DEVELOPMENT OF A MATRIX BASED UTILITY SCALE FEEDER RECONFIGURATION ALGORITHM FOR SUPPLY RESTORATION

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December 2023

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Dissertation submitted in partial fulfillment of the requirements for the

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DECLARATION OF THE CANDIDATE & SUPERVISOR

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Dr. P. S. N. De Silva

ABSTRACT

Handling of supply outages are critical task in electricity distribution utilities. One of major expectation of any electricity customer is receiving continues electricity supply. Responsibility of a utility is also supplying electricity continuously with minimum outage time duration. Although unplanned outages cannot be reduced to zero, those can be managed and restored the supply as early as possible to minimize the outage time duration and minimize affected area. Outage time duration and the area affected is directly influenced to revenue loss of both utility and commercial customers.

In an event of unplanned supply outage, utilities have to carried out fault localization, fault isolation and supply restoration temporary, until the fault is cleared to restore the supply to the fault occurred, isolated section. These steps are currently done as manual method. In this research utility network was modeled as a matrix and above-mentioned fault localization, isolation and supply restoration were done by an algorithm to maximize the efficiency and minimize outage time period.

Centrally handling of outages were focused on this research. Matrix-based utility network model and algorithm for the network calculations was expected to validate through this research. The algorithm produces switching instructions to fault localization, faulty section isolation and supply restoration based on the outage massages were fed. It was simulated in MATLAB environment. Algorithm was developed considering hypothetical network and different test cases of possible fault scenarios. Outage data were fed to the algorithm manually and compared the results given by the algorithm with manual method results for the same outages. Algorithm validated by actual network data with manually fed outage cases. Algorithm results were tallied with the manual results. It shows that centralized matrix-based utility network representation and matrix-based algorithm is suitable to solve networks related issues more efficiently than manual & local methods.

ACKNOWLEDGEMENT

I express my profound gratitude to all those who have helped me in successfully completing this research project.

First, I would like to express my sincere gratitude to my supervisor, Dr. P. S. N. De Silva, for providing me the concept of the project, especially for giving me such attention, time and guidance throughout the period.

Also, I would like to take this opportunity to express a deep sense of gratitude for the supervisor, Dr. J.V.U.P. Jayatunga, for her kind, continuous support and encouragement, which helped me in completing this task step by step.

Further, I appreciate the guidance by the evaluation panel, especially for their valuable comment and advice to enhance the quality and the accuracy of the research.

Then my sincere thanks go to my supervisors and senior officers of each division of LECO I worked while carrying out the research.: Mr. M. D. Gamage - Additional General Manager (Engineering), Mr. S. D. C. Gunawardhana - Additional General Manager (Operations), Mr. D. A. P. Amarasena – Deputy General Manager (Operations South), Mr. A. S. J. Dissanayaka - Chief Engineer (Control), Mr. R. M. Hettiarachchi – Chief Engineer (Galle Branch), Mr. Rasanga Fernando – Chief Engineer (Negombo Branch) and to all my colleagues at Lanka Electricity Company Private Limited, who helped me in many ways during this period.

Last but not the least, I express my heartiest gratitude and love to my wife, little son and parents, who dedicated not only valuable time of their lives but also provided me their patience from the beginning to the end of this research. Without their help and encourage, this research may not be this much successful. Thank you all for helping me in many ways to successfully complete this research.

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LIST OF ABBREVIATION

CEB	- Ceylon Electricity Board
LECO	- Lanka Electricity Company (Private) Limited.
LBS	- Load Break Switch
AR	- Auto Recloser
PSS	- Primary Sub-Station
MV	- Medium Voltage
ID	- Identification Number
LBC	- Load Break Cutout
DDLO	- Drift Down Lift On switch
GIS	- Geographic Information System

CHAPTER 1

1 INTRODUCTION

1.1 BACKGROUND

Electricity distribution networks are the backbone of modern society, providing the vital infrastructure needed to power homes, businesses, and industries. Without a reliable and efficient electricity distribution system, economic growth and development would be severely hindered. The importance of electricity distribution networks has increased as societies become more reliant on technology and electricity to power their daily lives. The reliability of the electricity distribution system is equally important as its existence. In the absence of a reliable electricity distribution system, daily activities of individuals, businesses, and institutions could come to a standstill, resulting in significant economic and social costs.

The reliability of the electricity distribution system refers to its ability to deliver electricity consistently and without interruption. In other words, a reliable electricity distribution system ensures that power outages are minimized, and when they do occur, they are quickly resolved. However, despite the critical importance of a reliable electricity distribution system, many countries continue to face significant challenges in achieving and maintaining high levels of reliability. Factors such as aging infrastructure, inadequate investment, and extreme weather events can all contribute to the breakdown of the electricity distribution system.

The electricity utility in Sri Lanka is divided into three sub-fields: power generation, transmission, and distribution. The distribution sub-field is responsible for the final stage of electricity delivery to end-users, and its operations are carried out by two primary license holders, the Ceylon Electricity Board (CEB) and Lanka Electricity Company (Private) Limited (LECO).

The CEB primarily uses a 33kV distribution network to deliver electricity to its customers, while LECO uses an 11kV network as its primary distribution voltage. These distribution networks are essential components of Sri Lanka's electricity infrastructure, and their reliable operation is critical to ensuring a consistent supply of electricity to end-users.

Utility network of LECO can be classified as a medium-scale utility network and is capable of being centrally monitored and controlled. This feature of the LECO distribution network is critical in ensuring the efficient management of electricity supply and reducing the impact of potential power outages on end-users. Centralized monitoring and control of the distribution network allow LECO to quickly detect and respond to any potential faults, minimizing downtime and ensuring a reliable supply of electricity to end-users. Figure 1.1 shows the

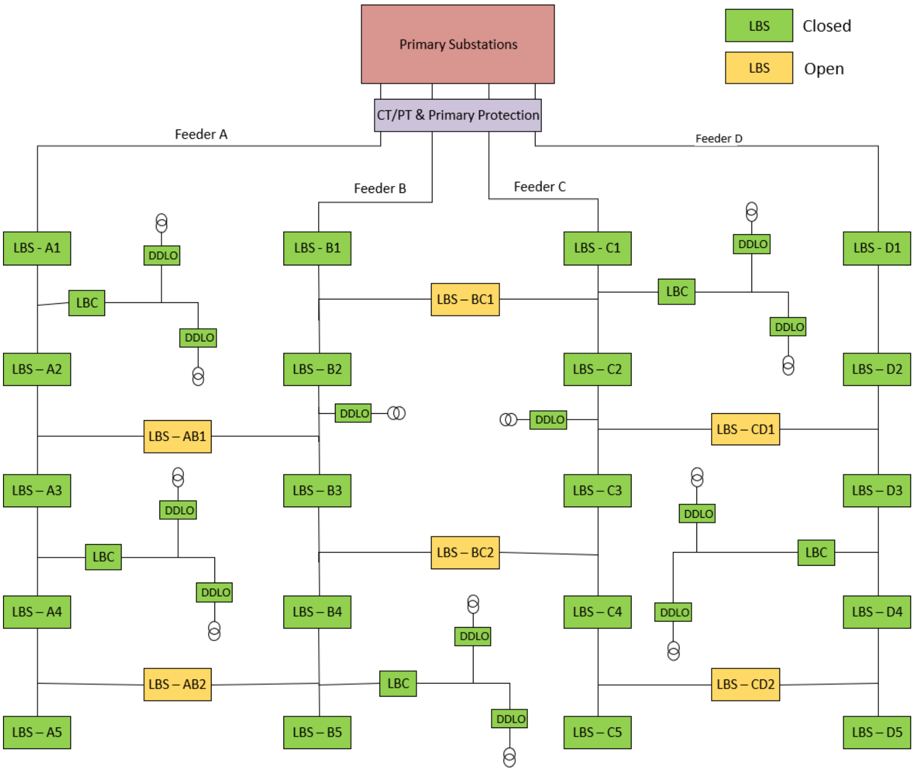


Figure 1.1. Radially operated ring connected MV distribution network

1.2 PROBLEM STATEMENT

The fault localization process in medium-voltage (MV) distribution systems is currently reliant on customers reporting outages, and field staff (breakdown team) dispatched to locate the fault by traveling along roads with tripped lines. Once the fault location is identified, field staff inform the distribution control center, which then provides instructions to isolate the faulty section of the network using MV switches. After the faulty section is isolated, the distribution control center provides further instructions to the field staff to temporarily restore supply to the tripped area using alternative paths that do not have any faulty line segments. This process is achieved by manually calculating available alternative sources and routes according to the loading level of each alternative line and primary substation. This process is represented as a diagram in the Figure 1.2.

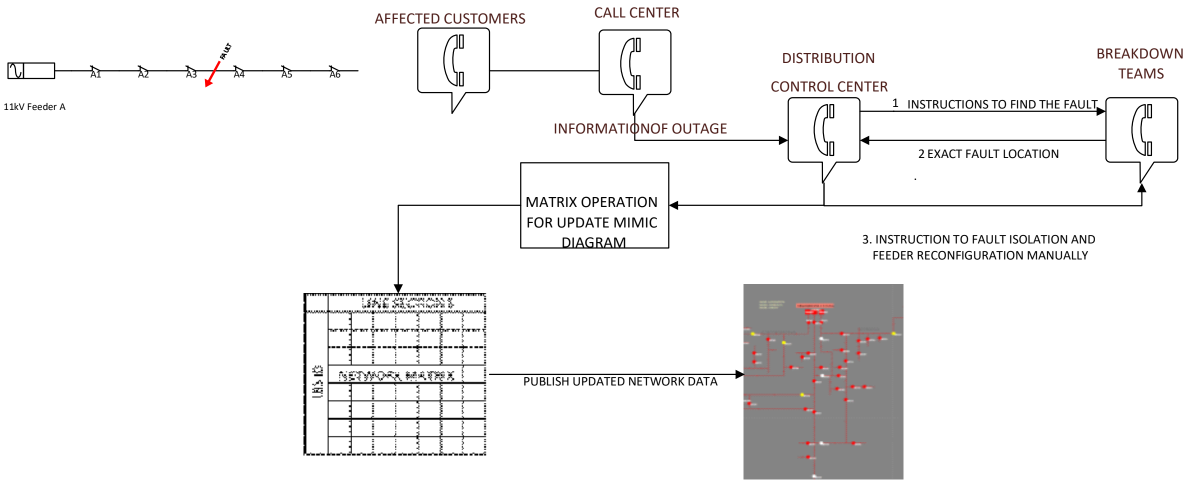


Figure 1.2. Existing method of fault localization, isolation, and supply restoration.

While this approach has been effective in restoring electricity supply to customers, it can result in longer outage durations and increased downtime for end-users. As shown in the Figure 1.2, LECO has developed its MV network as a matrix model that provides detailed information about energized line sections after providing the feeding points and open/ close switch details.

Controllers in the distribution control center manually gives inputs to the matrix model and obtain the updated single line diagram, mimic of the present distribution system. Supply restoration time is directly affected by the delay of reporting the outage, breakdown team dispatching delay, fault finding delay, switching instruction communication delay, alternative supply planning delay. Those are the main problems focusing in this research.

1.3 PROJECT SCOPE AND OBJECTIVES

The focus of this research is on the future 11kV network that will incorporate remote MV switches. These switches will communicate with a central server through an existing remote communication method such as 3G or 4G mobile network medium. To develop and validate the algorithm, messages anticipated to be received from the remote switches mentioned above were manually fed to the model. The objective of this research is to develop an algorithm that minimizes fault localization, fault isolation, and supply restoration delays by utilizing a utility network matrix model. With the rapid response of remote MV switches and the computational power of the proposed algorithm, it is expected that the fault localization by identification of faulty sections of the network, fault isolation, and restoration of electricity supply to end-users will be significantly improved. This research holds great potential for improving the efficiency and reliability of power distribution networks, which could lead to better service and reduced downtime for end-users.

1.4 THESIS ORGANIZATION

In the first part of Chapter 1, the significance of power distribution systems to a country's economy and the crucial role of power system reliability in ensuring uninterrupted electricity supply were discussed. The importance of maintaining the system's reliability to avoid the adverse impacts of power outages on various sectors was emphasized. In the latter part of Chapter 1, the current practice of supply outage handling was described, which includes a manual and time-consuming process of fault localization, fault isolation, and supply restoration. The proposed matrix-based algorithm's objectives were briefly discussed, highlighting the need to minimize delays in fault localization, fault isolation, and supply restoration, ultimately reducing the outage time and improving the overall reliability of the power system.

Chapter 2 of the research report is dedicated to the Literature Review, which provides a comprehensive overview of the existing research in the field of power supply restoration practices. The chapter starts by discussing the traditional approaches to power supply restoration and the limitations of those methods. It then moves on to highlight the need for automated approaches in the context of modern power systems, which are becoming increasingly complex and dynamic. The chapter also discusses the various feeder reconfiguration options that exist and their classifications. In addition, it examines the various matrix-based network models that have been proposed in the literature and their applications. The Literature Review section in this chapter is particularly important as it highlights the gaps in the existing research and justifies the need for the matrix-based utility scale feeder reconfiguration algorithm that is the focus of this research. By examining the existing research and identifying the limitations of the current approaches, the chapter sets the stage for the development of a more efficient and effective solution that can improve power supply restoration practices in the future.

Chapter 3 is a crucial part of the research that focuses on the development of the matrix-based feeder reconfiguration algorithm. It starts with the fundamental concepts of matrix-based modeling of utility networks, building upon them step-by-step to arrive at the final outcome level of the algorithm. The chapter provides detailed insights into the matrix-based modeling of the utility network, including the methodology and techniques used in developing the algorithm. It highlights the major functionalities of the algorithm, such as the fault localization and isolation features, and discusses how they are implemented using the matrix model. The chapter offers a comprehensive overview of the algorithm's development, from its initial conceptualization to its final design, providing a solid foundation for the verification and validation of the algorithm in Chapter 4.

In Chapter 4, the verification of the proposed algorithm was extensively discussed. This involved a thorough analysis of a hypothetical network to test the algorithm's performance under varying conditions. The algorithm was evaluated using several test cases to assess its reliability and accuracy in identifying faulty sections of the network, and its ability to isolate and restore power supply. The algorithm was also validated using actual network data to confirm its effectiveness in real-world scenarios. Finally, a comparison was made between manually calculated and algorithm-derived results to demonstrate the algorithm's superiority in terms of accuracy and efficiency. Overall, the verification process confirmed the viability and effectiveness of the proposed algorithm in improving fault localization, fault isolation, and restoration of electricity supply in the 11kV network with remote MV switches.

Chapter 5 serves as the concluding section of the thesis, offering a comprehensive summary of the entire study. This chapter begins by providing a synthesis of the key findings and outcomes of the algorithm developed throughout the research. It highlights the algorithm's strengths, limitations, and its potential for practical implementation in real-world medium-scale utility providers. By acknowledging and discussing these limitations, the chapter contributes to the overall transparency and integrity of the research. It offers recommendations for future research endeavors. These recommendations suggest potential directions for further developing and refining the algorithm, taking into account the identified limitations and emerging industry needs. By outlining these recommendations, the chapter encourages the continuation of research efforts in this field and offers guidance for researchers interested in exploring and advancing the algorithm's capabilities.

CHAPTER 2

2 LITERATURE REVIEW

2.1 INTRODUCTION

Power supply systems are fundamental components of modern electrical infrastructure and typically consist of three primary elements: sources, lines, and switches. The sources produce electrical power that is then transmitted through the lines. The lines are designed to efficiently transport electrical power to the destination with minimal loss of energy. The switches, on the other hand, are used to control the flow of electrical power and direct it to the appropriate destination. In essence, power supply systems can be seen as complex networks of interconnected components that work together to ensure the reliable and efficient delivery of electrical power.

Electric power distribution system modeling is a crucial area of focus for both utility engineers and academic researchers. It involves the development of algorithms and the execution of various testing categories to enhance system reliability and explore the system in greater detail. There are numerous techniques to enhance the reliability of electricity distribution systems and different methodologies to minimize the duration of outages caused by system failures. However, these methodologies are directly influenced by the relevant system designs. Based on the system design, various algorithms can be applied to optimize the system parameters [1].

As a result, several theories, methodologies, and concepts have been created through numerous research efforts. Some of these have already been implemented by utilities for operational purposes. This chapter reviews various research publications to identify supplements, limitations, and research gaps that can be addressed with regard to previous research work on specific topics. By reviewing and synthesizing these publications, this literature review aims to identify the most promising avenues not only for this research but also for future researches and developments.

2.2 POWER SUPPLY RESTORATION PRACTICES

Despite consumers' expectations for uninterrupted power supply, power systems are subject to two types of interruptions: planned and unplanned. Planned interruptions are typically scheduled in advance for maintenance and construction works, and as such, supply utilities can take all necessary precautions to minimize outage time and the number of affected customers. However, unplanned outages caused by system faults or accidents are outside the control of the supply utility, making it challenging to mitigate the effects of these events. To address unplanned outages, utilities must conduct in-depth analyses to identify potential causes and implement strategies to minimize outage time and the number of affected customers [2].

2.2.1 Traditional approaches

Traditional methods of supply restoration involve a range of techniques and practices aimed at restoring power supply in the event of an outage or disruption. These methods typically rely on manual intervention, physical inspection, and established protocols. Traditional approaches of supply restorations are as follows:

Fault Detection and Identification: It is typically involves receiving reports or calls from customers who experience a power outage, as well as monitoring system alarms and indicators. By analyzing these inputs, utility operators can narrow down the location of the fault and initiate the restoration process.

In reference [3], the implementation of an "Interactive Voice Response System" connected to an outage management system is highlighted. This system is particularly useful for rural utilities that may not have the infrastructure to implement remote switches with communication facilities. When overlooking this specific method, it can identify the utilization of binary search algorithm to identify the fault location by analyzing customer complaints about supply outages. This method relies on the feedback and information provided by customers to narrow down the fault location.

Reference [4] proposes the use of trained artificial neural networks to analyze customer complaints regarding service outages. By training the neural network with historical data, it can learn patterns and identify potential fault locations based on customer reports.

Manual Inspection and Repair: In this scenario utility workers are deployed to the affected area to conduct physical inspections of the power lines, equipment, and associated infrastructure. These inspections aim to assess the extent of damage and determine the necessary repairs.

Reference [5] highlights the importance of manual inspection as a traditional approach in the restoration process. Breakdown teams are dispatched to the tripped line, starting from the primary substation and moving downstream. Their primary task is to physically visit and inspect all components of the power line. When overlooking this method, it can identify that, this approach utilizes the sequential search algorithm, to ensure that every part of the line is thoroughly examined.

During the inspection, utility workers examine various components such as transformers, circuit breakers, switches, and conductors. Their objective is to identify any visible signs of damage, malfunctioning equipment, or faulty connections. This process requires a comprehensive assessment of the physical condition and integrity of the power infrastructure.

It is important to note that manual inspection, while essential, can be time-consuming. As mentioned in the reference, the sequential search algorithm employed by the breakdown teams consumes considerable time since they need to physically visit each section of the power line. This can potentially lead to delays in the overall restoration process.

Sectionalization and Isolation: This is also an important approach used in power distribution systems to minimize the impact of faults and expedite the restoration process [6]. This approach involves dividing the power distribution system into sections or zones and strategically opening and closing switches or breakers to redirect power flows and isolate the faulted area.

The technique of sectionalization and isolation is widely employed in power distribution systems to limit the extent of disruptions caused by faults. By dividing the distribution system into sections, the faulted section can be isolated from the rest of the network [7], allowing power to be restored to other unaffected sections. This is achieved through the coordinated operation of switches or breakers strategically located in the distribution network.

Coordination and Communication: Efficient supply restoration relies on effective coordination and communication among utility personnel, field crews, and control centers [8]. Timely and accurate information exchange ensures that resources are deployed to the appropriate locations, repairs are prioritized based on customer needs, and restoration progress is communicated to affected parties.

These traditional methods of supply restoration have been relied upon for many years and have proven to be effective in restoring power after outages or disruptions. However, advancements in technology and the emergence of smart grid systems are leading to the integration of more automated and sophisticated approaches to enhance the efficiency and reliability of supply restoration processes.

2.2.2 Need for automated approaches / limitations of existing methods.

The need for automated approaches in power supply restoration arises from the desire to improve efficiency, reduce downtime, and enhance the overall reliability of the electrical grid. While traditional methods have been effective, they have certain limitations that can be addressed by incorporating automation. Automated approaches and the limitations of existing methods in power supply restoration are as follows:

Limitations of fault detection systems: As mentioned in traditional approaches, relying solely on customer complaints to locate medium voltage (MV) network faults has several limitations. During nighttime, when customer complaints are limited, fault localization can become more challenging or even impossible. Moreover, false or fake calls can introduce errors into the neural network system used for fault analysis, thus impacting its accuracy. Additionally, the process of relying on customer calls and analyzing the data can be time-consuming [3,4].

It is important to consider these limitations and challenges when implementing fault detection and identification systems in power distribution networks. To overcome these drawbacks, the integration of advanced technologies can be beneficial. Automated fault detection algorithms, remote monitoring systems, and intelligent data analytics can enhance the efficiency and accuracy of fault identification processes. By leveraging these technologies, the reliance on customer complaints can be reduced, and faults can be detected and located more quickly and accurately.

Furthermore, establishing reliable communication channels with customers, such as mobile applications or online reporting systems, can enhance the speed and accuracy of fault reporting. This reduces dependence on traditional customer complaints and enables more efficient fault identification.

However, it is worth noting that in this research, the focus is on a higher-level infrastructure for fault localization. By employing remote switchgears in the network, the limitations and challenges associated with customer complaints mentioned earlier are mitigated. The use of remote switchgears provides direct access to fault information, bypassing the need for extensive reliance on customer reports.

While these advanced technologies and infrastructure improvements can address the limitations of traditional fault detection approaches, it is important to thoroughly evaluate their effectiveness and performance within the specific context of the research. Proper validation and testing are essential to ensure the reliability and accuracy of fault localization processes.

Limitations of manual inspection and repair: A significant limitation of manual inspection in the power distribution system is the considerable time it takes to locate faults. Therefore, it is crucial to explore the integration of advanced technologies and automated systems for more efficient fault detection and diagnosis. By leveraging these technologies, the identification of faults can be expedited, reducing the reliance on time-consuming manual inspections. Consequently, the time required for restoration can be minimized.

In the current context, the existing practice necessitates the breakdown gang to inspect the entire feeder to locate the fault. However, in the proposed system presented in this research, the breakdown gang is directed to the isolated section where the fault has been identified. This approach enables the repair process to commence promptly, within a shorter time.

By adopting advanced technologies and implementing an automated fault detection and diagnosis system, the proposed approach streamlines the restoration process by minimizing the time spent on fault localization. This can significantly enhance the overall efficiency and effectiveness of power distribution system maintenance and restoration procedures.

It is worth noting that the integration of advanced technologies and automation in fault detection and diagnosis is an area of ongoing research and development, and their application in the proposed system holds promise for improving the efficiency of fault localization and subsequent repair processes.

Improved Response Time: Automated approaches can significantly reduce the response time in detecting and restoring power outages [9]. With real-time monitoring and advanced fault detection systems, faults can be identified and located more quickly, allowing for faster dispatch of repair crews and restoration efforts.

Enhanced Accuracy and Precision: Automation can provide more accurate fault identification and diagnosis. Advanced analytics and algorithms can analyze data from various sensors and devices to pinpoint the exact location and nature of the fault. This precision enables quicker and more targeted repairs, minimizing downtime.

Efficient Fault Isolation and Restoration: Automation enables intelligent fault isolation and restoration strategies [10]. By leveraging smart grid technologies, such as remote-controlled switches and reconfiguration capabilities, faults can be isolated and power can be rerouted automatically, reducing the number of affected customers and expediting the restoration process.

Load Balancing and Optimization: Automated approaches allow for efficient load balancing during power restoration [11]. By dynamically managing load distribution and prioritizing critical loads, automated systems can optimize power allocation and reduce the impact on customers during the restoration process.

Despite the benefits of automation, it is essential to acknowledge the limitations of existing methods in power supply restoration:

Dependency on Manual Intervention: Traditional methods heavily rely on manual intervention and physical inspections, which can be time-consuming, labor-intensive, and subject to human error [3,4]. This can result in longer restoration times and potential delays in identifying and repairing faults.

2.3 CLSSIFICATION OF FEEDER RECONFIGURATION OPTIONS

Feeder reconfiguration refers to the process of adjusting the topology and configuration of power distribution feeders to optimize system performance, improve reliability, and minimize outage durations. Feeder reconfiguration options can be classified into several categories based on their characteristics and objectives [12].

Manual Reconfiguration: This involves manually adjusting the operation of switches and sectionalizing devices in the distribution network. Utility operators analyze system conditions, load patterns, and outage information to make informed decisions on switching operations. Manual reconfiguration allows for tailored and flexible adjustments based on real-time information and operator expertise [13].

Rule-Based Reconfiguration: Rule-based reconfiguration relies on predefined rules or algorithms to determine the optimal configuration of feeders based on certain criteria. These rules are typically based on load characteristics, system conditions, and reliability objectives. Rule-based methods automate the decision-making process and provide a systematic approach to feeder reconfiguration [14].

Event-Driven Reconfiguration: In this approach, feeder reconfiguration is triggered by specific events, such as a fault, an outage, or a significant change in load demand. When an event occurs, the system automatically initiates the appropriate reconfiguration actions based on predefined response strategies. Event-driven reconfiguration ensures quick response and efficient adaptation to changing system conditions [15]. This research is laid under this category.

Optimization-Based Reconfiguration: Optimization-based methods employ mathematical optimization techniques to determine the optimal configuration of feeders. These methods consider various objectives, such as load balancing, loss minimization, voltage regulation, and reliability improvement. Optimization algorithms iteratively search for the best configuration based on defined constraints and objective functions [16].

Distributed Reconfiguration: Distributed reconfiguration approaches involve the use of distributed control and communication systems to enable real-time coordination and decision-making among distributed energy resources, switches, and other network components. These approaches aim to improve system resiliency, load balancing, and power quality through decentralized control and coordination [17].

It's important to note that different distribution systems may employ a combination of these reconfiguration options based on their specific needs, resources, and goals. The choice of reconfiguration method depends on factors such as system characteristics, available technology, operational requirements, and desired performance objectives.

2.4 MATRIX BASED NETWORK MODELS AND THEIR APPLICATIONS

Matrix-based network models are mathematical representations used to describe and analyze complex networks, such as power distribution systems, transportation networks, social networks, and communication networks. These models represent the relationships between network components and enable the study of various network characteristics, behaviors, and phenomena. Different matrix-based network models and their applications are as follows [18]:

Adjacency Matrix: An adjacency matrix represents the connections or relationships between nodes in a network. It is a square matrix where each entry indicates whether an edge exists between two nodes. Adjacency matrices are commonly used in network analysis to study connectivity patterns, identify neighboring nodes, and analyze network properties like degree distribution and clustering coefficients.

Incidence Matrix: An incidence matrix represents the incidence relationships between nodes and edges in a network. It is a rectangular matrix where rows represent nodes and columns represent edges. The entries indicate whether a node is incident on an edge or not. Incidence matrices are used in various network analysis techniques, including network flow analysis, network optimization, and graph coloring.

Influence Matrix: Influence matrices are used to model influence propagation and dynamics in social networks. They capture the influence relationships between individuals or entities in the network. Influence matrices are employed in studies of viral marketing, opinion dynamics, and information spreading in social media networks.

Applications of matrix-based network models include [19]:

Power System Analysis: Matrix-based models are extensively used in power system analysis to study power flow, fault analysis, optimal power flow, and reliability evaluation. These models enable engineers to analyze and optimize the operation and performance of electrical grids.

Transportation Planning: Network models based on matrices are employed in transportation planning and traffic engineering. They facilitate the analysis of traffic flow, congestion, route optimization, and transportation system design.

Communication Network Analysis: Matrix-based models are utilized to analyze communication networks, including computer networks, social media networks, and telecommunications networks. They help in understanding network connectivity, routing algorithms, information diffusion, and network resilience.

CHAPTER 3

3 DEVELOPMENT OF MATRIX BASED FEEDER RECONFIGUURATION ALOGRITHM

3.1 INTRODUCTION

The hypothesis of this research posits that representing a utility network as matrices and analyzing its status through matrix operations, based on externally provided parameters, is an effective approach for medium scale utility networks for feeder reconfiguration under faulty situation. This chapter aims to provide a detailed exploration of the types of matrices involved in mathematically modeling a utility network. Additionally, it delves into the utilization of these matrices within the algorithm to derive results through matrix calculations. Furthermore, the chapter elucidates the functionalities of the algorithm in relation to the utility network analysis.

3.2 MATRIX BASED MODELING OF UTILITY NETWORK

The modeling of a utility network is essential for conducting comprehensive analyses across diverse domains. The main types of utility network models include Bus-Branch, Power Flow, Topological, Dynamic, State Estimation, and Optimization models. The selection of an appropriate model depends on the specific objectives of the study, the desired level of detail, and the availability of computational resources. Matrix-based modeling approaches, encompassed within the Topological Model, offer improved scalability and mathematical rigor compared to conventional topological models. Traditional models primarily focus on the network's connectivity and structure, rather than intricate electrical parameters. Topological models are commonly employed for reliability analysis, fault detection, and optimizing network reconfiguration. The matrix-based model is characterized by its dynamic nature, wherein the entire network can be represented using multiple matrices. This approach significantly enhances computational flexibility compared to the analysis of a graphical model within a computer system.

When it considers the matrix-based model, it includes power supply sources, power lines and switches as primary objects in the utility network. Status of the electrical instrument like open/ close, connected/ not connected and energized/ de-energized represent as binary value of “1/ 0” in a cell of the matrix. This simple representation enhances the speed of the matrix operations.

3.2.1 System inputs for matrix formation

The key inputs for constructing the matrices in the utility network modeling process include switches, line sections, feeding points, and normally open switches. These elements play a crucial role in determining the system's configuration. Additionally, loading data pertaining to each line section is required to accurately assess the system's status, such as the total power consumption at a given moment. Signals originating from remote switches serve as interruptions that affect the system's status, triggering the algorithm to update the system's state following the detection of an outage occurrence.

3.2.2 Classification of Matrices

Matrix-based utility network model consists of single-dimensional and two-dimensional matrices. Row space and column space of two-dimensional matrix extends up to total switch count of the network and total line section count of the network. When it considers the medium scale utility network, these counts are ranged from a few hundred to several thousand.

3.2.2.1 All Connection Matrix

The formation of the all-connections matrix relies on the vital input known as the all-connections table. This table serves as a fundamental component in the creation of the matrix. The all-connections matrix itself is a two-dimensional structure with rows corresponding to the total count of switches in the system and columns corresponding to the total count of line sections. General format of all-connection matrix is shown in Equation 3.1.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

$$n - count\ of\ total\ line\ sections\ in\ the\ network$$

$$m - count\ of\ total\ MV\ switches\ in\ the\ network$$

Equation 3.1. General format of two-dimensional all connection matrix.

The all-connections matrix captures the connectivity information between switches and line sections within the system. Each entry in the matrix represents a connection or relationship between a specific switch and a particular line section. The row index corresponds to a specific switch, while the column index corresponds to a specific line section, thus providing a comprehensive depiction of the network's connectivity.

By utilizing the all-connections table as an input, the resulting all-connections matrix facilitates the analysis and understanding of the relationships and interconnections between switches and line sections within the utility network.

3.2.2.2 Normally Open Points Matrix

The normally open points matrix is a one-dimensional matrix comprised of an array of switches that are typically maintained in an open position during the normal operation state of a system. These switches serve as physically connected, yet electrically disconnected points between two energized lines within a radially operated utility network. The primary characteristic of normally open switches is that they establish a physical connection while maintaining an electrical disconnection. Additionally, both sides of the normally open switch may receive power from the same or different sources, depending on the configuration and requirements of the network.

$$N = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_p \end{bmatrix}$$

$$p - count\ of\ the\ normally\ open\ switches\ in\ the\ network$$

Equation 3.2. General format of normally open points matrix

3.2.2.3 Feeding points matrix

The feeding points matrix, like the all-connections matrix, is a two-dimensional matrix that plays a significant role in utility network analysis. This matrix consists of arrays of switches that are connected on one side to a power source, such as substations. Each switch entry in the matrix is associated with the corresponding substation ID recorded in an adjacent column.

$$F = \begin{bmatrix} f_{11} & f_{12} \\ f_{21} & f_{22} \\ \vdots & \vdots \\ f_{q1} & f_{q2} \end{bmatrix}$$

$$q - count\ of\ the\ feeding\ points\ in\ the\ network$$

Equation 3.3. General format of feeding point matrix

By organizing the feeding points information in this matrix format, a comprehensive representation of the connections between switches and substations is achieved. The matrix provides insights into the feeding relationships within the utility network, identifying the switches that receive power from specific substations.

3.2.2.4 Energized Matrix

The energized matrix, similar to the all-connections matrix, is a two-dimensional matrix that encompasses the same dimensions and structure. It is derived through matrix operations involving the aforementioned three matrices: the all-connections matrix, the normally open points matrix, and the feeding points matrix. General format of energized matrix is shown in the equation 3.4.

$$\mathbf{E} = \begin{vmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ e_{21} & e_{22} & \cdots & e_{2n} \\ & & & \vdots \\ e_{m1} & e_{m2} & \cdots & e_{mn} \end{vmatrix}$$

$$n - count\ of\ total\ line\ sections\ in\ the\ network$$

$$m - count\ of\ total\ MV\ switches\ in\ the\ network$$

Equation 3.4. General format of energized matrix.

Switching the column and row operations repeatedly until all the rows and columns cover, the energized matrix obtained and it produced the information about the energized or active line sections within the utility network. It represents the connectivity and operational status of line sections based on the switches' positions, the presence of normally open points, and the feeding points' connections to substations. The energized matrix facilitates the identification of active line sections, enabling the determination of the current state of the utility network. By examining the energized matrix, critical information about the energized line sections and their associated characteristics, such as total power consumption of the system, can be extracted and analyzed. One important outcome of the energized matrix is the generation of a total energized line section array. This array represents a fundamental result that can be derived from the energized matrix. It provides a concise summary of the active line sections within the network, aiding in further analysis, optimization, and decision-making processes related to the utility network's operation and troubleshooting.

3.3 UTILIZATION OF THE MATRICES IN THE ALGORITHM

All-connection matrix is the key matrix in this algorithm. All the calculation related to network are run top of this connection matrix. In other words, it can identify all-connection matrix is the model of physical connection of the real network switches and the line segments.

When it considers the status of any MV switch connected to the distribution network, it should either opened or closed. Using the normally open switch list the total switches list is detailed and divided in to two categories. Those are the normally open switches and normally closed switches. After applying this switches status to the all-connection matrix, as the result matrix of electrical connections of the network is obtained. This is an intermediate matrix generating while the process of deriving the energized matrix. This matrix is obtained by switching the binary “1” values to “0” of the normally opened switches in the all-connection matrix by a row operation. The size of this matrix is also similar to the all-connection matrix, but this matrix gives electrical connectivity of the MV distribution network.

After preparation of the electrical connectivity matrix, row operation starts and multiply all the row by 11. Then the binary 1 value is updated as 11 in each row of feeding switches. it is similar to energizing the first switch of the network. Once the row operation completed for all feeding switches, column operation is started. If any line section has 11 values in their columns, all other values in the same column multiplied by 11 and make all the binary 1 value in the same column in to 11. Then the same operation is done to all rows again. This is similar to the power flowing in the distribution network switch to line and line to switch consecutively. After continuing this process until the total count of the 11 cells in the matrix saturated the columns and row operations stopped. It indicates the entire electrically connected network is energized.

In the energized matrix, a value of 11 in a cell indicates that the corresponding line section is energized. By analyzing each column of the matrix, one can identify the line sections that carry electrical power. If a column contains 11 value cells, it signifies that the corresponding line section is actively transmitting electricity within the network. This represents the fundamental input and output process of the main matrix, which serves as the foundation for the algorithm. Leveraging this matrix structure in conjunction with various parameters and constraints, the algorithm employs the matrix to perform crucial analyses such as identifying faulty sections, isolating these sections, and restoring power supply.

3.4 MAJOR FUNCTIONALITIES OF MATRIX BASED ALGORITHM

The matrix-based algorithm employed in this research demonstrates a fundamental functionality in which the input of all-connections, normally open points, and feeding points initiates the execution of the algorithm. The algorithm utilizes these inputs to construct a matrix representation of the network structure, capturing its interconnected components and relationships. Consequently, the algorithm generates an output that identifies the energized lines within the network.

This fundamental functionality serves as the foundation for the matrix-based algorithm. Building upon this foundation, the algorithm leverages the same matrix structure to perform additional analyses and computations. Specifically, it utilizes the matrix structure to identify faulty sections within the network, pinpoint the switches located at the boundaries of these faulty sections, determine the feeding end switch of the faulty feeder, and identify the tail end normally open switches of the faulty feeder. Complete flow chart of the algorithm is attached as ANNEXURE 1 and Figure 3.1 shows a section of the algorithm that formulate the matrices of the distribution network.

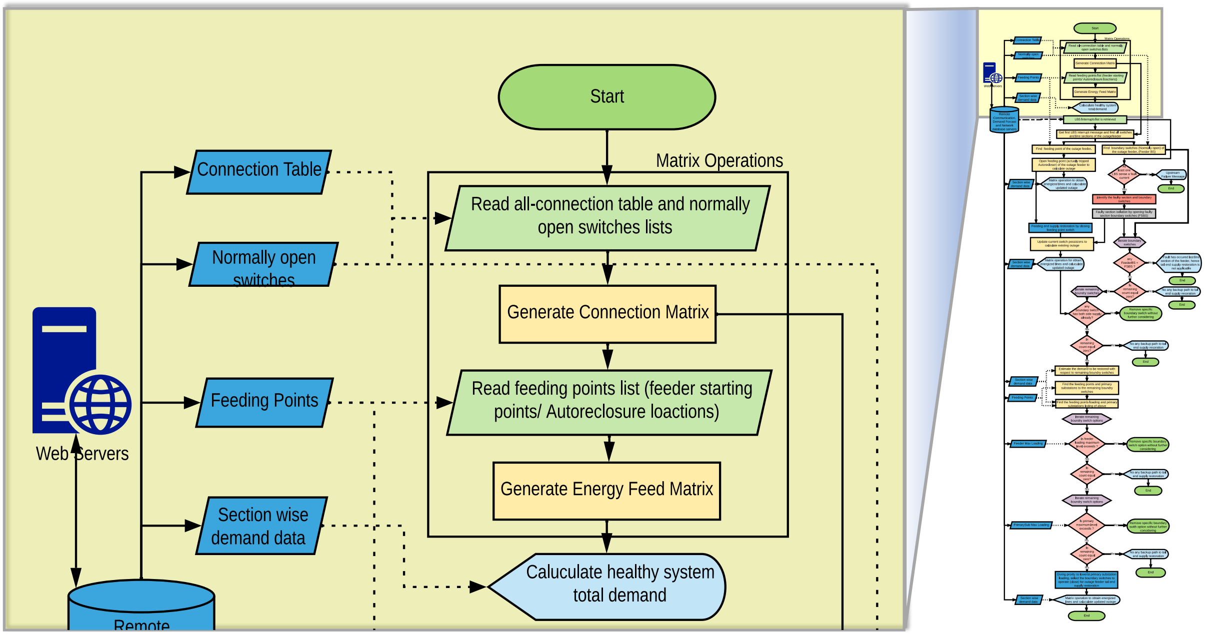


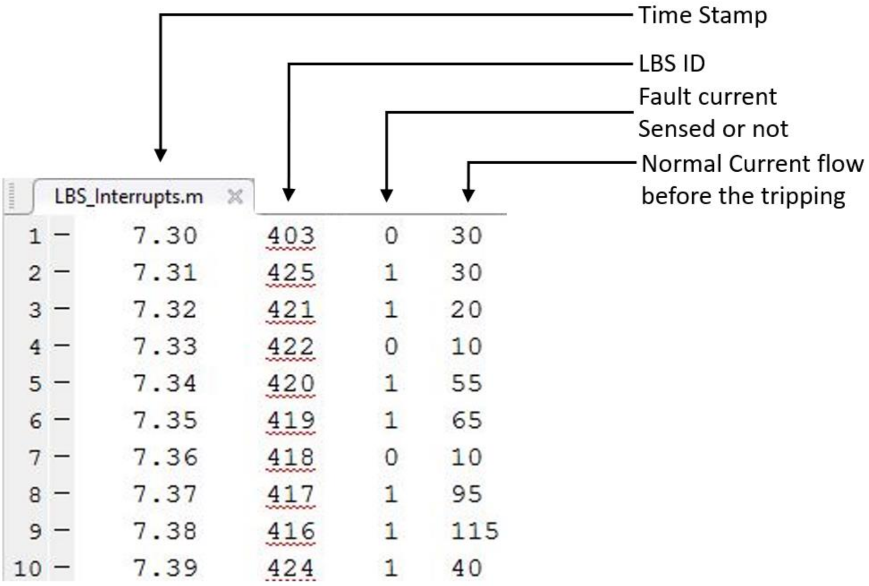
Figure 3.1. Formation of matrices.

The subsequent sections of this chapter delve into comprehensive discussions on these advanced functionalities of the algorithm. These discussions provide a detailed exploration of how the algorithm exploits the matrix structure to effectively detect and diagnose faults in the network. The algorithm's capacity to identify faulty sections, boundary switches, feeding end switches, and tail end normally open switches is extensively examined, providing detailed insights into the underlying details and mechanisms.

3.4.1 Fault localization

Fault localization is the first step of clearing a supply outage situation occurred in a power distribution network. But it takes considerable time period to fault localization in the manual process. Because network operators have to wait until the massage reach from the customers to identify there is an outage in the system and need to dispatch field staff along the power supply route until they find any visible fault in the network.

When the network operates with remote switches, distribution control center can easily obtain the tripping details with extra parameters such as, weather there was fault current or not, and before the tripping, loading level through each switch as well. Figure 3.2 shows a sample of LBS interrupts generated according to the fault occurred in the MV network.



```
7.30    403    0    30
7.31    425    1    30
7.32    421    1    20
7.33    422    0    10
7.34    420    1    55
7.35    419    1    65
7.36    418    0    10
7.37    417    1    95
7.38    416    1    115
7.39    424    1    40
```

Figure 3.2. Sample LBS Interrupts table

Load Break Switch (LBS) interrupts received from remote switches were deliberately generated and inputted manually into the algorithm to simulate its performance. The provided sample LBS interruptions table was also manually generated. Once these LBS interrupts were received by the system, the algorithm was triggered, and it underwent a series of steps, as illustrated in Figure 3.3, to identify the faulty section, thereby facilitating fault localization.

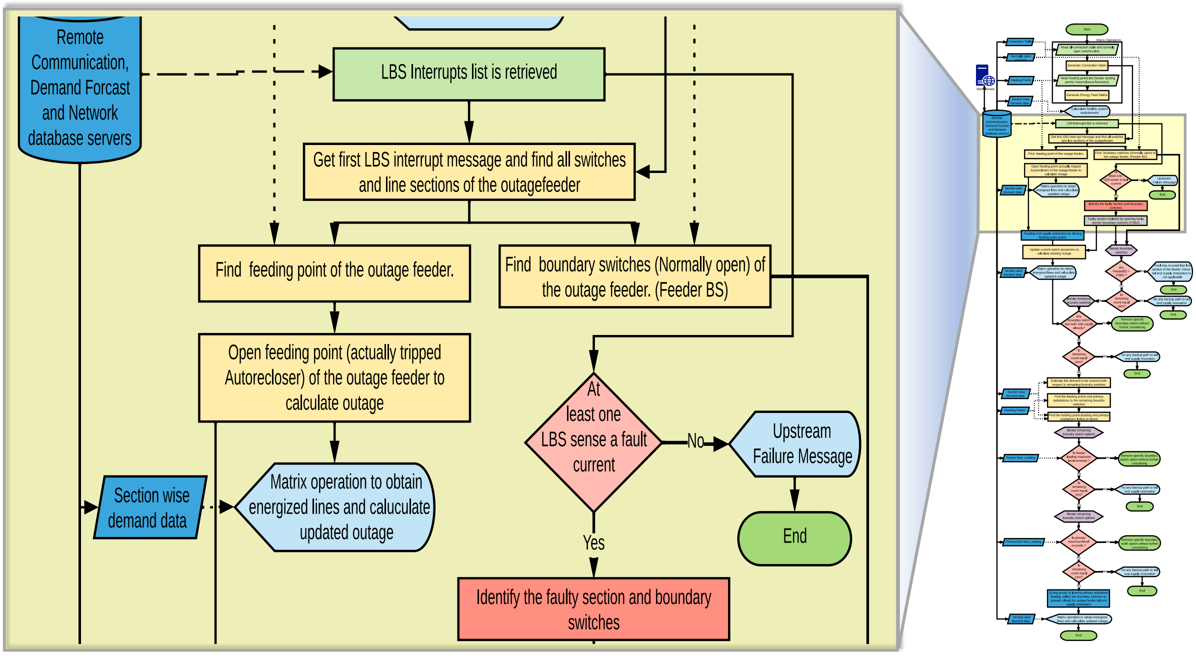


Figure 3.3. Fault localization

In the practical use of this algorithm, just after the fault localization is done, field staff to be informed and to be dispatched to observe the site and take measures to rectify the fault as early as possible.

3.4.2 Fault Isolation

After the fault localization is done, algorithm provides the switches to be opened (faulty section boundary switches) to isolate the faulty section. Since these all switches are remote switches, those can be operated remotely by distribution control center within few seconds. Figure 3.4 shows that where the fault isolation step included in the algorithm.

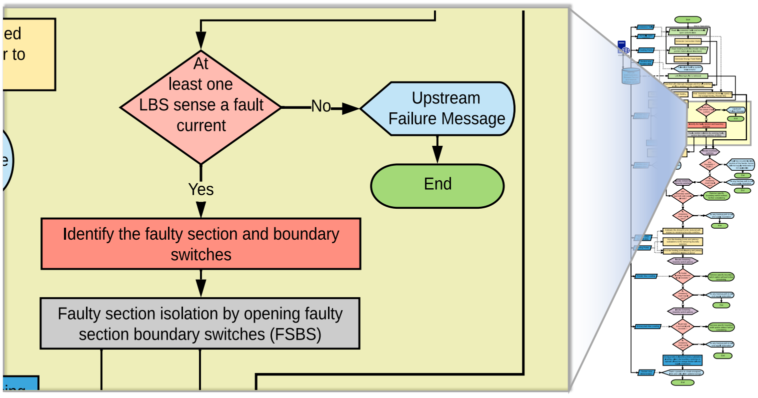


Figure 3.4. Faulty section isolation

3.4.3 Supply restoration

Supply restoration consists of two parts, the first one is the feeding-end supply restoration, the second one is the feeder tail-end supply restoration. Figure 3.5 shows the feeding-end and tail-end of a sample faulty feeder graphically.

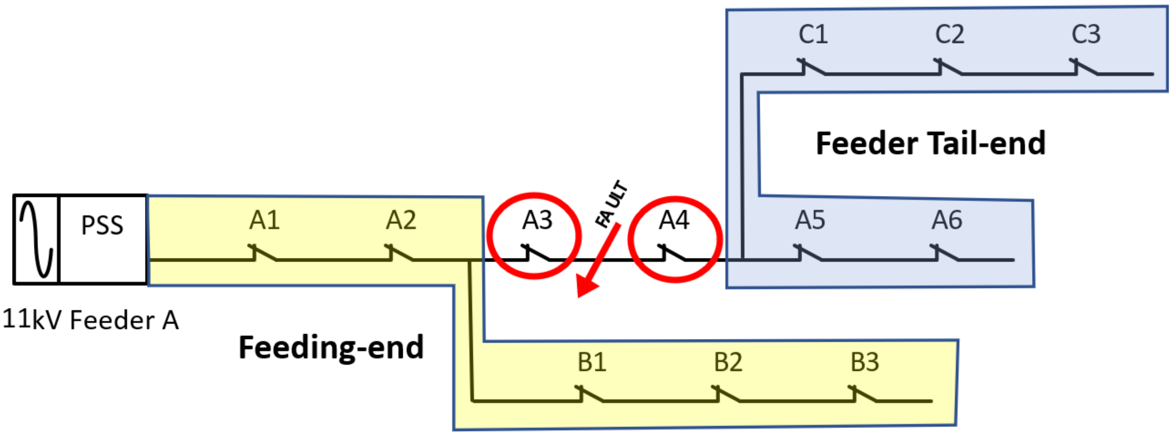


Figure 3.5. Feeding-end and tail-end of a faulty feeder.

The algorithm addresses the processes of feeding-end supply restoration and tail-end supply restoration as distinct entities. Given the straightforward nature of feeding-end supply restoration, it is handled independently. Conversely, the tail-end supply restoration, being more intricate, requires specialized treatment and is approached separately.

3.4.3.1 Feeding-end supply restoration

Feeding end is the section from the PSS to the just before switch of the faulty section. Energizing the

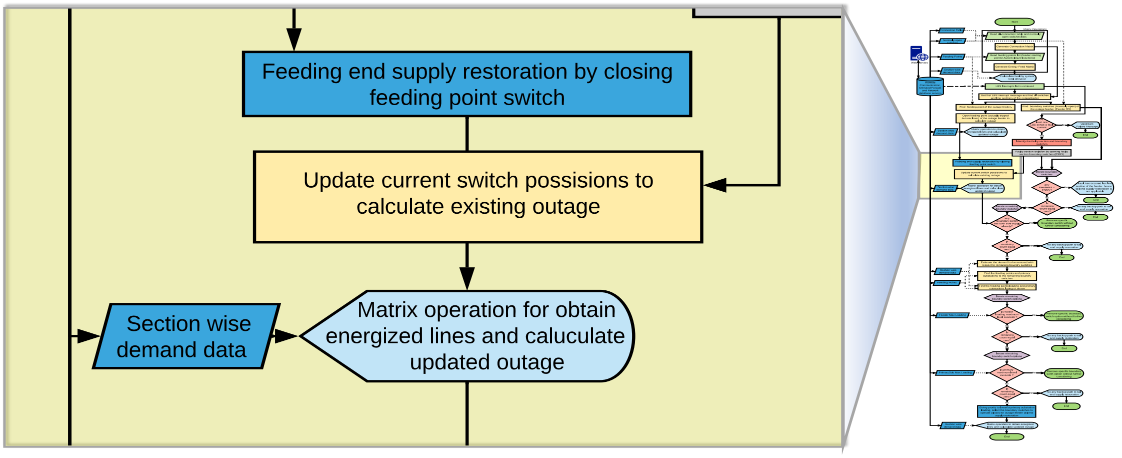


Figure 3.6. Feeding-end supply restoration

3.4.3.2 Feeder tail end supply restoration

Figure 3.5 shows the section of the algorithm that address for the feeder tail-end supply restoration.

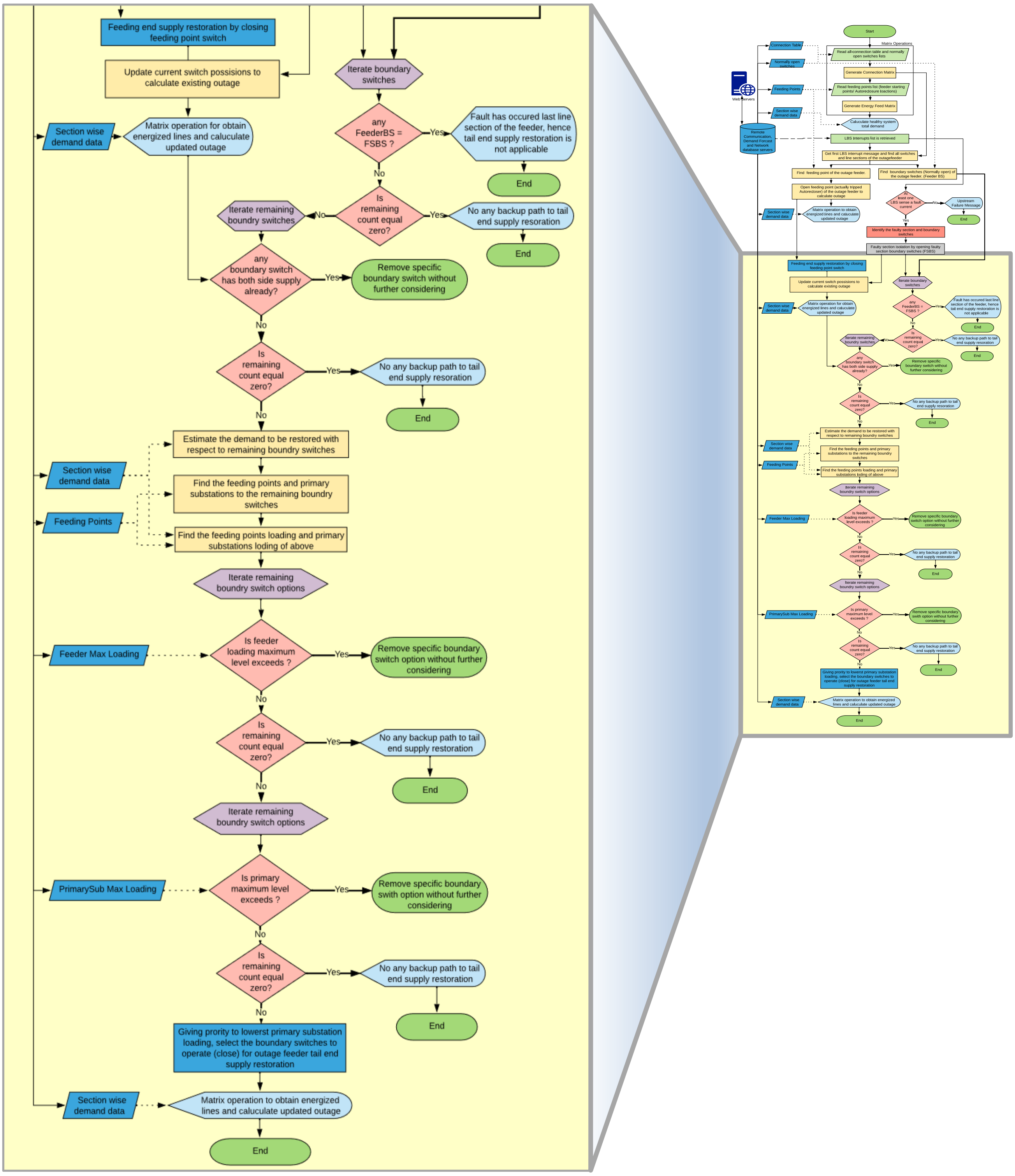


Figure 3.7. Faulty feeder tail end supply restoration

The summary of the complete algorithm is shown in Figure 3.8 below. The main functionality sections are circled of the algorithm.

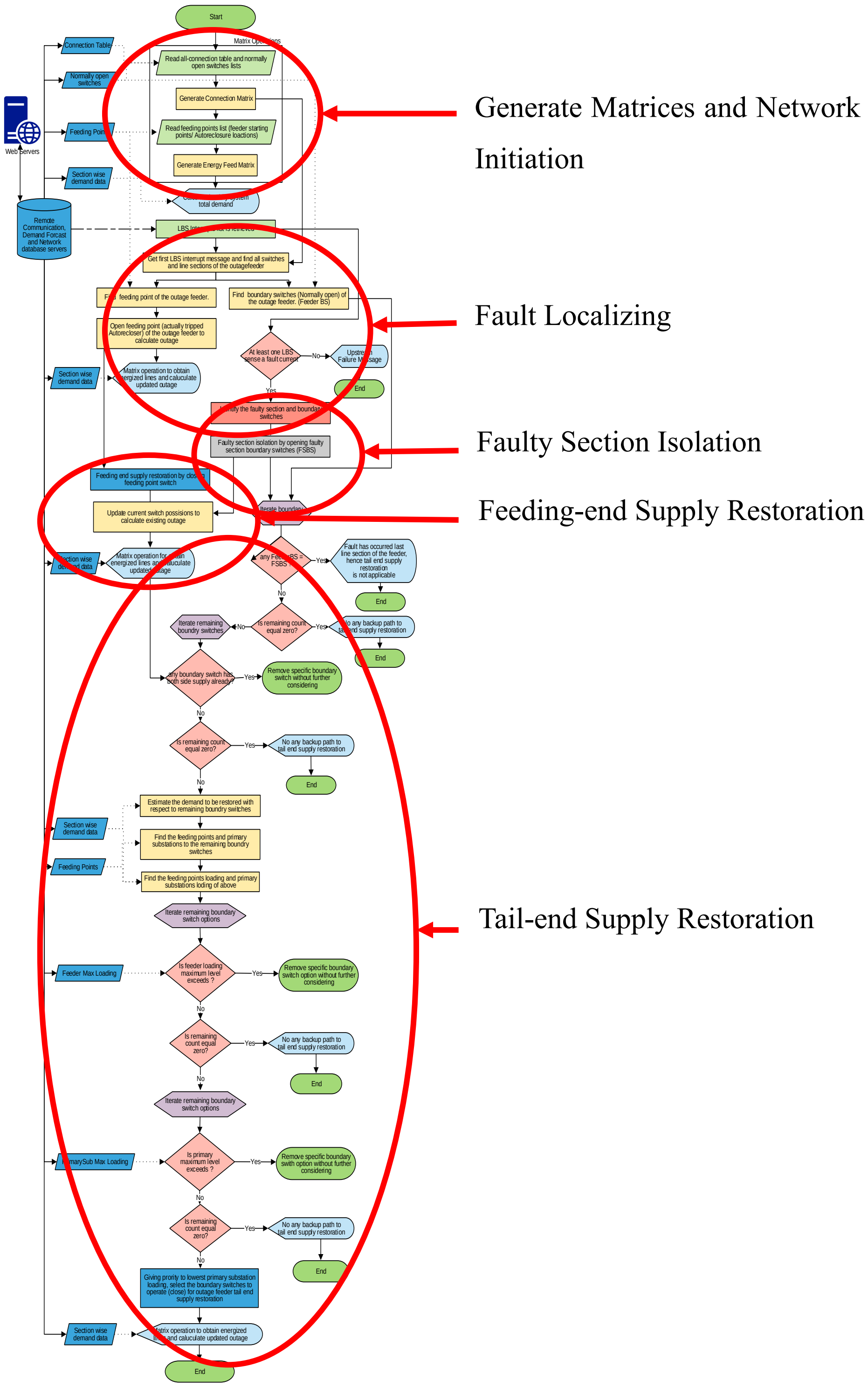


Figure 3.8. Summary of the algorithm

CHAPTER 4

4 VERIFICATIION OF THE PROPOSED ALGORITHM

4.1 INTRODUCTION

In this chapter, a comprehensive verification of the proposed algorithm was conducted to assess its performance and effectiveness. The verification process involved rigorous analysis and testing of the algorithm using both hypothetical and real-world MV network data. The objective was to evaluate the algorithm's capability to accurately detect and isolate faults, as well as restore power supply in the 11kV network with input interrupts manually fed as received by remote MV switches.

To initiate the verification process, a hypothetical network was thoroughly examined. This allowed for extensive testing of the algorithm under various conditions, ensuring its robustness and reliability. Several test cases were designed and executed, enabling a systematic assessment of the algorithm's performance and its ability to handle different fault scenarios.

In addition to the hypothetical network, the algorithm was also validated using actual network data. This step aimed to confirm the algorithm's effectiveness in real-world situations. By applying the algorithm to real network data, its practical performance was evaluated, taking into account the complexities and challenges of operational networks.

To ascertain the algorithm's accuracy and efficiency, a comparative analysis was performed. The results obtained from the algorithm were compared with those derived from manual calculations. This comparative assessment highlighted the algorithm's superior performance in terms of both accuracy and efficiency, underscoring its potential as a reliable tool for fault localization and power restoration.

4.2 ANALYSIS OF HYPOTHETICAL NETWORK

4.2.1 Network Parameters

The hypothetical network consisted of two primary substations, which acted as the sources of power. Additionally, it included 30 remote switches (AR/LBS) that functioned as medium voltage switches, as well as 23 line sections within the network. The schematic representation of this hypothetical network can be observed in Figure 4.1.

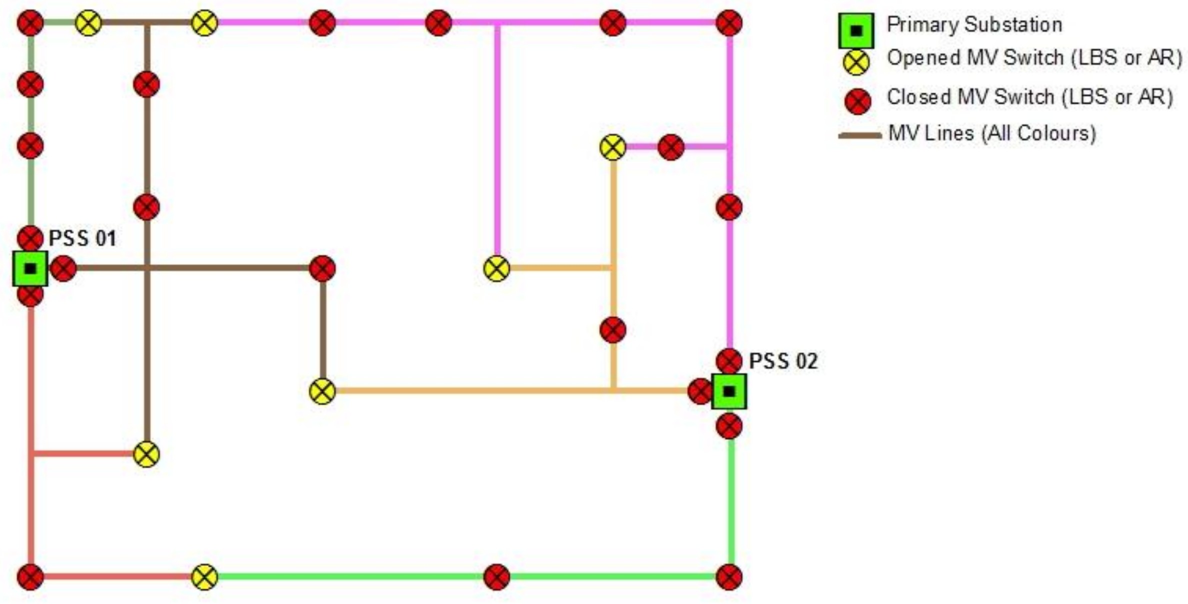


Figure 4.1. Hypothetical medium voltage network.

By utilizing this hypothetical network, it was able to create simulations that mimicked different fault conditions that may occur in a real-world distribution system. These simulations allowed us to observe how the algorithm performed in identifying and responding to these faults, providing insights into its capabilities and limitations.

The use of a hypothetical network provided a controlled environment for testing and evaluating the algorithm's performance. It enabled to assess its effectiveness in a simulated yet representative system, providing valuable information for further development and refinement of the algorithm. For the ease of referencing the detailed analysis of the hypothetical network, Figure 4.2 shows the hypothetical network with IDs of each network element,

For convenient reference, all the line sections were given 200~299 range IDs, all MV switches were given 400~499 range IDs and PSS 01 & PSS 02 were given 6001 and 6002 IDs respectively.

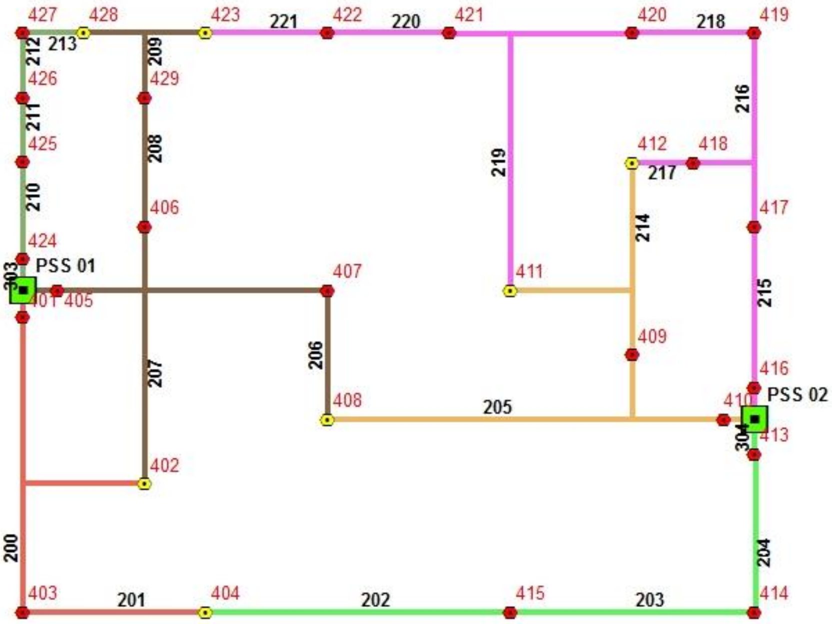
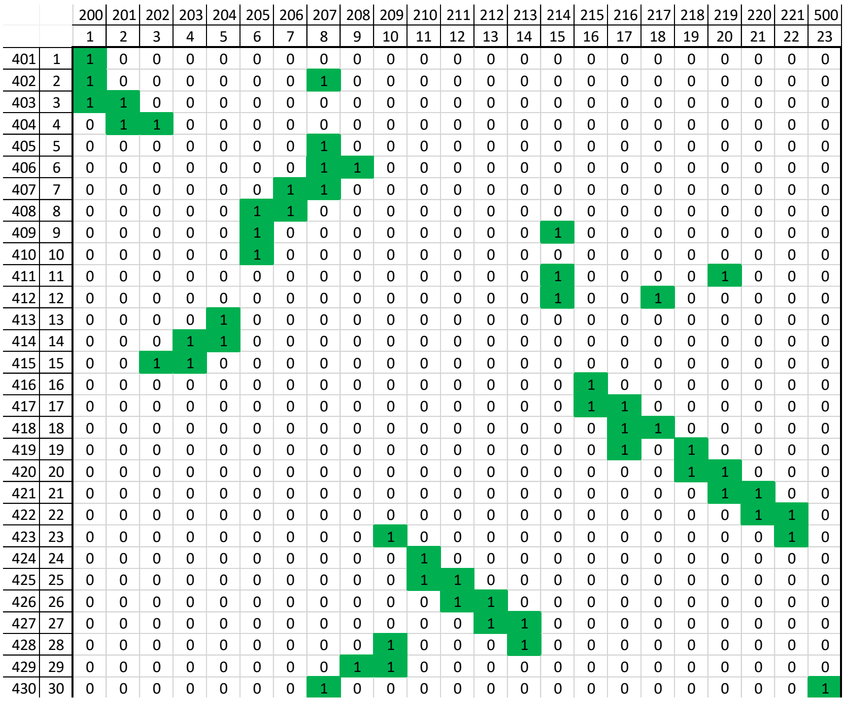


Figure 4.2. Hypothetical MV network with switches and lines IDs.

All-connection matrix of hypothetical network is shown in below Table 4.1. The matrix generated in this study is a 23 x 30 matrix, which corresponds to the number of switches and line sections in the hypothetical power distribution system. It consists of 30 columns representing the switches and 23 rows representing the line sections. Each element in the matrix represents the connectivity or state of a specific switch-line section combination, providing a comprehensive representation of the network topology and configuration.



		200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	500
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
401	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
402	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
403	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
404	4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
405	5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
406	6	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
407	7	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
408	8	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
409	9	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
410	10	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
411	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
412	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
413	13	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
414	14	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
415	15	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
416	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
417	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
418	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
419	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
420	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
421	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
422	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
423	23	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
424	24	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
425	25	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
426	26	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
427	27	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
428	28	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
429	29	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
430	30	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 4.1. All-connection matrix of the hypothetical network.

The mimic diagram, as shown in Figure 4.2, provides a visual representation of the hypothetical network under examination, highlighting the presence of 7 normally open switches. These specific switches are enumerated in Table 4.2 for reference and analysis. In the context of a fully energized system, normally open switches serve as key elements that create separation between two energized lines originating from the same or different primary substations. Their purpose is to establish a radial configuration within the distribution network.

It is worth noting that when these normally open switches are closed, the system transforms into a ring connection, allowing for alternative paths for power flow. However, in both the theoretical framework being investigated and practical scenarios, many utilities prefer ring-connected systems that are operated in a radial manner for medium voltage (MV) power distribution.

The choice of a ring-connected yet radially operated system in practical situations is a strategic decision made by utilities. This approach combines the advantages of ring topology, which offers redundancy and flexibility in power flow, with the operational simplicity and reliability associated with a radial operation. By adopting such a configuration, utilities can achieve enhanced system performance, efficient fault localization, and improved restoration times.

By considering the presence and significance of normally open switches in the hypothetical network and the practical preference for ring-connected but radially operated systems in real-world MV power distribution, gain valuable insights into the design and operational considerations of distribution networks. It contributes to a comprehensive analysis of the hypothetical network in relation to industry practices and requirements.

IDs of Normally Open Switches
402
404
408
411
412
423
428

Table 4.2. Normally open switches in the hypothetical network.

In the scope of the hypothetical network being studied, it is observed that there exist 6 feeding points. These feeding points, which are outlined in Table 4.3, serve as remote communication-enabled switches that establish a connection to the medium voltage (MV) distribution system immediately after the primary substation. It is important to note that while this network is hypothetical in nature, in actual distribution networks, similar functionalities are often fulfilled by employing auto reclosures.

In real-world distribution systems, auto reclosures play a crucial role in serving as the feeding points that connect the MV distribution system to the primary substation. These devices are designed to automatically interrupt and restore power supply in the event of transient faults, such as momentary faults caused by lightning strikes or temporary disruptions due to vegetation contact with power lines. Auto reclosures enable the swift restoration of power without the need for manual intervention, thereby enhancing the overall reliability and efficiency of the distribution system.

By considering the concept of feeding points and their association with remote communication-enabled switches or auto reclosures, researchers gain insights into the practical implementation and functionality of these components in real-world distribution networks. This understanding contributes to the overall analysis and evaluation of the hypothetical network within the context of actual distribution system practices and technologies.

Feeding Points	
Feeding Switch	Primary Sub.
424	6001
413	6002
410	6002
416	6002
401	6001
405	6001

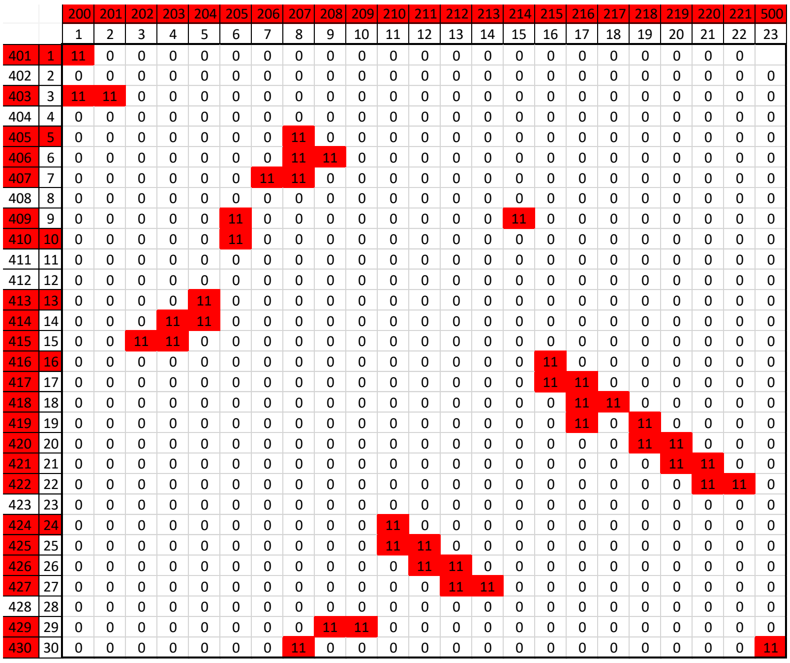
Table 4.3. Feeding switches with PSS IDs of the hypothetical network.

Utilizing the switches, line segments, feeding points, and normally open points outlined earlier, the initial phase of the algorithm is devoted to deriving the energized matrix. This matrix serves as a representation of all the energized lines within the system. During the analysis of the energized matrix, a column-wise examination is conducted, whereby each column signifies a specific line segment.

By assessing the values within each column, it is possible to determine the energization status of the corresponding line segment. If any row within a column contains a value of 11, it indicates that the particular line segment is energized. Consequently, by confirming the presence of at least one value of 11 in any row for every column, it can be inferred that the entire system has been successfully energized.

This approach of evaluating the energized matrix facilitates the identification and assessment of the energization state of each line segment in the network. By systematically examining the values within the matrix, researchers can accurately determine the overall energization status of the entire system.

The process of deriving and analyzing the energized matrix provides a systematic framework for understanding and assessing the energization of line segments within the network. Healthy state, energized network is shown as Energized matrix in the Table 4.4.



		200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	500
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
401	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
402	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
403	3	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
404	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
405	5	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
406	6	0	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
407	7	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
408	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
409	9	0	0	0	0	0	11	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0
410	10	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
411	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
412	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
413	13	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
414	14	0	0	0	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
415	15	0	0	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
416	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
417	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11	0	0	0	0	0	0
418	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11	0	0	0	0	0
419	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	11	0	0	0	0
420	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11	0	0	0
421	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11	0	0
422	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11	0
423	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
424	24	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0
425	25	0	0	0	0	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0	0	0	0	0
426	26	0	0	0	0	0	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0	0	0	0
427	27	0	0	0	0	0	0	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0	0	0
428	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
429	29	0	0	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0
430	30	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11

Table 4.4. Energized matrix of the hypothetical network.

4.2.2 Development of MATLAB based Simulation Platform

MATLAB is widely regarded as a highly suitable software environment for conducting matrix analysis. With its extensive set of built-in functions and specialized toolboxes, it provides a robust platform for efficiently handling and manipulating matrices. And also, the software provides a user-friendly programming language that allows for concise and intuitive expression of matrix operations. Its syntax and functionality are specifically designed to facilitate matrix manipulation, making it easier for researchers and practitioners to perform complex analyses on matrices. Considering these aspects, the MATLAB environment was chosen to build up the simulation platform for this research.

4.3 TEST CASES

This section focuses on the discussion of five distinct test cases that encompass a range of potential outage scenarios within the hypothetical network. These test cases were carefully designed to evaluate the performance and effectiveness of the algorithm in identifying and responding to various outage situations.

Each test case simulated a specific outage scenario, such as a fault on a particular line section. The algorithm was applied to these test cases to determine its ability to accurately localize the fault, isolate the faulty section and supply restoration of both feeding and tail end of the feeder.

To validate the algorithm's results, a comparison was made between the outcomes obtained from the algorithm with the expected result in manual method. This comparison aimed to assess the consistency and reliability of the algorithm's performance in relation to traditional manual techniques. Let’s consider the below healthy MV network shown in the Figure 4.3.

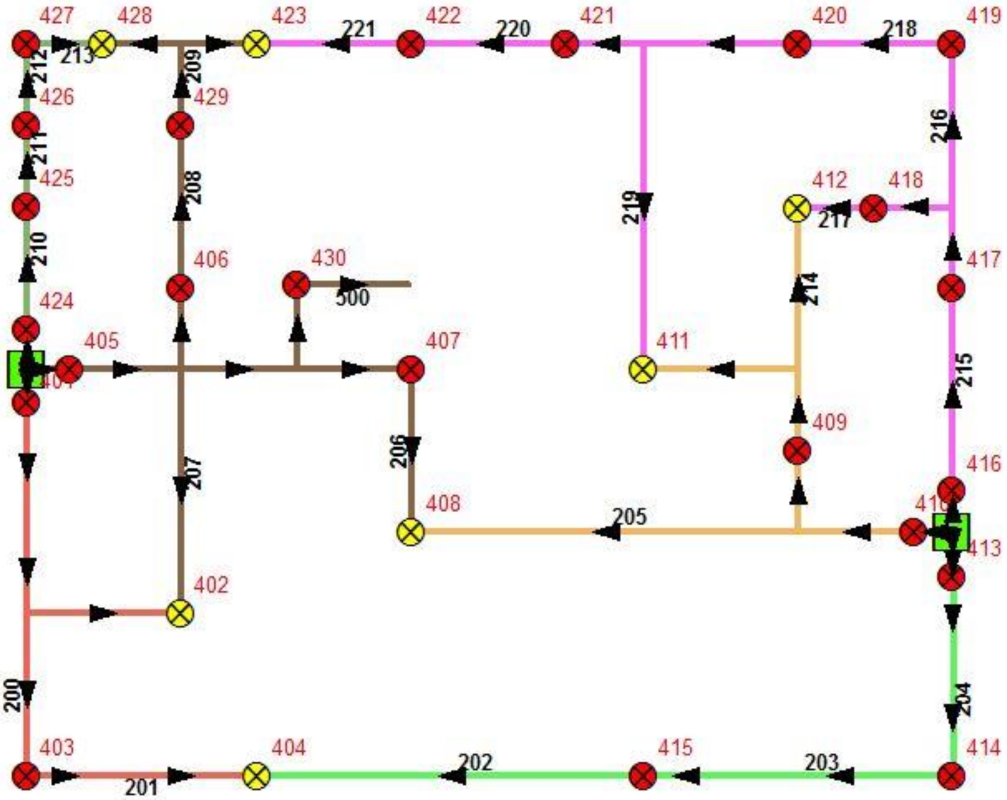


Figure 4.3. Hypothetical network - Healthy state

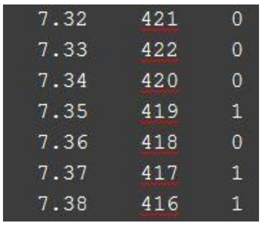
Normal state power flow directions are shown as black arrow heads. Primary substations are shown in green color, normally closed switches are shown in red color and normally open or abnormally open or tripped switches are shown in yellow color. Feeder starting switches 404, 405, 410, 413, 416 and 424 are considered as protection enabled switches which can trip off the line when downstream fault occurred. In general practice auto reclosures are used for the same purpose those are advance technical devices use in the MV distribution field. Those have remote communication capability in-built.

Testing method:

1. Select a section in the network and assume that section is the faulty section.
2. If fault is there, fault current path through the feeder is identified.
3. Identify the switches along the fault current path that sensed the fault current.
4. Considering total tripped feeder switches with the fault current sensed switches, LBS interrupts are manually generated to give as input to the algorithm.
5. Based on those inputs, algorithm manipulate data to identify the faulty feeder, faulty section, faulty section isolating switches, switches to be operated to supply restoration also came as outputs from the algorithm.
6. These results are compared with the expected results and check are there any deviation with the expected and received results.
7. When this process run for the different possible scenarios. It can be identifying whether the algorithm is correct or having any issues.

Test case 1:

A situation with fault on a middle section (218) of a feeder. Feeding end supply restoration is possible. Tail end supply restoring also possible. In this case, only one section is available to restore the supply at tail end. But it has two options, closing 423 or 411. feeder loading and relevant primary loading to be considered.



```
7.32    421    0
7.33    422    0
7.34    420    0
7.35    419    1
7.36    418    0
7.37    417    1
7.38    416    1
```

Figure 4.4. Test Case 1 - LBS Interrupts

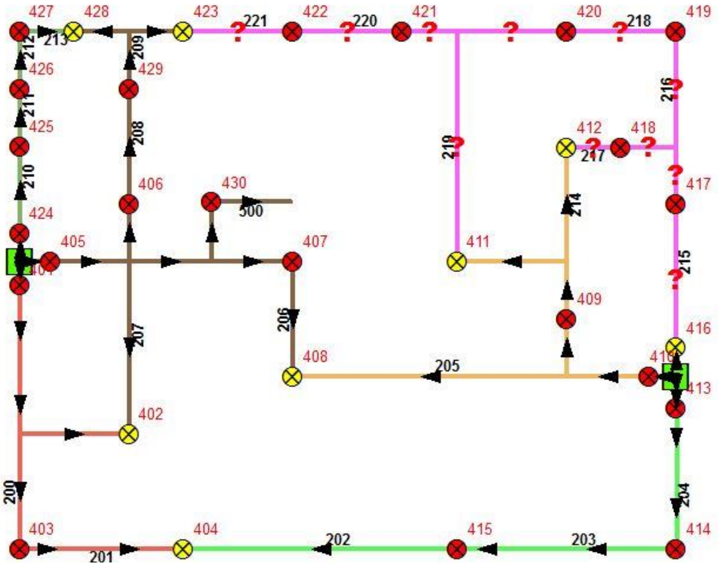
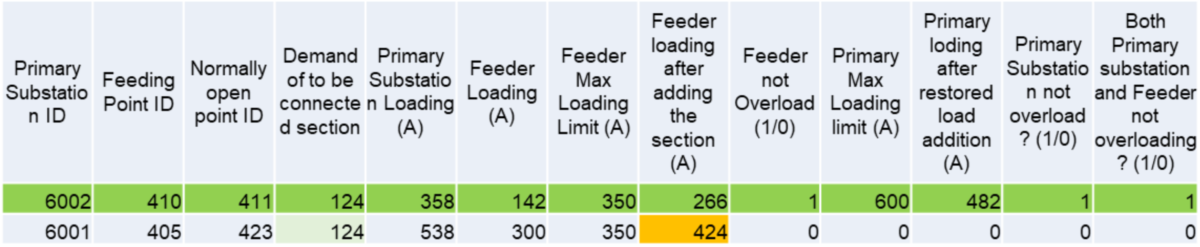


Figure 4.5. Test Case 1 - Outage Feeder

- #####---Summary of feeder reconfiguration process---######
- Healthy system total demand = 1042 A
- After fault system Outage = 233 A
- -----Fault Locating-----
- Faulty Line Section of Outage Feeder
- 218
- -----Fault Isolating-----
- Fault Isolating Switches
- 419
- 420
- ***Faulty section isolation by opening the Fault Isolating Switches***
- -----Feeding End Supply Restoration-----
- feeding Switch for outage feeder
- 416
- ***Supply restoration of feeding end by reclosing the Feeding Switch***
- After feeding end supply restoration total system Outage = 146 A
- -----Tail End Supply Restoration-----
- Normally open switches to be close to tail end supply restoration.
- 411
- After tail end supply restoration total system Outage = 22 A
- ##########-----------------End----------------##############



Primary Substation ID	Feeding Point ID	Normally open point ID	Demand of to be connected section	Primary Substation Loading (A)	Feeder Loading (A)	Feeder Max Loading Limit (A)	Feeder loading after adding the section (A)	Feeder not Overload (1/0)	Primary Max Loading limit (A)	Primary loding after restored load addition (A)	Primary Substation not overload ? (1/0)	Both Primary substation and Feeder not overloading ? (1/0)
6002	410	411	124	358	142	350	266	1	600	482	1	1
6001	405	423	124	538	300	350	424	0	0	0	0	0

Table 4.5. Test Case 1 - Critical decision to select restoration path.

In this case normally open 423 switch is rejected due to exceeding the feeder maximum loading level. Algorithm has been performed as expected for this scenario.

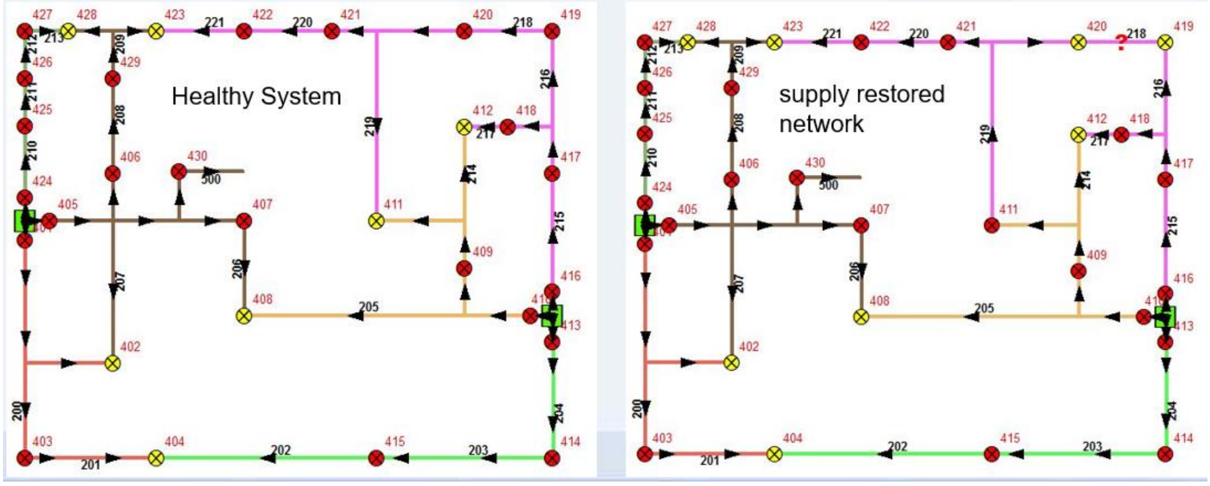
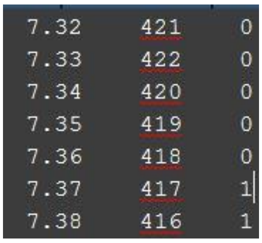


Table 4.6. Test Case 1 - Healthy system and supply restored system.

Test case 2:

A situation with fault on a middle section of a feeder. Feeding end supply restoration is possible. Tail end supply restoring also possible.

In this case, there are two sections to restore the supply at tail ends. As previous case among these two sections, one section has two options, closing 423 or 411. feeder loading and relevant primary loading to be considered.



```
7.32    421    0
7.33    422    0
7.34    420    0
7.35    419    0
7.36    418    0
7.37    417    1
7.38    416    1
```

Table 4.7. Test case 2 - LBS interrupts

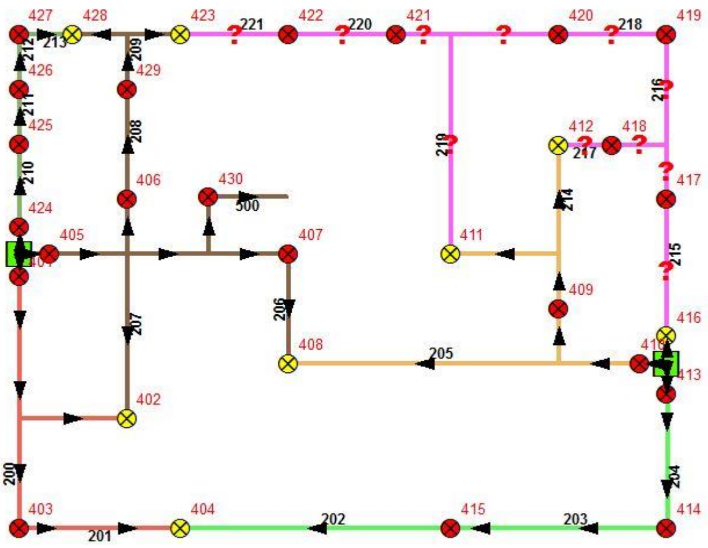
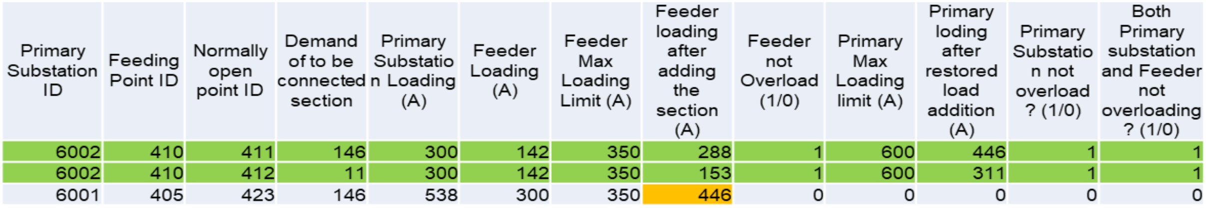


Table 4.8. Test case 2 – Outage feeder

- #####---Summary of feeder reconfiguration process---######
- Healthy system total demand = 1042 A
- After fault system Outage = 233 A
- -----Fault Locating-----
- Faulty Line Section of Outage Feeder
- 216
- -----Fault Isolating-----
- Fault Isolating Switches
- 417, 418, 419
- ***Faulty section isolation by opening the Fault Isolating Switches***
- -----Feeding End Supply Restoration-----
- feeding Switch for outage feeder
- 416
- ***Supply restoration of feeding end by reclosing the Feeding Switch***
- After feeding end supply restoration total system Outage = 204 A
- -----Tail End Supply Restoration-----
- Normally open switches to be close to tail end supply restoration.
- 412
- 411
- After tail end supply restoration total system Outage = 47 A
- ####################-----------------End----------------#################



Primary Substation ID	Feeding Point ID	Normally open point ID	Demand of to be connected section	Primary Substation Loading (A)	Feeder Loading (A)	Feeder Max Loading Limit (A)	Feeder loading after adding the section (A)	Feeder not Overload (1/0)	Primary Max Loading limit (A)	Primary loding after restored load addition (A)	Primary Substation not overload ? (1/0)	Both Primary substation and Feeder not overloading ? (1/0)
6002	410	411	146	300	142	350	288	1	600	446	1	1
6002	410	412	11	300	142	350	153	1	600	311	1	1
6001	405	423	146	538	300	350	446	0	0	0	0	0

Table 4.9. Test Case 2 - Critical decision to select restoration path.

Among two options, algorithm has chosen 411 switch to restore the supply. And 412 switch also closed to restore supply restore to section 217. In this case also normally open 423 switch is rejected due to exceeding the feeder maximum loading level.

In contrast with previous case, algorithm handled two isolated tail-end sections and restored supply of both.

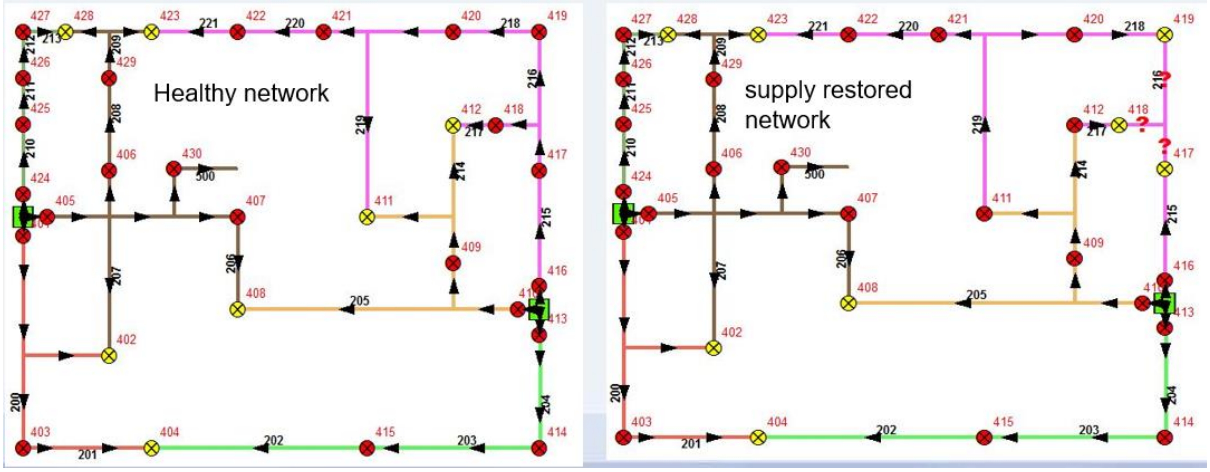
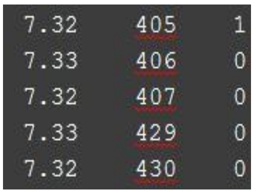


Figure 4.6. Test Case 2 - Healthy system and supply restored system.

Test case 3:

A situation with fault on a middle section of a feeder. Tail end supply restoring possible. In this case also, there are two sections to restore the supply at tail ends. As previous case among these two sections, one section has two options, closing 428 or 423. feeder loading and relevant primary loading to be considered.



```
7.32    405    1
7.33    406    0
7.32    407    0
7.33    429    0
7.32    430    0
```

Table 4.10. Test case 3 - LBS interrupts

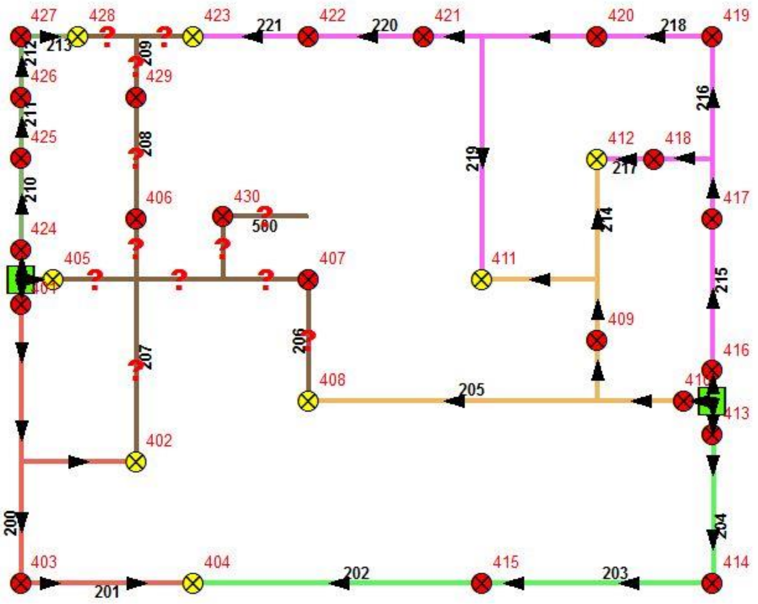
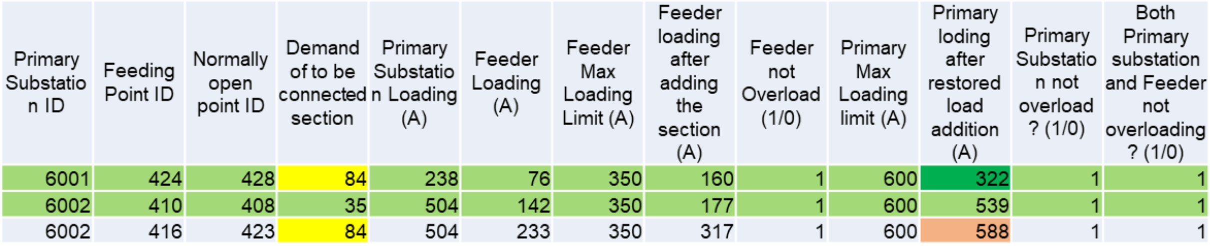


Figure 4.7. Test case 3 – Outage feeder

- #####---Executive Summary of feeder reconfiguration process---######
- Healthy system total demand = 1042 A
- After fault system Outage = 300 A
- -----Fault Locating-----
- Faulty Line Section of Outage Feeder
- 207
- -----Fault Isolating-----
- Fault Isolating Switches
- 402, 405, 406, 407, 430
- ***Faulty section isolation by opening the Fault Isolating Switches***
- -----Feeding End Supply Restoration-----
- feeding Switch for outage feeder
- 405
- ***Supply restoration of feeding end by reclosing the Feeding Switch***
- After feeding end supply restoration total system Outage = 300 A
- -----Tail End Supply Restoration-----
- Normally open switches to be close to tail end supply restoration.
- 408, 428
- After tail end supply restoration total system Outage = 181 A
- ####################----------------End----------------#################



Primary Substation ID	Feeding Point ID	Normally open point ID	Demand of to be connected section	Primary Substation Loading (A)	Feeder Loading (A)	Feeder Max Loading Limit (A)	Feeder loading after adding the section (A)	Feeder not Overload (1/0)	Primary Max Loading limit (A)	Primary loding after restored load addition (A)	Primary Substation not overload ? (1/0)	Both Primary substation and Feeder not overloading ? (1/0)
6001	424	428	84	238	76	350	160	1	600	322	1	1
6002	410	408	35	504	142	350	177	1	600	539	1	1
6002	416	423	84	504	233	350	317	1	600	588	1	1

Table 4.11. Test Case 3 - Critical decision to select restoration path.

In this case all the backup paths are compliance and below the maximum limits. But algorithm has selected the normally open 428 switch rather than choosing normally open switch 428. The reason is choosing 428 switch is considering the lowers primary loading level.

Same as the previous case, algorithm handled two isolated tail-end sections. But this time all the options were complied with limits. This scenario also proves the handling of critical events by the algorithm.

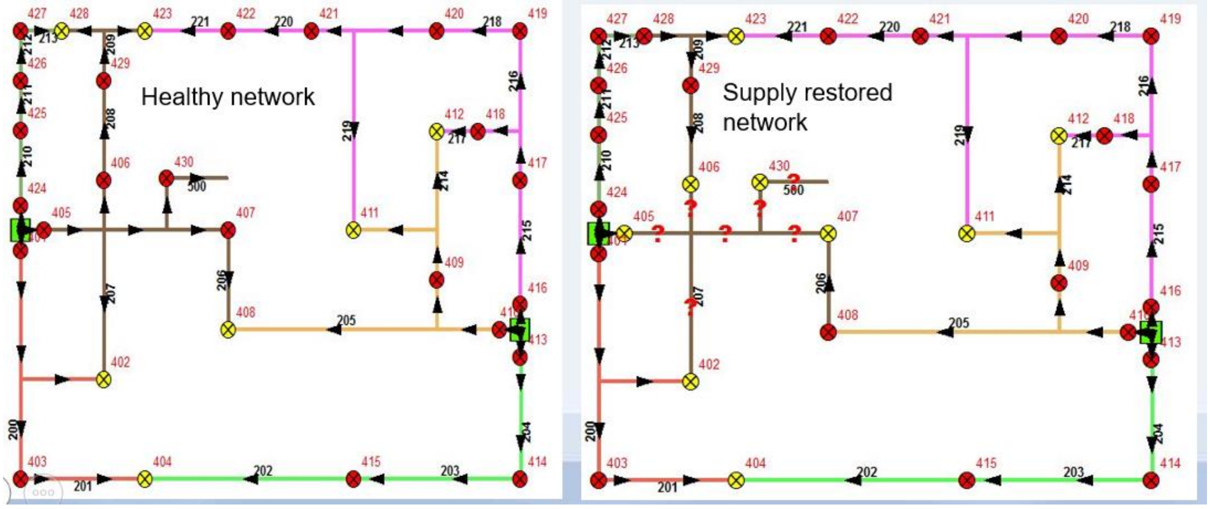
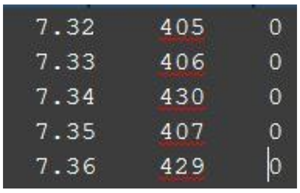


Figure 4.9. Test Case 3 - Healthy system and supply restored system.

Test case 4:

Consider a fault occurred in primary substation outgoing feeder. Then none of switch sense the fault current. Then the LBS interrupts as below:



```
7.32      405     0
7.33      406     0
7.34      430     0
7.35      407     0
7.36      429     0
```

Figure 4.10. Test case 4 - LBS interrupts

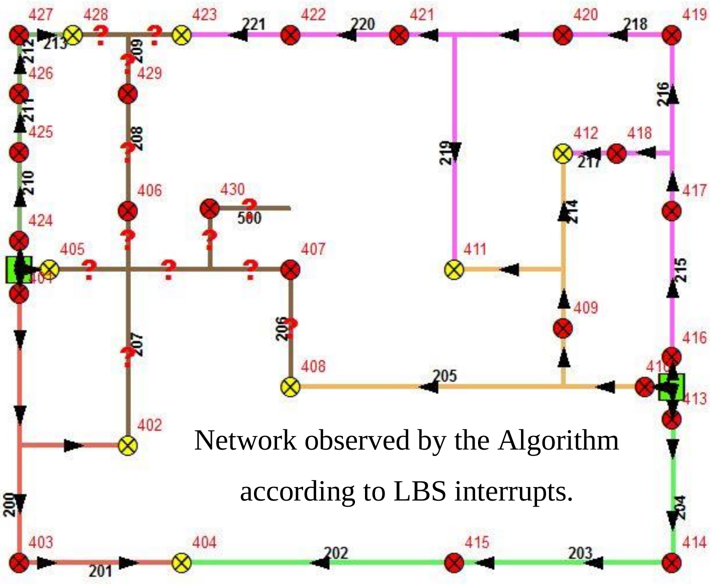
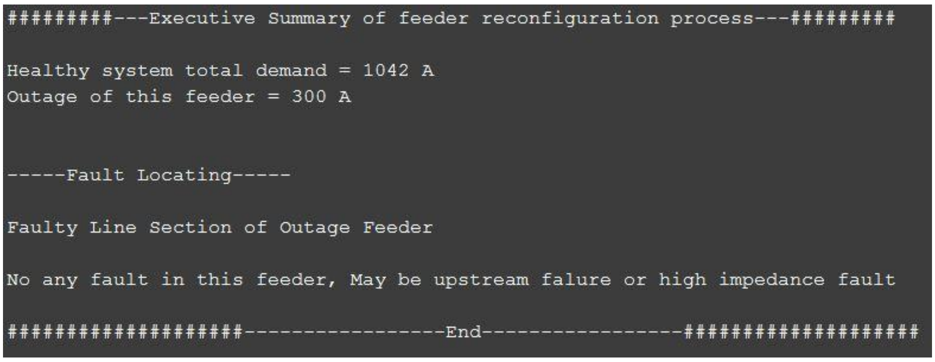


Figure 4.11. Test case 4 – Outage feeder



```
#########---Executive Summary of feeder reconfiguration process---#########

Healthy system total demand = 1042 A
Outage of this feeder = 300 A


-----Fault Locating-----

Faulty Line Section of Outage Feeder

No any fault in this feeder, May be upstream falure or high impedance fault

####################-----------------End-----------------####################
```

Figure 4.12. Summary of algorithm results

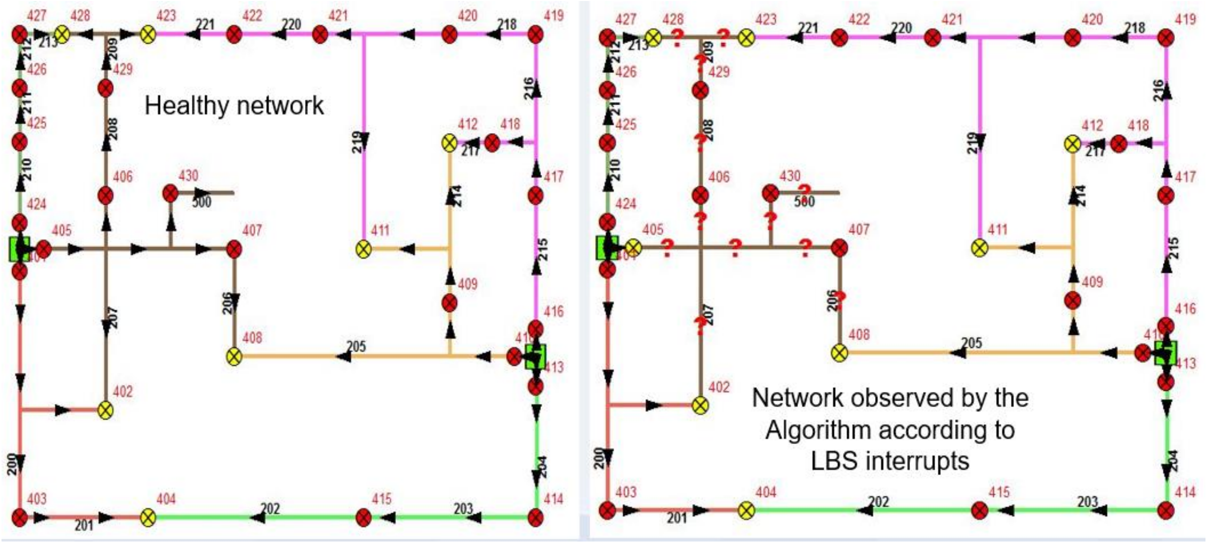
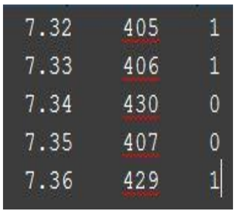


Figure 4.13. Test Case 4 - Healthy system and restoration hold system.

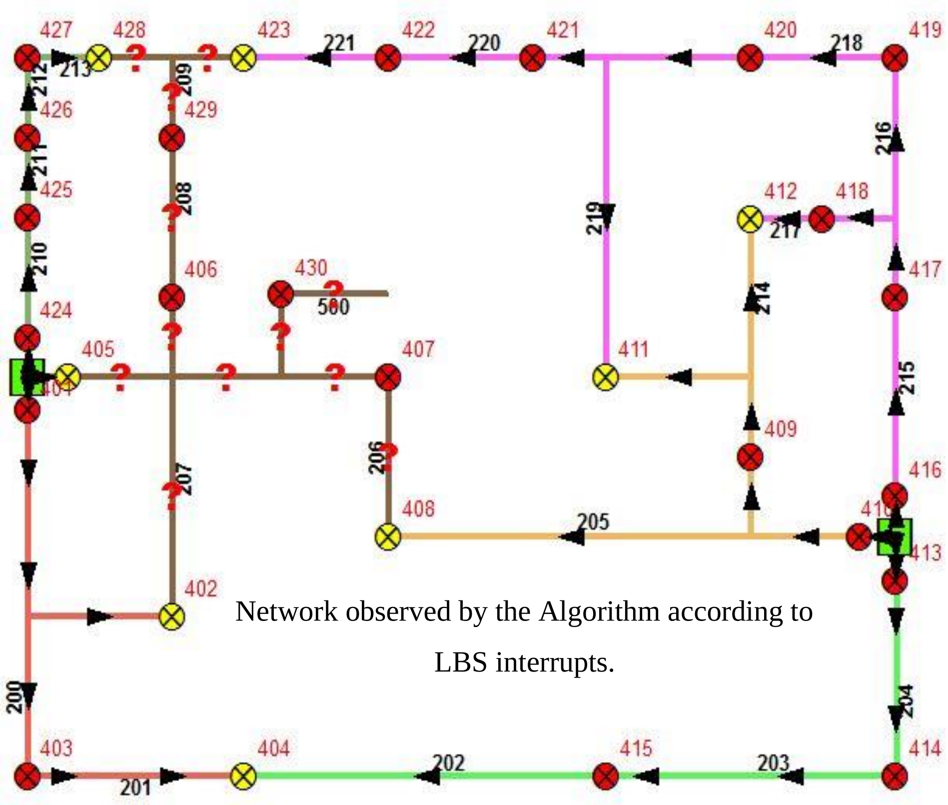
Test case 5:

In this case under scenario 5, Algorithm identified that the fault has occurred feeder-end section. Hence feeding-end supply restoration is only possible.



```
7.32    405    1
7.33    406    1
7.34    430    0
7.35    407    0
7.36    429    1
```

Table 4.12. Test case 5 - LBS interrupts



Network observed by the Algorithm according to LBS interrupts.

Figure 4.14. Test case 5 – Outage feeder

- #########---Summary of feeder reconfiguration process---#########
- Healthy system total demand = 1042 A
- Outage of this feeder = 300 A
- -----Fault Locating-----
- Faulty Line Section of Outage Feeder
- 209
- -----Fault Isolating-----

- Fault Isolating Switches
- 423, 428, 429
- ***Faulty section isolation by opening the Fault Isolating Switches***
- -----Feeding End Supply Restoration-----
- feeding Switch for outage feeder
- 405
- ***Supply restoration of feeding end by reclosing the Feeding Switch***
- After feeding end supply restoration total system Outage = 49 A
- -----Tail End Supply Restoration-----
- Fault has occurred last line section of the feeder, hence tail end restoration is not applicable.
- After possible all other supply restorations, total system Outage = 49 A
- #####################-----------------End-----------------#####################

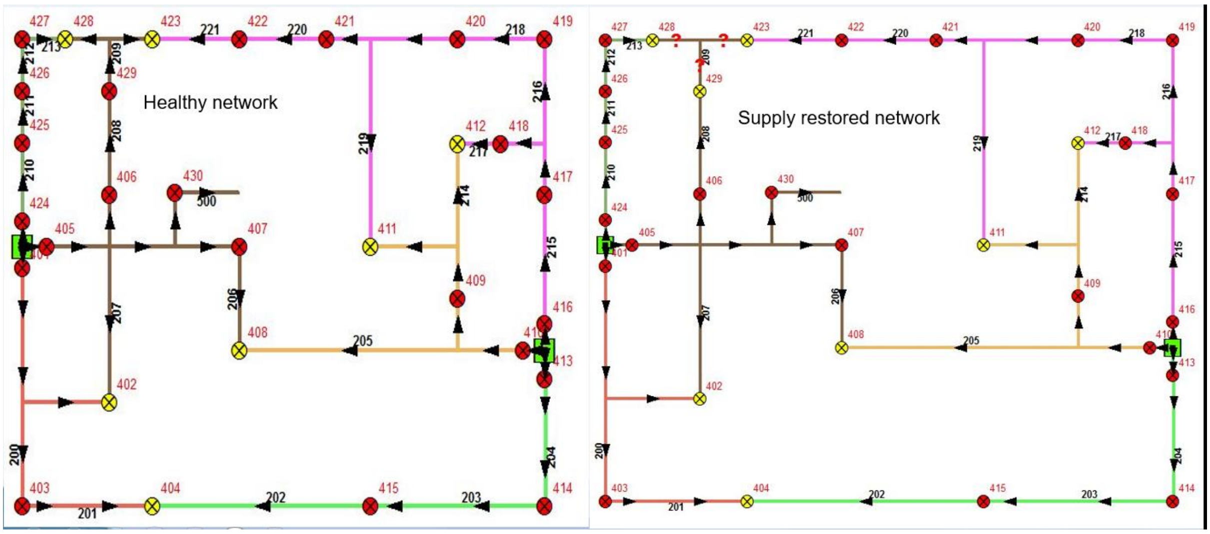


Figure 4.15. Test Case 5 - Healthy system and supply restored system.

4.4 VALIDATION WITH ACTURAL NETWORK DATA

The development and initial testing of the algorithm were conducted using a hypothetical network that followed a basic network format. This network served as the foundation for algorithm development and served to verify the algorithm's functionality and expected results. However, to ensure the robustness and real-world applicability of the algorithm, validation with a real network is an essential component of this research.

Considering the satisfactory performance of the algorithm in the hypothetical network scenarios, it was decided to apply the algorithm to real network data for validation purposes. The integration of real network data in the validation process allows for a more accurate assessment of the algorithm's performance in practical settings and ensures its reliability in real-world applications. This real network will provide the necessary context and data to thoroughly evaluate the algorithm's performance, effectiveness, and efficiency in a real-world scenario.

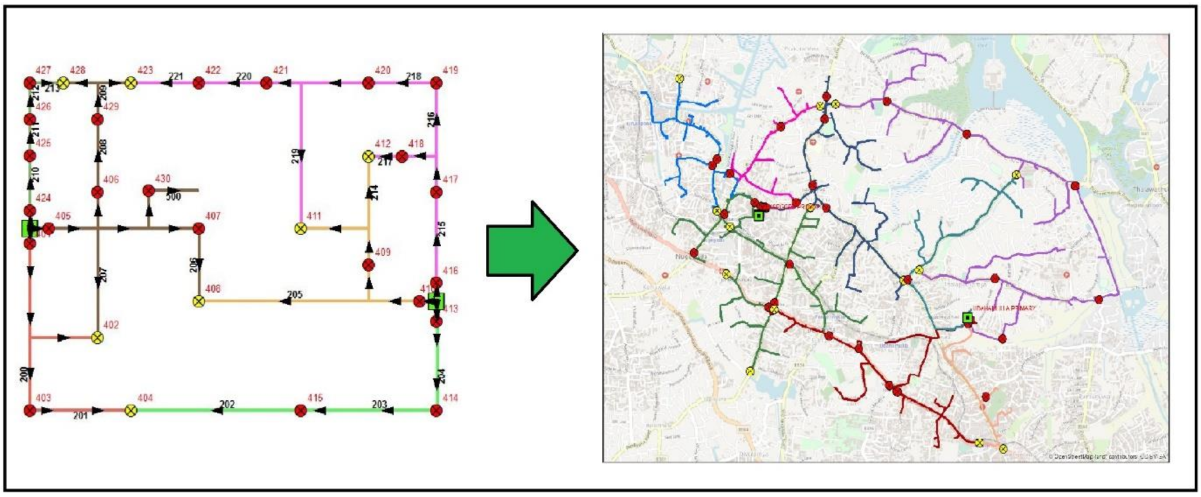


Figure 4.16. Hypothetical network and real network

By validating the algorithm with a real network, it can be assessed the ability to handle complex network configurations, varying data inputs, and potential challenges encountered in actual power distribution systems. This validation process enhances the credibility and reliability of the algorithm, providing valuable insights into its practical viability and potential for implementation in real-world contexts.

4.4.1 Original network

The original network was selected from one of the areas belong to Lanka Electricity Company (Private) Limited distribution region, Nugegoda Customer Service Area. Original network geographic information system (GIS) view is shown as Figure 4.5.

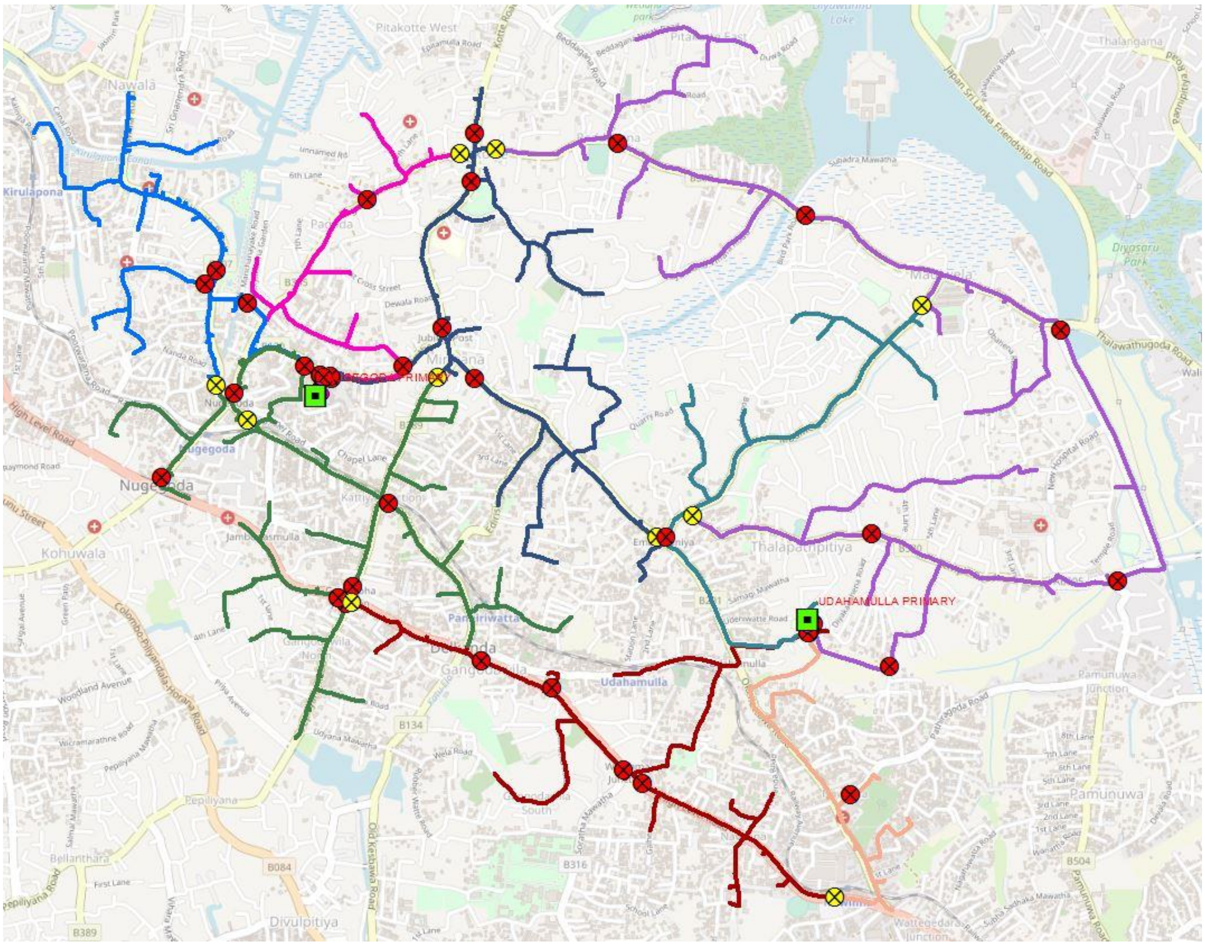


Figure 4.17. Original network GIS view.

The original network, as depicted in the geographic information system (GIS) view, encompasses two primary substations and a total of 46 switches. Among these switches, 14 of them are normally open. However, the complexity of the original network may not be sufficient for thorough algorithm validation. To address this limitation and ensure robust testing, additional primary substations and switches were incorporated into the system, resulting in a modified network specifically designed for algorithm validation.

By augmenting the network with extra primary substations and switches, the modified network provides a more comprehensive and realistic representation of a power distribution system. This expanded network allows for a more thorough evaluation and validation of the algorithm's performance under varying network conditions and complexities.

4.4.2 Modified network.

Validation was carried out using modified network data as described above. It allows more scenarios to test. Figure 4.6 shown the modified network in a GIS view.

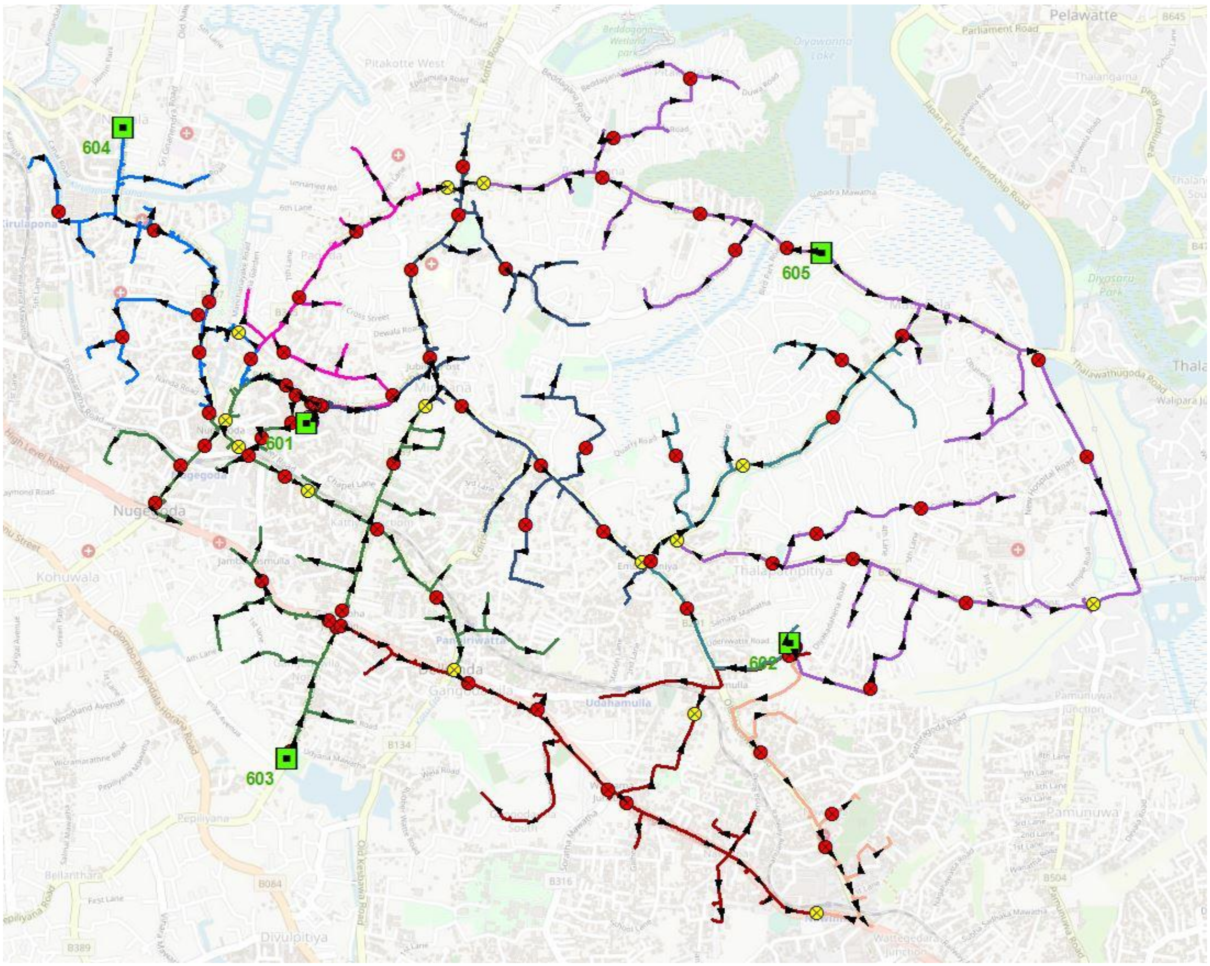


Figure 4.18. Actual network after the modification

After the modification of the network, main components of the system increased as follows:

- Total MV switches count: 92
- Total line sections: 80
- Normally open switches: 14
- Total feeding points: 13
- Total primary substation count: 5

Using this modified network same as the hypothetical network, different scenarios were checked.

4.5 COMPARISON OF MANUAL CALCULATED AND ALGORITHM DIRIVED RESULTS

Among the 20 test cases of deferent scenarios, one case is detailed below for demonstrate the steps of algorithm with modified actual network.

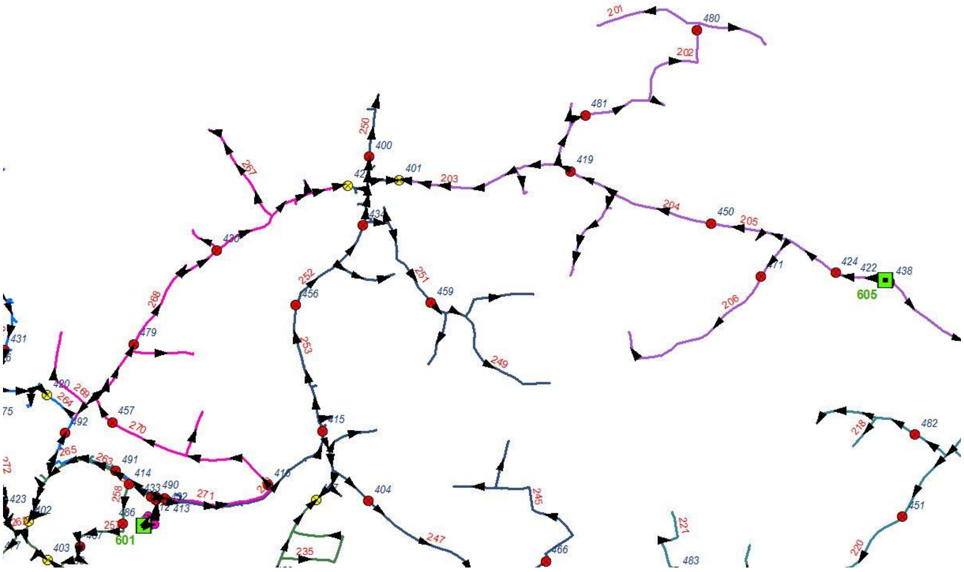


Figure 4.19. Focused area of the healthy network

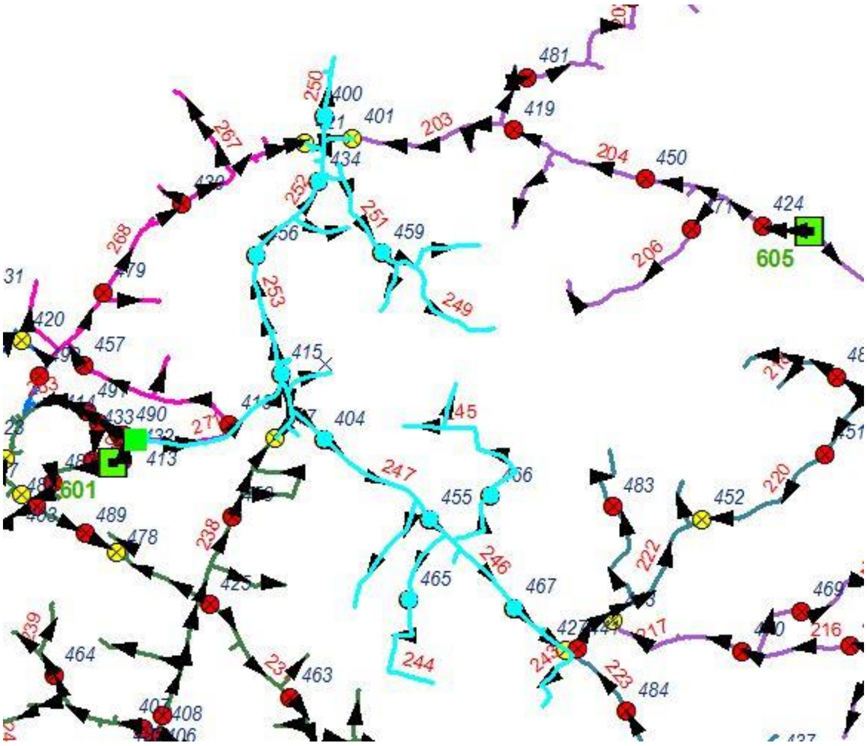
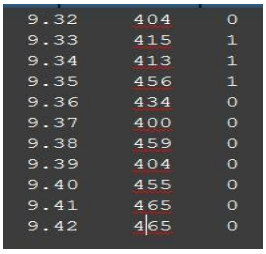


Figure 4.20. Tripped feeder (light blue color)



```
9.32    404    0
9.33    415    1
9.34    413    1
9.35    456    1
9.36    434    0
9.37    400    0
9.38    459    0
9.39    404    0
9.40    455    0
9.41    465    0
9.42    465    0
```

Table 4.13. List of LBS interrupts

After running the algorithm based on the modified network data, total process summarized as bellow. It can be clearly identified that the algorithm provided results are same as the manually calculated. But it computes the result more efficiently and accurately.

- #########---Executive Summary of feeder reconfiguration process---#########
- Healthy system total demand = 1759 A
- Outage of this feeder = 289 A
- -----Fault Locating-----
- Faulty Line Section of Outage Feeder
- 252
- -----Fault Isolating-----
- Fault Isolating Switches
- 434
- 456
- ***Faulty section isolation by opening the Fault Isolating Switches***
- -----Feeding End Supply Restoration-----
- feeding Switch for outage feeder
- 413
- ***Supply restoration of feeding end by reclosing the Feeding Switch***
- After feeding end supply restoration total system Outage = 125 A
- -----Tail End Supply Restoration-----
- Normally open switches to be close to tail end supply restoration.
- 401
- After tail end supply restoration total system Outage = 60 A
- ####################-----------------End-----------------####################

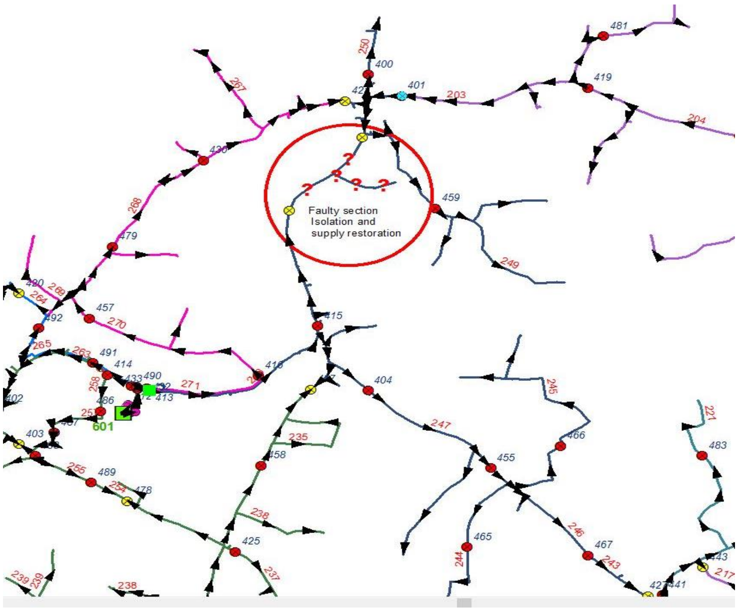


Figure 4.21. Faulty section isolated and supply-retorted system.

The modified network was tested with 20 cases and compared with the expected results. All the results were similar to the manually calculated and expected results. Checked parameters were summarized in the Table 4.6.

Summary of observation result of 20 numbers of cases with actual network data	Manual Method result vs Algorithm given results
Correct fault locating	No deviations
Correct fault isolating	No deviations
Correct feeding end supply restorations	No deviations
Correct tail end supply restorations	No deviations

Figure 4.22. Algorithm validation results

The algorithm's flexibility was evidenced through successful testing on both a hypothetical network and modified version of actual network, without requiring any modifications to the algorithm itself. This adaptability highlights its potential for broader application across diverse utility network contexts.

CHAPTER 5

5 CONCLUSIONS

5.1 LIMITATIONS OF THE STUDY

The matrix-based utility scale feeder reconfiguration algorithm has been developed, tested, and validated for future utilization by medium-scale utilities. The primary objective of this algorithm is to minimize outages and address faulty situations within the distribution network. It should be noted that the current implementation of the algorithm focuses on handling one outage at a time, to narrow down its scope.

Another limitation of the algorithm is that it solely considers the loading levels of feeders and primary substations during the restoration process. This constraint restricts the algorithm's ability to incorporate line losses on a per-occasion basis. Future development could address this limitation by expanding the algorithm's capabilities to factor in line losses for each specific occasion.

Additionally, the algorithm currently does not account for minimum system voltage requirements during the supply restoration process. The omission of this consideration represents another limitation of the study. Addressing this limitation in future iterations of the algorithm would enhance its effectiveness in maintaining adequate system voltage levels and ensuring reliable power delivery.

While these limitations exist, the developed algorithm still offers valuable insights and contributions to the field of utility-scale feeder reconfiguration. Its successful development, testing, and validation provide a foundation for further research and improvement. By considering and addressing these limitations, future iterations of the algorithm have the potential to enhance its functionality and applicability in real-world utility networks.

It is essential to recognize that ongoing research and development efforts are necessary to refine the algorithm and address its limitations. By continuously refining and expanding the algorithm's capabilities, it can evolve into a powerful tool for medium-scale utilities to proactively manage outages, minimize disruptions, and improve overall distribution network performance.

5.2 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

In conclusion, the proposed algorithm for fault detection, fault isolation, and power restoration in the 11kV network with remote MV switches has demonstrated its potential for significant improvement in utility network operations. The verification process, comprising thorough analysis, extensive testing, and successful validation, has established the algorithm's viability and effectiveness in real-world scenarios. The outcomes obtained from the verification process contribute to the overall confidence and reliability of implementing the algorithm within the utility network domain.

The matrix-based feeder reconfiguration algorithm, developed in this research, has consistently produced results in line with the intended design. This alignment between the algorithm's outputs and manual results was consistently observed throughout the validation process. Furthermore, the algorithm's independence from the specific network structure ensures its scalability, allowing for accurate outputs regardless of the distribution system's size or complexity.

The algorithm's adaptability was demonstrated by its successful testing on both a hypothetical network and a segment of an actual network, without requiring any modifications to the algorithm itself. This adaptability underlines the algorithm's potential for wider application in various utility network contexts.

The capabilities of the algorithm provide valuable contributions to the field of distribution system automation. By improving fault detection, isolation, and power restoration processes, the algorithm enhances system reliability, minimizes downtime, and optimizes network performance. These capabilities signify the algorithm's potential to revolutionize fault management practices and contribute to the overall efficiency and flexibility of distribution systems.

In summary, the developed matrix-based feeder reconfiguration algorithm has exhibited its effectiveness and reliability through comprehensive verification and validation processes. The algorithm's successful alignment with manual results, network independence, and demonstrated capabilities contribute to its potential as a valuable tool for utility companies seeking to enhance their distribution system operations and fault management strategies.

Main capabilities of the algorithm are as follows:

- ✓ Fault localization (provide the faulty section ID)
- ✓ Fault isolation (provide boundary switches IDs of faulty section)
- ✓ Supply restoration (provide switches IDs for supply restoration)
- ✓ Estimate system demand/ outage (prior to proceed switch operations, estimated demands and outage value are provided)

Direction to future studies:

- Multiple fault handling and scheduled interruptions handling capability to be achieved.
- When a backup path loading limit exceeds, section wise restoring capability to be achieved.
- When this algorithm implements practical level, voltage feedback also to be considered in the algorithm.
- This algorithm could be developed and could be used for medium voltage network planning purposes.

This algorithm was developed with the future requirements of manually operated distribution control centers in mind, aiming to automate fault localization, isolation, and supply restoration based on estimated demand data during supply outages. As distribution network infrastructures advance and remote Load Break Switches (LBS) and Auto Reclosers (AR) are implemented, allowing communication with central servers, the algorithm can be further modified to accommodate multiple fault scenarios. These enhancements enable practical implementation for medium-scale utilities, offering improved fault handling capabilities as the industry progresses.

Further, the algorithm under discussion prioritizes the provision of backup paths to restore the supply in the event of faulty situations within an electrical system. The emphasis on "n-1 reliability" in the utility sector is highlighted as a crucial factor for ensuring the overall reliability of the electrical system. This concept refers to the system's ability to maintain functionality even when one component, such as a distribution line or element fails.

The significance of n-1 reliability highlighted, indicating and that it is strongly recommended in both network planning and operational phases of the electrical system. This implies that the algorithm could plays a vital role not only in the day-to-day operations but also in planning and designing of the system if it modified accordingly for the purposes. The use of the algorithm is suggested to assess and verify the reliability level of the system, particularly in situations where a segment of lines in the network experiences faults.

In the process of planning a medium voltage distribution network, once the algorithm developed for the purpose, providing the calculated network parameters, and programming different fault scenarios it could checks if there are backup paths available, evaluating how reliable the system is in such situations.

What makes this algorithm user-friendly is that it doesn't depend on specific networks. It can easily adapt to the dynamic nature of systems due to the matrix model of the network. This means users can work with it seamlessly, no matter the complexity of the network configurations.

In essence, it is suggested that the algorithm contributes to the enhancement of the overall reliability of the electrical system by proactively testing and verifying backup paths. This proactive approach aligns with the industry's emphasis on n-1 reliability, ensuring that the system can withstand and recover from faults, thereby maintaining a continuous and dependable power supply. The algorithm's role is not confined to practical application during the operation of the electrical network but extends to theoretical planning ones it developed in future studies. Overall, the algorithm is positioned as a valuable tool for assessing and maintaining the reliability of the system, particularly in the face of faulty situations in specific network segments.

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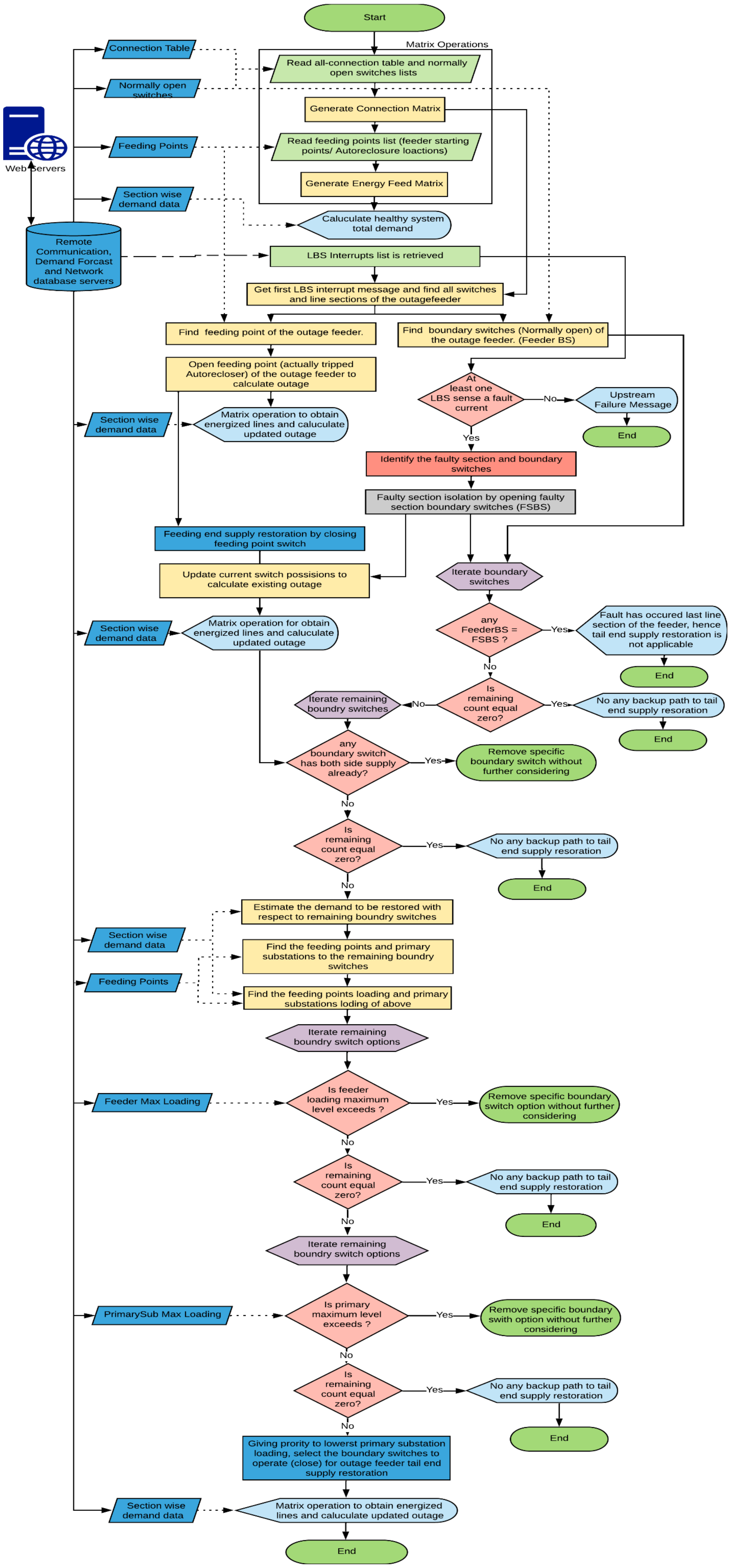
ANNEXURE 1



Matrix based utility scale feeder reconfiguration algorithm complete flow chart.

ANNEXURE 2

All Connections		
Switch	ne Sections I	
480	201	202
481	202	203
419	203	204
401	203	251
450	204	205
471	205	206
424	205	207
422	207	NaN
438	208	NaN
442	208	219
435	208	209
453	209	210
447	210	211
454	211	212
444	212	213
448	212	216
445	213	NaN
468	214	215
469	215	216
470	216	217
443	217	222
482	218	482
451	219	220
452	220	222
483	221	222
441	222	223
484	223	224
427	223	243
436	224	NaN
462	225	227
439	225	233
449	226	227
446	228	NaN
461	227	228
408	229	241
485	229	236
428	229	231
429	230	231
409	231	232
460	232	234
440	232	233
437	234	NaN
458	235	238
417	235	248
463	236	237
425	237	238
478	238	254

All Connections		
Switch	ne Sections I	
464	239	240
407	240	241
406	241	242
405	238	241
410	242	NaN
467	243	246
465	244	246
466	245	246
455	246	247
404	247	248
415	248	253
413	248	NaN
459	249	251
400	250	251
421	251	267
434	251	252
456	252	253
489	254	255
488	255	256
403	256	262
487	256	257
486	257	258
414	258	NaN
411	259	260
476	260	261
477	260	262
423	262	272
412	263	NaN
402	262	263
492	264	265
420	264	275
491	265	266
490	266	NaN
430	267	268
479	268	269
457	269	270
416	270	271
432	271	279
475	272	275
474	273	274
431	275	276
472	276	277
473	277	278
418	277	NaN
433	279	NaN

Normally Open Switches
Switch IDs
401
403
460
417
420
421
402
427
439
452
443
447
478
485

Section wise load estimate	
Section ID	Load in Amp.
201	14
202	14
203	21
204	18
205	15
206	14
207	4
208	60
209	13
210	24
211	30
212	59
213	18
214	19
215	23
216	25
217	20
218	13
219	24
220	13
221	9
222	43
223	12
224	33
225	55
226	8
227	31
228	54
229	14
230	2
231	30
232	15
233	42
234	50
235	15
236	24
237	12
238	36

Feeding Points	
Feeding Switch	Primary Sub.
412	601
490	601
414	601
433	601
413	601
437	602
436	602
446	602
445	602
410	603
418	604
422	605
438	605

Section wise load estimate	
Section ID	Load in Amp.
239	8
240	16
241	1
242	24
243	14
244	14
245	24
246	30
247	28
248	40
249	28
250	8
251	29
252	16
253	14
254	12
255	36
256	20
257	19
258	12
259	6
260	12
261	15
262	13
263	48
264	11
265	26
266	11
267	43
268	19
269	40
270	31
271	15
272	10
273	15
274	16
275	15
276	22
277	59
278	11
279	2

Primary Max Limit	
Primary	Max Loading
601	1200
602	1000
603	500
604	400
605	700

Conductor Max Loading
Loading Amp.
300

Input network data tables for algorithm validation in modified network