DEVELOPMENT OF A MULTI AGENT SYSTEM FOR VOLTAGE AND OUTAGE MONITORING

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Declaration

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The above candidate has carried out research for the Masters Dissertation under my supervision.

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Table of Contents

Abstract

This thesis presents a research work which is carried out to implement a multi agent system for voltage and outage monitoring system for Sri Lankan electricity distribution network. In Sri Lankan distribution network most of the new technological features can be seen in the different part such as automated meter reading, remote breaker operations. But distribution system fault identifications, voltage monitoring and network reconfiguration are carried out using basic technologies.

Automated Meter Reading (AMR) system is introduced to read analogue energy meters remotely. Research on agent based AMR system is established with four major projects. Those are Agent based meter reading system, network resource planning of the agent based system, agent network reconfiguration and restoration project and Agent based voltage and outage monitoring system

This particular research is on a development of Agent based voltage and outage monitoring system formulated for power distribution network using Multi Agent System. Establishment of agent based monitoring system is developed with the defined model in a part of the area network. The model is established to represent the distribution network and to collect voltage and interruption data to the server. Five major agents namely, Database Agent, Meter Agent, Breaker Agent, Area network Agent and Reporting Agent are defined.

Voltage data collected from GPRS meter reading technique in Maharagama area is selected for the case study. Six different data sets are considered under the case study. There are four different types of voltage failures are identified as High voltage, low voltage, Branch failures and individual meter faults. These four scenarios are compared with conventional method and agent based system.

Agent based monitoring system is continuously updated through GUI and it would visualise the voltage level of the network. It would enhance the functions of the control room operator. Transformer setting changes can be changed while monitoring high voltage and low voltage areas. Distribution network augmentation can be done with monitoring system by increasing transformer capacity or introducing new transformer in identified areas.

Different types of GUIs are established to maintain easy monitoring system and reporting system. The reporting system is included the agent based report generation for power quality measurement indexes. Individual index vales of each consumers and the whole area network index can be monitored through this system. Scalability and the flexibility of the monitoring system increased with defined Multi Agents.

Acknowledgement

First, I would like to extend my gratitude to the project supervisors, Dr. Narendra De Silva and Dr. K.T.M.U Hemapala who guided me throughout the project where finally it could be completed with promising outcomes within the allocated time. Also I would like give my sincere thanks to Prof. Nalin Wickramarachchi who gave me excellent support at the establishment of this project and also my sincere thanks go to all academic and non academic staff of the Department of Electrical Engineering, Faculty of Engineering, University of Moratuwa for facilitating me in very many ways on my M.Sc. studies. Also my sincere thanks go to all engineers and other staff members in the Lanka Electricity Company, who gave me excellent support to complete my research. Also my sincere thanks go to my family members for their dedication and support given throughout the project. Lastly, I should thank many individuals, friends and colleagues who have not been mentioned here personally, in making this research project a success.

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Description
CEB	Ceylon Electricity Board
LECO	Lanka Electricity Company
MAS	Multi Agent System
AMR	Automatic Meter Reading
GUI	Graphic User Interface
IEEE	Institute of Electrical and Electronics Engineers
USB	Universal Serial Bus
SCADA	Supervisory Control and Data Acquisition
CAIDI	Customer Average Interruption Duration Index
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
FIPA	Foundation for Intelligent Physical Agents
ACL	Agent Communication Language
JADE	Java Agent Development Environment
AMS	Agent Management System
DF	Directory Facilitator
MTS	Message Transport System
AP	Agent Platform

Chapter 1

Introduction

1.1 Introduction of Power Distribution Network of Sri Lanka

Sri Lankan power distribution network is controlled by Ceylon Electricity Board (CEB) and Lanka Electricity Company (LECO). At the primary substation; power is brought to the bulk power purchasing point or the distribution transformer level via different feeders. In Sri Lanka the power distribution system is powered through primary substations. From a primary substation several number of radial distribution feeders are started and they run over the area normally for 20-30 Km. Each feeder consist of several number of load break switches.

The end user of the power distribution network consists with an analogue meter to record the electricity consumption throughout the month. Then one of meter reader will access the meter manually and record the electricity consumption and provide the electricity bill. This is very conventional method and there are developed technologies used by developed and developing countries in this field.

In Sri Lankan distribution network most of the new technological features can be seen at the selected area networks such as automated meter reading. But distribution system fault identifications, voltage monitoring and network reconfiguration are carried out using basic technologies.

1.2 Introduction to Existing Technology

Automated Meter Reading (AMR) system is introduced to read analogue energy meters remotely. This AMR system further developed to identify the error code from the faulty meter and diagnosis the power failure. Faulty meter records were entered to the power network and quarry to identify the feeder. Significant outages can be identified through the system. But there are more data processing equipments, mass storage capacity and also high data separation technique needed to have high accuracy fault detection system.

Significance matrix method is used to define network cells. Network cells are made referring the network size and structure. This matrix method is used to measure the outage by probabilistic manner. Therefore this outage probabilistic index can be increased or decreased according to case occurred. If the probabilistic index is very high that recognizes as the power failure. However this will not represent whole power failures correctly. It has few advantages, such as required data base intensity considerably low and the availability of optimum data base usage. Main disadvantages are loss of primary data and analysing of previous data cannot be done for future decisions.

Agent based system is introduced to the power system applications to have flexible, scalable, social and traceable network. Power system applications are covered vast area in the power distribution industry. So these systems are complicated to handle and needed to be simplified. This can be simplified as per requirement and the flexibility of the system can be increased accordingly. This system is varied from others due to flexibility, because agent systems can be changed according to the requirement. In this system insignificant incidents will not be recognized as a fault. Data can be traced back to the origin when it required comparing.

1.3 Problem Identification

The Sri Lankan Electric Power System is evolving in complicated network. The Meter reading technology of the distribution network was started to update with AMR Systems. Development of AMR system has began a new era for power distribution networks.

AMR system is mainly considered to collect power consumption from individual bulk consumers. In addition to this it can be used to read end users voltage. Comparison of the voltage reading is used to identify the voltage drop for each and every customer. Qualities of the end user voltage depend on the voltage deviation.

In the existing system, no voltage quality measurement or outage monitoring system has been established. Presently all outages were recorded as a telephone complain to the control room operator. According to that information, technicians are attended to the breakdown. Time calculation for the outage was monitored through this information flow. Due to this unusual method, calculation of the System Average

Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI) are incorrect.

Requirement of the voltage and outage monitoring is recognized to improve the voltage quality of the end user and power system augmentation can be planned accurately with existing data. This can be developed through the voltage monitoring at the end of the line and can be emphasized through the calculated voltage drop through the power line. Defect meters are identified at the stage of the manual meter reading. This identification can be localized to the control system through outage monitoring system.

The problem studied in this research is the issue of outage monitoring through voltage readings. The outages will be reported instantly to the central controller once an AMR system was placed. But these reports will be in nature; none of the individual records will directly point an outage incident and therefore a record has low value. But the cumulative presence of these records along a network branch leads to a significant outage incidence. Therefore continuous monitoring of individual outage records have to be carried out from logically connected agents with owns behaviours and that would be the most appropriate method.

1.4 Motivation

In order to solve the above mentioned voltage and outage monitoring issue, most of data processing and analysing techniques were considered. Maintaining of online voltage monitoring system would be a challenge, low voltages and high voltages are required to be mapped to realistic network because bulk customers' main consideration is kept on the voltage quality. If voltage imbalance is frequently occurred, they cannot maintain a consistent power supply. Once the bulk customers made complains about low or high voltage situation, control system engineer cannot reason out any time period or he cannot prove the actual voltage levels.

It is very difficult to maintain the accurate SAIDI and SAIFI values with the present data logger system. The quality of the power provided by the power utility company is the key factor of measuring, its capabilities and the technology. With the existing programmes, it has to change whole programme when modifications were done for distribution network, such as installation of new meter or change meter location or introduce new breaker. These problems have to be overcome with new system and should introduce a flexible and scalable program with minimum changes. In this circumstance propose system has to be mainly focused on the simplicity and flexibility of the program, and to minimize the changes when new meter were introduce to the system.

This online data processing system can be used to predict the exact meter faults, low voltage and high voltage areas in the power distribution network, and locate the breaker failures to identify the exact outage area. The accuracy level of the data processing system has to be increased and it is required to introduce a proper method. With this exact objective, this work is presented. In this circumstance development of online voltage and outage monitoring system using multi agent system is a solution for real problem faced by the Sri Lankan Power distribution network.

1.5 Methodology

Power distribution network of Sri Lanka is very complicated and electricity suppliers currently focusing on the SMART grid concept. This research was developed as a part of this concept to monitor voltage and outages of the system. Accordingly following steps were considered to complete the project successfully.

1. Literature survey.
2. Study about the problems encountered with the voltage monitoring through AMR system.
3. Define respective agents to represent the network components virtually.
4. According to the network size develop suitable agent Architecture
5. Develop probabilistic relation and hypothesis related to outage area.
6. Use java base program to define agents and database management.
7. Develop a reporting agent to generate real values for power system quality measurement indexes base on actual outages.
8. Develop physical model to gather required voltages and represent outage areas manually and configure the agent model with this physical model values to validate the system functioning.

1.6 Requirement of Agent Based Monitoring System

A very traditional distribution network is available in Sri Lanka. These distribution networks need to be upgraded as SMART grid. Upgrading cannot be done in overnight and need more experimental base innovations. These innovations are carried out with in the LECO and few of them are functioning such as remote meter reading through direct dialling via GPRS and AMR system.

As another era to the distribution network, LECO started testing on fully Agent based operating distribution network establishment as an experiment. Accordingly four major agent based projects were started as illustrated in Figure 1-6.

Project 1 : Physical meter agent Communication

Project 2 : Network resource planning and optimization

Project 3 : Agent based Network reconfiguration and restoration

Project 4 : Agent based monitoring system.

Monitoring system of the network needed to be done because the agent based monitoring system should be completed with all other systems to run full agent based distribution network.

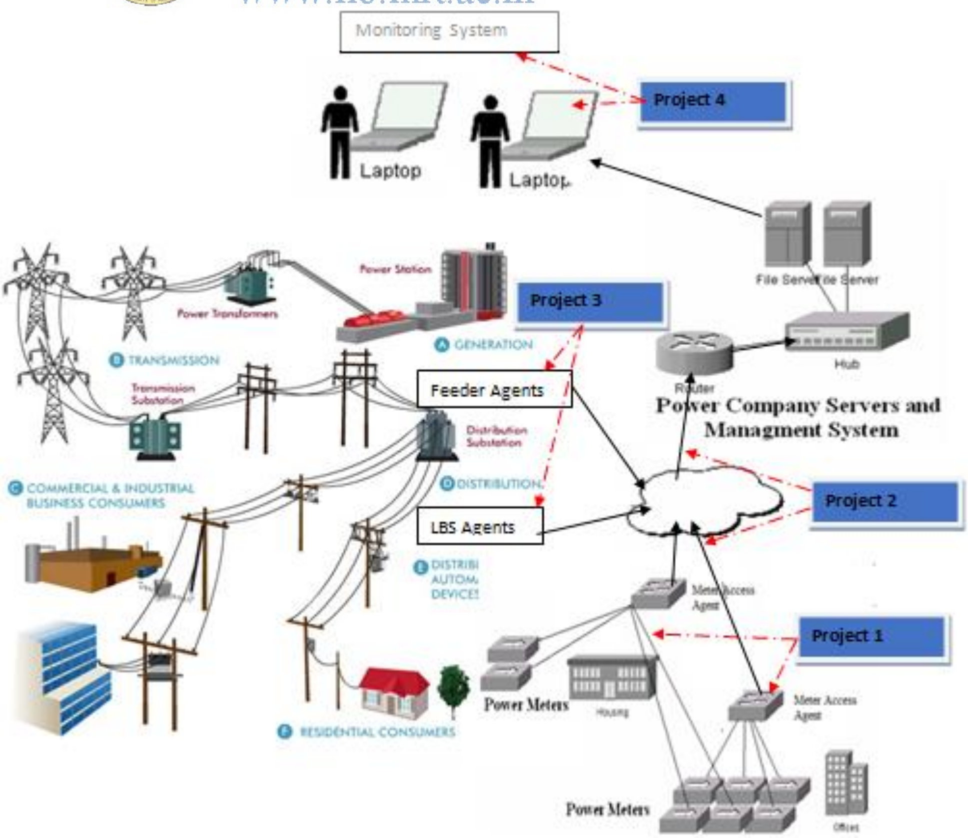


Figure 1-7: Agent Based Distribution network

1.7 Contribution

Having studied the available AMR system, it was identified that implementation of a proper monitoring system is very much essential to analyse available meter data. Based on this requirement, agents were defined to represent the actual distribution network components virtually. Accordingly main agent architecture was designed to implement the monitoring system.

Designed different type of GUIs running based on the respective agents and developed an online voltage monitoring chart for individual bulk customers. Separate database was developed to maintain outage data and calculate power quality measurement indexes more accurately. Demonstration model to represent area distribution network was designed and implemented the data acquisition system to database. Based on this model data, agent system was synchronised and run the system GUIs to show the real outages. Maharagama area network is selected for Case study and data for 34 Nos of meters were stored in to data base through GPRS direct calling method. These voltages are processed with monitoring system to find out changes the area network graphically.

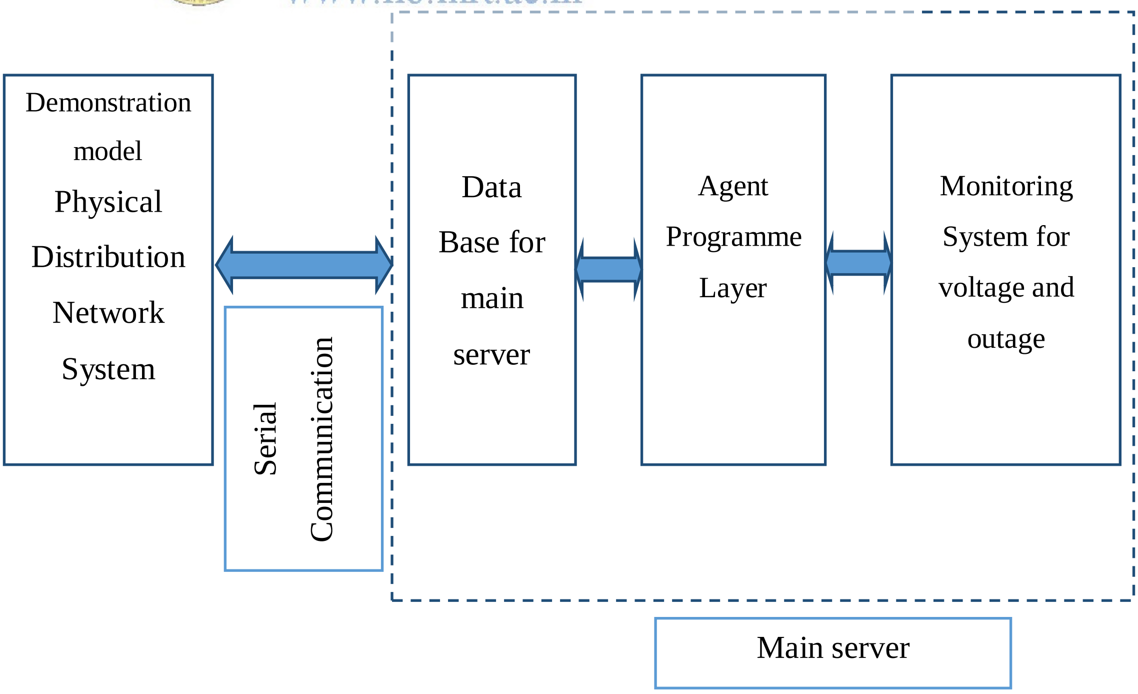


Figure 1-7: System Model

1.8 Thesis Organization

The remainder of this thesis is organized as follows. Chapter 2 provides details of the literature reviews, Main key papers are discussed which used to develop some features of this project. Chapter 3 discussed about the multi agent system and it's examples. Chapter 4, it is reviewed the proposed solution for existing power distribution network. In chapter 4, clustering technique, tree topology and the multi agent system are introduced to assist to implement monitoring system. Chapter 5 provides more detailed information related to the system implementation. In this chapter, it is discussed about agent designing and programming, probabilistic and hypothesis implementation, system model implementation and final GUI configurations. Chapter 6, results are discussed about GUI representation, database management, and related works of report agent. Chapter 7 presents the conclusions discussed in this research and includes ideas for future study.

Chapter 2

Literature Survey

2.1 Introduction

There are no any power network system operate through multi agents in Sri Lanka. This is happened because at the beginning of electricity industry we use analogue meters. Still we are in same position and did not get rapid change with world. Because the capital cost for energy meter is considerably high. Developed countries are used digital meters which having lot of options to record required meter data. These meter data were collected through AMR system to the central location. MAS is developed on the AMR system and introduced new era to the power restorations. Basically power restorations are introduced to the micro grids and that is helped to increase the power quality of the system and availability.

Traditional system was currently replaced by AMR system. The Lanka Electricity Company (LECO) has introduced AMR system to their networks. Required meter data are collecting to central data base via AMR system. This is handling as bulk data so important data cannot be sort out easily and gain the actual benefit of collecting those data. Because of this still they are practising the traditional methods of fault finding techniques, defect meter identifications and identifying electricity pilferage. Once the power failure is happened all consumers try to call to control centre to make complain about the failure. At that time telephone number of the call centre is engaged until rectify the failure. During this period any one cannot give important updates to area office. Also they cannot find the exact reason for the power failure and alternative solutions. Maintenance crew is attending to the faulty by searching whole network. They will take long period to rectify the network. They normally inform to area office after rectifying the fault. Alternative options will not to be considered to supply power through other primaries which having ring structure. Due to this reason power quality measuring indexes are going higher and higher so company mission drastically gone down.

2.2 Clustering for Partitioning a Power System

Clustering is the process of identifying the underlying structure in data and determining groups of similar behaviour. Various type of clustering methods are used for power restoration and found in literature [1]-[3]. Summiya Moheuddin, et al. Presented a reconfigurable distributed multi agent system optimized for scalability [1] is selected to consider future works. In this paper authors used a combination of cluster computing and multi agent system for scalability. Also the performance and scalability of a multi agent system is measured using indicators, such as number of concurrent agents and associate tasks and organization patterns of agents. This organisation pattern or agent architecture is depending on the number of cluster. Also it can be reduced the number of agents which used to communication.

In their research, authors have developed clustering techniques to identify logical power system partitions such that agents can monitor these dedicated clusters or partitions rather than employ an agent to monitor each node or device. By partitioning the entire system into clusters and assigning an agent to each cluster, task sharing is achieved which reduces the problem complexity. In comparison to the topology independent decentralized MAS.

As the number of agents involved in the communication is increase, the entire decision making process becomes more susceptible to faults and errors due to last message or problem with communication network. But when they use scalable MAS architecture with clustered network, it proved the best performance in their system.

2.3 Architecture of the MAS

Whole multi agent system performance is depending with the basic architecture design. Several agent architecture designs were developed and found in literature [4] – [9]. When selecting the number of agents to the system, it is needed to be considering following important policies.

- To decrease the resource requirement
- Simplifies the agent system topology
- Reduce the communication overhead
- Limit the number of possible interactions.
- Minimise the overall complexity of system.

A major challenge of agent architecture for power system applications is scalability. Most existing architectures associate an agent with an electronic component in the system [4]. The idea is to have agents with local information communicate with each other to reach a solution. The amount of communication and coordination reduced through the layered architecture. This layered architecture is helped to reduce the number of agents and complexity of the system [4],[6].

Moreover, several authors have addressed the issue of fault diagnosis and reconfiguration. Specially, the paper by Li Liu [10] describes the need of fault detection in naval shipboard power system. The paper discusses the practical fault detection and diagnosis problem along with prognostics from control engineering. This is related to my project base on the online voltage monitoring technique. Because in their fault diagnostic framework, the task has been defined as to constantly monitor the process and from the available observations to identify an indication to decide whether there is a fault or not also identify the fault location.

2.4 Tree Structured Network

Power distribution networks mostly deployed as tree structures. Tree structured networks are an important application for fault diagnosis due to their use as distribution networks[11]-[13]. The central site forms the root of the tree, while the consumers are located at the leaves of the tree. In such a network, a fault in one component of the network may affect all consumers connected downstream from that component. Tree structure development and divided to sub trees were considered base on the papers published by Christoper Leckie and Michael Dale, Telstra Research Laboratories about Locating Faults in Tree Structured Networks [12]and by Yue Zhao, Raffi Sevlian, Ram Rajagopal, Andrea Goldsmith and H. Vincent Poor about Outage Detection in Power Distribution Networks with Optimally- Deployed Power Flow Sensors[13].

In paper [13], authors have discussed about the deployment of extra sensors to collect data from the distribution network and optimization of sensor installation to the network. This use full to us when consider about the Sri Lankan network system we collect data directly from the meter accordingly we do not want to introduce new sensors but it is important to divide the network for sub trees to minimize the data processing time and increase the system efficiency.

2.5 Probabilistic Model

Different kind of approaches was taken to find out failures in the distribution network using the probabilistic approach. On the technical point of view, handling non-constant failure rates is a key requirement for the reliability analysis tools that are included into risk analysis or risk assessment programs. In the same way, the reliability tools should use the full probability density functions (PDFs) instead of limiting the analysis to the expected values and standard deviations [14]. In this paper mainly discussed about the reliability issues of the network and the first step for applying probabilistic reliability analysis is to define the random variables (RVs) involved in the study. However, some indices are defined under the assumption of exponential distribution of the time to failure with constant failure rate. Development of outage hypothesis were done base on the paper [13] and relation to the probabilistic values studied with references of [2],[14]-[17].

2.6 Existing voltage monitoring system

Remote monitoring and analyzing system of low voltage distribution lines is being developed in order to monitor and analyze low voltage, 50 Hz, three phase distribution system from a centralized control centre. Voltage measuring device is introduced to transformers and it will compare with the predefined voltage settings. High voltage failures can be identified by defined specific tolerance level. If voltage of the system is decreased or increased compare to the predefined voltage level, error message will send to centralized control centre.

GSM network is used to communicate (send and receive data) between Centralized control center and the measuring devices. The GSM modems are placed near the distribution transformers and the centralized control center. The modems which are placed near the transformers are connected to measuring devices via controller system. Measured data is sent to the Centralized control center as a text message via above GSM modems.First the measured data is sent to the microcontroller and then data is processed and converted to a SMS. After that the SMS is sent to the GSM modem which is placed in the control center through the GSM modem at the site. Interfacing between microcontroller and GSM modem is done by using integrated circuit. With this system voltages of individual bulk customers cannot be measured.

Chapter 3

Multi Agent System

Technology is developing day by day to provide best approach for the complex problem. Decentralized approach and Centralized approach are two main stream debated today. Each of above stream has its advantages and disadvantages.

Multi Agent System is simply developed based on the one important component named as agent and the system comprises of more than one agent is named as the multi agent system. There are various definitions for the multi agent system.

The MAS is defined as a system with component level intelligence. Those intelligent components are named as an agent and system with a group of agents is named as a MAS[20].

The agent is introduced as a software entity exists in some environment having sense on the changes and ability to react on them autonomously and goal directed manner. In a multi agent system, tasks are carried out by interacting agents that can cooperate with each other [21].

3.1. Features of MAS

The agent is the most important concept of the multi agent system and agent is defined as a software component having special features to bring its autonomy. With its special features agent can act as a human agent and it helps to model complex system and introduce the possibility of having common or conflicting goals. The agent comprises with the main special features of autonomous, social, reactive and proactive [22].

Autonomous- Agent can act without direct intervention of human or other factor and it can control its actions over the initial state.

Social- Agents are corporate with human or other agents to achieve the common complex goal.

Reactive-Agent perceives the environment changes and act over them in timely fashion.

Proactive- Agent is not simply act on the environment and it is able to exhibit goal directed behaviour by taking initiative.

In addition to above main features agents can have the ability to travel between different nodes in a computer network, which shows its mobility. Agent is truthful as it providing the certainty that it will not deliberately communicate false information. Agent is always acting to achieve the goals and never to prevent goals, and it can learn from its environment.

3.2. Applications of MAS

MAS is widely used in variety of application areas from small industrial application to space related activities. The core areas where the featured advantages of multi agent system are used are process control, system diagnosis, manufacturing, transport logistics and network management.

In process control systems, the study describes the application of MAS corporate with conventional hierarchical process control to provide advantages of both techniques. In the study reveals the application of features of Agents; goal oriented behaviour and social behaviour for the corporation control in process control.

In manufacture control it has to tackle the temporal dynamics, uncertainty, information sharing, coordination and corporation. These challenges are addressed and resolved in numerous manufacture controls by employing MAS [23], [24].

Transport and Logistic is very unpredictable and rising demanded area where the broad and fine attention required. Most conventional technologies face lots of challenges when it comes to the automation. The MAS has addressed these issues with the inherent features of agent and multi agent system [25], [26].

In network management; the conventional technologies becoming inadequate to solve the scalable, flexible and economic solution and these challenges has addressed using MAS [27], [28]. The network security agent application can employ its intelligence on reasoning, goal directed behaviour, corporation and communication.

3.3. The Foundation for Intelligent Physical Agents (FIPA)

The Foundation for Intelligent Physical Agents (FIPA) is the body to set the full standard specification for the agents and agent based systems.

The FIPA was established as an international non-profit institution to develop collection of standards. FIPA is the IEEE officially accepted standards organization for agent and multi agent system. The standards can be viewed in different categories such that agent communication, agent management, agent transport, agent architecture and application. Some of the core categories are discussed in below section.

3.3.1. Management of an Agent

This comprises several entities as illustrated in the Figure 3-1; Agent, Agent Management System, Directory Facilitator and Message Transport System[29].

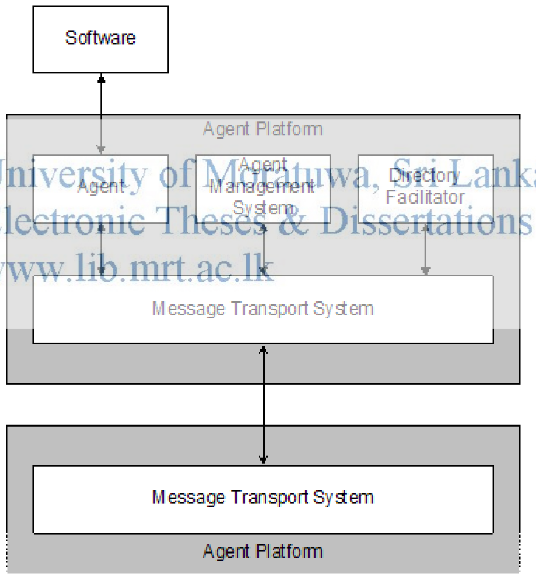


Figure 3-1: Agent Management Reference Model

Agent- Agent is a computer process entity having autonomous and communication ability. Agent is the main actor of an agent platform.

Agent Management System (AMS)–AMS is a mandatory element of an agent platform and there is only one agent platform in an agent platform. AMS maintain the details of the agent in the agent platform. AMS is responsible for managing the agent in the AP such as agent creating, agent deleting, agent migration, etc. The life cycle of the agent is managed by the agent management system and the lifecycle statuses are illustrated in the figure 3-2.

In the life cycle; when agent at active state Message Transport System (MTS) deliver the messages to agent as normal and at the initiated, waiting or suspended state, MTS buffers the messages until the agent become active. The transit state is for the mobility agent and MTS buffer the messages with it until the move get finished or it forward them if the forward function has set to another location.

Directory Facilitator (DF) – This is an optional component in agent platform and if DF present it provides the yellow page service to the agent. So it allow agent to register their services and agent to search the services among other agents.

Message Transport System (MTS) – This is the default communication between agents on different agent platforms

Agent Platform (AP) – This is the physical infrastructure for agent deployment.

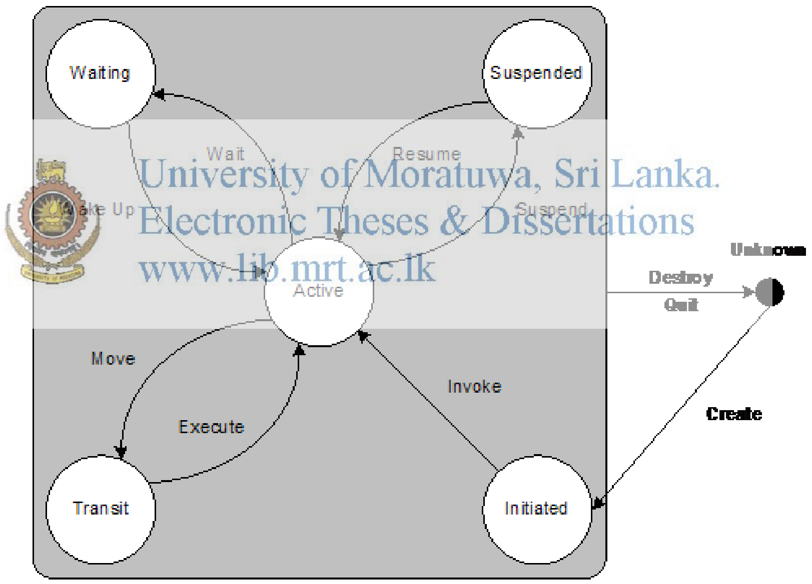


Figure 3-2: Agent Lifecycle

3.3.2. Agent Communication

FIPA agent communication deals with agent communication language, message exchange Interaction Protocol and Content Language representations.FIPA Agent Communication Language (ACL) define one or more parameter to make the communication effective. Though parameter "*Performative*" is the mandatory parameter, usually ACL message contains the sender, receiver and message contents[30].

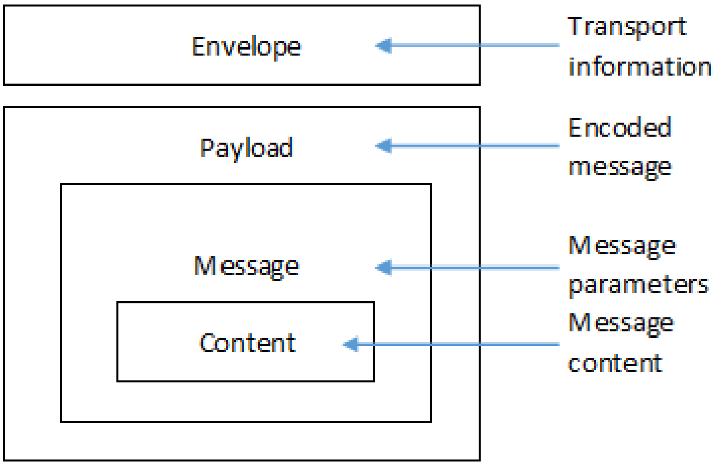


Figure 3-3: FIPA Message Structure

ACL message parameter and its description is illustrated in the table 3-1.

Table 3-1: ACL Message Parameter

Parameter	**Category of Parameter**
per formative	Type of communicative acts of the message
sender	Identity of the sender of the message
receiver	Identity of the intended recipients of the message
reply-to	Which agent to direct subsequent messages to within a conversation thread
content	Content of the message
language	Language in which the content parameter is expressed
encoding	Specific encoding of the message content
ontology	Refer to an ontology to give meaning to symbols in the message content
protocol	Interaction protocol used to structure a conversation
conversation-id	Unique identity of a conversation thread
reply-with	An expression to be used by a responding agent to identify the message
in-reply-to	Reference to an earlier action to which the message is a reply
reply-by	A time/date indicating by when a reply should be received

The Interaction Protocols (IP) deals with pre-agreed message exchange protocols. The request protocol and contract net protocol are described below as they are heavily used at the applications.

The request interaction protocol is illustrated its protocol steps in figure 3-4. In this protocol one agent request to perform an action from the participants and participant agree or refuse the request. Then agreed agents notify the status after performing action either done or failure [31].

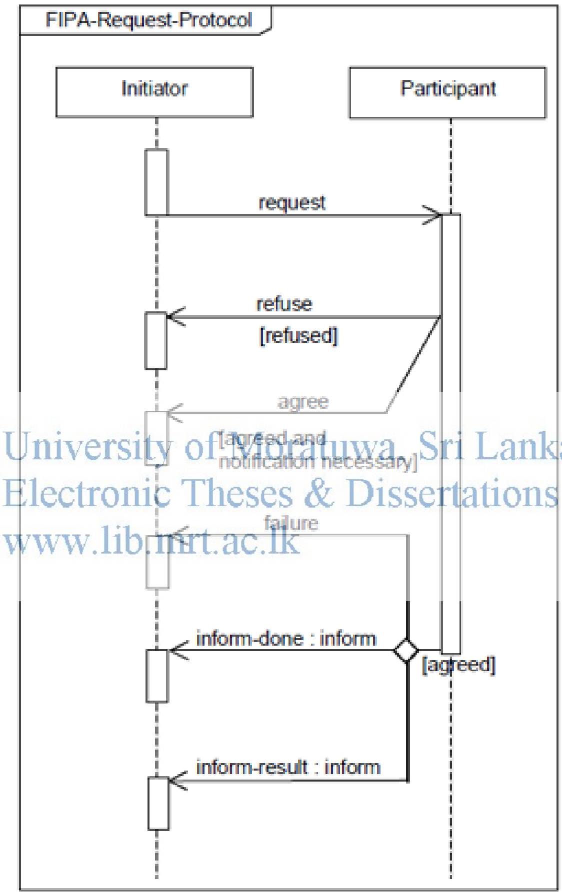


Figure 3-4: FIPA Request Interaction Protocol [31]

Similar to the request interaction protocol, the contract net interaction protocol initiate the conversation with participant to submit their bids or "*call for proposal - CFP*" as illustrated by the figure 3-5. The offers from the participant are evaluated by the initiator and select the best option and award the contract to the selected agent from proposal accepted message. Finally the contract awarded agent reply back to initiator either action done or failure [32].

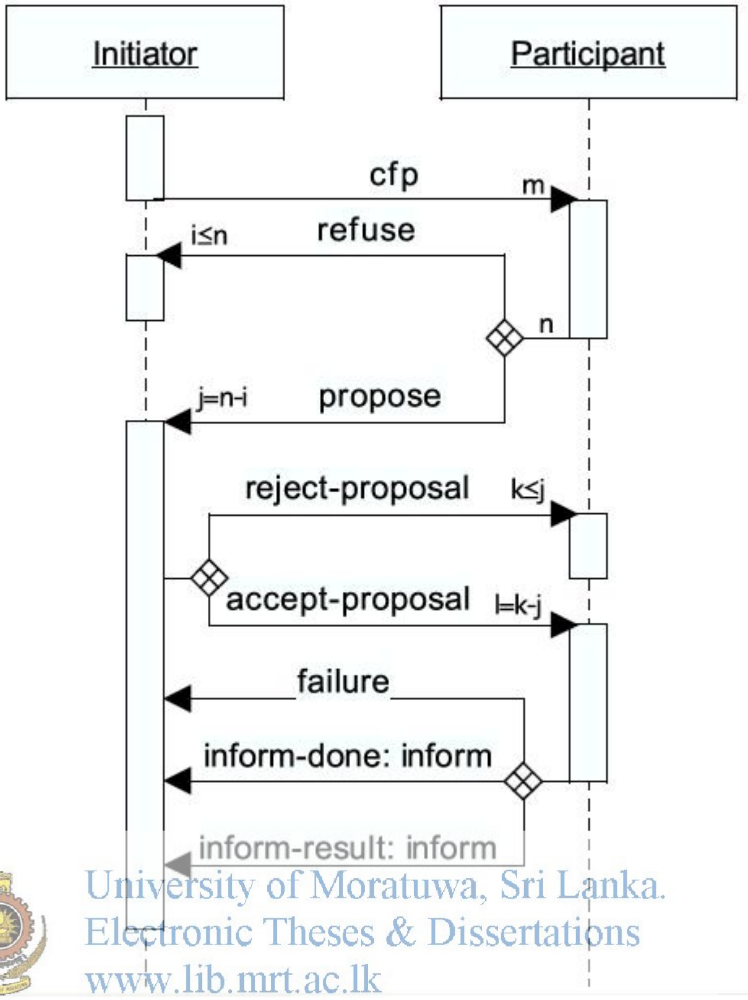


Figure 3-5: Contract Net Interaction Protocol [32]

3.4. Comparison to Agent Development Toolkits

The infrastructure to develop the agent system as specified in the FIPA standard is named as agent development tool kits. Toolkit provides support for application development, security for communication among agents, facilitation for agent mobility, etc. Present there are several developed agent toolkits such as JADE, Zeus, Aglet and the comparison between each is given in table 2[33].

Table 3-1: Agent Toolkit Comparison [33]

	Aglet	Voyager	JADE	Anchor	Zeus
Nature of Produce	Free, Open source	Commercial	Free, Open Source	Available in BSD license	Free, open source
Standard implemented	MASIF	-	FIPA Compliant	SSL, X.509	FIPA compliant
Communication Technique	Synchronous , Asynchronous	All methods	Asynchronous	Asynchronous	Asynchronous
Security Mechanism	Poor	Weak	Good	Strong security	Good
Agent Mobility	Weak	Weak	Not-so-weak	Weak	Do not Support
Agent Migration Mechanism	Socket	RMI	RMI	Socket	Null

From the available toolkits JADE is at the front line.

3.5. Java Agent Development Environment (JADE)

JADE is an agent development framework in compliance with FIPA and which was started by Telecom Italia Lab. JADE is open source since 2000 and it is released under the Lesser General Public License (LGPL) [34]. JADE is software platform that provides basic middleware-layer functionalities and jade implements software agent abstraction over a well-known object oriented language JAVA. Therefore MAS application flexibility has been improved by allowing the agent mobility via wired, wireless networks as indicated by the figure 3-6.

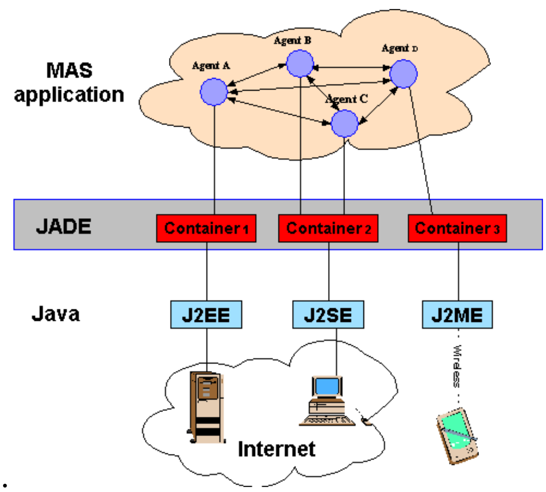


Figure 3-6: Java Agent Development Environment

3.6. JADE Architecture

Jade architecture comprises with several main components as illustrated in figure 3-7. They are;

- Agent
- Container
- Platform
- Main Container
- AMS & DF

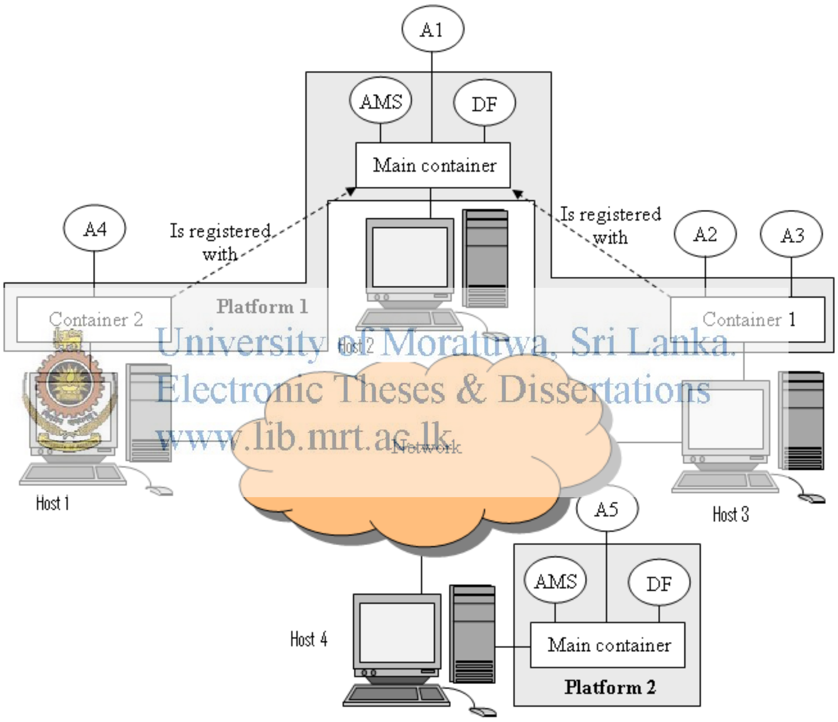


Figure 3-7: Jade Architecture [35] [36]

The agent framework; JADE essentially comprises with set of agents; which are having unique name. Agent is a software entity which executes its task while interacting with other agents exchanging messages. Agents are launched on the platform; which provides all base line infrastructures for the successful birth of agents. In a platform it contains one or more containers and main container is a special one. Containers can be launched at different host in same platform achieving the distributed ability of the platform [34]. The main container is launched at the time of first starting of the JADE platform. The main container holds important responsibilities of;

- Managing Container Table
- Managing global agent descriptor table (GADT)
- Provide assistance to the agent management system (AMS) and directory facilitator (DF) for their services.

When the main-container is launched the special agent of AMS and DF are automatically launched.

3.6.1. Agent Communication

Agents can communicate with other agents regardless of their origin or in other words the container or the platform. Communication is based on the asynchronous message passing and the message format is fully compliant with FIPA as described on 3.3.2. Asynchronous message exchange implemented in JADE is illustrated in figure 3-8.

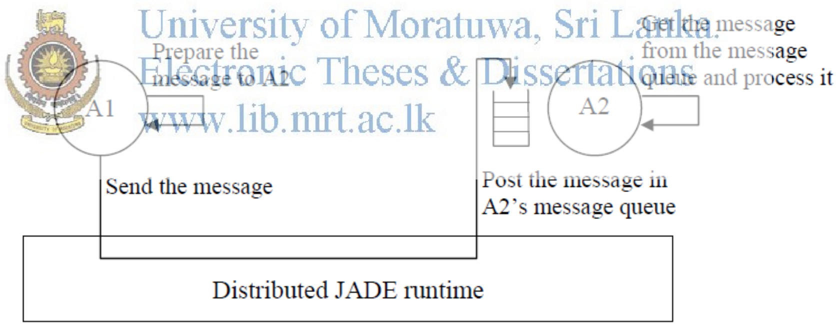


Figure 3-8: JADE Asynchronous messaging

3.6.2. Agent Behaviour

The behaviour represents the task that an agent can carry out; responding to the external events. As illustrated in figure 3-9; the behaviour scheduling is in round robin non pre-emptive manner. Therefore behaviour execution starts one after another and second behaviour starts only after first behaviour complete.

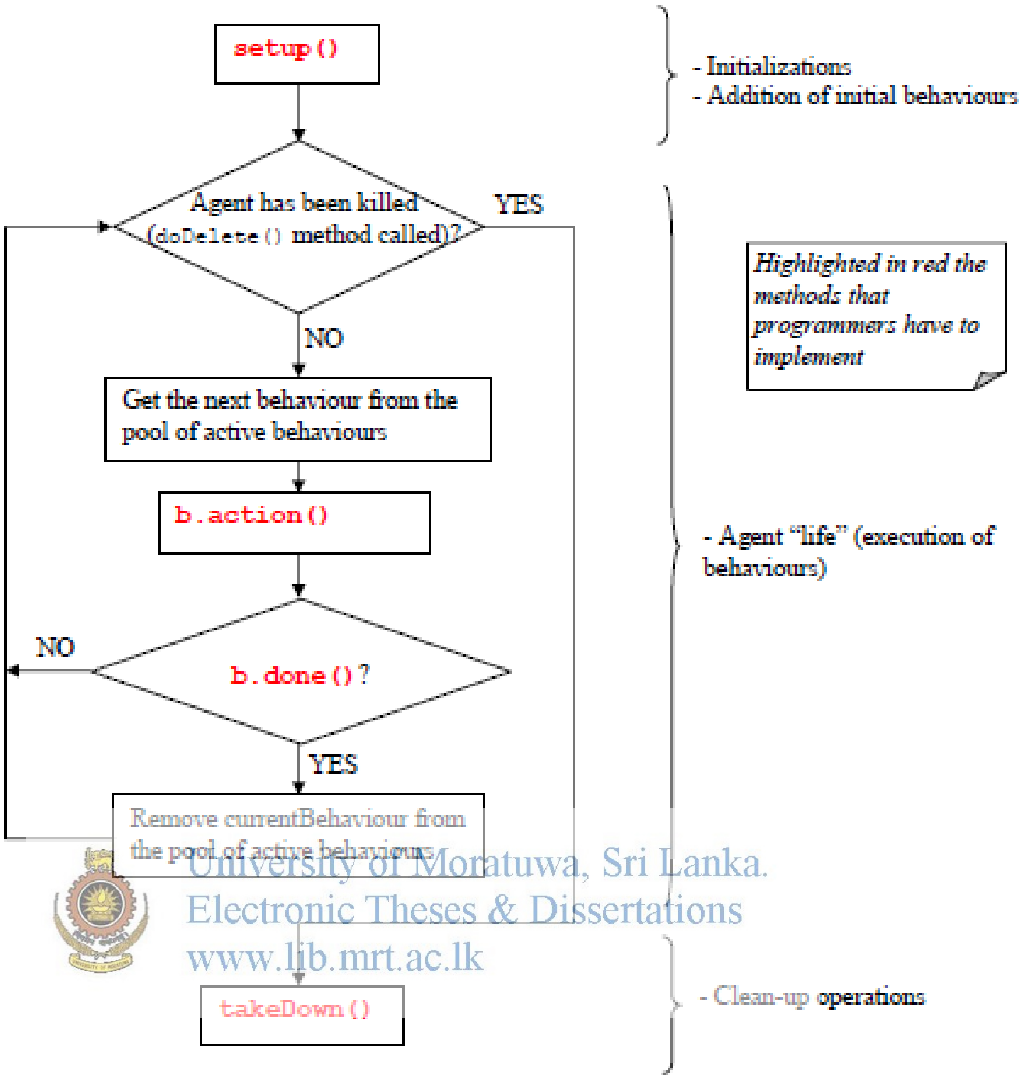


Figure 3-9: Agent Execution cycle [35]

There are exists several behaviour types and the hierarchy of the behaviour class is shown in figure 3-10. This behaviour class allows scheduling the agent tasks as well as managing the state transitions; starting, blocking and restarting.

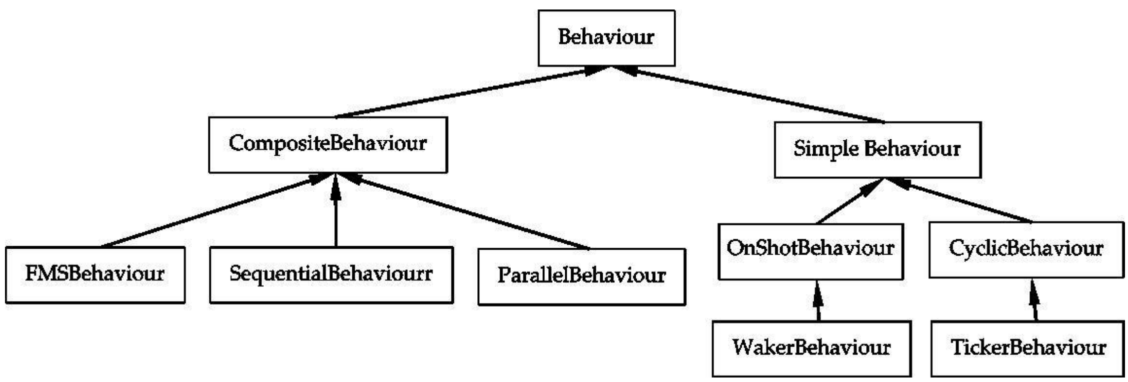


Figure 3-10: Behaviour Hierarchy

The agent behaviour can be blocked either calling block() method or it can be blocked until limited amount of time passing. A blocked behaviour can resume the execution when one of following conditions occurs;

- An ACL message received belongs to the behaviour.
- A timeout period expires.
- The restart () method call.

By having this blocking technique, it allows better agent control while scheduling the multitasking [36].

3.6.3. Interaction Protocols

FIPA specifies set of standards for the interaction protocols as described in section 3.3.2. JADE has created role of initiator (agent starting the conversation) and role of responder (agents engaging the conversation) successfully and all these roles terminated and removed from the task queue once it comes to the final state [36].

3.6.4. Yellow Pages Service

Yellow pages service allows agent to register one or more services and other agent can find successfully the services and use them as illustrated on figure 3-11. The yellow pages service in JADE is implemented using the special agent directory facilitator (DF) which is launched automatically when time of launching of agent platform. There are readily available the methods in JADE for successful agent registration, publishing services and finding services [35].

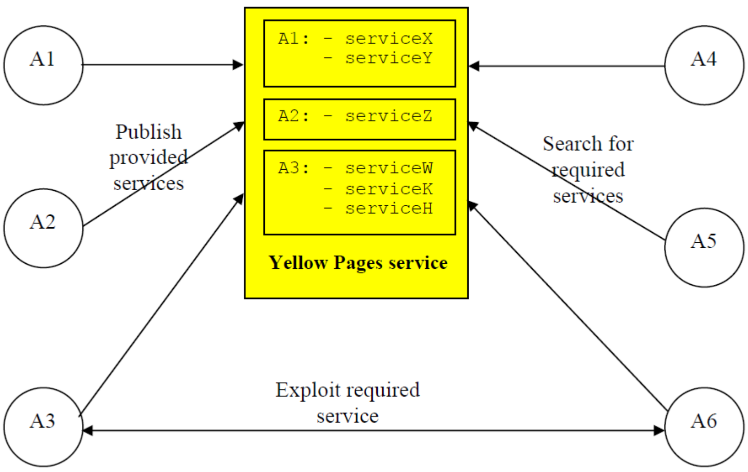


Figure 3-11: Yellow Pages Service [35]

3.7. Hardware Requirement for JADE implementation

The following subsections contain the recommended minimum hardware required to deploy JADE on a machine that hosts a JADE server.

- For 64-bit database server Intel dual core processor with 2 Ghz or faster.
- 2 Gigabytes RAM for error checking and correction, 128M bytes for each JADE node.
- Available disk space of four times the expected database size allowing to growth.
- TCP/IP network environment is required
- Data backup components (for example, a backup disk drive, tape drive, or an optical read-write drive)

.

Proposed Solution

4.1 Basic Outline of the Proposed Solution

In this research main objective is to develop multi agent system for online voltage and outage monitoring of the power distribution networks. Intelligent multi agents can be developed as software agents for the system. Online voltage monitoring is the key factor needed to be implemented to supply uninterrupted power supply to the users. Outage monitoring of the system is helped to avoid wrong data processing and real time monitoring of the required indexes such as SAIDI and SAIFI.

AMR system is used to read energy meters and record the meter data to central data base (Figure 4-1). Real time voltage of the relevant energy meter was sorted out from main data base and stored in to separate data base. The data base is very complicated, so after studying the main power distribution networks, Partial area was selected from Moratuwa North AMR meters in the system.

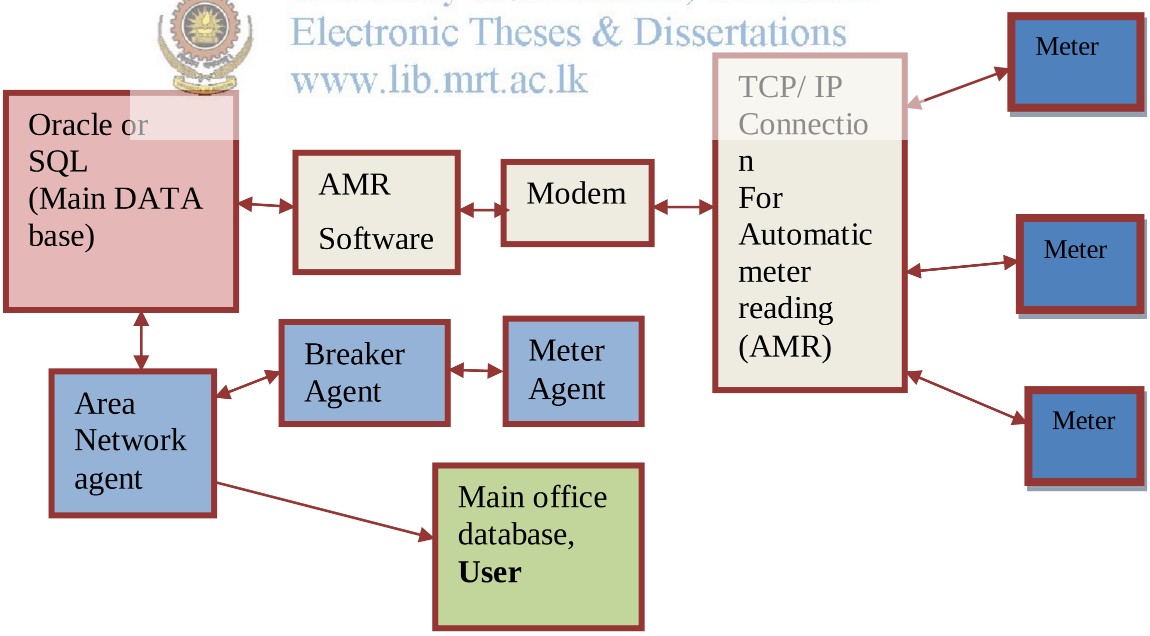


Figure 4-1 : Schematic Diagram of the whole data processing system.

4.2 Proposed Clustering method for distribution network

Power distribution network is very complicated when considering the whole network at once. This distribution network can be mainly divided base on the area network. Each area network is consisted with more primary stations (Figure 4-2). As per the power requirements of the bulk users, capacity of the primary stations is decided. It is not possible to design a one Graphical User Interface (GUI) for one area network. The GUI should be developed as user friendly environment. To implement this nature to the project, Moratuwa Area network is divided in to three main clusters such as, Moratuwa, Katubedda and Piliyandala base on the primary station.

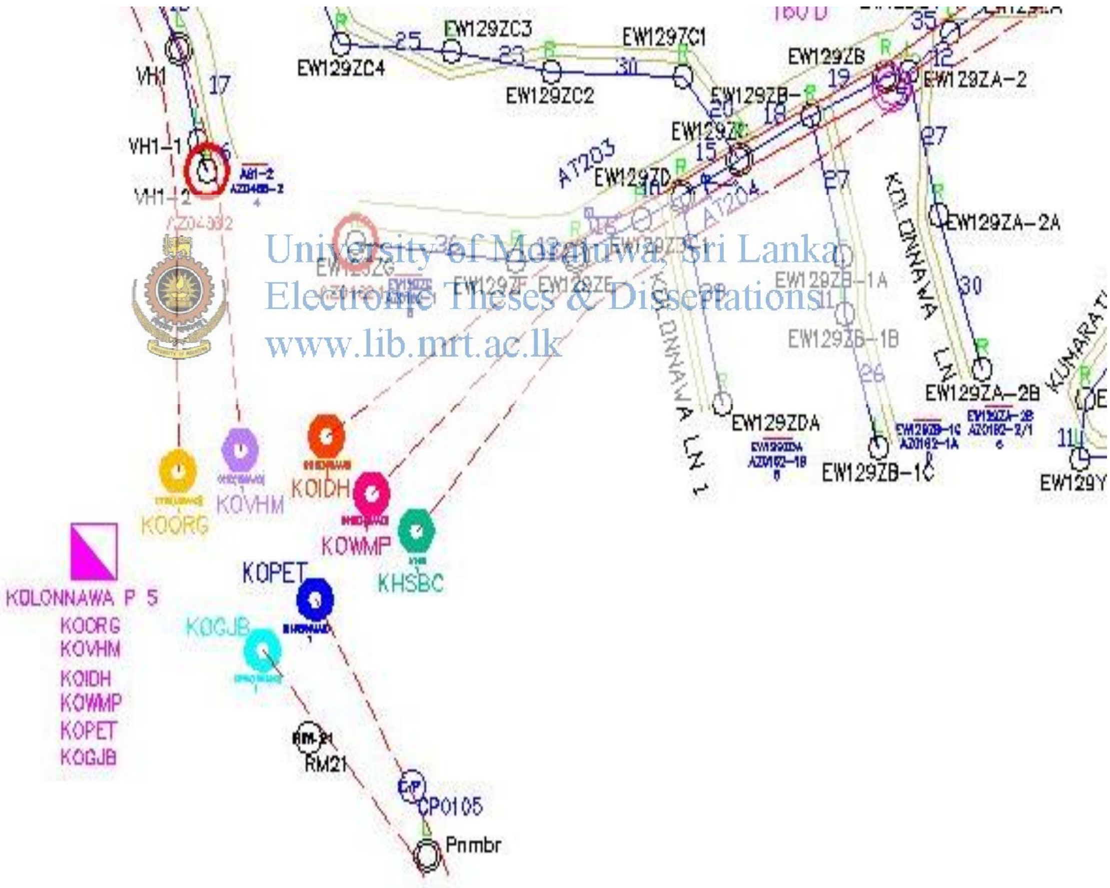


Figure 4-2: Primary Station of the Distribution Network

4.3 Proposed Agent Architecture

Several type of agent architectures were proposed in literature, The agent architectures can be divided into four main groups: logic based, reactive, BDI and layered architectures [42].

1. Logic-based (symbolic) architectures.

It draws its foundation from traditional knowledge-based systems techniques in which an environment is symbolically represented and manipulated using reasoning mechanisms. The advantage of this approach is that human knowledge is symbolic so encoding is easier, and they can be constructed to be computationally complete, which makes it easier for humans to understand the logic [42].

2. Reactive architectures

It implements decision-making as a direct mapping of situation to action and are based on a stimulus response mechanism triggered by sensor data. Unlike logic-based architectures, they do not have any central symbolic model and therefore do not utilize any complex symbolic reasoning [42].

3. BDI (Belief, desire, intention) architectures

This is probably the most popular agent architecture. They have their roots in philosophy and offer a logical theory which defines the mental attitudes of belief, desire and intention using a modal logic. Many different agent-based systems have been realized that implement BDI with a wide range of applications demonstrating the viability of the model. One of the most well-known BDI architectures is the Procedural Reasoning System (PRS) [42].

4. Layered architectures

These architectures allow both reactive and deliberative agent behaviour. To enable this flexibility, subsystems arranged as the layers of a hierarchy are utilized to accommodate both types of agent behaviour. There are two types of control flows within a layered architecture: horizontal and vertical layering [42].

In horizontal layering, the layers are directly connected to the sensory input and action output which essentially has each layer acting like an agent. The main advantage of this is the simplicity of design since if the agent needs n different types of behaviours, then the architecture only requires n layers.

In Vertical layer architecture, the sensory input and action output are each dealt with by at most one layer each The vertical layered architecture can be subdivided into one-pass and two-pass control architectures. In one-pass architectures, control flows from the initial layer that gets data from sensors to the final layer that generates action output. In two-pass architectures, data flows up the sequence of layers and control then flows back down [42].

Vertical layered two pass architecture is selected for this project considering the data flow pattern between the agents (Figure 4-3). The agent architecture is important when creating flexible and extensible multi agent systems. Agents of that can be explained as below;

a. Data base agent :
b. Meter Agent
c. Breaker Agent
d. Area Network Agent
e. Reporting Agent

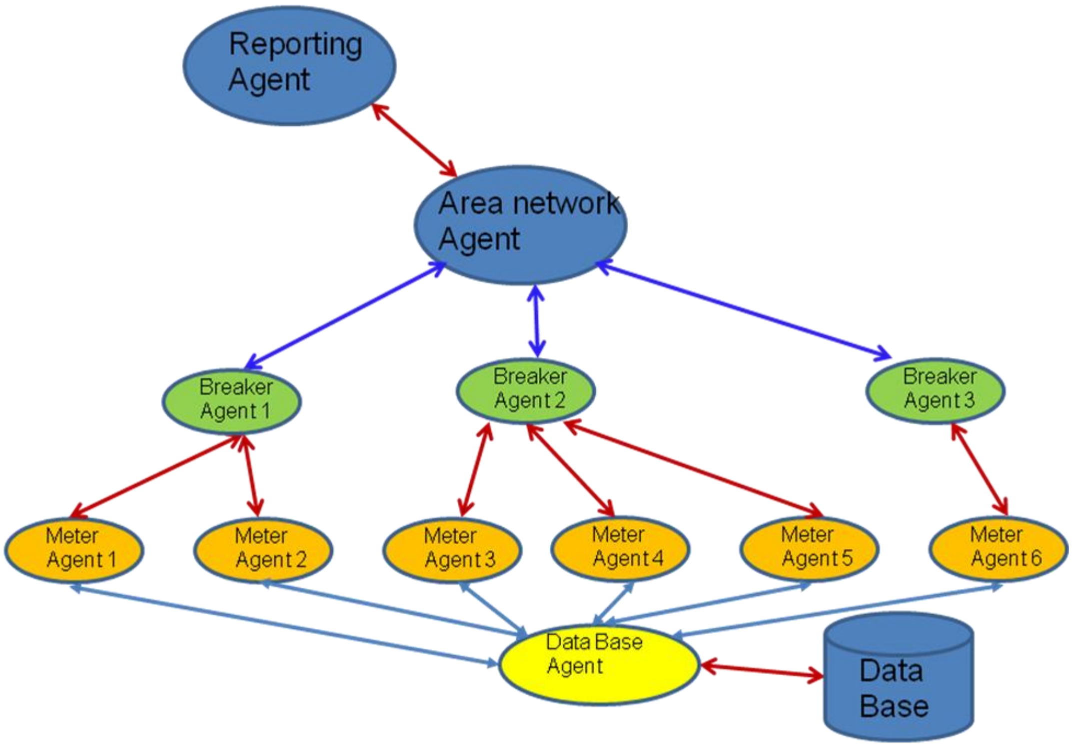


Figure 4-3: Proposed Agent Architecture

4.4 Data Base Management

XAMPP is a free open source program which can be used database management with MySQL. Open Source means, that it is possible for anyone to use and modify the software. Anybody can download the MySQL software from the Internet and use it without paying anything. it may study the source code and change it to suit as per needs. Since computers are very good at handling large amounts of data, database management systems play a central role in computing [12,[13], as standalone utilities, or as parts of other applications. The database structures are organized into physical files optimized for speed. The logical model, with objects such as databases, tables, views, rows, and columns, offers a flexible programming environment. The SQL part of “MySQL” stands for “Structured Query Language”. SQL is the most common standardized language used to access databases.

Scalability and Limits

- Support for large databases. It can be used MySQL Server with databases that contain 50 million records. It also has records that some users who use MySQL Server with 200,000 tables and about 5,000,000,000 rows[13].
- Support for up to 64 indexes per table (32 before MySQL 4.1.2). Each index may consist of 1 to 16 columns or parts of columns. The maximum index width is 767 bytes for InnoDB tables,

A database row represents a single, implicitly structured data item in a table. It is also called a record. A column is a set of data values of a particular simple type, one for each row of the table. The columns provide the structure according to which the rows are composed. A field is a single item that exists at the intersection between one row and one column

MySQL was used to develop following mentioned three tables to store required data and agent status.

a. Meter voltage table
b. Breaker status table
c. Faulty meter recording table

Chapter 5

System Implementation

There are several approaches were discussed in literature survey to develop multi agent based system to address power distribution system fault isolation and network reconfiguration. Multi agent based monitoring system is required for our distribution network to analysis data collect from AMR system.

5.1 What is an Outage?

Outage can be defined as low voltage, line outage, and Breaker failure corresponding downstream loads of the power distribution network. An outage can be caused by any type of fault event happened to the distribution network. A long –standing problem since the power distribution networks is introduced, outage detection and management has been standard. As the country becomes more electrify, the society becomes more dependent on electric power, and the economy of the country mainly depend upon the power. When the distribution outages were happened, economic loss and living standards were lost. Due to the short circuit faults in the distribution network, the outages were occurred because protective devices close to the fault will automatically isolate the faulty area. The loads downstream of the protective devices will be in outage.

5.1.1 Outage Monitoring

Monitoring of the outage area is key factor to identify the faulty area without delay. Online data acquisition system should be cooperating with this system. Using the gathered data fault location can be identified and the rectification time or restoration time can be reduced. Also essential individual failure records can be maintain for all customers and can be identified electricity pilferages. The Speed and accuracy of outage predictions can be improved while reducing wasting time of the crew and outage time. Through this monitoring, operational efficiency can be increased and crew resources utilization can be optimized. Other major thing is customer satisfaction can be rapidly increased through providing more accurate restoration time and exact fault. Improve service reliability by tracking all customers affected by an outage.

The complexity of this fault diagnosis problem arises and it is needed to deal with continuous-valued data readings, and the uncertainties of those measurements are generated by a fault. Fault localisation is trivial when a network component fails completely, since all consumers will report a total loss of service.

in practice, and there are several complicating factors that arise from these faults: (1) many types of fault cause a degradation of the quality of service received by the consumers, rather than a total failure; (2) the extent of the service degradation may vary between consumers; (3) even when there is no fault, there can be random fluctuations in the quality of service due to external effects; and (4) at any time, there can be more than one fault affecting the network. Thus, it needs a method that can cope with these uncertainties and infer a set of faults that best explains the measurement data.

5.2 System Model

It is considered a power distribution network as a tree structure. The power is supplied from the primary station, and it is drawn by all the downstream loads. It is considered an outage to be line tripping when it leads to loss of the corresponding downstream loads. An outage can be caused by any type of fault event that triggers protection devices to isolate the fault.

An important problem in outage diagnosis is to locate a faulty component in a system by analysing a set of available data from different parts of the system. Main problem is located faults in tree-structured networks. Networks with a tree topology are widely used in power distribution, where power is to be distributed from a central site to a large number of consumers. The central site forms the root of the tree, while the consumers are located at the leaves of the tree. In such a network, a fault in one component of the network may affect all consumers connected downstream from that component. By analysing measurements of the quality of service received by each consumer, it can understand the location of faults within the network.

5.2.1 Topology of the Distribution network

In tree-structured networks there is one path from each node to the root of the tree. Root, Node and connection should have identical notation method to identify the nodes individually. Then all meters of the distribution network are named as

$M_1, M_2, M_3 \ldots M_n$ (n>0), All breakers of the network are named as B_1, B_2, $B_3, \ldots B_n$ (n>0), and conetion between nodes or the root named as sectors and given the notation as $S_1, S_2 \ldots S_n$ (n>0) (Figure 5-1)

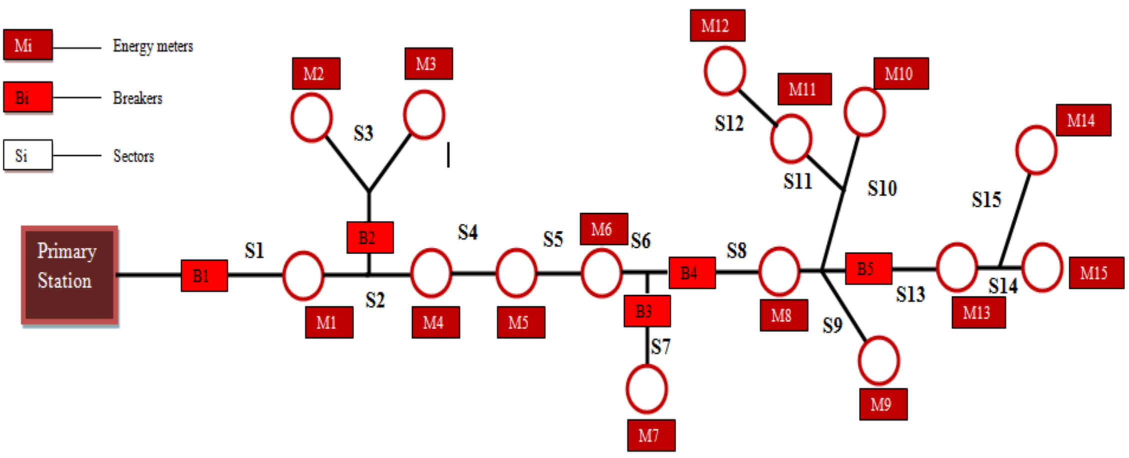


Figure 5-1 : 11kV distribution network of Moratuwa North Area(Partial diagram)

In tree-structured networks there is one path from each node to the root of the tree. Figure 5-2 shows a simple example of such a network containing eight nodes [14].

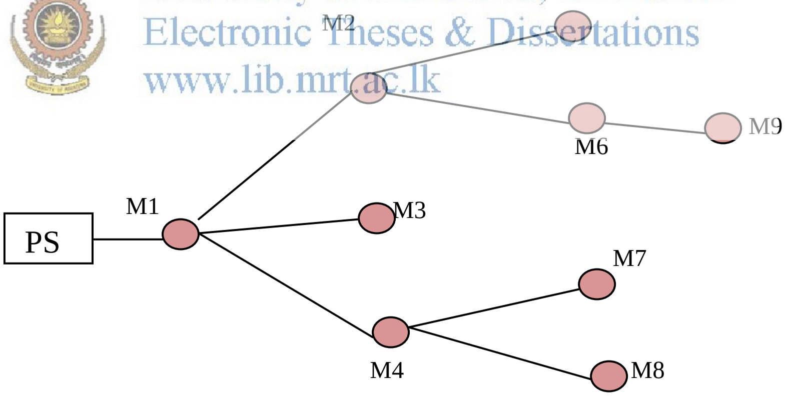


Figure 5-2 : Example of a Tree-Structured Network[12]

Consumers are attached to each of the nodes, and the distribution of power is from the PS to the leaves, e.g., from PS to nodes *M1, M2….M9*. In general, a fault can occur at any link or node in the network. However, since each node is fed by a single link, a fault in a link is indistinguishable from a fault in a node. Consequently, it can describe the fault diagnosis problem as a search for faults at nodes.

A fault at a node will not affect the distribution of power through the node to other node; actual connection of the node to the power distribution network is not series with other nodes. As an example M1 failure will not be affected to any other nodes because it is operation independent. If the failure occurs in the connection line (S1) then that will effect to all other nodes directly.

Typical Electrical Distribution Networks consist of various types of electrical components, interconnected by electrical lines. Power is input to the networks from high voltage transmission lines at *sub-stations [19]*. The power is eventually consumed, at a lower voltage, by customers or loads. When viewed in this way, an electrical distribution network forms a tree topology, with the sub-stations at the roots of the tree, and the loads at the leaves (Figure 5-3).

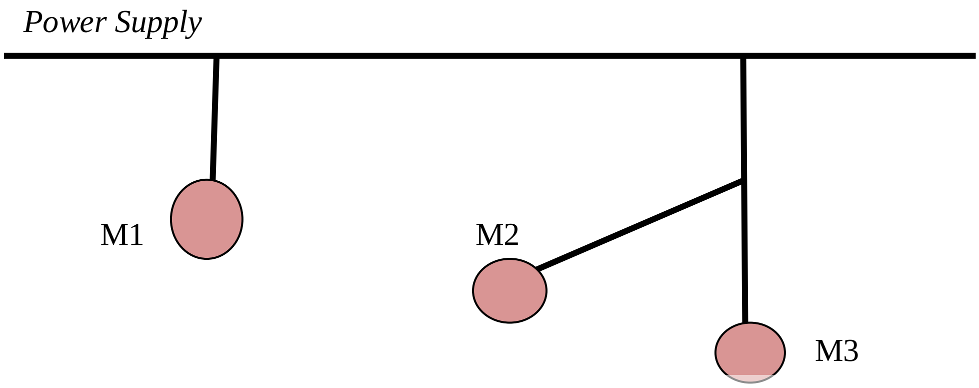


Figure 5-3 : Actual meter arrangement of the distribution network

5.3 Decoupling principle to Sub Trees

In article 11, they have introduced third party foreign sensors to the distribution network and divided the whole network in to sub trees base on the sensor installations. Sub tree categorised if the two adjacent sensors located series in the network and three sensors introduce at the "T" branch.

In the Sri Lankan Distribution network, it is not worth to install separate sensors with the MAS. Accordingly network divided in to sub trees base on the breaker installations. 'n' number of breakers(Bn) can be decouple to 'n' number of sub trees(Tn), where n =1,2,3,… n(Figure 5-4).

The condition of the adjacent next breaker to the power flow direction should be considered as meter for respective breaker.

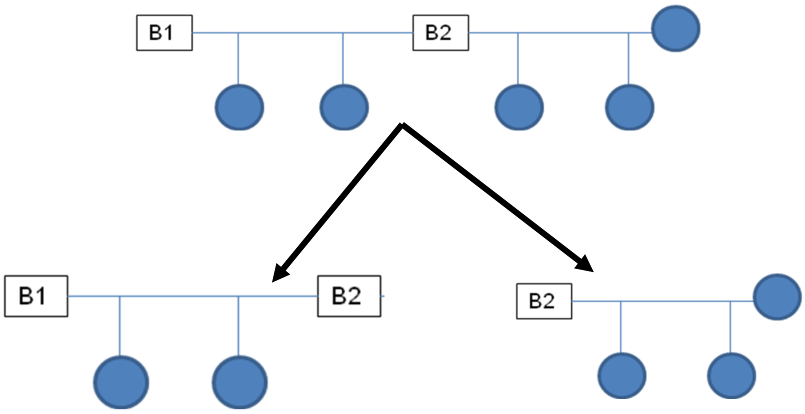


Figure 5-4: Decoupling Logic Diagram for Distribution Network

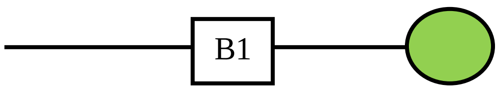
5.4 Outage Hypothesis for Distribution Network in Sri Lanka

As explain very early of this chapter outages detected as the disconnected sectors corresponding to the lines tripped by the breakers. For example, when we consider single line outages in a tree with N Meters, there exist N +1 hypotheses to consider: H_i that denotes the trip of Meter M_i [13], H_{N+1} that denotes the non-outage situation.

5.4.1 Developing Hypothesis as per the faults occur

Hypothesis development is done for selected Moratuwa North area. This development base on the meter voltage communicates through the AMR system. Accordingly Meter on status represent from “1” and Meter off status represent by “0”.

a). One Meter for Breaker

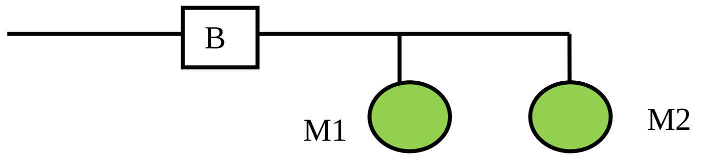


Possible outages Hypothesis are M1 in “off” condition or M1 in “on” condition. Accordingly following table is illustrated the relationship between the hypothesis and the outage.

Table 5-1: Hypothesis relations for One Breaker and One Meter

Hypothesis	Outage
H_{11} = 0	Breaker or Meter Fault
H_{12} = 1	Meter Working

b). Two Meters for One Breaker

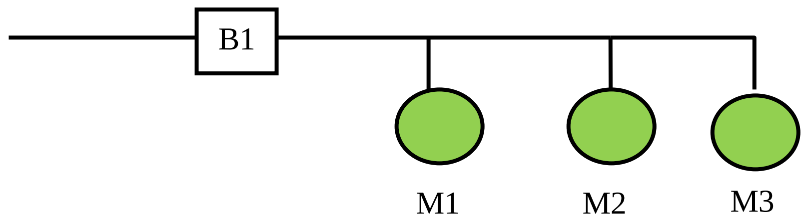


There are two meter accordingly three (03) hypothesis can be developed. That will illustrate three outages and one working condition of the meters as follows.

Table 5-2: Hypothesis relations for One Breaker and Two Meters

M1 Status	**M2 Status**	**Remarks**	**Hypothesis**
0	0	Both Meters off	H_{21} = B1 off
0	1	M2 Off	H_{22} = M1 off or M2 off
1	0	M1 off	
1	1	Both On	H_{23} = B1 on

c). Three Meters for One Breaker



There are three meters exist, based on that it can develop 04 Number of hypothesis as per the initial derivative of the hypothesis. Following table will illustrate all identified relationship between hypothesis and the outage of the system.

M1	M2	M3	Remarks
0	0	0	All Meters off
0	0	1	M3 On
0	1	0	M2 on
0	1	1	M2 and M3 on
1	0	0	M1 On
1	0	1	M1 and M3 On
1	1	0	M1 and M12 On
1	1	1	All on

Table 5-3: Hypothesis relations for One Breaker and Three Meters

Hypothesis	Outage
H_{11} = All Meters off	B1 off
H_{12} = one meter off	One Meter Fault
H_{13} = Two meters off	Two Meter Fault
H_{14} = All Meters On	B1 on

d). Four Meters for One Breaker

According to above, it can be easily simplified the hypothesis for next connection. When four meters were connected to single breaker then there are five hypotheses exist as follows.

Table 5-4: Hypothesis relations for One Breaker and Four Meters

Hypothesis	**Outage**
H_{11} = All Meters off	B1 off
H_{12} = one meter off	One Meter Fault
H_{13} = Two meters off	Two Meter Fault
H_{14} = Three meters off	Three Meter Fault
H_{15} = All Meters On	B1 on

e). "n" Meters for One Breaker

When there are "n" meters connected to single breaker. All identified hypotheses are categorised as follows.

Table 5-5: Hypothesis relations for One Breaker and "n" Meters

Hypothesis	**Outage**
H_{11} = All Meters off	B1 off
H_{12} = one meter off	One Meter Fault
H_{13} = Two meters off	Two Meter Fault
H_{14} = Three meters off	Three Meter Fault
H_{15} = Four Meters off	Four Meter Fault
… … $H_{1(n)}$	… … (n-1) meters Fault
$H_{1(n+1)}$	Breaker On

5.5 Probabilistic Model for Network

Probabilistic approach for outage diagnostic is more important when consider about the non availability of the sensors installed in the power distribution network to collect the data from the outage area. In Sri Lankan power distribution network also do not have deployed sensors, AMR system is functioning in selected area for bulk suppliers. Accordingly outages should map with this available data to minimise the down time and to have uninterrupted quality service.

Probability values of the single meter can be considered according to the number of meters connected to the breaker. All meters have equal probability for failure. Accordingly if there is one meter per breaker then probability of breaker faults if the meter fault occurs is 100%. Then if there is two meter, probability of one meter off and breaker to be off is 50%.

Accordingly,

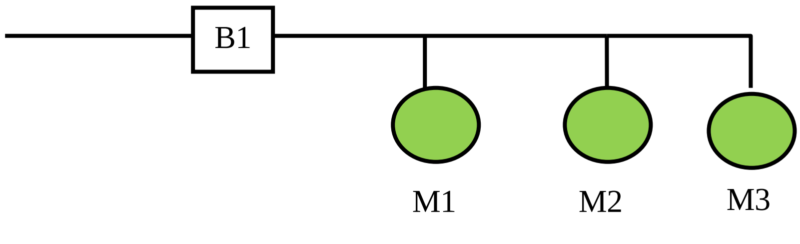
if there is "n" meters, probability of each meter is "(1/n) x 100%".

If "m" meter were fault,

then probability of that breaker to be off is {(1/n) x m x 100%}

4.5.1 Probabilistic Tree Diagram

Three Meters for One Breaker situation considered for tree diagram to implement the probabilistic values.



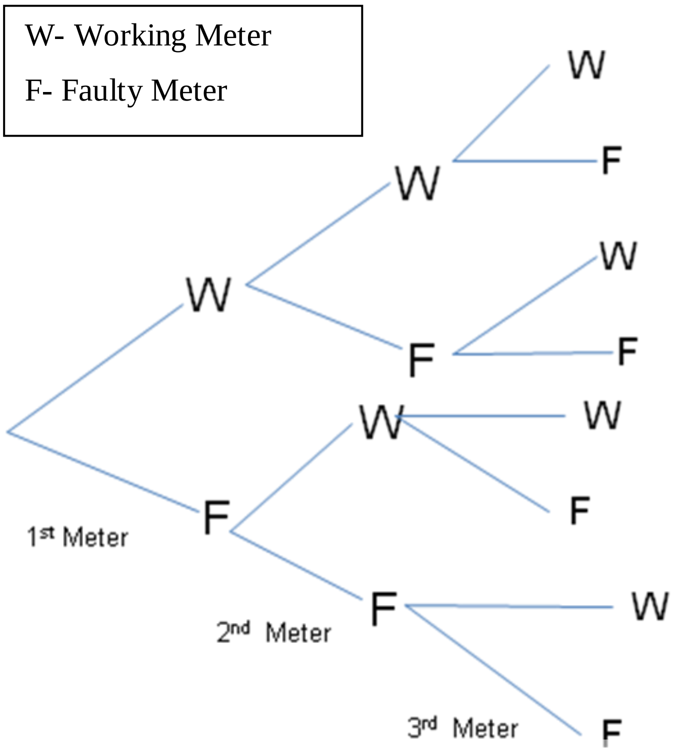


Figure 5-5: Probabilistic Tree Diagram

Based on above tree diagram, it can be concluded eight (08) probability values for different type of failure options. Here n= 3 and m=1,2,3

Table 5-6: Meter status VS Probability

Meter Status	**Probability of Breaker to be off**
WWW	(1/3) x 0 x 100% = 0%
WWF	(1/3) x 1 x 100% =33%
WFW	(1/3) x 1 x 100% =33%
WFF	(1/3) x 2 x 100% =66%
FWW	(1/3) x 1 x 100% =33%
FWF	(1/3) x 2 x 100% =66%
FFW	(1/3) x 2 x 100% =66%
FFF	(1/3) x 3 x 100% =100%

Above all probability values can be concluded for four probabilities base on the equal probability values as follows.

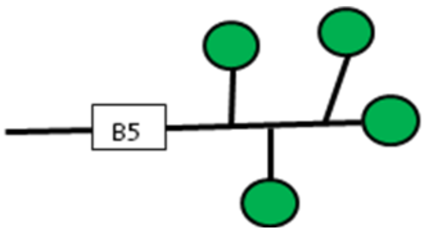
Meter Status	Probability
WWW	(1/3) x 0 x 100% = 0%
WWF , WFW, FWW	(1/3) x 1 x 100% =33%
WFF , FWF, FFW	(1/3) x 2 x 100% =66%
FFF	(1/3) x 3 x 100% =100%

These values can be directed to the defined hypothesis conditions for three meter situation with one breaker. Accordingly it can be mapped the hypothesis and the probabilistic values in to one table and can be concluded the outage scenarios based on the hypothesis conditions.

Table 5-7: Relation between Hypothesis and the probability

Hypothesis	Outage	Meter Status	Probability of breaker to be off
H_{11} = All Meters off	B1 off	FFF	100%
H_{12} = one meter off	One Meter Fault	WWF, WFW, FWW	33%
H_{13} = Two meters off	Two Meter Fault	WFF , FWF, FFW	66%
H_{14} = All Meters On	B1 on	WWW	0%

Four meter for one sub tree situation considered for more explanations.

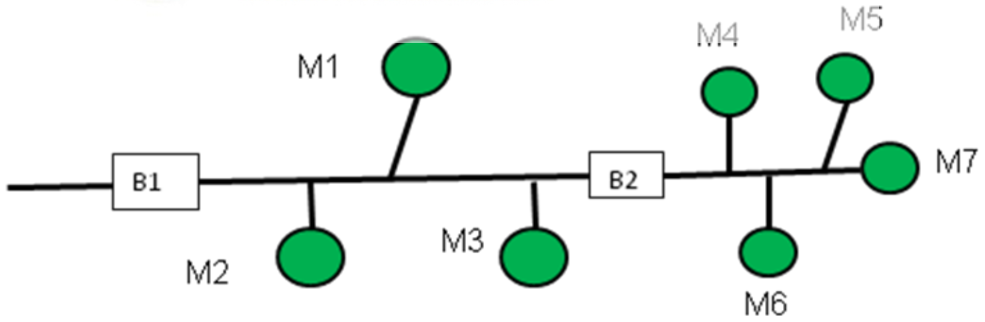


See table 5-8 for probabilistic combination related to this scenario. These all hypothesis developments are very essential, when this implemented to real distribution network. It will decide the final outage area based on this information.

Table 5-8: Hypothesis prediction for four meter sub tree

Hypothesis	Meter Status	Probability Breaker to be off	Result
H1	1110	(1/4) x 1 x100% = 25%	One meter fault
H2	1100 0011	(1/4) x 2 x100% = 50%	
H3	1000	(1/4) x 3 x100% = 75%	Breaker Off
H4	0000	(1/4) x 4 x100% = 100%	Breaker off

Two breakers consider at once



This is different scenario; it can be divided in to sub trees when faults are occurred in two sub trees separately. As an example, if only one meter fault from M1, M2 or M3 and another situation faults were happened only after the breaker B2. Then two sub trees can be considered separately for evaluation. But if random faults happen in all three meter then it have to consider one sub tree for B2 and another sub tree for B1. Following different type of fault scenarios will be illustrated the situations can be occurred. For calculation of B1 fault probability, first it needs to calculate B2 probability and then it condition consider as one another meter to the B1.

Table 5-9: Hypothesis comparison for Two Breakers

Case	**Fault**	**Hypothesis for B2 to be off (%)**	**Hypothesis for B1 to be off (%)**
01	M1=Red M4=Red	H1 = 25% (B2 On)	H1=25% (B1 On)
02	M1, M2 = Red M4 = Red	H1 = 25% (B2 On)	H2=50% (B1 On)
03	M1, M2= Red M4,M6=Red	H2 = 50% (B2 On)	H2=50% (B1 On)
04	M1, M2,M3= Red M4,M6=Red	H2 = 50% (B2 On)	H3=75% (B1 Off)
05	M1, M2,M3= Red M4,M6,M7=Red	H3 = 75% (B2 Off)	H4=100% (B1 Off)

Case 01 – Based on the probability values of the breakers, it can be decided that both breakers are on and individual faults were happened.

Case 02- As per the probabilities and hypothesis B1 breaker should be “on” and B2 breaker should be “on” individual faults were happened.

Case 03 – As per the probabilities and hypothesis B1 breaker should be “on” and B2 breaker should be “on” individual faults were happened.

Case 04 - as per probabilities B2 is on and B1 off, this cannot be existed that mean B1 breaker failure is happened and B2 breaker is in good condition.

Case 05 – B1 Breaker is off, First it needs to check the B1 in actual situation and system should restore then if there is a fault in B2 it will appear as a separate fault.

5.6 Redefine probability with SAIDI

Here it considers equal probability for all meter failures for easy reference and to present the situation properly. But when it considers about the area network topology we can consider SAIDI value for (1/n).

$$SAIDI = \frac{\text{Sum of Customer Interruption Duration}}{\text{Total No of Customers Served}}$$

Monthly SAIDI of the Network = N

Total Hour for Month = 720

Percentage of Network Failure = N/720 = p

Breaker failure Probability = $(p)^n * (1 - P)^{(1-n)}$

This can be implemented for the area networks when the SAIDI values are calculated properly.

5.7 Agent Development

As described in figure 4-3, Agent architecture was finalized. Agent architecture is consisted of five different types of agents. These agents were function as ghost agents to the system because mainly this is monitoring package for voltage and outages of the distribution network. Agent developments were considered mainly to simplify the distribution network and to introduce scalability to the system. Simplifying of the system gives easy outage monitoring and fault finding GUI for separate clusters of the system. Scalability is introduced to include new breaker or meter to the system, then, it is not needed to change whole program and while programming agent and set up communication responsibility, then it can be started the functioning.

5.7.1 Data Base Agent

Data of the relevant meters to the power distribution network is currently collecting through the AMR system. Data from the AMR system is linked to the main data base of the system and it needs to analysis these data while sort out most important data from the system. The main purpose of the development of this data base agent is managing meter data and communicates these data in to the respective meter agents.

This developed agent architecture should be applied for each clustered areas separately. Accordingly one data base agent for each cluster should be developed to manage certain meter agents. The flow chart of the Data Base agent is as follows.

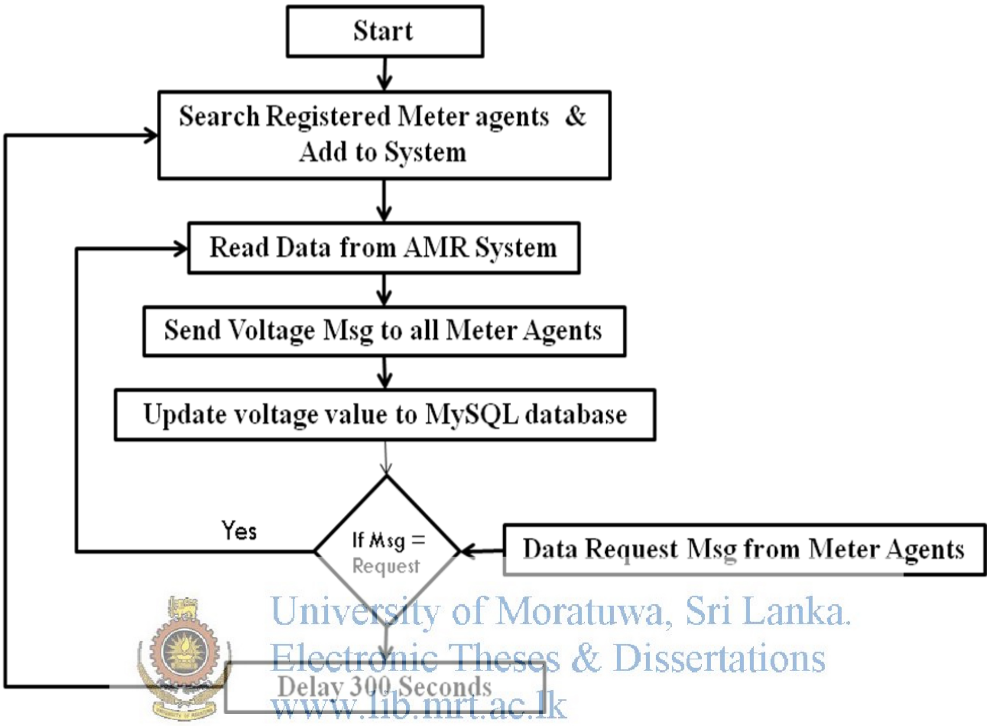


Figure 5-6: Database Agent Flow Chart

Agent programming was done base on the Net Beans Java program, development of data base agent was done . Here setting connection to the meter agent was developed and the data passing to the data base was completed to start error reporting calculations.

5.7.2 Meter Agent

Once the voltage was received from the data base agent, Meter agent has to check the with the effective (specific) voltage range (Figure 5-7). The main purpose of development of this meter agent is managed meter voltage with GUI and communicates meter status to breaker agent.

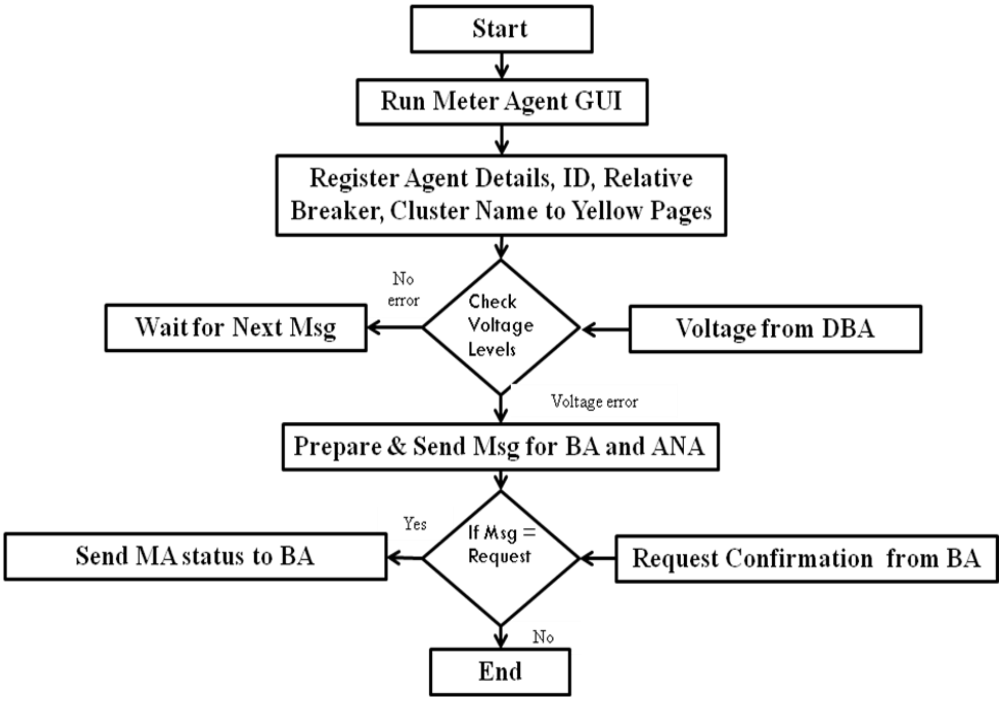


Figure 5-7: Meter Agent Flow Chart

5.7.3 Breaker Agent

Once the update from meter agent received, check the status of the meters and Check the probabilistic value relevant to that status of the meters and finally send feed back to the GUI regarding the failure (Figure 5-8).

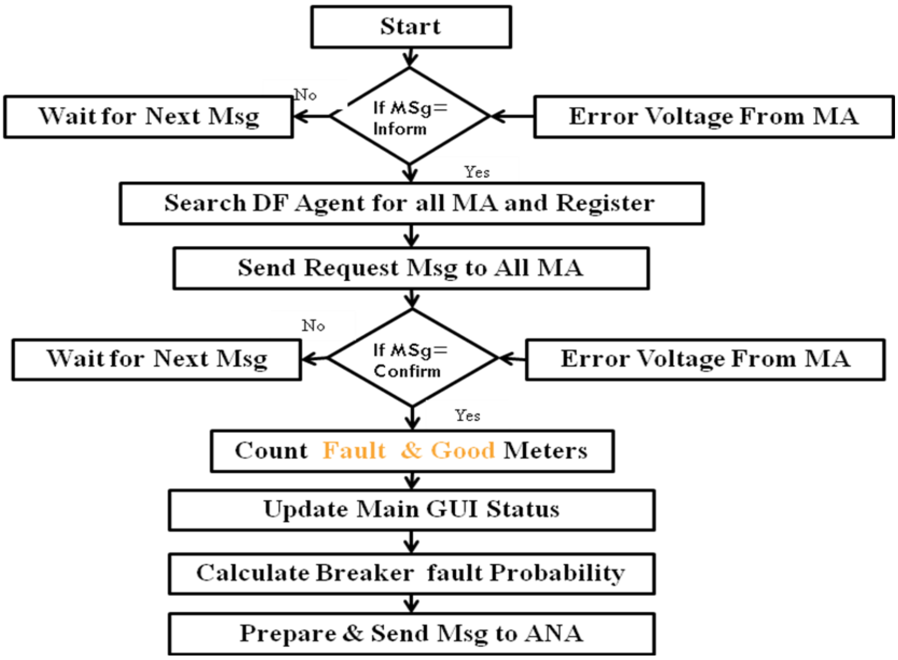


Figure 5-8: Breaker Agent Flow Chart

5.7.4 Area Network Agent

Main GUI for area network is functioned under this agent. Accordingly area clusters were performed individually to monitor the outage area. Network updates have to be carried out with this agent while faulty areas to be locate correctly.

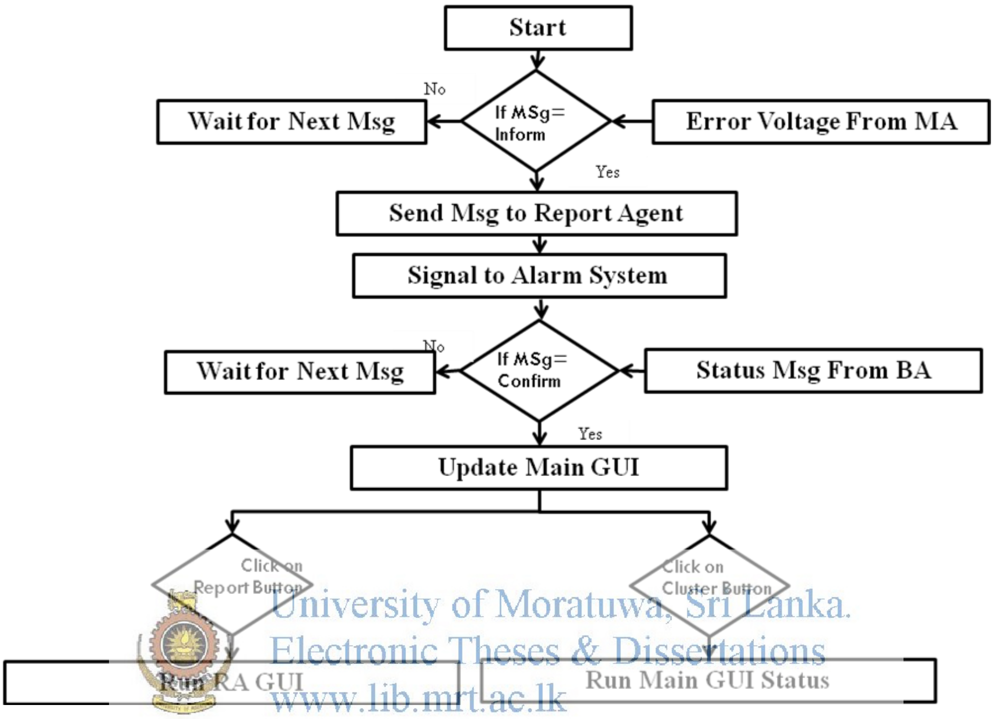


Figure 5-9: Area Network Agent Flow Chart

5.7.5 Reporting Agent

With the faulty message from the area network agent, reporting agent have to managed separate database to update all faulty meter data. It is main function is to monitor the down time and fault duration. Then it has to calculate measuring indexes for respective meters and the network.

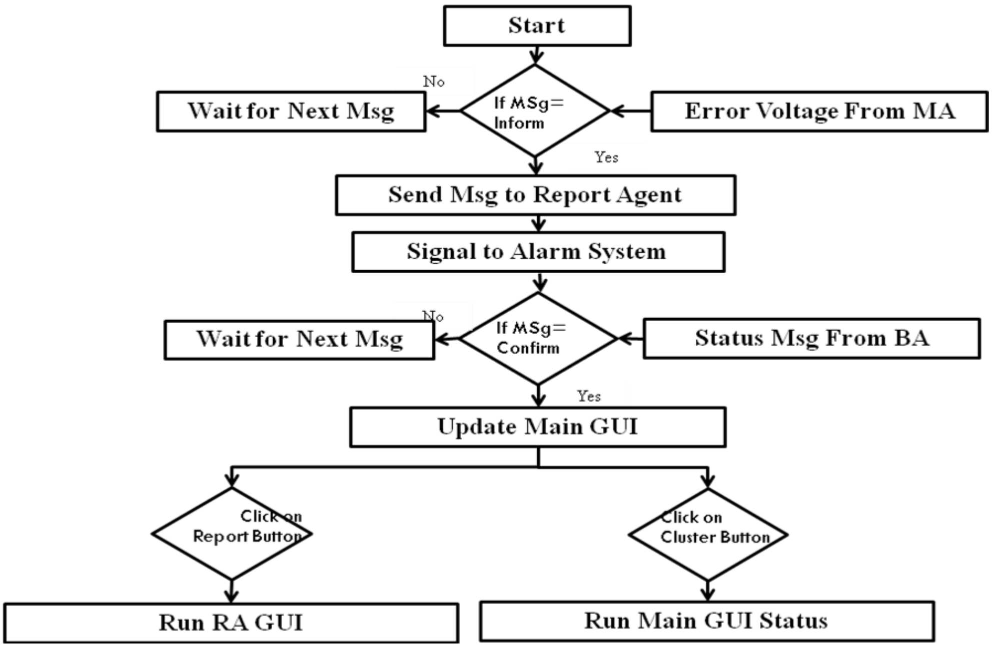


Figure 5-10: Reporting Agent Flow Chart

5.7.6 Alarming System

Once the Area Network agent received the faulty message it will send a signal to the alarm system to start buzzer. Accordingly control room operator can be easily recognized the faulty of the system (Figure 5-11).

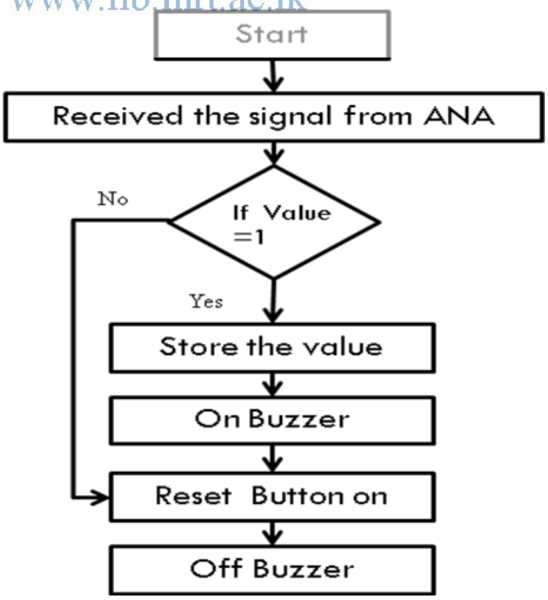


Figure 5-11: Alarm System Diagram

5.8 Multi Agent System Main Process

The whole process after the fault occurs is summarised to the flow diagram shown in figure 5-12.

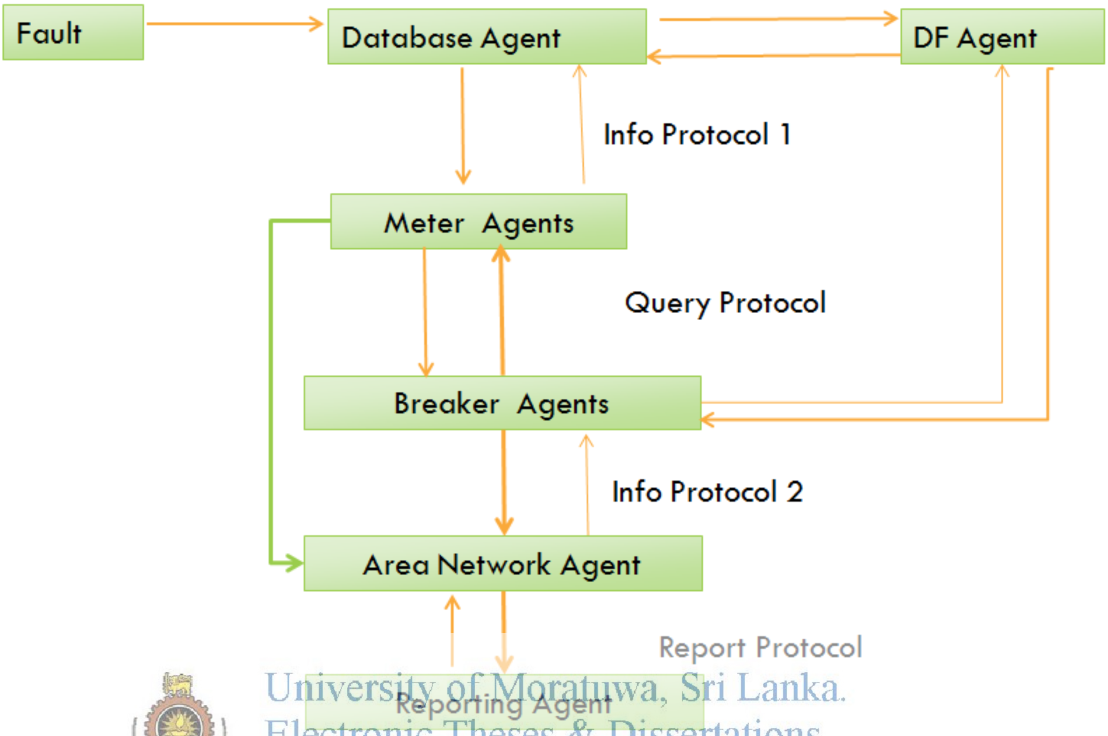


Figure 5-12: Fault Processing Diagram

Once the fault occurs in the system, data will be sent to data base through the AMR system to the Data base. Then Database Agent will start his process to through info protocol 1 to inform to all meter agents. For that he has to find out his ration agent registered with the system. The protocol; is shown in figure 5-13.

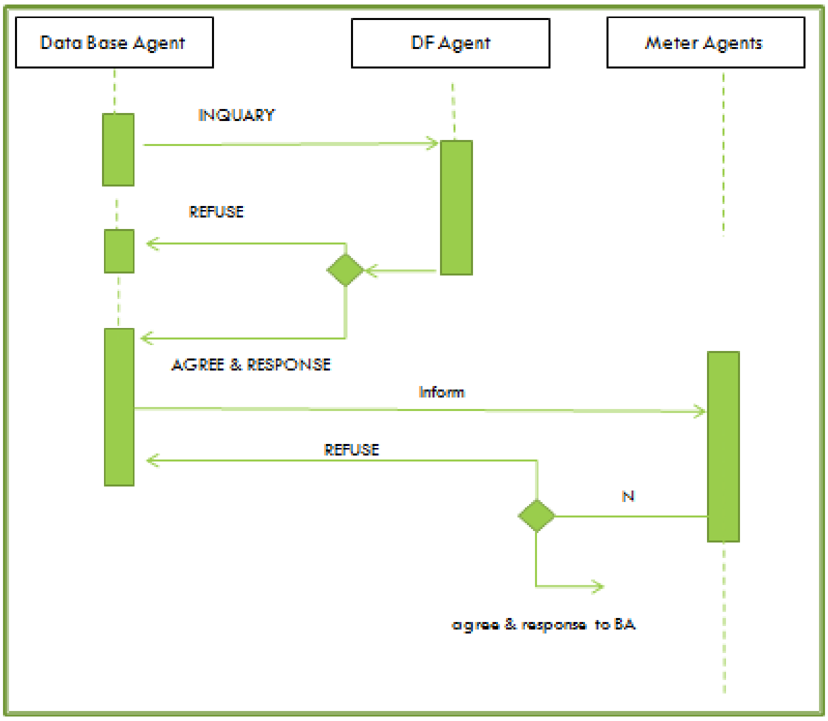


Figure 5-13: Info Protocol 1

After message was received from the Database Agent, Meter Agent checks his current status by comparing the voltage value and if it is faulty, it would informed to the respective Breaker Agent. This communication is handled through the Info Protocol 2 (figure 5-14).

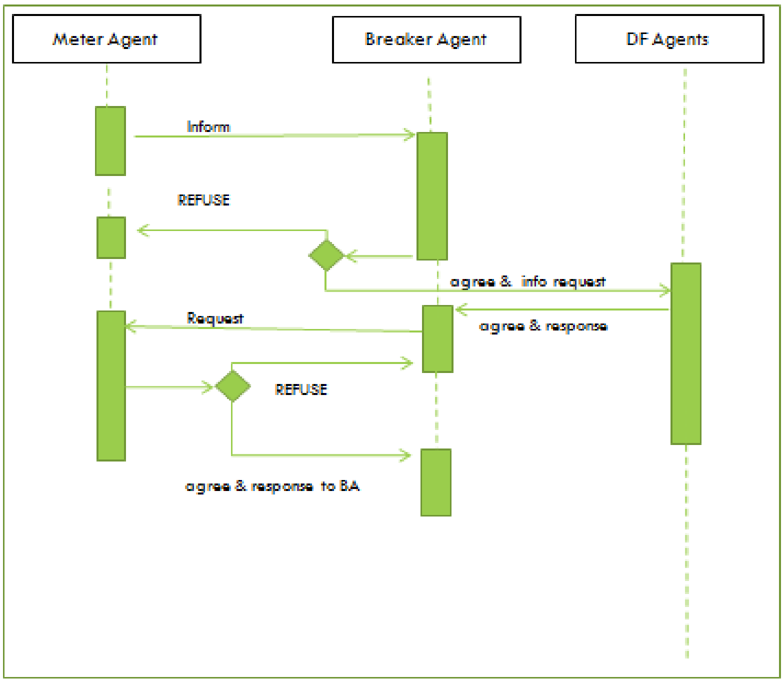


Figure 5-14: Info Protocol 2

If the Breaker Agent needs any voltage confirmation from the Meter Agent he will query it through protocol shown in figure 5-15.

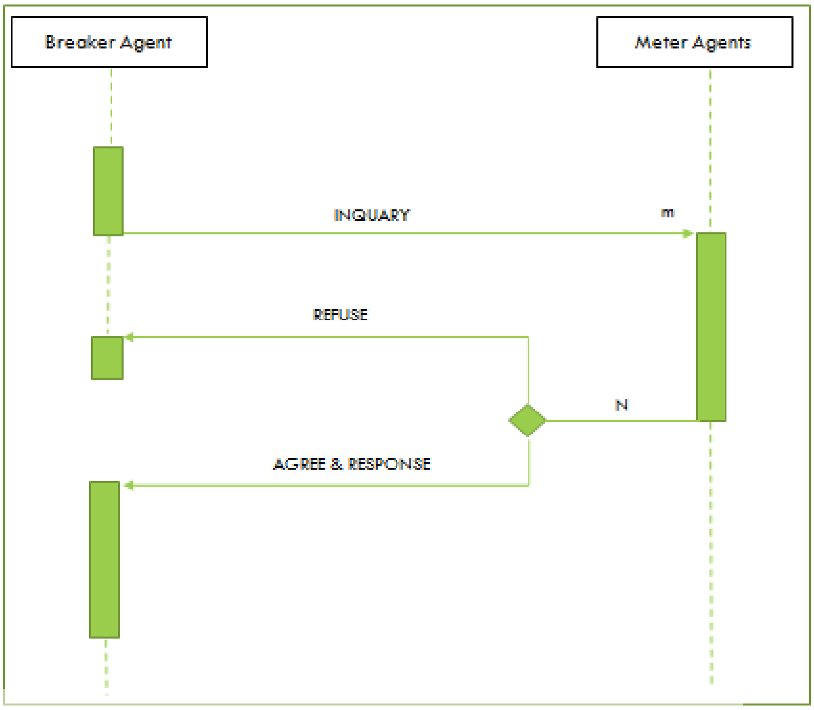


Figure 5-15:Query Protocol

Breaker Agent will calculate the probabilistic value for failure and sent it to the Area network Agent and then he will inform Report agent to start monitoring of failure time duration. This will be done through the report protocol shown in figure 5-16.

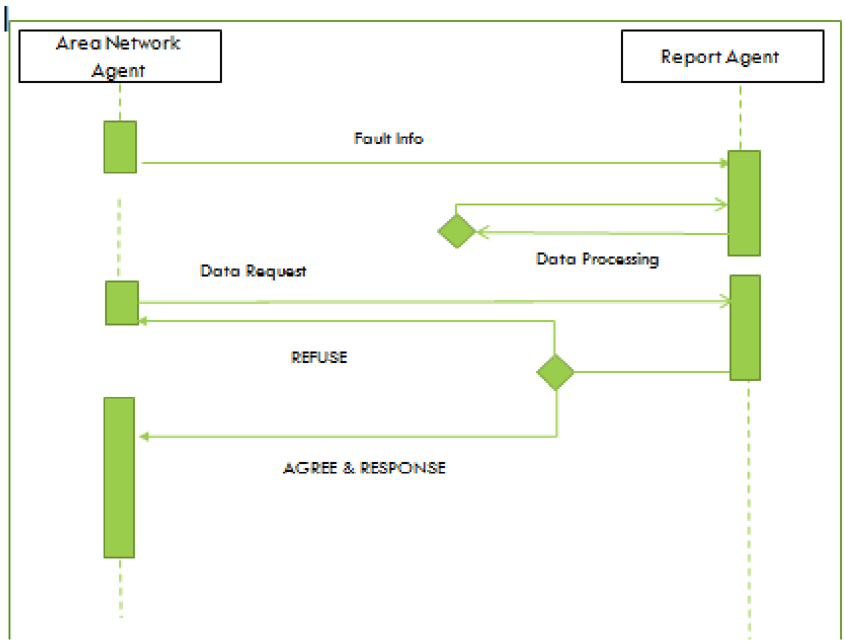


Figure 5-16: Report Protocol

5.9 Data Base Management

The XAMPP use as a free open source application to combined with Microsoft windows as a web server. This is used to handle MySQL data base components. MySQL is the world's most popular open source database. It is a Relational Database Management System (RDBMS) - data and its relationships are stored in the form of tables that can be accessed by the use of MySQL queries in almost any format that the user wants. As a initiation step it needs to start the Apache server to run these programmes (Figure 5-17)

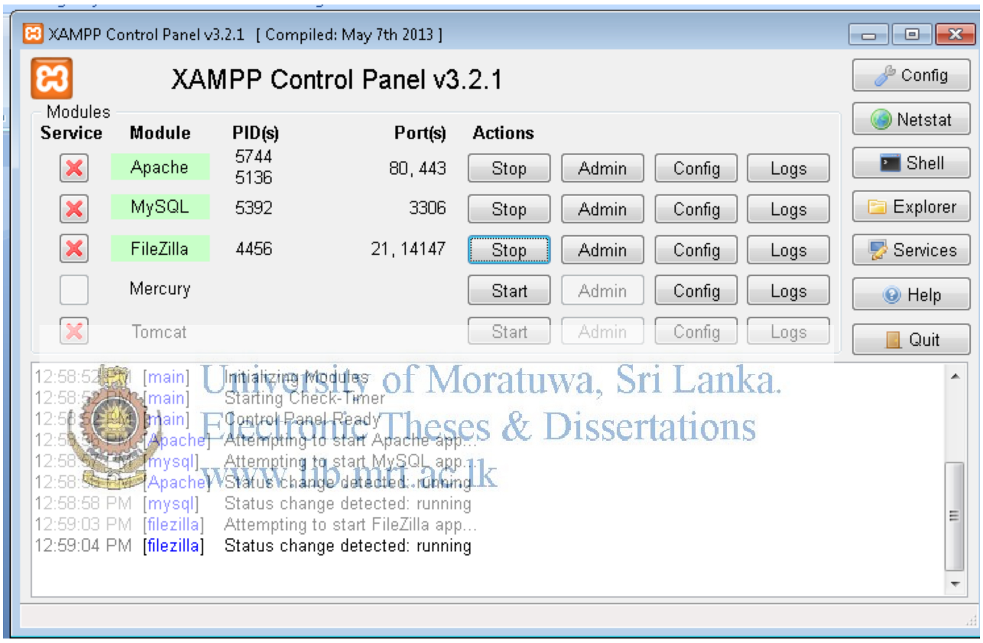


Figure 5-17: XAMPP Control Panel

a). Meter Voltage Table

Develop a database to keep current record of the meter voltage (Figure 5-18). This was developed mainly to maintain separate voltage table from all other data focusing on voltage monitoring of individual bulk customers. Based on this data voltage value plotting, recoding voltage fluctuations and getting feed back to voltage error table was done.

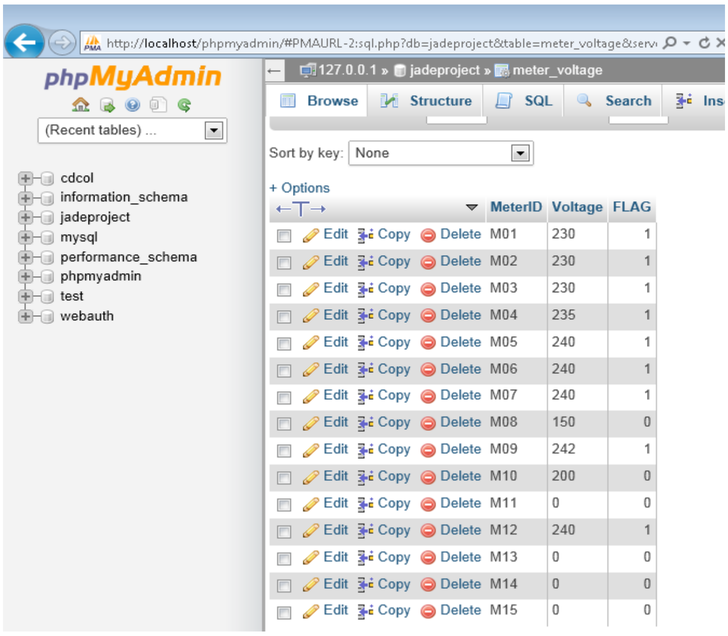


Figure 5-18: Voltage Table

b). Breaker Status table

Main purpose of this data table is to maintain current status of the breakers to keep last record of breaker status of area network. Without this data it cannot update next status of the breaker to GUI(Figure 5-19).

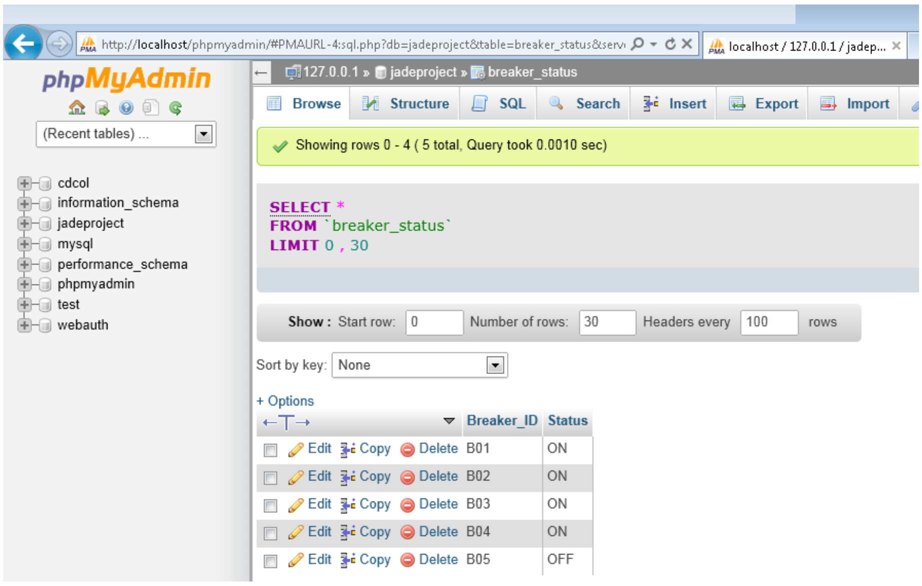
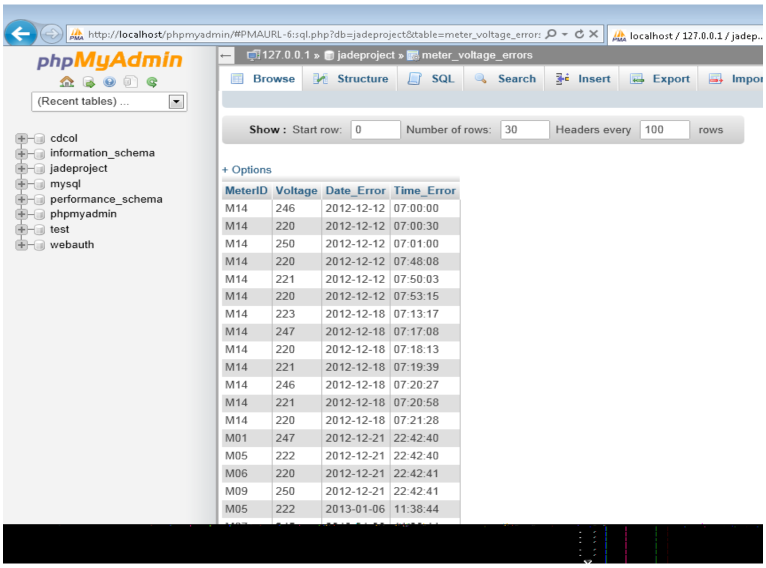


Figure 5-19: Breaker Status Table

c).Faulty meter recording table

Meter fault data should be recorded separately to calculate the SAIDI, SAIFI values for relevant network. Based on that Meter number, date and time of the failure and the duration of fault has to monitored (Figure 5-20).



MeterID	Voltage	Date_Error	Time_Error
M14	246	2012-12-12	07:00:00
M14	220	2012-12-12	07:00:30
M14	250	2012-12-12	07:01:00
M14	220	2012-12-12	07:48:08
M14	221	2012-12-12	07:50:03
M14	220	2012-12-12	07:53:15
M14	223	2012-12-18	07:13:17
M14	247	2012-12-18	07:17:08
M14	220	2012-12-18	07:18:13
M14	221	2012-12-18	07:19:39
M14	246	2012-12-18	07:20:27
M14	221	2012-12-18	07:20:58
M14	220	2012-12-18	07:21:28
M01	247	2012-12-21	22:42:40
M05	222	2012-12-21	22:42:40
M06	220	2012-12-21	22:42:41
M09	250	2012-12-21	22:42:41
M05	222	2013-01-06	11:38:44

Figure 5-20: Meter fault data Table

5.9 System Model Implementation

It is very important to validate the system running condition for selected area. Accordingly demonstration model was constructed to collect voltage values and individual meter failures from the system.

5.9.1 Features of the demonstration Board

Maharagama area network was selected to develop the demonstration board (Figure 5-21). Following key components use for development.

a). Toggle Switch

1. To represent the individual meter fault
2. To represent breaker on, off conditions

b). Potentiometer

To fluctuate the voltage

c). LED Bulb

To represent the individual meter working conditions.

d). Data Acquisition

Use Arduino Mega 2560 board, to communicate real time data through USB port to computer. Use “PLX-DAQ” software to upload data to data base.

Figure 5-21: Demonstration Board

5.9.2 Communication to Computer

Arduino is a tool for making computers that can sense and control more of the physical world. It's an open source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. Arduino can be used to develop interactive objects, taking inputs from a variety of switches or sensors, and controlling a variety of lights, motors, and other physical outputs. Arduino projects can be stand alone, or they can be communicated with software running on computer [18].

a). Features

- Schematic design of the open source development interface free download, and also according to the needs of their own changes
- Download the program is simple and convenient.
- Simply with the sensor, a wide range of electronic components connection (such as: LED light, buzzer, keypad, photo resistor, etc.), make all sorts of interesting things.

- The development of language and development environment is very simple, easy to understand, very suitable for beginners to learn.

b). Performances of Board

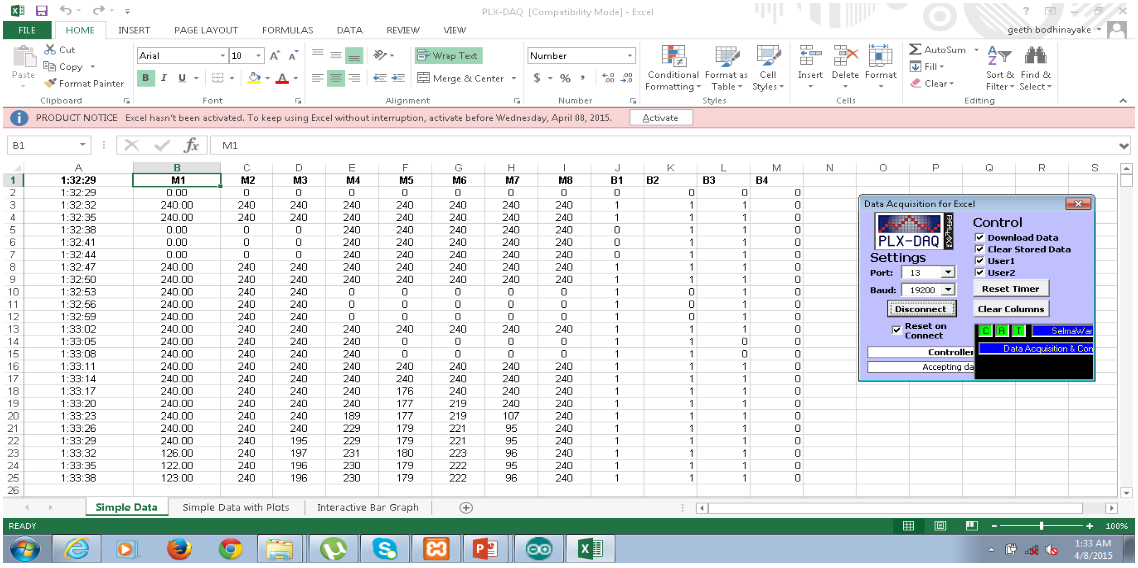
- Digital I/O 0~13.
- Analog I/O 0~5.(R3 is 0~7)
- Support ISP download function
- Input voltage: when connected to the USB without external power supply or external 5 v
- output and external power input.
- Atmel Atmega328 micro processing controller.
- Arduino size: width of 70 mm X high 54 mm

c). Data Acquisition from ARDUINO board

Use PLX-DAQ software to download data from Arduino board to data base.

Following features are available(Figure 5-22)

- Plot or graph data as it arrives in real-time
- Record up to 26 columns of data
- Mark data with real-time (hh:mm:ss) or seconds since reset
- Read/Write any cell on a worksheet
- Read/Set any of 4 checkboxes on control the interface
- Example code for the BS2, SX (SX/B) and Propeller available
- Baud rates up to 128K



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1:32:29	M1	M2	M3	M4	M5	M6	M7	M8	B1	B2	B3	B4
2	1:32:29	0.00	0	0	0	0	0	0	0	0	0	0	0
3	1:32:32	240.00	240	240	240	240	240	240	240	1	1	1	0
4	1:32:35	240.00	240	240	240	240	240	240	240	1	1	1	0
5	1:32:38	0.00	0	0	240	240	240	240	240	0	1	1	0
6	1:32:41	0.00	0	0	240	240	240	240	240	0	1	1	0
7	1:32:44	0.00	0	0	240	240	240	240	240	0	1	1	0
8	1:32:47	240.00	240	240	240	240	240	240	240	1	1	1	0
9	1:32:50	240.00	240	240	240	240	240	240	240	1	1	1	0
10	1:32:53	240.00	240	240	0	0	0	0	0	1	0	1	0
11	1:32:56	240.00	240	240	0	0	0	0	0	1	0	1	0
12	1:32:59	240.00	240	240	0	0	0	0	0	1	0	1	0
13	1:33:02	240.00	240	240	240	240	240	240	240	1	1	1	0
14	1:33:05	240.00	240	240	240	0	0	0	0	1	1	0	0
15	1:33:08	240.00	240	240	240	0	0	0	0	1	1	0	0
16	1:33:11	240.00	240	240	240	240	240	240	240	1	1	1	0
17	1:33:14	240.00	240	240	240	240	240	240	240	1	1	1	0
18	1:33:17	240.00	240	240	240	176	240	240	240	1	1	1	0
19	1:33:20	240.00	240	240	240	177	219	240	240	1	1	1	0
20	1:33:23	240.00	240	240	189	177	219	107	240	1	1	1	0
21	1:33:26	240.00	240	240	229	179	221	95	240	1	1	1	0
22	1:33:29	240.00	240	195	229	179	221	95	240	1	1	1	0
23	1:33:32	126.00	240	197	231	180	223	96	240	1	1	1	0
24	1:33:35	122.00	240	196	230	179	222	95	240	1	1	1	0
25	1:33:38	123.00	240	196	230	179	222	96	240	1	1	1	0

Figure 5-22: Data Acquisition table for Database

5.9.3 Synchronize model with system

Developed model was synchronised to computer database and then it configure to the agent system to run the GUIs (Figure 5-23). See figure 4-15 for model implementation.

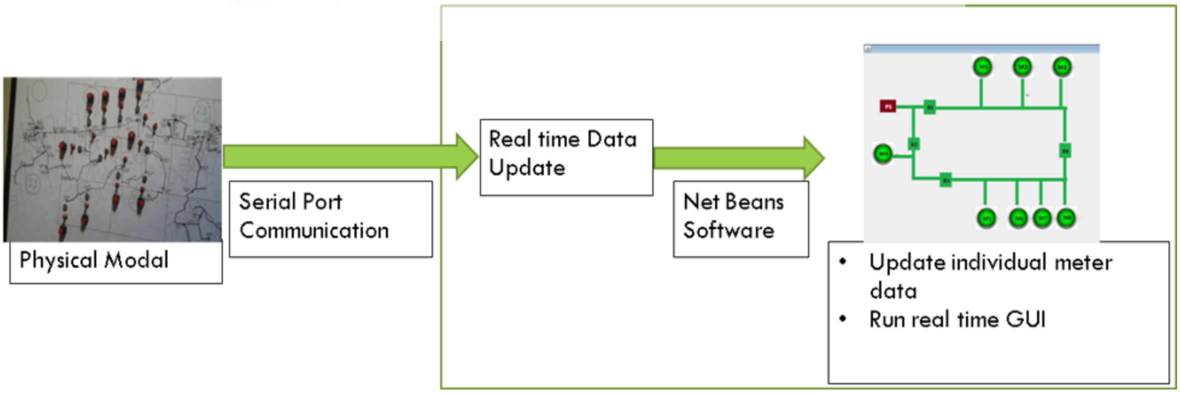


Figure 5-23: Synchronize Physical model and Agent System

Chapter 6

Results and Discussion

Using the hardware and software mentioned above, several experimental test runs were conducted to verify the system performances as well as to identify the improvement points. Two type of validation method were considered. One system was considered with the automated random value generation and other system was considered with design physical model and synchronizes with the agent system.

6.1 Agent Communication and Data Management

Meter voltage and current readings were updated to the relevant agents and the data base for meter agents, breaker agents and reporting agent were updated instantly when data received. This data were received related to the AMR system as explained in above chapters. Function of the data base agent can be validated through both methods of data receiving. Especially through the physical model, it can be proved that one the potentiometers change the real value of the meter agent change accordingly.

Meter Agents were registered in yellow pages with their duties(Figure 6-1) and Agent communication was established to have proper data processing system.(Figure 6-2)

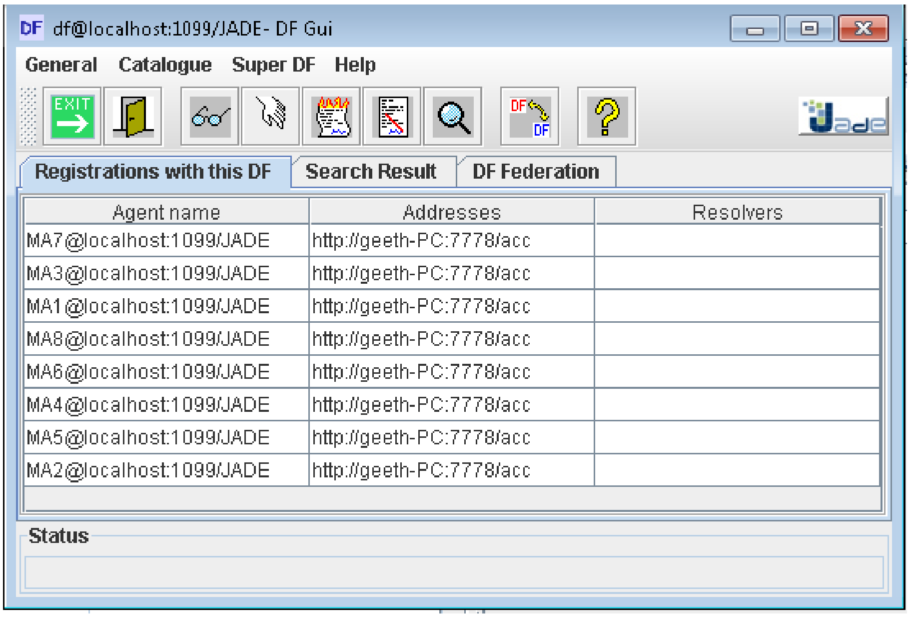


Figure 6-1: Meter Agent Register in Yellow pages

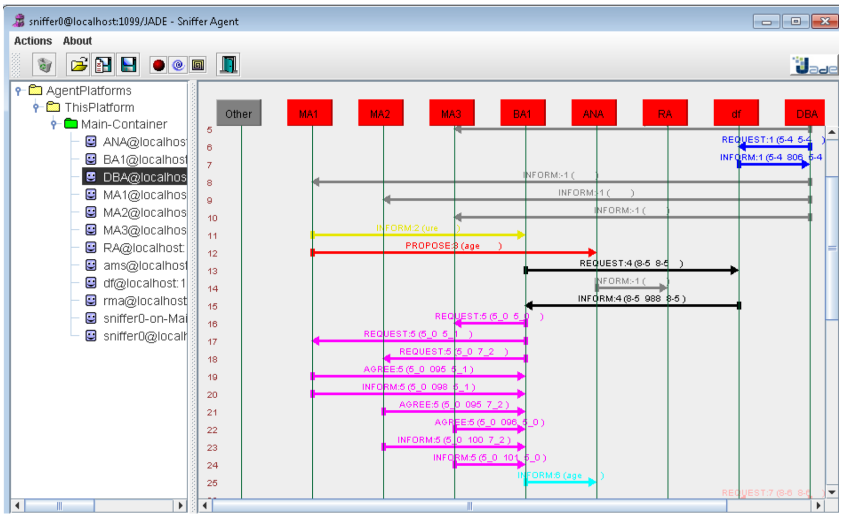


Figure 6-2: Agent Communication

6.2 Flexibility of the Multi Agents

a). Adding new meter to the system.

This is very important advantage. When a multi agent system was introduced, a new meter it only needed to register in yellow pages and then all other communications will be setup automatically with the multi agent system. Monitoring GUI and the Report GUI should be manually changed and added physical meter to the GUI. All other communications is shown in figure 6-3.

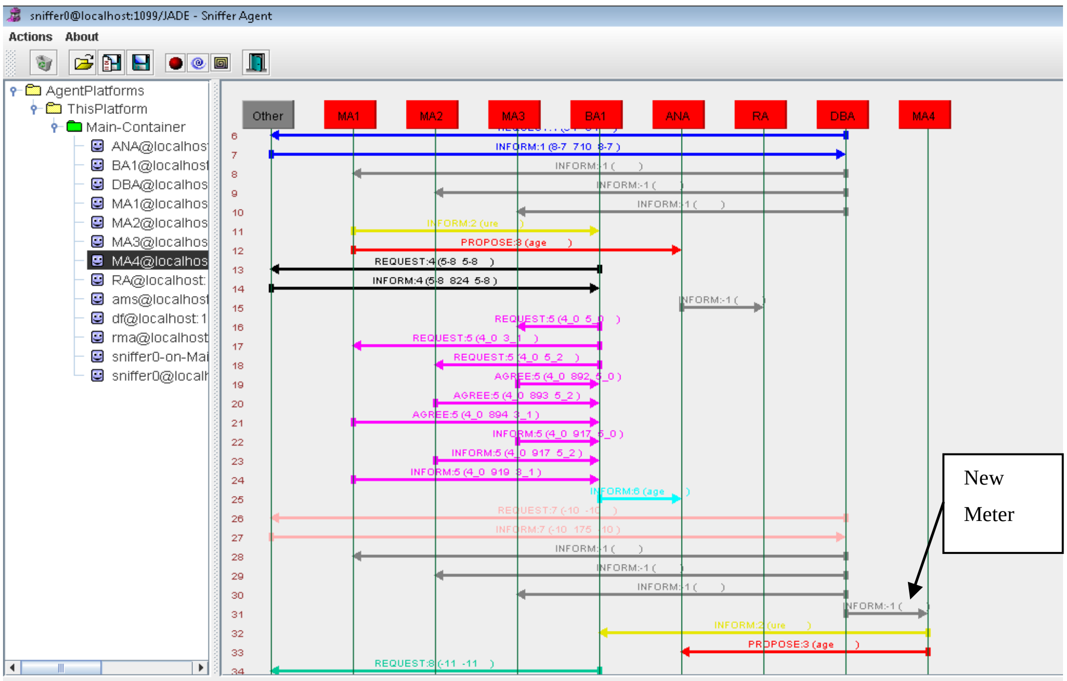


Figure 6-3: New Meter Agent communication

b). Change meter properties

It is possible to change the meter properties with the system. As an example in figure 6-4, first MA2 connect to the BA1 and having communicated changed his breaker to BA2. Accordingly MA2 is started the communication with BA2 and proceed the decision making process.

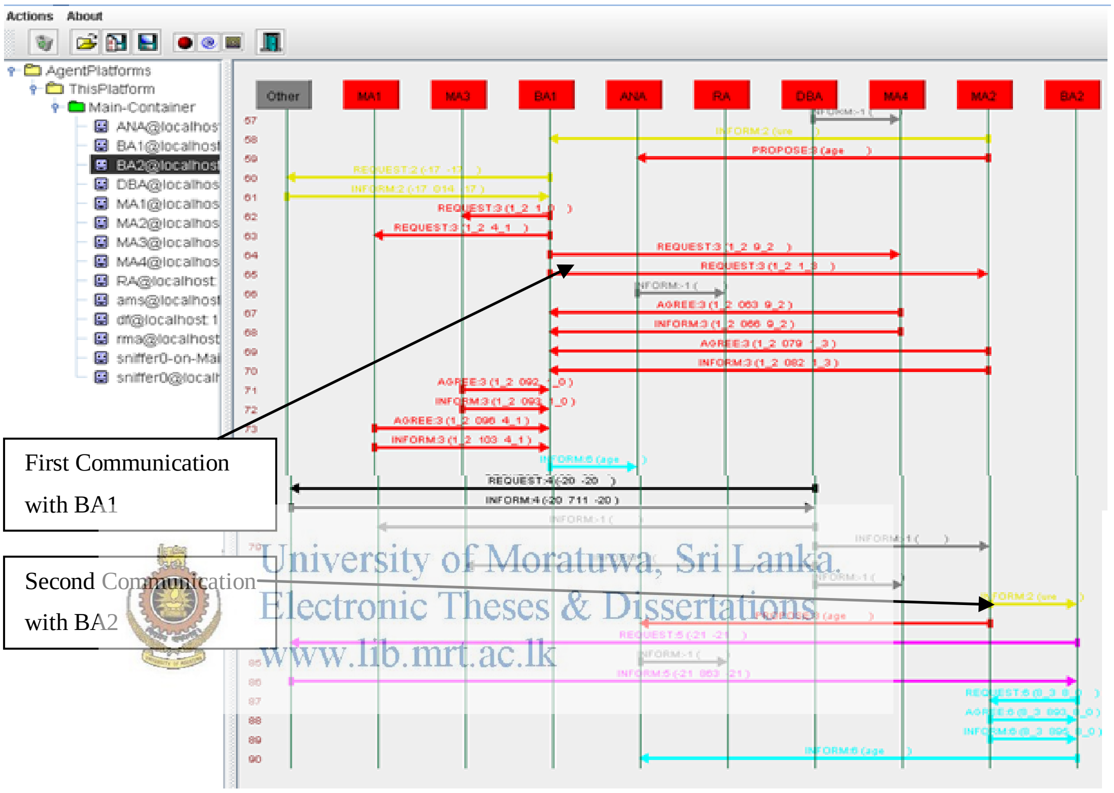


Figure 6-4: Meter Agent Property change

6.3 Remote Monitoring Interface

There were few interfaces developed to monitor the voltage and the outages of the distribution network. These interfaces run with real time data of the physical model and outages can be monitored through the GUI.

a). GUI for Clustered Area network

This GUI is essential to simplify the whole area network into small areas and monitor the important part of the distribution network (Figure 6-5)

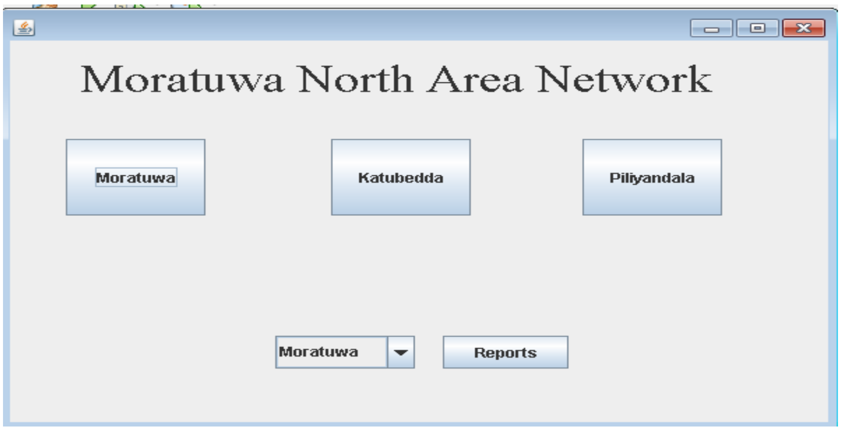


Figure 6-5: GUI for Area Network

According to the faulty area system control monitoring person can popup the required cluster by just clicking on the respective button. Major advantage of this is that it can be flexibly modified to any other area easily. One area office will get this GUI with all clusters were represented into buttons.

b). GUI for Clustered Area

Individual GUIs are designed for each and every cluster. Moratuwa GUI(Figure 6-6) is run with the automatically generated data and the GUI for Katubedda (Figure 6-7) area is run with the physical system model.

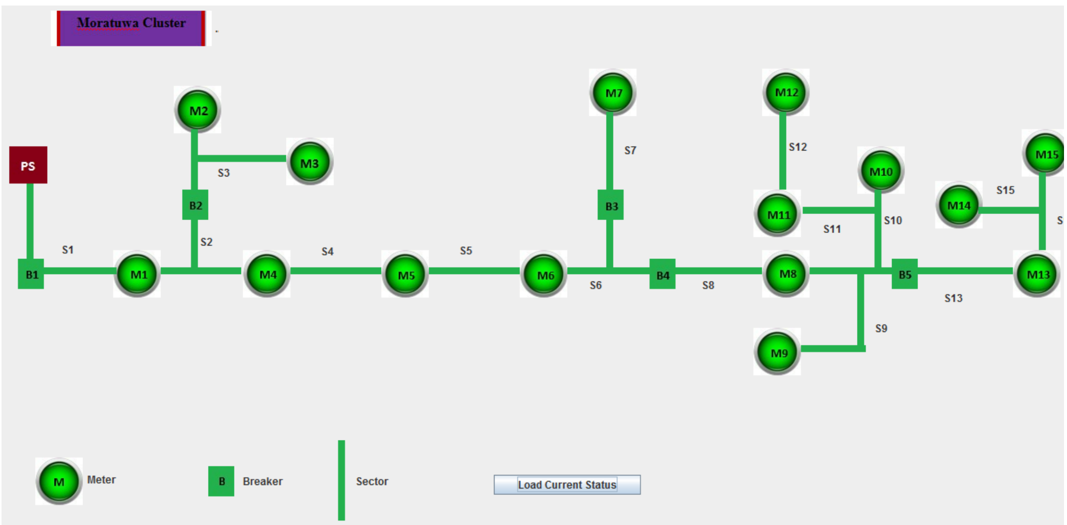


Figure 6-6: GUI for Moratuwa Cluster

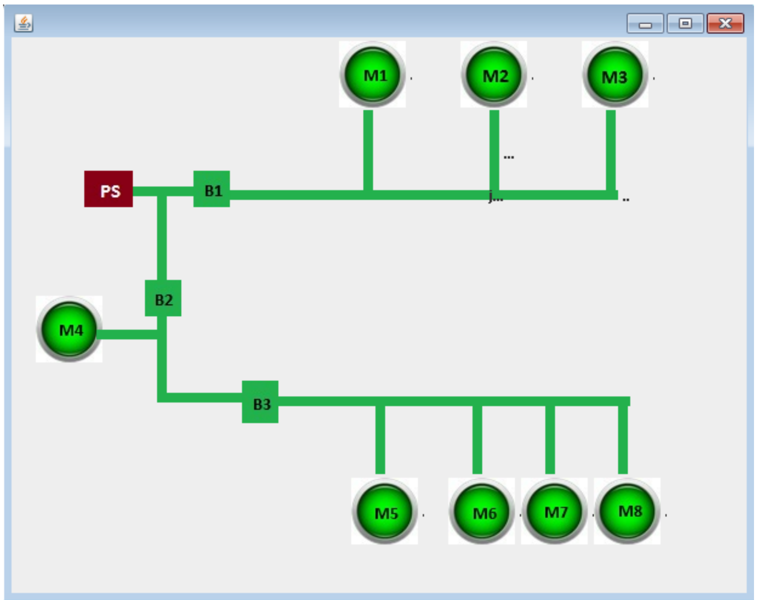


Figure 6-7: GUI for Katubedda Cluster

c). failure notification

This is very important to the user at the control room, he may no need to make attention all the time with the clustered GUI. It is very time consuming and not essential while this function was running. (Figure 6-8). Alarming system is introduced with the buzzer for easy identification of the fault without look at the monitor.

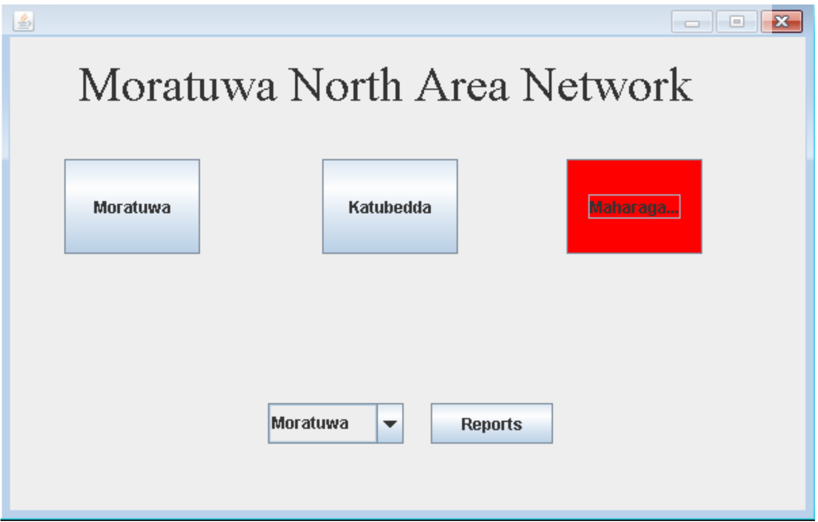


Figure 6-8 : Failure Notification

d). Voltage Graph to check failure rectification

This is very important to monitor individual voltage of the relevant meter, if there are frequent voltage drops or outages. It can easily be recognised the failure time and the reconfigured time of the system (Figure 6-9.)

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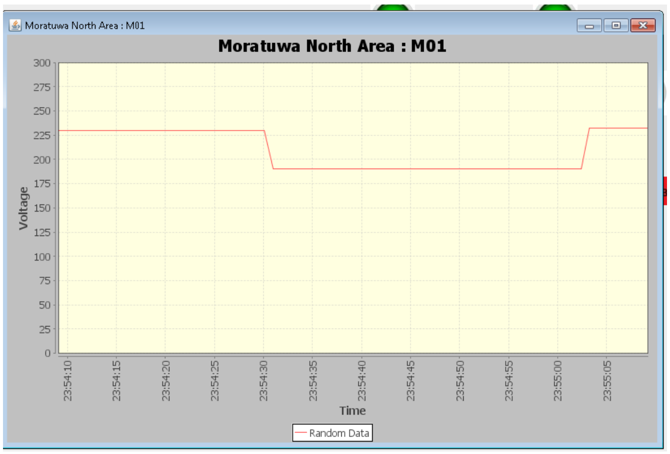

Figure 6-9: Meter Voltage Graph

6.4 Fault Meter Record Updating

Error reporting database monitored through the reporting agent and it would update frequently with the real time data (Figure 6-10). It is more essential data to show customers about the system reliability and the availability of the distribution network. Based on this it is very convenient to calculate SAIDI and SAIFI values of each distribution network effectively and accurately. Using these data, the power output quality of the individual area networks can be compared and it can be added to monitor as KPI value to each network.

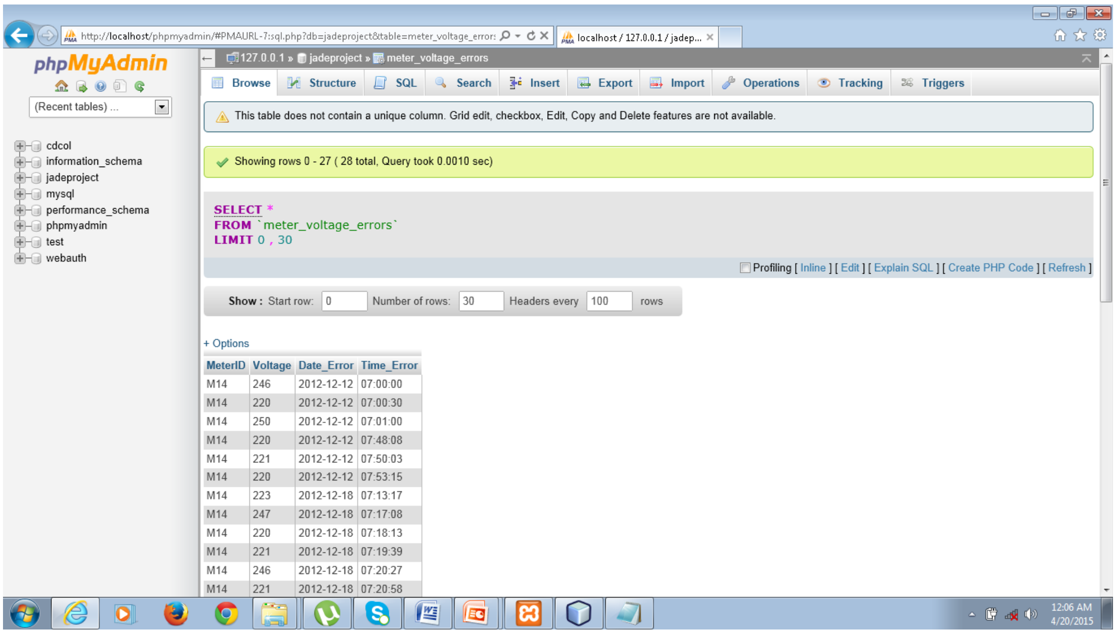

Figure 6-10: Data base for Error reporting

6.5 Power Quality Measurements

Power quality measurement standards can be identified as CAIDI, SAIDI and SAIFI of the system.

i. Customer Average Interruption Duration Index (CAIDI)

$$\text{CAIDI}=\frac{\text{Sum of Customer Interruption Duration}}{\text{Total No of Customers Interuptions}}$$

ii. System Average Interruption Duration Index (SAIDI)

$$\text{SAIDI}=\frac{\text{Sum of Customer Interruption Duration}}{\text{Total No of Customers Served}}$$

iii. System Average Interruption Frequency Index (SAIFI)

$$\text{SAIFI}=\frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Served}}$$

Based on the user request it can be generated separate reports for above mention indexes to compare the individual customers and the area network performances.

First select the clustered area name and press the report button (Figure 6-5) to have initial report window (Figure 6.11A).

Then Click on the Chart button to have a voltage graph (Figure 6-9), and click on CAL index button to see Figure 6-11B for power quality indexes values. By clicking on the CAL area network same window will be appeared with indexes values reference to the area network.

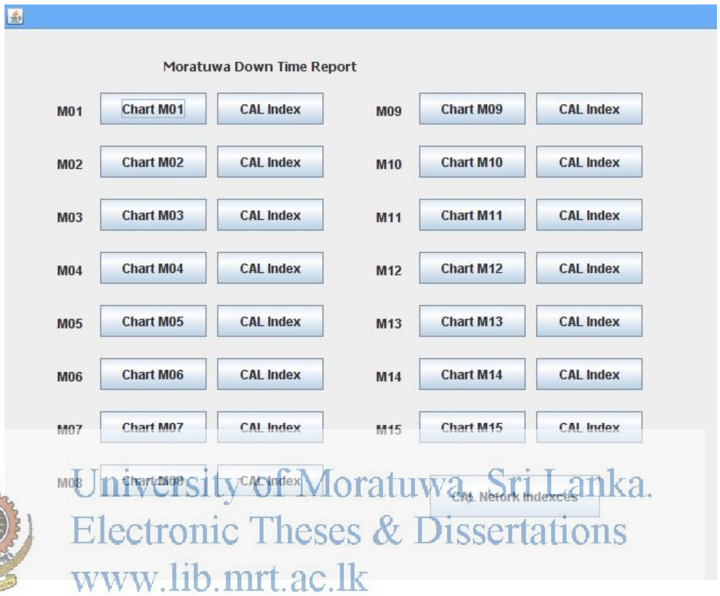

Figure 6-11A : Power quality measurement indexes

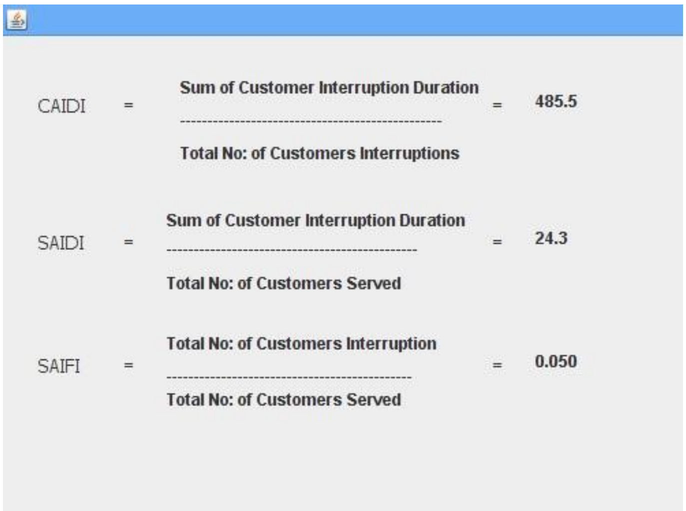

Figure 6-11B : Power quality measurement indexes

6.6 Case Study

This case study is carried out within one primary substation; it was implemented to Maharamaga area network. There are 34 meters and 10 breakers were considered and attached to one primary station. (Figure 6-12).

Normal voltage rating = 230V

6% variation allowed from public utility commission and therefore it can be varied from 216 V to 244 V.

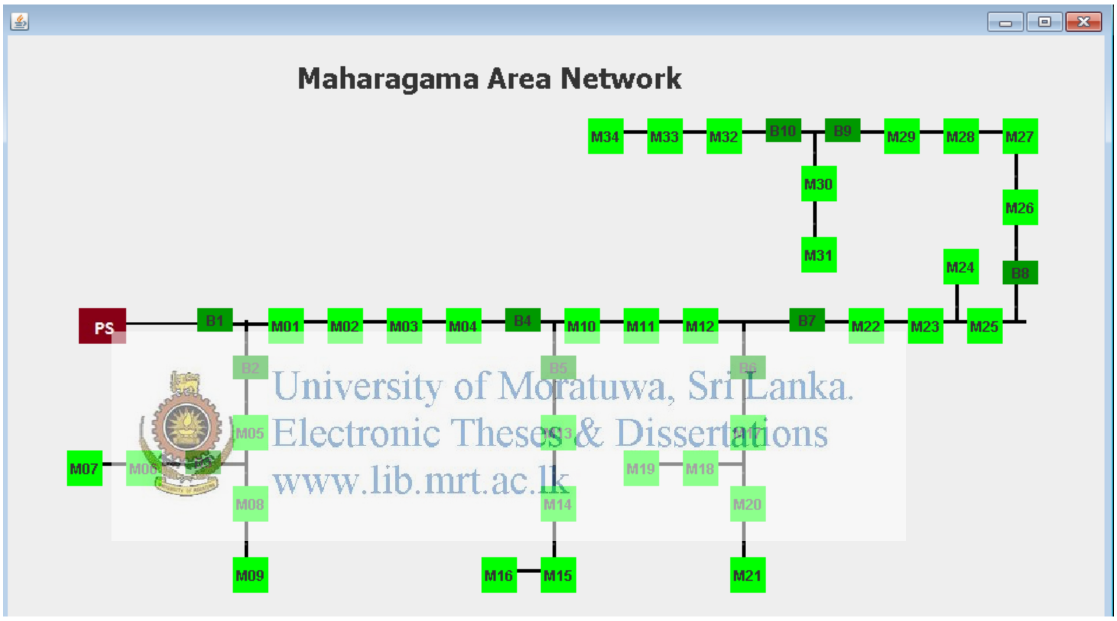

Figure 6-12 : Maharagama Area Network

Voltage meter reading data was collected from LECO office as tabulated in Table 6-1.

Table 6-1: Collected Data set arrangement

Time	**Date**	
	02/06/2015	**03/06/2015**
00.30	Data Set 1	Data Set 4
10.30	Data Set 2	Data Set 5
18.45	Data Set 3	Data Set 6

Above data sets were collected to represent off peak time period, day time and the peak hours of the day. These voltage readings were plotted in line graphs in Figure 6-13 and Figure 6-14. After analysing, four different cases were identified to evaluate from agent base monitoring system.

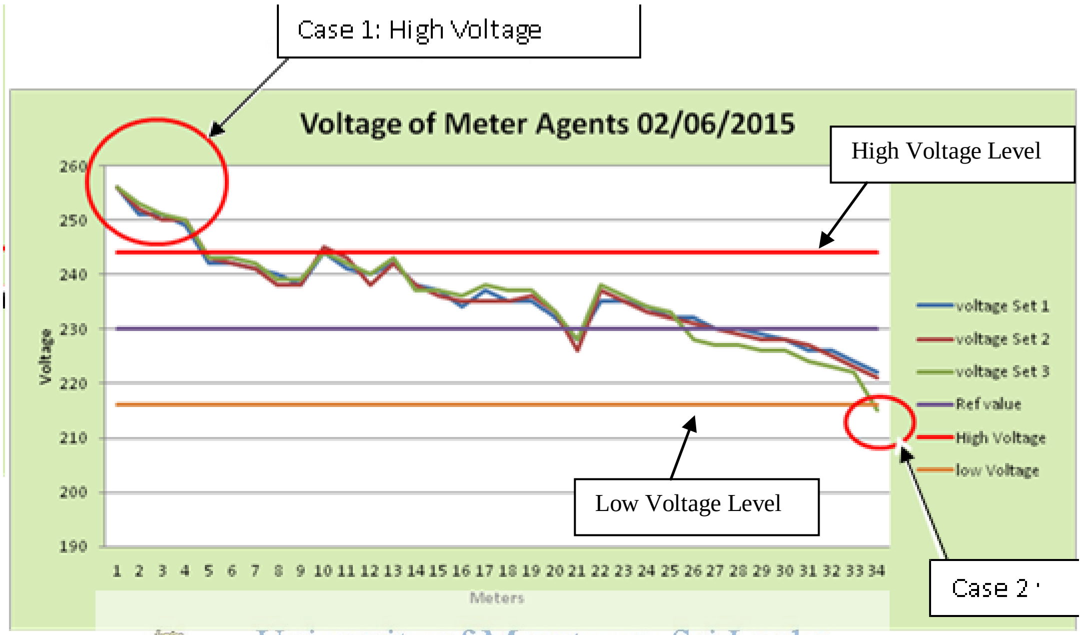

Figure 6-13 : Graph for voltage data on 02/06/2015

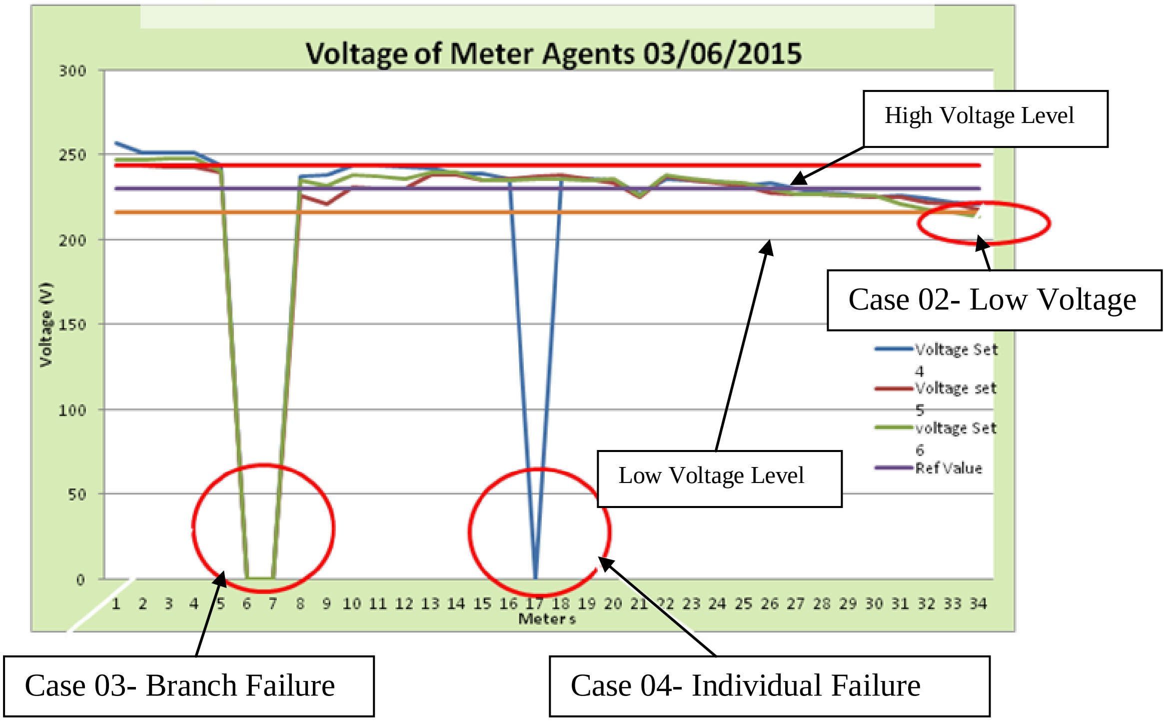

Figure 6-14 : Graph for voltage data on 03/06/2015

Case 01: Monitoring of High Voltage Area

As shown in Figure 6-13 high voltage was occurred close to the primary station. First four meters were deviated from accepted voltage variation (Figure 6-15).

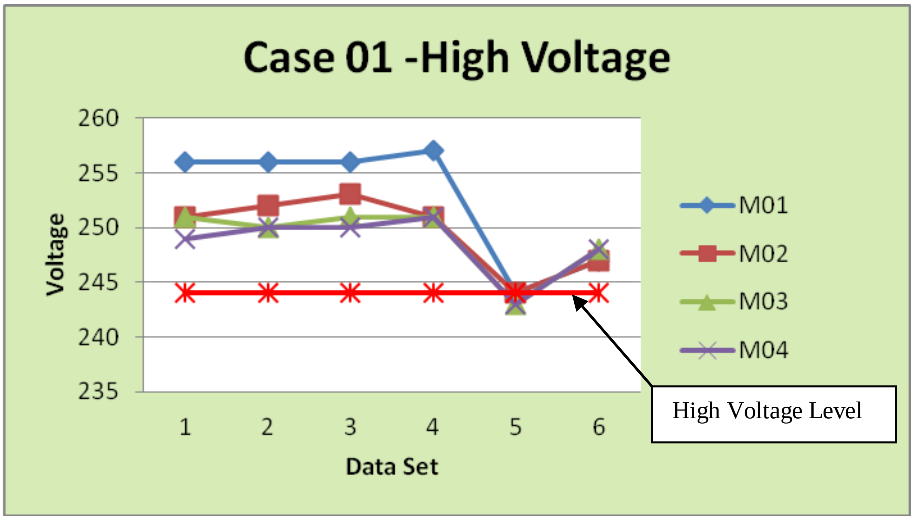

Figure 6-15 : voltage data for Case 1

Above variations were not monitored through data analysing and it is difficult method to sort out important data from huge a data base. If the agent base monitoring system was implemented, voltage variation can be seen in graphical user interface as shown in Figure 6-16.

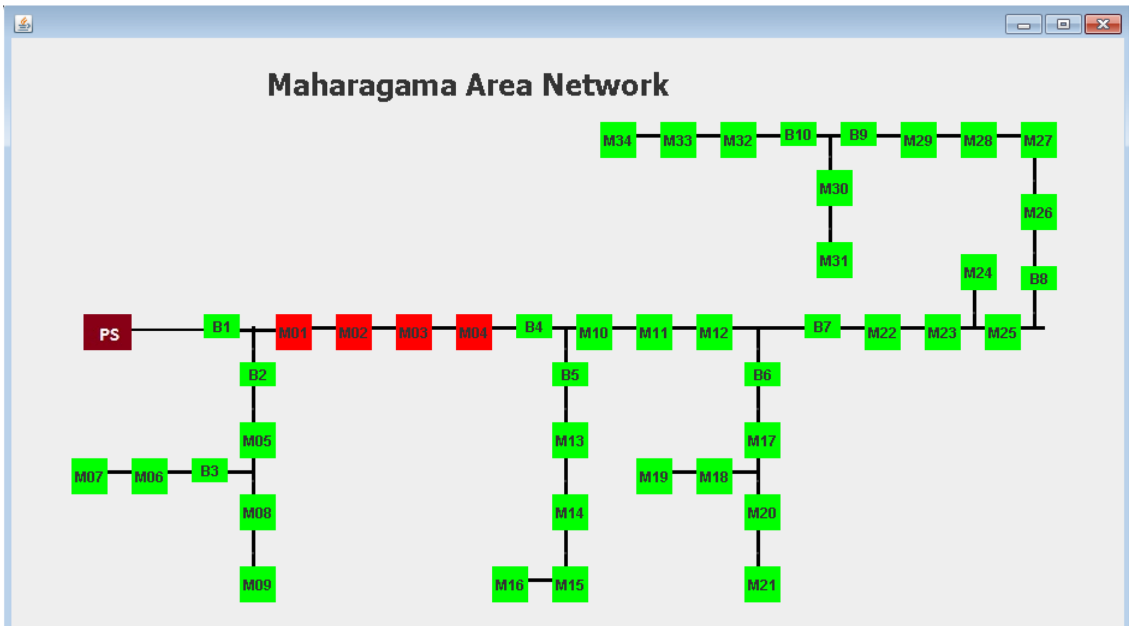

Figure 6-16 : GUI for Dataset 1(02/06/2015 @ 00.30am)

High voltage failures cannot be recognised with the conventional method and has to be waited until the customers raised the complained about the high voltage. Most of the bulk customers implemented high voltage tripping conditions only allowing 5% variation from original. In that case individual power failures would be occurred for those customers until the voltage rating was rectified by power utility company. Very important case is if the customers not implemented tripping conditions that would be very critical and can be faced for serious damages for very high expensive and important equipment.

With the monitoring system, instantaneous update can be figured out from GUI (Figure 6-16). Based on this control room operator can check the actual voltage readings from the database. With these values utility company can access the consumers before he make complain. It would help to explain situation and increase the loyalty to the customers. If frequent high voltage situations were identified then transformer settings can be changed as per the situation. It was observed that most of high voltage situations were occurred at the off peak time. With these information, maintenance team can be directed to the correct failure location without delay.

Case 02: Monitoring of Low Voltage Area

As shown in Figure 6-13 and Figure 6-14 low voltage cases can be identified at end of the area network. Last two meters were faced, this situation as per data set 6 collected on 03/06/2015 at 16.30pm (Figure 6-17).

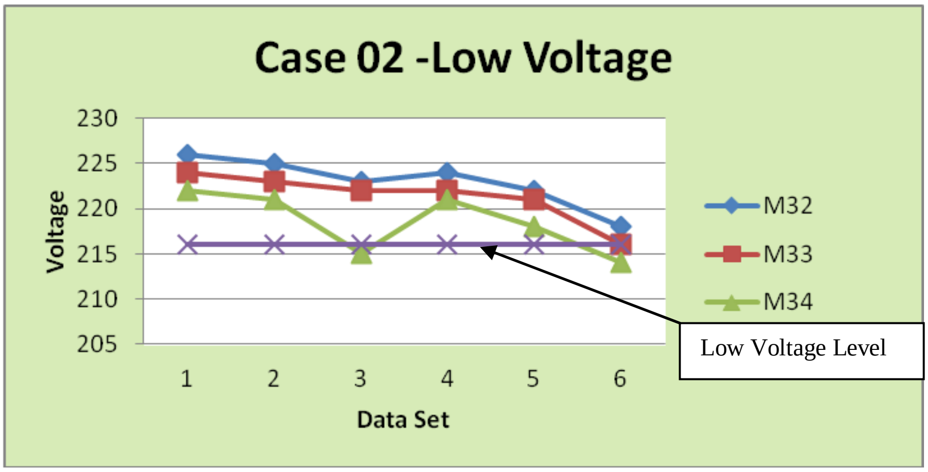

Figure 6-17: voltage data for Case 2

As per the present practise, customers will not be recognised the low voltage until the electrical appliances get damaged or not functioned. Identification of low voltage area is difficult, this has to be carried out few selected locations to cover full area network. Few points close to primary station and middle area and the end lines of the network will be checked by maintenance staff for identification. This scenario has to be conducted for few days before final decision to be taken.

When the monitoring system is functioned, GUI will be updated instantaneously as shown in Figure 6-18. Based on that low voltage area can be identified effectively and this was happened at the peak hours of the distribution network. Immediate decisions can be taken to overcome these situations by adjusting transformer setting values or changing power flow directions.

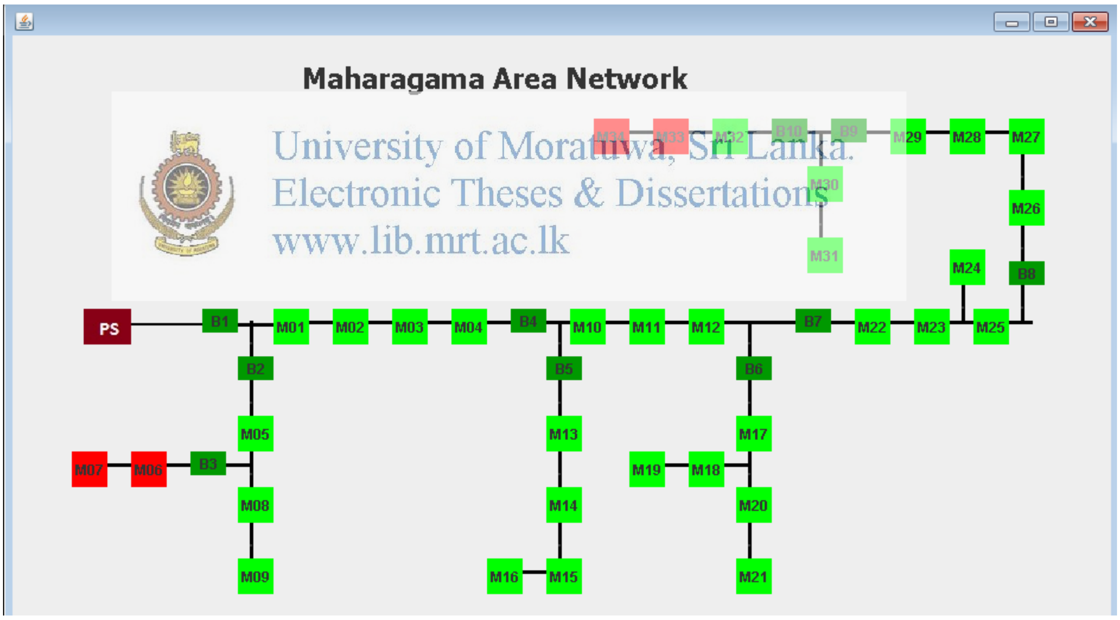

Figure 6-18 : GUI for Dataset 6(03/06/2015 @ 18.30pm)

Case 03: Monitoring of Branch Failures

This case was shown in Figure 6-14, Voltage of meter no 06 and 07 were zero this can be happened due to breaker failure of the communication failures of the system. This scenario was happened throughout the day on 03/06/2015 (Figure 6-19). This was a failure in that branch.

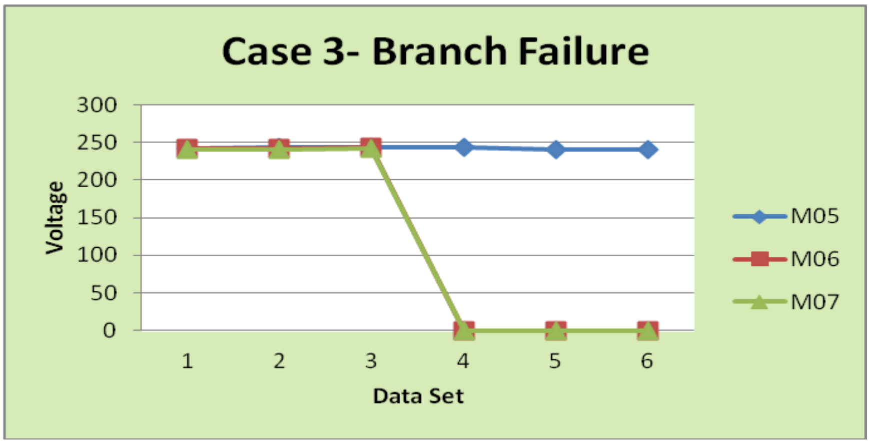

Figure 6-19 : Voltage Values for Case 3

These kinds of failures cannot be figured out and control room will aware about this with the customer complains through telephone calls. Break down handling team has to be finding out possible failure location by experience or checking all components.

If the monitoring system were implemented then GUI would indicate the failure location correctly (Figure 6-20). Based on that break down rectification time can be reduced by reducing the fault finding time by directing the maintenance team for correct location effectively.

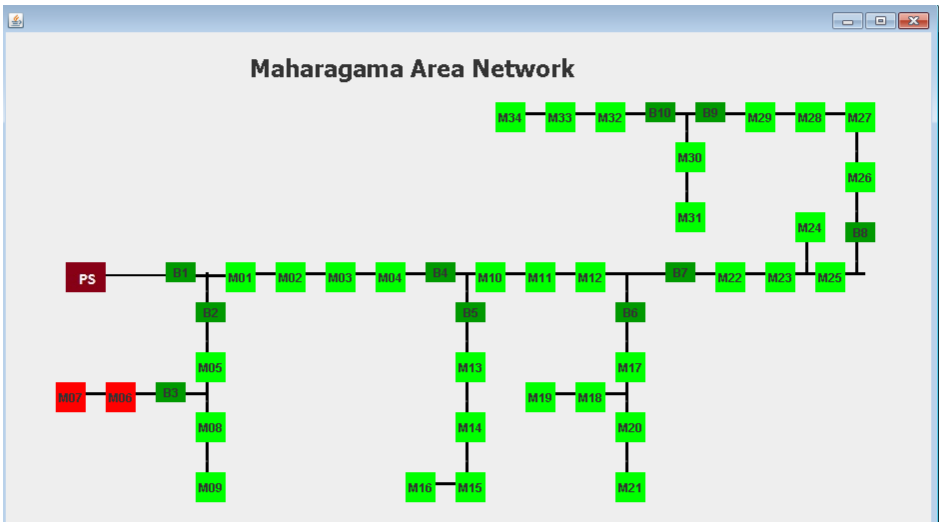

Figure 6-20 : GUI for Dataset 4(03/06/2015 @ 00.30am)

Case 04: Monitoring of Individual Failures

Individual meter reading errors, communication errors, faulty meter incidents and actual individual power failure can be categorised to this scenario. As per data set 5 shown in Figure 6-21 and the voltage of meter 17 was zero at 10.30am on 03/06/2015.

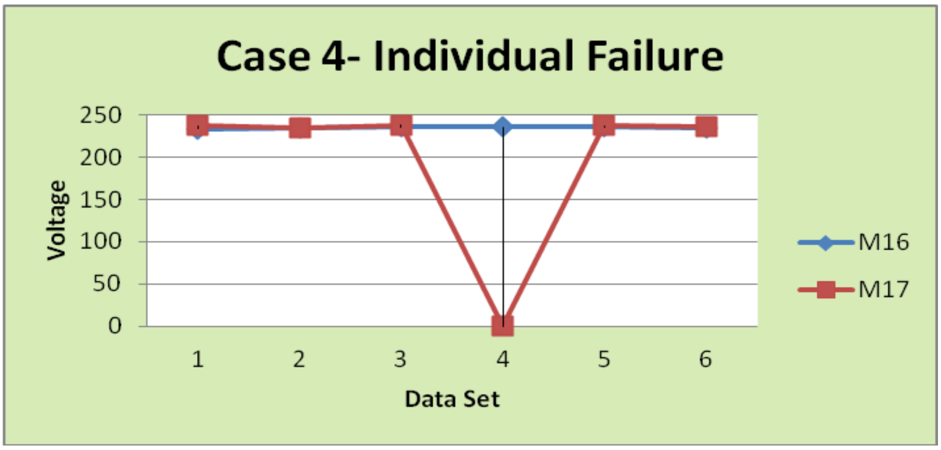

Figure 6-21 : Voltage Values for Case 4

Proper methods to identify these scenarios were not implemented and the consumers would inform to control centre by telephone call. When monitoring system was implemented individual case will shown in GUI as shown in Figure 6-22. If these situations are occurred for several data readings, Break down team can be directed to rectify this or to identify the failure mode. If this is a communication failure, that can be rectified without any delay within the system. If it is occurred as the meter fault, meters can be calibrated using these data. Otherwise meters were checked once a year and calibrations were done on that time.

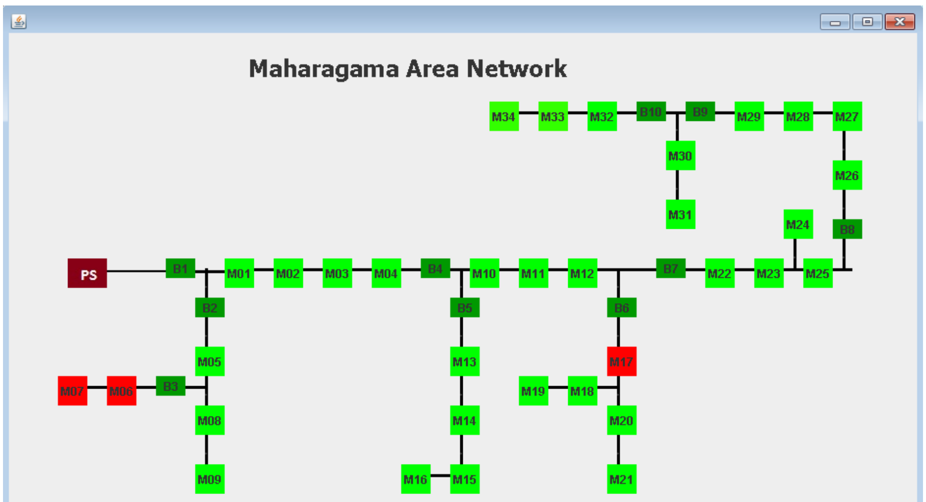

Figure 6-22 : GUI for Dataset 5(03/06/2015 @ 00.30am)

Chapter 7

Conclusions

7.1 Conclusions

Energy meters are generated various tiny data packets at various frequencies which used to calculate energy consumption to produce the bill, study the power quality and fault identification. In AMR, these data were pushed into the main server database and analysed and data monitoring is not implemented properly.

Due to non availability of the voltage quality measurement and outage monitoring system, all outages were recorded as a telephone complains to the customer care centre. According to that information, technicians are attended to the breakdown. Time calculation for the outage was monitored through this information flow. Due to this unusual method measurement of power quality indexes are inaccurate. This is overcome with the system by calculating real faultier time for each customer.

The voltage quality measurements of the end user can be recognized if there is frequent voltage drop within the system through improving voltage and outage monitoring system. The voltage measurement at the end of the line is critical when considering the line augmentation of the network. This is developed through the voltage monitoring at the end of the line and emphasized through the calculated voltage drop through the power line.

Defect meters are identified at the stage in the manual meter reading. This identification is localized to the control system through this outage monitoring system. When it is considered about the whole network system it is more complicated to figure out the outage breaker of the system. Outages are happened individually and also for whole area. If it is total blackout for specific area it can be figured out the faulty point just monitoring the GUI for respective area network.

The objective of this research is to develop an agent based voltage and outage monitoring system for power distribution network using Multi Agent System. Voltages and outage monitoring is done by introducing separated GUIs for system functioning with different agents. Agent system is introduced to have scalability and to reduce the complexity of the network.

Development of agent system is involved with existing Sri Lanka power distribution network configurations. There are five agents defined and introduced to act as software agents for physical components. Agents are defined as the Data Base Agent, Meter Agent, Breaker Agent, Area network Agent and the Reporting Agent. Agents are designed in the JADE frame work and the goals and the behaviours of each agent are implemented with layered architecture. This full agent system is run with the data base management system implemented with the MySQL free open source software.

In this research as a first step, data is generated automatically and conveyed to the database to function the agent system. Based on these data agents are functioned and achieved their objective as explain in chapter four and five. Voltage updates to the meter agents are done through database and the individual functions of the meter agents are completed to communicate with main GUI. Based on that, Main GUI for individual clusters is functioned as explained in section 5.2 of chapter five. If there is frequent complaint from the customer about the voltage quality and frequent voltage fluctuations then it can be easily monitored through the introduced voltage graph. Voltage of that respective customer has to call frequently and can be separately plotted and monitor the variations.

Power quality measurements are calculated for individual meters and also for each cluster separately. Based on these data it can be identified the customers those who have frequent voltage fluctuations and can be find out the problems encountered with distribution network.

Main four scenarios were identified with this case study done in Maharagama area as high voltage case, low voltage case, branch failures or individual meter failures. By analysing these scenarios with the agent base monitoring system, it can be concluded that control room operator can directly handle maintenance team and direct them to correct fault location that can be established. Frequent high voltage areas can be monitored and suggestions for transformer setting changes can be implemented. This can be implemented four low voltage cases. Individual meter faults can be identified and meter calibrations can be arranged with instant notification.

Distribution system augmentations can be done with this voltage monitoring system by identifying low voltage area correctly. Requirement of new transformers or upgraded the transformer to higher level can be identified. Power flow direction changes can be implemented to overcome the low voltage area and to avoid the high voltage situations.

As explained in this dissertation, agent based monitoring system for voltage and outage monitoring was developed for the betterment of the distribution network functions.

7.2 Future Developments

In this research is developed to handle the data which is coming from the AMR system, but it needs to synchronise the physical meter with the virtual or ghost agent in the computer to communicate directly and collect data upon the agent requirement. When the whole distribution network is functioning as SMART grid, these agents have to communicate with the system physical agents' function the fault isolations, restoration and fault identification.

These developed GUIs can be linked to web page through developing another agent to function as web agent. Then area engineer can access the database and the GUI updates easily and can be directed the repair team for exact location of fault occurred. Also it can be introduced one repair agent who can be linked to power restoration process and maintain all repair records of each meter and then can be accessed earlier faults and the correction techniques done for particular fault.

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References

[1] Summiya Moheuddin, Afzel Noore, and Muhammad Choudhry " A Reconfigurable Distributed Multiagent System Optimized for Scalability "World Academy of Science, Engineering and Technology 27, 2009– [8]

[2] Mahshid Rahnamay-Naeini, Zhuoyao Wang, Andrea Mammoli, and Majeed M. Hayat, "A Probabilistic Model for the Dynamics of Cascading Failures and Blackouts in Power Grids" Power and Energy Society General Meeting, 2012 IEEE. IEEE, 2012. [16]

[3] I. Dobson, B. Carreras, and D. Newman, "Branching process models for the exponentially increasing portions of cascading failure blackouts," in 38th Annual Hawaii International Conference on System Sciences, HICSS, Jan. 2005.

[4] T. Nagata and H. Sasaki,"A Multi-Agent Approach to Power System Restoration", IEEE transactions on power systems, vol. 17, no. 2, may 2002

[5] I. H. Lim, Y. I. Kim , H. T. Lim, et al., "Distributed Restoration System Applying Multi-Agent in Distribution Automation System". Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE.

[6] K. Nareshkumar, M. A. Choudhry, J. Lai, A.Feliachi, "Application of Multi-Agents for Fault Detection and Reconfiguration of Power Distribution Systems" Power & Energy Society General Meeting, 2009. PES'09. IEEE. IEEE, 2009

[7] Ioannis S. Baxevanos and Dimitris P. Labridis, "Implementing Multiagent Systems Technology for Power Distribution Network Control and Protection Management" Power Delivery, IEEE Transactions on 22.1 (2007): 433-443

[8] Jakob Stig Ravn, "A Multi-Agent Approach for Distribution System Restoration" Diss. Technical University of Denmark, DTU, DK-2800 Kgs. Lyngby, Denmark, 2008.

[9] Mladen Kezunovic, "Smart Fault Location for Smart Grids "IEEE transactions on smart grid, vol. 2, no. 1, march 2011

[10] L. Liu, K. P. Logan, D. A. Cartes and S. K. Srivastava, "Fault Detection, Diagnostics and Prognostics: Software Agent Solutions," IEEE Transactions on Vehicular Technology, Vol. 56, No 4, pp 1613 – 1622, July 2007

[11] Yinliang Xu, and Wenxin Liu, " Novel Multi agent Based Load Restoration Algorithm for Micro grids". *Smart Grid, IEEE Transactions on 2.1 (2011): 152-161.*

[12] Christoper Leckie and Michael Dale, Telstra Research Laboratories, "Locating Faults in Tree Structured Networks" IJCAI (1). 1997.

[13] Yue Zhao, Raffi Sevlian, Ram Rajagopal, Andrea Goldsmith and H. Vincent Poor "Outage Detection in Power Distribution Networks with Optimally-

Deployed Power Flow Sensors" Power and Energy Society General Meeting (PES), 2013 IEEE. IEEE, 2013.

[14] Radu Porumb, Nicolae Golovanov, Petru Postolache, Cornel Toader "Power Quality in Modern electric Distribution Systems Assessment using Probabilistic Approach" Modern Electric Power Systems (MEPS), 2010 Proceedings of the International Symposium. IEEE, 2010

[15] Bill C.P. Lau, Eden W.M. Ma, Tommy W.S. Chow " Probabilistic fault detector for Wireless Sensor Network" Expert Systems with Applications 41.8 (2014): 3703-3711.

[16] Don Torrieri and Matthew C. Valenti, "The Outage Probability of a Finite Ad Hoc Network in Nakagami Fading" communications, IEEE Transactions on 60.11 (2012): 3509-3518

[17] Brian W. Ricks , Ole J. Mengshoel , "Methods for Probabilistic Fault Diagnosis: An Electrical Power System Case Study" Annual Conference of the Prognostics and Health Management Society. 2009.

[18] www.sainsmart.com, introduction to Arduino

[19] Saeed Monemi, Ph.D. , Michael S. Moore, Ph.D. Jianfeng Wang "An Outage Restoration Management System for Power Distribution Networks" ESRI Electric and Gas user conference, Fall. 1999.

[20] S. K. a. N. N. S. Jignesh M. Solanki, "A Multi-Agent Solution to Distribution Systems Restoration," in *Power Systems, IEEE Transactions on (Vol:22, Issue:3)*, Aug. 2007.

[21] D. P. Buse, et al. "Agent-based substation automation." Power and Energy Magazine, IEEE 1.2 (2003): 50-55.

[22] G. C. D. G. Fabio Bellifemine, Developing Multi-Agent systems with JADE, West Sussex, England: Jhon Wiley & Sons Ltd, 2007.

[23] J. Barbosa and P. Leitao, "Simulation of Multi-agent Manufacturing Systems using Agent-based Modelling Platforms," in *Industrial Informatics (INDIN), 2011 9th IEEE International Conference on*, Caparica, Lisbon, July 2011.

[24] B. S. Germain, P. Valckenaers, H. V. Brussel, Hadeli, O. Bochmann, C. Zamfirescu and P. Verstraete, "MULTI-AGENT MANUFACTURING CONTROL: AN INDUSTRIAL CASE STUDY," pp. 1-6.

[25] N. Anand, D. R. V. Duin and P. L. Tavasszy, "A SITUATED MULTI-AGENT SYSTEM FOR URBAN FREIGHT IN THE RANDSTAD," in *11th TRAIL Cogress*, Nov 2010.

[26] H. Franker and W. Dangelmaier, "Decentralized management for transportation-logistics -A Multi Agent based approach," *Integrated Computer-Aided Engineering*, vol. 10, no. 2, pp. 203-210, Aprl 2003.

[27] Z. Wang and H. Tianfield, "A Study of Multi-agent System for Network Management," in *International Conference on High Performance Computing and Application*, Shanghai P.R, China, 8-10 Aug 2004.

[28] N. D. D. M, M. H. M. S., G. Isaza and A. Morales, "Multi Agent System Implementation for Network Management based on SNMP Protocol," in *International Symposium on Distributed Computing and Artificial Intelligence, Vol 50*, 2008.

[29] FIPA Agent Management Specification- Standard, fab@fipa.org, 2004/18/03.

[30] FIPA ACL Message Structure Specification- Standard, fab@fipa.org, 2002/12/03.

[31] FIPA Request Interaction Protocol Specification-Standard, fab@fipa.org, 2002/12/03.

[32] FIPA Contract Net Interaction Protocol Specification-Standard, fab@fipa.org, 2002/12/03.

[33] A. Singh, D. Juneja and A. Sharma, "Agent Development Toolkits," in *International Journal of Advancements in Technology*, Jan 2011.

[34] T. I. L. Team, F. Bellifemine and G. Caire. [Online]. Available: http://jade.tilab.com/.

[35] G. Caire, JADE TUTORIAL-JADE PROGRAMMING FOR BEGINNERS, Free Software Foundation,, June 2009..

[36] F. Bellifemine, G. Caire, T. Trucco and G. Rimassa, JADE PROGRAMMER'S GUIDE, Free Software Foundation,, April-2010.

[37] http://www.w3schools.com/php/default.asp

[38] http://stackoverflow.com

[39] http://dev.mysql.com/tech-resources/articles/ddws/21.html

[40] https://dev.mysql.com/doc/refman/5.1/en/what-is-mysql.html

[41] http://www.siteground.com/tutorials/php-mysql/php_mysql_connection.html

[42] Fabio Bellifemine, Giovanni Caire and Dominic Greenwood "Developing Multi-Agent Systems with JADE" published by John Wiley & Sons Ltd.