ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

POWER DISTRIBUTION NETWORK RECONFIGURATION USING A HEIRUSTIC METHOD

CASE STUDY: ADDIS ABABA CITY DISTRIBUTION NETWORK

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Signed Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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This is certifying that the above statement made by the student is correct and true to the best of my knowledge and belief.

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"I will give thanks to you, Lord, with all my heart." Psalm 9:1

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LIST OF SYMBOLS

R	Resistance of a distribution line.
X	Reactance of a distribution line
P	Branch active power
Q	Branch reactive power
V	Voltage Magnitude
I_i	Branch current
R_i	Branch resistance
P_{loss}	Total real power loss of the system
LB_j	Branch load balancing index
LB_{sys}	System load balancing index
S_j	Apparent power of branch j
$S_j^{\max}$	Maximum Apparent power capacity of branch j
PSS/E	Power System Simulator for Engineering
NO	Normally Open
x	System state

ABSTRACT

Electric distribution systems consist of tie and sectionalizing switches. Tie switches are normally open and sectionalizing switches are normally closed. By opening and closing these switches the distribution network can be reconfigured. This reconfiguration can be done for the objective of loss minimization, load balancing etc. In order to get feasible results the reconfiguration must meet some constraints, like Kirchhoff's voltage and current laws, other equality and inequality constraints. Distribution network reconfiguration is an optimization problem and needs a suitable algorithm (method).The method used for this optimization problem is a heuristic optimization method (algorithm). The heuristic algorithm will be described in detail and then applied specifically to the network reconfiguration problem. In the optimization process load flow of the distribution system should be computed. For this purpose and simulation of the distribution network PSS/E software, developed by Siemens PTI, is used. PSS/E software is a powerful commercial program which converges for solving distribution system load flows in microseconds even though it uses full Newton-Raphson method.

The test system and on which the case study is done, is a practical large Addis Ababa MV distribution network. This network is simulated and reconfiguration is done by the heuristic method which is described in the thesis. After reconfiguration for loss minimization, the power losses decreased from 1379.5KW to 416.9 KW, which is 69.78% reduction. Also after reconfiguration for load balancing, system load balancing index decreased from 100.9 % to 35.05 %, which is 65.26 % reduction, which means protective system tripping of the distribution network is decreased. Finally conclusions are made on reconfiguration of the distribution feeder. Also recommendations are made for Ethiopian Electric Utility how to reconfigure their distribution system and be able to reduce the losses, improve voltage profiles and ultimately solve the common power interruptions in Addis Ababa.

Key words: Heuristics optimization technique, switch allocation, electric power distribution networks, reconfiguration, loss reduction, load balancing.

Chapter 1

Introduction

1.1 Background

Distribution system is the largest portion of network in electrical power system. It can be defined as the part of power system which distributes power to various customers in ready-to-use form at their place of consumption. Hence, utilities have to ensure reliable and efficient cost effective service, while providing service voltages and power quality within the specified range.

There are some distribution networks and feeders which are meshed or supply power in a ring. However, most electric distribution feeders are configured radially, for effective coordination of their protective systems. The feeders must remain radial and satisfy all load requirements and voltage constraints.

The most important measures which can improve the performance of the operation and control of a distribution system are: (i) reconfiguration of the system (ii) variation and control of the reactive power flow by capacitor banks, etc. (iii) variation and control of the voltage by using on-load tap-changers for power transformers and (iv) changing the operating scheme of the parallel connected power transformers, etc. In this thesis optimization of distribution line reconfiguration is studied.

Distribution systems are also increasingly being automated in recent times. Utilities can save significant operating and maintenance cost by automating their distribution networks. There are many areas the automation can be done, one of which is distribution network reconfiguration.

Distribution network reconfiguration is the changing of the network topology by opening and closing of sectionalizing and tie switches. Sectionalizing switches are normally closed while tie switches are normally open. Network is reconfigured mainly for the following objectives:

- Power losses reduction.
- Load balancing (Overload relieving).
- Voltage deviations reduction.
- System restoration, etc.

As the loading conditions on the system change it may become profitable to reconfigure in order to reduce the real power losses in the network. This is usually referred to as network reconfiguration for loss reduction. Residential, commercial and industrial type loads appears on distribution lines varying time to time. Hence, reconfiguration may also become necessary in order to eliminate overloads on specific system components such as transformers or line sections. In this case it is known as load balancing. During some time of operation, the bus voltage deviations from the rated voltage may be out of the range, set by standards. Reconfiguration done to reduce these voltage deviations is referred to as network reconfiguration for bus voltage improvement. Faults can occur on distribution systems and some part of the system may lose power. Reconfiguration may be done to give power for that part of the system and this is referred to as reconfiguration for power restoration. In this thesis the network will be reconfigured for loss minimization and load balancing.

Reconfiguration of the distribution system can be used as a planning tool as well as a real-time control tool. Most of the distribution systems are reconfigured radially and modifying the radial structure of the distribution lines from time to time, by changing the open/closed states of the switches to transfer loads from one feeder to another, from one line to another ,may significantly improve the operating conditions of the overall system. Network reconfiguration allows the transfer of loads from heavily-loaded distribution lines to relatively lightly-loaded distribution lines and from higher-resistance routes to lower-resistance routes to obtain minimum losses, where the resistance route is the total resistance from the source to the load point. Such transfers are effective not only in terms of altering the level of loads on the distribution line being switched, and reducing the losses, but also in improving the voltage profile along the feeders and affecting reductions in the overall system power losses.

Few utilities have implemented network automatic reconfiguration to minimize system losses and to obtain other objectives. One of the reasons for the main objection to reconfiguration is that it is computationally expensive, i.e., as system size grows, so does computation time. If there are n switches in a distribution network, there are 2^n possible configurations. For modern urban distribution systems, the number of distribution transformers may reach thousands, and each transformer may be supplied by multiple feeders and substations. Such systems are very complex, very difficult to monitor, and difficult to control optimally in real-time. Losses associated with each configuration must be calculated, and this requires a load flow. The problem is compounded by the desire to maintain the radial configuration of the distribution system and by operational constraints, i.e., ensuring feeders and transformers are not overloaded and ensuring voltage drop limitations are not exceeded.

Network reconfiguration problem have been studied by different methods. Heuristic methods are used by [1], [2],[3]. Ant colony is used by [4]. Heuristic methods are also used by [5]-[11]. Linear programming is used by [12],[13].Fuzy logic is used by [14],[15].Tabu search is used by [16]. Genetic algorithm is used by [17], [18], [19]. Simulated annealing is used by [20].

1.2 Statement of the Problem

Addis Ababa city is experiencing frequent power interruptions in recent times. One of the reasons of this problem, which is also acknowledged by Ethiopian Electric Utility, is that the distribution system is not designed and built to handle the current load demands. The solution for this problem can be coordinated reconfiguration and upgrading of the distribution system. It is expected that the results, conclusions and recommendations of this thesis are helpful for finding the solution of this problem.

1.3 Objectives of the Thesis

The main objective of this thesis is to study distribution network reconfiguration and apply it on a feeder of Addis Ababa city distribution network for power loss minimization and load balancing. The general and specific objectives of the thesis are described in the problem formulation of the thesis in detail.

1.4 Methodology

Network reconfiguration is a combinatorial optimization problem. So, an optimization method is needed to quickly find the network reconfiguration for the objective function, satisfying all of the system constraints.

The reconfiguration problem is one of the multi criteria optimization problem, where the solution is chosen after the evaluation of some indices like active power losses, branch load limits, etc., which represent multiple purposes. These criteria can be grouped in two different groups: (i) objective functions and (ii) constraints. Moreover, some criteria can be modeled, at the same time as objectives and constraints. For instance, the power losses must be minimized but we can simultaneously impose a maximal acceptable value.

In this thesis a heuristic optimization method is used.Heuirstic methods have been used many times before and have the advantages in terms of less computation times, ease of use and applicability. However no global optimum is guaranteed.

1.5 Organization of the Thesis

The thesis is organized as follows. In Chapter 2, the problem is formulated with objective functions, equality and inequality constraints. In chapter 3 literatures about network reconfiguration and different optimization methods used earlier is reviewed. In chapter 4 the new heuristic methodology which is used in this thesis is discussed in detail. In Chapter 5, the Addis Ababa distribution network is reconfigured using the heuristic method and PSS/E software. Conclusions and recommendations are made in the last chapter.

Chapter 2

Problem Formulation

It is becoming more and more important for power distribution companies to be able to meet efficiently and reliably the demands of their customers. This means that one of their goals is to be able to find an operating state for a large, three-phase, distribution network which minimizes the cost for the power company supplying the power, while satisfying the requirements of the customer. In developing countries like Ethiopia, the utility companies should also reconfigure and redesign their distribution system in order to improve the reliability of their distribution system, which is unacceptably low by many standards. This chapter states the general and specific objectives of the research, introduces some mathematical model of network reconfiguration problem and presents a formulation of the network reconfiguration problem for loss reduction and load balancing.

2.1 General Objective

The general objective of the research is to study the network reconfiguration of distribution networks and its benefits and using it to reconfigure one of the Addis Ababa distribution network for power loss minimization and load balancing. In doing so to show that the performance and reliability of the Addis Ababa distribution system can be improved by network reconfiguration.

2.2 Specific Objectives

The specific objectives of the research are to:

1. Collect data from Ethiopian Electric Utility which are needed for distribution network and other necessary data.

2. Reconfigure the chosen feeder of a distribution network, feeder 3 of Weregenu substation, for loss minimization using a heuristic method.
3. Reconfigure the chosen feeder of a distribution network, feeder 3 of Weregenu substation, for load balancing using a heuristic method.
4. Make conclusions and recommendations based on the above network reconfigurations.

2.3 Mathematical Model of the Network Reconfiguration Problem

Let us consider a distribution network with n nodes. The optimization problem is then finding an optimal radial network u among all possible radial networks in search space S generated with the switch condition changes that minimizes the objective function without violation of the constraints.

The mathematical model can be expressed as

$$\underset{u \in S}{\text{Minimize}}\ F(x,u) \quad (2.1)$$

Subject to

$$G(x, u) = 0 \quad (2.2)$$

$$H(x, u) \leq 0 \quad (2.3)$$

F(x,u) is the objective function

G(x,u) is the vector of equality constraints and represents the load flow equations.

H(x,u) is the vector of inequality constraints and corresponds to certain constraints for the network.

x is the system state (a vector consisting of voltage magnitudes and angles at all buses of the considered system).

u is radial network reconfiguration.

S is the set of all possible network configurations. Any solution u satisfying the constraints of F and G is called a feasible configuration.

In power system context, equality constraints (2.2) are power flow equations, which must always hold true. Inequality constraints (2.3) typically express security limitations. It is possible that the network configuration which theoretically minimizes the real power losses in the system might require one or several of the components in the system to be operated at a level beyond its physical limitations. This obviously must be disallowed. Each line, transformer, and switch in the system has a certain thermal limitation which restricts the maximum allowable current through that component. In general, these physical limitations can be accounted for by constraining line currents, line flows, and bus voltages to lie within appropriate bounds. These operational constraints are inequality constraints which can be included in Equation (2.3).Also power utility customers have certain requirements for the electrical power they receive. The power company must be able to maintain a certain voltage level at each bus in the system while supplying the power demand. This constraint, which requires the voltage magnitude of each phase at each bus to lie in the appropriate range, can be considered as inequality constraint.

In this thesis, the main objectives of network reconfiguration are loss minimization and load balancing. The problem is then finding the network configuration which minimizes the objective function subjected to satisfying the following constraints.

- Radiality, which means that no loops are allowed in the network
- Electrical constraints that includes Kirchhoff's current and voltage laws.
- Operational constraints that includes the physical limitation of network components.
- Load constraints that require maintaining the voltage within appropriate bounds.
- The loads must not be isolated without output supply from any feeder.

Calculation of the losses for a configuration provides values for only one instant in time, based on current bus loads. However, distribution systems are very dynamic, and customers include industries, commercial centers and residential homes, all of which have changing load demands throughout the day, week and season of the year. Thus, reconfiguration must be carried out on a regular basis (i.e., on-line and in real-time) as demand changes, further increasing the computational load.

2.4 Minimization of Real Power Losses

This objective is to minimize the system power losses subject to operating constraints under a certain load pattern.

Therefore the objective function is

$$\text{Minimize } P_{loss} = \sum_{i=1}^{n} R_i I_i^2 \tag{2.4}$$

Where

i any feeder branch

n is the number of network branches.

I_i is the current magnitude flows in branch i.

R_i is the resistance of branch i.

Subject to constraints,

$$|V_{\min}| \leq |V_i| \leq |V_{\max}|$$

$$|I_j| \leq I_{j,\max}$$

Where $|V_{\min}|$ is voltage magnitude of node i, $|V_{\min}|$ and $|V_{\max}|$ are minimum and maximum node voltage magnitude limits. $|I_j|$ and $I_{j,\max}$ are current magnitude and maximum current limit of branch j, respectively.

2.5 Load Balancing

Different loads like domestic, commercial, industrial type of loads, which vary from time to time, occur on distribution lines. From this one can understand that some parts of the distribution system are heavily loaded at certain times and less loaded at other times in a different way in a day. Since overloads shorten the life time of equipment and sometimes damage it, it should be relieved. Distribution networks are reconfigured for load balancing to relieve overloads without changing the radial structure.

The problem of load balancing is formulated using branch load balancing index(LBj) and system load balancing index (LB sys). Branch load balancing index (LBj) is defined as a measure of how much a branch can be loaded without exceeding the rated capacity of that branch. The objective is to optimize the branch load indices so that the system load balancing index is minimized. The load balancing problem is formulated in the form of branch load balancing and system load balancing indices, as defined by distribution network experts, as the following:

The branch load balancing index, $$LB_j = \frac{S_j}{S_j^{\max}} \quad (2.5)$$

The system load balancing index, $$LB_{Sys} = \frac{1}{nb}\sum_{j=1}^{nb}\frac{S_j}{S_j^{\max}} \quad (2.6)$$

Where nb is the total number of branches in the system

S_j is the apparent power of branch j

$S_j^{\max}$ is maximum capacity of branch j

Hence the objective function is,

Minimize $$F = \frac{1}{nb}\sum_{j=1}^{nb}\frac{S_j}{S_j^{\max}} \tag{2.7}$$

Subject to constraints,

(i) The voltage magnitude of each node must be within limits, That is:

$$|V_{\min}| \le |V_i| \le |V_{\max}|$$

(ii). Current capacity of each branch shouldn't be exceeded, that is

$$|I_j| \le I_{j,\max}$$

The system load balancing index is minimized when the branch load indices are Optimized by rescheduling the loads. In effect, all the branch load balancing indices, (LBj) are made approximately equal to each other and also closely approximate to the system load balancing index (LBsys).

When the load balancing index, LBj of the branch is equal to 1 then the condition of that branch will become critical and the branch rated capacity will be exceeded if it is greater than 1. The system load balancing index, LBsys will be low if the system is lightly loaded and its value will be closer to zero, and the individual branch load balancing indices will also be low.

If the loads are unbalanced, the load balancing indices of individual branches will differ widely, whereas, the balanced load will make the load balancing indices of all the branches nearly equal. It is not practically possible to make all the branch load balancing indices, LBj exactly equal. However, it is possible that by reconfiguration the load balancing indices of the branches will be adjusted, and hence the load balancing in the overall system improved.

Chapter 3

Literature Review

More than 40 years ago, the French engineers A. Merlin and H. Back [1] perceived an opportunity to reduce technical losses by exploring a change in the status of normally closed and normally open switches. They proposed the "network reconfiguration problem", for which the solution should provide the best status for all the switches in a primary distribution network, best in the sense that they provide a radial configuration supplying loads with the minimum of power loss.

Between 1988 and 1990 heuristic methods were used to solve the problem. The developments during this period were focused on increasing the number of operating constraints. From 1990, new solution strategies appeared: linear programming simulated annealing, and genetic algorithms, whose objective function is power losses minimization and the operating constraints previously used. In addition, load models are improved with more precise models.

In 1993, solutions to the problem were presented through neural networks, which initially model few operating constraints and simple load models. In 1997 models with more constraints were used. Between 1995 and 1996 the heuristic method was proposed again in order to optimize energy losses using more precise load models. From 1997 until now, the techniques used are combinations of the previous techniques, aiming to complement each method's strengths. Also new methods like ant colony (ACO) and particle swarm optimization (PSO) are used. According to the historic development, the computational searching methods are classified into three large groups:

- **Knowledge-based methods**

- **Methods based on evolutionary techniques**
- **Mixed methods**.

In addition to network reconfiguration for loss reduction, load balancing, voltage deviation minimization and power restoration are also taken into account in recent times. Also algorithms for multi objective optimization have been used. Reconfiguration of distribution network with distribution generation (DG), for capacitor placement, for service restoration is the current hot topics on which many researches are going on.

3.1 Knowledge Based Methods

They are based on the operators' experience in the system operations. Based on this Knowledge, algorithms have been designed to facilitate searching for the new distribution network configuration, trying to find an option close to the optimal.

Heuristic methods, linear programming, expert systems, fuzzy logic etc, belong to this category. Heuristic methods used many times by different researchers. The solution process leads to the optimum or near optimum in less computation time.

3.1.1 Heuristic optimization methods For Network Reconfiguration

Several methods have been proposed to solve the reconfiguration problem. In 1975, Merlin and Back [1] proposed a branch and bound type heuristic method to determine the network configuration for minimum line losses. Its solution scheme starts with a meshed network by initially closing all switches in the network. The switches are then opened one at a time until a new radial configuration is reached. In this process the switch to be opened at each stage is selected in order to minimize line losses of the resulting network.

Branch and bound method will work better if the initial solution is close to optimal, because more pruning will occur. Branch and bound also benefits from breaking the problem into sub problems, each of which can be optimized separately. Even so, branch and bound is a combinatorial method and hence too slow for practical use.

Therefore, most of the recent work on reconfiguration has used either a branch exchange method or sequential switch opening method. Heuristics are applied in most cases to reduce the number of switching options considered

Shirmomohammadi and Hong [5] improved the method of Merlin and Back. As a result, it shares the two principle benefits of that methodology, convergence to the optimum or near optimum solution and the independence of the final solution from the initial status of the network switches. At the same time, this method avoids all the major drawbacks of Merlin and Back.

Civanlar [6] developed a branch exchange method. In this method, loss reduction is achieved by exchange operation corresponds to the selection of a pair of switches, one for opening and the other for closing so that the resulting network has lower line losses while remaining connected and radial. The major drawbacks of this method are:

- The final network reconfiguration is dependent on the initial state of the network switches.
- Optimum solution is not guaranteed.
- Selection of each switches exchange operation becomes very time consuming.

Baran and Wu [7] presented a heuristic reconfiguration methodology based on the branch exchange to reduce losses and balance the loads in the feeders. To assist in the search, two approximated load flows for radial networks with different degrees of accuracy are used. They are simple power flow method and back and forward update of power flow method. The method is very time consuming due to the complicated combinations in large scale system and converges to a local optimum solution, that is, convergence to the global optimum is not guaranteed.

G.J Peponis, M.P. Popadopoulos and N.D Hatziargyrion [9] used a combined method, the switch exchange (SEM) and sequential switch opening method (SSOM) for reconfiguration of the network for loss reduction.

Its main advantage is optimum or near optimum configuration is obtained using one of the two basic methods, SEM where closing switch and opening another in the loop formed. SSOM where all tie switches are initially closed and an optimal load flow is obtained. The system is returned to a radial configuration by successive opening of the switches having the least current flow until network radiality is obtained.

SEM requires less computation time and SSOM is independent from the initial configuration and thus more likely leads to the actual optimum.

Broadwater and Khan [10] suggested a reconfiguration algorithm which calculates switch patterns as a function of time. Either seasonal or daily time studies may be performed. Both manual and automatic switches are used to reconfigure the system for seasonal studies whereas only automatic switches are considered for daily studies. Such a continuous reconfiguration is allowed by today's distribution automation, information technology and equipment. It is shown that switching at the system peak can reduce losses but cause a marginal increase in system peak. The practical aspects of such an optimization remain to be carefully analyzed through costs, transient effect and influence to system reliability.

R. Safri, M.M.A Salama and Y. Chickani [11] proposed an algorithm that is based on network portioning into groups of load buses such that the line section losses between the groups of nodes are minimized, the proposed method overcomes the size restriction imposed by reconfiguration techniques. By dividing the distribution network into groups of buses, the combinatorial nature of reconfiguration problem is reduced while simultaneously minimizing losses.

3.1.2 Linear programming Techniques

A. Borghetti, M. Paolone and C.A. Nucci [12] used mixed integer linear programming (MILP) model for the solution of the minimum loss reconfiguration problem of distribution networks, including embedded generation. The proposed MILP model takes into account the main operating constraints other than radiality, such as the lower and upper bounds of the bus voltages and the upper limits of the line currents. The solution of the MILP model does not require the knowledge of an initial feasible configuration of the network.

G. Celli, M. Loddo, F. Pilo and A. Abur [13] formulated and solved the network reconfiguration problem with DGs using a simple linear programming approach. Optimal configurations are determined by considering the effects of DG outputs, load variations, and various other contingences such as faults and maintenance outages. Demand Side Management actions have also been taken into account.

3.1.3 Fuzzy Logic Method

Ramadoni Syahputra [14] presented a fuzzy multi-objective approach for achieving the minimum active power loss and the maximum voltage magnitude in order to improve the efficiency of radial distribution networks with distributed generations. Multi-objective function are considered for load balancing among the feeders, minimization of the real power loss, deviation of nodes voltage, and branch current constraint violation, while subject to a radial network structure in which all loads must be energized. The effectiveness of the method has been demonstrated by a 70-node distribution network test system.

Abhisek Ukil and Willy Siti [15] used Fuzy Logic for load balancing. They presented a fuzzy logic-based load balancing system along with a combinatorial optimization-based implementation system for implementing the load changes. The input to the fuzzy step is the total load (kW) per phase of the feeders. Output of the fuzzy step is the load change values, negative value for load releasing and positive value for load receiving. Sum of the positive and negative values is zero, i.e., the total load remains unchanged for the entire phase balancing.

3.1.4 Tabu Search Method

Tabu Search is a meta-heuristic that guides a local heuristic search procedure to explore the solution space beyond local optimality. One of the main components of Tabu search is its use of adaptive memory, which creates a more flexible search behavior. Memory-based strategies are therefore the hallmark of Tabu search approaches, founded on a quest for "integrating principles," by which alternative forms of memory are appropriately combined with effective strategies for exploiting them.

N. Rugthaicharoencheep and S. Sirisumrannukul [16] used Tabu Search (TS) for loss reduction of distribution networks with distributed generation. The developed methodology is tested with a 69-bus distribution system having 48 load points. The study results indicate that for a given set of distributed generators and their locations, the proposed method can identify optimal on/off patterns of the switches that yield the minimum loss while satisfying the constraints.

3.2 Evolutionary Techniques Based Methods for Network Reconfiguration

Evolutionary algorithms (EAs) are developed to arrive at optimum or near-optimum solutions to a large scale optimization problem. The problem having very large number of decision variables and non-linear objective functions are often solved by EAs. EAs mimic the metaphor of natural biological evolution or social behavior like how ants find the shortest route to a source of food and how birds find their destination during migration. The behavior of such species is guided by learning and adaptation. The evolutionary algorithms are based on population based search procedures that incorporate random variation and selection.

EAs have an important characteristic: the lack of a rigorous mathematical formulation that allows establishing their operation in each situation with certainty. These techniques start from a solution and improve it.

Genetic algorithm, simulated annealing, neural networks, ant colony (ACO), particle swarm optimization (PSO), etc. belong to this category. Genetic algorithm is a search based on the mechanism of natural selection and natural genetics. It can be used to solve the multi objective optimization problem. It is used by [17], [18],[19]. Simulated annealing method can avoid local optima but requires an excessive computation time. It is used by [20].Artificial neural network methods were also used by [21].

3.2.1 Genetic Algorithm (GA)

The first evolutionary-based optimization technique was the genetic algorithm (GA).Genetic algorithms have become very popular as a method of finding global optimums. As applied to reconfiguration [17],[18], the switch states are encoded in strings of 0/1 "chromosomes", and a population of, for example, 30 topologies is built at random. At each iteration, two parent topologies are selected at random for crossbreeding which is a process of combining the chromosomes according to some defined algorithm. Then mutation, a random alteration of some chromosomes, may occur with a certain probability. If the resulting child is better, it replaces an existing topology in the population of 30. This process of crossbreeding continues for a number of iterations. The population also has to be re-seeded periodically with random strings to avoid in breeding. As the population evolves, there will always be a best solution that should steadily improve.

Genetic algorithms are most attractive for parallel processing environments, and when each child can be evaluated quickly. The cross breeding and mutation algorithms must be custom designed and tested for each application. Parameters such as the number of crossbreeding per generation, mutation probability, number of generations, population size, and percentage of population reseeded must all be determined by testing.

Applications to reconfiguration have used simplified network analysis because many thousands of topologies are considered, so the resulting solution may not be optimal with a more detailed model.

Nara [18] used the genetic algorithm (GA) which is a search algorithm based on the mechanism of natural selection and natural genetics. It combines the adaptive nature of the natural genetics or the evolution procedure of organs with functional optimization. The simple feature of GA makes it suitable for different multi objectives optimization problem. The principle problem in using GA rests on an efficient coding and decoding mechanism of the chromosome representing the distribution network and the structure of fitness function.

Fudou, Fukuyama and Nakanishi [19] present a GA using three phases unbalanced load flow. A proper string representation for loads and power supplies is devised and a method to yield a good problem dependent initial string population is presented. A repair operator which modifies the string so as to improve the objective function of the problem and to satisfy the radial network constraints. A modification to the fitness function is made to reinforce the satisfaction of the power source limits and voltage as well as current constraints.

3.2.2 Simulated Annealing

The name and inspiration came from annealing process in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. The heat causes the atoms to become unstuck from their initial positions (a local minimum of the internal energy) and wander randomly through states of higher energy; the slow cooling gives them more chances of finding configurations with lower internal energy than the initial one. In the simulated annealing method each point of the search space is compared to a state of some physical system, and the function to be minimized is interpreted as the internal energy of the system in that state. Therefore the goal is to bring the system, from an arbitrary initial state, to a state with the minimum possible energy.

Ray Daniel Zimmerman [20] used simulated annealing for loss reduction of three phase power distribution system. It is used on larger, more complex, unbalanced three-phase system. Computer program was developed and was able to find the optimal configuration of the 147 bus, 12 switch example system, demonstrating the feasibility of such an approach for the solution of the network reconfiguration problem.

3.2.3 Artificial Neural Network

Ali Reza Fereidunian, Hamid Lesani and Caro Lucas [21] used an intelligent neural optimizer with two objective functions which is designed for electrical distribution systems. The presented method is faster than alternative optimization methods and is comparable with the most powerful and precise ones. The optimizer is much smaller than similar neural systems. The proposed method has established a relation between two applications of neural networks: Optimization and Pattern Recognition.

Kim [22] presented the strategy of feeder reconfiguration to reduce the power loss by artificial neural (ANN) network. This approach developed is basically different in the aspects that the load transfer and the corresponding load flow solution during the search process are not required. The set of ANN is the optimal system topology corresponding to various load patterns which minimizes the load under given conditions.

3.2.4 Ant Colony Optimization

Ant colony (ACO) optimization is based on ant social behavior. In the real world, ants (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep traveling at random, but instead follow the trail laid by earlier ants, returning and reinforcing it, if they eventually find any food. Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over faster, and thus the pheromone density remains high as it is laid on the path as fast as it can evaporate. Thus, when one ant finds a good (short) path from the colony to a food source, other ants are more likely to follow that path, and such positive feedback eventually leaves all the ants following a single path.

Abdullah M. Alshehri [4] used ACO for optimal reconfiguration of distribution network for loss minimization and load balancing.MATLAB program which uses ACO was developed and tested on Baran and Wu 33 bus system and two large practical distribution systems.The results was also validated using Power World simulation software.

3.2.5 Particle Swarm Optimization

The Particle Swarm Optimization (PSO) is inspired by the social behavior of a flock of migrating birds trying to reach an unknown destination. In PSO, each solution is a bird in the flock and is referred to as a particle. A particle is analogous to a chromosome in GAs. As opposed to GAs, the evolutionary process in the PSO does not create new birds from parent ones. Rather, the birds in the population only evolve their social behavior and accordingly their movement towards a destination. Each bird looks in a specific direction, and then when communicates together, they identify the bird that is in the best location. Accordingly, each bird speeds towards the best bird using a velocity that depends on its current position. Each bird, then investigates the search space from its new local position, and the process repeats until the flock reaches a desired destination

Tamer M. Khalil, and Alexander V. Gorpinich [23] used selective particle swarm optimization (SPSO) for loss reduction. This algorithm is a simple modification to the binary particles warm optimization (BPSO). The search space of the algorithm is a set of branches (switches) which are normally closed or normally opened, this search space may be dissimilar for different dimensions. The process of solving reconfiguration problem is divided in to two steps. First, finding search spaces after closing all switches and second, using SPSO to find switches that would be opened. The presented technique is applied to a 33-node system and a 69-node system. The results obtained via SPSO are compared with some previous methods to demonstrate the effectiveness of the proposed algorithm

3.3 Mixed Methods.

These methods are in use since 1996 and are combinations of previous methods to gather their combined strengths; hence better results are obtained. Mixed methods like linear programming with heuristics [24] and Fuzzy Logic and heuristics [25] were used.

King and Radha [26] used a fuzzy logic controller to adapt the cross over and mutation probabilities based on the fitness function. The main advantages of fuzzy control system over the conventional method are: ability of modeling the quantities aspects of human knowledge and reasoning process, model free estimator, robustness, and easy implementation. The fuzzy logic controlled GA always finds the global optimum and has proved to have faster convergence than a GA using fixed cross over and adaptive mutation.

Mehdi Assadian [27] investigated the ability of particle swarm optimization (PSO) in cooperation with graph theory for network reconfiguration to reduce the power loss and voltage profile enhancement of distribution system. The numerical results are presented on a distribution system to illustrate the feasibility of the proposed method. Furthermore, to validate the obtained results by PSO using graph theory, Genetic Algorithm (GA) using graph theory is applied and the results are compared.

3.4 Summary of Literature Reviews

According to, no free lunch theorem, one optimization algorithm cannot be superior to other algorithms in all kinds of cases. Hence, for the class of problem being studied, one has to find out which algorithm is better for the optimization problem and its objectives. The following Table 3-1 compares different algorithms when applied to network reconfiguration problem [28].

Table 3-1. Optimization Methods Comparison when applied to Network Reconfiguration

Methods Indexes	Method	Evaluation Classification						
		Large systems	% losses reduction	General Application	Flexibility	Running Time	Constraints Management	Model Precision
Knowledge Based	Heuristics	Good	Fair	Good	Fair	Good	Fair	Fair
	Linear Programming	Poor	Fair	Good	Poor	Poor	Poor	Poor
	Expert Systems	Good	Poor	Poor	Fair	Poor	Poor	Poor
	Fuzzy Logic	Good	Poor	Good	Fair	Good	Fair	Poor
	Tabu Search	Fair	Good	Good	Fair	Fair	Fair	Fair
Evolutionary Techniques Based	Simulated Annealing	Poor	Good	Good	Poor	Poor	Fair	Fair
	Genetic Algorithms	Poor	Good	Good	Poor	Poor	Fair	Fair
	Neural Networks	Poor	Poor	Poor	Poor	Good	Poor	Poor
	Ant Colony	Poor	Good	Good	Fair	Fair	Fair	Fair
	Particle Swarm Optimization	Poor	Good	Good	Fair	Fair	Fair	Fair
Mixed Methods	Linear Programming + Heuristics	Poor	Fair	Poor	Poor	Good	Fair	Poor
	Genetic Algorithms + Fuzzy Logic	Poor	Fair	Good	Poor	Good	Fair	Poor
	Fuzzy Logic + Heuristics	Good	Fair	Good	Poor	Good	Fair	Poor
	Simulated Annealing + Heuristics	Poor	Fair	Good	Poor	Good	Fair	Poor

Chapter 4

Research Methodology

4.1 Heuristic Optimization Methodology

Heuristic methods have been proposed [6-8] for finding the optimal or near optimal solution with fast computational time. Usually the heuristic technique requires a fewer number of iterations compared to any analytical method. One of the heuristic methods to reach an optimal configuration for minimizing system losses was proposed by Wagner et al, [24]. They considered all the possible switching options that may lead to a reduction in losses, calculated the losses and determined which option leads to minimum losses. Switching option means closing a normally open tie switch and opening a normally closed sectionalizing switch to restore the radiality of the distribution system. Figure (4.1) illustrates a flow chart to demonstrate this method.

Wagner et al. [24] based their method on results given by Civanlar et al. [6]. These results show that the switching options that may lead to reduction in the system losses can be reduced to a workable number after disregarding those options that may lead to an increase in the system losses, lead to voltage limit violation, current excess or customer outages. Therefore the proper switching options can be predicted before calculating the losses. This can be performed by calculating the system voltages. And then the open switches with negligible voltage differences across are disregarded from switching options because closing these switches does not lead to a reduction in the losses. Then, to obtain a reduction in the system losses the switches having large voltage differences are considered. Then the transfer of the loads should be from the low voltage side of the switch to the higher voltage side. This means that the two voltage drops from the substation to the open switch ends are calculated and it is necessary to transfer loads from the higher voltage drop side to the lower voltage drop side. Using this technique the number of considered switching options is reduced. Although this method gives good results for system reconfiguration it is still difficult regarding the large number of switching options considered and the optimal solution is not guaranteed to be reached especially for a very large system where the number of 4+0nodes are of the order of thousands. Also a drawback of this method is that the final solution depends mainly on the original configuration. The Following is the flow chart of the heuristic method [29].

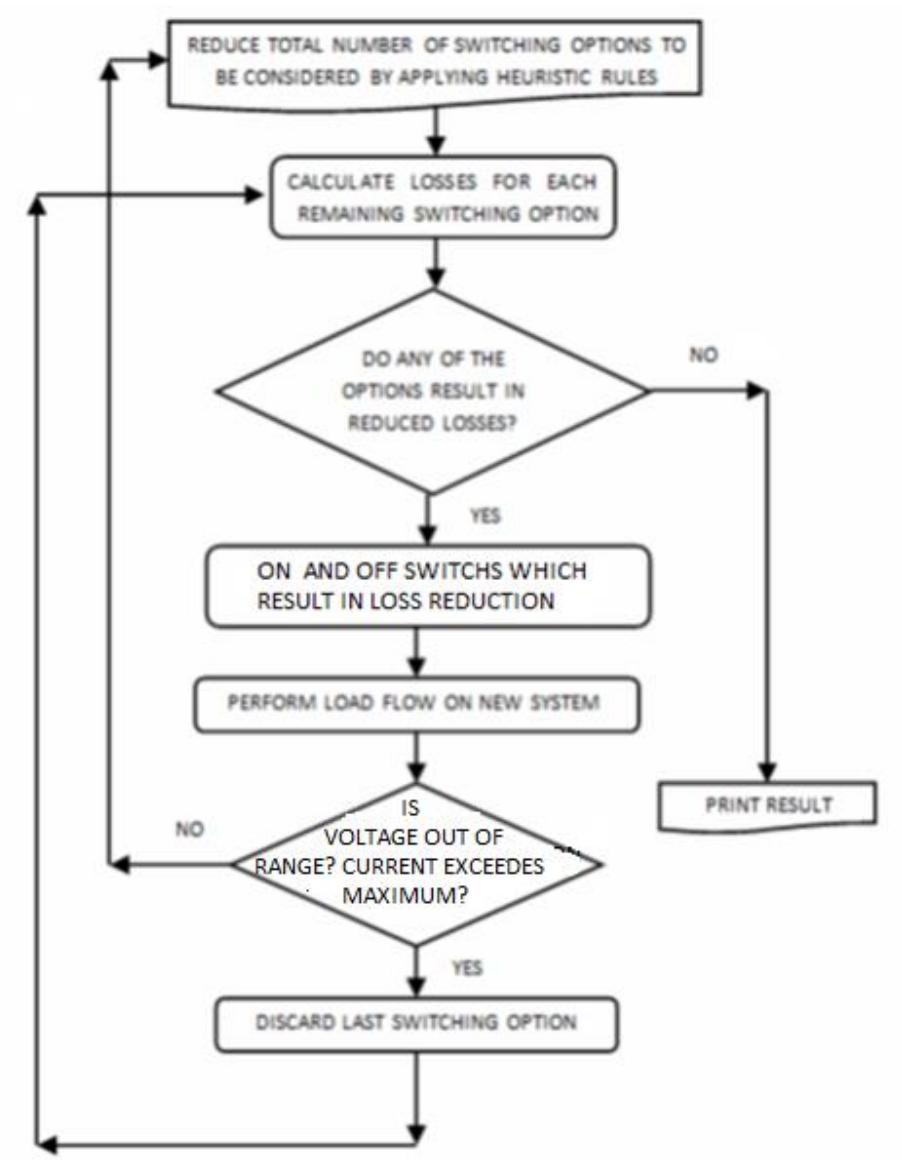


Figure 4-1: A flow chart for the heuristic method to find the optimal System configuration for loss minimization

The methodology which will be used in this thesis is based on the heuristic method described above. The solution starts with initial configuration with all NO switches are in open position. The voltage differences across all NO switches and the two node voltages of each NO switch are computed using load flow with PSS/E program. Among all the tie switches, a switch with maximum voltage difference is selected first subject to the condition that the voltage difference is greater than the pre-specified value. The NO switch with the maximum voltage difference is closed and the sectionalize switches are opened in sequence starting from the minimum voltage node of the NO switch. The power losses due to each sectionalize switch are calculated and the opening sectionalize switches are stopped when the power loss obtained due to previous sectionalizing is less than the current one. As the power loss due other sectionalize switches is more than the current, it is not necessary to open the sectionalize switches further in the loop. Based on the above procedure, the best switching combination of the loop is noted. The same procedure is repeated to all the remaining NO switches.

4.2 The Heuristic Algorithm for Loss Minimization

The algorithm for the network reconfiguration process for loss reduction of the distribution network is given below:

Step 1) Read system data (P, Q, R, X);

Step 2) Run the load-flow program for distribution networks;

Step 3) Compute the voltage difference across the open tie switches (i.e., for i = 1,2,…, n-tie);

Step 4) Identify the open tie switch across which the voltage difference is maximum and its code k (i.e., $\Delta V_{tie\max} = \Delta V(k)$);

Step 5) If $\Delta V_{tie\max}. > \varepsilon$ go to Step 6); otherwise, go to Step10);

Step 6) Select the tie switch “k” and identify the total number of loop branches (Nk)

Step 7) Open one branch at a time in the loop and evaluate the loss by equation (2.4) including the tie branch when the tie-switch “k” is closed;

Step 8) Obtain the optimal solution for the operation of tie-switch “k”, (i.e., stop when the loss obtained by opening the current switch is greater than the previous one, for i = 1, 2, …, Nk);

Step 9) Rearrange the coding of the rest of the tie switches and go to Step 2);

Step 10) Print output results;

Step 11) Stop.

4.3 The Heuristic Algorithm for Load Balancing

The algorithm for the network reconfiguration process for load balancing of the distribution network is given below:

Step 1) Read system data (P, Q, R, X);

Step 2) Run the load-flow program for distribution networks;

Step 3) Compute the voltage difference across the open tie switches (i.e., for i = 1,2,…, n-tie);

Step 4) Identify the open tie switch across which the voltage difference is maximum and its code k (i.e., $\Delta V_{tie\max} = \Delta V(k)$);

Step 5) If $\Delta V_{tie\max}. > \varepsilon$ go to Step 6; otherwise, go to Step10;

Step 6) Select the tie switch "k" and identify the total number of loop branches (Nk)

Step 7) Open one branch at a time in the loop and evaluate the system load balancing index by equation (2.7), including the tie branch when the tie-switch "k" is closed;

Step 8) Obtain the optimal solution for the operation of tie-switch "k", (i.e., stop when the Load balancing index obtained by opening the current switch is greater than the previous one, for i = 1, 2, …, Nk);

Step 9) Rearrange the coding of the rest of the tie switches and go to Step 2);

Step 10) Print output results;

Step 11) Stop.

4.4 Load Flow/Power Flow

Load Flow Studies are performed on Power Systems to understand the nature of the installed network. This understanding gives the knowledge of the installed generation systems, loads connected, losses incurred, and also the flexibility of the system to allow future load connections. So, Load Flow or Power Flow analysis is a vital part of any power system, as without this information, maintaining the network and regulating it within specified limits becomes just a blind control of some wires, in which current flows. Generally distribution systems are radial and the R/X ratio is very high. For this reason distribution systems are ill-condition, and conventional Newton Raphson (NR) and fast decoupled load flow (FDLF) methods are inefficient in solving such systems.

The distribution power flow involves, first of all, finding all the node voltages. From these voltages, it is possible to compute current directly, power flows, system losses and other steady state quantities .some applications, especially in the fields of optimization of distribution system, and distribution automation (i.e., VAR planning, network optimization, state estimation, etc.), need repeated fast load flow solutions. In these applications it is important that the load flow problem is solved as efficiently as possible.

For a large distribution system, where the number of nodes is the order of thousands, computation time is important and system reconfiguration techniques require an efficient load flow calculation algorithm.

The efficient load flow technique for solving the radial distribution system is a forward/backward sweeping method.

This method develops a new load flow technique for radial distribution systems by using node and branch numbering scheme. The forward/backward sweeping method solves a recursive relation of real, reactive power and voltage magnitudes.

In this thesis PSS/E, commercial software developed by Siemens, is used for load flow calculations and simulating the distribution system.

4.5 PSS/E

Professional software package PSS/E (Power System Simulator for Engineering) is developed by Siemens PTI (Power Technologies International)

PSS/E is a comprehensive time tested tool for performing power flow (including optimal power flow), short circuit, and transient stability simulation (including long term) of power system networks. The program, used by utility engineers and others worldwide for well over three decades, employs the latest numerical algorithms to efficiently solve networks with up to 150,000 buses with no loss of solution accuracy or computer time.

The PSS/E-31 program package has a modern, easy-to-use, Microsoft Foundation Class (MFC), graphical user interface (GUI) for power flow as well as dynamic simulation. The GUI contains commands for recording capability which can be used to automate repetitive calculations.

User-switchable choice of five solution methods including Newton-Raphson (full, decoupled, fast decoupled), Gauss-Seidel, and modified Gauss-Seidel.

PSS/E is comprised of the following calculation modules:

- PSS/E Power Flow
- PSS/E Optimal Power Flow (PSS/E OPF)
- PSS/E Balanced or Unbalanced Fault Analysis
- PSS/E Dynamic Simulation

Module is basic PSS/E program module and it is powerful and easy-to use for basic power flow network analysis. Besides analysis tool this module is also used for Data handling, updating, and manipulation

4.5.2 Overview of PSS/E Functionality

PSS/E is not set up to solve any specific problem, rather, it is set of computational tools that are directed by the user in an interactive manner. By applying these tools in the appropriate sequence, the engineer can handle a wide range of investigations for the planning and operation of electric power systems.

Through the PSS/E interface the following functions and analyses are available:

- Power flow and related network functions
- Optimal power flow
- Open access
- Fault analysis
- Network equivalencing
- Dynamic simulation
- One-line diagrams
- Program automation

Additionally, one of the most basic premises of PSS/E is that the engineer can derive the greatest benefit from computational tools by retaining intimate control over their application. IPLAN program language and or Python programs can be used within PSS/E for batch control and automation of the simulation processes.

4.5.3 Overview of the PSS/E User Interface

The PSS/E interface supports a variety of interactive facilities including:

- Introduction, modification and deletion of network data using a spreadsheet.
- Creation of networks and one-line diagrams.
- Steady-state analyses (load flow, fault analysis, optimal power flow, etc.).
- Presentation of steady-state analysis results.
- Dynamic simulations (transient, dynamic and long term stability analysis).

• Presentation of Dynamic simulation results.

Once PSS/E opened, the key elements of the user interface are the Tree View, Spreadsheet View, Diagram View and the Output Bar, as pointed out in Figure 4-2.

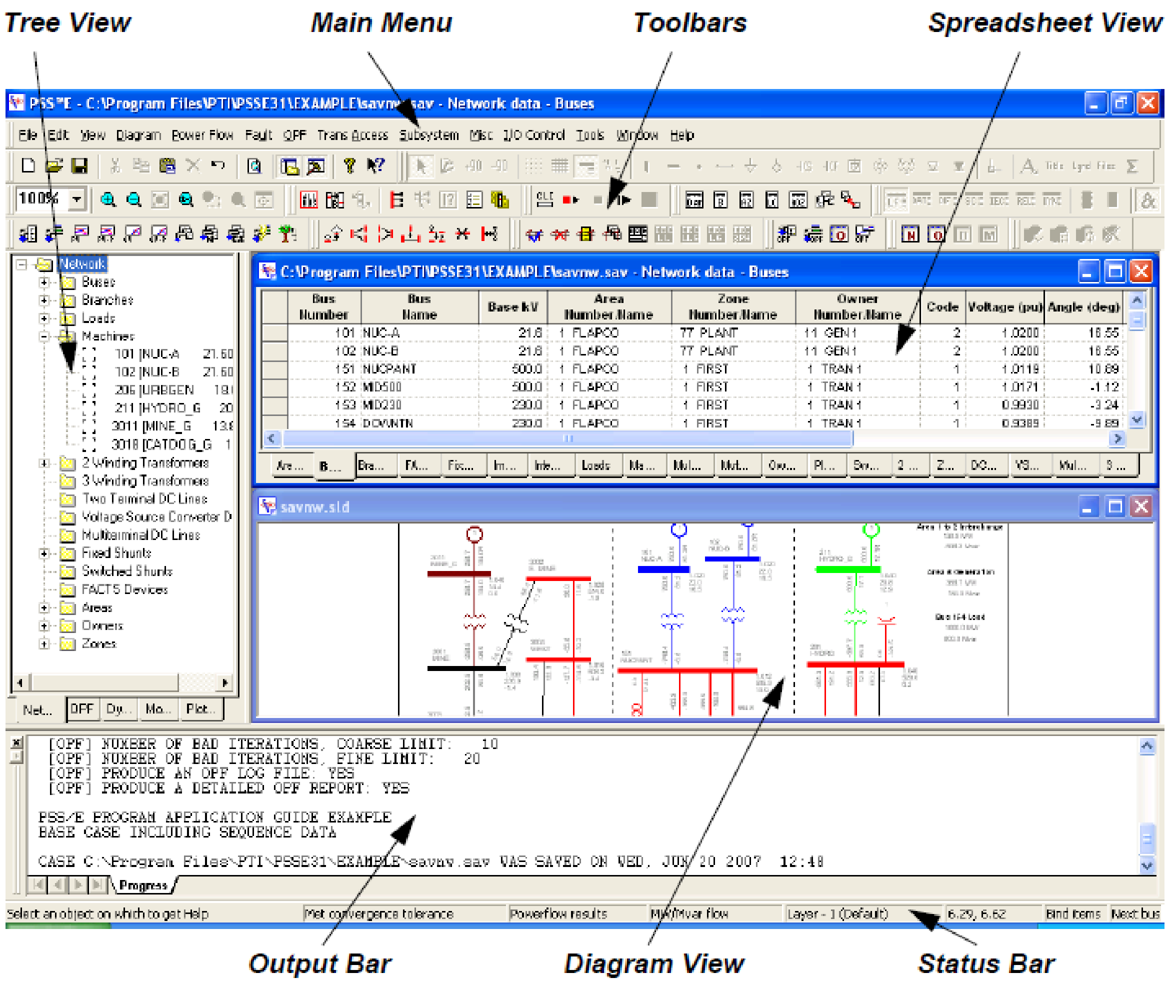


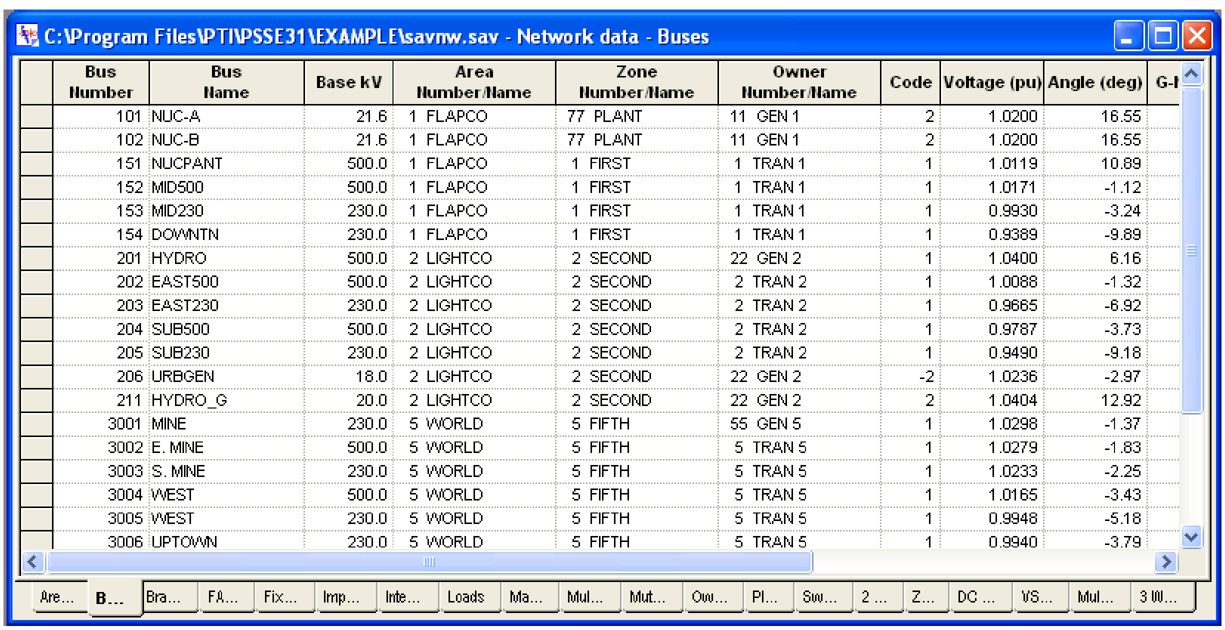
Figure 4-2: Key Elements of the Interface Tree View, Main Menu, Toolbars, Spreadsheet, View Output Bar Diagram, View Status Bar

4.5.4 Spreadsheet View

All network data components (e.g., buses, lines, loads) are represented within worksheet style tabs on the spreadsheet. The spreadsheet, or workbook, is synchronized with the bus subsystem selector so that only a subset of the data may be viewed at any time. New network elements may be entered or modified directly in the appropriate worksheet, or existing ones deleted. In the Spreadsheet View, standard Windows commands such as copy and paste actions are supported.

Sorting and filtering capabilities are provided to increase usability, especially with large systems. At program startup the Spreadsheet View is not shown. It will appear when a raw data or saved case file is opened. The Spreadsheet View is the default view for the interface and remains open once it is populated. It can be minimized, but if closed will remove the current network from PSS/EE.

In Figure 4-3, the Bus tab has been selected and the spreadsheet reflects the bus data records within the working case. Other data items may be viewed by clicking on the other tabs located at the bottom of the spreadsheet view.


C:\Program Files\PTI\PSSE31\EXAMPLE\savnw.sav - Network data - Buses

Bus Number	Bus Name	Base kV	Area Number/Name	Zone Number/Name	Owner Number/Name	Code	Voltage (pu)	Angle (deg)	G-I
101	NUC-A	21.6	1 FLAPCO	77 PLANT	11 GEN 1	2	1.0200	16.55	
102	NUC-B	21.6	1 FLAPCO	77 PLANT	11 GEN 1	2	1.0200	16.55	
151	NUCPANT	500.0	1 FLAPCO	1 FIRST	1 TRAN 1	1	1.0119	10.89	
152	MID500	500.0	1 FLAPCO	1 FIRST	1 TRAN 1	1	1.0171	-1.12	
153	MID230	230.0	1 FLAPCO	1 FIRST	1 TRAN 1	1	0.9930	-3.24	
154	DOWNTN	230.0	1 FLAPCO	1 FIRST	1 TRAN 1	1	0.9389	-9.89	
201	HYDRO	500.0	2 LIGHTCO	2 SECOND	22 GEN 2	1	1.0400	6.16	
202	EAST500	500.0	2 LIGHTCO	2 SECOND	2 TRAN 2	1	1.0088	-1.32	
203	EAST230	230.0	2 LIGHTCO	2 SECOND	2 TRAN 2	1	0.9665	-6.92	
204	SUB500	500.0	2 LIGHTCO	2 SECOND	2 TRAN 2	1	0.9787	-3.73	
205	SUB230	230.0	2 LIGHTCO	2 SECOND	2 TRAN 2	1	0.9490	-9.18	
206	URBGEN	18.0	2 LIGHTCO	2 SECOND	22 GEN 2	-2	1.0236	-2.97	
211	HYDRO_G	20.0	2 LIGHTCO	2 SECOND	22 GEN 2	2	1.0404	12.92	
3001	MINE	230.0	5 WORLD	5 FIFTH	55 GEN 5	1	1.0298	-1.37	
3002	E. MINE	500.0	5 WORLD	5 FIFTH	5 TRAN 5	1	1.0279	-1.83	
3003	S. MINE	230.0	5 WORLD	5 FIFTH	5 TRAN 5	1	1.0233	-2.25	
3004	WEST	500.0	5 WORLD	5 FIFTH	5 TRAN 5	1	1.0165	-3.43	
3005	WEST	230.0	5 WORLD	5 FIFTH	5 TRAN 5	1	0.9948	-5.18	
3006	UPTOWN	230.0	5 WORLD	5 FIFTH	5 TRAN 5	1	0.9940	-3.79	

Are... B... Bra... FA... Fix... Imp... Inte... Loads Ma... Mul... Mut... Ow... Pl... Sw... 2 ... Z... DC ... VS... Mul... 3 W...

Figure 4-3: Overview of the Spreadsheet View

4.5.5 Tree View

The Tree View provides a hierarchical, expandable and collapsible list view of the network, OPF, dynamics, model, and plot data in the system (as shown in Figure 4-4). It is synchronized with the bus subsystem selector to enable the user to reduce the amount of data presented at any one time. The Tree View is also synchronized with the Spreadsheet and Diagram Views, reflecting their current content.

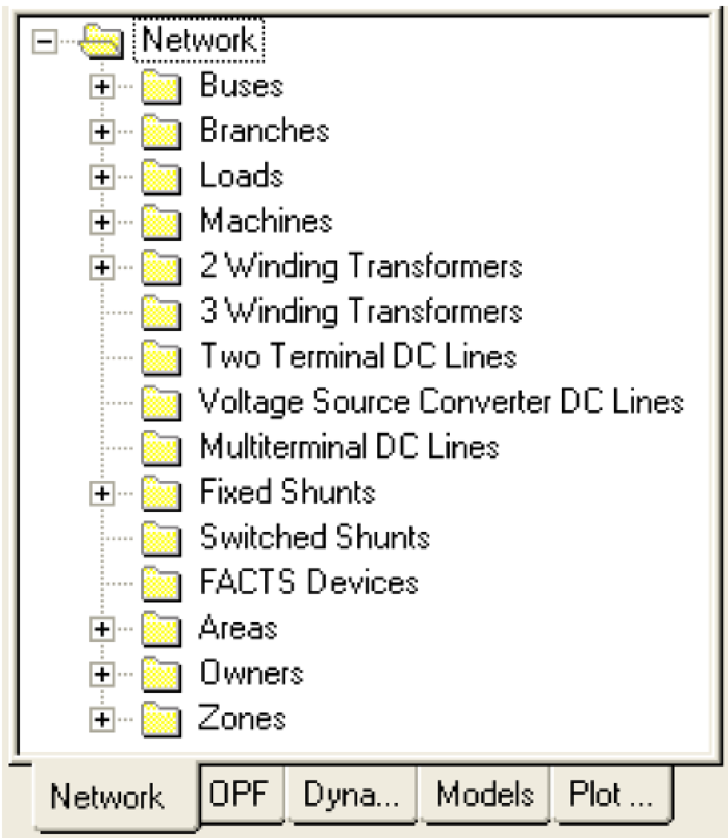


Figure 4-4: Tree View (expandable form of network components)

4.5.6 Diagram View

The Diagram View is used to create, expand and display one-line diagrams of the electrical system (as shown in Figure 4-5). As new elements are added to the diagram, the Spreadsheet and Tree Views are automatically updated to reflect the addition.

Additional diagram capabilities include the ability to view power flow, short-circuit analysis, reliability and dynamic simulation results.

The Diagram View is not automatically opened. It is initiated by opening an existing one-line drawing file, or by starting a new diagram window.

The Diagram View can directly import old PSS/E DRAW files, which can then be saved to the new diagram Slider (SLD) format.

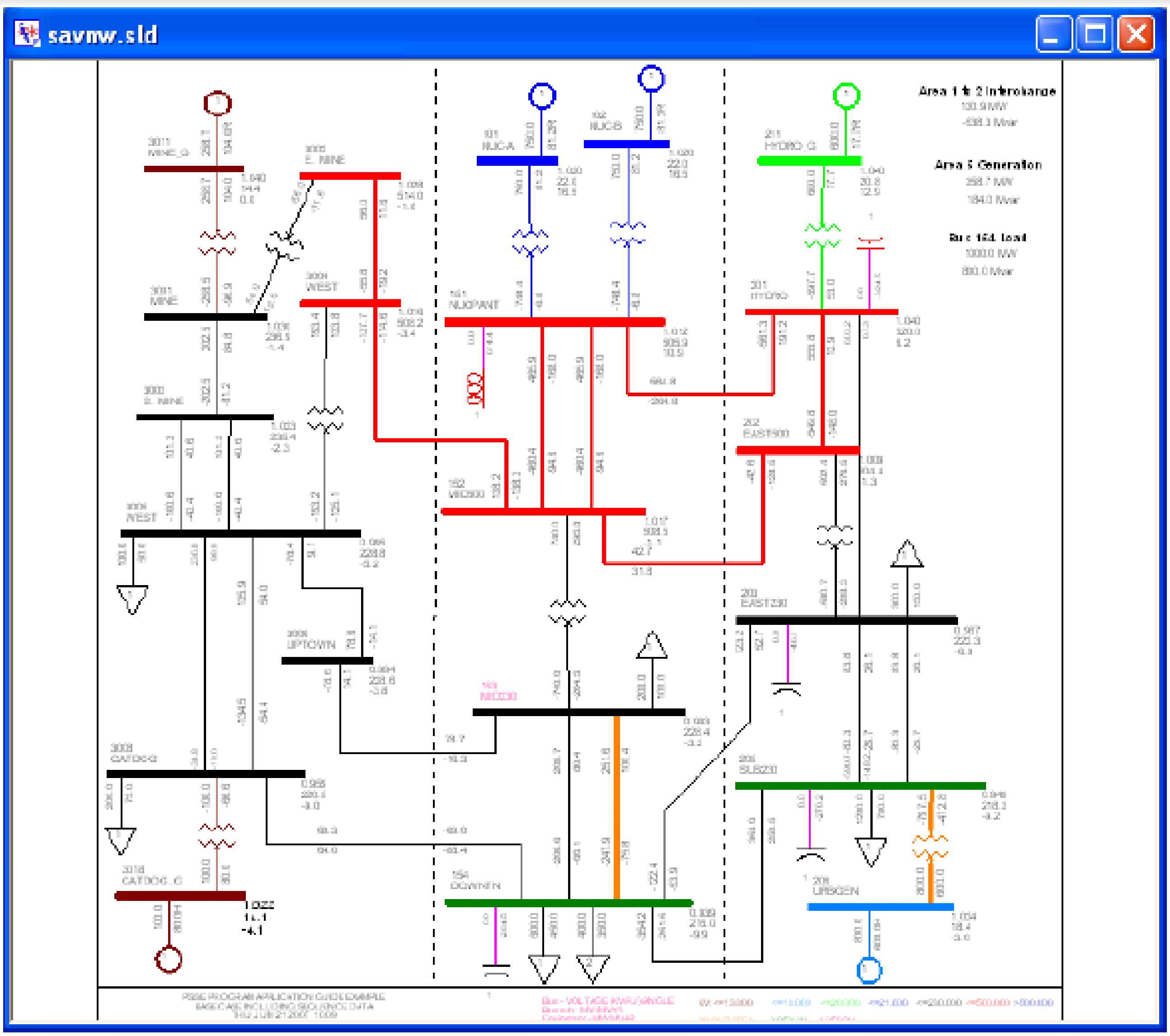


Figure 4-5: Overview of Diagram View of a sample system

Given an existing PSS/E case, a one-line diagram may easily be built or expanded, bus by bus. This is accomplished by activating a Diagram View, right-clicking on an existing bus within the diagram or tree view, and selecting Grow. All items connected to the selected bus are automatically drawn on the diagram. Simple mouse operations may then be used to rearrange elements on the diagram.

Chapter 5

Simulation Results and Discussions

This chapter discusses the results obtained from PSS/E by applying the proposed heuristic method on the distribution system of the Addis Ababa city, feeder 3 of Weregenu substation. The Addis Ababa city distribution system is represented in the PSS/E as shown in Figures A-1 in The Appendix.

5.1 Test System: Addis Ababa Distribution system

5.1.1 System Description

The example which is used to test the proposed reconfiguration algorithm is Addis Ababa distribution system, From Weregenu substation feeder 3, which is shown in Figure 5-1. It consists of a feeder, 80 buses, 79 normally closed switches (sectionalizing switches), and 5 normally open switches (tie switches). The PSS/E simulation is shown in Fig A-1.The system is a three phase system, 15KV and the input data is shown in Table A-1 (Appendix A). The system loads are assumed constant and Vbase and Sbase are 15KV and 100MVA respectively. The Following conductors are used in the feeder.

Over head lines

AAC 95 sqmm, AAC 50 sqmm, AAC 25sqmm, ACSR 65 sqmm, ACSR 46, ACSR 30

Under ground lines

3x 16 sqmm Cu , 3x 120 sqmm Cu

Proposed tie lines

AAAC 240 sqmm , AAC 95 sqmm

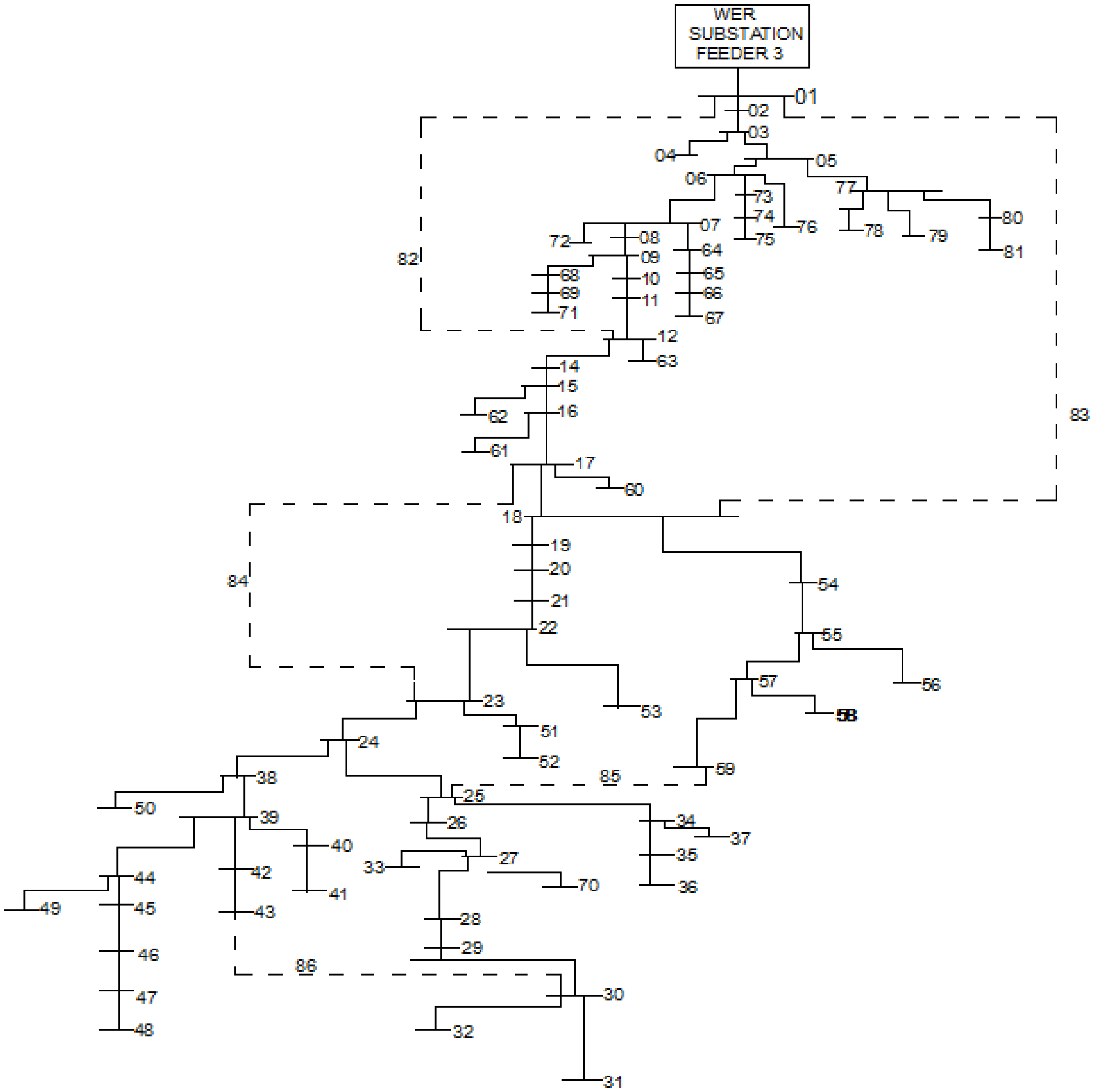


Fig 5-1. Feeder 3 MV distribution Network of Weregenu Substation

The normally open switches are 82, 83, 84, 85 and 86 and normally close switches are 1 to 81. For this base case, the initial losses with applying PSS/E program simulation can be computed as follows .The PSS/E simulations of the feeder at its initial point (gantry) before reconfiguration is shown in Fig.5-1. (There is an updated EEU grid for 2015 behind 132KV B.Weregenu busbar)

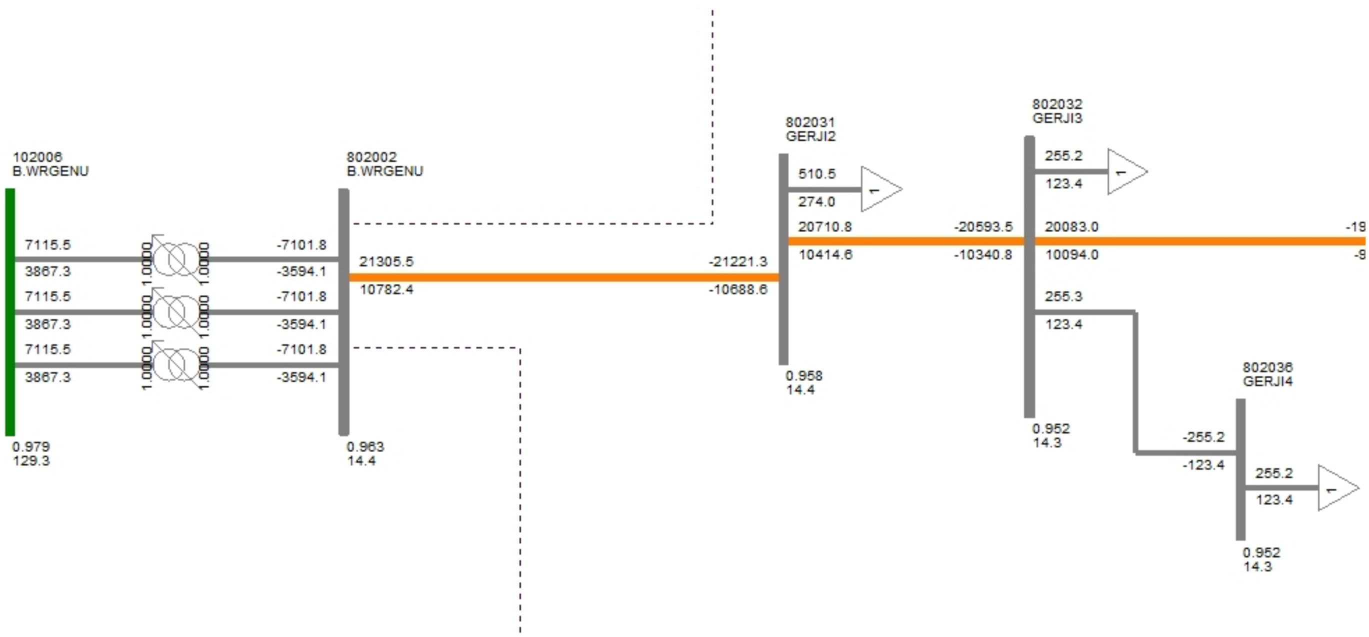


Fig.5-2 Part of the simulation around substation before reconfiguration

From Fig.5-1, the total power of the system is 21305.5 KW and from Table. A-1 of the appendix the total load is 19.926MW, which is obtained from EEU.

Loss=21305.5KW-19926KW=1379.5KW

Hence the loss of the feeder before reconfiguration is 1379.5KW

The Following Figures show some parts of the feeder before reconfiguration.

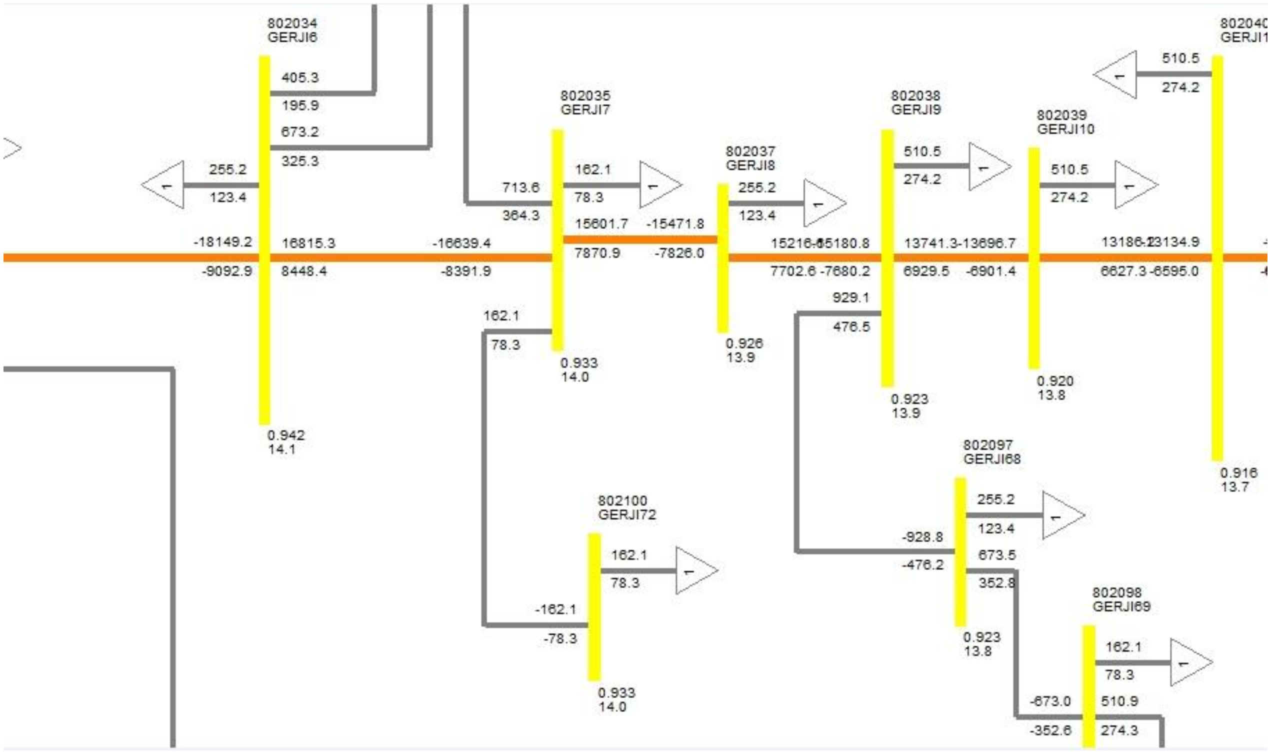


Fig 5-3 Part of the simulation before reconfiguration around tie Switch 82.

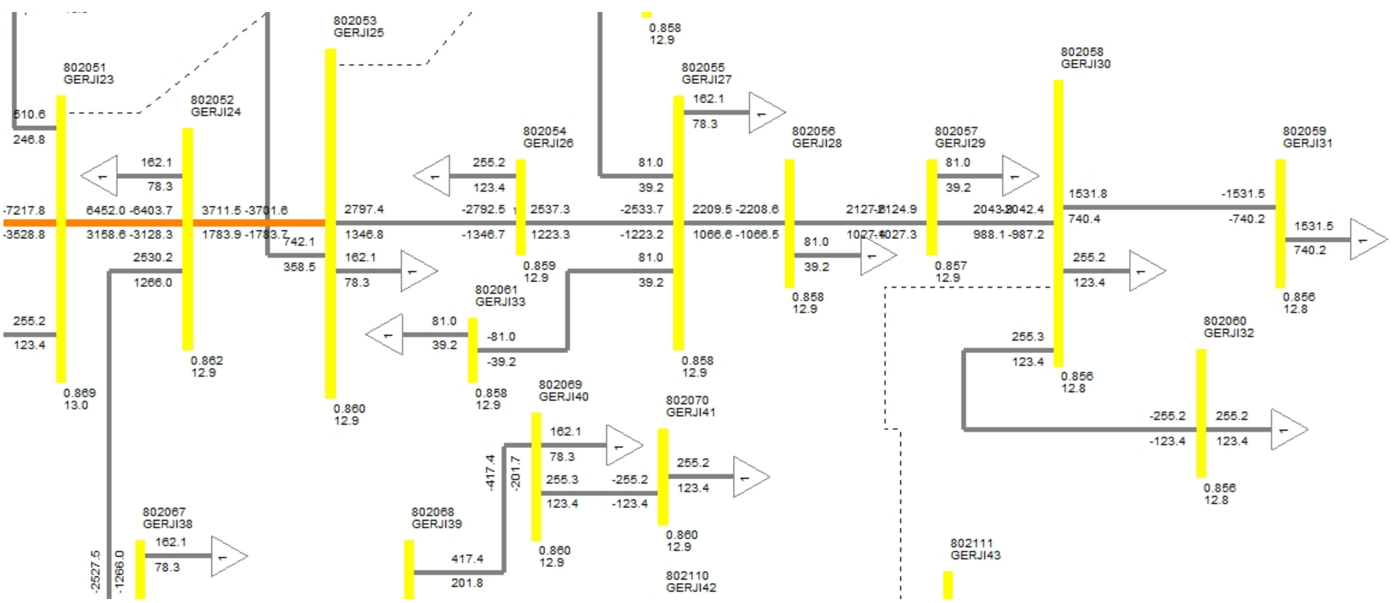


Fig 5-4 Part of the simulation before reconfiguration around tie Switch 86.

5. 2 Reconfiguration for Loss Minimization

The reconfiguration of the feeder is done using the Heuristic methodology in section 4.1 as follows. The voltage differences across all NO switches are calculated with applying load flow in the PSS/E program for the network shown and results are shown in Table 5-1.

Table 5-1.Voltage Difference across All Open Tie Switches

Tie switch No	NO Voltage difference across tie switch (pu)
82	0.05
83	0.073
84	0.034
85	0.028
86	-0.004

It is observed that the maximum voltage difference occurs across NO switch 83. Hence, the tie switch 83 is closed first as the voltage differences across the remaining NO Switches are smaller in magnitude.

Now, if the tie switch 83 is closed, a loop will be formed. Opening of each branch in this loop is an option. In this method, sectionalizing branches are opened (to retained the radiality) either left or right of the selected tie switch based on the minimum voltage node of the tie switch.

This procedure is explained as follows. The two node voltages of the tie switch 83 are evaluated and the minimum of two node voltages is noted. In this case, the minimum node voltage of the tie switch 83 is 18 because the voltage of node 18 is equal to 0.89 and node voltage 1 is 0.963.Therefore, one branch at a time in the loop is opened starting from the node 18 and power loss due to each objective is obtained till the power loss (due to current objective is greater than the previous objective). In this loop, the first sectionalize branch (18-17) is opened as it adjacent to the node 18 and power loss is computed and shown in Table 5-6. In the same manner, next adjacent sectionalize branches 17-1 6 is opened and power loss is computed and shown in the Table 5-6.

As the power loss due to sectionalize branch 17-16 is greater than 18-17, the optimal opening branch in the loop is between the nodes 18 and 17.Further opening of the branches beyond the branch 17-16 in the loop, is giving either more power loss than the minimum already obtained at the branch 18-17or infeasible solution.

Hence, the opening of the remaining branches is discarded. The optimal radial loop for the first switching operation is obtained by closing the tie switch 83 and opening the branch between the nodes 18 and 17. The advantage of this procedure is that it is not necessary to visit all the sectionalizing switches in the loop. Therefore, the search space of sectionalizing switches in the loop is drastically reduced. For the second switching operation, the voltage difference across remaining tie switches (discarding tie switch 83) are computed and shown in Table 5-2.

Table 5-2.Voltage Difference across the Remaining Open Tie Switches

Tie switch No	NO Voltage difference across tie switch (pu)
82	0.017
84	0.07
85	0.03
86	0.001

From Table 5-2, it is observed that the maximum voltage difference occurs across tie switch 84 and it is greater than the specified value (ϵ =0.01). The minimum voltage node of the tie switch 84 is 23 because the voltage of node 23 is equal to 0.875 and node voltage 17 is 0.945. Repeating the same procedure as in case of tie switch 83, the optimal radial configuration for the second switching operation is obtained by closing the tie switch 84 and opening the sectionalize branch between the nodes 23 and 22. Among the tie switches 82, 85 and 86, the voltage difference across tie switch 85 is greater than remaining two and is shown in Table 5-3.

Table 5-3. Voltage Difference across the Remaining Open Tie Switches

Tie switch No	NO Voltage difference across tie switch (pu)
82	0.041
85	0.11
86	0.003

Therefore, the tie switch 85 is selected for the third switching operation as voltage difference is greater than the specified value. The minimum voltage node of tie switch 85 is 25 because the voltage of node 25 is equal to 0.831and node voltage 59 is 0.941. Repeating the same procedure as in case of tie switch 84, the optimal radial configuration for third switching operation is obtained by closing the tie switch 85 and open the sectionalize branch between the nodes 25 and 24. The voltage difference across the remaining two tie switches 82 and 86 are shown in Table 5-4.

Table 5-4. Voltage Difference across The Remaining Open Tie Switches

Tie switch No	NO Voltage difference across tie switch (pu)
82	0.027
86	0.004

For fourth switching operation, tie switch 82 is considered as the voltage difference across it is greater than 86 and it is also greater than the specified value (ϵ =0.01). The minimum voltage node of 82 is 12 because the voltage of node 12 is equal to 0.936 and node voltage 1 is 0.963. As can be seen from Table 5-6, The lowest power loss is obtained when branch 9-8 is opened.Hence,in this case the optimal configuration of the loop is obtained by closing the tie switch 82 and opening the sectionalize branch between the nodes 9-8. The voltage difference across the remaining one tie switches 86 is shown in Table 5-5.

Table 5-5. Voltage Difference Across The Remaining Open Tie Switche

Tie switch No	No Voltage difference across tie switch (pu)
86	0.018

For Fifth switching operation, tie switch 86 is considered as the voltage difference across it is greater than the specified value (ϵ =0.01). The minimum voltage node of 86 is 30 because the voltage of node 30 is equal to 0.899 and node voltage 43 is 0.917. In this case the optimal configuration of the loop is obtained by closing the tie switch 86 and opening the sectionalize branch between the nodes 30-29.

The distribution network is reconfigured for the real power loss minimization. As can be seen from Table 5-6, the loss after reconfiguration is 416.9 KW.

As explained at the beginning of this section (on page 36), the power loss before reconfiguration is 1379.5KW.Therefore the reduction in power loss is

Power loss reduction=1379.5 KW -416.9KW=962.6 KW

962.6 KW which is approximately 69.77% of the loss before reconfiguration. High percentage of reduction in power loss obtained because the proposed tie switches are strategic ones and their cable cross sections deliberately selected to be higher ones.

Table 5-6. Real Power Loss, Node of Minimum Node Voltages Of The Tie Switches, Sectionalizing Switches Open

Tie switch (Closed)	Node of the Minimum Node voltage of the NO switch	Sectionalize switch open between nodes	Power loss (KW) (After each tie switch is closed)
83	18	**18-17**	**978.4**
		17-16	1038.5
84	23	**23-22**	**916.4**
		22-21	990.2
85	25	**25-24**	**677.8**
		24-23	915.3
82	12	12-11	482.6
		11-10	476.2
		10-9	472
		9-8	**471.2**
		8-7	472.6
86	30	**30-29**	**416.9**
			419.3

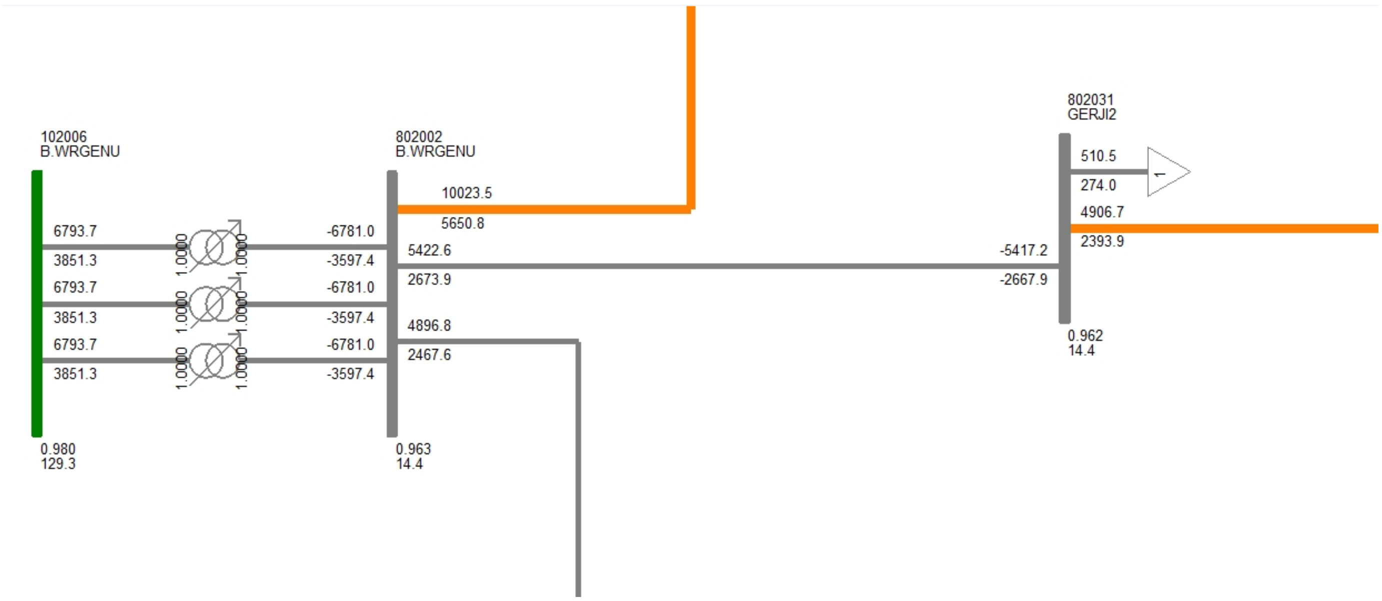


Fig.5-5 Part of Feeder 3 around the substation After Reconfiguration for Loss Minimization

From Fig 5-4 the total power after reconfiguration is 20342.9 KW (20342.9=10023.5+5422.6+4896.8), the values can be seen on bus 802002, B.WREGENU. The total load of the distribution system from Table A-1 is 19926. Hence,

The power loss after reconfiguration =20342.9-19926= 416.9 KW.

The Following figures shows the simulations after reconfiguration

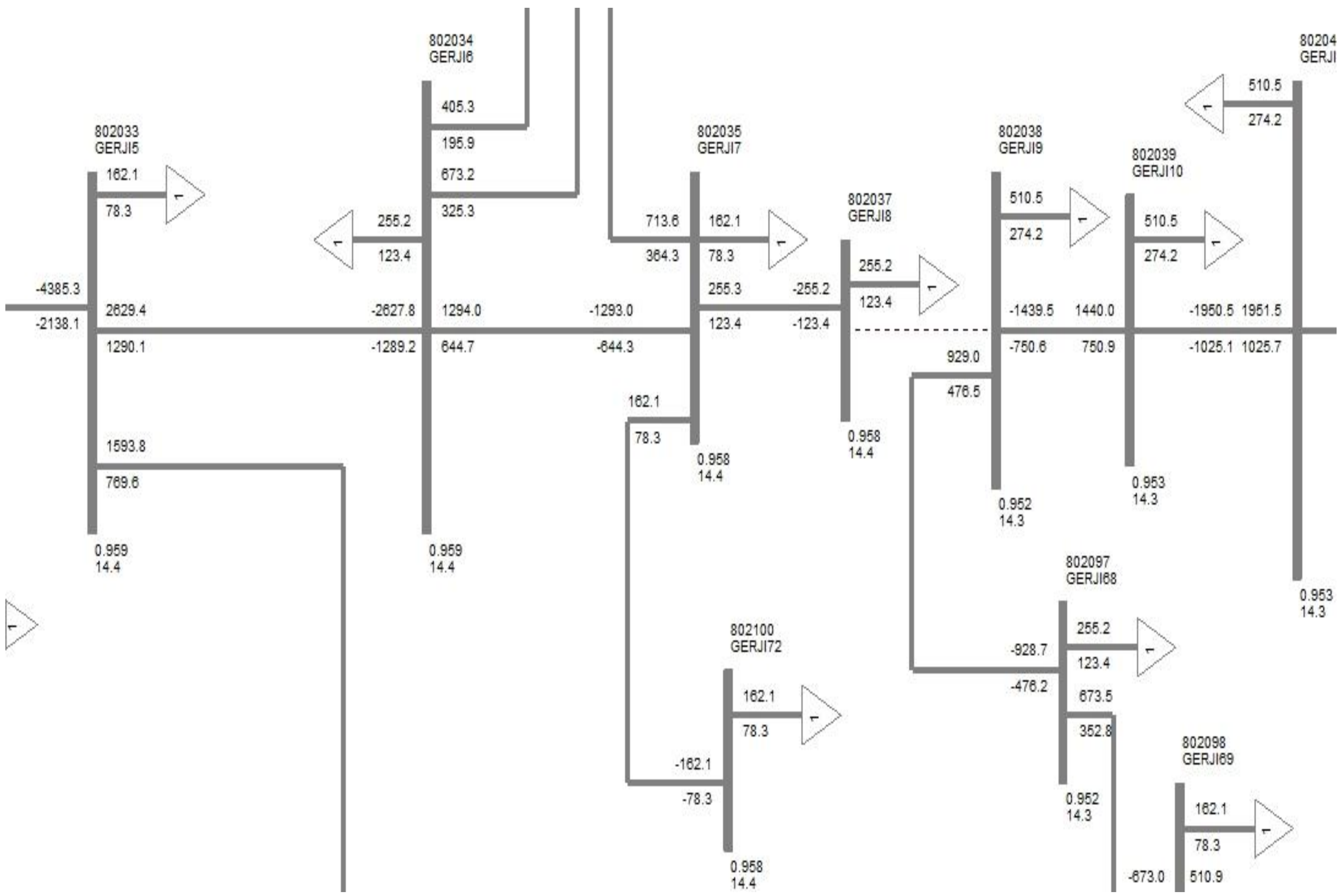


Fig.5-6 Part of Feeder 3 Simulation after Reconfiguration for Loss Minimization around tie Switch 82.

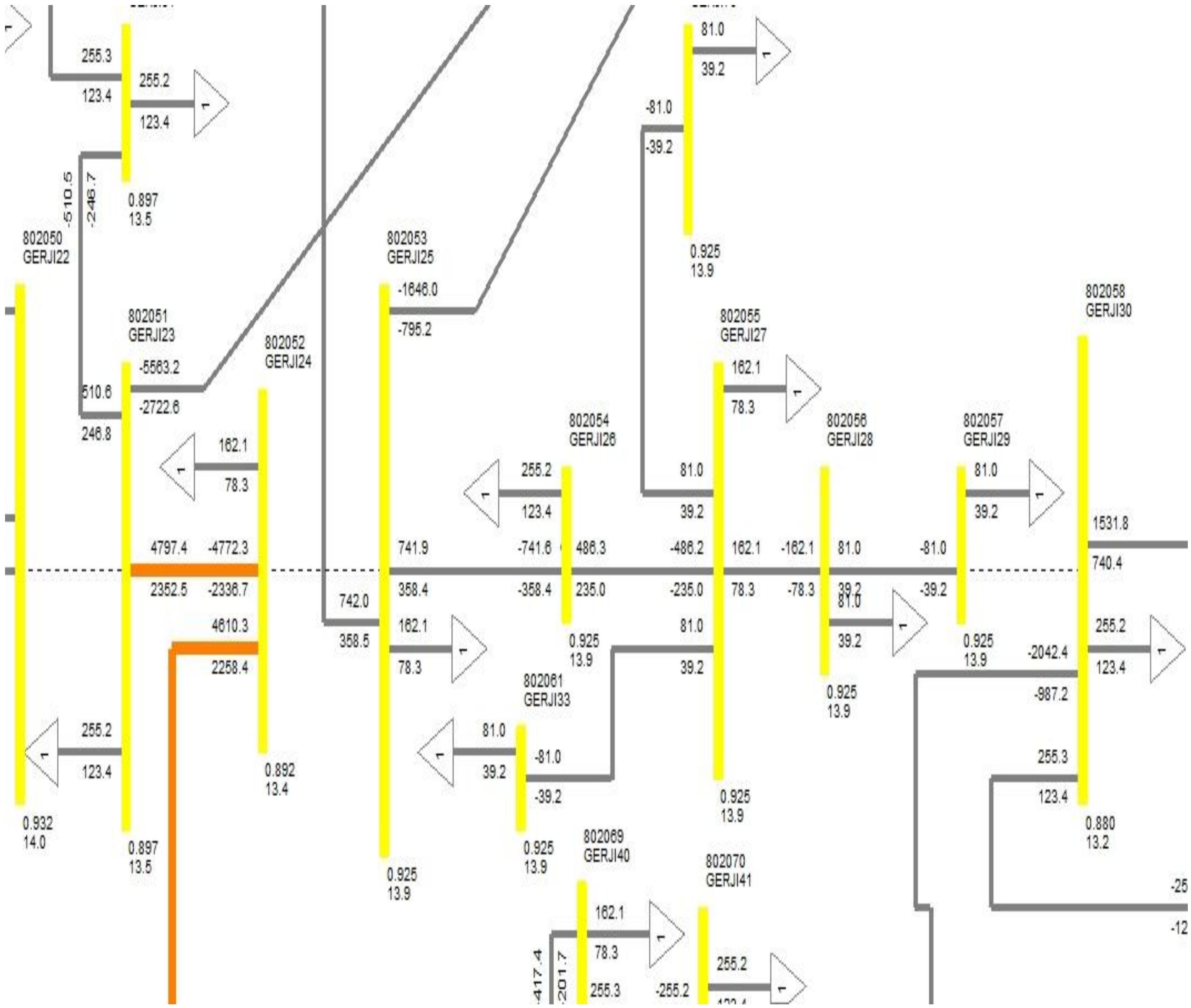


Fig.5-7 Part of Feeder 3 Simulation after Reconfiguration for Loss Minimization around tie Switch 86.

The system after reconfiguration for loss minimization can be seen from Fig A-2 in in the Appendix

5.3 Reconfiguration for Load balancing

The loading of the system before reconfiguration around the substation can be seen from the following diagrams. The system load balancing index, before reconfiguration is 100.9%.

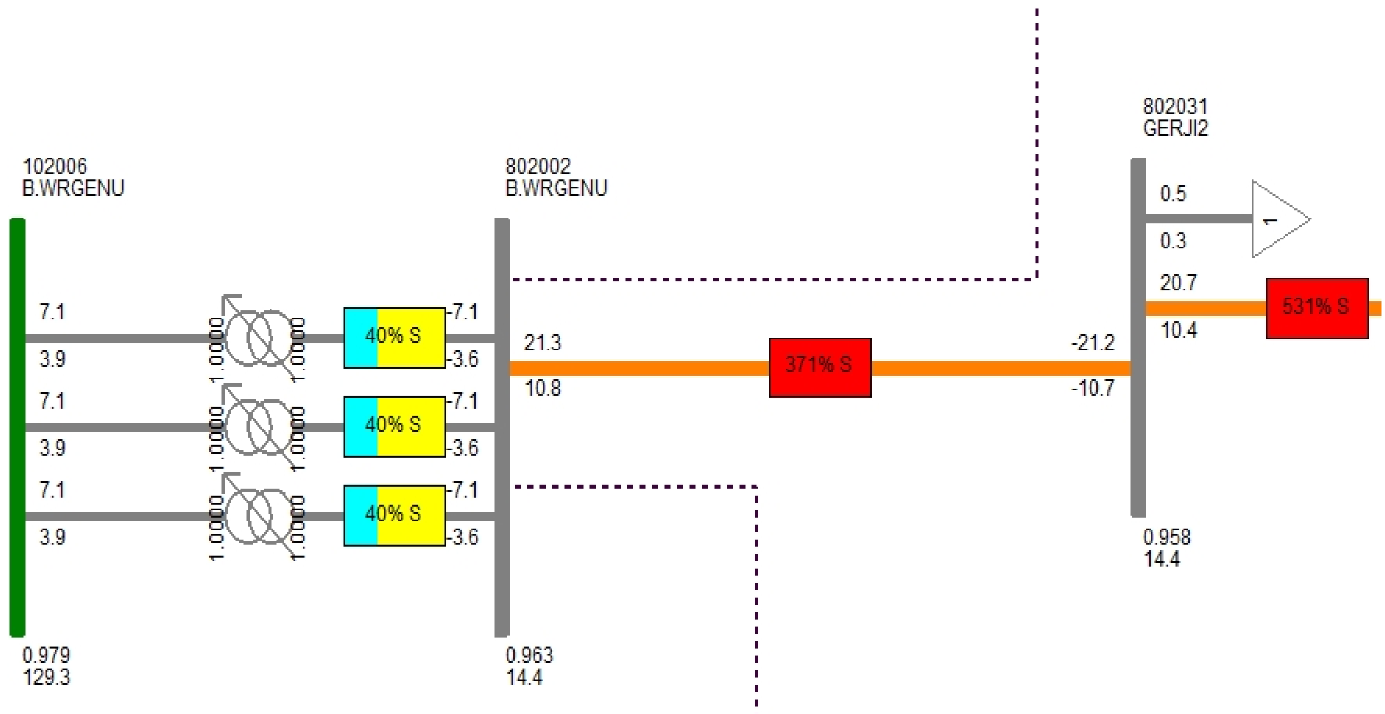


Fig.5-9 Part of Feeder 3 Simulation around substation before Reconfiguration for Load Balancing

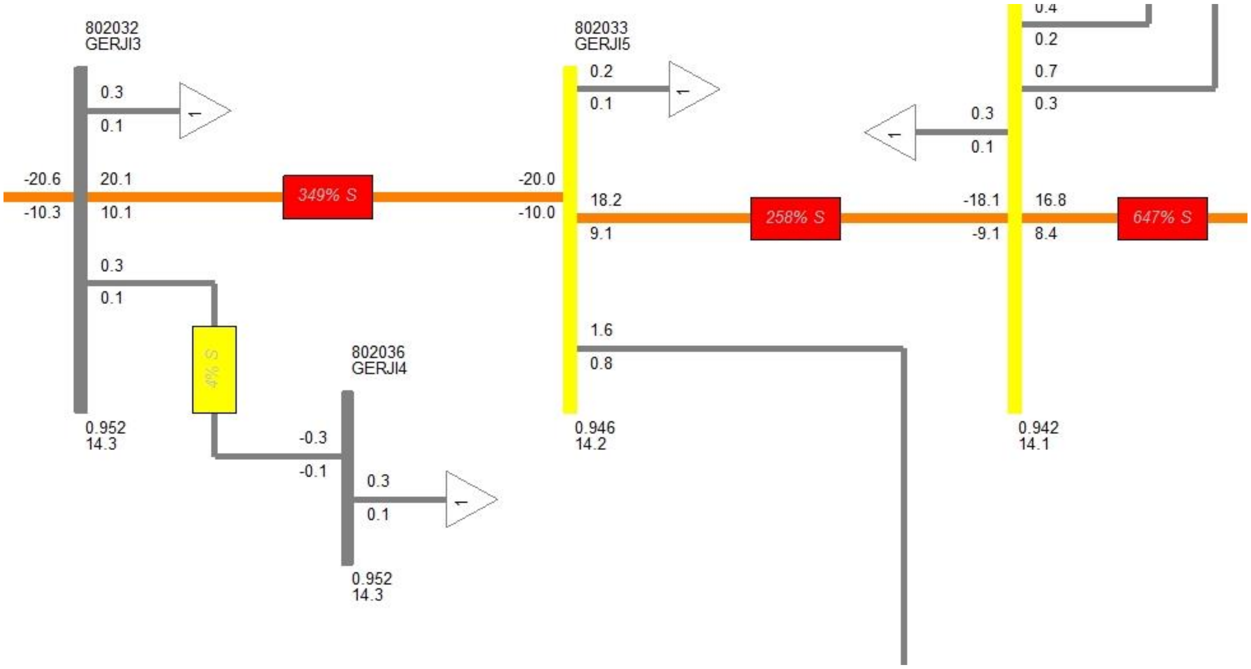


Fig.5-10 Part of Feeder 3 Simulation before Reconfiguration for Load Balancing Around Tie Switch 82

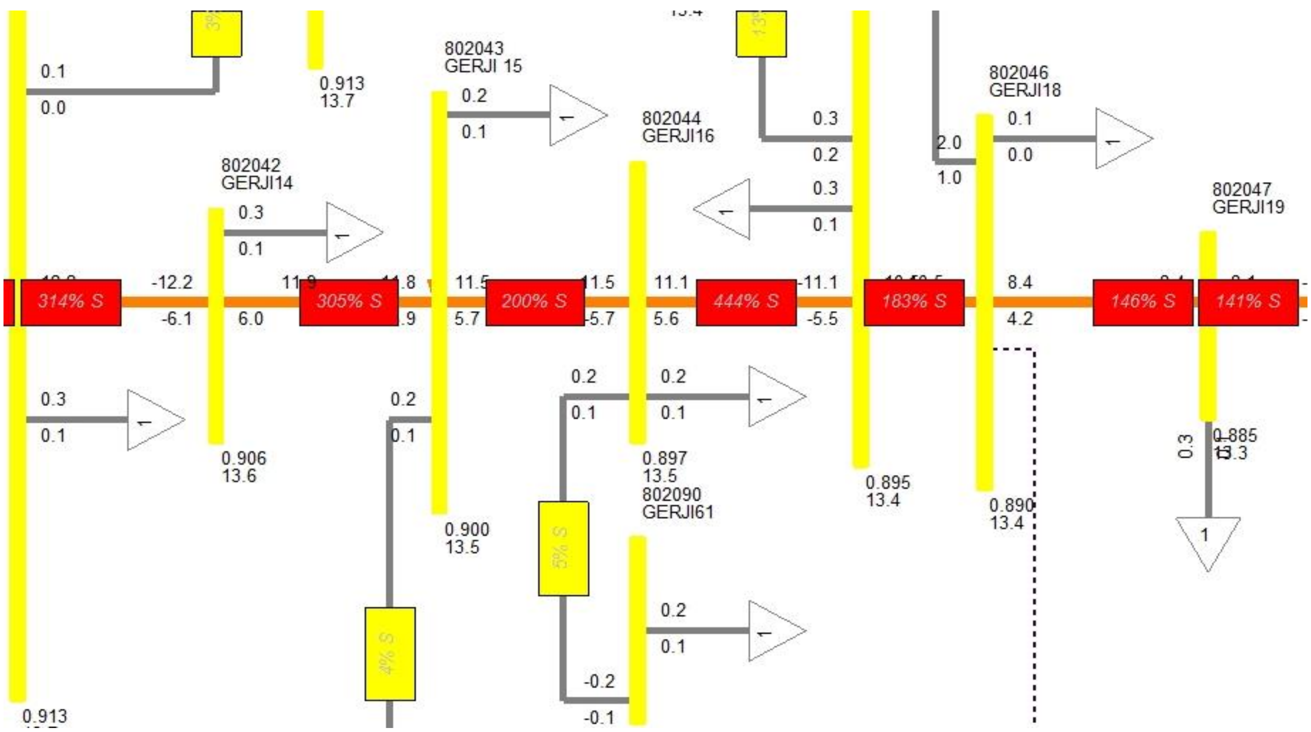


Fig.5-11 Part of Feeder 3 Simulation before Reconfiguration for Load Balancing around tie Switch 83.

The reconfiguration of the feeder is done using the heuristic methodology in section 4.1 as follows. The voltage differences across all NO switches are calculated with applying load flow in the PSS/E program for the network shown and results are shown in Table 5-7.

Table 5-7. Voltage Difference across All Open Tie Switches

Tie switch No	NO Voltage difference across tie switch (pu)
82	0.05
83	0.073
84	0.034
85	0.028
86	-0.004

It is observed that the maximum voltage difference occurs across NO switch 83. Hence, the tie switch 83 is closed first as the voltage differences across the remaining NO switches are smaller in magnitude.

Now, if the tie switch 83 is closed, a loop will be formed. Opening of each branch in this loop is an option. In this method, sectionalize branches are opened (to retain the radiality) either left or right of the selected tie switch based on the minimum voltage node of the tie switch.

The two node voltages of the tie switch 83 are evaluated and the minimum of two node voltages is noted. In this case, the minimum node voltage of the tie switch 83 is 18 because the voltage of node 18 is equal to 0.89 and node voltage 1 is 0.963.Therefore, one branch at a time in the loop is opened starting from the node 18 and system load balancing index due to each objective is obtained till the system load balancing index is higher one from the previous computed (current objective is greater than the previous objective). In this loop, the first sectionalize branch (18-17) is opened as it adjacent to the node 18 and the system load balancing index LB_{sys} is computed and shown in Table 5-12. In the same manner, next adjacent sectionalize branches 17-1 6 is opened and is LB_{sys} computed and shown in the Table 5-12.

As can be seen from Table 5-12, the LB_{sys} due to sectionalize branch 8-7 is greater than 9-8, hence the optimal opening branch in the loop is between the nodes 9 and 8.Further opening of the branches beyond the branch 9-8 in the loop, is giving either more LB_{sys} than the minimum already obtained at the branch 9-8 or infeasible solution.

Hence, the opening of the remaining branches is discarded. The optimal radial loop for the first switching operation is obtained by closing the tie switch 83 and opening the branch between the nodes 11 and 10. For the second switching operation, the voltage difference across remaining tie switches (discarding tie switch 83) are computed and shown in Table 5-8.

Table 5-8. Voltage Difference across the Remaining Open Tie Switches

Tie switch No	NO Voltage difference across tie switch (pu)
82	0.106
84	0.02
85	0.029
86	0.004

From Table 5-9, it is observed that the maximum voltage difference occurs across tie switch 82 and it is greater than the specified value (ϵ=0.01). The minimum voltage node of the tie switch 82 is 12 because the voltage of node 12 is equal to 0.855 and node voltage 1 is 0.961. Repeating the same procedure as in case of tie switch 83, the optimal radial configuration for the second switching operation is obtained by closing the tie switch 82 and opening the sectionalize branch between the nodes 15 and 16. Among the tie switches 84, 85 and 86, the voltage difference across tie switch 36 is greater than remaining two and is shown in Fig 5-9.

Table 5-9. Voltage Difference across the Remaining Open Tie Switches

Tie switch No	NO Voltage difference across tie switch (pu)
84	0.021
85	0.027
86	-0.004

Therefore, the tie switch 85 is selected for the third switching operation as voltage difference is greater than the specified value. The minimum voltage node of tie switch 85 is 25 because the voltage of node 25 is equal to 0.86 and node voltage 59 is 0.887. Repeating the same procedure as in case of tie switch 82, the optimal radial configuration for third switching operation is obtained by closing the tie switch 85 and opening the sectionalize branch between the nodes 25 and 24. The voltage difference across the remaining two tie switches 82 and 86 are shown in Table 5-10.

Table 5-10. Voltage Difference across Remaining Open Tie Switches

Tie switch No	No Voltage difference across tie switch (pu)
84	0.011
86	0.006

For fourth switching operation, tie switch 84 is considered as the voltage difference across it is greater than 86 and it is also greater than the specified value. The minimum voltage node of 84 is 23 because the voltage of node 17 is equal to 0.89 and node voltage 23 is 0.879. In this case the optimal configuration of the loop is obtained by closing the tie switch 84 and opening the sectionalize branch between the nodes 21-22 As can be seen from Table 5-12.

The voltage difference across the remaining tie switches 86 is shown in Table 5-11

Table 5-11. Voltage Difference across the Remaining Open Tie Switches

Tie switch No	No Voltage difference across tie switch (pu)
86	0.023

For Fifth switching operation, tie switch 86 is considered. The voltage difference across it is greater than the specified value ($\varepsilon = 0.01$). The minimum voltage node of 86 is 43 because the voltage of node 43 is equal to 0.842 and node voltage 30 is 0.865.Closing the tie switch 86 and opening the sectionalize branch between the nodes 43-42, the system load balancing index is not improved as can be seen from Table 5-12.

Hence, after reconfiguration of the distribution system, the load balancing index decreased to 35.05 %.

Some parts of the distribution system after reconfiguration can be seen from Fig 5-9, Fig 5-10, Fig 5-11, Fig 5-12 and Fig 5-13.

The system load balancing index before reconfiguration is 100.9%.It is 35.05 % after reconfiguration. The reduction in load balancing index is 65.26 %, which is significant reduction.

Table 5-12. Load Balancing Index, Node of Minimum Node Voltages Of The Switches, Sectionalizing Switches Open

Tie switch (Closed)	Node of Minimum Node voltage of the NO switch	Sectionalize switch open between nodes	System Load Balancing Index (%) (during reconfiguration, after indicated tie switch is closed)
83	18	18-17	50.54
		17-16	48.13
		16-15	47.12
		15-14	46.25
		14-12	45.73
		12-11	45.27
		11-10	44.89
		10-9	44.89
		9-8	**44.85**
		8-7	45.72
82	12	12-14	40.77
		14-15	40.50
		15-16	**40.35**
		16-17	40.36
85	25	**25-24**	**38.48**
		24-23	39.39
84	23	**23-22**	35.21
		22-21	35.08
		21-20	**35.05**
		20-19	35.22
86	43	43-42	35.40

+

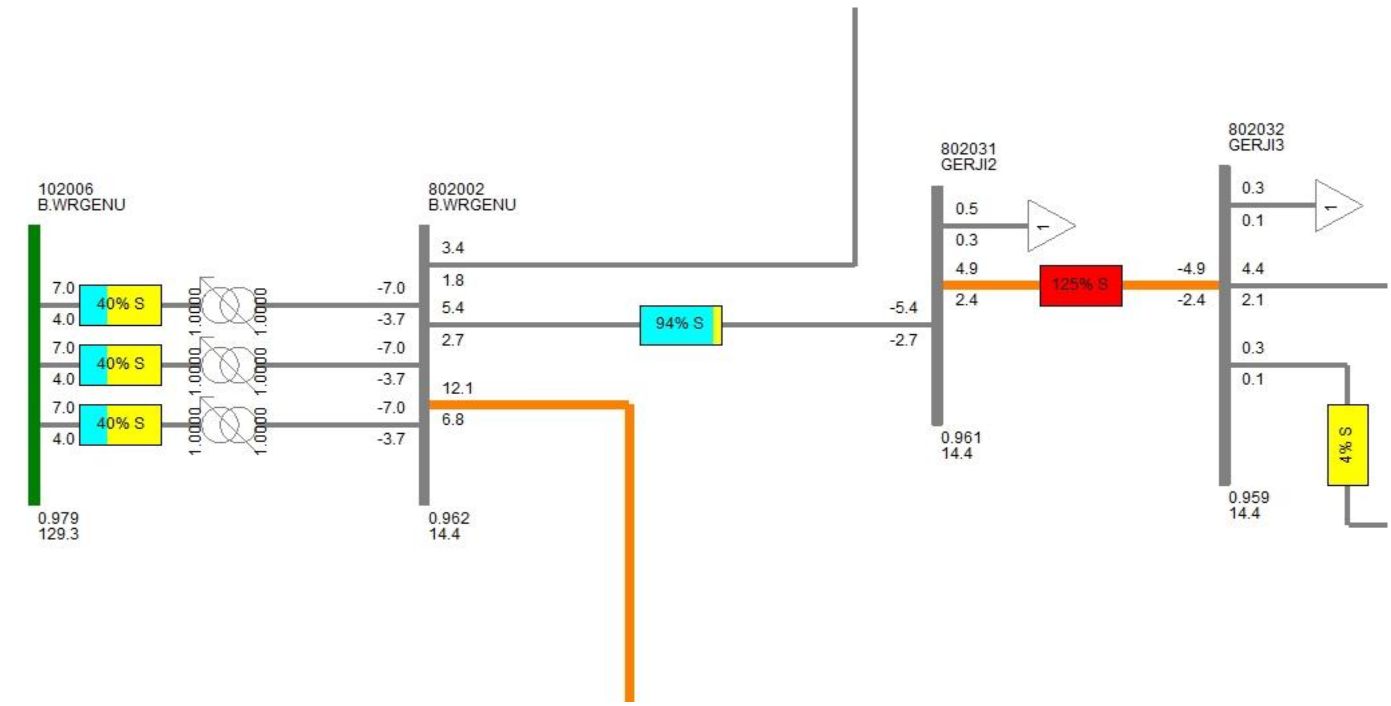


Fig.5-12 Part of Feeder 3 Simulation around substation After Reconfiguration for Load Balancing

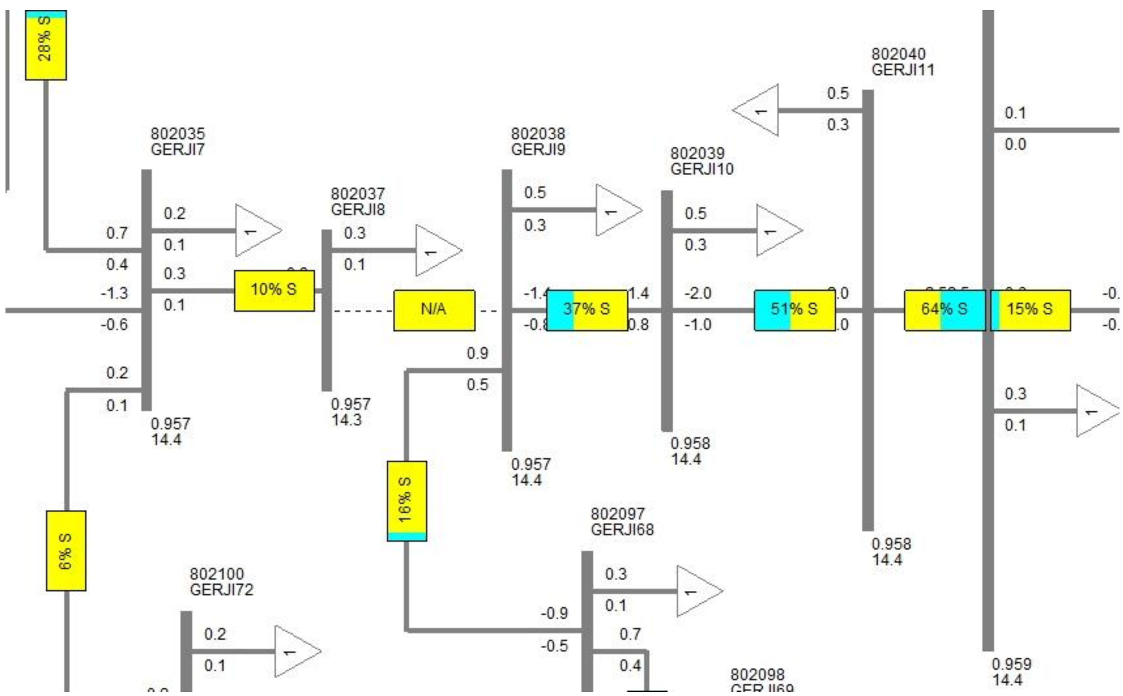


Fig.5-13 Part of Feeder 3 Simulation after Reconfiguration for Load Balancing around tie Switch 82.

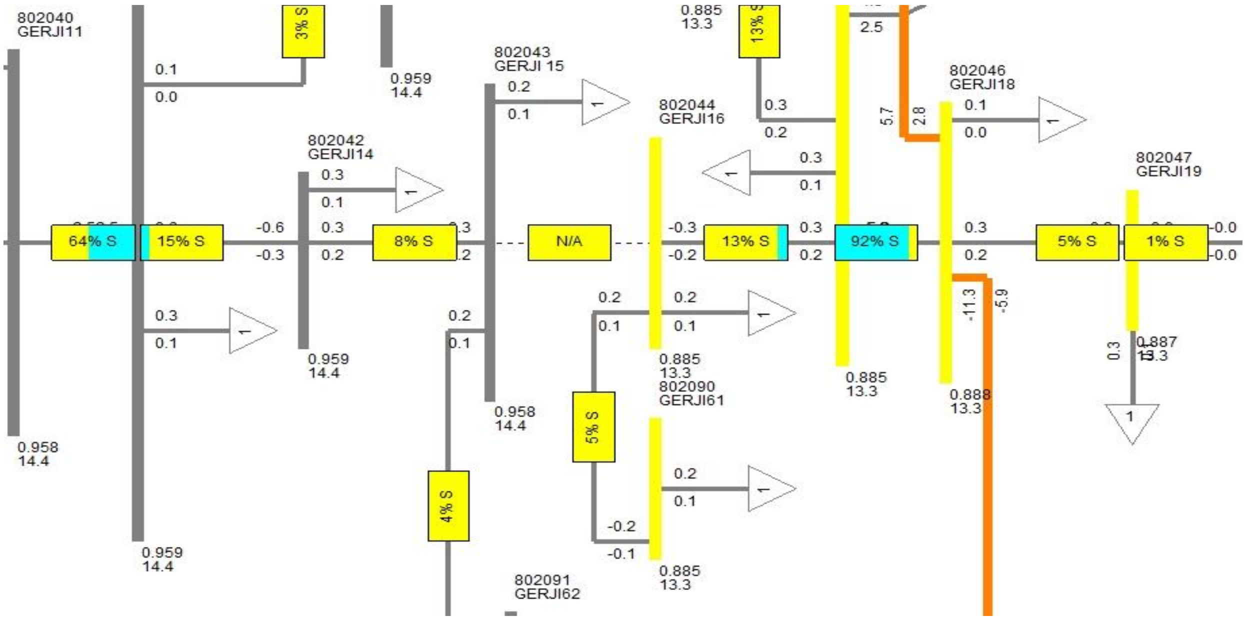


Fig.5-14 Part of Feeder 3 Simulation after Reconfiguration for Load Balancing around tie switch 83.

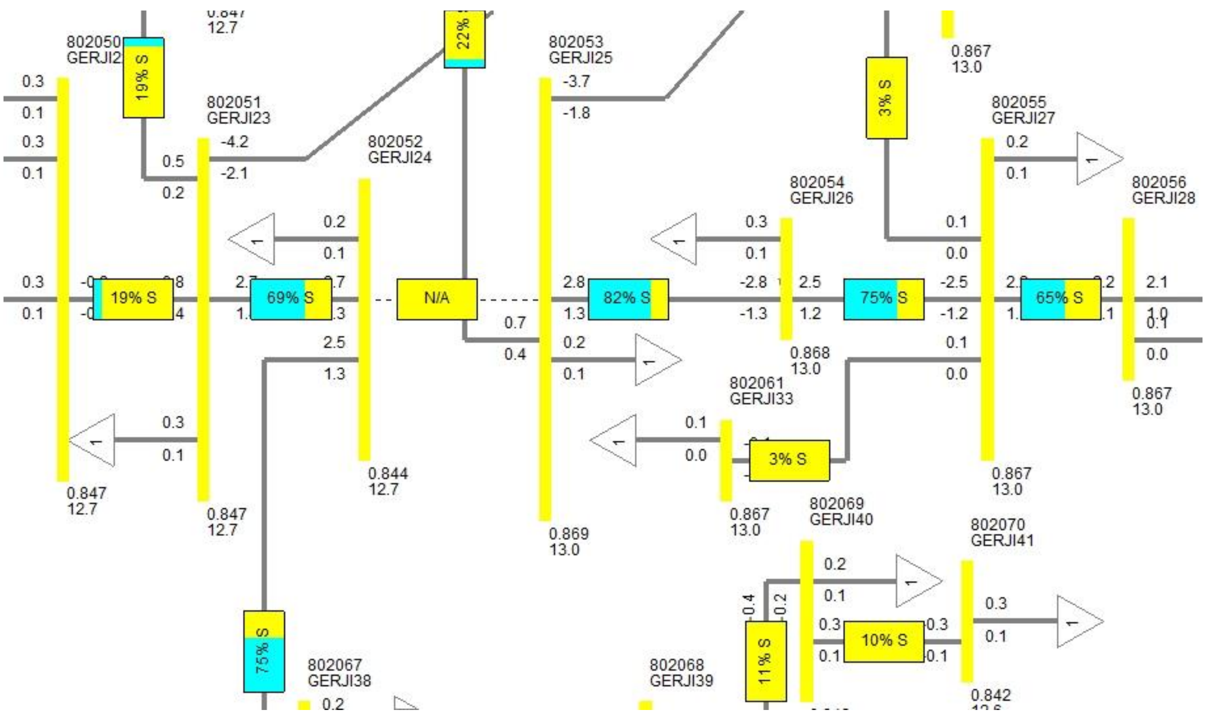


Fig.5-15 Part of Feeder 3 Simulation after Reconfiguration for Load Balancing around tie Switch 85.

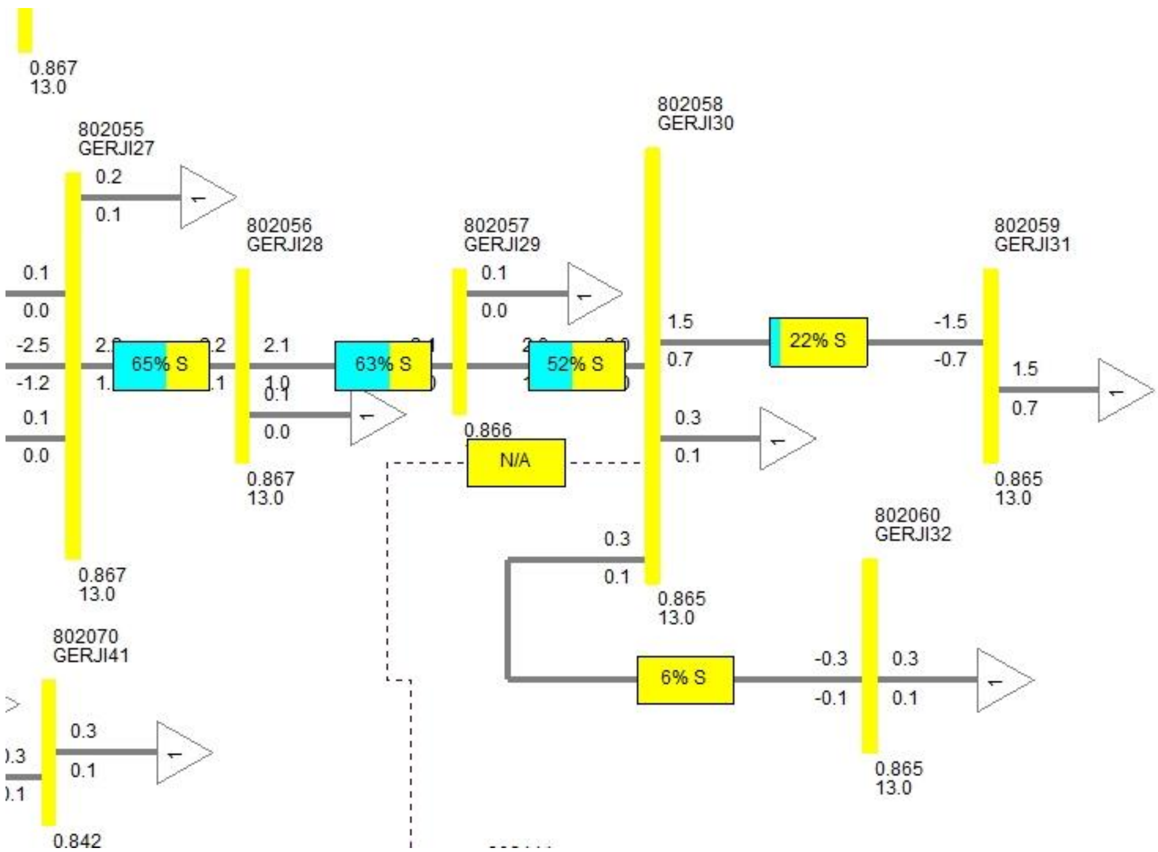


Fig.5-16 Part of Feeder 3 Simulation after Reconfiguration for Load Balancing around tie Switch 86.

The LB_{sys} before reconfiguration is 100.90 %.and after reconfiguration is 35.05%. The system load balancing index decreased significantly.

Chapter 6

Conclusions

The objective of this thesis is to use a heuristic method to reconfigure the distribution line or network of Addis Ababa city for loss minimization and load balancing.

Addis Ababa city is experiencing frequent power interruptions in recent times. One of the main causes of it given by the utility and experts is that the distribution system is not designed and built to handle the current load demands. This work can be expanded to the feeders of Addis Ababa distribution power system in order to coordinately reconfigure and solve the frequent power interruption.

6.1 Major Conclusions of the Research

The following points are the major conclusions of the research:

1. As can be referred from the simulation and result discussion of chapter 5, power loss reduction of 962.5 KW is obtained after reconfiguration of feeder 3 of Weregenu substation using the heuristic methodology described. This reduction is 69.78%, which is significant. Hence reconfiguration of distribution networks can reduce power loss and operating cost of distribution systems.

2. As can also be referred from chapter 5, the system load balancing index is decreased from 100.9% to 35.05% by reconfiguration of the distribution network using the heuristic method. This reduction is 65.26 %, which is also significant. This means the tripping of the protection systems of the distribution system due to overloads is greatly reduced and also the life times of the power equipment in the distribution network is increased.

6.2 Summary of What Was Accomplished in the Research

The following points summarize what was accomplished in the research:

1. In this thesis detail literature review was done. It has been 40 years since French engineers A.Merlin and H. Back [1] proposed the network reconfiguration problem for loss minimization. Since then many researches had been done on the topic. Hence it is necessary to review literatures of the researches done in detail on the topic and related subjects.

2. The Heuristic optimization method used in the research is described in detail to provide a foundation for the implementation used in the simulation. Also PSS/E software is introduced and its functionality and overview described since it is the main tool to implement the simulation and reconfigure the distribution network.

3. Data was gathered from the offices of Ethiopian Electric Utility (EEU). The AutoCAD file obtained was reorganized and redrawn to make it suitable for network reconfiguration. Manufacturer cable data sheets were used for determination of the overhead and underground cables reactance and resistances.

4. The parameters of the distribution network were converted to per unit values since the PSS/E analysis is based on per unit values. The base MVA and Base KV are 100MVA and 15KV respectively.

5. The data was entered to the PSS/E program. The program was run and the errors were fixed until realistic results were obtained. The PSS/E program converged in micro seconds even though the full Newton-Raphson was used. This shows the power and efficiency of the PSS/E software.

6. The tie switches were switched on and appropriate sectionalizing switches were switched off and on using the heuristic methodology described in the thesis and the distribution network was reconfigured for loss minimization. Loss reduction of 962.5 KW was obtained. There are 16 substations in Addis Ababa, and 71 such type of feeders and other feeders which supply power to

industries. If 962.5KW of power loss is decreased from a feeder, assuming that the remaining 70 feeders are nearly the same, then for 71 of such feeders,

$$\text{Power Loss reduction} \approx 71*962.5\ \text{KW} \approx 68.34\ \text{MW}$$

Approximately 68.34MW of power can be saved if the entire Addis Ababa distribution network is reconfigured.

7. The distribution network was also reconfigured for load balancing. The system load balancing index before reconfiguration is 100.9% and after reconfiguration is 35.05%. If we assume the 71 feeders are nearly the same and all of the 71 feeders of Addis Ababa city is reconfigured for load balancing, the system load balancing index will be approximately around 35 % which means tripping of the protection systems decreased. Hence, the current frequent interruption of the power supply can be greatly reduced.

6.3 Recommendations

The following are the recommendations based on this research

1. The existing Addis Ababa distribution network is not designed and built according to international standards. Large cross section area conductors are used after small cross section conductors on main lines and also on branch lines of the distribution network. In order to use full capacity of the large cross section of conductors, it should be built before the small cross sectional area conductors.

2. Most of the conductors used on the distribution network are AAC and ACSR conductors below 95 sq mm cross section areas. As can be seen from Fig. 5-10, some lines are loaded up to 647% of their capacity, which is unacceptably high. Therefore it is better to use conductors like AAAC with cross sectional areas of 150 sq mm and above, which is recommended for main lines for cities like Addis Ababa, based on the loads connected.

3. Most of the feeders of the Addis Ababa city have no tie switches on a feeder, even though there are tie switches between feeders. Since these tie switches are very useful for reconfiguration as shown by this research and has also other advantages, it is highly recommended if the distribution feeders have these tie switches.

4. From this research reconfiguration of distribution network has shown to decrease the power loss and system load balancing index significantly. Therefore it is highly recommended if all the distribution feeders of Addis Ababa city to be reconfigured for the objectives wanted by the utility.

6.4 Suggestions for Future Works

In the future researches can be done on the distribution networks of Addis Ababa city including the following suggestions

1. The simulation of the distribution network can be made to include strategically placed distribution generators (DG) and the network can be reconfigured. In doing so the voltage profiles, the real power losses and the system load balancing index can be improved.

2. The simulation of the distribution network can also be used for optimization for capacitor placement. Optimum placement of capacitors can improve the voltage profile, reduce real power losses and improve the load balancing of the network.

3. Other optimization algorithms, some of which described in literature review, can also be used to improve the reconfiguration of the distribution network and find global optimum solutions. Especially if mixed methods can be used, further reduction of real power losses and the improvement of the system load balancing index can be obtained. The time required for reconfiguration can also be reduced.

4. The Addis Ababa distribution network has no communication systems, such as SCADA (supervisory control and data acquisition), for automatic reconfiguration of the distribution system, except some lines built for rehabilitation of the distribution network. Most of distribution

networks have no such communications around the world and few utilities implemented automatic reconfigurations of their distribution network. However one can attempt to write suitable programs using appropriate programming language, such as Python, which can be integrated to the PSS/E program and reconfigure the distribution network using the optimization techniques.

5. The efficient power flow methods, like forward/backward methods can also be used for the reconfiguration of the distribution networks. Programs can be written which uses these efficient load flow methods and suitable optimization techniques and the reconfiguration can be done for different objectives.

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Appendix

This appendix consists of figures for Weregenu feeder 3 before reconfiguration, after reconfiguration for loss minimization, after reconfiguration for load balancing and data for weregenu fedeer 3.

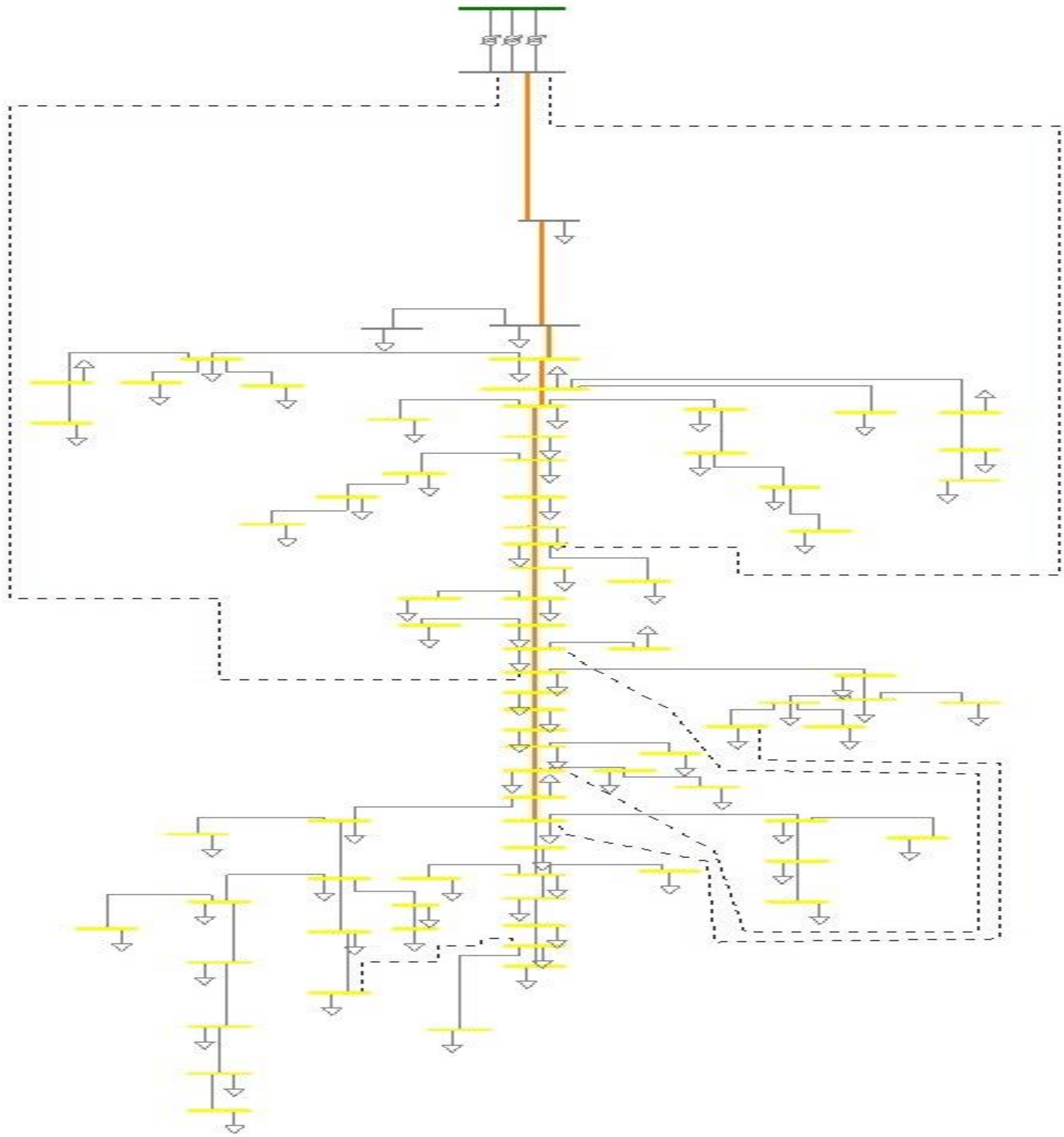

Fig A-1.Simulation of Weregenu Feeder 3 before Reconfiguration using PSS/E

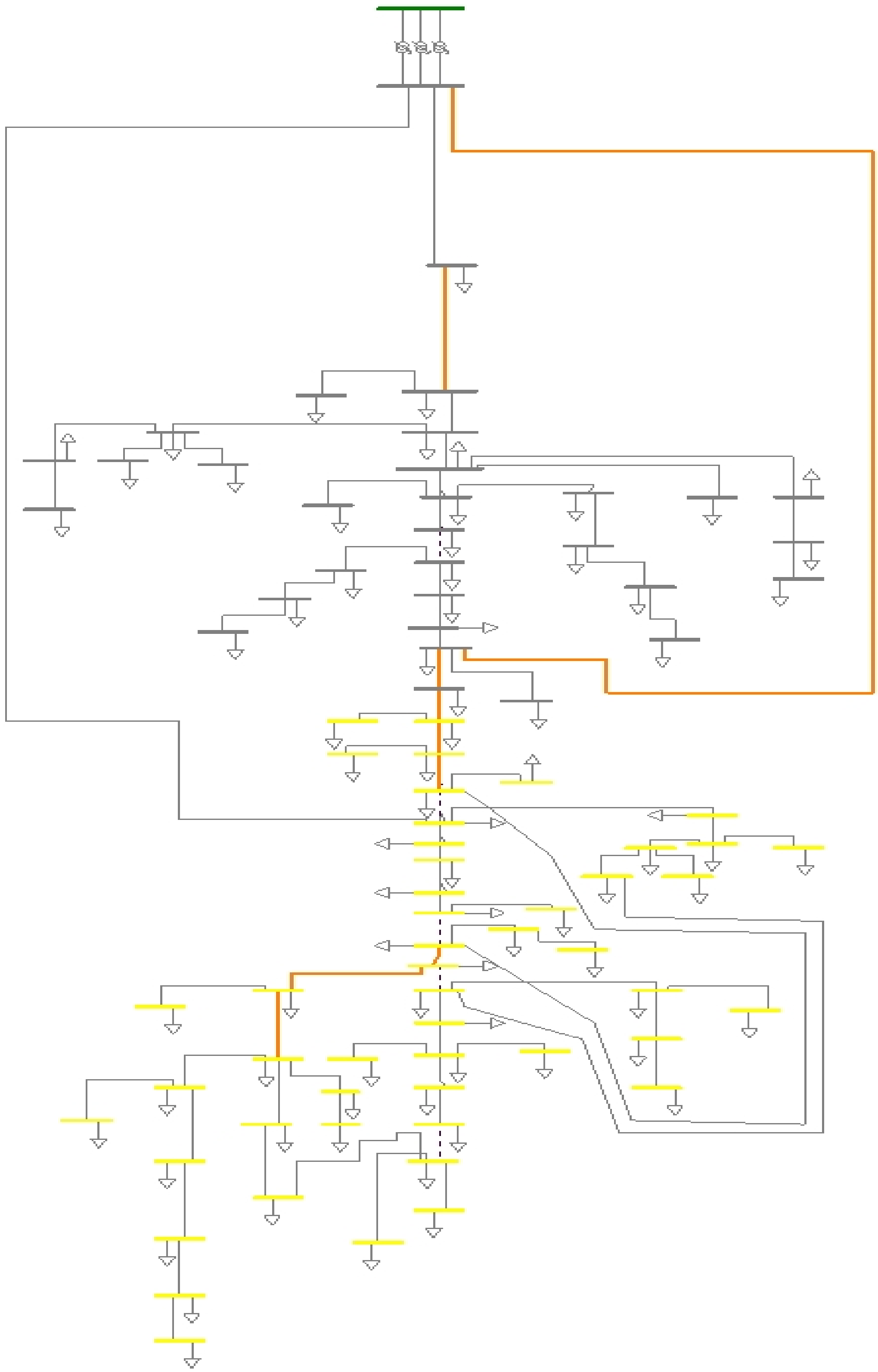

Fig. A-2, Weregenu Feeder 3 after Reconfiguration for Loss Minimization

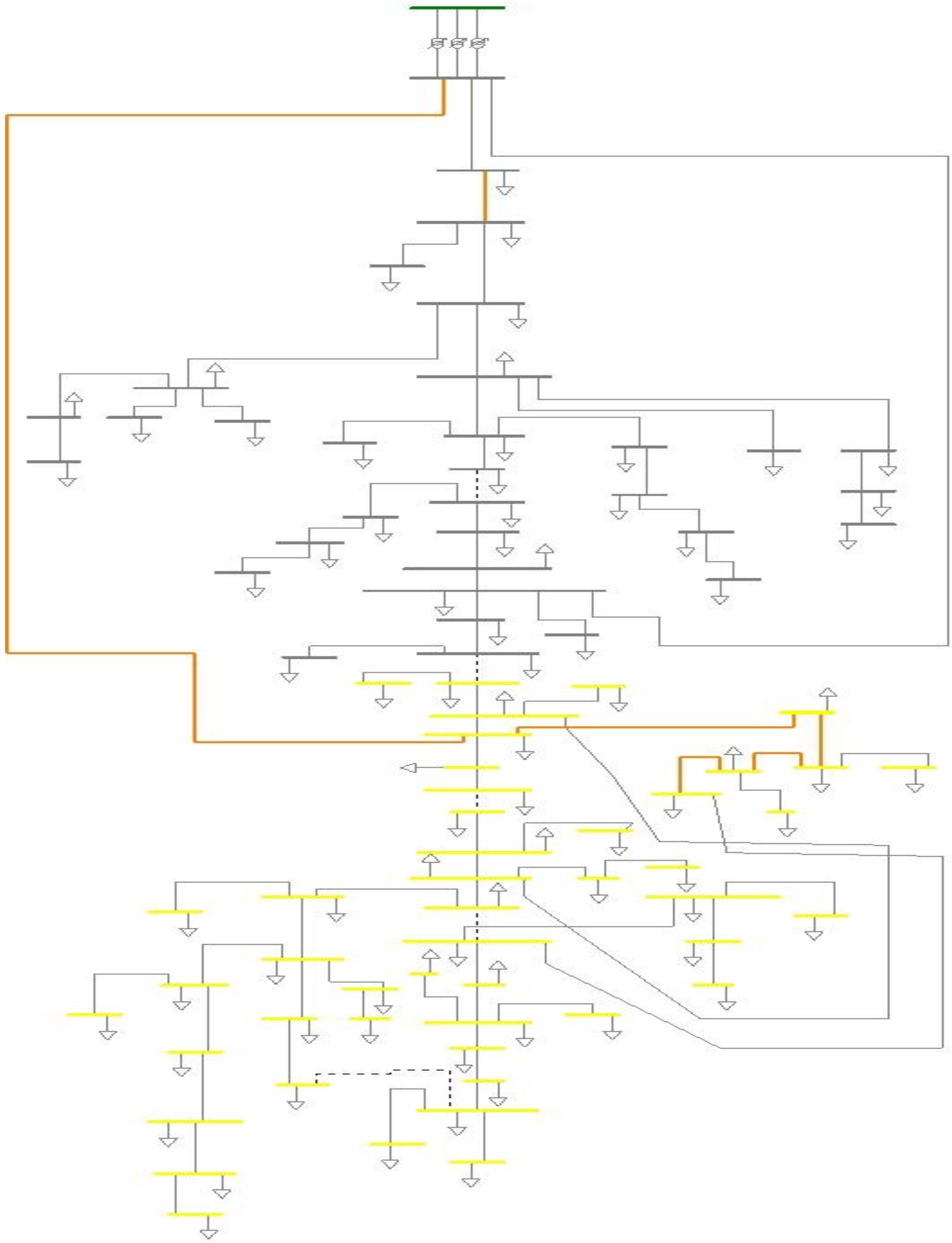

Fig. A-3, Weregenu Feeder 3 after Reconfiguration for Load Balancing

Table A-1 Network Data of Feeder 3 of Weregenu Substation

Node	Real Power Load P(MW)	Reactive Power Load Q(MVAR)	Line	R(p.u)	X(p.u)
2	0.510	0.274	1-2	0.1360	0.1516
3	0.255	0.123	2-3	0.2507	0.1578
4	0.255	0.123	3-4	0.1360	0.1516
5	0.162	0.078	3-5	0.1360	0.1516
6	0.255	0.123	5-6	0.0871	0.0489
7	0.162	0.078	6-7	0.4844	0.1556
8	0.255	0.123	7-8	0.5333	0.1844
9	0.510	0.274	8-9	0.2507	0.1578
10	0.510	0.274	9-10	0.2507	0.1578
11	0.510	0.274	10-11	0.2507	0.1578
12	0.255	0.123	11-12	0.2507	0.1578
14	0.255	0.123	12-14	0.2507	0.1578
15	0.162	0.078	14-15	0.2507	0.1578
16	0.162	0.078	15-16	0.1360	0.1516
17	0.255	0.123	16-17	0.5333	0.1844
18	0.081	0.039	17-18	0.1360	0.1516
19	0.255	0.123	18-19	0.1360	0.1516
20	0.041	0.039	19-20	0.1360	0.1516
21	0.255	0.123	20-21	0.1360	0.1516
22	0.255	0.123	21-22	0.2507	0.1578
23	0.255	0.123	22-23	0.2507	0.1578
24	0.162	0.078	23-24	0.2507	0.1578
25	0.255	0.123	24-25	0.2898	0.0076
26	0.162	0.078	25-26	0.2898	0.0076
27	0.162	0.078	26-27	0.2898	0.0076
28	0.081	0.039	27-28	0.2898	0.0076
29	0.081	0.039	28-29	0.2898	0.0076
30	0.255	0.123	29-30	0.2507	0.1578
31	1.531	0.740	30-31	0.1960	0.1100
32	0.255	0.123	30-32	0.2507	0.1578
33	0.081	0.039	27-33	0.5333	0.1844
34	0.162	0.078	25-34	0.2898	0.0076
35	0.162	0.078	34-35	0.2382	0.1556
36	0.255	0.123	35-36	0.2382	0.1556
37	0.162	0.078	34-37	0.4844	0.1556
38	0.162	0.078	24-38	0.2898	0.0076
39	0.162	0.078	38-39	0.2898	0.0076
40	0.162	0.078	39-40	0.2507	0.1578

41	0.255	0.123	40-41	0.5333	0.1844
42	0.162	0.078	39-42	0.2898	0.0076
43	0.162	0.078	42-43	0.2898	0.0076
44	0.162	0.078	39-44	0.2898	0.0076
45	0.162	0.078	44-45	0.4844	0.1556
46	0.255	0.123	45-46	0.4844	0.1556
47	0.041	0.039	46-47	0.2507	0.1578
48	0.510	0.274	47-48	0.2507	0.1578
49	0.162	0.078	44-49	0.0871	0.0489
50	0.162	0.078	38-50	0.2898	0.0076
51	0.255	0.123	23-51	0.4844	0.1556
52	0.255	0.123	51-52	0.4844	0.1556
53	0.255	0.123	22-53	0.4844	0.1556
54	0.081	0.039	18-54	0.2507	0.1578
55	0.081	0.039	54-55	0.2507	0.1578
56	0.255	0.123	55-56	0.2507	0.1578
57	0.255	0.123	55-57	0.2507	0.1578
58	0.648	0.313	57-58	0.0871	0.0489
59	0.648	0.313	57-59	0.2507	0.1578
60	0.324	0.313	17-60	0.5333	0.1844
61	0.162	0.078	16-61	0.4133	0.0578
62	0.162	0.078	15-62	0.2507	0.1578
63	0.081	0.039	12-63	0.5333	0.1844
64	0.162	0.078	07-64	0.4844	0.1556
65	0.255	0.123	64-65	0.2898	0.0076
66	0.041	0.039	65-66	0.2898	0.0076
67	0.255	0.123	66-67	0.2898	0.0076
68	0.255	0.123	09-68	0.1360	0.1516
69	0.162	0.078	68-69	0.4844	0.1556
70	0.081	0.039	27-70	0.5333	0.1844
71	0.510	0.274	69-71	0.4844	0.1556
72	0.162	0.078	07-72	0.4844	0.1556
73	0.081	0.039	06-73	0.4844	0.1556
74	0.162	0.078	73-74	0.4844	0.1556
75	0.162	0.078	74-75	0.4844	0.1556
76	0.673	0.325	06-76	0.5333	0.1844
77	0.081	0.039	05-77	0.2898	0.0076
78	1.013	0.490	77-78	0.2898	0.0076
79	0.081	0.039	77-79	0.2898	0.0076
80	0.162	0.078	77-80	0.2898	0.0076
81	0.255	0.123	80-81	0.2898	0.0076
Total	**19.926**	**10.011**			