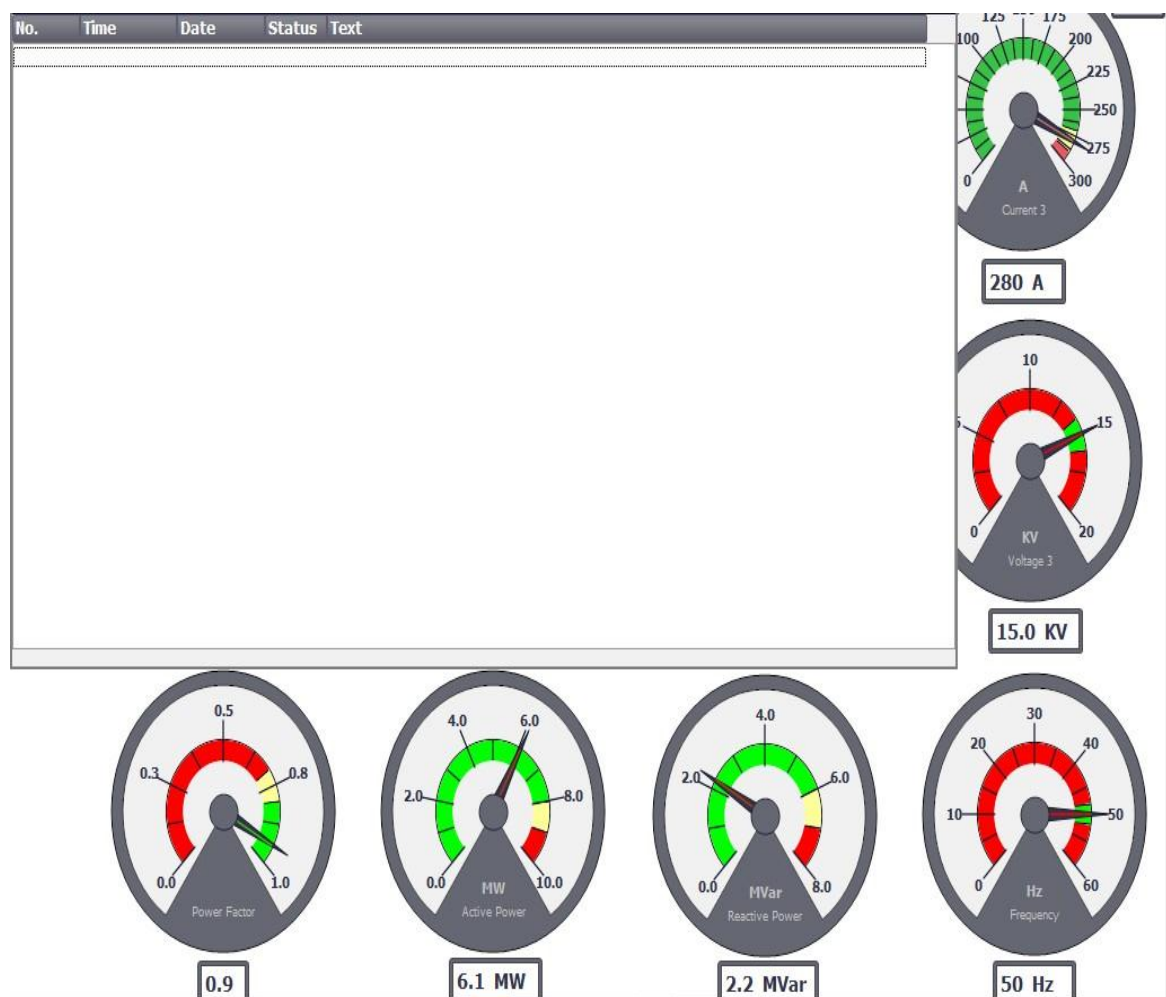


Figure 4. 14 Alarm texts

Since all parameters are normal, there is no text displayed in the above screen.

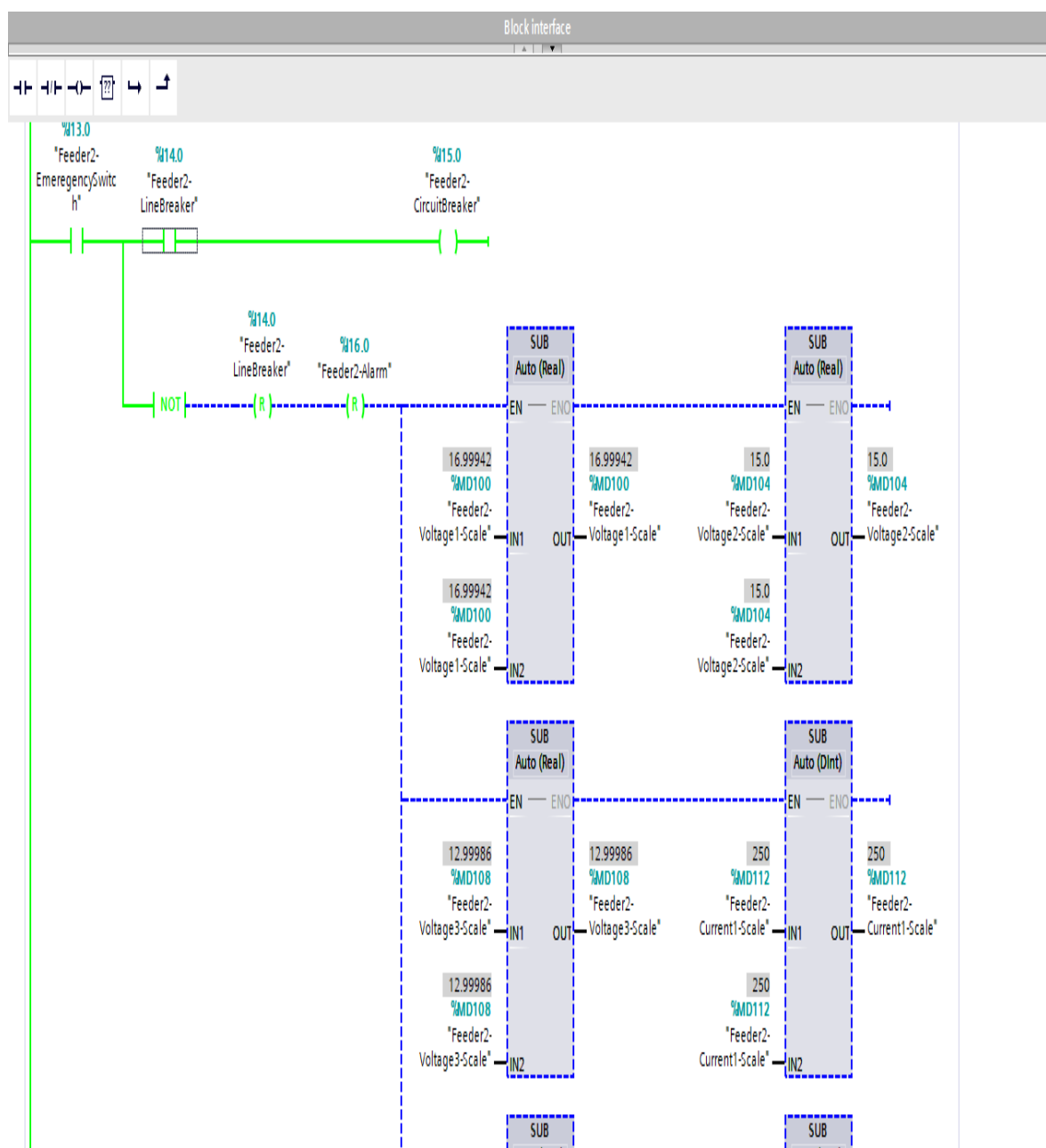


Figure 4. 15 Feeder 2 Emergency Switch, Circuit Breaker and PLC Memory Ladder Diagram Simulation Results

Remote switching substation can be controlled by remote switching operation of Circuit Breakers. This remote switching operation of the system (i.e the opening and closing operation) of switch and Circuit Breakers of the switching substation can be done after monitoring PLC program.

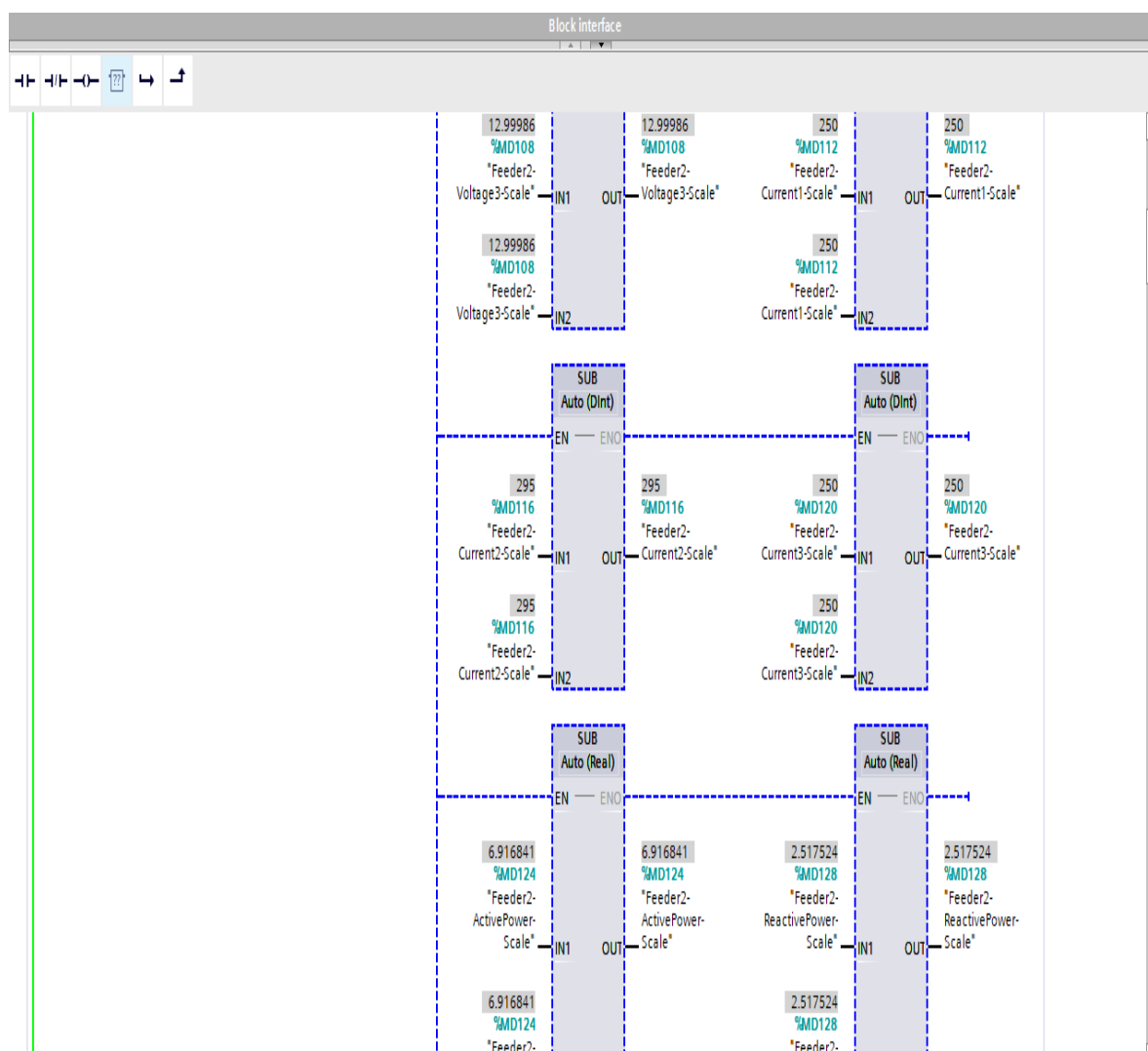


Figure 4. 16 Feeder 2 PLC Memory Ladder Diagram Simulation Results

The above figure shows us each block in the memory of the PLC, the CPU completes three processes during its operation;

1. It reads, or accepts the input data from the field devices via the input interface.
2. It executes, or performs the control program stored in the memory system.
3. It writes, or updates the output devices via the output interface.

This processes of sequentially reading the inputs, executing the program in the memory and updating the output is known as scanning

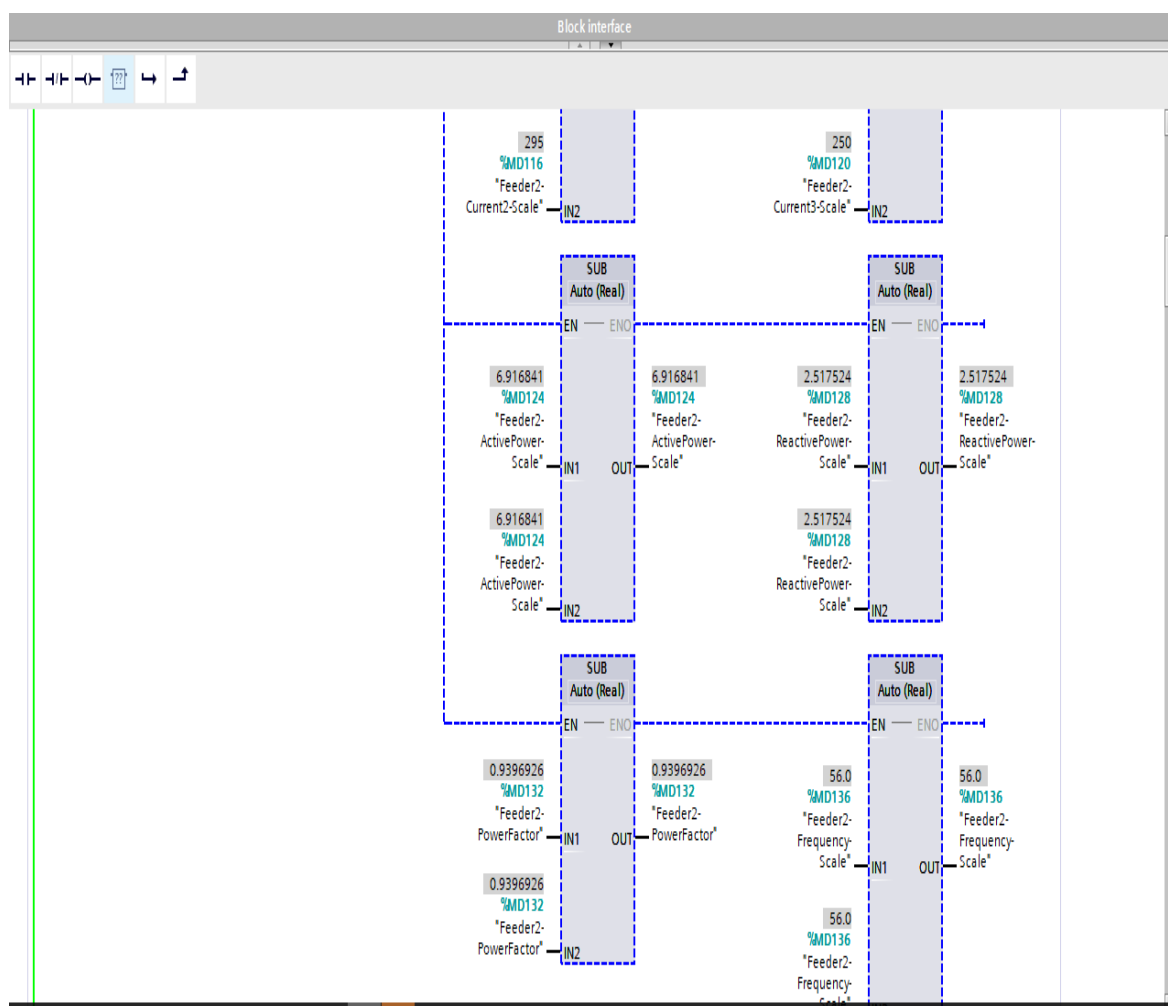


Figure 4. 17 Feeder 2 PLC Memory Ladder Diagram Simulation Results

The above figure shows us each block in the memory of the PLC, the CPU completes three processes during its operation;

1. It reads, or accepts the input data from the field devices via the input interface.
2. It executes, or performs the control program stored in the memory system.
3. It writes, or updates the output devices via the output interface.

This processes of sequentially reading the inputs, executing the program in the memory and updating the output is known as scanning

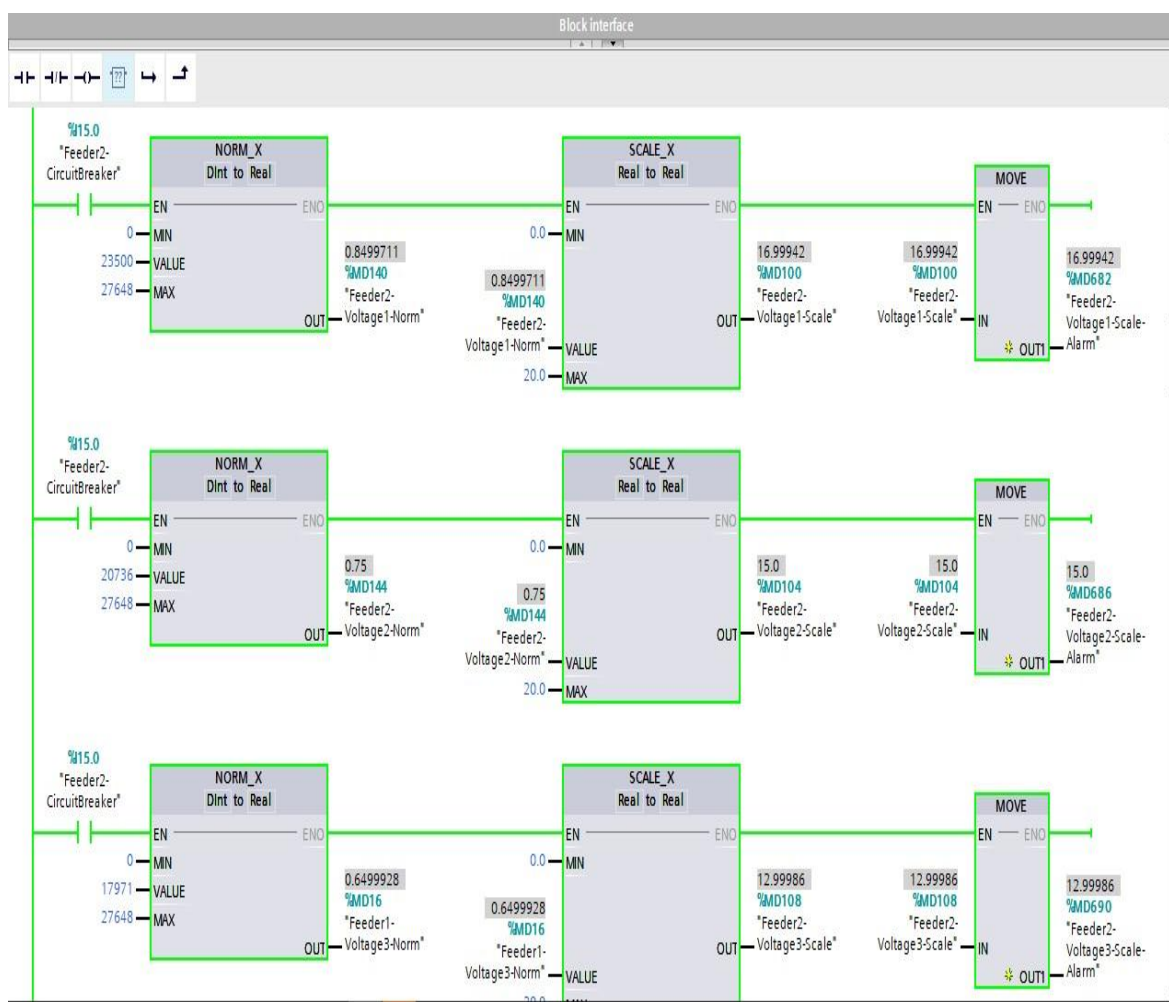


Figure 4. 18 Feeder 2 Line Voltages PLC Ladder Diagram Simulation Results.

In the above figure each block in the first column is a normalizer block. This is one of the Siemen's standard block with the indicated input range values. This normalizer block normalizes and scales the given inputs with the given range and give the required output voltage ratio scale. The second blocks in the second column are the voltage scale blocks which give the require amount voltages, in this case 15KV. The third blocks in the third column are the move blocks. The output of each block is connected to the respective alarm circuits for the purpose of getting alarm texts during fault conditions.

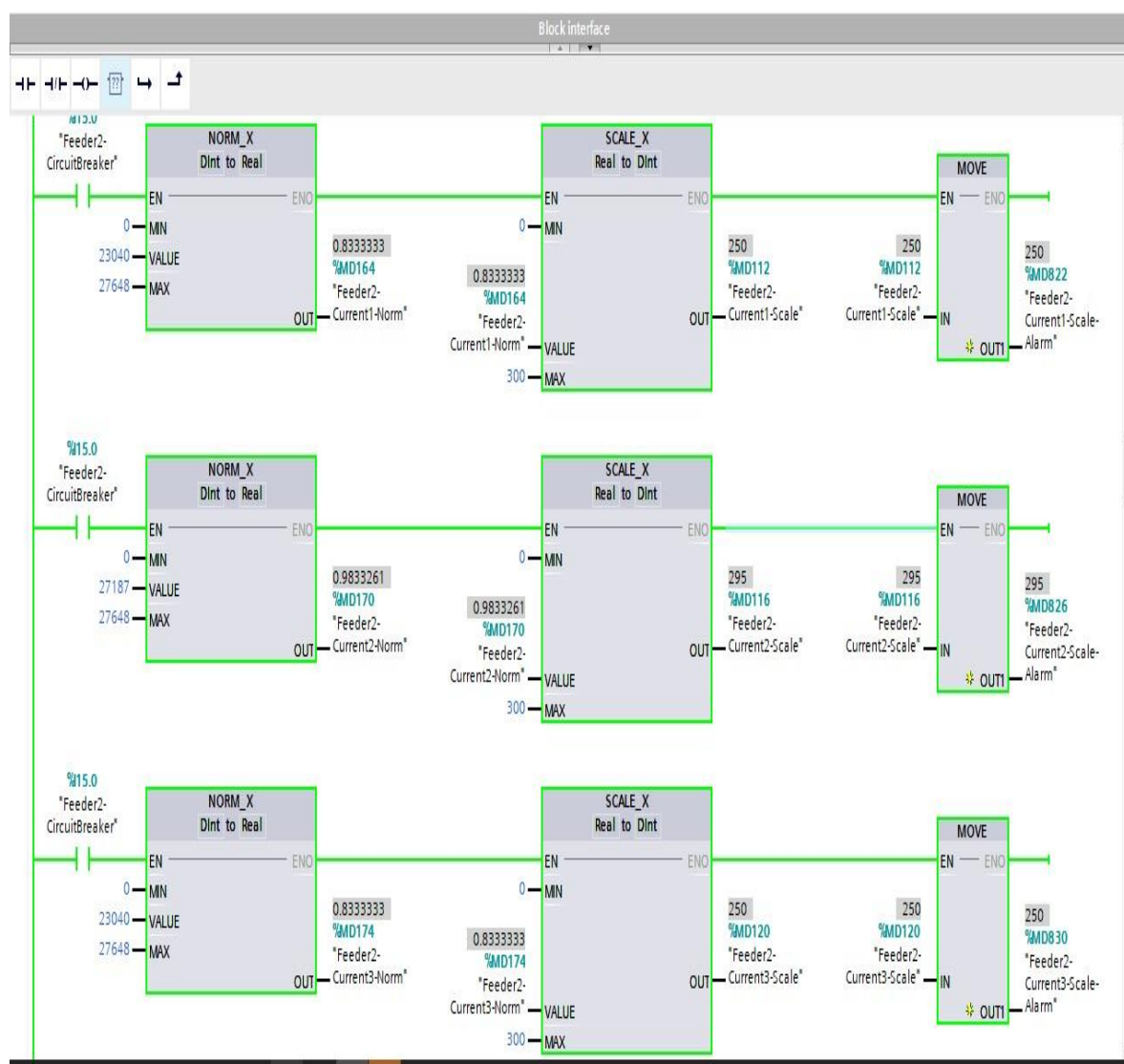


Figure 4. 19 Feeder 2 Line Currents PLC Ladder Diagram Simulation Results.

Here I2 is Over loaded. Referring to the above figure the first down ward blocks are also the normalizer blocks with the given input ranges. These blocks normalize and scale the input currents with the given range and give the output required current scale ratios. The second blocks are the current scale blocks which give the required amount of currents as an output. The output of each block is connected to the respective move blocks. Each move block is connected to their respective alarm circuits to get the access of alarm texts when a fault happens.

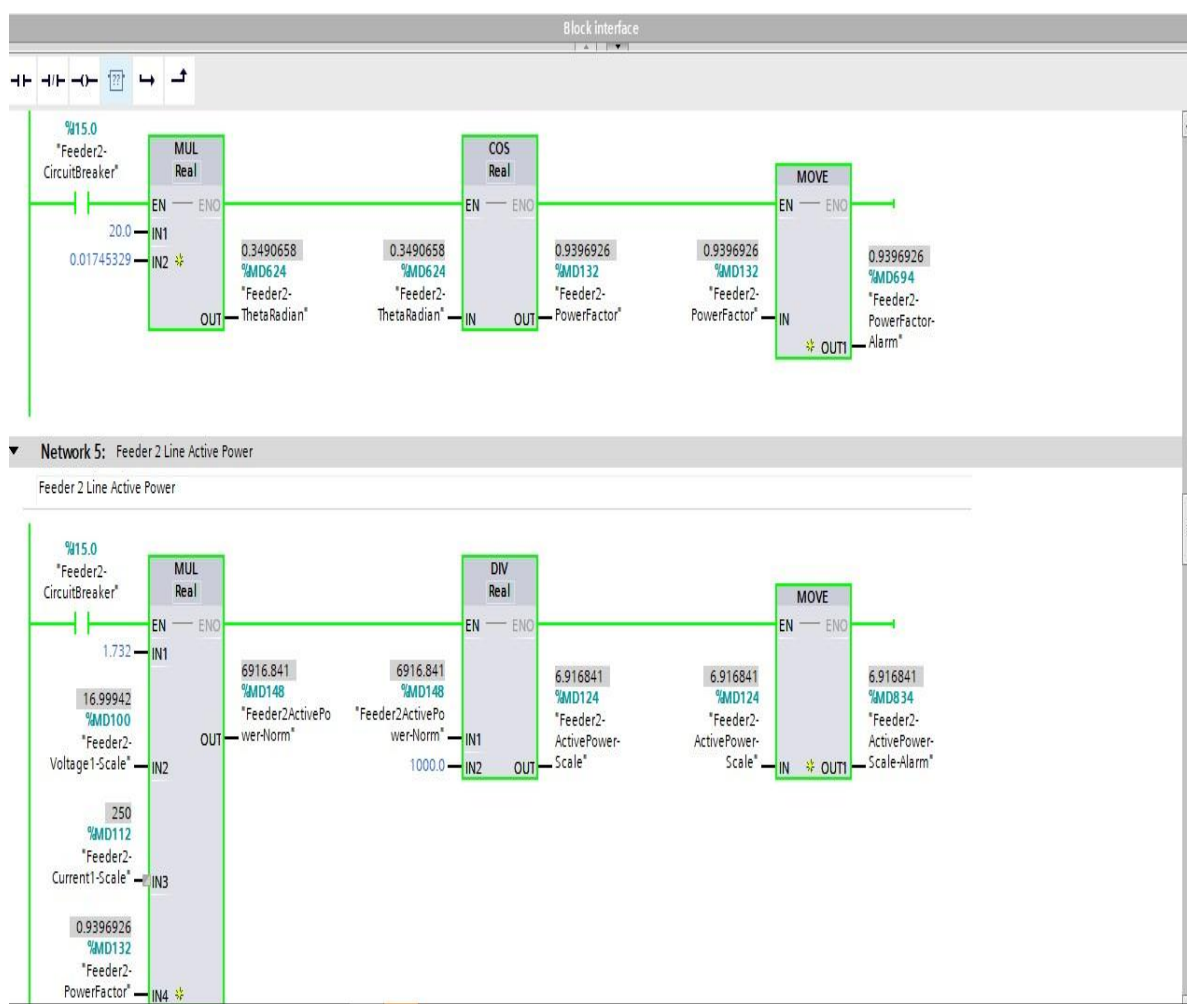


Figure 4. 20 Feeder 2 Line Power Factor and Line Active Power PLC Ladder Diagram

Referring to the power factor block, the first block is the multiplication or conversion block that converts the given input degree in to electrical radian degree to have electrical parameter. Since power factor is the cos theta of the given degree in radian, the second block, the cosine block gives the cosine value of the given degree. As indicated above, this is the power factor of the present system. The last block that is the move block connected to the alarm circuit for the purpose of obtaining alarm texts during fault.

For the active power block, the multiplication block calculates the three-phase active power. The second block is the division block which converts the three- phase power in Mega Watts. The move block is then connected to the alarm circuit to get an access of alarm texts during fault.

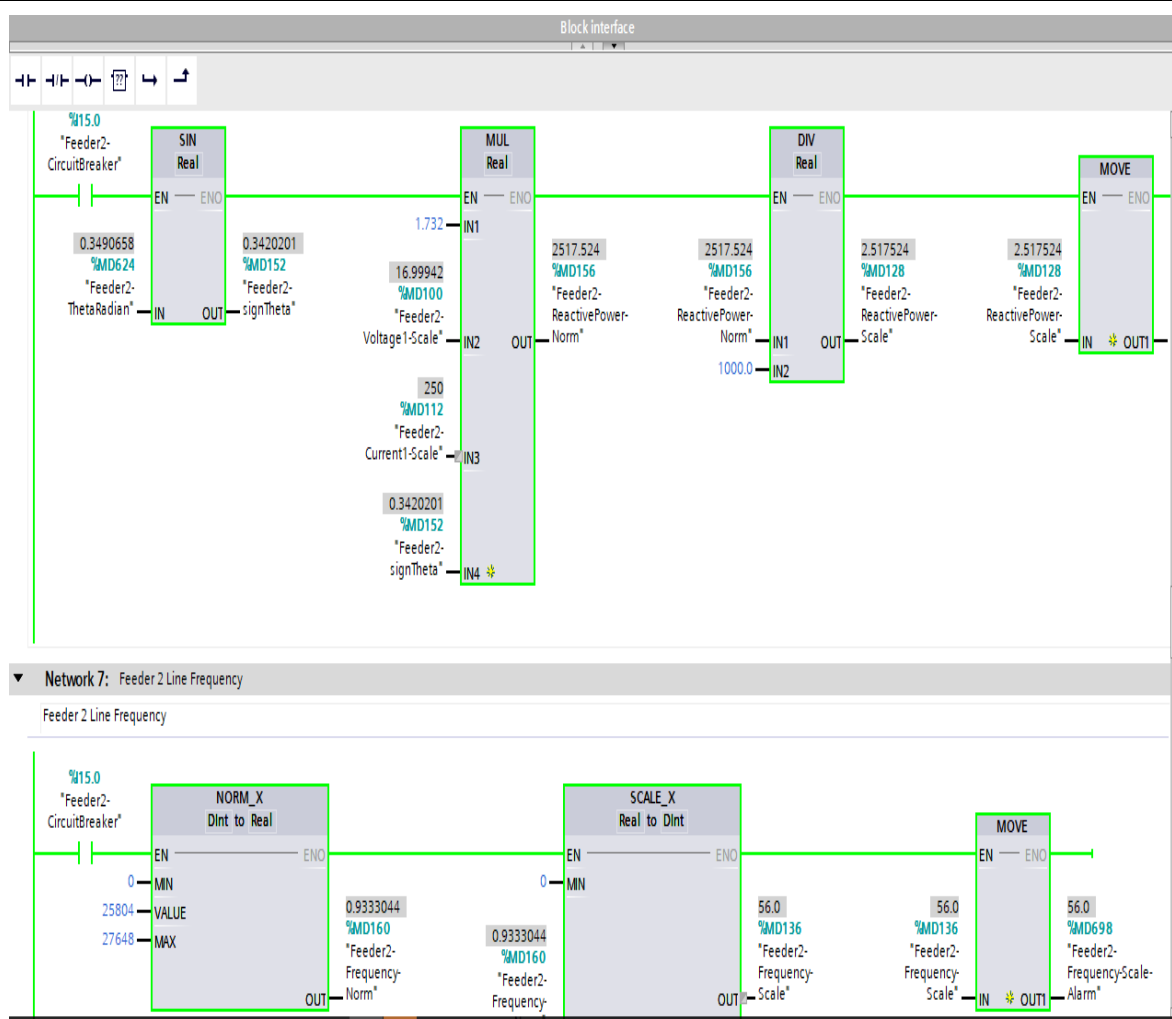


Figure 4. 21 Feeder 2 Line Reactive Power and Line Frequency PLC Ladder Diagram

Referring to the above diagrams, For the Reactive power block the first block the sine block that converts the radian value of the given degree in to its sine value. The multiplication block calculates the total three phase reactive power of the system. The division block converts the total reactive power of the system in to equivalent unit, that is MVAR. To obtain alarm texts during fault condition the move block should be connected to the alarm circuits.

The operating principle of all the blocks in the line frequency is the same as the operating principles of all the respective block of the line voltage blocks and line current blocks except that the frequency blocks process the frequency of the system.

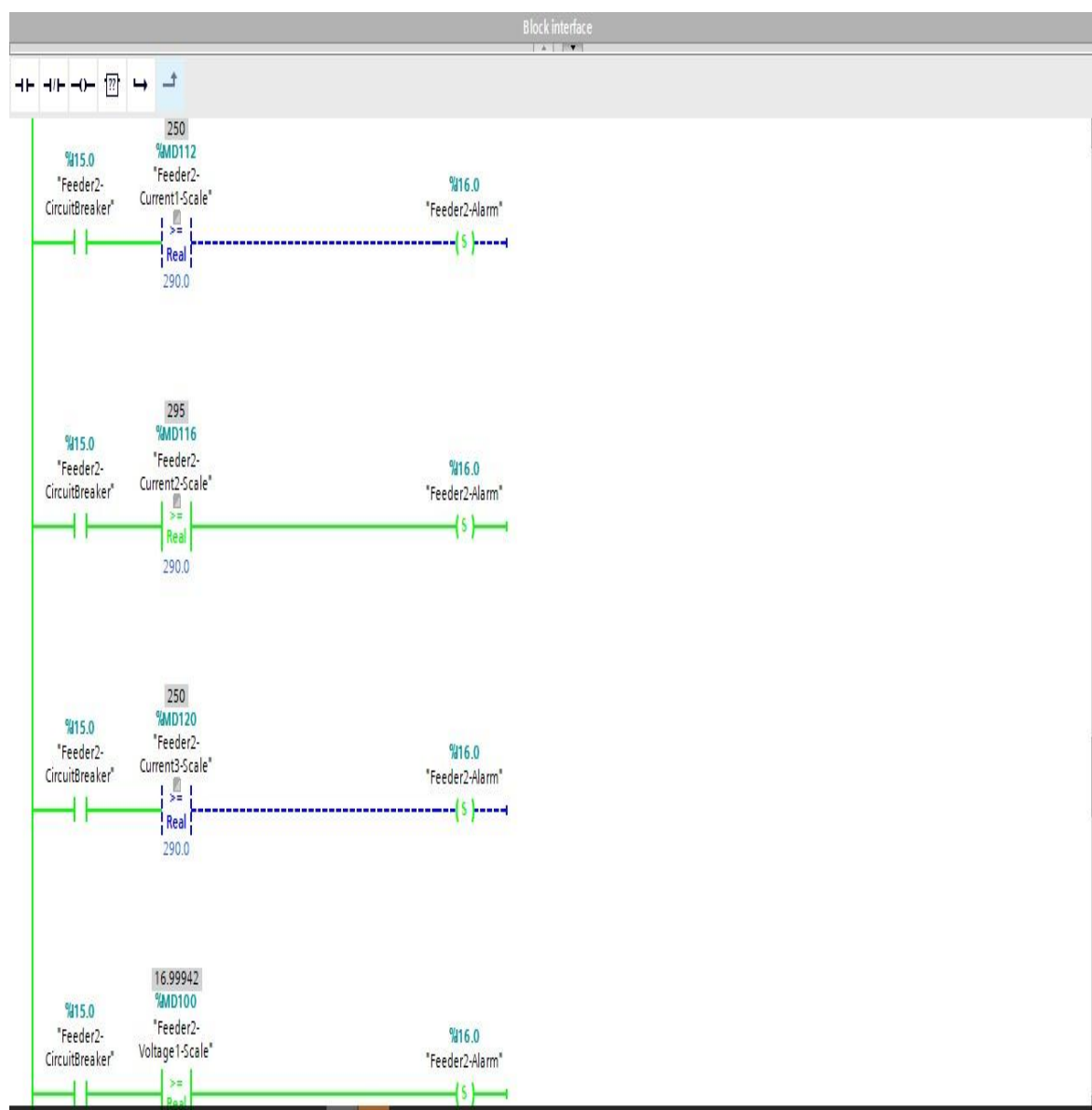


Figure 4. 22 Feeder 2 Alarm Circuit PLC Ladder Diagram Simulation Results.

Here I2 and V1 alarm circuits are activated. The above figure depicts us the three-line currents I1 and I3 all are under the predetermined values. But Line2 is in Over current condition and Line1 is in Over voltage situation. The alarm Circuit of Line1 and Line2 are activated to open the Circuit Breakers of the respective Circuit. Each circuit is connected to its respective alarm circuits to activate the circuit breakers to be operated to protect the system from damage under fault conditions.

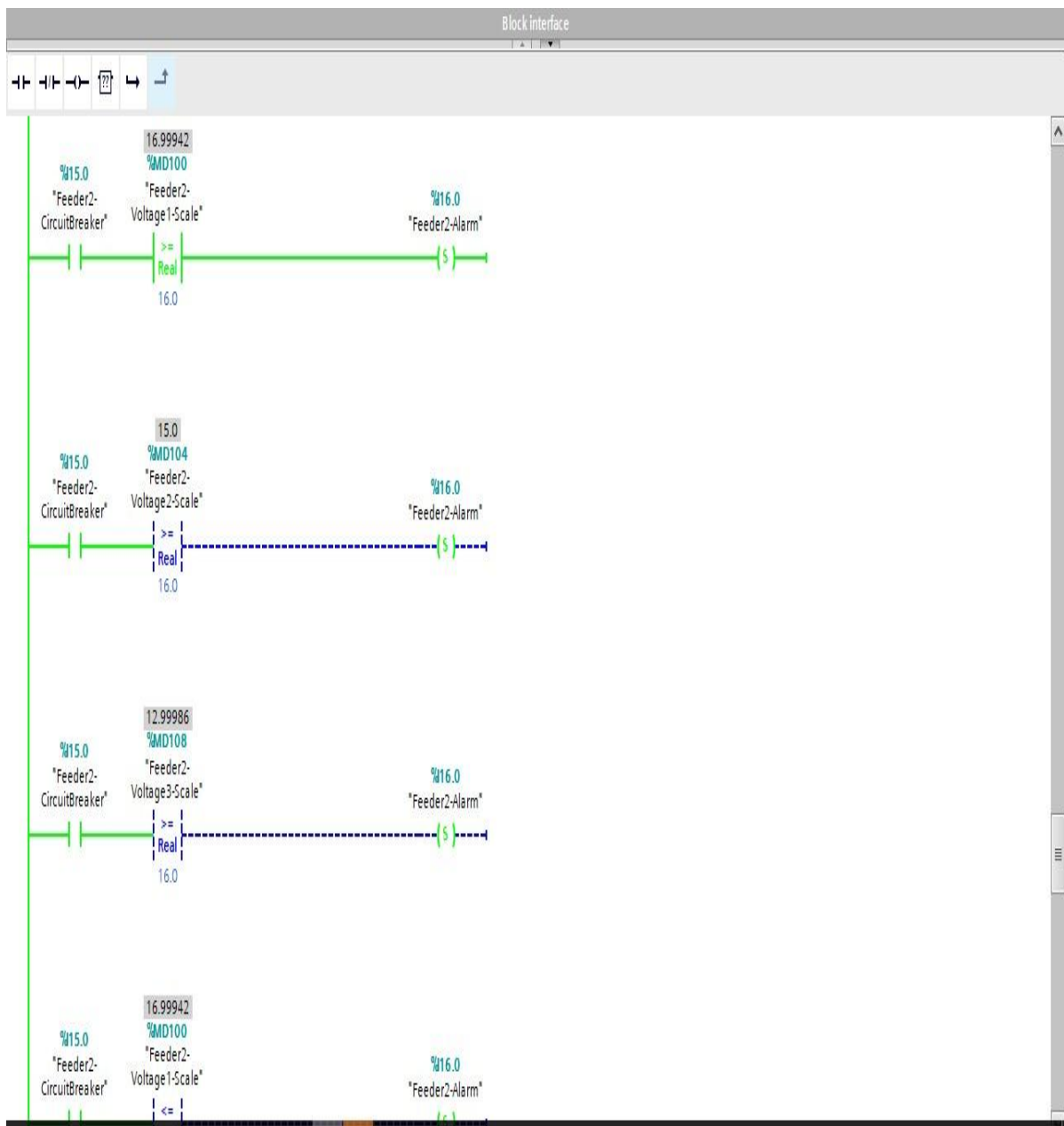


Figure 4. 23 Feeder 2 Alarm Circuits PLC Ladder Diagram Simulation Results

Here V1 Alarm is activated. In the above figure, the simulation result shows there is over voltage problems in Line1 that is why the alarm Circuit is activated. All the other parameters are within the predetermined values. Hence they are in normal condition. Each circuit is connected to the alarm circuit to activate the circuit breakers to be operated when they get a control signals from the alarm circuit to protect any device under control.

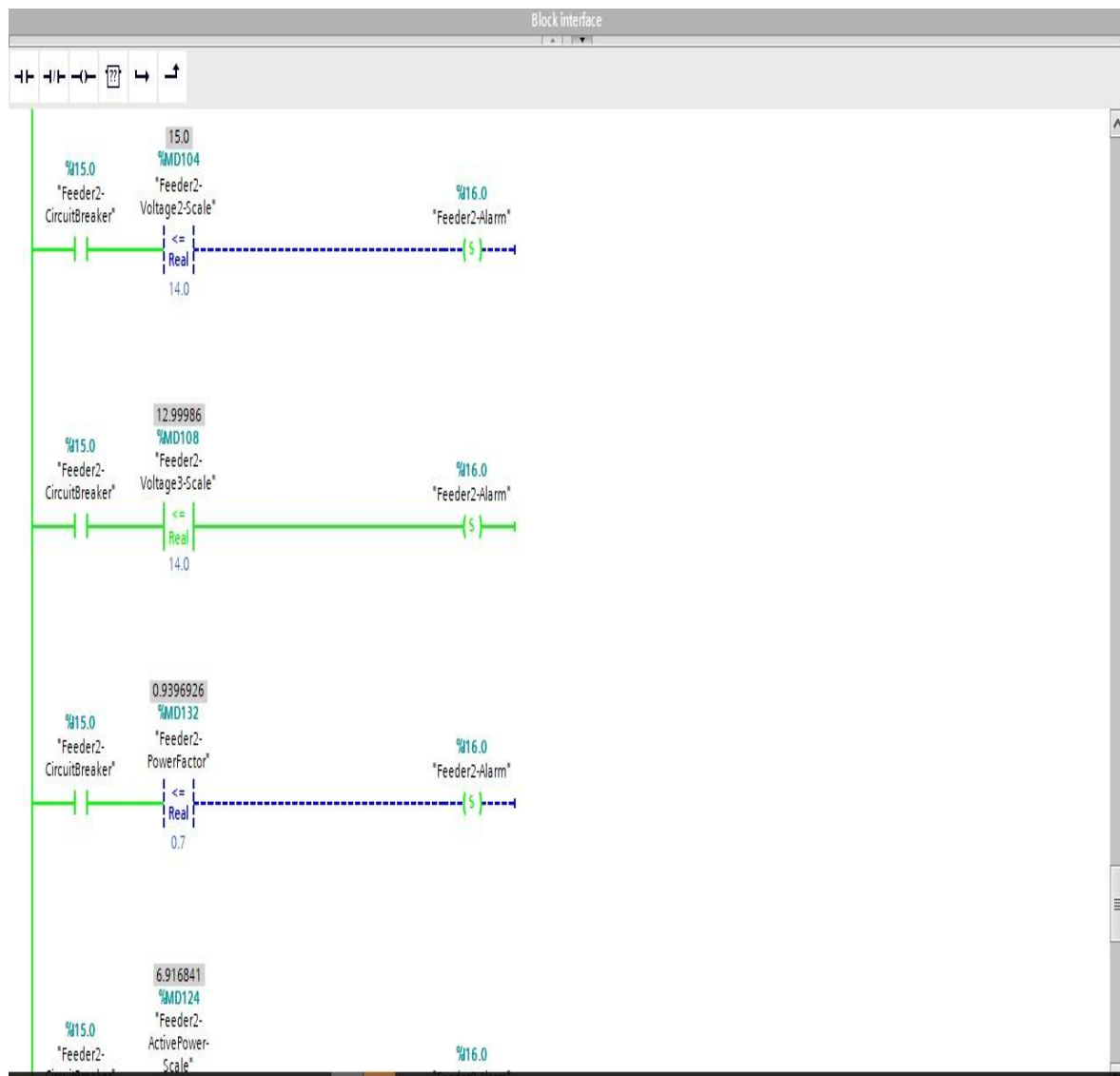


Figure 4. 24 Feeder 2 Alarm Circuits PLC Ladder Diagram Simulation Results.

Here V3 Alarm alarm circuit is activated. In the above figure, the simulation result shows there is Under voltage problems in Line3 that is why the alarm Circuit is activated. All the other parameters are within the predetermined vales. Hence they are in normal condition. Each circuit is connected to the alarm circuit to activate the circuit breakers to be operated when they get a control signals from the alarm circuit to protect any device under control.

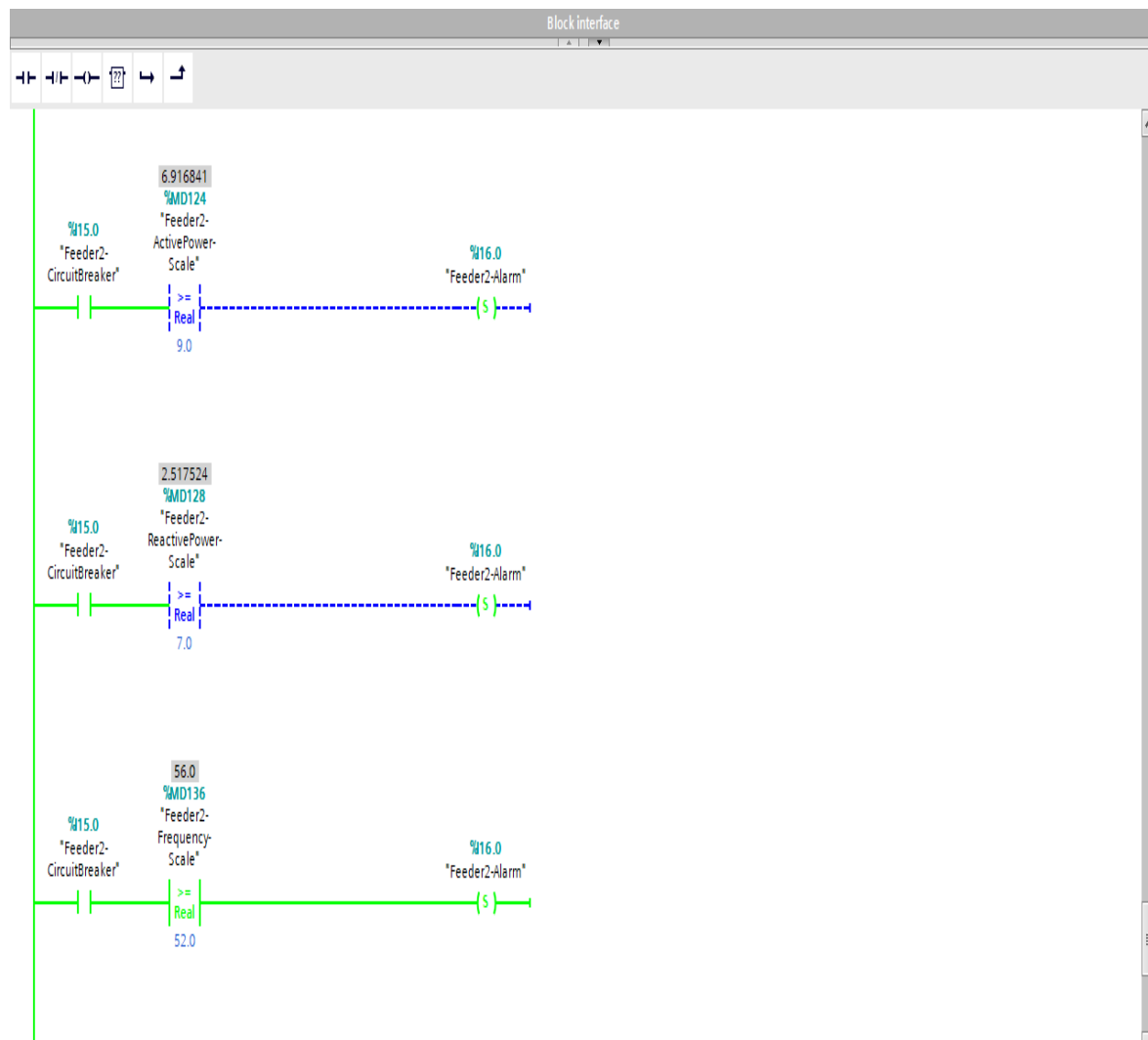


Figure 4. 25 Feeder 2 Alarm and Timer Circuit PLC Ladder Diagram Simulation Results

Here the Frequency Alarm Circuit is Activated. Referring to figure 4.25, the simulation result shows us the two described electrical parameters (i.e. Active power, and Reactive power) are within the predetermined values. But there is an Over frequency problem in the system(56Hz). If any one of the parameters is out of the predetermined values, the alarm circuit cross-ponding to it will be green (in this case the frequency alarm circuit) to initiate the circuit breaker to be operated. After some seconds this breaker takes an action (opens) to protect the system from damage.

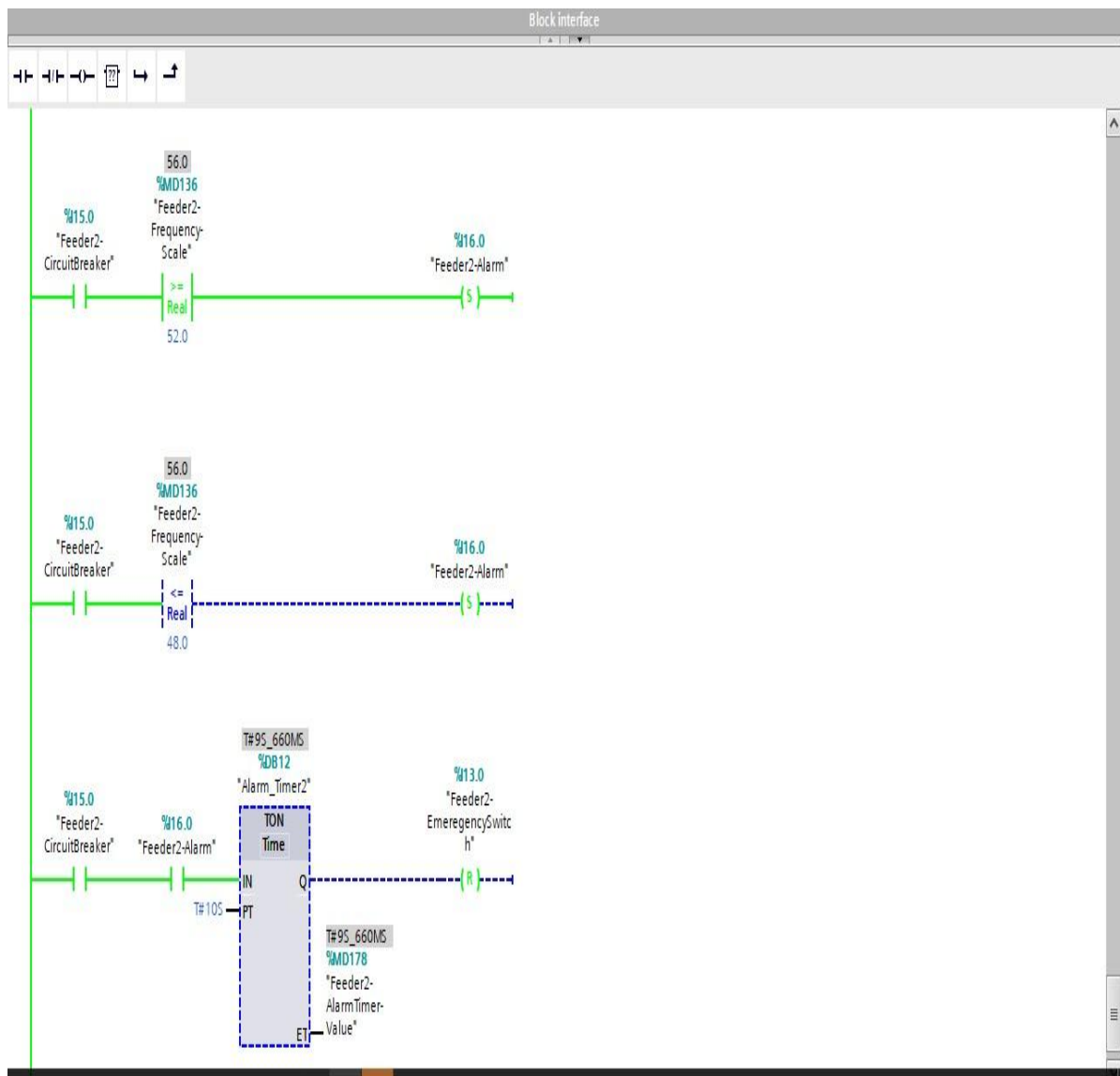


Figure 4. 26 Alarm and Timer Circuit PLC Ladder Diagram Simulation Results

Here the Frequency Alarm Circuit and Timer Circuits Are Activated. Referring to figure 4.26, the simulation result shows us there is an Over frequency problem in the system (56Hz). If any one of the parameters is out of the predetermined values, the alarm circuit cross-ponding to it will be green (in this case the frequency alarm circuit) to initiate the circuit breaker to be operated. After some seconds this breaker takes an action (opens) to protect the system from damage.

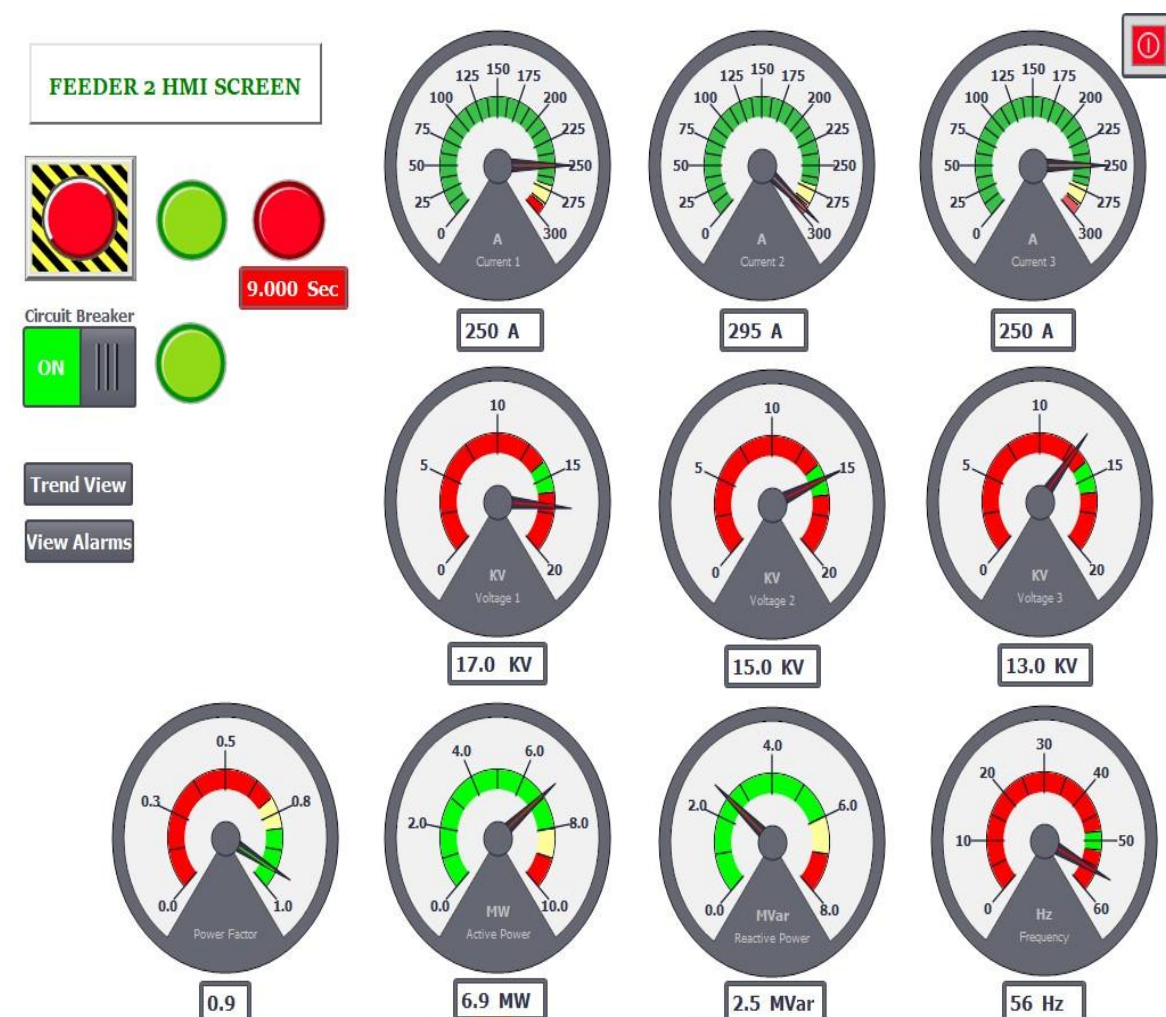


Figure 4. 27 HMI screen

In the above figure, the HMI screen showed the abnormal condition of the substation status. The status showed at 9.00 seconds. I_2 is over current, V_1 is overvoltage condition, V_3 is under voltage condition and Frequency is over. The rest parameters are in normal condition. The alarm is on and alerts the operator to take the necessary action. If the operator didn't take an action, the circuit breaker opens after 10seconds so as to protect the system.

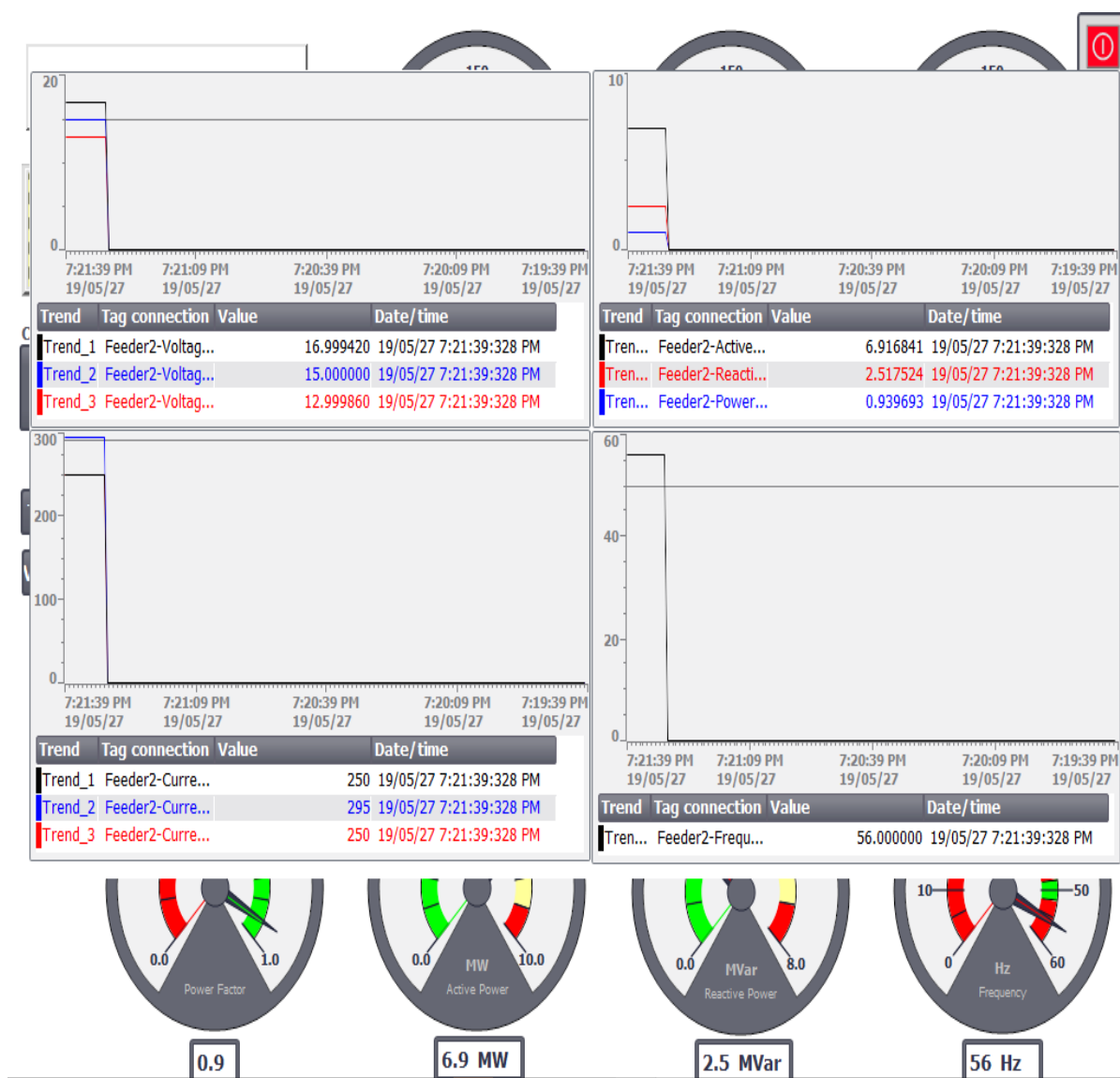


Figure 4. 28 Trends

The trends on the above screen described as the different electrical parameters. These are line voltages, line currents, active power, reactive power and frequency.



Figure 4. 29 Alarm text abnormal conditions

Since feeder 2 is in abnormal conditions, the SCADA system opened the circuit breaker to protects the system. After the circuit breaker is opened texts displayed on the operator screen in the following manner:

Feeder 2 high frequency problem

Feeder 2 line 3 shows under voltage due to short circuit

Feeder 2-line 1 overvoltage problem

Feeder 2 line2 overcurrent problem

In general, the simulation result depicted as High reliability of the power system operation. Thus, Increased the efficiency of the power system distribution and Highly cost effective (Reduce maintenance cost. It Quickly indicates and identifies the fault and increases power reliability by reducing the frequency and duratation of interruption / power outage/.

The system warns the operator before the fault by sending alarm signals. Due to this, the operator can check, Monitor, control and take the necessary action before the fault happens. In addition, the operator can check the real status of the substation.

The system restores the power in a short period of time to avoids the unnecessary arguments between the utility and the customers. Therefore, the system improves service quality that satisfies power demands of the consumer

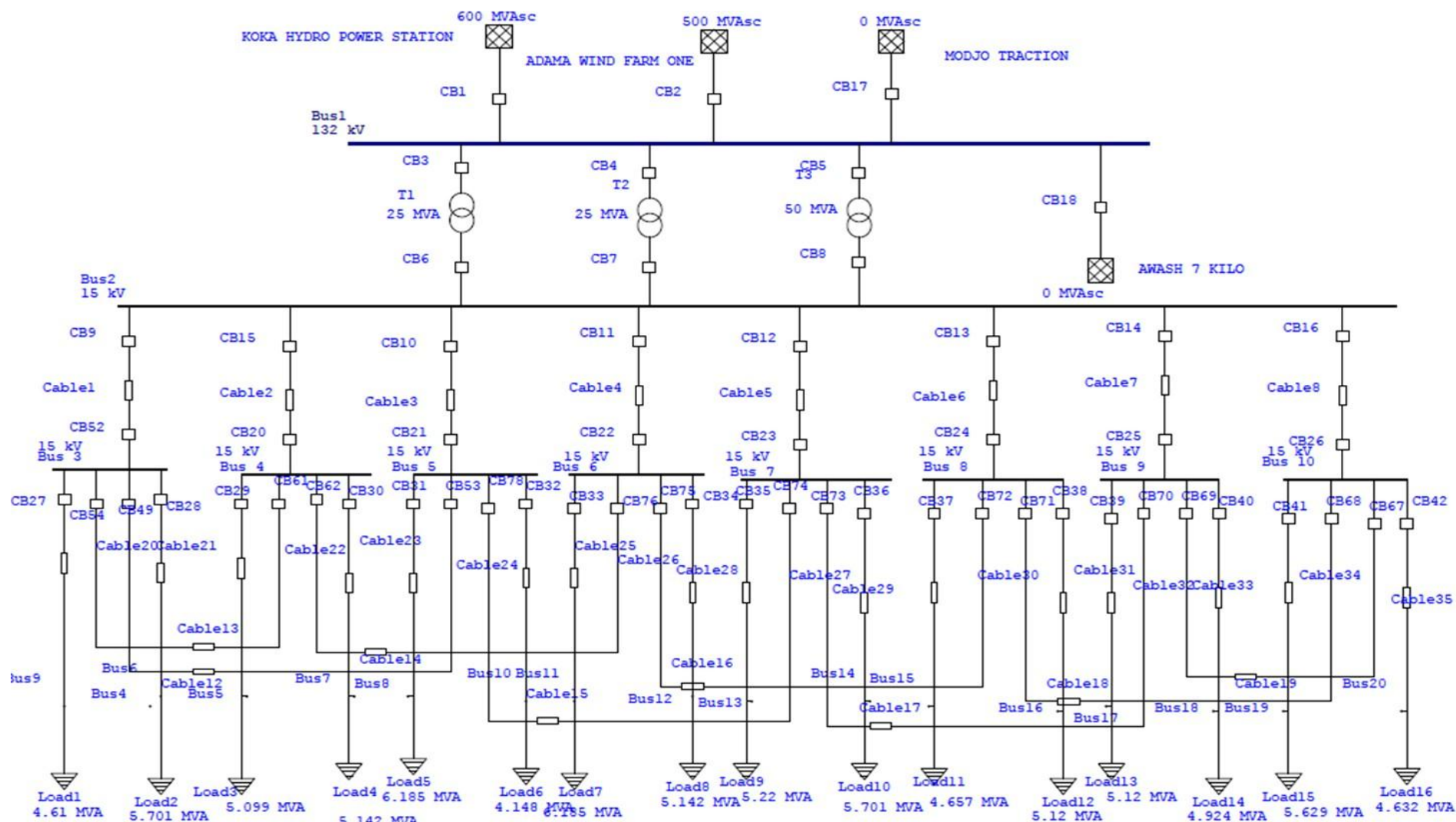


Figure 4. 30 proposed design of Substation to improve reliability

4.2. Result and Discussion of the system Before SCADA

Table 4. 2 Summary of reliability before SCADA

Project:	ETAP	Page:	1
Location:	12.6.0H	Date:	03-07-2019
Contract:		SN:	
Engineer:		Revision:	Base
Filename:	Study Case: RA	Config.:	Normal
Kedir			

System Indexes

SAIFI	312.0614 f / customer/year
SAIDI	428.8393 hr / customer/year
CAIDI	1.374 hr / customer interruption
ASAI	0.9510 pu
ASUI	0.04895 pu
EENS	31894.070 MW hr / yr
ECOST	0.00 \$ / yr
AENS	1993.3790 MW hr / customer/year
IEAR	0.000 \$ / kW hr

SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
CAIDI	Customer Average Interruption Duration Index
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
EENS	Expected Energy Not Supplied
ECOST	Expected Interruption Cost
AENS	Average Energy Not Supplied
IEAR	Interruption Energy Assessment Rate

From table 4.2 above, it can be seen that the simulated base case system reliability indices resulted in a value for SAIFI 312.0614 times/customer/year, SAIDI 428.8393 Hrs/customer/year and the Energy not supplied is 31894.070 MWhr/year. This shows us Adama distribution substation doesn't meet the requirements set by the regulatory body that is, either Ethiopian Electric Agency (EEA) or IEEE standards.

4.3. Result and Discussion of the system After SCADA

Table 4. 3 Summary of reliability after SCADA

Project:	ETAP	Page:	1
Location:	12.6.0H	Date:	02-07-2019
Contract:		SN:	
Engineer:		Revision:	Base
Filename: reliability and summery	Study Case: RA	Config.:	Normal

SUMMARY

System Indexes

SAIFI	108.2489 f / customer/year
SAIDI	144.6856 hr / customer/year
CAIDI	1.337 hr / customer interruption
ASAI	0.9835 pu
ASUI	0.01652 pu
EENS	10788.200 MW hr / yr
ECOST	0.00 \$ / yr
AENS	674.2622 MW hr / customer./year
IEAR	0.000 \$ / kW hr

From the above table 4.3 it can be seen that PLC based SCADA system is applied to the MV Feeders (Switching substations) and the simulation is conducted. The result of the simulation shows that the overall system improvement in the indices SAIFI, SAIDI and ENS is 65.31%, 66.26% and 66.175% respectively. Thus we can say that SCADA system has definitely increased the reliability and performance of the power distribution system of the substation.

CHAPTER FIVE

5. Conclusion and Recommendation

Based on the results obtained from this research work on automatic monitoring, control, protection and reliability problems of Adama distribution substation and the simulation conducted with PLC based SCADA system for mitigating the automatic monitoring, reliability and overloading problems, the following conclusions and recommendations have been made.

5.1. Conclusion

The main purpose of Energy management system (EMS) or SCADA system is to generate, transmit and distribute electrical energy effectively and efficiently. The main function of SCADA is to supervise, control and manage power networks in an integrated manner. The whole distribution can be seen on displayed screen and periodic data changes can be acquired automatically.

This research work shows that the reliability of Adama distribution substation does not meet the requirements set by the regulatory body that is, Ethiopian Electric Agency(EEA)or IEEE standards. The System Average Interruption Frequency Index(SAIFI) at the substation is 312.0614 interruptions per customer per year and the System Average Interruption Duration Index(SAIDI) is 428.8393 hours per customer per year at the existing system. Also there is high unavailability of electric power in the distribution network due to poor Energy Management System. In the base case study there is a huge loss of unsupplied energy due to planned and unplanned outages. Therefore, there is a higher vulnerability in terms of reliability worth; ENS (31894.070 MWh/ year) PLC based SCADA system was proposed to be used to the seven feeders (L1, L2, L3, L4, L5, L6 and L7) which experience more interruptions. As a result of this SCADA, the overall monitoring, controlling and protection system to increase the reliability and performance the power distribution network is improved. So PLC based SCADA should be applied on each switching substations to reduce the frequency and duration of power interruption and increase quality of service.

Based on the simulation result, the application of PLC based SCADA system on each switching substation were achieved 65.31 % improvement in SAIFI value and 66.26 % improvement in SAIDI value ENS 66.175%. Thus Ethiopian Electric Utility can apply PLC

based SCADA system to reduce costs of operation, to increase service quality and satisfy consumer demands.

5.2. Recommendation

In power distribution SCADA system, the data acquisition is accurate, and the data storage, measurement, parameter adjustment and various signal alarms of substation can be realized. It reduces the pressure of electricians on duty, ensuring the safe and reliable power supply. Power distribution SCADA system greatly improves the degree of automation in terms of remote meter reading, data archiving and analysis. It can achieve the digitalized and intelligent substation and scientific management, which has broad application prospects. This thesis recommends and urge Electric Utilities to use SCADA systems for Electrical Distributions because it is said to be the brain of Energy Management System by contributing the following benefits for Electrical Distribution system.

- Increases reliability power distribution through Automation.
- Eliminates the need for manual data collection.
- Alarms and system-wide monitoring enable operators to quickly spot and address problems.
- Automation protects workers by enabling problem areas to be detected and addressed automatically.
- Operators can use powerful trending capabilities to detect future problems, provide better routine maintenance of equipment and spot areas for improvement.
- Historians provide the ability to view data in various ways to improve efficiency.

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Appendix A Substation status

Table A:1 substation status data Recorded on date 06/11/2009 E.C

Substation status																				
Feeders	7:00 Hour					9:00 Hour					11:00 Hour					19:00 Hour				
Lines	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15.1	260	6.6			15	305	7.8			15	290	7.5			15	323	8		
L2	15.1	250	6.4			15	290	7.6			15	280	7			15	290	7.6		
L3	15.1	273	6.8			15	300	7.8			15	310	8			15	295	7.7		
L4	15.1	220	5.8			15	280	7			15	285	7			15	260	6.6		
L5	15.1	200	5.4			15	260	6.4			15	240	6.2			15.1	220	5.8		
L6	15.1	45	1.0			15	60	1.4			15	55	1.3			15.1	42	1.0		
L7	15.2	208	5.2			15	180	5			15	160	4.8			15	280	7		
TR I	15.1	620	16.5	6		15	672	17	7		15	680	17	7		15	830	21	8	
TR II	15.1	620	16.5	6		15	672	17	7		15	680	17	7		15	830	21	8	

V = Voltage (KV)

P= Active Power (MW)

PF = Power factor

I = Current (A)

Q = Reactive Power (MVAR)

L6 (I >>) is opened at 7:00Hr due to short circuit L1 (I =323 A) at 19:00Hr is over loaded

L6 (I >>) is opened at 9:00Hr due to the same case L6 (I >) is opened at 19:00Hr due to over load

Table A : 2 substation status data Recorded on Date 25/12/2009 E.C

Substation Status																				
Feeders	7:00 Hour					9:00 Hour					11:00 Hour					19:00 Hour				
Lines	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15.1	180	5.0			15	170	4.5			15	220	5.2			15	240	6.0		
L2	15.1	120	2.8			15	220	5.0			15	240	5.6			15	260	6.5		
L3	15.1	170	4.2			15	240	6.0			15	230	5.8			15	250	6.6		
L4	15.1	160	4.0			15	190	5.4			15	260	5.5			15	210	5.2		
L5	15.1	130	3.0			15	250	6.0			15	252	6.0			15	240	6.1		
L6	15.1	120	3.1			15	150	4.0			15	150	4.0			15	100	2.2		
L7	15.1	120	2.8			15	170	4.6			15	170	4.6			15	160	4.4		
TR I	15.1	500	13	6		15	600	16.6	7		15	610	16.6	7		15	680	17	7	
TR II	15.1	500	13	6		15	600	16.6	7		15	610	16.6	7		15	680	17	7	

V = Voltage (KV)

P= Active Power (MW)

PF = Power factor

I = Current (A)

Q = Reactive Power (MVAR)

Table A: 3 substation status data Data Recorded on Date 01/02/2010 E.C

Feeder Lines	Substation Status																			
	7:00 Hour					9:00 Hour					11:00 Hour					19:00 Hour				
	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	P.F
L1	15.1	209	5			15.1	180	4.6			15	180	4.4			15	210	5.2		
L2	15.1	290	7.4			15.1	295	7.5			15	305	7.7			15	320	8.1		
L3	15.1	240	6			15.1	230	6			15	240	5.8			15	290	7.6		
L4	15.1	200	5.2			15	200	5			15	205	5.2			15	230	5.6		
L5	15.1	210	5.4			15	240	6			15	260	6.6			15	220	5.2		
L6	15.1	120	2.9			15	120	2.6			15	45	1.2			15	200	5		
L7	15.1	32	1.0			15	110	2.2			15	110	2.2			15	43	1.2		
TR I	15.1	720	18	5		15.1	640	16	10		15	680	17	12		15	730	19	11	
TR II	15.1	720	18	5		15.1	640	16	10		15	680	17	12		15	730	19	11	

V = Voltage (KV)

P= Active Power (MW)

PF = Power factor

I = Current (A)

Q = Reactive Power(MVAR)

L7 (I >) is opened at 7:00Hr due to over load L7 (IE >) is open at 19:00Hr due to ground fault

L6 (I >) is opened at 11:00Hr due to over load L2 (I=320 A) at 19:00Hr is over loaded

Table A: 4 substation data Recorded on Date 22/02/2010 E.C

Feeder	7:00 Hour					9:00 Hour					11:00 Hour					19:00 Hour				
Lines	V	I	P	Q	PF	V	I	P	Q	P.F	V	I	P	Q	P.F	V	I	P	Q	PF
L1	15	225	5.4			15	190	4.6			15	198	5			15	240	6		
L2	15	320	8.2			15	290	7.6			15	330	8.2			15	299	7.8		
L3	15	300	7.6			15	210	5.2			15	260	6.4			15	295	7.4		
L4	15	240	6			15	200	5			15	180	4.4			15	210	5.2		
L5	15	150	3.6			15	240	6			15	260	6.4			15	210	5		
L6	15	140	3.4			15	170	4.4			15	190	4.8			15	180	4.4		
L7	15	130	3.2			15	120	2.6			15	110	2.2			15	150	3.6		
TR I	15	790	21	8		15	650	16	7		15	720	15	10		15	750	19	11	
TR II	15	790	21	8		15	650	16	7		15	720	15	10		15	750	19	11	

V = Voltage (KV)

P= Active Power (MW)

PF = Power factor

I = Current (A)

Q = Reactive Power(MVAR)

L2 (I=320 A) at 7:00Hr is over loaded

L2 (I=330 A) at 11:00Hr is over loaded

Appendix B: Simulation Result of Feeder Four

