UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPLICATION OF DISTRIBUTION AUTOMATION SYSTEM (DAS) FOR LOW VOLTAGE SUBSTATION

This report is submitted in accordance with the requirement of Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electrical Engineering Technology (Industrial Power) with Honours

by

SELVAKUMAR S/O K.MARIAPPAN

B071310462

FACULTY OF ENGINEERING TECHNOLOGY

2016

"I hereby declare that I have read through this report entitle " **Application Of Distribution Automation System (DAS) For Low Voltage Substation"** and found that it has complied the partial fulfilment for awarding the Degree of Bachelor Of Electrical Engineering Technology (Industrial Power) With Honours"

Signature :...

Supervisor Name :...

Date :...

APPLICATION OF DISTRIBUTION AUTOMATION SYSTEM (DAS) FOR LOW VOLTAGE SUBSTATION

Submitted By:

SELVA KUMAR S/O K.MARIAPPAN

B071310462

A progress report submitted in partial fulfilment of the requirement for the degree of

Bachelor Of Electrical Engineering Technology

(Industrial Power) With Honours

Faculty of Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

(UTeM)

2016

"I declare that this report entitle " **Application Of Distribution Automation System (DAS) For Low Voltage Substation"** is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidate of any other degree."

Signature : ....

Name : SELVA KUMAR S/O K.MARIAPPAN

Date : ....

Dedicated to my beloved parents,

Mariappan S/O Kandasamy

Balger Kaur D/O Terlock Singh

ACKNOWLEDGEMENT

First and above all, I would like to thank my beloved parents for their prayers and blessings that kept me motivated throughout this journey. Plus, my lovable thanks to my sweetheart, Kanageswari Satianarainan for believing in me even when I didn't believe in myself. I tried my best and gave full commitment to finish this project at the right time as required. I would like to express my deepest thanks to, Assoc. Prof. Mohd Ariff Bin Mat Hanafiah, my supervisor for the Final Year Degree Project at Faculty of Engineering Technology, for giving me many advices, ideas, guidance and motivations to complete this assignment. His flexibility gave me the opportunity to complete this task without any pressures and headaches.

Also, my deepest thanks to my project evaluator, Madam Siti Nur Suhaila Binti Mirin for her advices and guidance which contributes to the success of this project. Do not forget my deepest thanks and appreciation to my family members and friends for their cooperation, encouragement, constructive suggestions, and full of support for the project completion, from the beginning till the end. A sincere thanks to "Gym Master" Kugaishan for lending his car in order to ease my travelling to laboratories for project construction. Thanks to all those who have contributed directly or indirectly by supporting my work and helped me during this final year project completion. Last but not least, thanks to God for allowing me to complete this task with His blessings.

ABSTRACT

Distribution Automation System (DAS) is the technology implemented in electric power system on distribution level. Some of the electric components on distribution level are automated in order to improve the service reliability and efficiency. One of the purposes of DAS is to increase the reaction speed during outages and reduce the outages duration. Therefore, in this study, a DAS technology is built in a low voltage (LV) substation so that a Fault Location, Isolation and Service Restoration (FLISR) can be implemented. A Human Machine Interface (HMI) is constructed using Indusoft software. The HMI provides the Supervisory Control and Data Acquisition (SCADA) operations for the system so that it can be monitored and controlled remotely.

ABSTRAK

Automasi Sistem Pengagihan (DAS) adalah teknologi yang diaplikasikan dalam sistem elektrik pada tahap pengagihan. Sesetengah komponen-komponen elektrik di peringkat pengagihan diautomasikan untuk meningkatkan kebolehpercayaan dan kecekapan perkhidmatan elektrik. Salah satu tujuan DAS adalah untuk meningkatkan kelajuan tindak balas semasa gangguan dan mengurangkan tempoh gangguan itu. Oleh itu, dalam kajian ini, satu teknologi DAS dibina pada pencawang voltan rendah (LV) supaya "*Fault Location, Isolation and Service Restoration (FLISR)*" dapat dilaksanakan. Satu "*Human Machine Interface (HMI)*" dibina dengan menggunakan perisian Indusoft. "*HMI*" dapat menyediakan operasi-operasi "*Supervisory Control and Data Acquisition (SCADA)*" untuk sistem ini supaya ia dapat dipantau dan dikawal dari jauh.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGES

CHAPTER	TITLE	PAGES

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

I/O	-	Input/Output
kΩ	-	kiloOhms
kV	-	kiloVolt
mV	-	milliVolt
V	-	Volt

LIST OF ABBREVIATIONS

ABB	-	ASIA Brown Boveri
CDMA	-	Code Division Multiple Access
DAS	-	Distribution Automation System
DNP	-	Distributed Network Protocol
ELCB	-	Earth Leakage Circuit Breaker
FLISR	-	Fault Location, Isolation and Service Restoration
GSM	-	Global System for Mobile Communication
GUI	-	Graphical User Interface
HMI	-	Human Machine Interface
IEC	-	International Electrotechnical Commission
IED	-	Intelligent Electronic Device
IEEE	-	Institute of Electrical and Electronics Engineers
IWS	-	Indusoft Web Studio
KEPCO	-	Korea Electric Power Corporation
LAN	-	Local Area Network
LV	-	Low Voltage
MODEM	-	Modulator/Demodulator
NC	-	Normally Close
NO	-	Normally Open
OLDC	-	Operation Logic Down-Counter
OLUC	-	Operation Logic Up-Counter
PIC	-	Peripheral Interface Controller
PLC	-	Power Line Carrier
PLC	-	Programmable Logic Controller
RS	-	Recommend Standard
RTU	-	Remote Terminal Unit
SCADA	-	Supervisory Control and Data Acquisition
SOE	-	Sequence of Events
TDD	-	Total Demand Distortion
TNB	-	Tenaga Nasional Berhad
UDAS	-	Underground Distribution Automation System
UTeM	-	University Technical Malaysia Melaka
VB	-	Visual Basic
WAP	-	Wireless Application Protocol
WLAN	-	Wireless Local Area Network

WMAN	-	Wireless Metropolitan Area Network
WNIC	-	Wireless Network Interface Card
WPAN	-	Wireless Personal Area Network
WWAN	-	Wireless Wide Area Network

CHAPTER 1

INTRODUCTION

1.1 Project Background

Electricity has become one of the major needs in everyday life, especially with increasing demand for energy nowadays. Electric power system is divided into several parts such as generation, transmission, distribution and load (customers). The power grids transmit electricity at different voltage levels for each part, which are Extra High Voltage (above 230 kV), High Voltage (35 kV to 230kV), Medium Voltage (1 kV to 35 kV), and Low Voltage (up to 1 kV) [1]. Automation of the electric parts or components on distribution level is called Distribution Automation System (DAS), and it is in the Low Voltage level. According to IEEE, "DAS is a system that enables an electric utility to monitor, coordinate, and operate distribution components in a real-time mode from remote locations [2]."

The main purpose of DAS is to remotely control the switches in order to locate faults, isolate the faults and restore the supply services to the consumers [3]. This is known as Fault Location, Isolation and Service Restoration (FLISR). Some of the terms used to describe FLISR are "self-healing" and "smart-grid". FLISR will locate a fault occurred in the distribution power line, isolate the fault by controlling reclosers and sectionalizers, and restore supply to the healthy section of the power system. A Human Machine Interface (HMI) is used to establish a Supervisory Control and Data Acquisition (SCADA) on the system. HMI will interface with the real components in the substation through a communication protocol. In addition, the HMI is a useful component in which aids the operating personnel in handling the system.

In this project, a distribution substation model is build for the DAS application. The distribution substation consists of the incoming, outgoing, and the load. The controller circuit of this substation is based on input and output of ABB RTU560. Moreover, a HMI will be constructed and interfaced with this substation so that its functions can be monitored and controlled from remote locations. Developments will be made so that the distribution substation will be able to perform the FLISR operation.

1.2 Problem Statement

When a fault occurs in distribution power lines, the supply will be interrupted and there will be outage of power. This outage results in disturbances for consumers, especially for industries which wanted to reach a production target. The outages often cost industries a huge amount of money. This affects the reliability and efficiency of the electric utility in providing electric supply. The main challenge for any power distribution utility is to locate or identify the faulty section, isolate them and restore the non faulty sections as quickly as possible. This is impossible to be achieved with manual procedure in which the utility staffs have to patrol in the area for hours to locate the faulty section.

Thus, Distribution Automation System (DAS) provides the solution for this problem. DAS with FLISR implementation will automatically locate the fault, isolate the fault and restore the supply to unaffected areas. The fault can be easily located and repaired by the utility staffs. This saves the time and fuel cost needed for patrolling since the fault can be located and identified through HMI. Furthermore, the operating personnel can monitor and control the automated devices from a remote location via HMI. Thus, the outage time of the distribution supply is mitigated. After the faulty section is repaired and cleared, the DAS will restore the original condition of the distribution system.

1.3 Objectives

The objectives of this project are:

1) To build a low voltage substation prototype with controls circuits for automation implementation.

2) To construct a Human Machine Interface (HMI) using Indusoft software for SCADA purposes.

3) To build a town model which is capable to execute the Fault Location, Isolation, and Service Restoration (FLISR) function.

1.4 Project Scope

The main objective of this project is to build a complete components of the Distribution Automation System (DAS). The substation model will be build by installing the necessary equipments or components in the substation. Some of the devices that are installed in the substation for the automation purposes are Remote Terminal Unit (RTU), Intelligent Electronic Device (IED), and communication protocols. The RTU used is ABB RTU560 while the IEDs used are MK2200 and UMG96S.

MK2200 is an over current and earth fault detection relay, while UMG96S is a universal measuring device used to measure the electric parameters. The communication protocols that are used include RS485, RS232, and IEC61850. These protocols are responsible for communication between the devices. What is more, a Human Machine Interface (HMI) will be constructed using Indusoft software and will be interfaced with the hardware for future development. Indusoft is a powerful and efficient HMI SCADA software platform that provides supervisory control and data acquisition applications [4]. Thus, the operating personals can monitor and control the operation of the substation using the HMI from remote locations.

Besides, a town model will be build and it must be capable to perform the FLISR function so that the substation can perform the self-healing process. The FLISR system will locate the fault, isolate the fault and restore the supply to unaffected areas. Some algorithm will be developed in future and uploaded in the system. The algorithm programs are responsible to make the system to take decisions during fault conditions.

1.5 Contribution of Project

This project is anticipated to contribute to the modernization of electric distribution networks in our country. There are numerous benefits from the implementation of this project. Some of the benefits are to the operational, maintenance, financial, and customers. This project will improve the reliability by mitigating outage duration using auto restoration process. It also provides better fault detection and diagnostic analysis. Besides, it also minimizes man hour and man power in managing the utility.

From financial viewpoint, application of this project increase revenue due to quick restoration. Quick restoration means more power is being sold by the utility. Moreover, utility with the implementation of this project will be customer's first choice because of their improved quality of supply. For customers, they will obtain better service and minimization of interruption cost especially for industrial or commercial customers. Last but not least, this work can be a guideline for other researchers who want to make advancements on this project at the later time.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, it will describe the theoretical information and methods that have been used in order to accomplish the objectives. Numerous studies have been carried out which comprises the hardware and software parts. Moreover, information from previous works also has been analyzed in this chapter. Thus, this chapter provides comprehensible information about the system.

2.2 Distribution Automation System (DAS)

As stated by IEEE, DAS is a system that enables an electric power provider to monitor, coordinate, and operate distribution components or devices in a real-time mode from remote locations [2]. Distribution automation system utilizes the modern communication technologies in carrying out its interaction between devices. The rapid development of communication technologies, such as wireless devices contributes to the feasibility of constructing automation systems.

In addition, DAS consists of SCADA systems which assist the operating personnel in carrying out necessary actions from remote locations. There are 3 levels of architecture for distribution automation system. Level 1 consists of field devices such as switch gears, current transformers, and power transformers. It carries out the measurement of system parameters. In level 2, the protection and control devices such as protective relays, RTUs, and IEDs are situated. The data received from level 1 is processed in this level. On the other hand, level 3 is composed of operator displays and workstations for executing, monitoring, and controlling the program [5].

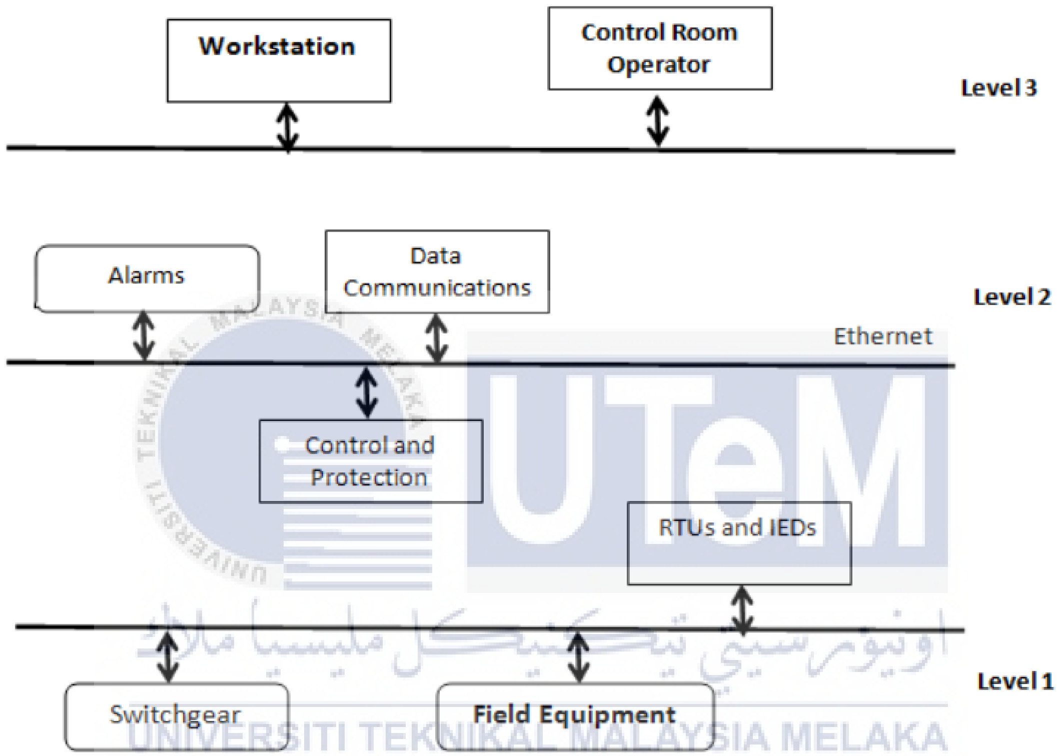

Figure 2.1: Architecture for Distribution Automation System [5].

2.2.1 Benefits of Distribution Automation System (DAS)

The significant benefits of automation are as follows:

a) Enhanced electric service efficiency, quality, and reliability.

b) Mitigate manpower intervention and operating costs.

c) Power outages duration are minimized by the implementation of auto restoration process.

d) Data can be collected and stored for improvement and maintenance of the system.

e) Improvised fault detection and behavior analysis.

f) Quick regeneration contributes to revenue elevation.

g) Interruption cost is mitigated especially for important customers such as industrial and commercial customers.

2.3 Fault Location, Isolation, and Service Restoration (FLISR)

FLISR implementation has the objective of locating a fault on a distribution line, isolating the fault, and restoring service to the healthy sections in an automated fashion without or with slight personnel intervention. FLISR implementation increases reliability and reduces outage duration. It also contributes to efficient use of personnel and resources such as vehicles. In fact, reliability is naturally increased since shorter time is required for locating and isolating the faulted areas, as well as for restoring consumers located on unaffected areas. Figure 2.2 below depicts the comparison of time taken to solve faulted section by FLISR and conventional restoration. On the other hand, Figure 2.3 illustrates a simple FLISR operation.

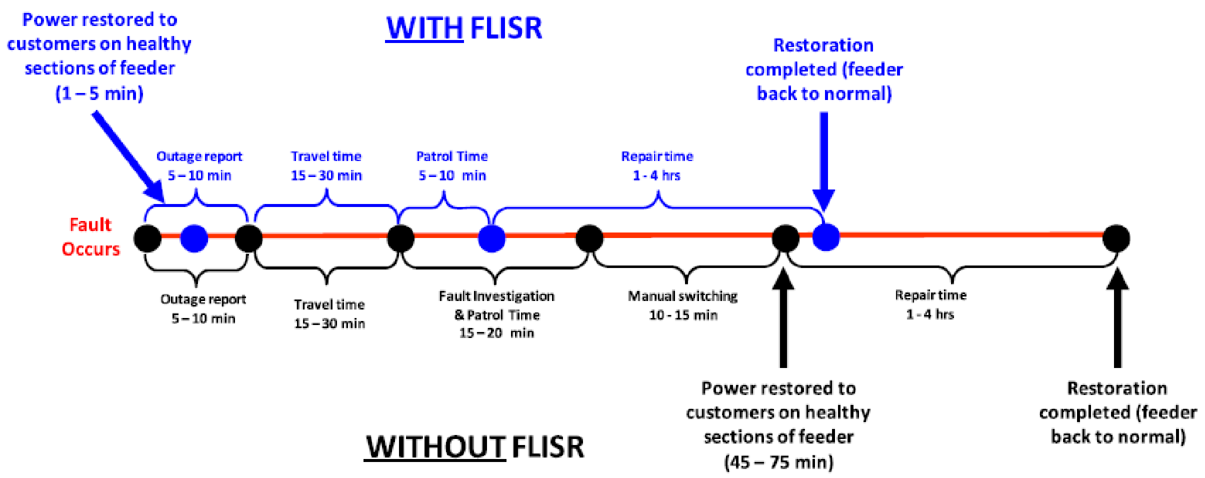

Figure 2.2: Difference between conventional restoration and FLISR implementation [6].

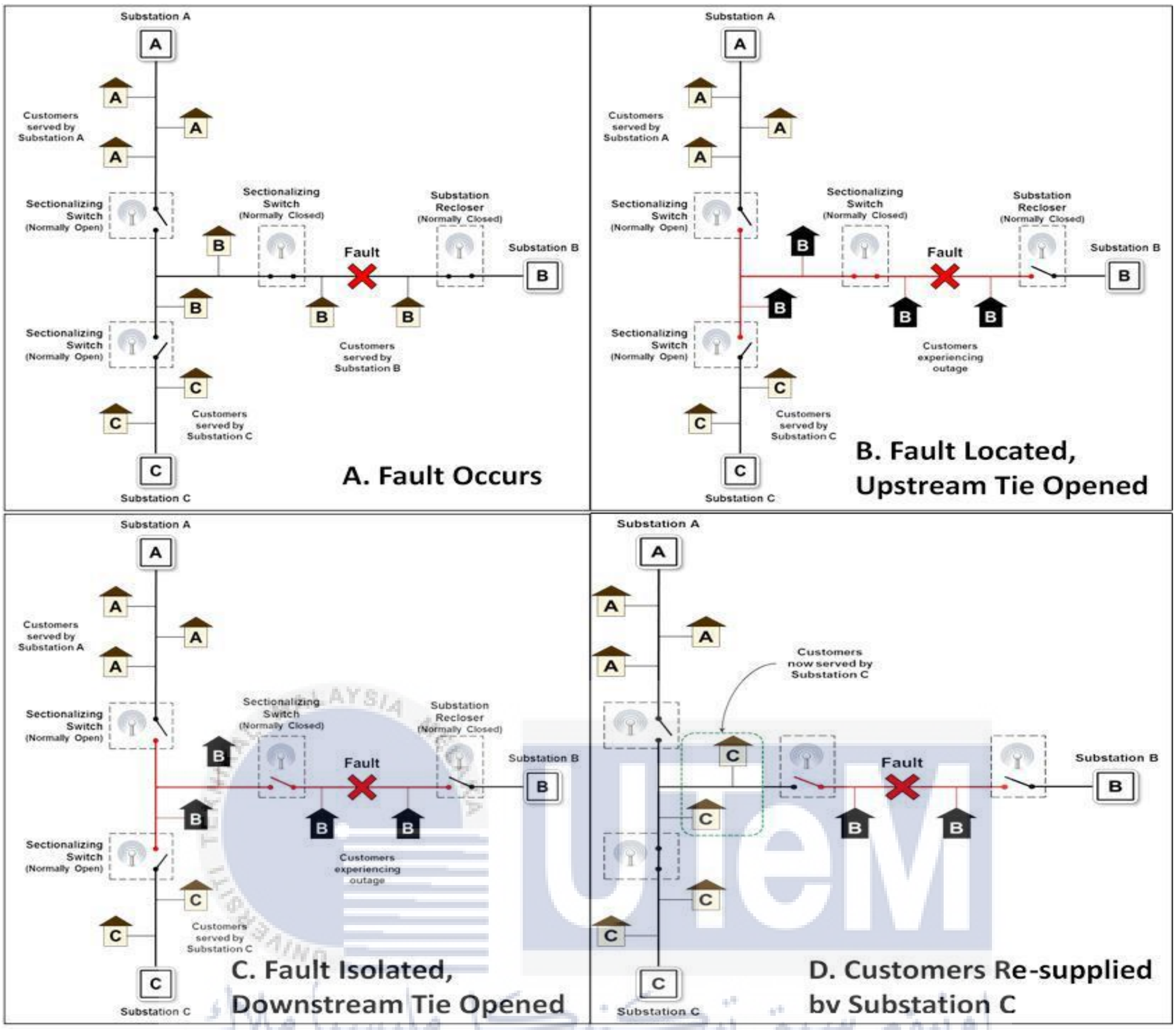

Figure 2.3: Illustration of a simple FLISR operation [7].

2.4 Human Machine Interface (HMI)

Human Machine Interface (HMI) also known as User Interface, Operator Panel or Terminal, provides a method of controlling, monitoring, managing, and visualizing device processes [8]. It is simply the method by which humans interact with machine. It provides a graphical manner that can be used by the users to interact with machines. The users can view all the statuses and data from a monitor. There are many types of HMI software available nowadays. Some of the HMI software is delineated in Table 2.1.

Table 2.1: Types of HMI [9].

Type	Description
Indusoft Web Studio (IWS)	- A full-featured Supervisory Control and Data Acquisition (SCADA) or HMI applications for automation can be constructed. - Uses build-in language, which is simple to use.
Visual Basic (VB)	- A program that constructs a software application using the components provided. - It requires immense understanding in programming languages.
LabVIEW	- Provides a system design platform and development environment for a visual programming language.

2.5 Remote Terminal Unit (RTU)

One of the vital devices for the implementation of SCADA system or DAS is the Remote Terminal Unit (RTU). It basically allows remote monitoring and controlling of substations. RTU plays an important role in allowing the operators at the control center to manage and operate the distribution system. Other than that, it also provides historical data and Sequence of Events (SOE) data for fault analyses. Furthermore, RTUs also offers historical trend data for network planning and monitor plant parameters that can be used for condition based maintenance as well as trend data for predictive based maintenance [10].

2.5.1 ABB RTU211 Basic Functions

One of the RTUs available in the market is the ABB RTU560. Table 2.2 below summarizes the ABB RTU560's features of power quality monitor, fault detection and protection function, communication types, temperature monitoring, and the firmware upgrade. This information represents the ability of the RTU to perform certain required functions. In addition, Figure 2.4 shows the image of ABB RTU560.

Table 2.2: Features of ABB RTU211 [3].

Hardware	**Functionality**
Power Quality Monitor	• Monitors electric parameters such as: a) Power drop and power rise. b) Power interruption. c) Total harmonic distortion (current and voltage).

	d) Current TDD. e) Current unbalance ratio. f) Over and under voltage.
Fault Detection and Protection Function	• Handles new algorithm of fault indicator and restrain inrush current. • Sectionalize operations. • Detects the direction of fault current. • Detects fault in non-grounding feeder. • Save and transmit the current and voltage wave in fault.
Communication Types	• DNP 3.0 • MODBUS • Bluetooth • RS-232, RS-485, Ethernet
Temperature Monitoring	• Provides data on the temperature and humidity readings inside and outside of the control box.
Firmware Upgrade	• Firmware can be upgraded remotely by file transferring function.

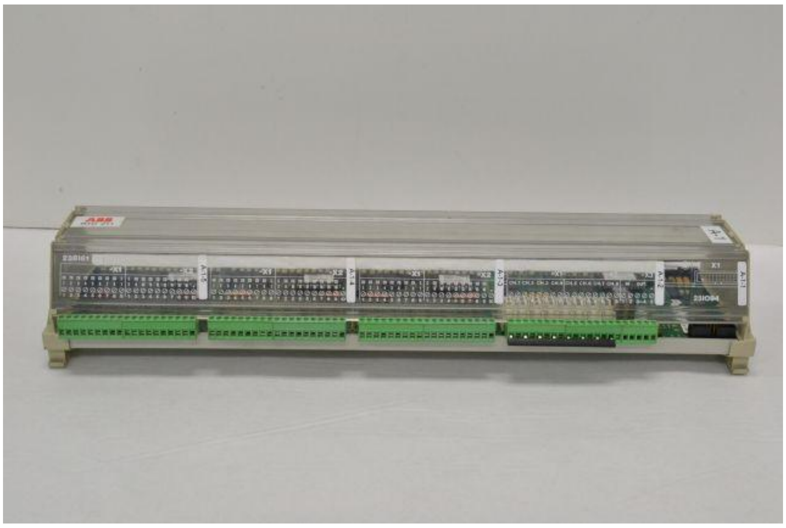

Figure 2.4: ABB RTU 560 [11].

2.5.2 Advantages of Remote Terminal Unit (RTU)

There are numerous advantages of RTU which makes it a good component for DAS implementation. Some of the advantages are [3]:

a) One engineering tool for the whole RTU family.

b) Mitigated operating and maintenance expenses via advanced diagnostic tools.

c) Integrated HMI operations, Programmable Logic Controller (PLC) operations, and network components in one RTU device.

d) Utilization of efficient engineering tools reduces system's construction time.

e) Small-scaled of configurable hardware components for all applications reduces spare part expenses.

2.6 Communication Networks

Communication networks are classified into two types, which are wired and wireless network. Wired network uses cables as a communication medium. Some examples of the wired network are fiber optic cables, power line carrier (PLC), and coaxial metallic cables. Moreover, wireless network usually uses radio waves. Some of the wireless networks are Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN), and Wireless Wide Area Network (WWAN). Table 2.3 below discusses the pros and cons of wired and wireless networks.

Table 2.3: Pros and cons of wired and wireless network [9].

Type	Pros	Cons
Wired Network	• Ethernet cables, hubs, and switched are very cheap. • Some connection sharing software packages are free. • Highly reliable. • Wired LANs provides superior performance.	• Obstacles during cables installation in difficult environments such as through walls, floors, and ceilings. • Cables detachment and frequent faults causing poor connection.
Wireless Network	• Devices do not need to be attached with cables. • Can roam freely within the WLAN signal range.	• Interference in radio waves due to bad weather, other wireless devices, or obstructions like walls.

	• Easy to set up WAP and configure WNIC using a wireless connection.	• If the main device malfunctions, for example the router, the whole network will fail.

2.7 Low Voltage Distribution Substation Panel

The distribution substation panel consists of incoming, outgoing, and load. There are some electrical devices installed in the substation for the purpose of implementing DAS. Some of the devices are over current and earth fault detection relay (MK2200), universal measuring device (UMG96S), and electric relays. The MK2200 and UMG96S are Intelligent Electronic Devices (IEDs). These devices will interface with the RTU and provide data on the conditions and statuses of the system.

The protective relay's functions are fault detection and obtain measurements from connected devices such as current transformers, voltage transformers, positions indicators, etc. The MK2200 provides protection and acts as a measuring unit for the power system. It also able to detect low current, over current, and earth fault conditions. Moreover, the universal measuring devices are utilized for measuring, recording, and monitoring of electrical parameters in power system. These devices will deliver data in real time value in which will be displayed on the HMI. Figure 2.5 shows the MK2200, while Figure 2.6 shows the UMG96S.

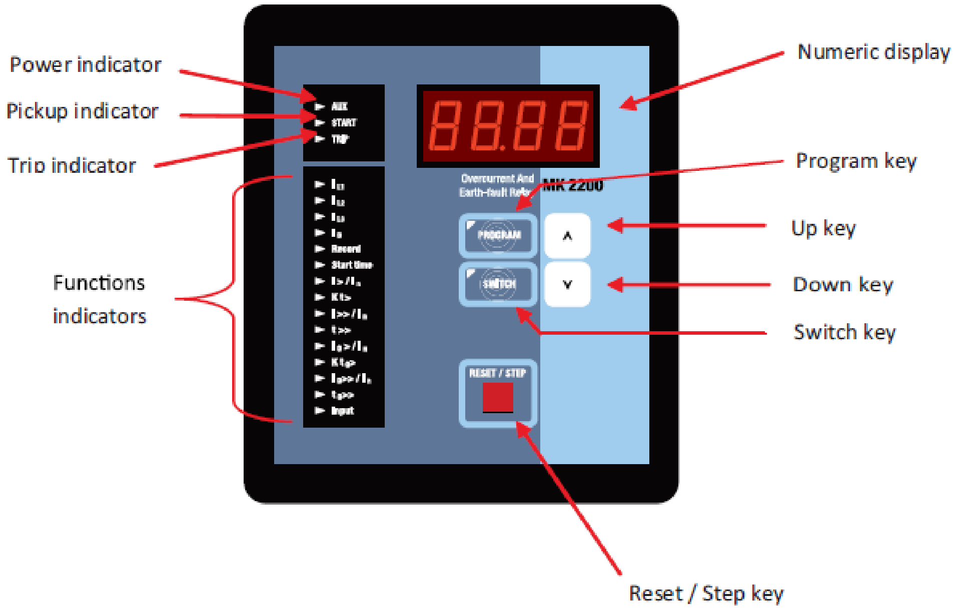

Figure 2.5: Over Current and Earth Fault Detection Relay (MK2200) [12].

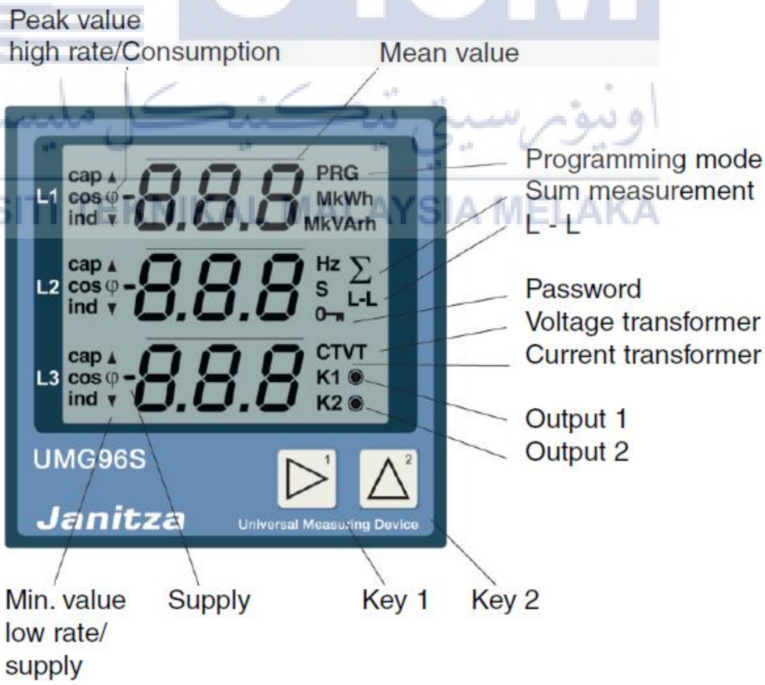

Figure 2.6: Universal Measuring Device (UMG96S) [13].

In addition, relays are switches that open and close circuits electromechanically or electronically. Relays control an electric circuit by opening and closing its contacts in another electric circuit. As illustrated in Figure 2.7, for the relay contact in normally open (NO) condition, there is an open contact when the relay is de energized. Meanwhile, for the relay contact in normally closed (NC) condition, there is a closed contact when the relay is de energized. Applying electric current to the coil of the relay will change its state in both cases.

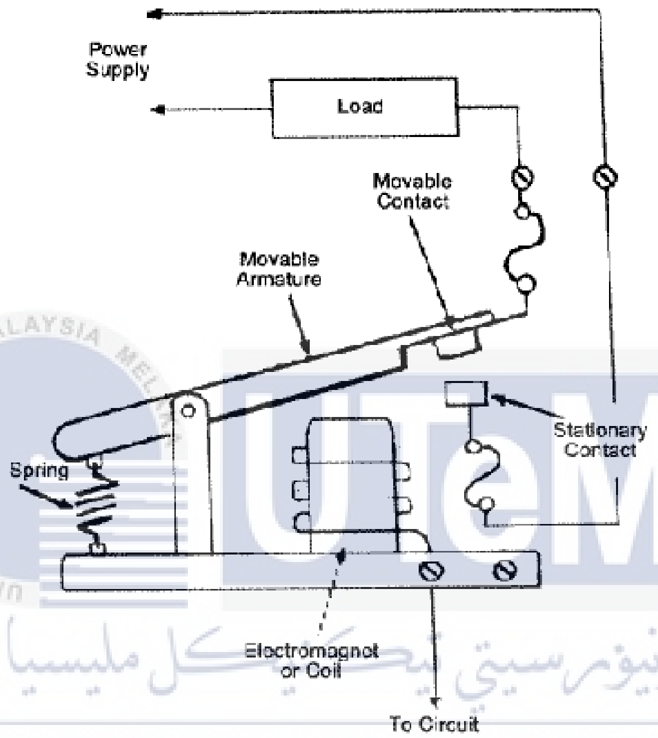

Figure 2.7: Overview of the electric relay structure [14].

2.8 Industrial or Business Review

Reliability on the power utilities is vital for industrial and commercial customers. This is because the power interruption that causes severe outages cost tremendous amount of money for the customers especially industrial customers. These unexpected outages affect the equipments in the industries such as in extrusion processes, silicon wafer fabrications, data processing, chemical processes, and papermaking. IEEE states that an interruption of 10 cycles in the power supplied can cause motors and productions at some factories to halt and require restarting [15].

We consider the paper making process for example. Paper manufacturing is a continuous process that requires definitely controlled speeds of hundreds of rollers in a machine that are 500 meters in length [16]. Any outage on the power supply will cause loss of synchronization, and stops the process. Moreover, all the part processed paper and pulp should be cleared from the machine before restarting the process. This may take hours to settle. In addition, this causes the loss of output, waste of raw materials and labour force, and inability to supply the products to the customers.

This project will be a vital suggestion for power companies in Malaysia for upgrading their power system. Power companies such as TNB, Sarawak Energy, Sabah Electricity, and other independent power producers could modernize and automate their system more firmly by applying this project on their system. Poor power quality supplied will result in dissatisfactions from their customers. By implementing this project, the utilities can sell more revenues due to mitigated down time and they can charge more for premium customers who want priority for energy supply.

Furthermore, the FLISR projects that were applied by some foreign countries have shown good results. For example, a power company, Pacific Gas & Electric piloted FLISR in Rio Vista, a small town in California's Eastern Solano. The FLISR equipment isolated the bad section and restored service to 1,774 of 2,294 customers in under two-and-a-half minutes [17]. Another example is in the City of Chattanooga, United States, which deployed FLISR system to reduce the aftermath of power outages. The utility realized a 55% minimization in outage durations experienced by their customers during a storm in July 5, 2012. It was estimated that the utility saved roughly $1.4 millions in restoration costs [18].

Thus, it is important for the utilities to improve their supply quality and reduce the outages duration. Figure 2.8 shows the typical financial loss per outage for certain industries.

Industry	Cost
Semiconductor Production	$5,300,000
Financial Trading	$8,400,000 per hour
Computer Center	$1,000,000
Telecommunications	$45,000 per minute
Steel Works	$500,000
Glass Industry	$350 000

Source: *"The Costs of Poor Power Quality"*, David Chapman, Copper Development Association, July 2002.

Figure 2.8: Typical financial loss per outage [19].

2.9 Related Previous Works

2.9.1 Customized Fault Management System for Low Voltage (LV) Distribution Automation System

This research was carried out in University Technical Malaysia Melaka (UTeM) by M.M Ahmed, W.L. Soo, M.A.M. Hanafiah, and M.R.A. Ghani. In this research, a SCADA system was built to perform automatic fault location in low voltage distribution system. A complete fault isolation algorithm was constructed based on open loop distribution system. The algorithm used in this research was Operation Logic Up-Counter (OLUC) and Operation Logic Down-Counter (OLDC). The HMI constructed will communicate with the I/O devices to obtain the data required. The ELCB and MK2200 were integrated with the SCADA system via an embedded Ethernet controller. According to the authors, the outcome of the research shows that the system correctly locates the faulted point, isolates it and restores supply to the un-faulted loads [20].

2.9.2 The Implementation of Fault Management in Distribution System Using Distribution Automation System (DAS) in Conjunction with SCADA

This research was carried out in University Technical Malaysia Melaka (UTeM) by S.H. Raman, M.R. Ab. Ghani, Z.A. Baharudin, M.A.M. Hanafiah, and W.N.S.E. Wan Jusoh. This research was conducted based on an open loop distribution system, which means the loads are connected to two feeders and any section of feeder feasible of being isolated without any interruption. A C language programming was used in this research for the system to conduct its operation sequences. There are five major actions such as power input, mode state, reset program, operation logic up-counter (OLUC), and operation logic down-counter (OLDC). System also operates in two modes which are manual mode and automatic mode. According to the authors, the results of this system can be monitored from a Graphical User Interface (GUI) display [21].

2.9.3 Development of Customized Distribution Automation System (DAS) for Secure Fault Isolation in Low Voltage Distribution System

This research paper was written by M.M. Ahmed, W.L. Soo, M.A.M. Hanafiah, and M.R.A. Ghani from University Technical Malaysia Melaka (UTeM). In this research a customized SCADA system was constructed to execute automatic fault isolation in low voltage distribution system. This research focuses mainly on the development of a HMI that is able to interface with I/O devices and able to carry out fault isolation method. The SCADA system consists of GUI, alarm system, data logging, and report management facilities which are convenient for the operators. The SCADA interacts with the equipments in the service substation and the customer service substation. The use of Remote Terminal Unit (RTU) in this research allows for future expansion or improvement. The authors of this paper claims that the system correctly locates the fault, isolates it and restores supply to the healthy loads [22].

2.9.4 A Low Cost Wireless Data Acquisition System for Distribution Automation System

This research paper was written by S.H. Raman, W.N.S.E Wan Jusoh, M.A. Mat Hanafiah, M.R. Ab. Ghani, and Z.A. Baharudin from University Technical Malaysia Melaka (UTeM). This paper describes about the design and development of a PIC16F877A microcontroller-based wireless data acquisition system. Various data transmission techniques were studied in this paper mainly regarding wireless systems such as satellite, radio, GSM, and paging. This system will be utilized for reading, storing, and analyzing data that obtained from DAS. The wireless communication used in this system is GSM network while the HMI software used is Visual Basic. The authors stated that this system contributes to control the functioning of distribution systems and produce data under real conditions. Authors also highlighted that implementing GSM network as a communication media reduces the cost of system management [23].

2.9.5 Distribution Automation Case Study: Rapid Fault Detection, Isolation, and Power Restoration for Underground Distribution System

The authors of this research paper are David Gomes and Richard Colunga from Center Point Energy, along with Payal Gupta and Ashok Balasubramanian from Schweitzer Engineering Laboratories, Inc. In this paper, the authors explained the operating principles of a centralized and automated Underground Distribution Automation System (UDAS). The objectives of UDAS are to rapidly identify faults, isolate the faulted parts, and automatically restore power to the unaffected feeder sections. This system uses fiber optic communications network in order to monitor the power system state by polling information and sending quick control signals to the field IEDs. Moreover, when a fault is detected, the UDAS performs an automatic reconfiguration sequence in which the system updates itself with the up-to-the-minute state of the power system. The authors claim that the system's efficiency is immensely enhanced with mitigated power interruptions and outage times along with lower maintenance cost [24].

2.9.6 Communication System for Distribution Automation Using CDMA

This research paper was written by Tae-Il Choi, Kwang Y. Lee, Dong Ryul Lee, and Jeong Kil Ahn. All the authors are from Korea Electric Power Corporation (KEPCO). This paper describes the usage of Code Division Multiple Access (CDMA) wireless communication network in distribution system. CDMA technology uses the same frequency band in the whole service area and this gives superior efficiency of frequency utilization compared to other communication methods. CDMA terminals can be installed inside the control of automatic switch at any place in a distribution line and it can be easily moved at any time. The frequent communication errors due to insufficiency of communication channels can be sorted out by using CDMA network without the need of additional communication channels. The authors also stated that CDMA network is suitable to be implemented at regions where repeated maintenance and transfer is required [25].

CHAPTER 3

METHODOLOGY

3.1 Overview of Project Flow

The low voltage distribution substation that was constructed was tested and all its wiring connections were properly checked. The substation designed functions flawlessly. Therefore, the DAS with the implementation of FLISR will be applied on this substation. The Intelligent Electronic Devices (IEDs), Remote Terminal Unit (RTU), and Human Machine Interface (HMI) was all integrated via communication protocols (RS-232, RS-485, IEC61850) in order to obtain a successful running system.

The Human Machine Interface (HMI) was constructed using Indusoft Web Studio (IWS) software. Then, it was simulated and tested before it was interfaced with the hardware. When the constructed HMI functions faultlessly, it will be tested with the hardware and the complete system will be operated for FLISR function. The town model built will also be interfaced with the whole system and its operation will be tested. Figure 3.1 below shows the overall project architecture.

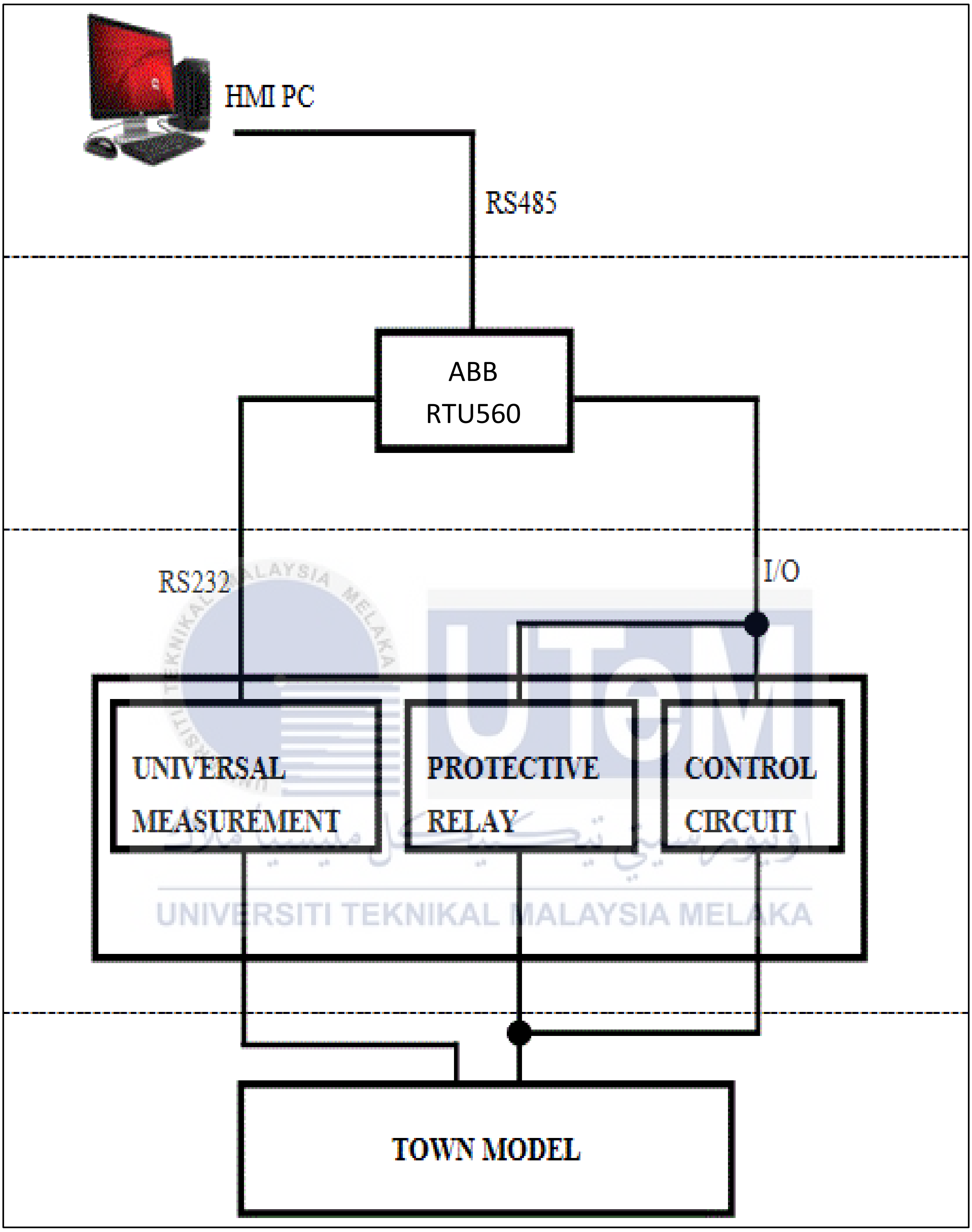

Figure 3.1: Overall project architecture.

3.2 Progress of the Project

This project will be conducted and completed within the time limit provided. Table 3.1 shows the Gantt Chart for the Final Year Project 1 planning. This project planning concentrates mainly on the researching of DAS and FLISR systems. In addition, the Indusoft software was also explored and constructed basically.

Table 3.1: Gantt Chart for Final Year Project 1.

No.	Task	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Gathering and studying of previous researches.														
2	Gathering and studying of electrical components that are used.														
3	Exploration of the Indusoft software for HMI development.														
4	Practical approach of DAS in laboratory.														
5	Basic HMI construction using Indusoft software.														
6	Report Progress.														
7	Presentation.														

Planned

Actual

On the other hand, Table 3.2 shows the Gantt Chart for the Final Year Project 2 progression. During this time period, the HMI was developed and simulated. It concentrates mainly on system's hardware and software integration and testing. The system was tested by focusing on its ability to carry out FLISR and SCADA functions.

Table 3.2: Gantt Chart for Final Year Project 2.

No.	Task	Weeks													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Development of HMI using Indusoft software.														
2	Simulation and testing of the developed HMI.														
3	Integration of HMI with hardware of the system.														
4	Testing of the complete system on its ability to perform DAS.														
5	Testing of the complete system on its ability to perform FLISR.														
6	Report Progress.														
7	Presentation.														

Planned

Actual

Moreover, Figure 3.2 depicts the all-inclusive processes of developing this project. It represents the approaches taken step-by-step throughout the progression of this project.

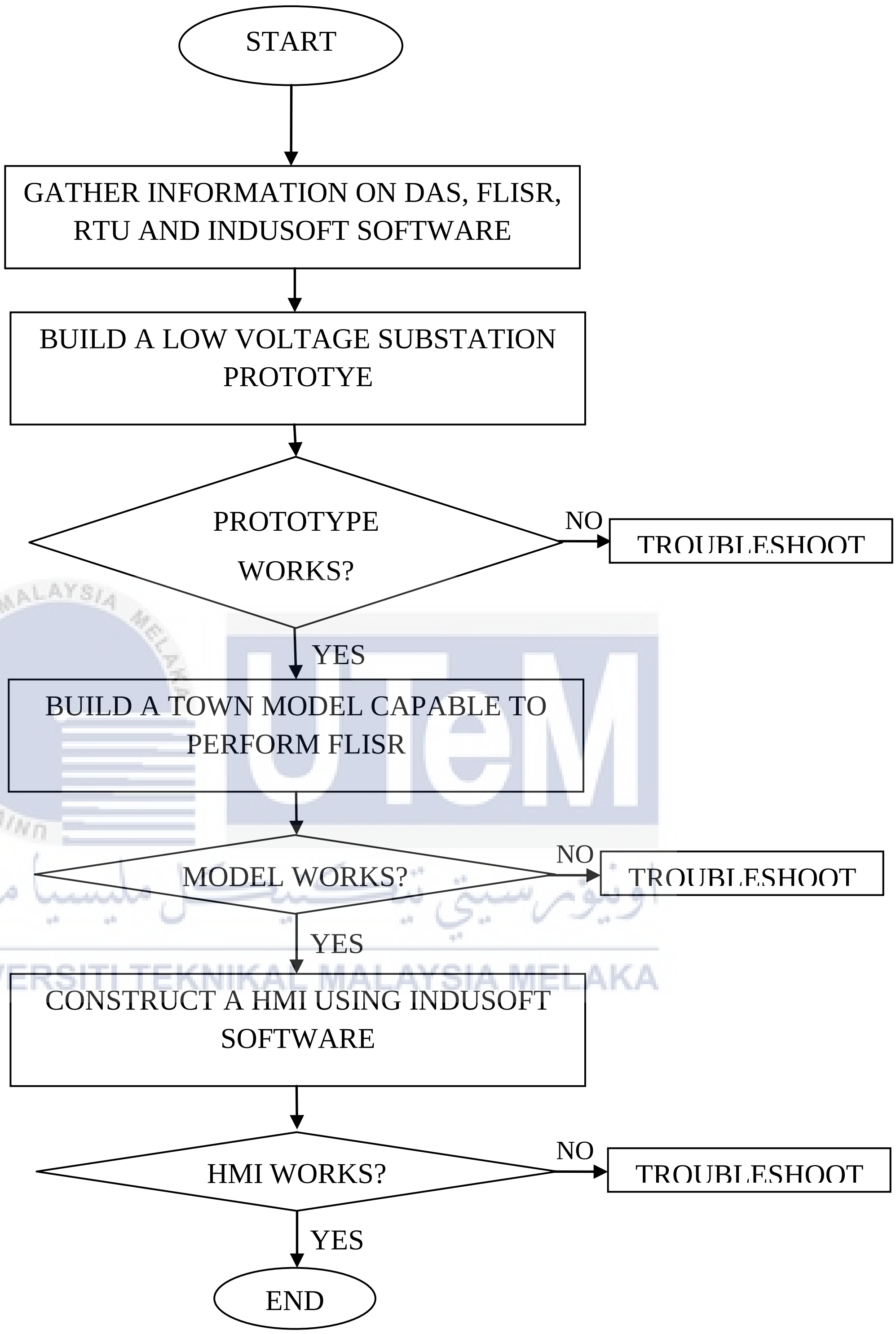

Figure 3.2: Flow chart of the project development.

3.3 Software

The software application that was used to develop the Human Machine Interface (HMI) for this project is Indusoft Web Studio (IWS). Indusoft is potent software that is convenient to be used to construct a full feature SCADA system. Its features can be used with Microsoft operating systems such as Windows. Other than that, IWS is easy to explore and can be mastered quickly by the user. There are useful tutorials provided in their webpage that aids the development of this project.

Figure 3.3 below shows the flow chart of the HMI construction process. It begins with the creation of a new project file in the IWS software. Later, some group of screens is constructed and its designs are up to the designer's creativity. Then, the tags provided in the software are used to embed on the screens and it represents the button, slider, meter, etc. Moreover, a complete graphical view that represents the real hardware system will be designed on the software. At last, the HMI will be executed and simulated.

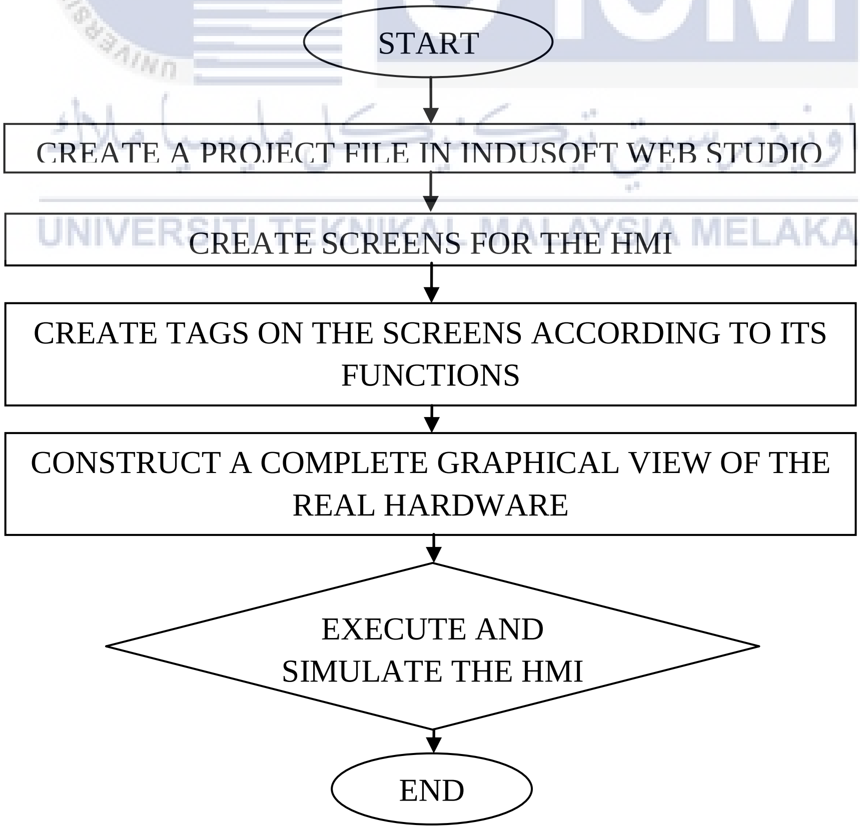

Figure 3.3: Flow chart for the Human Machine Interface (HMI) development.

3.4 Hardware

3.4.1 Low Voltage Substation Prototype

The distribution substation prototype used in this project was built and tested for functionality. It is a custom made substation which functions as the real distribution substation. This substation prototype consists of electrical devices that aid in automation process. Some of the devices are over current and earth fault relay (MK2200) and universal measuring device (UMG96S). Besides, this substation prototype are also capable of operating in both Remote and Local conditions. Figure 3.4 shows the distribution substation prototype while Figure 3.5 shows the overall substation system single line diagram.

Figure 3.4: The low voltage substation prototype.

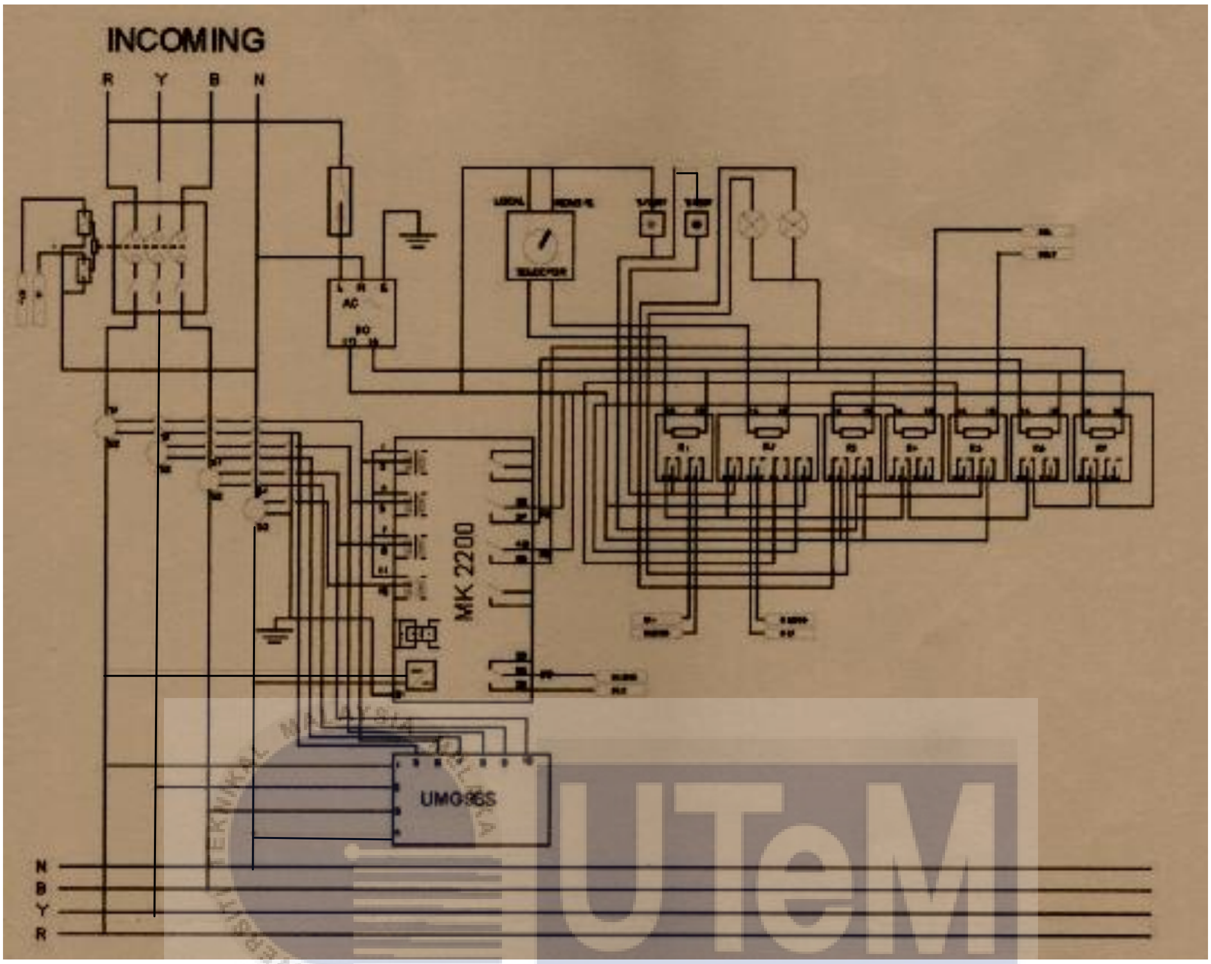

Figure 3.5: The overall substation system single line diagram [3].

3.4.2 Control Circuit of the Substation Prototype

The single-line diagram of the control circuit was sketched from the schematic diagram of the substation prototype. This makes the substation prototype's connections comprehensible and the I/O can be easily identified. The single-line diagram of the control circuit also provides a clear path on what the HMI need to control and monitor, as well as assisting in connecting the interfacing devices. Figure 3.6 displays the single-line diagram of the control circuit of the substation prototype.

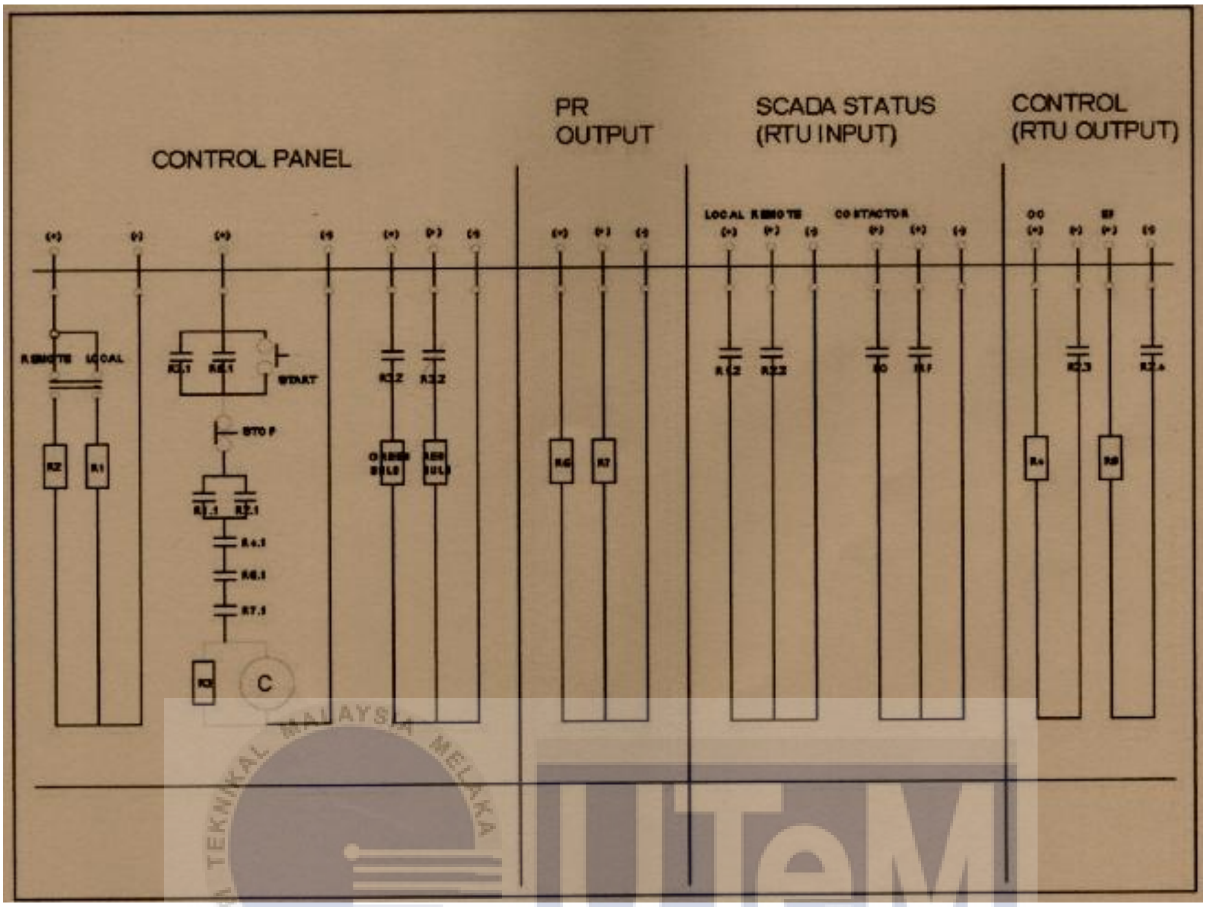

Figure 3.6: Single-line diagram of the control circuit [9].

3.4.3 Protective Relay

MK2200 is used as the protective device for this substation prototype. MK2200 is a combined over current and earth fault relay. It contains a digital microprocessor that carries out advanced numerical technique for the computation of fault currents and protection functions [12]. MK2200 can be networked with the SCADA system by using RS-485 MODBUS-RTU serial communication and this method is used in this project. Figure 3.7 illustrates the typical connection diagram of MK2200.

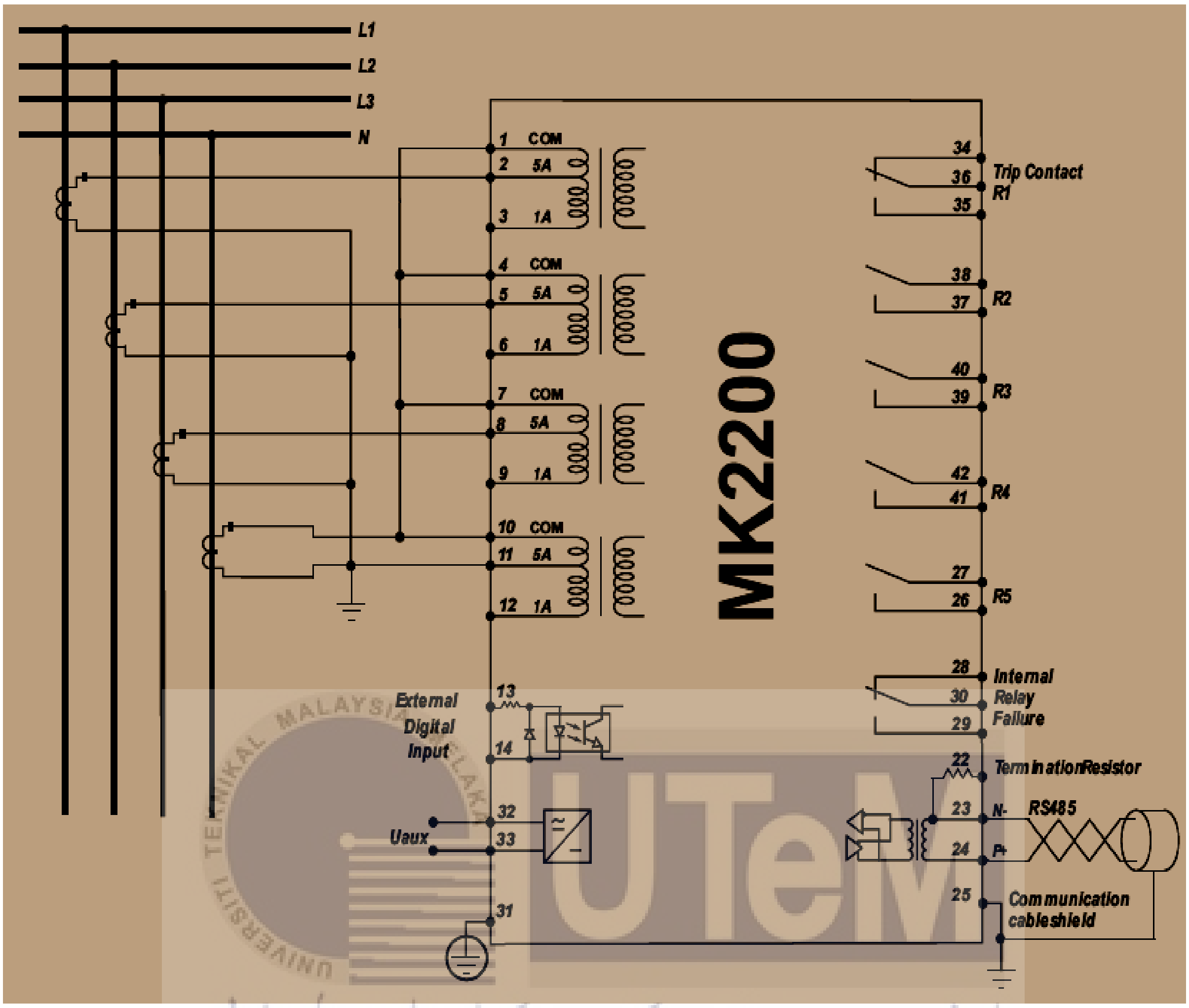

Figure 3.7: Typical MK2200 connection diagram [12].

3.4.4 Measurement Device

Measurement devices play an important role in measuring electric parameters. In this project, the measuring device used is the universal measuring device, UMG96S. It is used for measuring voltage, current, power, etc. in low voltage distribution system. Moreover, it is also designed for measuring 3 phase systems with neutral conductor. In this project, the RTU is interfaced with UMG96S in order to obtain the readings of electric parameters from the substation and display it on the HMI. From this, the electric parameters can be monitored through the HMI. Figure 3.8 shows the connection diagram of UMG96S with RS232, RS485, and digital outputs.

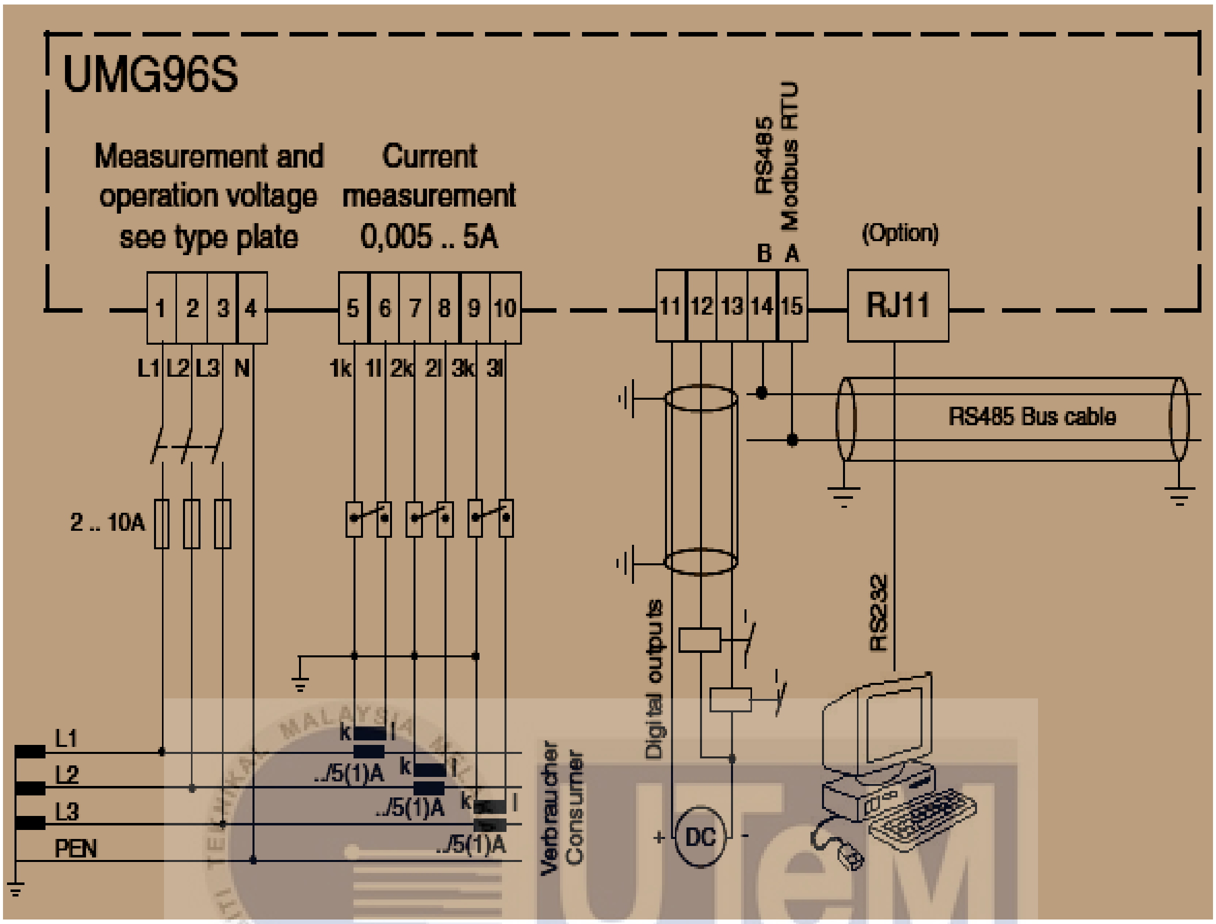

Figure 3.8: Connection diagram of UMG96S with RS232, RS485, and digital outputs [13].

3.4.5 Interfacing Device

The interfacing device used in this project is the remote terminal unit, ABB RTU560. Based on Figure 3.9, the Master Control Module represents the RTU itself. Meanwhile, the Measurement and Fault Detection module represents the Intelligent Electronic Devices (IEDs) used, which are MK2200 and UMG96S. Moreover, the serial communication RS-232 to RS-485 is the communication media used to connect IEDs with the RTU.

The status display module is the HMI of the system. In addition, the Optical MODEM represents the communication media from the RTU to the control room server and it is establish via DNP 3.0 connection. The power supply module is the power source and regulator for the RTU to function. Last but not least, the Digital I/O is the signals processed from the substation and transferred to the RTU.

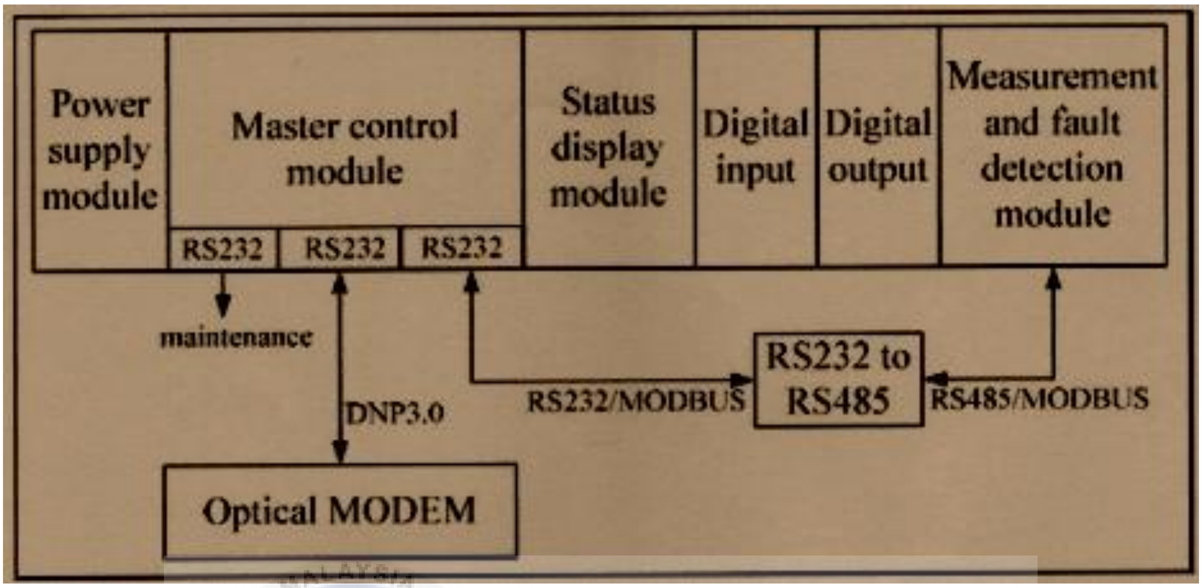

Figure 3.9: Remote Terminal Unit (RTU) block configuration [3].

3.5 Communication Network

This project uses the wired communication for interfacing functions between devices. The communication protocols that were used are RS-232 and RS-485 protocols. All the devices in the substation prototype were connected using these communication protocols. Basically, RS-232 is suitable to be used for short distance and low speed usage. Plenty of components are available to conduct the interface. It is a simple and cheap protocol. On the other hand, RS-485 is used for higher speed and longer distance. Figure 3.10 shows the comparison of characteristics of RS-232 and RS-485.

KEY CHARACTERISTICS OF THE RS-232 AND RS-485 SERIAL INTERFACES		
Parameter	RS-232	RS-485
Line configuration	Single-ended	Differential
Mode of operation	Simplex or full duplex	Simplex or half duplex
Maximum cable length	50 feet	4000 feet
Maximum data rate*	20 kbits/s	10 Mbits/s
Typical logic levels	±5 to ±15 V	±1.5 to ±6 V
Minimum receiver input impedance	3 to 7 kΩ	12 kΩ
Receiver sensitivity	±3 V	±200 mV

* Maximum rate at maximum cable length

Figure 3.10: Comparison between RS-232 and RS-485 [26].

3.6 Low Voltage Substation Prototype Operation and Testing

3.6.1 Overall Operation

When the START button is switched ON, the R3 relay begins to energize and the contactor will latch the power supply for the controller circuit. Other than that, the Main Contactor will get magnetized too and it will allow the 415V supply to flow into the substation. Moreover, the STOP button will cut off all the operations when it is pressed regardless whether in local mode or remote mode. The system can be resumed by the restoration process in remote mode or in local mode.

3.6.2 Local Operation

Local operation is used when there is maintenance processes occur in the substation and the system is manually restored by the operating personnel or crew. During this operation, the remote access to the system is isolated. Thus, any responses from the control station will be blocked. When isolated, the selector will switch ON the R1 relay. The relay will energize and turn ON the contactor which will give signal to the RTU about the status of the current selection. Other contactors will complete the power source circuit to be run when the START button is pressed. As stated in Table 3.3, the selector switch turns ON the R1 relay and this will activate R3 relay to latch the control circuit. The contactor will respond according to the status of R3 relay. R3 relay isolates the control circuit and the contactor which puts the substation in local mode.

Table 3.3: Relay status on local mode operation.

Relay	**Status**
R1	ON
R2	OFF
R3	ON
R4	OFF
R5	OFF
R6	OFF
R7	OFF
CONTACTOR	ON

3.6.3 Remote Operation

During the remote operation, the system is controllable from the control station through SCADA. At this stage, the system can be disconnected manually and remotely too. Furthermore, the remote access can be executed to gather data as well as reconfigure the MK2200 protection relay remotely. Based on Table 3.4, the selector switch turns ON R2 relay which allow the control actions to take place form SCADA system. The contact of R2 relay will complete the power supply circuit as well as activates R3 relay.

Table 3.4: Relay status on remote mode operation.

Relay	Status
R1	OFF
R2	ON
R3	ON
R4	OFF
R5	OFF
R6	OFF
R7	OFF
CONTACTOR	ON

3.6.4 Cut Off and Restoration Process

Cut off process can only be executed in remote access mode. This is where the control room is disconnecting the whole system by sending a step signal from the control room. Table 3.5 shows the R4 relay placed to bypass and disconnect all the signals sent to R3 relay.

Table 3.5: Relay status during cut off process.

Relay	Status
R1	OFF
R2	ON
R3	OFF
R4	ON
R5	OFF
R6	OFF
R7	OFF
CONTACTOR	OFF

The restoration process too can only be made in remote mode in which the SCADA system sends a pulse signal to the system and activates R5 relay. R5 relay will complete the main control circuit as well as continuing to latch the control circuit. The pulse signal will be sent to the External Digital Input of the MK2200 protective relay. As required by its specifications, it will be triggered with 24 VDC or 240 VAC. For this system, 24 VDC is selected for triggering. Table 3.6 below shows the relays status during restoration process.

Table 3.6: Relay status during restoration process.

Relay	**Status**
R1	OFF
R2	ON
R3	ON
R4	OFF
R5	ON
R6	OFF
R7	OFF
CONTACTOR	ON

3.6.5 Fault Detection from MK2200 Protection Relay

During the overcurrent event, R6 relay will disconnect the main control circuit. On the other hand, R7 will disconnect the system during the earth fault event. The contacts of MK2200 are connected to the relays. MK2200 will send a step signal to the relays and makes the system to stay OFF until the system is reset. The MK2200 can be restored to its initial operation by using the restoration process mentioned before, or by manually resetting the reset button in the substation. Other than that, it can also reset by itself automatically based on the settings made for FLISR operation. Table 3.7 shows the relay status for the overcurrent condition while Table 3.8 shows the relay status for the earth fault condition.

Table 3.7: Relay status for overcurrent condition.

Relay	Status
R1	ON (If in Local Mode)
R2	ON (If in Remote Mode)
R3	OFF
R4	OFF
R5	OFF
R6	ON
R7	OFF
CONTACTOR	OFF

Table 3.8: Relay status for earth fault condition.

Relay	Status
R1	ON (If in Local Mode)
R2	ON (If in Remote Mode)
R3	OFF
R4	OFF
R5	OFF
R6	OFF
R7	ON
CONTACTOR	OFF

All the relays are perfectly wired and connected in the substation to avoid any malfunction. The substation is tested and the operation of every relay for every process was observed and checked. Based on the testing made, the substation prototype is functioning as required and it is viable to be applied for distribution automation system. Figure 3.11 depicts the relays placement in the substation prototype.

Figure 3.11: The relays placement in the substation prototype.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

In this chapter, the results of this project will be presented and explained. The Human Machine Interface (HMI) developed using the Indusoft software is shown in detail. Each screen and its' functions are also presented. Moreover, the small town model was built and presented in this chapter. The schematic circuit of the town model is constructed using Proteus software and the hardware of the town model was built.

4.2 Human Machine Interface (HMI)

The Human Machine Interface (HMI) for this project is constructed using the Indusoft software. The HMI will be interfaced with the substation prototype and the town model. There are 8 screens in the HMI that shows different features and functions of the system. The operators can conduct the Supervisory Control and Data Acquisition (SCADA) using this HMI. There are a lot of functions included in this HMI such as sending emails when alarm is triggered, changing of colours that represent certain situations, and messages that pop up according to situations.

4.2.1 Main Screen

The main screen of the Human Machine Interface (HMI) is the start up screen. Whenever the HMI is run in the computer, the main screen will be the first screen that will be shown. The main screen contains the basic information of this project such as the title, student's name, student's matrix number, and supervisor's name. Moreover, the username of the operators, the Internet Protocol (IP) address of the computer, date, and time are also shown on the header of the screen. On the left side, the navigation buttons are placed and they are used to open the required screens. The header and navigation will appear all the time and only the centre screen will change. Figure 4.1 depicts the main screen of the HMI.

Figure 4.1: The main screen of the HMI.

4.2.2 Grid Screen

The grid screen in the HMI depicts a small town with power system grid. There are 3 substations shown in the town model. The town is divided into 7 sections where the electricity supply for each section is controlled using the reclosers. Whenever the electricity supply is cut off in a section, the section will turn dark indicating a power cut off. When the power is supplied, the section will appear bright. There are also online alarm window, parameters measurement, and smart message indicator in the screen. Figure 4.2 shows the grid screen when the system is normal, while Figure 4.3 shows the grid screen when the system is blackout.

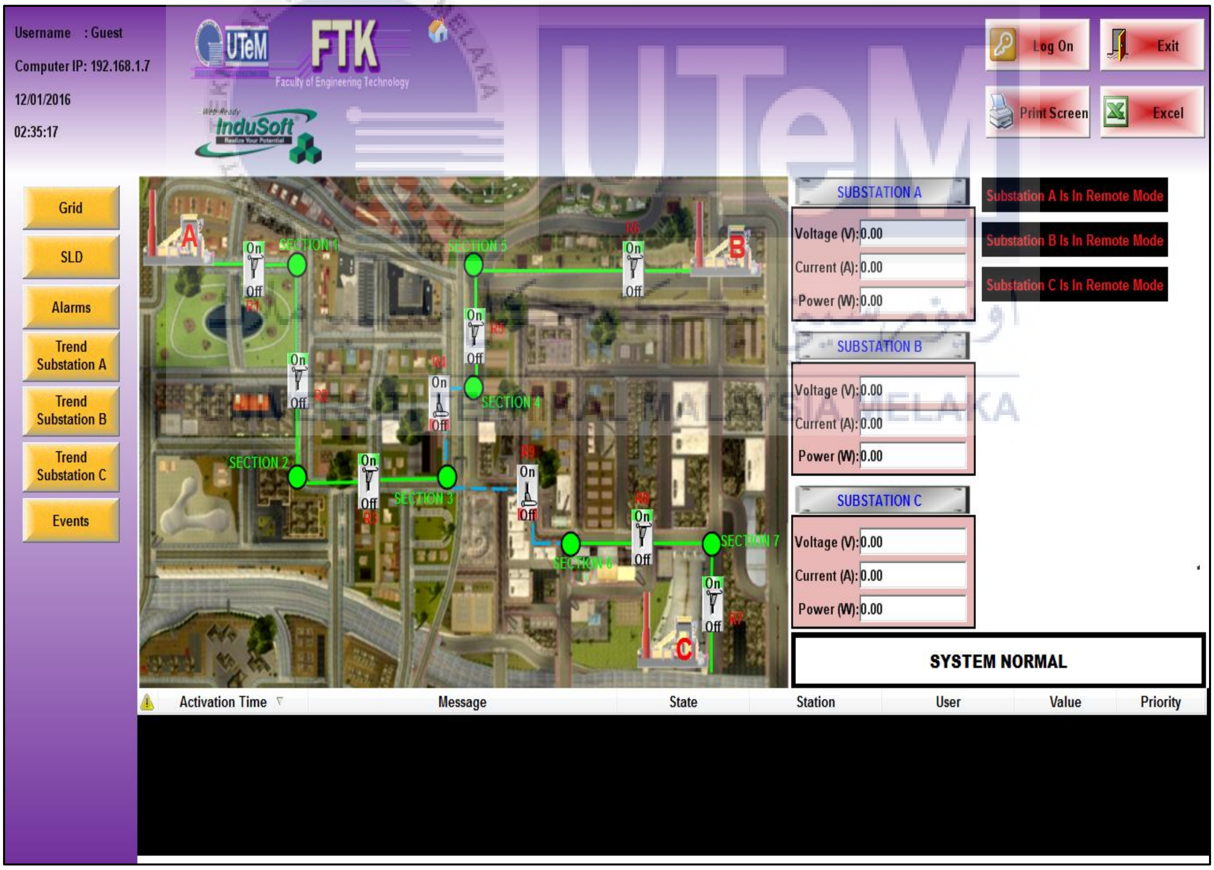

Figure 4.2: The grid screen when the system is under normal condition.

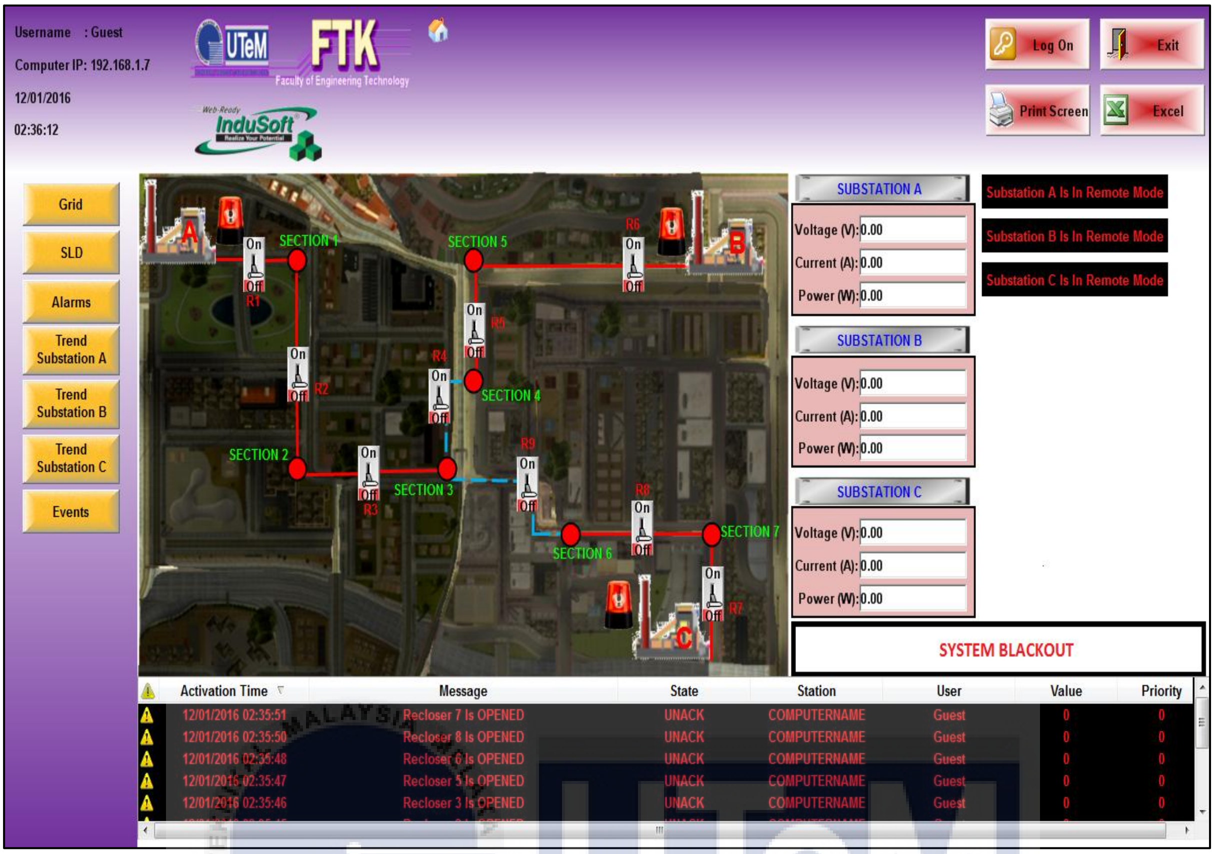

Figure 4.3: The grid screen when the system is in blackout condition.

4.2.3 Single Line Diagram Screen

The single line diagram screen shows the single line diagram of the power system. It follows the grid screen conditions. When the reclosers are in closed condition, it will appear in green colour indicating the power is supplied. When the reclosers are in opened condition, it will appear in red colour indicating power cut off. The load will also appear in green colour when power is supplied and in red colour when power is cut off. There are switches in the screen that is used to control the reclosers condition. Moreover, the parameters measurement are also shown. The substations' remote or local condition switches are also included and its condition will be shown in the smart message box. Figure 4.4 shows the single line diagram during normal condition, while Figure 4.5 shows the blackout condition.

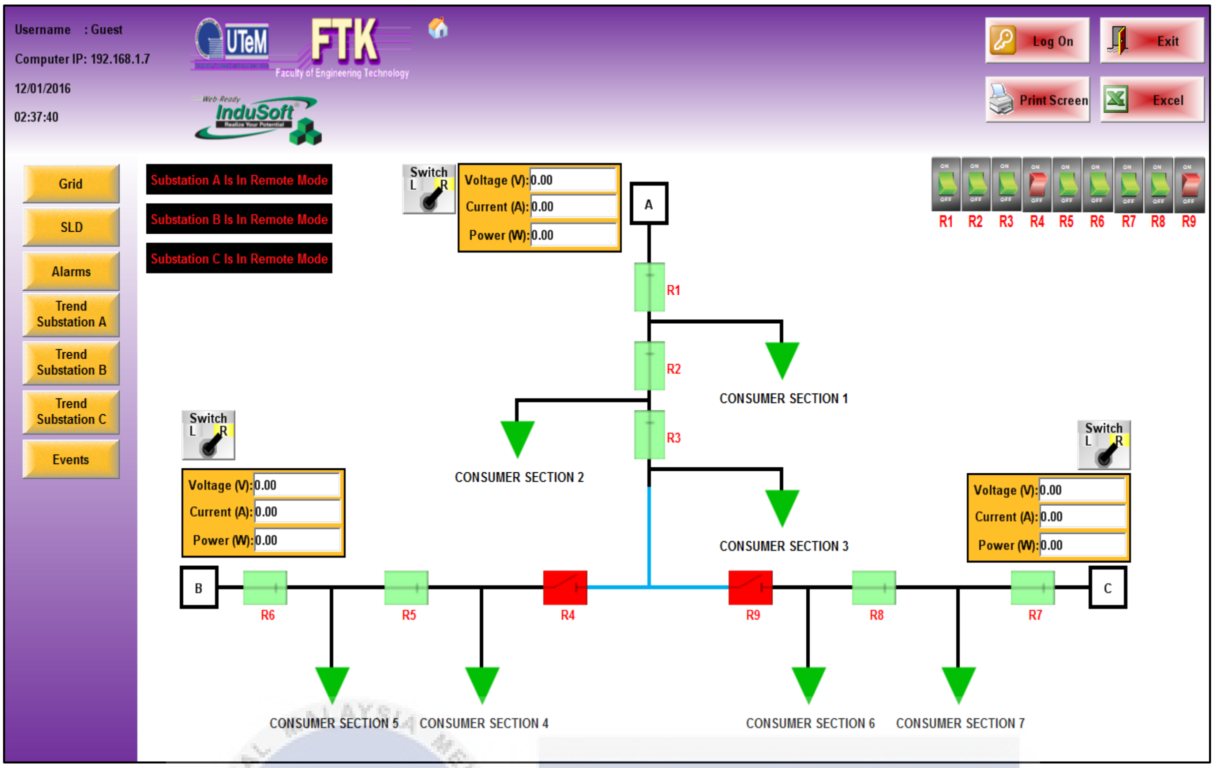

Figure 4.4: Single line diagram during normal condition.

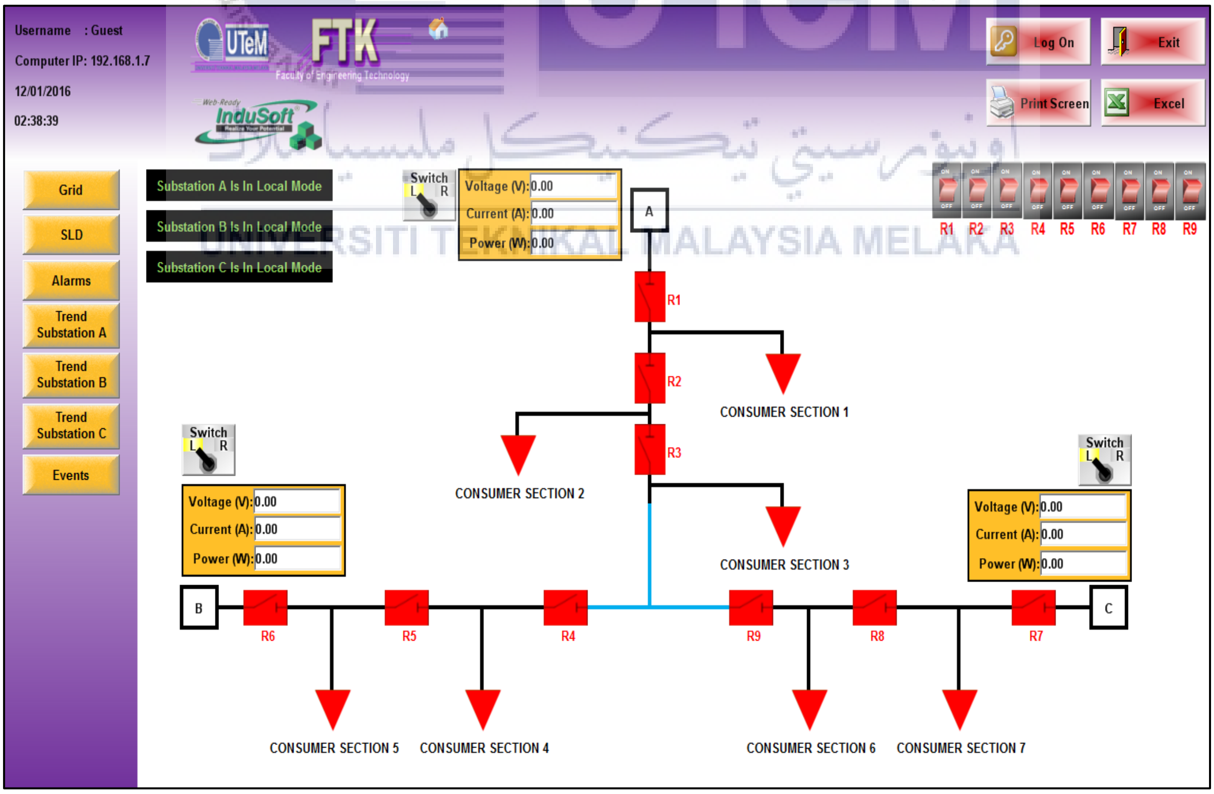

Figure 4.5: Single line diagram during blackout condition.

4.2.4 Alarms Screen

The alarm screen shows the alarm triggered during the system operation. In this screen the online alarm and the history alarm is shown and it can be selected using the buttons provided. The online alarm shows the alarms that is triggered in real time while the alarm history shows the overall history of the triggered alarms. Furthermore, the alarms can be filtered using the filter button and its specifications such as time range, dates, names, and conditions can be selected to be filtered.

In addition, the print button will print the alarm list while the acknowledge all button will acknowledge all the alarms that was triggered. The alarm acknowledgement have its own features. For example, the unacknowledged alarm will appear in red colour, the acknowledged alarm will appear in green colour, and the normalized alarm will appear in orange colour. Moreover, the information that are presented in the alarm window consist of activation time, acknowledged time, message, state, station, user, value, and priority. Figure 4.6 shows the online alarm, while Figure 4.7 shows the alarm history.

Figure 4.6: The online alarm.

Figure 4.7: The alarm history.

4.2.5 Trend Screens

The trend screen in the HMI represents the parameters data in graph form. The parameters measured for this system are voltage, current, and power. Each parameter have its own trend and the values will be presented in the graph. There are 3 screens for trend where each of it represents trend for Substation A, Substation B, and Substation C. There are a lot of functions in the trend screen that can be used by the operator. Analogue meters are also included in the screen which shows the reading of the parameters. Figures 4.8, 4.9, and 4.10 shows the trend screens for Substation A, Substation B, and Substation C respectively.

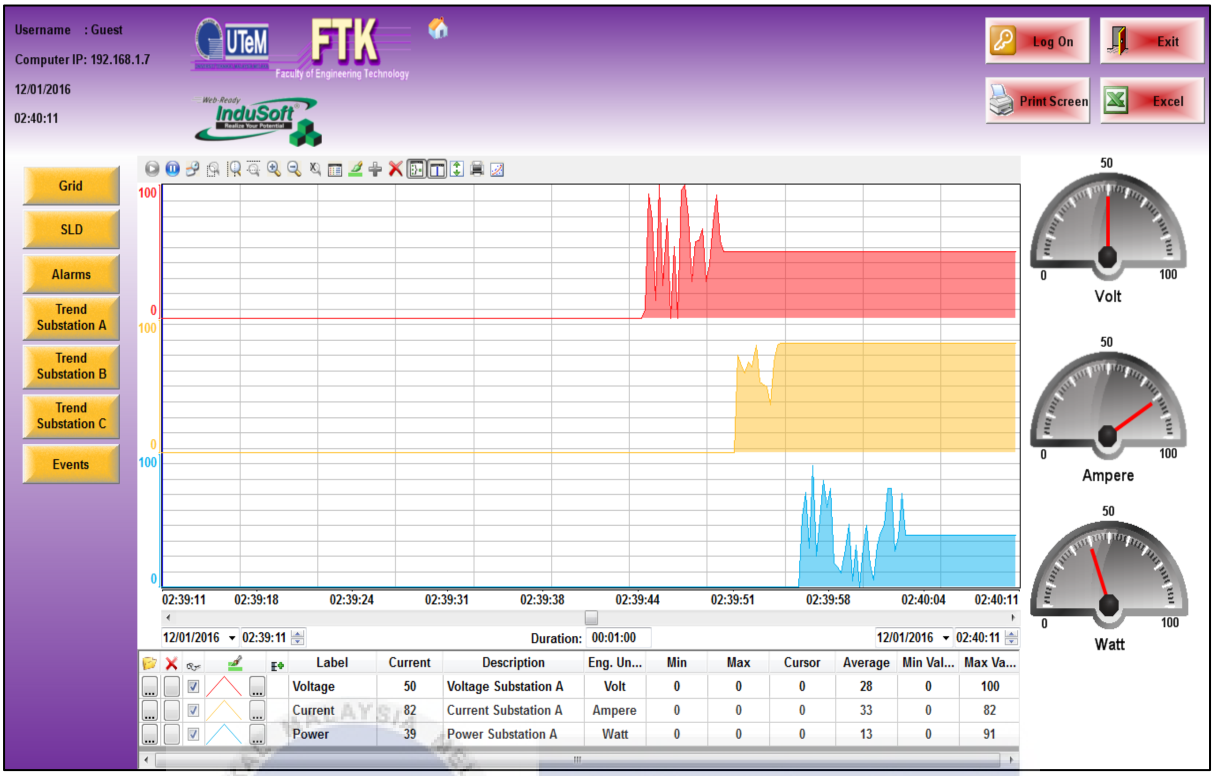

Figure 4.8: Trend screen for Substation A.

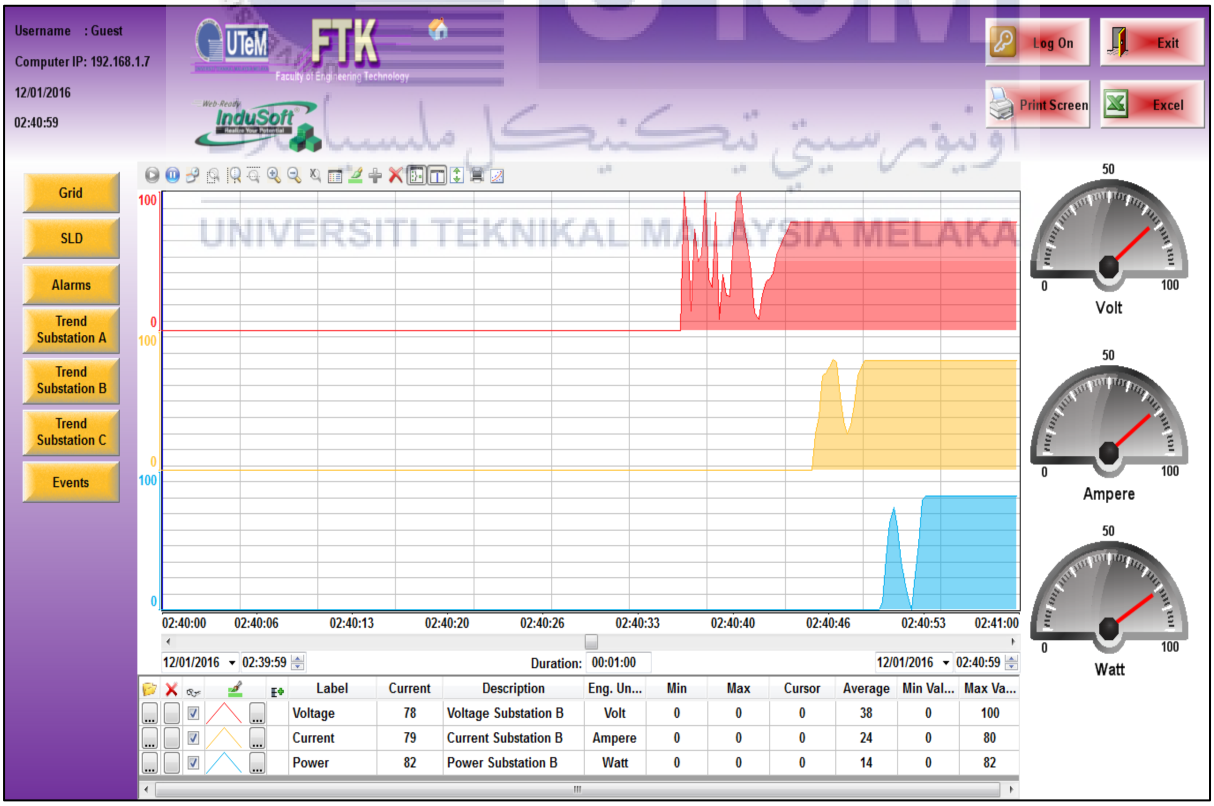

Figure 4.9: Trend screen for Substation B.

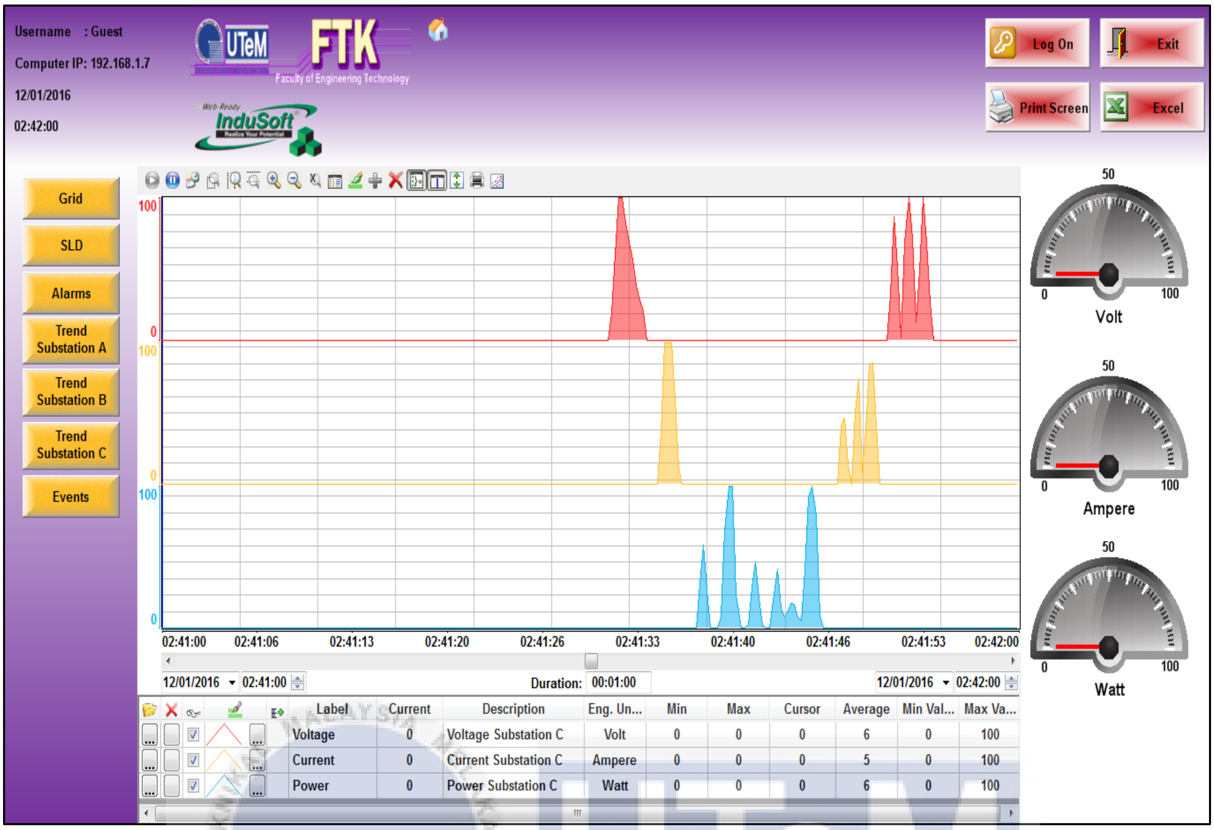

Figure 4.10: Trend screen for Substation C.

4.2.6 Events Screen

The events screen shows all the activities that took place in the system. Every event that took place such as opening of screens, users logging, and email notifications are all shown in the events window. The events filter button, print button, and comment button are also included in this screen. Information such as event time, message, comment, station, user, and type are presented in the event window. Figure 4.11 shows the events screen for this HMI.

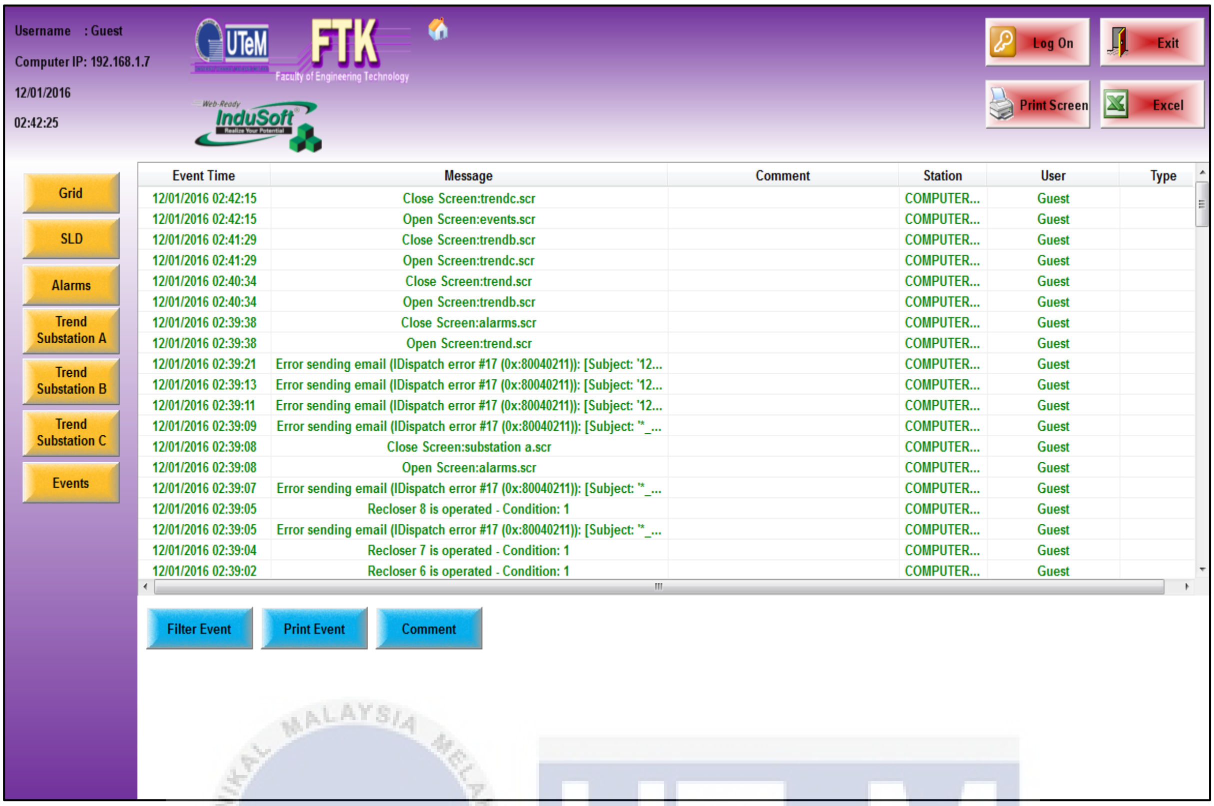

Figure 4.11: The events screen.

4.3 Town Model

The town model was built using materials such as plywood and woods. The wiring was first made in Proteus and simulated. Then, based on the wiring configured in Proteus, the town model was wired. There are 7 sections on the town model. The contactors act like reclosers, while the load is represented by the lights bulbs. The contactors will be controlled by relays which are connected to remote terminal unit (RTU) inputs and outputs. The overload fault and earth fault will be artificially applied. Extra light bulbs are placed to demonstrate overload fault when switched on. Moreover, a connection between live wire and earth wire is made to demonstrate the earth fault. Figure 4.12 shows the circuit schematic of the town model using Proteus. On the other hand, Figure 4.13 depicts the hardware of the town model.

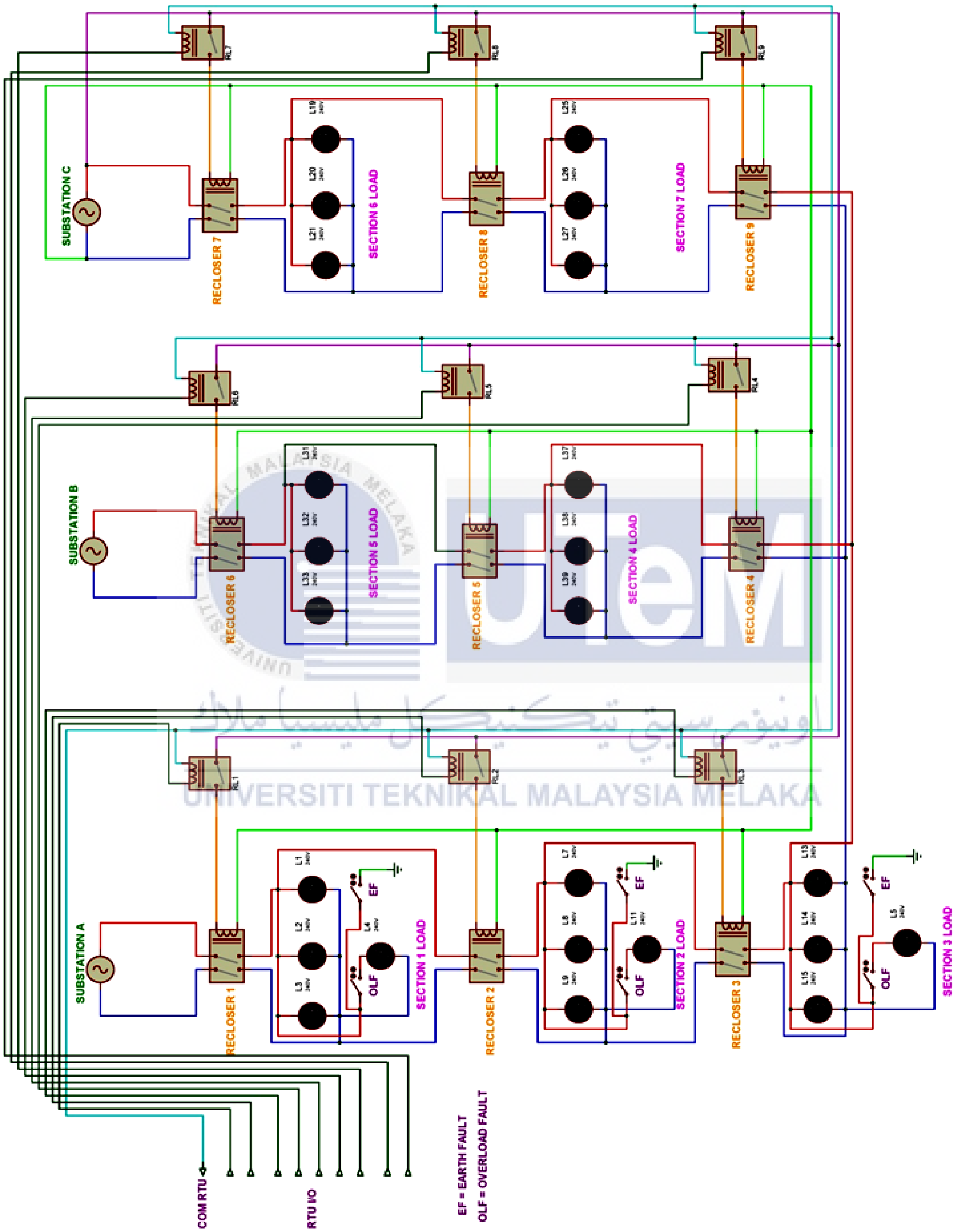

Figure 4.12: The schematic circuit of the town model.

Figure 4.13: The town model.

4.4 Overall System Operation

Power will be supplied to the town model from the substation prototype. The system will be interfaced with the Human Machine Interface (HMI) to conduct the Supervisory Control and Data Acquisition (SCADA) functions. Artificial faults are placed for Substation A in the section 1, 2, and 3. All the contactors act as reclosers which supply power to each section. When there is a fault occurred in section 1, 2, or 3, the protective relay in Substation A will be tripped and the power will be cut off. Then, the power will be supplied from Substation B or Substation C through Reclosers 4 or 9 respectively to the unaffected sections.

Reclosers 4 and 9 are the backup power line for the system. The affected section will be isolated until the fault is cleared. For an example, when a fault is occurred in section 1, Substation A will be tripped and Reclosers 1, 2, and 3 will be opened. Then, the system will isolate the fault by keeping the Reclosers 1 and 2 in opened condition. Later, the power will be supplied to the unaffected sections, which are section 2 and section 3. Recloser 4 will be closed and the power will be supplied from Substation B. Power will be restored in section 3 and then Recloser 3 will be closed to restore power in section 2. The system will only return to normal condition when the fault is cleared. Figures 4.14, 4.15, and 4.16 illustrate the example mentioned.

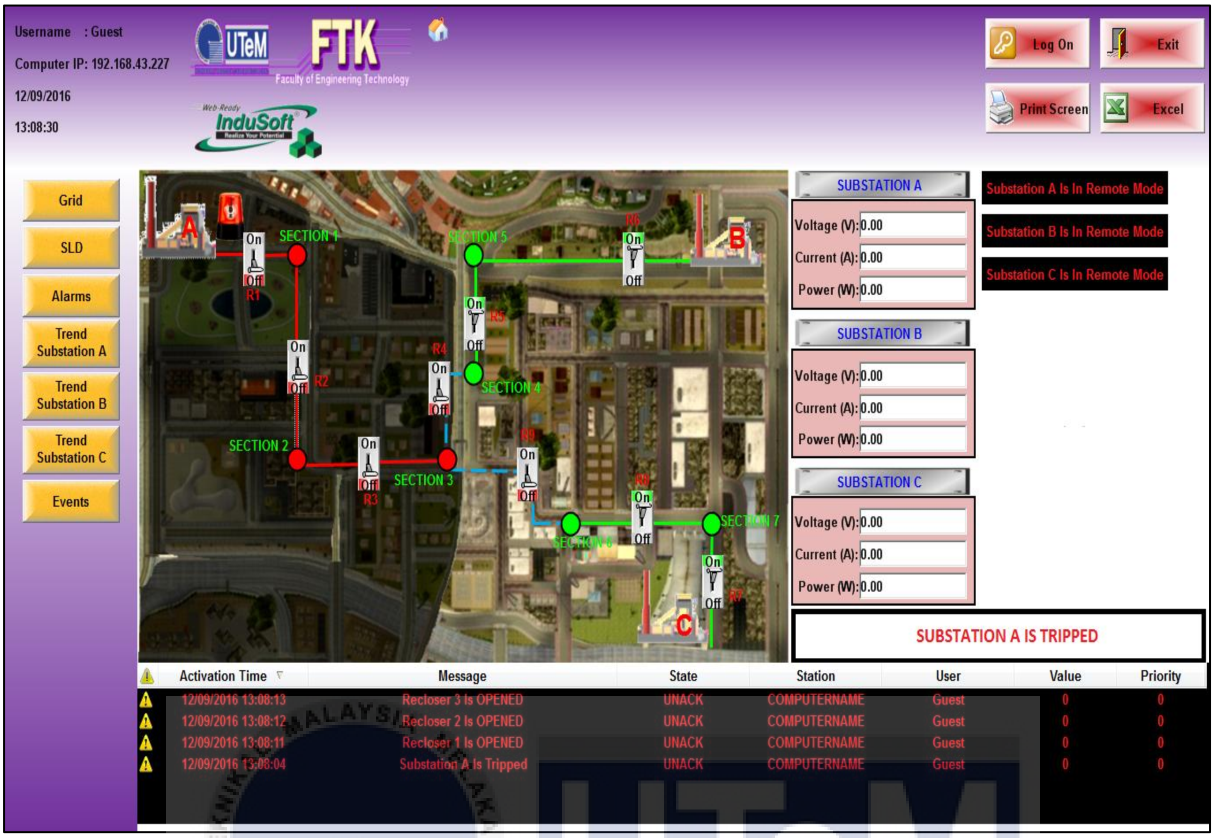

Figure 4.14: Fault occurred in sections supplied by Substation A.

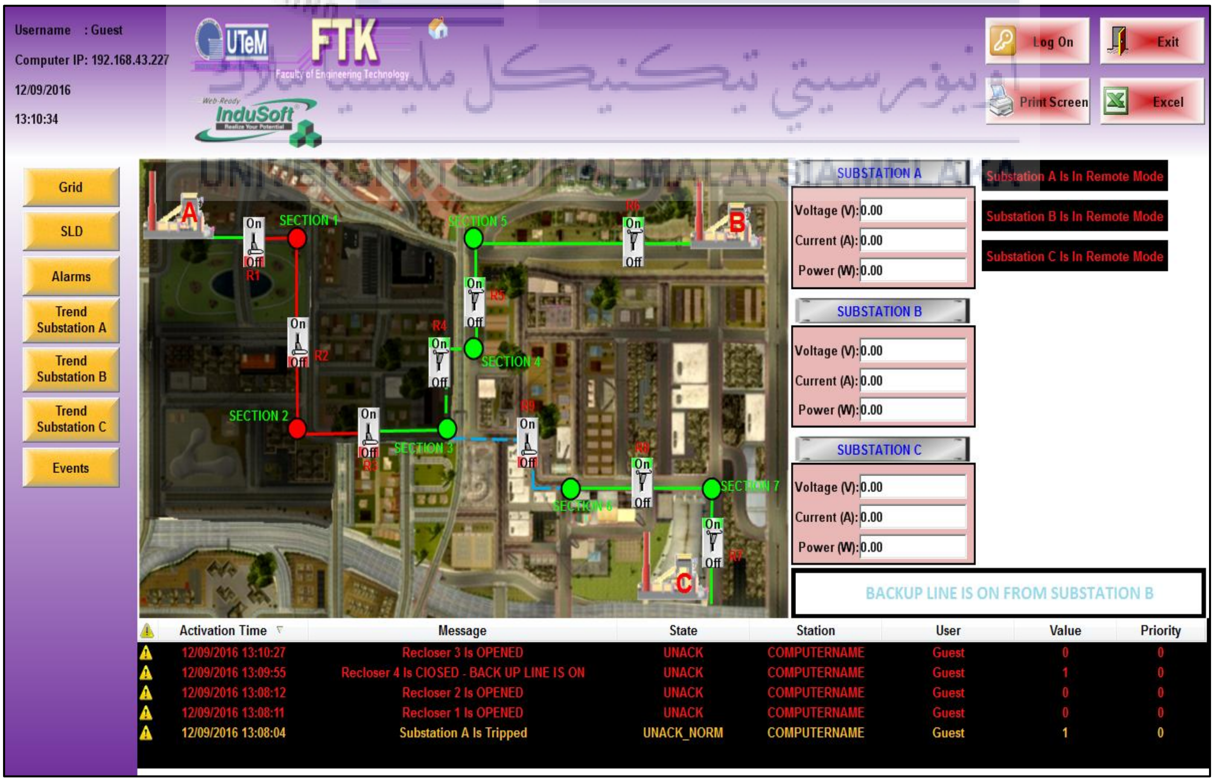

Figure 4.15: Section 3 is supplied by the backup line through Recloser 4.

Figure 4.16: Section 2 is supplied by closing Recloser 3.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this project, the objectives stated earlier was successfully achieved. The Distribution Automation System (DAS) was applied on the Low Voltage (LV) substation to perform the Fault Location, Isolation, and Service Restoration (FLISR) operation. The substation prototype was built and tested successfully. The town model was also built and tested. Moreover, the Human Machine Interface (HMI) was constructed and developed successfully too. Through the implementation of the FLISR system, the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) can be mitigated.

SAIDI represents the average amount of time that consumers are without service per consumer served. On the other hand, SAIFI refers to the total number of outages experienced by consumers per consumer served. Both of these indexes show the data of the power system performance quality. A low value indicates a high quality. This project can be used for educational purposes in order to expose learners about the Distribution Automation System (DAS). Last but not least, greater demand on the distribution grid for power is being recognized by the distribution network operators and this leads to the necessity to improve the level of power supply quality. Thus, the implementation of FLISR system in DAS could be a better approach to solve this problem.

5.2 Recommendation

With new technologies and devices keep emerging, the implementation of Distribution Automation System (DAS) can be upgraded and improved. Due to cost constraints and limitations, the devices used for this project is limited. The Universal Measuring Device, UMG 96S is only fixed for one of the substations. The UMG 96S could be fixed in all three substations in future for the whole parameters measurement of the system. This will increase the quality of this project.

Moreover, with wireless technologies rapidly developing, the communication system of this project can be upgraded. This project fully utilizes the wired communication for its operation. All the data sending and receiving use the wired communication such as RS232, RS485, and LAN connections. Implementation of wireless communication could reduce the requirement for communication cables and increase the communication distances. Even though wireless communication is quiet costly, it has a better quality and low maintenance compared to wired communication.

Last but not least, the SCADA system of this project can also be improved. By using the mobile applications which are trending nowadays, the SCADA can be constructed to be used in smart phones. Operators could monitor and control the system whenever and wherever they are. Smart phones are more compatible and portable compared to computers used in control stations. The system's performance could be increased when the operators could access the system anytime and anywhere.

REFERENCES

[1] Voltage Classification, LV, MV, EHV, viewed 2 March 2016, http://www.electrotechnik.net/2011/03/voltage-classification-lv-mv-and-ehv.html.

[2] Parikh, P, "Distribution System Automation," *ES 586b Course Project Report*, pp. 2.

[3] Razak, MYA 2014, "The Development of Low Voltage Distribution Automation System based on Remote Terminal Unit, ABB RTU 211," pp. 4.

[4] Indusoft Web Studio, Indusoft Web Studio HMI SCADA Development Software, viewed 11 March 2016, http://www.indusoft.com.

[5] LECTURE 6: POWER SYSTEM AUTOMATION, viewed 4 March 2016, http://www.nptel.ac.in/courses/108106022/LECTURE%2011.pdf.

[6] Aguero, JR 2012, "Applying Self-Healing Schemes to Modern Power Distribution Systems," *IEEE*, pp. 1 - 4.

[7] American Recovery and Reinvestment Act of 2009, 2014, "Fault Location, Isolation, and Service Restoration Technologies Reduce Outage Impact and Duration," *Smart Grid Investment Grant Program*, pp. 1 - 3.

[8] Texas Instrument, HMI Guide, viewed 24 March 2016, http://www.ti.com/lit/sl/slyy049a/slyy049a.pdf.

[9] Zarir, MH 2014, "Development of Human Machine Interface (HMI) and Interfacing fro Low Voltage Distribution Automation System (DAS)," pp. 7, Jun.

[10] Wan Jusoh, WNSE, Ghani, MR Ab., Mat Hanafiah, MA, & Raman, SH 2014, "Remote Terminal Unit (RTU) Hardware Design and Development for Distribution Automation System," *IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA)*, pp. 572 - 576.

[11] AUCTO-NRI INDUSTRIAL, ABB RTU 211, viewed 6 April 2016, https://www.aucto.com/live/nriindustrial/pine-falls-pf/abb-rtu-211-1knu300080-23io94-binary-i-o-module-pcb-circuit-board-b214363/2495241.

[12] Mikro, Combined Overcurrent and Earth Fault Relay MK2200 - User's Manual.

[13] Janitza, Universal Measuring Device UMG 96S - Operating Instructions.

[14] Galco, Relay - How Relay Works, viewed 3 April 2016 http://www.galco.com/comp/prod/relay.htm how relay works.

[15] Ben Kellison, Greentech Media - FLISR of the Future: Tiering Reliability to Meet Consumer Needs, viewed 4 April 2016, http://www.greentechmedia.com/articles/read/flisr-of-the-future-tiering-reliability-to-meet-consumer-needs.

[16] Chapman, D 2001, "Costs - The Cost of Poor Power Quality," *Power Quality Application Guide, Copper Development Association*, pp. 1 - 4.

[17] Energy Central, Intelligent Utility – FLISR Provides a Smart Brain, viewed 5 April 2016, http://community.energycentral.com/community/intelligent-utility/flisr-provides-smart-brain.

[18] NEMA, Grid Resilience, Smart Grid Solutions – Integrating a Fault Location, Isolation, and Restoration System into an Outage Management System, viewed 5 April 2016, https://www.nema.org/Storm-Disaster-Recovery/Smart-Grid-Solutions/Pages/Integrating-a-Fault-Location-Isolation,-and-Restoration-System-into-an-Outage-Management-System.aspx.

[19] Gauci, A & Eng, P, "Smart Grid Fault Location, Isolation, and Service Restoration (FLISR) Solutions to Manage Operational and Capital Expenditures," *Schneider Electric - North America*, pp. 1 - 6.

[20] Ahmed, MM, Soo, WL, Hanafiah, MAM & Ghani, MRA 2010, "Customized Fault Management System for Low Voltage (LV) Distribution Automation System," *Research Gate*, pp. 51-69.

[21] Raman, SH, Ghani, MR Ab., Baharudin, ZA, Hanafiah, MAM & Wan Jusoh, WNSE 2012, "The Implementation of Fault Management in Distribution System Using Distribution Automation System (DAS) in Conjunction with SCADA," *Power and Energy Conversion Symposium (PECS 2012),* pp. 305-309.

[22] Ahmed, MM, Soo, WL, Hanafiah, MAM & Ghani, MRA 2010, "Development of Customized Distribution Automation System (DAS) for Secure Fault Isolation in Low Voltage Distribution System," *Research Gate*, pp. 131-150.

[23] Raman, SH, Wan Jusoh, WNSE, Mat Hanafiah, MA, Ghani, MR Ab. & Baharudin, ZA 2013, "A Low Cost Wireless Data Acquisition System for Distribution Automation System," *3^{rd} International Conference and Exhibition on Sustainable Energy and Advanced Material*, pp. 1-6.

[24] Gomes, D, Colunga, R, Gupta, P & Balasubramanian, A 2015, "Distribution Automation Case Study: Rapid Fault Detection, Isolation, and Power Restoration for a Reliable Underground Distribution System," *68^{th} Annual Conference for Protective Relay Engineers,* pp. 1-10.

[25] Choi, T, Lee, KY, Lee, DR & Ahn, JK 2008, "Communication System for Distribution Automation Using CDMA," *IEEE Transactions on Power Delivery, Vol.23, No.2*. pp. 650-656.

[26] Electronic Design, What are the Difference between RS232 and RS485 Serial Interfaces, viewed 7 April 2016, http://electronicdesign.com/what-s-difference-between/what-s-difference-between-rs-232-and-rs-485-serial-interfaces.