AUTONOMOUS FAULT ISOLATION AND POWER RESTORATION SYSTEM FOR MV/LV DISTRIBUTION

D.M.D.K.Dissanayaka

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Degree of Master of Science

Department of Electrical Engineering

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(Dr. W.D.A.S. Rodrigo)

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(Dr. K.T.M.U. Hemapala)

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ABSTRACT

The term "Distribution Automation" generally refers to a distribution network switching subsystem devices equipped with the advanced technologies dedicated for purposes such as, ease of real time monitoring and controlling, reliability improvement management, integrating of distribution network and electricity market operation. Improving the reliability of electric power delivered to the end users is one of the main targets of employing distribution automation. Therefore, developing autonomous fault isolation and power restoration system for LV/MV distribution can be attractive reliability enhancement solution for the electric utilities.

Electrical utility industries are not focusing on automating Low Voltage (LV) distribution system due to complexity of the LV distribution network feeders. However, there is a room available for automation if an algorithm could be developed for autonomous fault isolation and power restoration. Development of a comprehensive algorithm opens up a new pathway for LV distribution.

Electrical distribution system network consists in large numbers of Remote Switching Subsystem Devices (RSSD) and these devices communicate in different protocol. These devices can be monitored and controlled remotely by linking with Supervisory Control and Data Acquisition (SCADA) system. However, investing on a fully fledge SCADA is not so economical for a small scale distribution utility. As a solution; scalable distribution automation will enable small scale distribution utilities to enter into distribution automation with optimal capital investment. Hence, developing a scalable SCADA is the solution for smaller distribution automation.

Results of this thesis are, a proto type LV distribution system has been developed to demonstrate the algorithm for autonomous fault isolation and power restoration system. Also has been implemented open platform SCADA system in view of acquiring multi-protocol remote switching subsystem devices.

Key words Distribution automation, Fault management activities, Fault isolation and power restoration, SCADA system, Protocol, Algorithm

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LIST OF ABBREVIATIONS

Abbreviation	Description
ACR	Auto Circuit Recloses
ADSS	All-Dielectric Self-Supporting
AFIPR	Autonomous Fault Isolation and Power Restoration
CB	Circuit Breaker
CIS	Customer Information System
DAS	Distribution Automation System
DCC	Distribution Control Center
DDNS	Dynamic Domain Name System
DDLO	Drop Down Lift Off
DMS	Data Management System
DNP	Distributed Network Protocol
EF	Earth Fault
FI	Fault Indicators
FIS	Feeder Information System
GIS	Geographical Interface System
GPRS	General Packet Radio Service
GSM	Global System for Mobile
GSS	Grid Substation
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Electrical and Electronic Engineers
kWh	kilo Watt hour
LBS	Load Break Switches
LKR	Lanka Rupees
LV	Low Voltage
MFCS	Micro Feeder Control System
Mn	Million
MSCADA	Micro SCADA

MV	Medium Voltage
OC	Over Current
O&M	Operation & maintenance
OPC	Object linking & embedding for process control
OPGW	Optical Power Ground Wire
RSSD	Remote Switching Subsystem Devices
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SIM	Single Inline Module
SMS	Short Message Service
TCP/IP	Transport Control Protocol/Internet Protocol
UF	Under Frequency
UHF	Ultra High Frequency
VHF	Very High Frequency
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
WOC	Wrapped Optical Cable
WPS II	Western Province South II

Chapter 1

INTRODUCTION

1.1 Background

The quality of life of people living in the present era has been tremendously improved as most of daily activities are automated. Traditionally, use of electricity powered utilities played a major role in enhancing quality of life of people. Globally around 17% of total energy consumed is electrical energy [1]. The electricity consumer always expects an efficient, more reliable and consistent delivery of power and in order to achieve these objective the electric power distribution system needs constant evolution. However, generally about 80 to 90 percent of the consumer reliability problems are originated from the electric power distribution systems [2-4]. Hence, introduction of automation to the traditional electrical distribution system is an efficient solution [5-6].

The word automation implies to carry out particular task automatically, fast and in an accurate manner without involving human activity. Automation cannot be achieved without microcontroller system, communication network and some relevant firmware system. Distribution Automation System (DAS) is one application of automation. Distribution Automation System helps to automatically monitoring, protecting and controlling switching operation through intelligent electronic devices in a real time mode. Once automated the electricity power utilities can isolate and restore power service when there is a fault within Seconds. Distribution Automation Systems have been defined by the Institute of Electrical and Electronic Engineers (IEEE) as systems that enable an electricity utility to monitor, coordinate, and operate distribution component in a real time mode from remote locations [7].

Supervisory Control and Data Acquisition (SCADA) works as the Human Machine Interface (HMI) of distribution automation system. It provides status of the distribution network concerned & generates alarms & trends based on real time information. It works as an information translator between operator & field installed smart grid devices. [8]

1.2 Introduction to Distribution Automation System

Distribution Automation System helps to automatically monitoring, protecting and controlling switching operation through intelligent electronic devices in a real time mode. Once automated the electricity power utilities can isolate and restore power service when there is a fault within Seconds.

Following three major areas expected to benefit from Distribution Automation system implementation.

- ❖ Operational and Maintenance Benefits
  - Reliability improved by reducing outage duration hours to seconds using auto fault isolation and restoration system
  - Optimized man hour, man power and breakdown vehicle usage
  - Real time fault detection and diagnostic analysis
  - Accurate and real operational data information
- ❖ Consumer related Benefits
  - Better quality of supply
  - Better service reliability
  - Reduce interruption cost for Industrial and Commercial Consumers
- ❖ Financial Benefits
  - Increased revenue due to quick restoration

Most Electrical utility industries in the world are modernizing and automating their Generation, Transmission and Medium Voltage (MV) distribution system. However Electrical utility industries are not focusing on automating Low Voltage (LV) distribution system due to complexity of the LV distribution network feeder arrangement. The most financially valuable element in the Electrical utility industry is the end user consumer. These valuable end user consumers connect to the system through LV distribution system. Most of the time; end user or the consumer suffers from electricity interruption without any fault in itself LV distribution section and due to fault in same feeder. However, electricity utilizer take from minutes to hours for power restoration for these faultless consumers by manually find and isolate the faulty section and restore power in alternate feeding arrangement [9]. Hence, introduction of Autonomous Fault Isolation and Power Restoration System for LV distribution system is important for improving the end user reliability.

It is usually considered that the LV distribution system is too complex. But there is room available for automation if an algorithm could be developed for Autonomous Fault Isolation and Power Restoration. Development of a comprehensive algorithm opens up a new path way for LV distribution.

1.3 Importance of introducing Scalable SCADA

Electrical distribution system network consists in large numbers of Remote Switching Subsystem Devices (RSSD) and these devices communicate in different protocol [10-12]. These devices can be monitored and controlled remotely by linking with Supervisory Control and Data Acquisition (SCADA) system. However, investing on a fully fledge SCADA is not so economical for a small scale distribution utility. As a solution; scalable distribution automation will enable small scale distribution utilities to enter in to distribution automation with optimal capital investment.

Acquiring multi-protocol RSSD and smart grid devices into open platform is the challenge. Hence, developing a scalable SCADA is the solution for smaller distribution automation.

- ❖ Features of the solution
  - Scalable
  - Open to Multiprotocol devices

- Zero cost for implement
- Zero cost for operation
- Lower level of technical expertise requirement
- Improve local engineering skills

1.4 Literature Review

Three main literature surveys have been conducted for the purpose of this research thesis. The first literature survey aimed at finding the major fault finding activities in LV distribution system and time taken for each activities and then identifying activities which are possible for introducing automation and finally how can be reliability enhancement of distribution systems by introducing automation. The second literature survey was concerned finding possibilities to introduce open platform MV distribution SCADA system for MV distribution system with existing Remote Switching Subsystem Devices. The third literature survey was concerned with the previous research activities related to the LV and MV distribution automation. In the following, the result of this literature survey and also contribution of this thesis are described.

The work by Katja Hannele [27] discussed, how can be integration of LV distribution automation to the traditional distribution automation system using intelligent micro grid subsystem. Several issues have been considered in this paper when automation introduced to LV system. Integration low voltage distribution systems to distribution automation concerned functions and by technologies. Katja Hannele studied main element in the LV distribution system and approach to the integration evolution of LV distribution system automation. Katja Hannele evaluated on distribution automation function, management architecture and requirement for communication. However, Katja Hannele never discussed fault management activities. Also how can be automation used to power restoration for customers who are unaffected fault in LV distribution system.

The work by Lawler [26] present reliability impact of distribution automation on the Athens utilities board. Several scenarios have been conducted in this paper by providing the remote controlling facilities for target manually operated switching devices. Lawler only focus about reliability improvement by modifying the switching time of the retrofitted MV switching devices. . Lawler not concerned about isolation of faulty section and power restoration method to faultless customers.

In [28, 29], it has been studied optimal allocation of the automatic sectionalizing switching devices. These automatic switching devices are able to diagnose the fault and eventually to reschedule the configuration of the network for restoration the power to the affected customers. In this targeted automation scheme, discussed that they have been model ignoring the customers who have not affected by the fault. They are not focusing on the power restoration method by using automatic switching devices.

The work by M. Lehtonen [30] discussed how can be identifying fault occur in the distribution system using fault passage indicator. However, past and present market available fault passage indicators are not functioning with earthed wire. Sri Lankan MV distribution network consists with earth wire under the MV network. Hence, fault passages indicators method cannot be successfully used to identify real time fault occur in the distribution network. In addition it is not applicable for LV network.

Article on the newspaper [15] presented capital cost for the implement automated distribution network to the capital city. It is highly expensive for developing countries. Hence it is required to introduce financially viable distribution automation system to improve reliability in the distribution network using maximum allocated resources.

The work by T.S. Sidhu [14] presented importance of the open protocol for communication for power system automation. He discussed how can be used open communication protocol for remote data acquisition from various equipment installed at the distribution network.

K. Ghoshalm [31], presented SCADA is the key factor of distribution automation. K. Ghoshalm describe distribution system automation is a complete system that enables a utility to monitor, coordinate and operate the distribution network component in a real time mode from remote locations. Distribution automation allows utilities to implement a flexible monitoring and control of an electric power distribution system that can be used to enhance efficiency, reliability and quality of the electric services. He concerned SCADA is the key factor of distribution automation to achieve above.

The work by Nisal Amarasinghe [32], discussed importance of the retrofitting of Non – standard protocol based supervisory control and data acquisition system (SCADA) to a standard system to standardize the system in electric field. Also present in this paper retrofitting of non – standard protocol based SCADA to a standard system to standardize the system enabling the future expansions, modifications and additions with lesser cost, using market available standard tools and equipment mitigating the risk of running into sudden failures.

The work by R.J.N Rathnayaka [33], discussed investing on a fully fledge SCADA is not so economical for a small scale distribution utility. Proposed scalable distribution automation solution will enable small scale distribution utilities to enter in to distribution automation with lesser capital investment. Introducing automation to distribution system concerned in these work limited to MV distribution system and ignoring LV distribution automation.

The proposed LV and MV distribution automation in the above described works have the following shortfalls.

- Very few works are done for LV distribution automation. However, the most financially valuable element in the Electrical utility industry is the end user consumer. These valuable end user consumers connect to the system through LV distribution system. Most of the time, end user or the consumer suffers from electricity interruption without any fault in LV distribution section and due to fault in same feeder. However, electricity utilizers in developing countries such as Sri Lanka do not care about minimizing the time taken for power restoration. Traditional fault management activities done by manually finding and isolating the faulty section and restore power in alternate feeding arrangement. Hence introduction of Autonomous Fault Isolation and Power Restoration System for LV distribution system is required for improving the end user reliability.

- Usually LV distribution system is too complex comparing with MV distribution network system. Number of switching devices in LV distribution network is multiple of 100. It is required algorithm to develop LV distribution automation system, because without comprehensive data structure handling switching devices in LV distribution network is hopeless. But there is a room available for automation if an algorithm could be developed for Autonomous Fault Isolation and Power Restoration. Hence, Development of a comprehensive algorithm opens up a new path to LV distribution.

- The proposed distribution automation systems are depending on the cutting edge technologies. They have almost been designed for a specific technologies used in the electricity utilities in the developed countries. The application of these methods even for other similar solution but with the existing traditional LV and MV distribution system to converting automated system is questionable with the cost to be invested. Hence, it is required developing electricity distribution system automation by using local engineering knowledge and skills.

- Most of the time; developing countries purchase switching devices for distribution network by considering the cost with technical specification. Then feature for automation, not considered as key point when purchasing switching devices. As a result, Electrical distribution system network consists in large number of Switching Devices and these devices communicate in different protocol. These devices can be monitored and controlled remotely by linking with Supervisory Control and Data Acquisition (SCADA) system.

However, investing on a fully fledge SCADA is not so economical for a small scale distribution utility.

This research aimed at overcoming the shortfalls described above. The research activities were organized to develop algorithm for autonomous LV fault isolation and power restoration system and open platform MV SCADA system. Final result of the research is to implement prototype autonomous LV fault isolation and power restoration together with algorithm. Also develop an open platform SCADA system in view of acquiring multi-protocol remote switching subsystems devices in Western Province South II of Ceylon Electricity Board. It is also possible to evaluate the distribution automation systems available in the developed countries that are implemented at the same time. However, this research is focused on local engineering knowledge and skills. The result of proposed and developed systems is improving efficiency as well as reliability and quality of the power system benefits both the utility & its consumers. Once implemented, there will be a definite improvement in quality of life of customers and will contribute positively on the economy of the country.

1.5 Identification of the Problem

Sri Lanka consists of five electric power distribution utilities. Here; the MV network is equipped with RSSD that is Auto Circuit Recloses (ACR), Load Break Switches (LBS), Fault Indicators (FI) and Sectionalizes. However, these devices operate in Local/Standalone Mode due to the Reluctance to work with Computerized Systems and the Absence of a Distribution Control Center (DCC). Electricity power utilities spent more and more money for this incorporated Remote Switching Subsystems facility. But, until now there is no considerable improvement in the reliability of electricity power supply to justify the investment for Remote Switching Subsystems Devices.

To have a good picture of our system, when a breakdown occurs the repair crew needs to visit each and every RSSD along the MV feeder and LV feeder. Then they open and close the particular point just to isolate the faulty section of the feeder. The procedure leads to hours of time loss and it becomes worst in case of a very long MV feeder and LV feeder.

Undoubtedly; the system reliability is at a poor status. To increase reliability, time taken for rectification of faults should be brought to seconds & minutes from hours. A DCC helps this by utilizing the inherited remote facility and centralized control.

In order to continue distribution licenses, the Public Utilities Commission of Sri Lanka (PUCSL) in its distribution code requires each distribution utilities to implement a Distribution Network Control Centre (DNCC) [13].

As per the distribution code, to improve reliability of the electricity distribution system in Sri Lanka, distribution automation system can be introduce to MV system with existing installed Remote Switching Subsystems Devices. Convert traditional MV distribution system into automated MV distribution system the initial capital investment is lesser. Also operating cost is almost zero.

The biggest problem is that the existing switching subsystems are procured from various manufactures. Different manufacturers develop their systems based on different communication protocols. Further; the Human Machine Interfaces of those products were proprietary to the manufacturer.

Now it is evident that an open platform is needed these different platforms to house. An open platform would make integrating existing switching subsystems to a common central system. Hence before implementing DCC, finding a solution for integrating switching devises into one SCADA system is absolutely crucial.

All switching subsystems are already equipped with remote operation facility. Therefore, installing new RSSD is unnecessary. Only by purchasing a personnel computer and SCADA software alone is sufficient to implement the DCC. Hence; the cost saving is at its maximum when compared to a direct vendor solution.

Communication infrastructure is a vital organ in automation [14] and the cost effectiveness and reliability of the communication infrastructure increases the relevance of the automation.

MV distribution automation problem can be solved by "Developing open platform scalable SCADA for integrating existing switching subsystem devises to a common central system together with a cost effective communication infrastructure"
Time for LV fault isolation and power restoration can be brought to seconds & minutes from hours by introducing algorithm and introduce automation together with microcontroller based switches.

1.6 Motivation

There are two outcomes of this project. Developing algorithm for autonomous LV Fault Isolation and Power Restoration system and implement prototype is one. The second outcome is developing an open platform MV SCADA system for Ceylon Electricity Board- Western Province South II (WPS II). This will enhance control center operation & will increase network reliability level of WPS II and open door to LV distribution automation.

As a result; improving efficiency as well as reliability and quality of the power system benefit both the utility & its consumers. Once implemented; there will be a definite improvement in quality of life of customers and will contribute positively on the economy of the country.

1.7 Objective of the Study

Following are the major objectives of this study,

- Develop algorithm for complex LV fault isolation and power restoration method

- ❖ Developing of open platform SCADA system in view of acquiring multi-protocol remote switching subsystems devices in Western Province South II of Ceylon Electricity Board.

1.8 Contribution

A proto type LV distribution system has been developed to demonstrate the algorithm for autonomous fault isolation and power restoration system. Also has been implemented open platform SCADA system in view of acquiring multi-protocol remote switching subsystems devices in Western Province South II of Ceylon Electricity Board as pilot project.

1.9 Organization of the thesis

After this introductory chapter, chapter 2 provides LV feeder automation. It consists of average time duration for each activity calculated from the collected data and how this activity time can be reduced by automation, introduces the LV feeder automation and description of proposed architecture of LV feeder automation. Furthermore, the developed algorithm for autonomous fault isolation and power restoration system is described in the chapter 2. Chapter 3 deals with the remote switching subsystem devices in MV network and solution for open platform SCADA system in view of acquiring multi-protocol remote switching subsystem devices. Financial feasibility of proposed MV open platform SCADA system for WPS II province is evaluated in the chapter 4. Demonstration of the algorithm for autonomous fault isolation and power restoration system and pilot project implementation of MV open platform SCADA system is presented in the Chapter 5. Finally, Chapter 6 provides the concluding remarks.

Chapter 2

LV FEEDER AUTOMATION

2.1 Case Study: Time duration for fault management activities for Manual operated LV distribution network

Manual operated LV distribution network has several activities for fault management. Most of activities are unwanted time consuming activities due to a lack of automation to the LV distribution network. Hence, before proposed an automation system to the LV distribution network, study about time duration for fault management activities has been done.

This case study aims to find average time duration taken for fault management activities. For this case, study twenty LV distribution networks related to twenty distribution secondary substations in Western Province South II, Ceylon Electricity Board has been selected Geographically Western Province South II divides into five areas named Sri Jayawardanapura, Homagama, Avissawella, Horana and Bandaragama [16]. Western Province South II is a mix of urban and rural area with around 0.5 million end users.

Time duration for activities depend upon many inputs such as distance from Consumer Service Center to the fault area, road condition, traffic, performance of crew, time for manual operation, time for decision making about fault management activities etc…

Time duration for fault management activities collected for one year period (2013 May to 2014 June). The collected time duration for fault management activities is presented in Table 2.1. This table shows only fault occur in feeders. LT power failure due to absence of HT, Transformer failure, Scheduled interruptions are not considered as fault. Table 2.2 shows the average time duration taken for fault management activities.

Table 2.1: Time duration taken for fault management activities

Event	Duration (Min.)	Sri JPura				Homagama				Avissawella				Horana				Bandaragama				Average time (Min.)
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Report the Break down	0-10	4	5	8	3	4	6	10	5	7	6	6	15	9	4	4	5	3	10	6	6	**14**
	11-20	4	8	7	3	3	6	6	1	3	3	3	6	4	0	2	4	3	4	4	3	
	21-30	2	4	5	6	1	3	0	2	1	1	1	3	2	2	5	3	1	2	1	2	
	> 30	1	1	3	2	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	
Reach to the Substation	0-10	1	2	7	0	0	2	1	0	1	0	2	3	2	1	2	1	2	2	1	0	**35**
	11-20	4	12	8	4	3	5	4	2	2	0	2	4	1	3	5	3	2	3	2	1	
	21-30	4	4	6	7	4	7	10	5	7	6	5	14	8	3	4	7	2	2	4	3	
	> 30	2	2	2	3	1	2	2	2	2	4	2	4	5	0	1	2	2	7	5	8	
Find fault section	0-10	2	4	3	1	0	1	1	1	1	0	0	1	2	0	1	3	2	1	0	1	**25**
	11-20	3	9	6	4	0	1	7	3	3	1	2	3	4	3	3	2	0	3	1	3	
	21-30	4	4	11	7	7	12	7	4	5	7	6	16	6	4	5	6	5	8	6	5	
	> 30	2	1	3	2	1	2	2	1	3	2	3	5	4	0	3	2	1	5	5	3	
Isolate fault section	0-10	3	2	7	0	0	1	1	0	0	1	1	0	3	1	0	1	1	2	0	1	**25**
	11-20	5	11	8	4	2	3	0	0	2	2	0	1	3	4	3	1	1	2	3	2	
	21-30	3	4	7	7	5	9	13	7	7	5	6	19	8	1	6	9	3	10	7	3	
	> 30	0	1	1	3	1	3	3	2	3	2	4	5	2	1	3	2	3	3	2	6	
Restore power for the healthy section	0-10	1	2	4	1	1	0	1	0	0	0	0	1	0	1	0	0	0	1	1	0	**33**
	11-20	2	5	5	1	2	2	2	0	2	0	0	1	2	0	0	2	0	4	3	0	
	21-30	3	4	6	5	1	8	1	2	4	2	3	8	11	1	2	4	0	5	4	5	
	> 30	5	7	8	7	4	6	13	7	6	8	8	15	3	5	10	7	8	7	4	7	
Attend to the regulate breakdown	0-10	1	0	1	1	0	0	1	0	0	1	2	0	0	1	0	2	0	1	1	1	**28**
	11-20	2	3	4	4	1	1	0	1	2	3	4	5	2	1	4	2	1	1	2	1	
	21-30	4	13	16	6	3	11	11	6	8	5	3	7	8	4	5	6	3	3	4	1	
	> 30	4	2	3	3	4	4	5	2	2	1	2	13	6	1	3	3	4	12	5	9	
Reset the system	0-10	5	4	3	1	1	0	1	0	1	0	2	0	1	0	0	0	0	1	2	1	**25**
	11-20	6	8	9	4	1	2	2	0	1	2	3	1	2	2	3	2	1	3	2	3	
	21-30	0	4	9	7	5	11	10	5	8	5	4	22	9	3	7	8	3	5	2	3	
	> 30	0	2	2	2	1	3	4	4	2	3	2	2	4	2	2	3	4	8	6	5	

Table 2.2: Average time duration taken for fault management activities

Average time to report the Breakdown (Minute)	15
Average time required to reach the Substation (Minute)	35
Average time required to find the faulty section (Minute)	25
Average time required ot isolate faulty section (Minute)	25
Average time required for restore power for the healthy section (Minute)	35
Average time required for attend to the regulate breakdown (Minute)	30
Average time required for reset the system (Minute)	25

The results of the study shows that manual operating LV distribution system may take a long time. Also take nearly half an hour to re-settle the system after regulating the fault.

Time required to reach the Substation & attend to regulate breakdown, all other activities such as reporting the Breakdown, finding faulty section, isolating faulty section, restoring power for the healthy section & resetting the system, could be completed within 5 Min by converting manual operation switch in to a remotely operated switch.

However, a suitable feeder automation scheme can be used to perform fault management activities in much more efficient manner. Hence, depending on the characteristics of the implemented feeder automation scheme, the above process can be used to complete more efficiently with less people in much less time, which increase the LV distribution system reliability and efficiency.

Figure 2.1, shows how the fault management activities might process without and with employing an advanced feeder automation schemes.

Figure 2.1: Time durations for fault management activities without and with automation schemes.

2.2 Fault Management Activities in LV Feeder

LV distribution networks in Sri Lanka are mainly overhead radial. However, in order to ensure uninterrupted supply of electricity in some of the areas like Colombo city & Kandy city, a fully automated SCADA controlled underground system of MV & LV distribution had been installed and commissioned with the help of Germany and India [15]. It also forms an open ring system. The LV distribution is a manually operated system in whole country, except Colombo city & Kandy city. Part of this research is dedicated to explore ways of improving reliability of LV distribution system to the same level as the automated LV distribution system of Colombo city & Kandy city. General form of LV distribution network in Sri Lanka is presented in Figure 2.2

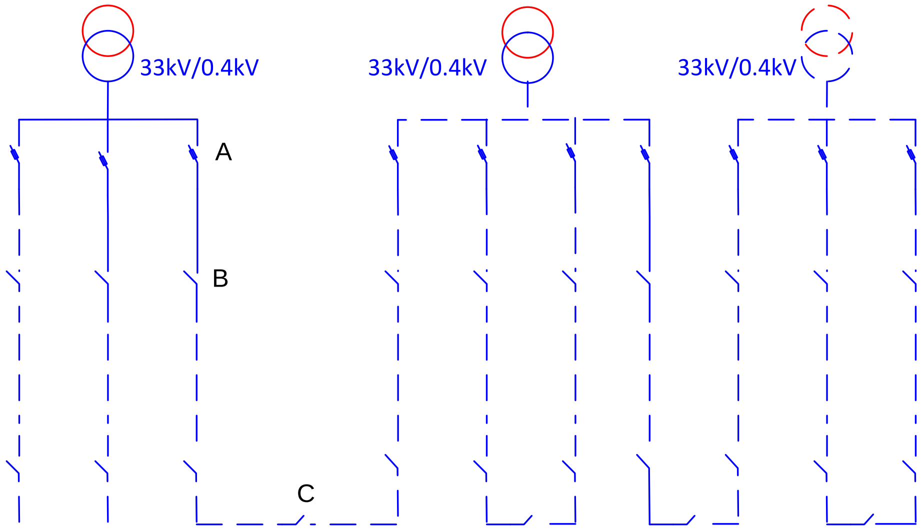


Fig 2.2: General form of LV distribution network in Sri Lanka

Existing LV distribution network comprise of a pole mounted Secondary Substation rated 33/0.4kV, pole mounted fuse switches and overhead line (bare Aluminum) or Arial Bundle Cable (ABC) to customers. In the secondary substation, there are five feeders maximum. Feeder starts with fuse switch (A as shown in figure 2.2). Each feeder consists of series of switches called "Wire jumper" (B as shown in figure 2.2), which is used to connect or disconnect the section of feeders. Generally there is an open jumper point at two feeders meet (C as shown in figure 2.2). This existing LV distribution network is operated manually containing switching under normal operation and supply restoring after a fault situation.

With manually operated LV distribution network system, Ceylon Electricity Board perform the fault management activities based on the customer's outage calls. After receiving the breakdown call from the customer, call agent gathers more and more information to identify or guess the outage area. Then breakdown crew reaches the outage area. As a practice, the crew inspects first, the fuse switch in the distribution substation. If fuses are blown, then replace the blown fuse with good one and wait few seconds for response. In this stage; if the fuse does not blow up it mean feeder is in healthy condition. When the fuse is blown the crew perceives that there is a fault in the feeder. Now they have range of options by which the faulty section could be identified. In the process of fault section identification, as first step the crew visually inspect along the feeder. In the first stage if they are unable to find fault section, open the jumper points and re-energizing the feeder and check whether the fuse is blown or not. By doing this manual step, finally they find the faulty section. Most of the time, power is restored for the healthy section by extending from the adjacent feeder by closing jumpers. Finally attend to the regulate fault. After regulate the breakdown again reset the existing feeder arrangement. The diagnosis of the fault in this manner can be unproductive, inefficient and time consuming task, which final result in the poor service reliability.

Biggest injustice of this manual faulty section isolation is some consumers not having electricity without any fault in feeder section and with possibility to power restoration from alternate feeding arrangement.

2.3 LV Feeder Automation for Fault Management Activities

In the above it was discussed the low reliability and efficiency of manual operated fault management activities in a LV distribution system. However, a suitable feeder automation scheme can be used to perform fault management activities in much more efficient manner.

In a broad sense, the term "smart grid" is referred to conventional electric power system that has been equipped with advanced technologies for purpose such as reliability improvement, ease of control and management, integrating of distributed energy resources and electricity market operations. The smart grid technologies can be categorized in the following five key areas [17]:

Integrated Communications – High-speed, fully integrated, two-way communication technology will make the modern grid dynamic, interactive "mega-infrastructure" for real-time information and power exchange. Open architecture will create a plug-and-play environment that securely networks grid components to talk, listen and interact.

Sensing and Measurement – These technologies will enhance power system measurements and enable the transformation of data into information. They evaluate the health of equipment and the integrity of the grid and support advanced protective relaying.

Advanced Components – Advanced components play an active role in determining the grid's behavior. The next generation of these power system devices will apply the latest research in materials, superconductivity, energy storage, power electronics, and microelectronics. This will produce higher power densities, greater reliability and power quality, enhanced electrical efficiency producing major environmental gains and improved real-time diagnostics.

Improved Interfaces and Decision Support – In many situations, the time available for operators to make decisions has shortened to seconds. Thus, the modern grid will require wide, seamless, real-time use of applications and tools that enable grid operators and managers to make decisions quickly. Decision support with improved interfaces will amplify human decision making at all levels of the grid.

Advanced Control Methods – Advanced control methods are the devices and algorithm that will analyze, diagnose, and predict conditions in the smart gird and determine and take appropriate corrective actions to eliminate, mitigate, and prevent outage and power quality disturbances. To a large degree, these technologies rely on and contribute to each of the four technology areas. For instance, they will monitor essential components (Sensing and Measurements), provide timely and appropriate response (Integrated Communication; advanced Component), and enable rapid diagnosis (Improved Interfaces and Decision Support) of any event.

New methods will be applied to monitor essential components, enabling rapid diagnosis and timely, appropriate response to any event. These will also support market pricing and enhance asset management and efficient operations.

Automation is part of smart grid technologies. Smart grid technologies are used in Generation, Transmission and MV distribution network. However Smart grid technologies did not adapt to the LV distribution system because of complexity. There are two main emphases in this thesis. One is to highlight the developed algorithm for Autonomous LV feeder Fault Isolation and Power Restoration and second is to implement proto type LV distribution system for simulate the algorithm.

2.3.1 Feeder Automation

An automatic control scheme can be introduced to automatic fault detection, isolation and service restoration in the electricity distribution network [18-19]. This is called Feeder automation. When a fault occurs in the electricity distribution network, there are two groups of affected end users. First group is there in faulty section in the feeder. They have to wait until the end of the process to restore the faulted section before power restoration. In contrast, the second groups consist of end users whose power supply can be restored through main or alternative supplies by changing appropriate position of the switch installed in the feeder. Usually, the number of end users in the second group is much greater than the first group. Before restoring power supply to the second group it is needed to isolate the healthy section and the fault section from feeder. After that the power can be restored from main or alternative supplies by changing appropriate position of the switch installed in the feeder. In manually operated distribution system, fault isolation and service restoration activities are done after the fault location, detected by the breakdown team. However, by introducing feeder automation scheme, the interruption duration experienced by the affected end users can be considerably reduced. Intelligent feeder automation system can automatically detect faults and run the algorithm to isolate the faulted section from healthy once and restore power as soon as possible to the affected end users.

2.3.2 Proposed architecture for LV feeder automaton

The aim of this research is to develop an algorithm for Autonomous Fault Isolation and Power Restoration and propose automated LV Distribution system. Before developing the algorithm, research was carried out to explore possibilities of switching manually operated system into automated system.

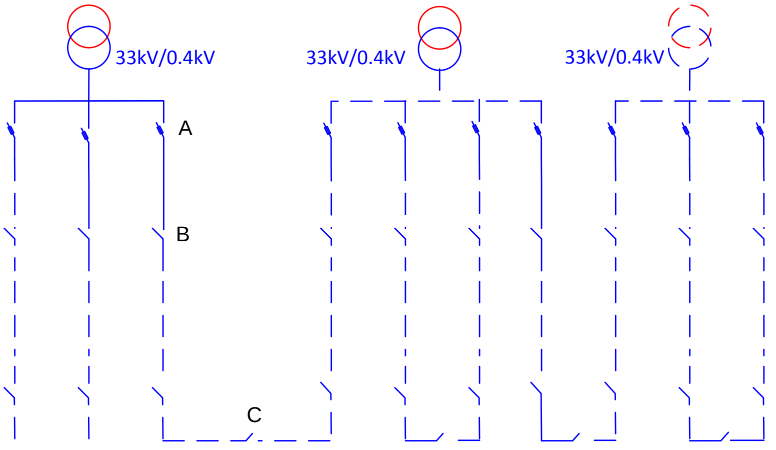


Figure 2.3: General form of LV distribution network in Sri Lanka

General form of LV distribution network in Sri Lanka is presented in Figure 2.3. Where A, and B are HRC fuse, normally closed wire jumper and normally opened wire jumper respectively.

Converting, the Field devices in the LV distribution system into Remote Controlled Switching devices is not complicated because, in the existing manually operated LV distribution system, there are only two switches mentioned as Fuse and Wire Jumper. Fuse can be replaced with Motorized Circuit Breaker. The various products of Motorized Circuit Breakers are commercially available. Also Wire jumpers can be replaced with Isolators. Many choices of isolators are commercially available. However both these switches cannot be controlled remotely. Hence microcontroller based Remote Terminal Unit/ Intelligent Electronic Device should be integrated with these two switches. This filed device can operate in standalone mode. By operating in standalone mode, will not achieve expected automation. To achieve LV feeder automation, it is required these field devices to operate as slaves in master control system. Hence master control system should be introduced for autonomous Fault Isolation and Power Restoration system. Master control unit should be installed at the control center. A communication medium is required to integrate the field switch devices and master control unit. Communication medium may be wired or wireless.

However, when selecting communication medium the higher reliability should be ensured. LV distribution fault management activities cannot be fully automated. The automation only achieves Fault Isolation and Power Restoration. Because, breakdown should be attended by breakdown crew. Hence, Human Machine Interface (HMI) is essential. After accomplishing all above, system fault detection, isolation and power restoration can be done automatically. Without suitable fault isolation and power restoration algorithm feeder automation is again meaningless. Hence, LV feeder distribution automation can be achieved by developing both hardware and algorithm fault isolation and power restoration together.

Proposed LV feeder automation architecture is shown in figure 2.4. Proposed system has mainly two parts, Main control Center and Field Devices.

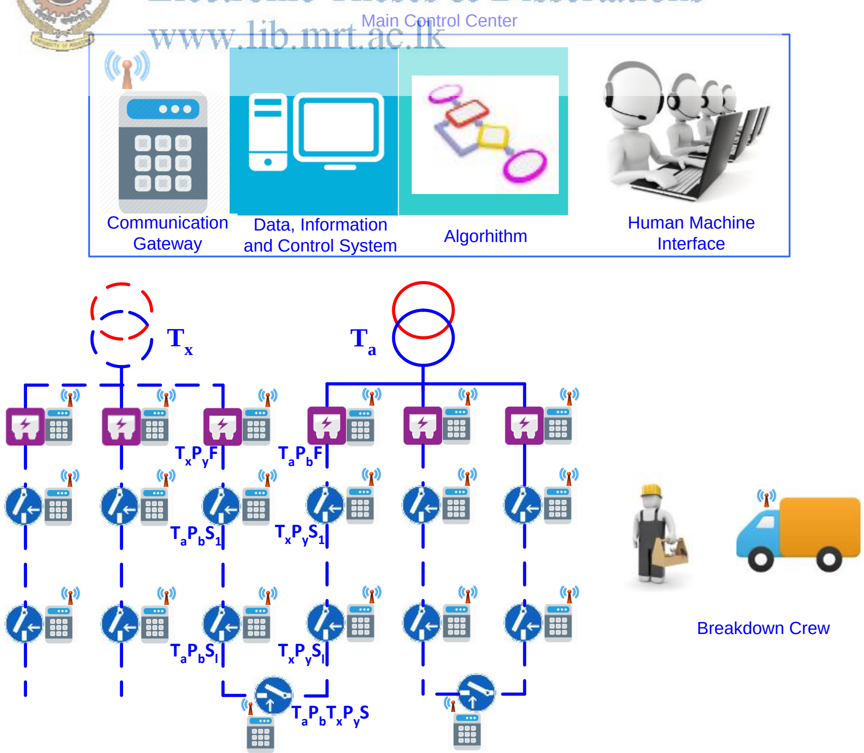


Figure 2.4: Proposed LV feeder automation architecture

Main functions of the system are required to be controlled centrally. Hence Main control center is to be established. It is consist of, communication gateway, Data, Information and Control system, Algorithm and Human Machine Interface.

Communication Gateway used to connect Substations RTU/IED (not introduce separated Substation RTU/IED it is also first Circuit Breaker with RTU/IED). Data, Information and Control system comprises of SCADA/DMS Server, Which are connected to Substation RTU/IED by means of communication gateway.

Major components of Data, Information and Control system are:

SCADA or Feeder Control System (FCS) is central host server or servers. SCADA or FCS enables reading the state of field devices, event data, remote control, remote setting of devices and report back.

Geographical Interface System (GIS) is a system, which collects background maps and data for coordination of network object in the LV network.

Feeder Information System (FIS) is the data base for feeder information. It consists of substation number, feeder number, field devices number, initial state of switches, etc… according to the algorithm data structure.

Customer Information System (CIS) is data base of customer information. It is for further development, such as customer service, calculate reliability indices etc…

Data Management System (DMS) is a real time system for decision support, which functions based on real time data from feeders integrated with static data from feeder information system (FIS). Geographical Interface System (GIS) and Customer Information System (CIS). It is meant to record real time switching status of Circuit Breakers and Isolator switch in feeder and condition of feeders.

The algorithm is used to solve the complex network switching configuration to fault isolation and power restoration. Human Machine Interface displays information in graphical form. It is a software application. That presents information to the operator about the state of switchers in feeders. . Also accept and implement the operator control instruction.

Field devices comprise of Circuit breaker, Isolators integrated with RTU/IED. RTU/IED consists of a communication interface, a processor, Interface board which is interfacing RTU/IED with Circuit breaker and Isolators.

There are many feeders in the LV distribution network. In these feeders there are many numbers of circuit breakers and isolators. If all these field devices are connected to main control center, can making communication and management of field devices very complicated. Hence, Micro SCADA (MSCADA) or Micro Feeder Control System (MFCS) is introduced.

First RTU/IED in the substation (Example; RTU/IED integrated with T_aP_bF) operates as MSCADA or MDCS. It is directly communicate with main control system by representing other remaining Circuit breakers and isolators related to the relevant Substation. It is not a decision maker. It scans the state of Circuit Breakers and isolator within equal time interval. Then send to the main control system. Also broadcast control signal received from main control system for remaining Circuit breakers and isolators related to the relevant substation.

Breakdown vehicle communicate with main control system. Crew in the breakdown vehicle attends to regulate breakdown according to the instructions given by main control system. HMI system also is inbuilt in the breakdown vehicle. Then crew in the vehicle update with real time situation in the feeders.

2.4 Algorithm to LV Feeder Automation for Fault Management Activities

Developed algorithm based on data structure. General LV distribution network configured according to the data structure and it is shown in the figure 2.5.

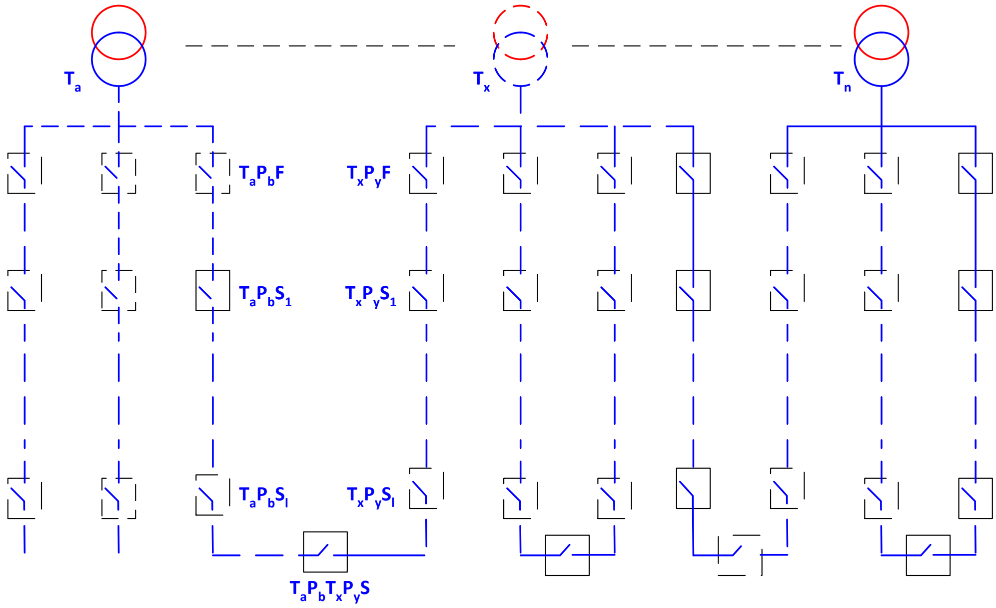


Figure 2.5: General LV distribution network configured according to the data structure.

Data Structure

- There are **n** numbers of Transformer
- There are P_1 to P_m Parallel Feeders in a transformer
- In T_aP_b feeder is connected to the T_a Transformer through Motorized Circuit Breaker T_aP_bF
- Under the Motorized Circuit Breaker T_aP_bF there is series of controllable Isolators $T_aP_bS_1$ to $T_aP_bS_l$, where l is the last
- Each feeder has either 0 or 1 adjoining feeders. If there is adjoining feeder,S is the switch which used to connect to or disconnect from the adjoining feeder

Flags

- T_aP_bF_Tripped - Set when T_aP_bF is tripped, due to fault in T_aP_b feeder
- T_aP_bF_RST - Set when T_aP_bF is required to normalize the feeder (Reset the feeder after clear the fault in feeder)
- T_aP_bF_BD - To be set when TaPbF is tripped and feeder is broken down & need to be attended
- $T_aP_bS_i$ _DB - To be Set when Faulty Section Detected between $T_aP_bS_i$ & $T_aP_bS_{i+1}$

- T_aP_bF_DFS - To be Set when Starting Faulty Section Detection
- $T_aP_bT_xP_yS$_Available - Set when switch is available for connect to adjoining feeder
- $T_aP_bT_xP_yS_T_xP_y$_Need - To be Set when $T_aP_bT_xP_yS$ need to be closed by T_xP_y
- $T_aP_bT_xP_yS_T_aP_b$_Need - To be Set when $T_aP_bT_xP_yS$ need to be closed by T_aP_b

There are only four faulty sections and power restoration configurations available in the general LV distribution network. Considering two separate feeders X and Y describe the configurations. Blue colour indicates power through Circuit Breaker 1 (CB1) and Pink indicates power through CB2. Red indicates faulty section and yellow colour too indicates faultless section.

The first configuration of faulty sections and power restoration illustrate in the figure 2.6.

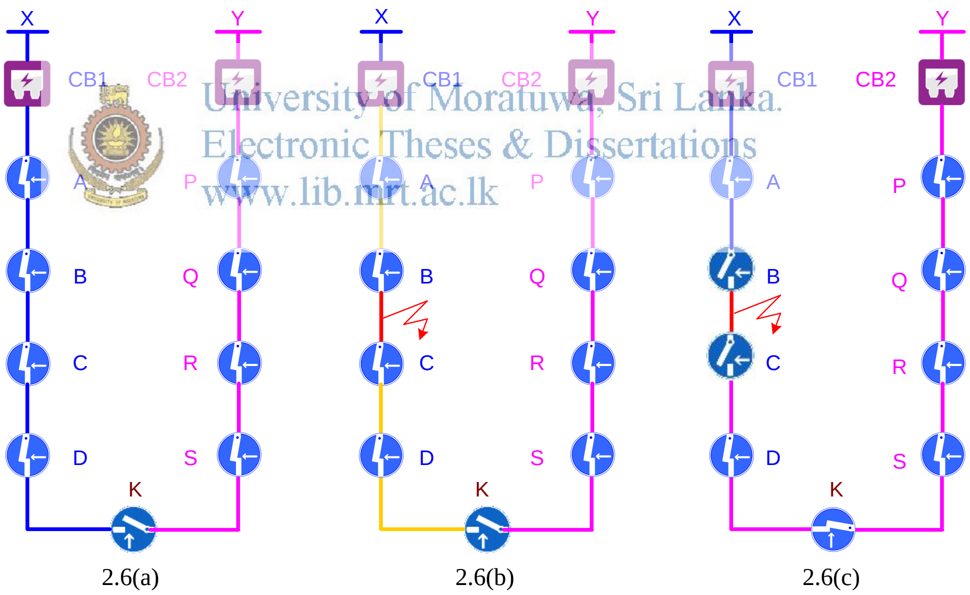


Figure 2.6: The first configuration of faulty sections and power restoration

Figure 2.6(a) illustrates two separate feeders and they are in healthy condition. The adjoining switch is open. Figure 2.6(b) illustrates, when fault occurred in between Isolator B and Isolator C, Circuit Breaker1 (CB1) tripped and hence supply absence in the feeder X. Figure 2.6(c) illustrates power restoration for faultless section by open and close appropriate Isolators.

The second configuration of faulty sections and power restoration illustrate in the figure 2.7.

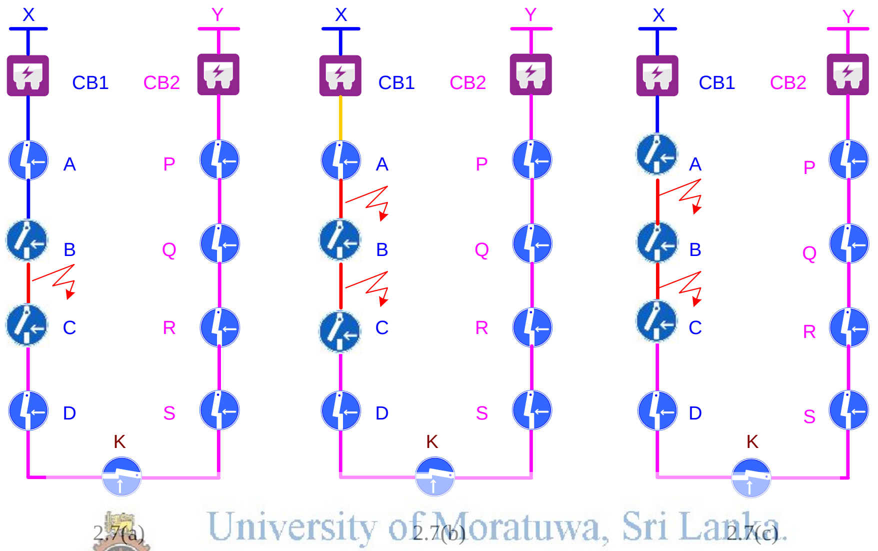


Figure 2.7: The second configuration of faulty sections and power restoration

Figure 2.7(a) illustrates in X feeder, there is a fault between Isolator B and Isolator C and power restored to faultless remaining section by open and close appropriate Isolators. Figure 2.7(b) illustrates, still fault remaining between Isolator A and Isolator C and new fault occurred in upstream of the same feeder, between Isolator A and Isolator B. Figure 2.7(c) illustrates power restoration for faultless section by open and close appropriate Isolators.

The third configuration of faulty sections and power restoration illustrate in the figure 2.8.

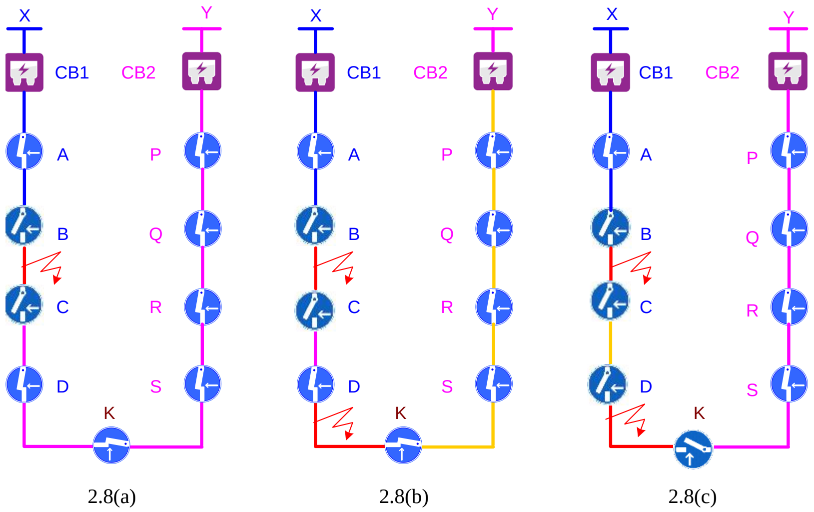


Figure 2.8: The third configuration of faulty sections and power restoration

Figure 2.8(a) illustrates in X feeder there is a fault between Isolator B and Isolator C and power restored to faultless remaining section by open and close appropriate Isolators. Figure 2.8(b) illustrates, still fault remaining between Isolator A and Isolator C and new fault occurred in downstream of the same feeder, between Isolator D and adjoining switch (Isolator) K. Figure 2.8(c) illustrates power restoration for faultless section by open and close appropriate Isolators.

The fourth configuration of faulty sections and power restoration illustrate in the figure 2.9.

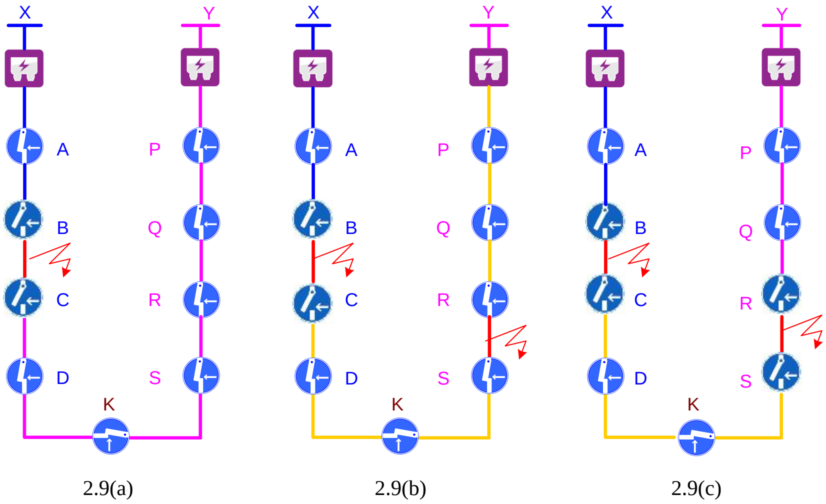


Figure 2.9: The fourth configuration of faulty sections and power restoration.

Figure 2.9(a) illustrates in X feeder there is a fault between Isolator B and Isolator C and power restored to faultless remaining section by open and close appropriate Isolators. Figure 2.9(b) illustrates, still fault remaining between Isolator A and Isolator C and new fault occurred in the connected adjoining feeder Y, between Isolator R and Isolator S. Figure 2.9(c) illustrates power restoration for faultless section by open and close appropriate Isolators.

Base of the developed algorithm is above four configurations. There are several techniques used for developing the algorithm. First step of the algorithm is to separate the faulty section occurred either sides of adjoining switch. In this step special features also included. That is an Auto Circuit Reclose (ACR) function. When, a tripped Motorized Circuit Breaker is detected, before running to find faulty section in algorithm, closes Motorized Circuit Breaker and waits once more for tripped signal. If tripped signal is not detected, requirement for running the faulty section in algorithm is not needed.

Second step is faulty section finding algorithm. After identifying a faulty feeder, if faulty section in first feeder. Isolator switch open and close the Motorized Circuit Breaker and check whether the Motorized Circuit Breaker tripped or not. If Motorized Circuit Breaker not tripped then close the Isolator switch and open adjacent isolator switch and again check whether Motorized Circuit Breaker tripped or not. Until Motorized Circuit Breaker tripped, continues the process and stop the process. This technique is used for identifying the faulty section in upstream. If fault occurred during adjoining switch closed mention above procedure start from last switch to first switch and identify the faulty section. In this step check more factors before open or close isolator switch, such as isolators are already in breakdown condition, action taken at the last switch, adjoining switch availability, etc… going through the algorithm you can find more.

Third step is power restoration algorithm for faultless section. For this, the technique used is after isolating the faulty section supply restores to upstream through the

Circuit breaker. This is applicable when supply restoration from adjoining feeder through adjoining switch is used.

Last step is Reset the system. At this step all flags to be cleared and checked requests from feeders to close adjoining switch. If there is a requested adjoining switch is closed.

Developed algorithm to detect faulty section in either side in adjoining switch algorithm for detect faulty section in same side and power restoration, algorithm for detect faulty section in adjoining side and power restoration and algorithm for reset the system is shown in figure 2.10, figure 2.11, figure 2.12, and figure 2.13 respectively.

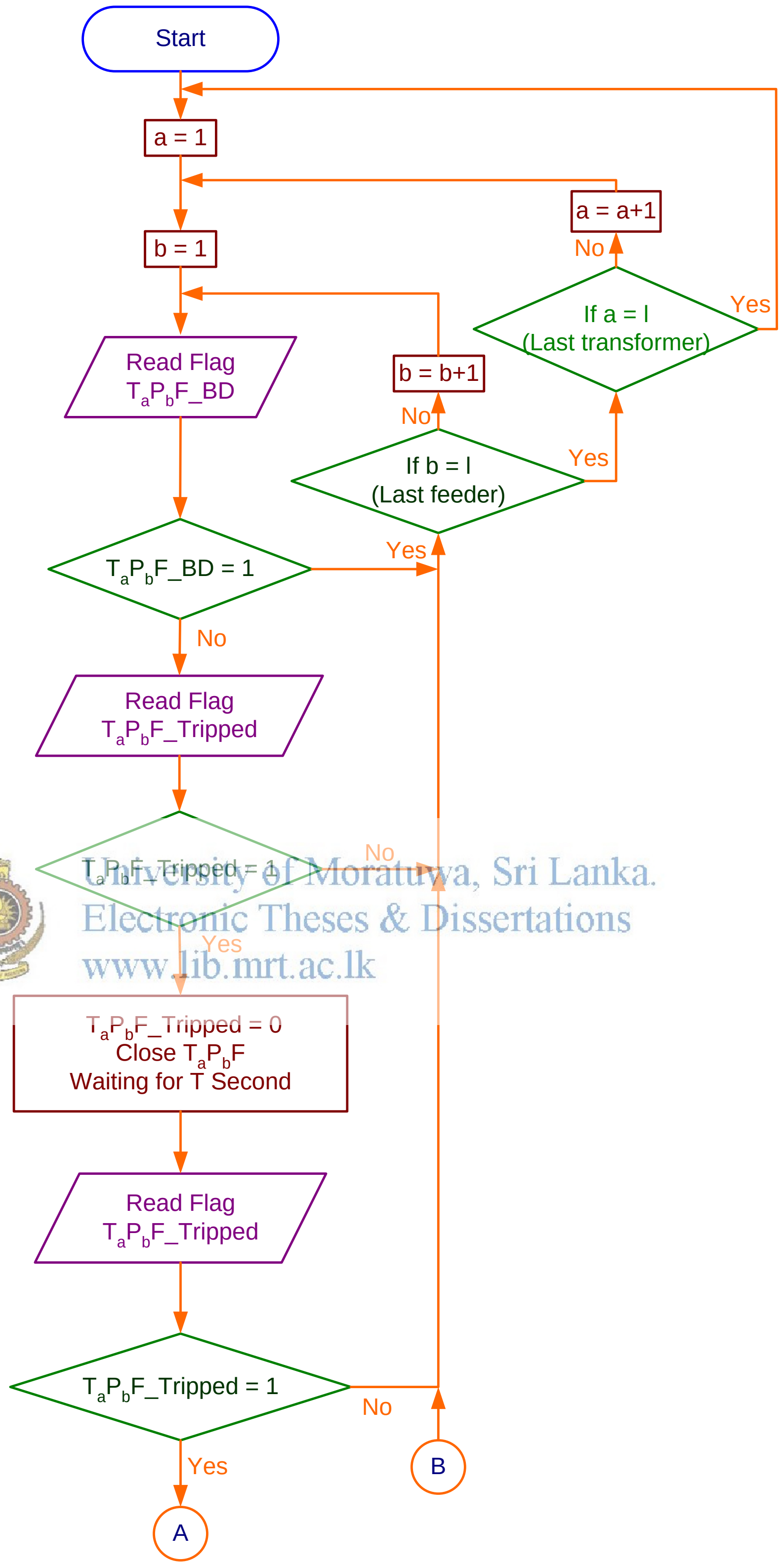


Figure 2.10: Algorithm for detect faulty section in either side in adjoining switch (part 1 of 2)

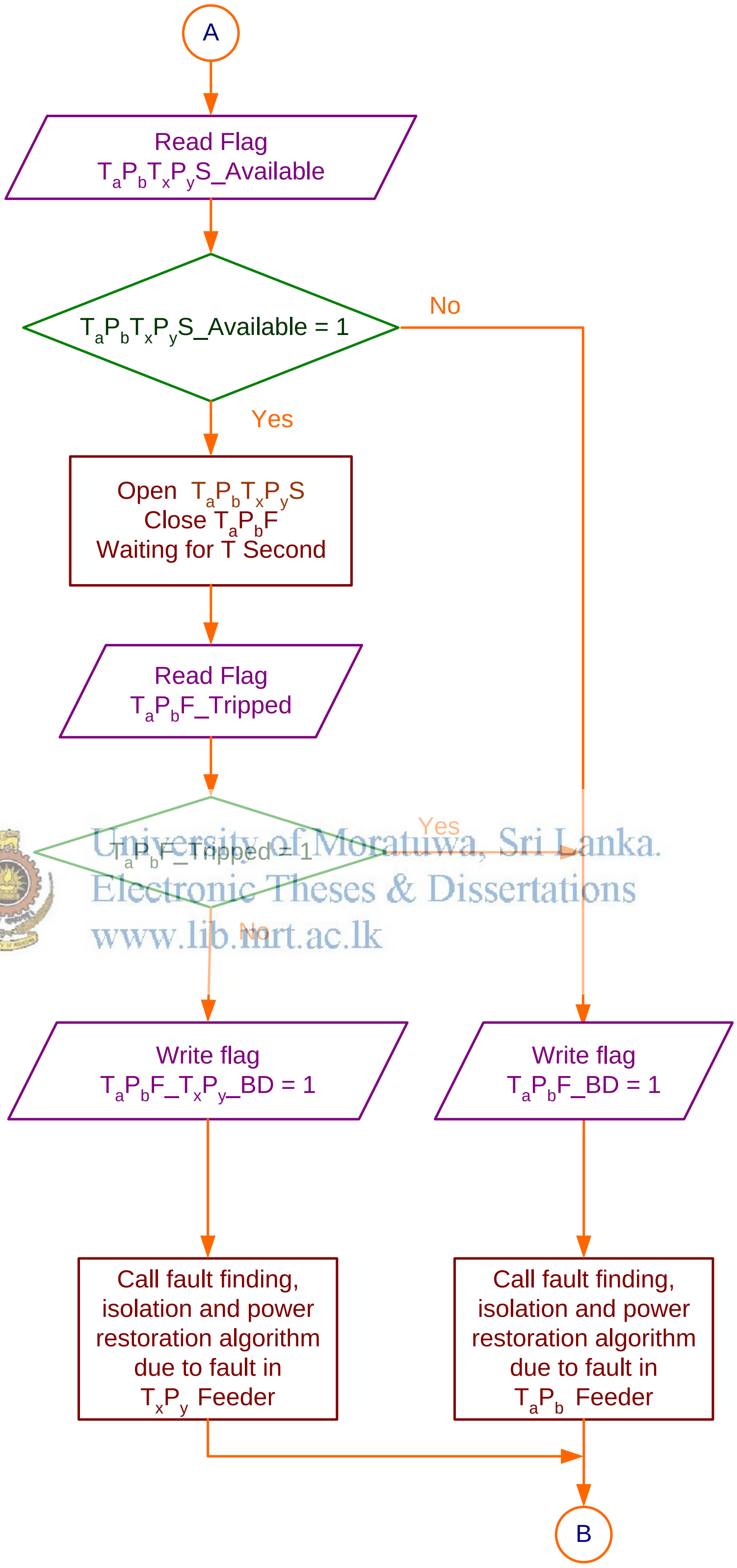


Figure 2.10: Algorithm for detect faulty section in either side in adjoining switch (part 2 of 2)

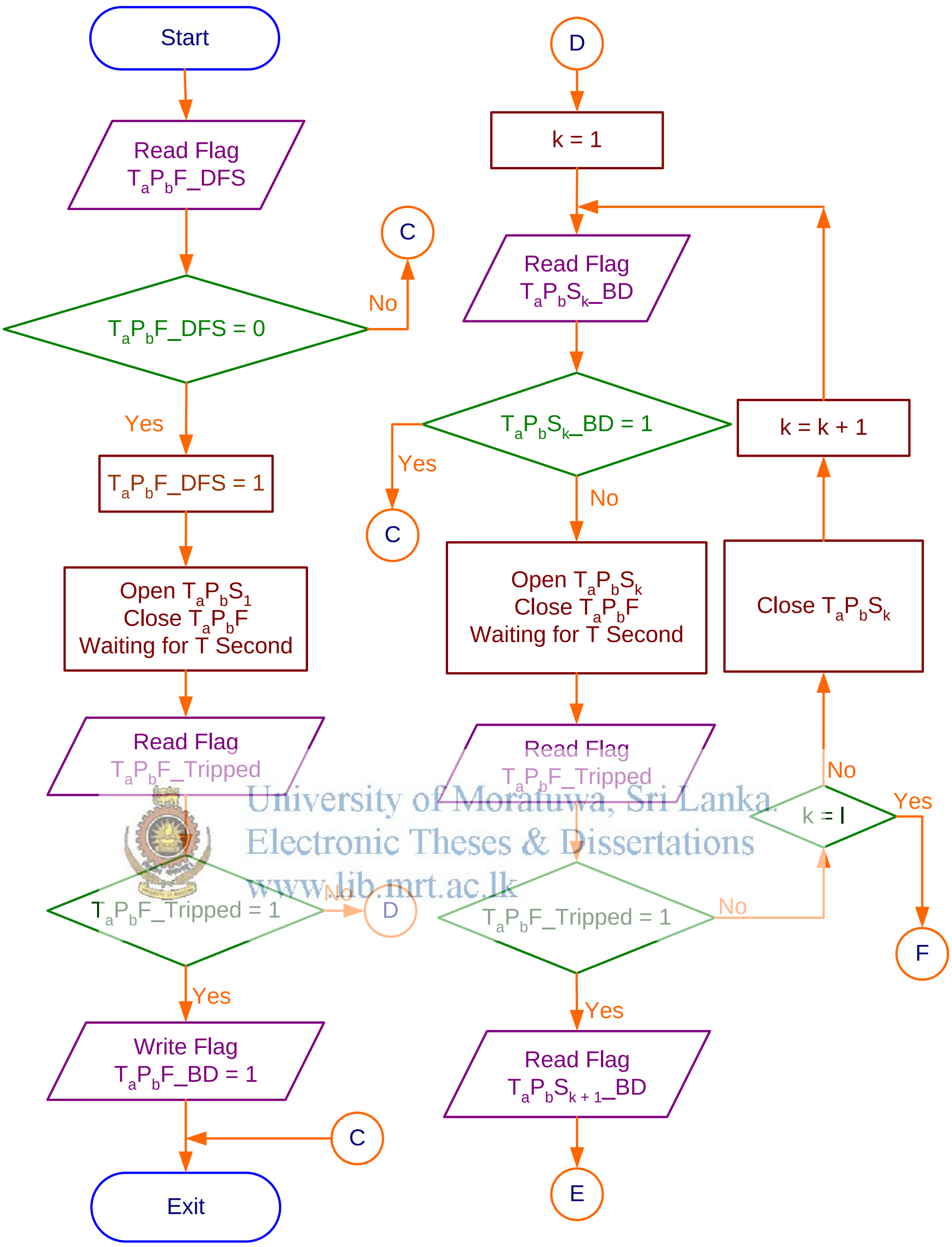


Figure 2.11: Algorithm for detect faulty section in same side and power restoration (part 1 of 2)

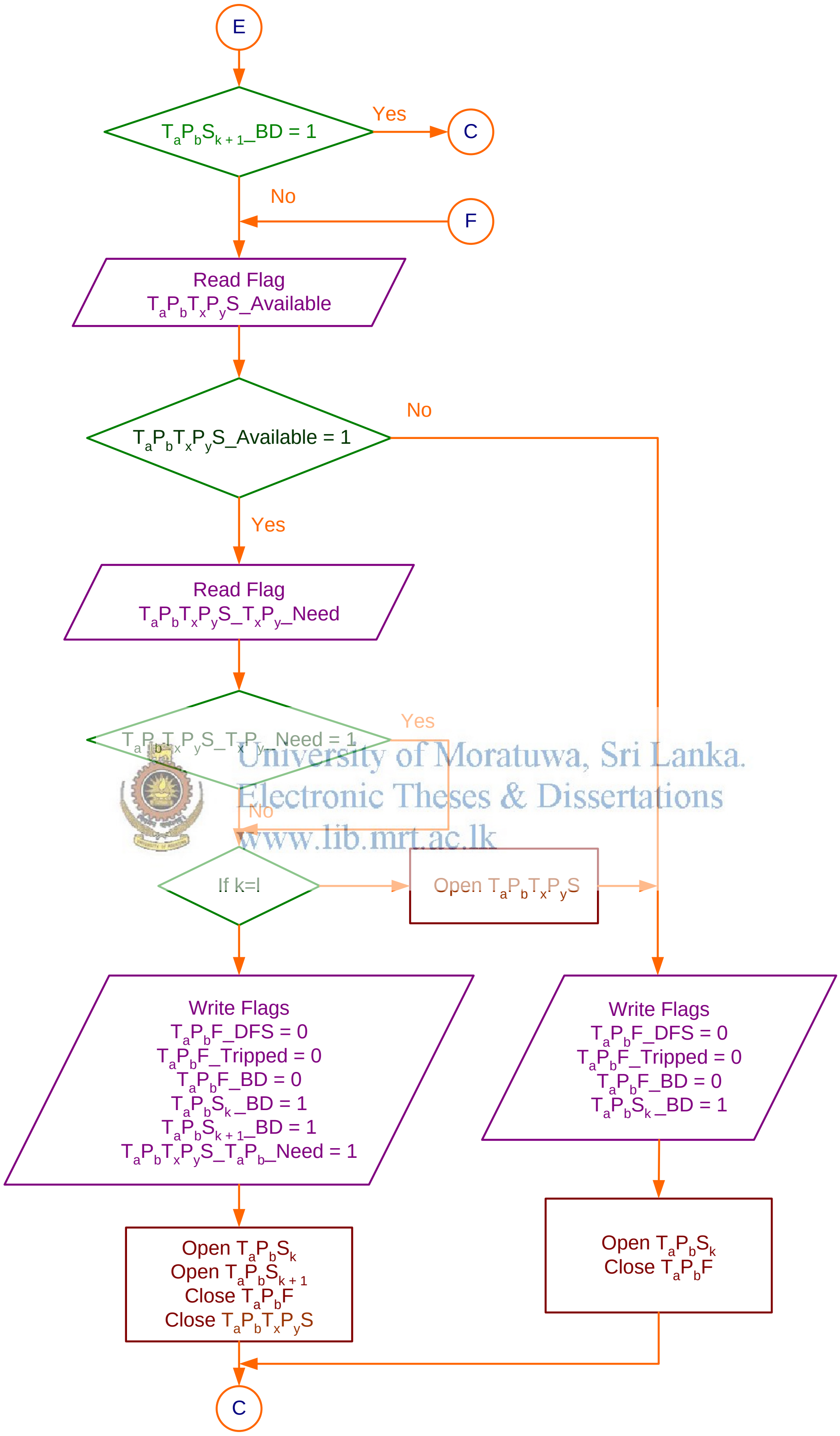


Figure 2.11: Algorithm for detect faulty section in same side and power restoration (part 2 of 2)

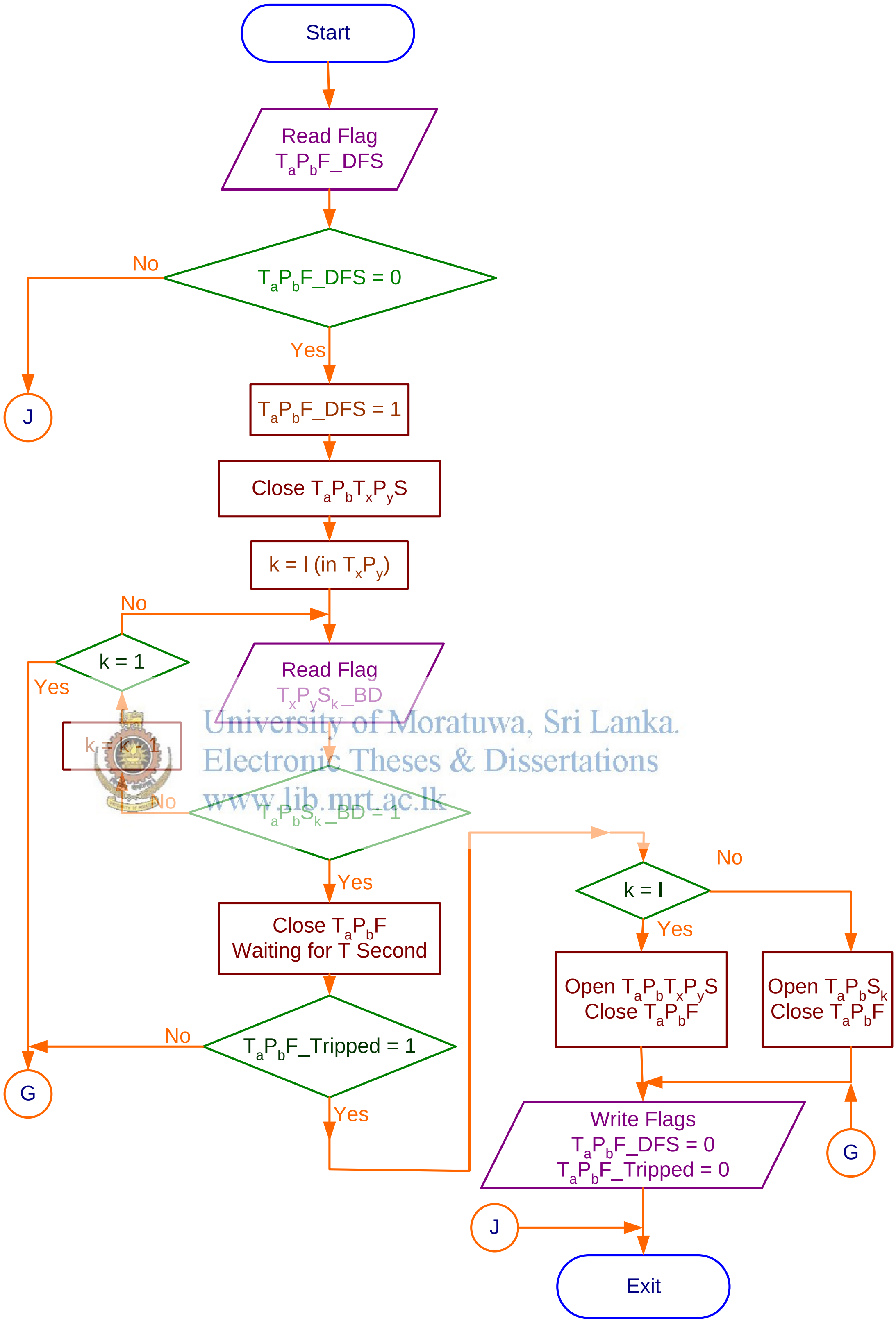


Figure 2.12: Algorithm for detect faulty section in adjoining side and power restoration

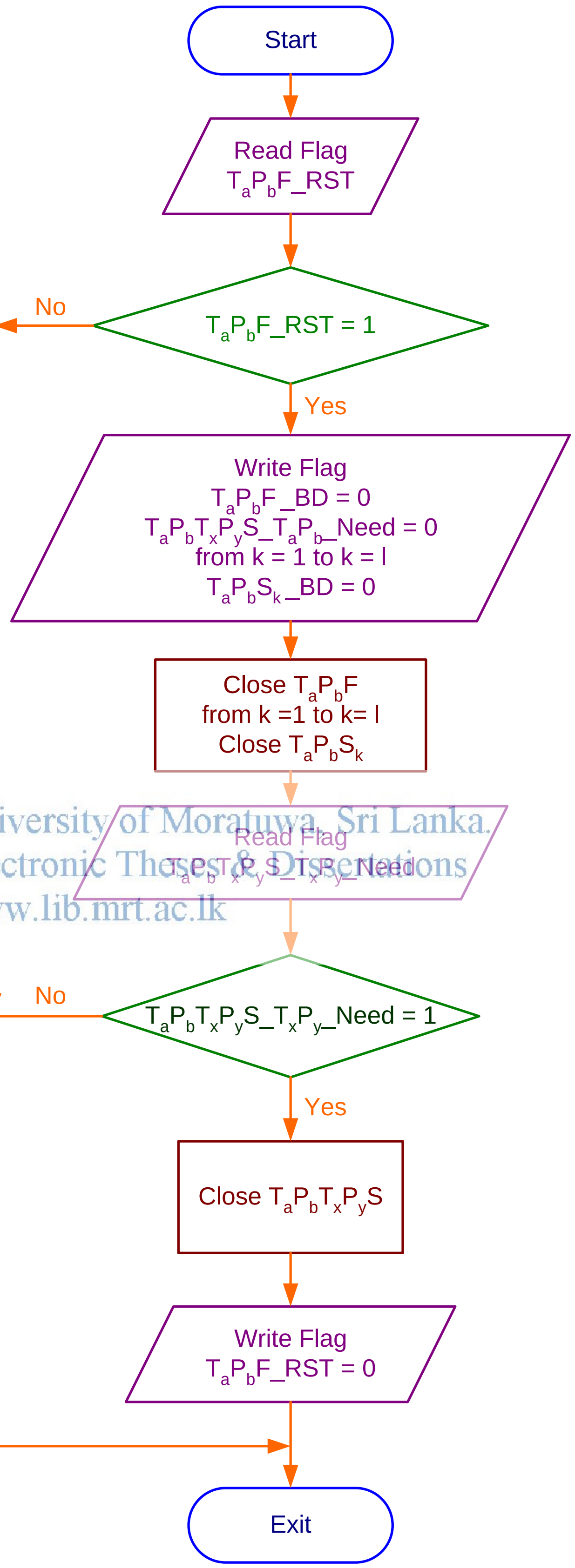


Figure 2.13: Algorithm for reset the system

Chapter 3

MV SCADA SYSTEM

Second part of the research is to find a solution for single SCADA system for existing installed and future installing Remote Switching Subsystem Devices (RSSD). This chapter describes about the total solution to open platform SCADA system for Remote Switching Subsystem devices in the medium voltage network.

3.1 Remote Switching Subsystem Devices

Western Province South II (WPS II) is one distribution province in Ceylon Electricity Board. There are 352,462 consumers in the province [20]. Power demand of WPS II meets through 33 kV feeders coming from 6 Nos. grid substations. These incoming feeders are connecting to the Gantries for split & arrange these feeders before connecting to loads. There are around 8 Gantries located in WPS II. Following Remote Switching Subsystem Devices can be found in the medium voltage network in the WPS II.

a. Auto Re-closures (ACR)

b. Remote operated Load Break Switches (LBS)

d. Digital energy meters (DEM)

e. Fault indicators (FI)

Detail of the existing and proposed Remote Switching Subsystem Devices about SCADA data are shown in table 3.1.

Table 3.1: Detail of the existing and proposed Remote Switching Subsystem Devices about SCADA data.

RSSD	Manufacturer	Micro SCADA	Protocol used for Micro SCADA	Existing Device Nos. in WPS II	Proposed Nos.
ACR	NuLecTM	WSOS	Proprietary	14	0
	EnTec TM	EVR2CA-n	Proprietary	8	12
LBS	NovexiaTM	NORTroll	Proprietary	28	30
FI	LineTrolTM	NORTroll	Proprietary	15	60
	ComTrolTM				
DEM	EDMI	No	No	8	0

3.2 Proprietary protocols, open standards & Interoperability

According to the table 3.1 manufactures of remote switching subsystem devices are developed proprietary protocols for communication. They developed the proprietary protocols due to specific needs of a particular industry. However proprietary protocols have more disadvantage than the advantage for user. One of most significant disadvantage is when user looked into expansion or further developing of the system, user must select same manufactures equipment. If user select different product, then user compelled to replace substantial parts of the system to change to another manufacturer's protocol.

The key benefit of an open standard is that it enabling interoperability between equipment from different manufacturers. [21]

3.3 Communication protocols available in Remote Switching Subsystem Devices

A communication protocol is a system of digital rules for message exchange within or between computers or any other intelligent hardware. Communicating systems use well-defined formats for exchanging messages. Each message has an exact meaning intended to provoke a particular response of the receiver [22].

During the research period it was found that following open communication protocols are in cooperated in most of the remote switching subsystem devices. Table 3.2 shows available open communication protocols in the existing remote switching subsystem devices. Control units of the both Auto Circuit Re-closures support multiple numbers of protocols. It is more benefited when, designing a single SCADA.

Table 3.2: Available open communication protocols

RSSC	Manufacturer	Available Open Protocol
ACR	NuLecTM	DNP3 IEC-870-5-101 MODBUS
	EnTec TM	DNP3 IEC-870-5-101 MODBUS
LBS	NovexiaTM	IEC870-5-101
FI	LineTrolTM	
	ComTrolTM	
DEM	EDMI	DNP3

3.3.1 IEC 870-5-101

IEC 60870-5 refers to a collection of standards produced by the International Electrotechnical Commission, or IEC, to provide an open standard for the transmission of SCADA telemetry control and information. IEC 60870-5 provides a detailed functional description for telecontrol equipment and systems for controlling geographically widespread process. The standard is intended for application in the electrical industries, and has data objects that are specifically intended for such applications, however it is not limited to such applications as it has data objects that are applicable to general SCADA applications in any industry. Nevertheless, the IEC 60870-5 protocol is primarily used in the electrical industries of European countries [21].

IEC 60870-5-101 is a standard for power system monitoring, control & associated communications for telecontrol, teleprotection, and associated telecommunications for electric power systems. This is completely compatible with IEC 60870-5-1 to IEC

60870-5-5 standards and uses standard asynchronous serial tele-control channel interface between devices.

3.3.2 DNP3

DNP3 or Distributed Network Protocol is a telecommunication standard that defines communications between master stations, remote telemetry units (RTUs) and other intelligent electronic devices (IEDs). It was developed to achieve interoperability among systems in the electric utility, oil & gas, water/waste water and security industries.

DNP3 was created as a proprietary protocol by Harris Controls Division initially for use in the electrical utility industry [21].

DNP3 was designed specifically for SCADA (supervisory control and data acquisition) applications. These involve acquisition of information and sending of control commands between physically separate computer devices. It is designed to transmit relatively small packets of data in a reliable manner with the messages involved arriving in a deterministic sequence [21].

DNP3 offers substantial features as well as flexibility and security. These are summarized in the following list [21]:

- Supports time stamped messages for sequence of event (SOE) recording
- Breaks messages into multiple frames to provide optimum error control and rapid communication sequences
- Allows peer–peer topology as well as master–slave
- Allows multiple master topology
- Provides user definable objects
- Provides for reporting by exception/event without polling by master
- Provides for 'changed data' only responses
- Broadcast messages

- Secure configuration/file transfers
- Addressing for over 65 000 devices on a single link
- Provides time synchronization and time-stamped events
- Data link and application layer confirmation

3.4 Proposed multi - protocol device integration method

Existing Remote Switching Subsystem Devices support to DNP3, IEC-870-5-101 and MODBUS open protocol. One of objectives of the second part of my research is integrating this Remote Switching Subsystem Devices in to one SCADA. However integrating multi-protocol issue can be resolved using industry standard Object linking & embedding for process control (OPC).

Object linking & embedding for process control (OPC) protocol to work as a middleware & translate various protocols to a single protocol called OPC. OPC was designed to provide a common bridge for Windows based software applications and process control hardware. Standards define consistent methods of accessing field data from plant floor devices. This method remains the same regardless of the type and source of data. An OPC Server for one hardware device provides the same method for an OPC Client to access its data as any and every other OPC Server for that same and any other hardware device.

There are several OPC Server available in the market. Few of them are given below.

- Kepware OPC Server
- IO Server
- Cooper-DNP3-OPC-Server-Master
- Matrikon OPC DNP3
- Industrial Gateway

Industrial Gateway OPC server software supports more than 20 communication protocols including DNP3, IEC-870-5 & Modbus. Hence, Industrial Gateway OPC server proposes as the OPC Server to integrate multi-protocol device.

3.5 Communication media and technology

The communications network is intended to provide the means by which data can be transferred between the SCADA software application located in the central server and the field installed RTUs. The Communication Network refers to the equipment needed to transfer data to and from different sites. There are many communication mediums available both wired & wireless. [23]

Up to date installed Existing Remote Switching Subsystem Devices controlled by remotely using micro SCADA. However this is not centralized. Area Electrical Engineer in relevant distribution area, controls this Remote Switching Subsystem Devices through proprietary micro SCADA. This proprietary micro SCADA are developed by the Remote Switching Subsystem Devices manufactures. There are two GSM MODEM installed in both end of Remote Terminal Unit and micro SCADA server. Global System for Mobile (GSM) Communication technology is used for communication. Main disadvantage of existing communication method is the inability to do operations in real time and also at a time can only operate one Remote Switching Subsystem Device. Hence, existing communication technology has changed to fast and real time communication technology such as Transport Control Protocol/Internet Protocol (TCP/IP) connection over General Packet Radio Service (GPRS).

3.6 Communication media options

Nowadays there are so many possibilities for selecting a communication medium. Following communication medias are considered for selecting communication media for SCADA.

- Twisted pair & Coaxial cables
- Fiber Optics cables
- Radio link
- Satellite link

- Cellular (GPRS/3G)

3.6.1 Twisted pair & Coaxial cables

Twisted pair medium are highly used in telecommunication utilities. The twisted pair conductor name implies, the use of twisted two wires. However, we can see overhead twisted pair cable bunch suspended on the poles. Also Coaxial cables are used for communication utilities. It is a copper cable with polyvinyl chloride (PVC) insulation. Coaxial cable can transmit high frequency signals up to several MHz with low attenuation compared to twisted pair wires used for telephone service. They can be installed underground, direct burial, overhead, and on existing power line structures.

3.6.2 Fiber Optic Cable

Principle of total internal reflation of light is used in fiber optic cable. It is consist of an inner core and cladding of silica glass and a plastic jacket that physically protects the fiber. Basically fiber optic cables are use in communication utilities. However, special types of fiber optic cables have been developed for the power industry. One type of fiber cable is the Optical Power Ground Wire (OPGW) that is an optical fiber core within the ground or shield wire suspended above transmission lines. Another type of optical fiber cable is the All-Dielectric Self-Supporting (ADSS) cable that is a long-span of all dielectric cables designed to be fastened to high voltage transmission line towers underneath the power conductors. A Wrapped Optical Cable (WOC) is also available that is usually wrapped around the phase conductor or existing ground/earth wire of the transmission or distribution line. Aerial fiber optic cable can be fastened to the distribution poles under the power lines.

3.6.3 Radio link

Radio link is also popular communication media. Radio link can be categoried according to the frequency range used. Lowest frequency Radio link is Very High Frequency (VHF) band extends from 30 to 300 MHz and is usually used by utilities for mobile radio. Then the Ultra High Frequency (UHF) band extends from 300 to 3000 MHz. The bands typically considered for UHF radio are in the 400 MHz and 900 MHz range. Most of the suitable radio products for SCADA applications available operate in the 900 MHz frequency range. Finally, Microwave radio is a term used to describe UHF radio systems operating at frequencies above 1 GHz.

3.6.4 Satellite link

Any geographical area can be covered by satellite communication link because, the satellites are positioned in geo-stationary orbits above the earth's equator and thus offer continuous coverage over a particular area of the earth. Satellites work as transceiver, it contain a number of radio transponders which receive and retransmit frequencies to ground stations within its "footprint," or coverage, on the earth's surface. According to the frequency range satellites use two bands namely, C-band and the Ku-band. Very Small Aperture Terminal (VSAT) technology has advanced to the point where a much smaller antenna (down to about one meter) can be used for Ku-band communications. This has resulted in the Ku-band being preferred for sites with modest communications requirements.

3.6.5 Cellular (GPRS/3G)

In recent years, with the development and progressive implementation of packet switching technologies over mobile networks (GPRS/UMTS/EDGE), a new range of possibilities has opened up which may make them viable for SCADA applications. On the one hand, a Transport Control Protocol/Internet Protocol (TCP/IP) - based service is offered, which guarantees the reception of traffic and the "always online" nature of this type of service. Further, charges based on exchanged traffic volume, as opposed to circuit switching connections which are charged by connection time, may be a very attractive feature for utilities.

3.7 Proposed Communication Media

Table 3.3 shows summary of option for selecting communication media.

Table 3.3: Summary of option for selecting communication media

	Twisted pair & Coaxial cables	Fiber Optic Cable	Radio link	Satellite link	Cellular
Economical distances	Short	Very long	Long	Wide coverage	Long
Channel capacity	Low	Very high	high	Very high	Medium
Immune to Radio Frequency	More	Zero	Zero	Zero	Zero
Capital cost	Less	Very high	High	High	Very less
Installation	Very difficult	Very difficult	Difficult	Less difficult	Easy
Maintenance	Very difficult	Very difficult	Very difficult	Difficult	Less difficult

Considering factors about communication media to the table 3.3 wired communication media is not practically viable. Because of, Electrical distribution network spread over large geographical area. Hence installation, maintenance is very difficult. Also cost for installation, labour charges are higher. Hence, wireless communication media is preferred for selecting a communication media. Comparing wireless communication media cellular communication media is viable and it is an economical solution due to wide availability, lower capital investment & relatively low operational cost.

3.8 Proposed communication architecture

Existing micro SCADA uses serial connection between the RTU and central control unit. Master Central control unit communicates with slave RTU through GSM Modem. Data conversion method is Short Message Service (SMS). This method is very slow and only one device can be connected at once. This serial connection can be replaced with a TCP connection over GPRS, instead using two IP modems. It can be done if IP modem is replaced by installing a TCP to Serial conversion software. Function of the software is to direct incoming TCP traffic comes through the TCP port (TCP port 10000) to a virtual serial port of the PC.

When convert serial conversion method to IP conversion, needs resolving of IP address issues. This is because of Cellular service provider, often assign temporary IP addresses to their clients to access the Internet. Compared with static IP addresses, using dynamic IP addresses make it difficult for the PC to keep in constant contact with remote devices. This issue has termed as “dynamic IP issue” & method of resolving this issue discussed in the following.

Traditional SCADA systems use a polling architecture that will only work properly if the SCADA host knows the IP addresses of the field installed RTU. The trouble with field installed RTU in GPRS environment is that the devices receive a different IP address every time they connect to the GPRS cellular network. This has termed “Dynamic IP Issue”. To overcome dynamic IP issue, three distinct solutions have been considered. [24]

The first solution is to get public static IP address. In this solution cellular provider provide a specific Single Inline Module (SIM) card with a public static IP address, and then field installed RTU will have their own static IP address and the entire system will operate in the same manner as a traditional monitoring system that uses physical wiring. However, none of the cellular providers operating in Sri Lanka had offered this kind of service, and when they do, the cost will be very high.

The second solution is Dynamic Domain Name System (DDNS). It is used to convert a device’s name into a dynamic IP address so that RTU can communicate with the control center using a fixed domain name. DDNS is one type of DNS server. The difference between DDNS and DNS is that DDNS takes care of the Dynamic IP address of a device, and DNS the static IP address of a device. With most remote GPRS devices, there is a need to apply for a hostname for each of the devices handled by the DDNS server. When GPRS devices get an IP from the cellular provider, they will automatically connect to the GPRS network. Each time a GPRS device's built-in DDNS client gets a new IP address, it will send the IP address to the DDNS sever. The mapping table in the DDNS server is refreshed each time the DDNS receives a new IP address from the devices.

The host can find a device's IP address from the DDNS's mapping table by looking up the device's hostname. For this solution there are two concerns:

(1) A majority of DDNS servers do not have standard protocols to implement IP address updates, which makes it difficult for GPRS devices to provide client APs to the DDNS.

(2) The quality of the service; as DDNS service is usually provided by a third party service provider, the system may crash when the DDNS loses connection or is being maintained. In addition, it may be necessary to pay a premium to the DDNS service provider for better quality of service.

Third solution is Virtual Private Network (VPN). It is a secure Local area Network (LAN) solution for groups specific devices together. VPN has two major functions security and grouping. VPN grouping concept solves the dynamic IP address issues. The grouping of the devices into one private network prevents unauthorized persons from accessing the data. To obtain a VPN solution, utilities need to consult cellular service providers operated in the concerned area. When the GPRS device dials up, the cellular service provider will assign a private IP address to it and because the private IP address is on the same network segment as the SCADA host, the host and devices can maintain bi-directional communication using a polling architecture.

A VPN solution can be obtain from out of above three distinct solutions to Dynamic IP issue. Ceylon Electricity Board already used VPN network for voice communication from Mobitel Pvt. (Ltd). Hence obtaining VPN network for data is not an issue.

Proposed communication architecture shown in figure 3.1.

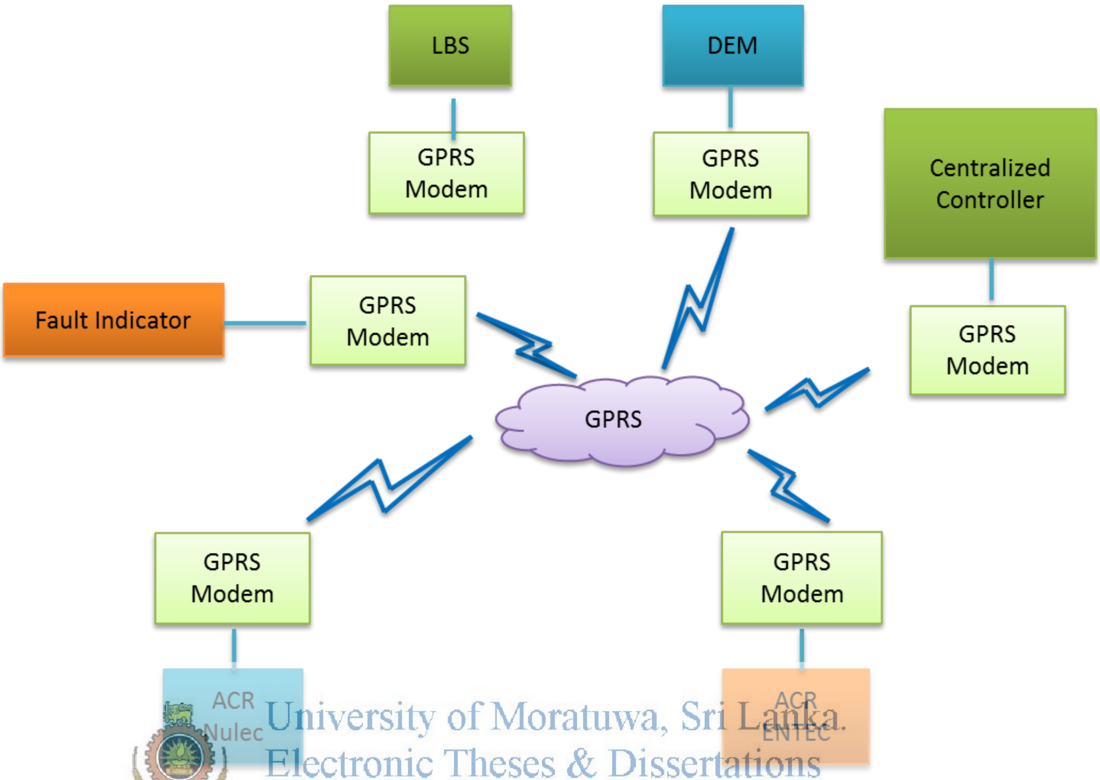


Figure 3.1: Proposed communication architecture

3.9 Software package to developed SCADA

Propriety SCADA provides with Remote Switching Subsystem Devices to only support their product. Hence software package chooses for integrate all Remote Switching Subsystem Devices. Selecting a software package is a critical due to following factors.

- Security
- Capital cost Operational criticalness
- Maintainability
- Easiness of operation
- Number of devices can be integrated

There are several software packages available on the market for SCADA. Few of them are below.

- General Electric (GE) iFIX
- Schneider Clear SCADA
- Siemence Spectrum

Before selecting a software package, their trail versions are tested with Remote Switching Subsystem Devices.

Software evaluation concentrated on the basic SCADA features such as the configuration tools, the Human Machine Interface (HMI), alarm and event handling, logging and archiving as well as the access control mechanisms. These were evaluated from both a functional, as well as, from usability point of view criteria against which the SCADA systems could be evaluated. [25]

3.10 Key area of the Software package

Following major key areas considered for SCADA software package selection.

- Cost
- Scalability
- Security
- Supported Operating Systems
- Software architecture
- Alarm handling , reporting, trending & data logging

Basic features of software packages are almost same. Hence selecting a software package is done by point assigning for each characteristics for each characteristics. Weighting factors were assigned to each of the feature to calculate total points gained by a software package.

Each characteristic are discussed in the following sections.

3.10.1 Cost

Cost is considerable key for selecting a software package, as it has already provided micro SCADA for the existing Remote Switching Subsystem Devices. Cost of the software package varies with the number of supported tags. Cost for software package that supports 15,000 on demand tags with one development license & three client licenses. Cost of software packages are as shown in table 3.4.

Table 3.4: Cost of software packages

Software Package	Price (LKR)
General Electric iFIX SCADA	5,800,000.00
Schneider Clear SCADA	3,800,000.00
Siemence Spectrum	2,400,000.00

3.10.2 Scalability

Scalability is an important key factor, at the system expansion stage. A Scalable SCADA allows a utility to start with a SCADA system that matches its size and budget requirements, then grow as the utilities need for units, I/O, and system intelligence increases.

3.10.3 Security

Software package should provide a configurable security component that can be used to restrict access, application navigation and configuration of databases or displays in SCADA system. It should also support configuration of different sets (or policies) of individual users. It should support categorization (grouping) of those users. All of the above mentioned software support above criteria.

3.10.4 Supported operating systems

Software used to develop SCADA system must be based on proper computing platform in order to take leverage the advantages of larger memory capacity (greater than 4 GB of RAM), hardware acceleration, multi-core processors and multi-threading.

3.10.5 Software architecture

Software architecture shall be based on a modular architecture (separate stand-alone modules for Dynamic Graphic Displays, Real-Time Trending and Historical Data Logging, Alarm Management, Security, GEO-SCADA, Data Management, Real-time OPC) and be inherently based on a distributed architecture that supports Microsoft Windows networking as well as OPC-based technology, since OPC being used to address multi protocol device communication issue.

3.10.6 Alarm handling, trending, data logging & reporting

Alarm handling, reporting, trending & data logging capabilities of all the software packages are equally good.

3.11 Proposed Software package to developed SCADA

Each SCADA software package gained mark is shown in the table 3.5. Following marking scheme ware used to grade software packages.

Excellent - 5, Very Good - 3, Good - 2, Fine - 1

Table 3.5: Each SCADA software package gained mark

	Feature	Assign weight	General Electric (GE) iFIX		Schneider Clear SCADA		Siemence Spectrum	
1	**Cost**	10	Excellent	50	Very Good	30	Excellent	50
2	**Scalability**	25	Very Good	75	Good	50	Fine	25
3	**Security**	15	Excellent	75	Very Good	45	Very Good	45
4	**Supported Operating Systems**	15	Very Good	45	Very Good	45	Very Good	45
5	**SCADA software architecture**	15	Very Good	45	Very Good	45	Very Good	45
6	**Alarm handling , reporting trending & data logging**	20	Good	40	Good	40	Good	40
	Total	100		330		255		250
	Average (Total/500)			**0.60**		**0.51**		**0.50**

From the above table it can be seen that General Electric (GE) iFIX shows salient features than other two software packages. Therefore, General Electric (GE) iFIX software package proposed to develop the SCADA system.

3.12 Developed Open Platform scalable MV SCADA system for integrating Remote Switching Subsystem Devices

According to the Distribution Code by Public Utilities Commission of Sri Lanka (PUCSL), each distribution utilities should implement a Distribution Network Control Centre (DNCC) [13] for continue distribution licenses.

As per the distribution code for improving reliability of the electricity distribution system in Sri Lanka, distribution automation system can be introduced to MV system with existing installed Remote Switching Subsystems. Convert traditional MV distribution system into automated MV distribution system the initial capital investment is very less. Also operating cost is almost zero.

Now it is evident that an Open platform can be developed. MV distribution automation problem can be solved by "Developing Open Platform scalable SCADA for integrating Existing Switching Subsystems to a common central system together with a cost effective communication infrastructure"

Proposed Developing Open Platform scalable SCADA for integrating Existing Switching Subsystems to a common central system together with a cost effective communication infrastructure" shown in the figure 3.2.

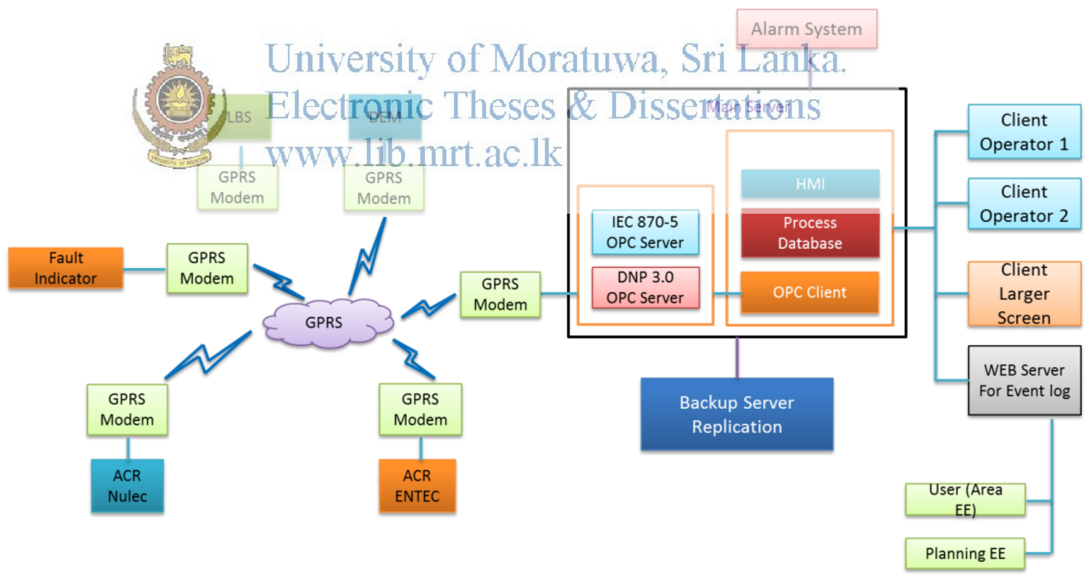


Figure 3.2: Proposed Developing Open Platform scalable MV SCADA system

Pilot project implemented for WPS II province, Ceylon Electricity Board done by this solution describe in the Chapter 7.

Chapter 4

FINANCIAL FEASIBILITY FOR IMPLEMENTING OPEN PLATFORM MV DISTRIBUTION SCADA SYSTEM

Now developing of an open platform MV distribution SCADA system has been reviewed in detail. Automation can be initiated with starting implementation and operation of the MV distribution SCADA system. Implementing cost for developed system is negligible when compare with introducing total solution available in the market. However reasonable amount of capital expenditure needed to be spent to implement SCADA system. Quantifying benefits obtained through distribution automation in financial terms are not straight forward. Therefore reduction in outage duration & reduction in crew travel time considered for quantifying potential saving due to distribution automation. Reducing outage time is directly proportional to the income of the electricity utility. Here cost analysis and financial feasibility based only the implementing SCADA system from existing Remote Switching Subsystem Devices.

4.1 Project Cost Estimation

4.1.1 Capital cost

Implement a SCADA system control center purchasing of land and building is not required. Because already CEB – WPS II call center building is in existence. Hence Land & building costs were not considered as the SCADA system control center. Capital cost estimation is LKR 12 Mn. Details are shown in the table 4.1

Table 4.1: Capital cost estimation for WPS II open plat form MV SCADA system

Item	Qty	Capital Expenditure (LKR)
SCADA software (Development & runtime license) (iFIX SCADA)	1	5,800,000.00
OPC Server Software for SCADA (Industrial Gateway)	1	200,000.00
1.5kVA UPS for Control center PCs	6	100,000.00
52 inch LCD display for SCADA	2	200,000.00
60 inch seamless LCD display for SCADA video Wall	4	800,000.00
Low end Server Computer (SCADA development & server station)	2	250,000.00
Desktop PC (SCADA Client station)	4	400,000.00
Serial data servers for Auto re-closure & LBS automation	100	3,500,000.00
Miscellaneous		750,000.00
Total Capital Investment		**12,000,000.00**

4.1.2 Operation & maintenance (O&M) cost

SCADA system control center operates around the clock. Hence, shift basis operation staff required. Therefore additional cost is needed for smooth operation of staff. Communication infrastructure requirement is also fulfilled by the service provider. It is also accounted in the operation cost. In addition for smooth operation of the system, it is necessary to maintain a stock of relevant spare parts in the stores. Therefore maintenance cost also accounted to the O&M cost comprising of following three key components.

- Salary for staff
- Cost of communication infrastructure
- Spare parts cost for maintenance

Salary for staff

No. of employees	-	10 Nos.
Average salary per month	-	LKR 250,000.00
Cost per year	-	LKR 3.00 Mn

Cost of communication infrastructure

Subscription fee for VPN	-	LKR 25,000.00
No of data SIMs	-	100 Nos.
Average data charge for a SIM	-	LKR 250
Cost per year	-	LKR 0.600 Mn

Cost of spare parts

4 % of Capital Expenditure/ Year	-	LKR 0.40 Mn

4.2 Benefits due to MV distribution automation.

Following two key areas were considered to quantify the benefit of MV distribution automation.

- Reduction in outage duration
- Reduction in Manpower due to reduction in crew travel time

4.2.1 Reduction in outage Duration

Outage duration is the most valuable power quality indices in the power system. Hence to determine reduction in outages, it is important to study feeder tripping details. Table 4.2 shows feeder failure data recorded in GSS for past years 2012, 2013, 2014 in WPS II Province.

Table 4.2: MV feeder failure data for year 2012, 2013, 2014

Year	EF	OC	OC-EF	UF	Other	Total
2012	1803	331	1243	54	67	3948
2013	1764	258	1409	45	79	3555
2014	1792	234	1534	57	54	3671
Avg./year	1787	274	1395	52	67	3725
Avg./month	149	23	116	4	5	297
Failure/month/feeder	2.2	0.3	1.7	0.06	0.07	4.3

There are 69 MV feeders & failures per month per feeder were calculated as follows. Where,

EF - Earth Fault

OC - Over Current

UF - Under Frequency

Feeder failure records from the grid substation breaker is installed at grid substation. Can be seen from Table 4.2, there are around 116 failures per month per feeder due to Earth fault & over current. Therefore we can come to a conclusion that there would be more faults in the network which were not detected by the protection schemes installed in grid substations. Such as faults down steam of auto re-closures & DDLO fuses.

Temporally faults that cause auto re-closure lockout due to higher fault current can be identified from the feeder tripping data by considering outage duration. Faults having outage duration less than 20 minutes can be considered as temporally faults. Table 4.3 gives number of EF & OC tripping with outage duration less than 20 min with average feeder current just before the tripping of the circuit breaker for year 2012, 2013 & 2014.

Table 4.3: Average outage duration and average feeder load

Year	No of EF/ OC/ EF+OC (outage duration less than 20 Min.)	Avg. feeder loading before the fault (A)
2012	3122	85.6
2013	2987	81.7
2014	3015	96.5
Avg./year	3041	88
Avg./month	154	-
Failure/month/feeder	2.3	-

Major portion of above mentioned faults may have occurred in the protection zone-1 marked on Figure 4.1 Therefore we can come to an conclusion that there must be similar number (even greater) of temporary faults occurred downstream of branch protection ACR which may cause auto re-closures to lockout.

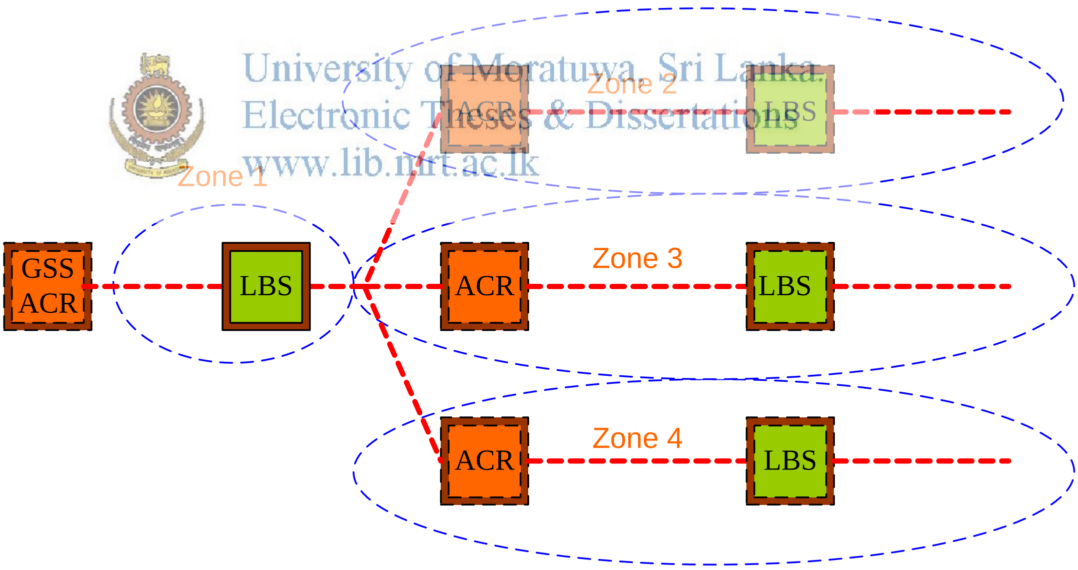


Figure 4.1: Protection zones in a typical 33 kV radial distribution feeder

Once ACR gets into lockout state it must be reset by the operator locally or remotely. Without any means of automation only available option is to reset the re-closure locally. Depend upon the location of the ACR; time taken by field staff to reset an ACR may vary from 20 Min~ 45 Min on average. This time includes the time taken to detect the outage (typically 10 min) & crew travel time. During rainy days it may take much longer time due to higher number of breakdowns. Therefore 25 Min duration considered as an average time taken by the field staff to reset a lockout ACR.

According to table 4.3 average failures (EF & OC with outage duration less than 20 Min) per year 3041 & average feeder loading just before the fault is 88 Amps.

Above information can be used to determine annual loss of electricity sales in kWh due to above mentioned failures.

Following factors considered during the calculation.

- Power outages less than 20 Min. considered for calculation
- 33% of the feeder loading at the time of feeder tripping considered for loss of energy calculation for a particular power outage.
- Network power factor considered as 0.9
- Profit margin of LKR 3.60 were calculated from 2012 financial data of WPS II & used the same value for year 2013 & 2014

Average Failures (EF & OC with outage duration less than 20 Min) per yr. = 3041

Average feeder loading just before the fault = 88 A

Time taken to reset a ACR = 25 Min

Annual loss of electricity sales $= \frac{33}{100} x88x33x0.9x1.732x\frac{25}{60} x3041$

= 1,890,620 kWh

Annual saving by reducing the outage duration = 1,890,620 X 3.6

= LKR 6,806,232.00

4.2.2 Reduction in Manpower due to reduction in Crew travel time

Following factors were considered for the calculation

No of Workers involved in breakdown restoration	= 3 Workers
Worker hourly rate	= LKR 240.00
Avg. Transportation cost	= LKR 800.00
Travel time (to return trip)	= 35 Min
Cost of crew travel time per single fault	= [3 X 240 X (35/60) + 800]
	= LKR 1220.00
Annual saving due to reduction in crew travel time	= 1220 X 1845
	= **LKR 2,250,900.00**

4.2.3 Cost Benefit Analysis

Capital expenditure	-	LKR 12.00 Mn
O & M Cost		
Salary	-	LKR 3,00 Mn
Telecommunication	-	LKR 0.60 Mn
Spares	-	LKR 0.40 Mn
Total	-	LKR 4.00 Mn
Cost Saving due to automation		
Reduction in outage duration	-	LKR 6.80 Mn
Reduction in crew travel duration	-	LKR 2.25 Mn
Total	-	LKR 9.05 Mn

Profit and loss statement

Year		0	1	2	3	4	5	6	7	8	9	10
Reduction in outage Duration			6.80	6.80	6.80	6.80	6.80	6.80	6.80	6.80	6.80	6.80
Reduction in Crew Travel time	5%		2.25	2.36	2.48	2.60	2.73	2.87	3.01	3.16	3.32	3.49
Total Savings (LKR Mn)			9.05	9.16	9.28	9.40	9.53	9.67	9.82	9.97	10.12	10.29
O&M cost	5%		4.00	4.2	4.41	4.63	4.86	5.10	5.36	5.62	5.90	6.20
Depreciation			2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Finance cost			0	0	0	0	0	0	0	0	0	0
Profit before tax			3.05	2.96	2.87	2.77	2.67	2.57	2.45	2.34	2.21	2.09
Tax (0% and 30%)	0%		0	0	0	0	0	0	0	0	0	0
Profit After Tax			**3.05**	**2.96**	**2.87**	**2.77**	**2.67**	**2.57**	**2.45**	**2.34**	**2.21**	**2.09**

Cash Flow

Profit After tax			3.05	2.96	2.87	2.77	2.67	2.57	2.45	2.34	2.21	2.09
Add												
Depreciation			2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Finance cost												
Net Flow of Project		-12.00	3.05	2.96	2.87	2.77	2.67	2.57	2.45	2.34	2.21	2.09
Discounting Factor		14.00%	5.05	0.82	0.75	0.68	0.62	0.56	0.51	0.46	0.42	0.38
Project IRR		19.57%										
NPV @ 14%	2.1	-12.00	2.67	2.27	1.93	1.64	1.38	1.16	0.98	0.81	0.68	0.56
SPP	4 Years & 2 Months											

Above cost benefit analysis gives simple payback period of 4years and 2 months & project gives positive Net Present Value of 2.1Mn (which is discounted at 14%). Hence project is viable to continue in future. Therefore implementing distribution automation can be considered as economically feasible. Most of the tripping's recorded due to wayleave problem in the MV and LV distribution network. However, if utilities conduct their wayleave programme at the correct time, then; number of tripping in the distribution network can be minimized. As a result this implementation is economically cannot be feasible.

Chapter 5

RESEARCH IMPLEMENTATION

Main objectives of this research is to:

1. Implement a prototype autonomous LV Fault Isolation and Power Restoration together with Algorithm.
2. Develop an open flat form SCADA system in view of acquiring multi-protocol Remote Switching Subsystem devices in Western Province South II of Ceylon Electricity Board.

Now I will complete the research work with a solution for the above two main objectives. Implementation of the objectives as follows.

5.1 Implement a prototype autonomous LV Fault Isolation and Power Restoration together with Algorithm

Implement proto type autonomous LV Fault Isolation and Power Restoration system using Relays, and ARDUINO micro controller hardware and software. Figure 5.1shows schematic diagram of proto type feeder with Motorized Circuit Breaker, Isolator and Remote Terminal Unit. ARDUINO micro controller operates as the Micro SCADA for a transformer as discussed at Chapter 2. Function of Motorized Circuit Breaker demonstrates using 12V DC Double Pole Single Trough Relay. Relay wired as latching relay circuit, it is fulfill required trip function of the Motorized Circuit Breaker. Same type of Relay used to demonstrate Isolator. Switch “S” used to demonstrate fault, when switch “S” closed 12V DC line dead short. All Relays controlled by ARDUINO micro controller output pins. Input pins of the ARDUINO micro controller always scan availability of 12V DC in the feeder. DS1 lamp is used for avoiding dead short of the 12V DC supply. DS2 lamp is used as indicator for supply available or not in the relevant feeder section.

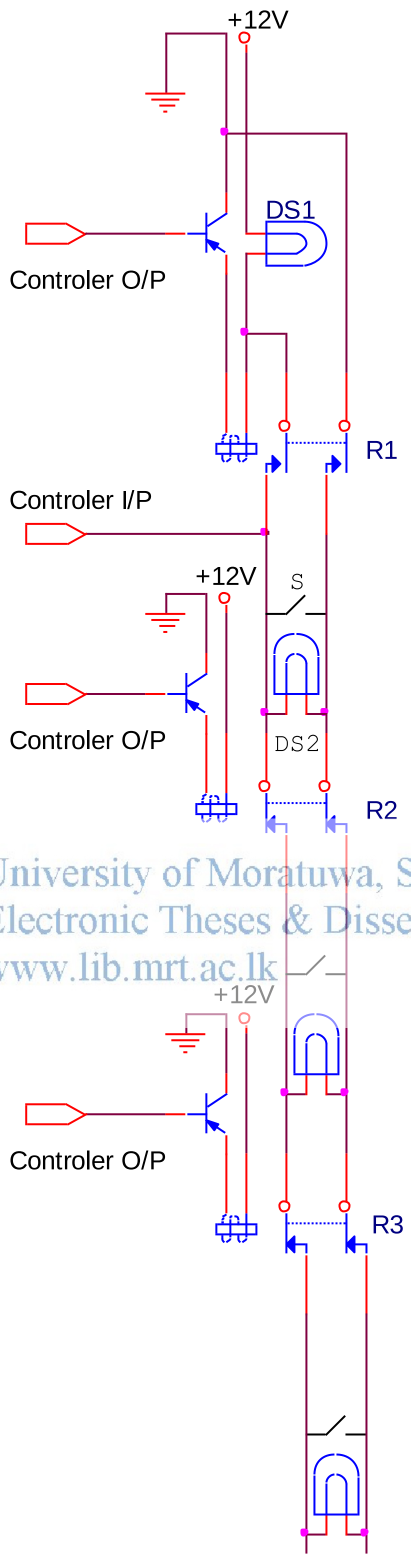


Figure 5.1: Schematic diagram of proto type

Figure 5.2 shows designed and implemented hardware part of the autonomous LV Fault Isolation and Power Restoration system, this proto type demonstrate two transformers. Each transformer consists with four feeders. In each feeder there are three isolators. Also consist of adjoining switch, which used to connect to or disconnect from the adjoining feeder.

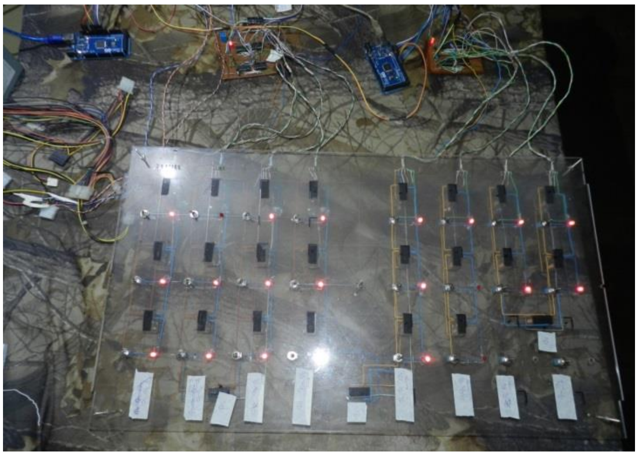


Figure 5.2: Designed and implemented hardware part of the autonomous LV Fault Isolation and Power Restoration system

After completing the hardware developing, start the developing algorithm using software. Figure 5.3 shows one stage of software development.

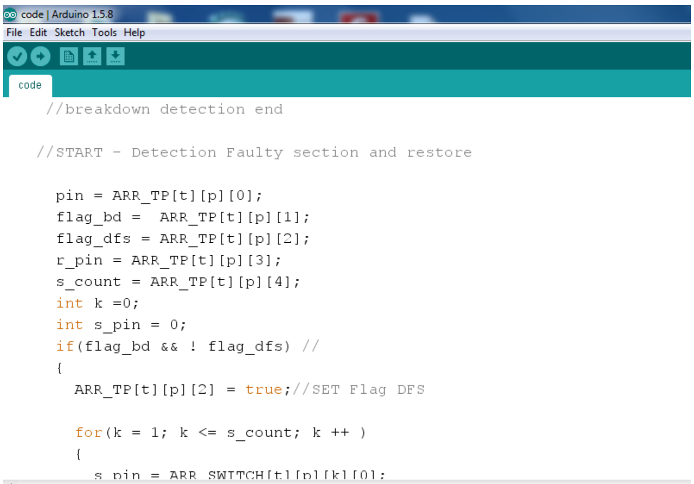


Figure 5.3: Stage of software development

Simultaneously, developing of Human Machine Interface (HMI) started. Figure 5.4 shows completed HMI of the system. Developed software is attached in Appendix A

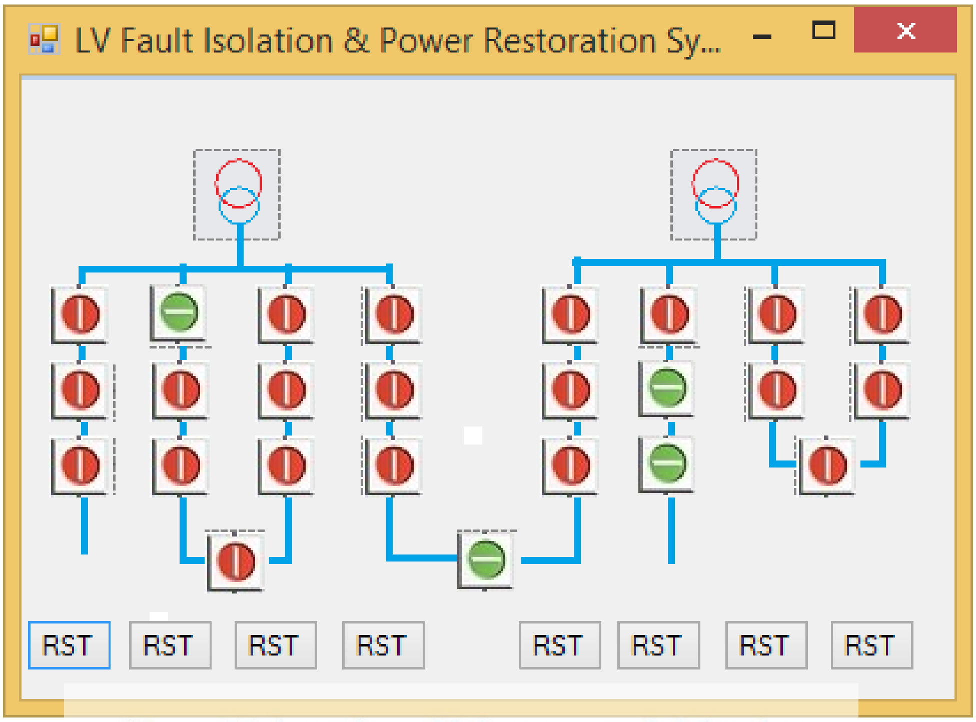


Figure 5.4: HMI of the system

5.2 Developing of open plat form SCADA system in view of acquiring multi-protocol Remote Switching Subsystems devices in Western Province South II of Ceylon Electricity Board

Developing of open plat form SCADA system is done by step by step. As per discussed in the introduction chapter, remote switching subsystems devices purchased from various manufactures are centrally operated through open plat form SCADA system is the one goal of research. In the chapter 5 discussed and developed open flat form SCADA system.

At the first stage installed GPRS Modem was installed at selected Load Break Switch and Auto Circuit Recloser in WPS II. Figure 5.5 shows installation of GPRS Modem.

Figure 5.5: Installation of GPRS Modem

After that communication stablished between Computer and Remote Terminal Unit through Mobitel VPN network by assigning IP address. Figure 5.6 shows success of communication.

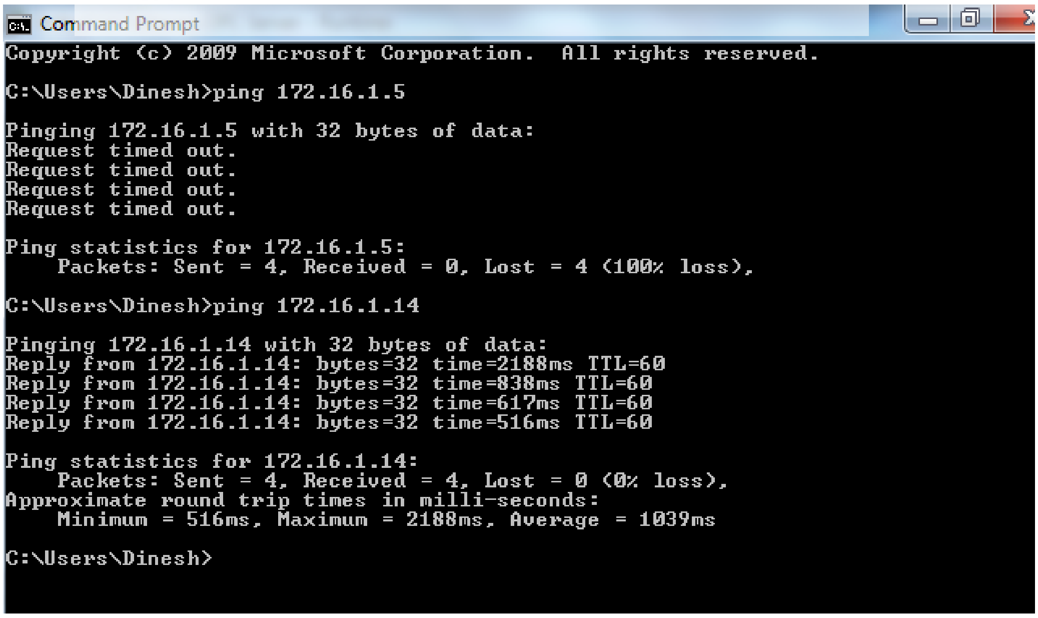


Figure 5.6: Success of communication

Completing of established communication RTU are connected to Industrial Gateway OPC Server. Figure 5.7 shows adding RTU to OPC Server.

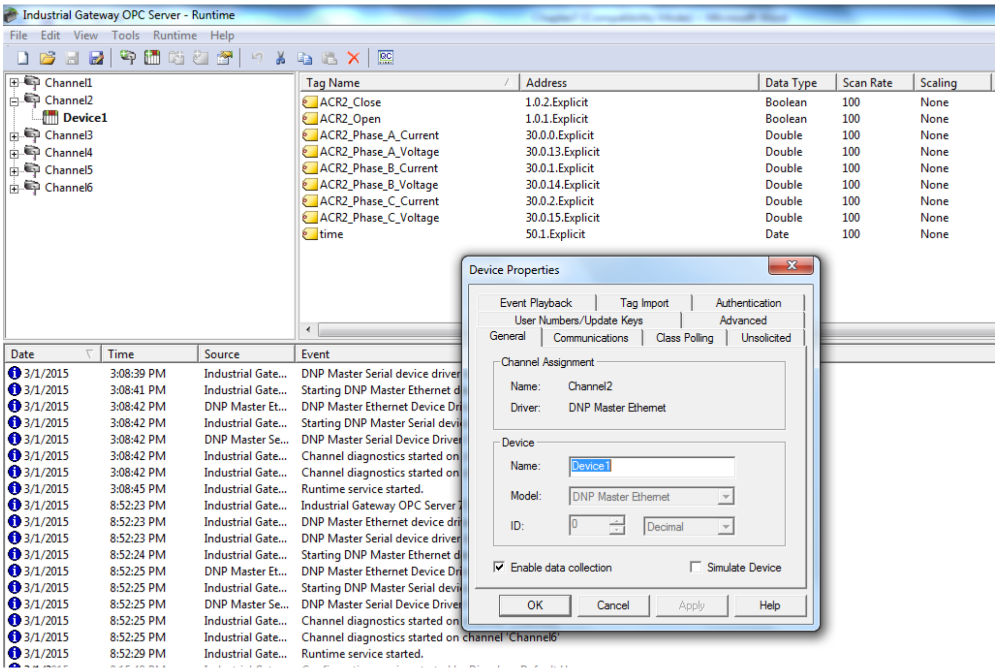


Figure 5.7: Adding RTU to OPC Server

Figure 5.8 shows data acquisition to OPC server from Auto Circuit Recloser.

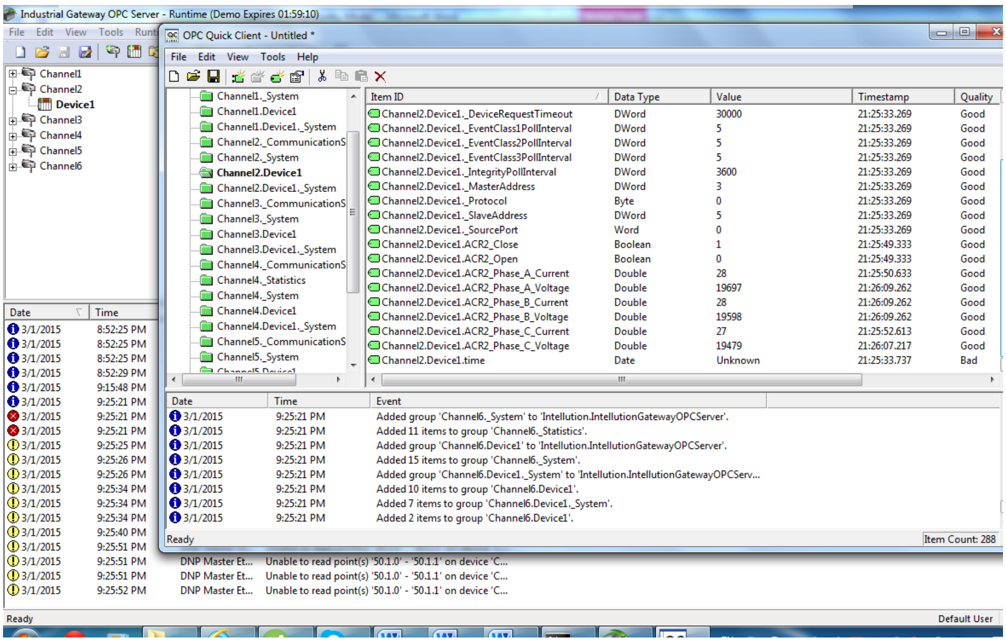


Figure 5.8: Data acquisition to OPC server from Auto Circuit Recloser

Successful completion of data acquisition to OPC server from RTU then started developing SCADA using iFIX software. As the first step Graphical User Interface to be developed. Figure 5.9 shows one of page Graphical User Interface.

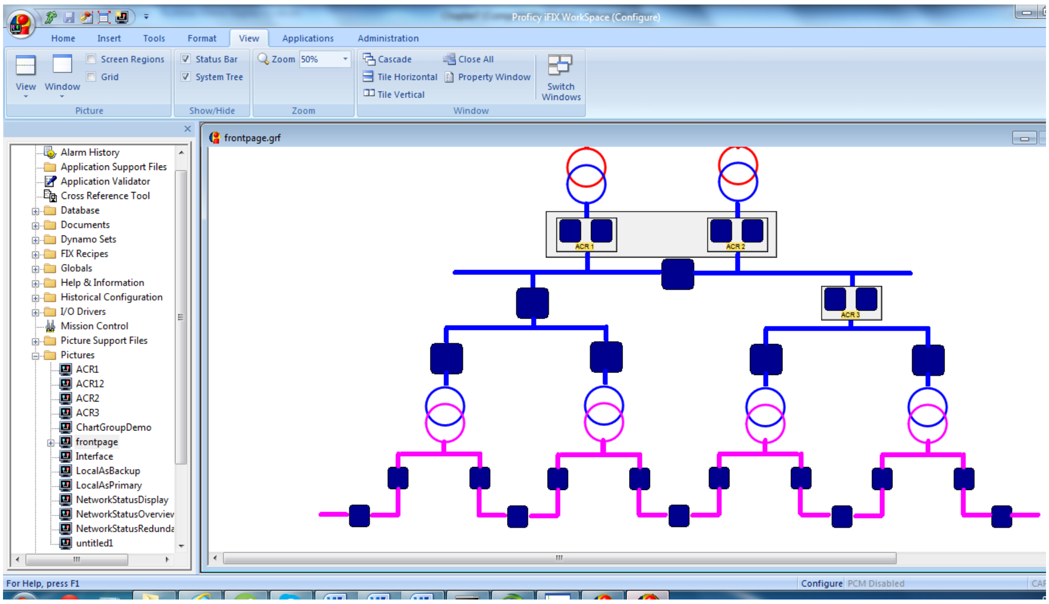
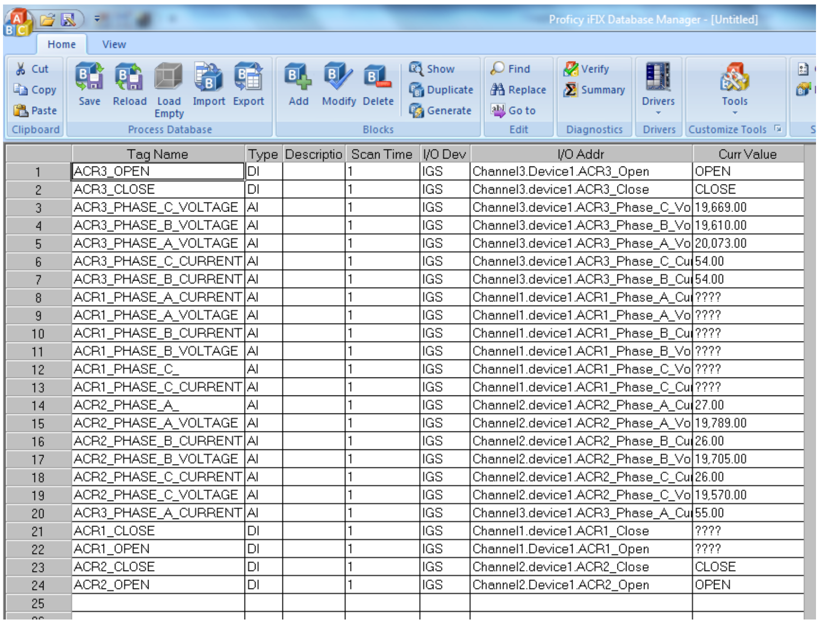


Figure 5.9: One of page Graphical User Interface

After completion of developing GUI database was added. Added database is shown in figure 5.10.



	Tag Name	Type	Descriptio	Scan Time	I/O Dev	I/O Addr	Curr Value
1	ACR3_OPEN	DI		1	IGS	Channel3.Device1.ACR3_Open	OPEN
2	ACR3_CLOSE	DI		1	IGS	Channel3.device1.ACR3_Close	CLOSE
3	ACR3_PHASE_C_VOLTAGE	AI		1	IGS	Channel3.device1.ACR3_Phase_C_Vo	19,669.00
4	ACR3_PHASE_B_VOLTAGE	AI		1	IGS	Channel3.device1.ACR3_Phase_B_Vo	19,610.00
5	ACR3_PHASE_A_VOLTAGE	AI		1	IGS	Channel3.device1.ACR3_Phase_A_Vo	20,073.00
6	ACR3_PHASE_C_CURRENT	AI		1	IGS	Channel3.device1.ACR3_Phase_C_Cu	54.00
7	ACR3_PHASE_B_CURRENT	AI		1	IGS	Channel3.device1.ACR3_Phase_B_Cu	54.00
8	ACR1_PHASE_A_CURRENT	AI		1	IGS	Channel1.device1.ACR1_Phase_A_Cu	????
9	ACR1_PHASE_A_VOLTAGE	AI		1	IGS	Channel1.device1.ACR1_Phase_A_Vo	????
10	ACR1_PHASE_B_CURRENT	AI		1	IGS	Channel1.device1.ACR1_Phase_B_Cu	????
11	ACR1_PHASE_B_VOLTAGE	AI		1	IGS	Channel1.device1.ACR1_Phase_B_Vo	????
12	ACR1_PHASE_C_	AI		1	IGS	Channel1.device1.ACR1_Phase_C_Vo	????
13	ACR1_PHASE_C_CURRENT	AI		1	IGS	Channel1.device1.ACR1_Phase_C_Cu	????
14	ACR2_PHASE_A_	AI		1	IGS	Channel2.device1.ACR2_Phase_A_Cu	27.00
15	ACR2_PHASE_A_VOLTAGE	AI		1	IGS	Channel2.device1.ACR2_Phase_A_Vo	19,789.00
16	ACR2_PHASE_B_CURRENT	AI		1	IGS	Channel2.device1.ACR2_Phase_B_Cu	26.00
17	ACR2_PHASE_B_VOLTAGE	AI		1	IGS	Channel2.device1.ACR2_Phase_B_Vo	19,705.00
18	ACR2_PHASE_C_CURRENT	AI		1	IGS	Channel2.device1.ACR2_Phase_C_Cu	26.00
19	ACR2_PHASE_C_VOLTAGE	AI		1	IGS	Channel2.device1.ACR2_Phase_C_Vo	19,570.00
20	ACR3_PHASE_A_CURRENT	AI		1	IGS	Channel3.device1.ACR3_Phase_A_Cu	55.00
21	ACR1_CLOSE	DI		1	IGS	Channel1.device1.ACR1_Close	????
22	ACR1_OPEN	DI		1	IGS	Channel1.Device1.ACR1_Open	????
23	ACR2_CLOSE	DI		1	IGS	Channel2.device1.ACR2_Close	CLOSE
24	ACR2_OPEN	DI		1	IGS	Channel2.Device1.ACR2_Open	OPEN
25							

Figure 5.10: Added database

Finally completed developing of open flat form SCADA system. Figure 5.11 shows developed open flat form SCADA system.

Figure 5.11: Developed open flat form SCADA system

Chapter 6

CONCLUSION AND RECOMMENDATION

The electricity consumer always expects an efficient, more reliable and consistent delivery of power and in order to achieve these objectives the electric power distribution system needs constant evolution. Introduction of automation to the traditional electrical distribution system is an efficient solution. This dissertation discussed about how to minimize time taken for fault management activities in LV feeders by introducing an autonomous system with proper algorithm. Also it discussed MV Distribution automation with lesser capital investment by utilizing smart grid devices that already reside in the distribution network.

At the beginning of the research, the LV fault management activities has studied.. Finally found there are seven fault management activities as per discussed chapter 1. Average time taken for these fault management activities were 03 H 10 Min in traditional LV distribution system. Time taken to these activities can be reduced hours to minute by introducing LV feeder automation except two activities. Introducing feeder automation is meaningless without proper fault detection, isolation and power restoration to the healthy section. As a solution, an algorithm was introduced for fault detection, isolation and power restoration to the healthy section. It is an open algorithm. Hence open the door to electric utilities for LV feeder automation with developed algorithm. The proposed algorithm is tested on a prototype.

Proposed for MV distribution automation is discussed. Already proprietary micro SCADA are available with Remote Switching Subsystems Devices. Due to proprietary protocol and very slow communication medium MV distribution automation was unpopular. Hence finding a solution for open platform SCADA system in view of acquiring multi-protocol Remote Switching Subsystems devices is became one aim of the research.

Communication protocol availability for Remote Switching Subsystems devices communication was investigated by conducting a field survey in Western Province South II (WPS II) of Ceylon Electricity Board. Literature survey conducted to select a cost effective communication media in view of linking geographically dispersed distribution assets. GPRS considered as a viable media for the communication & required communication hardware were selected accordingly.

Object linking & embedding for process control (OPC) used to integrate multi protocol Remote Switching Subsystems devices in to the central SCADA system. Various features of the SCADA software packages were considered when selecting a suitable SCADA software package for distribution automation task.

Financial viability of implementing distribution automation in Western Province South II (WPS II) of Ceylon Electricity Board was investigated & came up with favorable results with regards to project financial feasibility.

Important components in a SCADA system, such as Data logging, trending & alarm generation were discussed related to the SCADA software package selected for the distribution automation task. Finally, was developed an open flat form SCADA system in view of acquiring multi-protocol Remote Switching Subsystems devices.

Investing on a fully fledge SCADA is not so economical for a small scale distribution utility. Therefore Scalable distribution automation solution will enable small scale distribution utilities to enter in to distribution automation with lesser capital investment. Lower initial capital investment must be support with a lower level of operating cost. Communication infrastructure contribution to the operation cost is significant & selecting a cost effective communication media is essential.

Developing of a scalable SCADA in view of acquiring multi-protocol Remote Switching Subsystems devices with GPRS data communication infrastructure will bring in a solution for a smaller distribution utility to enter in to distribution automation with lesser pain.

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