Hawassa University Institute of Technology

Department of Electrical and Computer Engineering

Power Loss Reduction and Voltage Profile Improvement of Distribution Feeder (Case study: Hawassa Substation Distribution Feeder 7)

Thesis Submitted in

Partial Fulfillment of the Requirements for the Degree of Master of Science in Power System and Energy Engineering

By: Tigist Taye

Advisor: Baseem Khan (PhD)

Hawassa, Ethiopia

Jun, 2021

Hawassa University Institute of Technology

School of Electrical and Computer Engineering

Power Loss Reduction and Voltage Profile Improvement of Distribution Feeder (Case study: Hawassa Substation Distribution Feeder 7)

By: Tigist Taye

APPROVAL BY BOARD OF EXAMINERS

------------------------ -----------------------

Chairman, School of electrical and Signature

Computer engineering

Dr. Baseem Khan -----------------------

Advisor Signature

--------------------------- ------------------------

Internal examiner Signature------------------------
----- -------------------------

External examiner Signature

Declaration

I declare that this thesis “Power Loss Reduction and Voltage Profile Improvement of Distribution Feeder (Case study: Hawassa Substation Distribution Feeder 7)” is my own original work, has not been presented for a Degree award in this or any other universities, and all sources of materials used for the thesis have been fully acknowledged.

Tigist Taye ____________________

Signature

This MSC thesis has been submitted to the School of Electrical and Computer Engineering, for examination with my approval as a university advisor.

Dr. Baseem Khan ______________________

Thesis advisor Signature

Date of submission: -----------------------------

ACKNOWLEDGEMENTS

My sincere gratitude goes to Dr. Baseem Khan, my advisor for his support, guidance, helpful suggestions and continued monitoring of my progress during this thesis. Thank you for believing in me.

Then, I would like to extend my appreciation to EEP and EEU co-worker who is willing to share their experience, give me the data I need and supported me.

I would like to express my gratefulness to my family especially to my mom Etemete and husband Dr. Getenet Feleke for their continuous care and support.

Special thanks for my beloved father Taye if it is not you I will not be here where I’m standing by my own two fetes.

Lastly and most importantly I thank God for keeping me healthy during thesis period and also for insight in what I was undertaking.

ABSTRACT

Power quality issues, mainly voltage sag, are the major problem inside the distribution network. Further, losses also create serious concerns in the power distribution. As a result, in this work, capacitors are optimally placed using the Genetic Algorithm (GA) to mitigate voltage sag and power losses. A practical data set from Hawassa substation, which has nine 15kV outgoing feeders and four 33kV outgoing feeders, is being utilized to show the implementation of the proposed work. From those 15kV outgoing lines, feeders 7, 5, 8, 4, 3, 6, 2, 9 and 1 have high power loss and voltage drop respectively from load flow results. Feeder 7 is selected from this work due to its high power loss compared to the rest of the feeder by load flow analysis. This feeder has been modeled in ETAP software and Newton Raphson load flow is performed. From load flow simulation of feeder 7, it has been seen that the feeder has a power loss of 0.472MW. The objective function of this thesis work is to minimize power loss, improve voltage profile and power factor with minimum investment cost. This is achieved by optimal capacitor placement for reactive power compensation of the network. The operation of the capacitor bank is done by the CQ930 automatic capacitor controller, which provides a reliable method of monitoring and switching. By using GA, the power loss is improved from 0.472MW to 0.276MW, the minimum voltage magnitude is improved from 90.24% to 95.62%, and the power factor is improved from 87.35% to 90.49%, and finally, the system capacity is increased from 2.612MVA to 3.152MVA. Due to this overall improvement in the network, EEU can save $39,707.22 while the total investment cost is 63,200 with a payback period of seven months.

Keywords: optimal capacitor placement, ETAP, CQ930, power loss minimization

Contents

List of figure

List of table

List of Acronyms

DNR	Distribution Network Reconfiguration
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
ETAP	Electrical Transient Analyzer Program
EP	Evolutionary Program
GA	Genetic Algorism
IAGA	Improved Adaptive Genetic Algorithm
ISO	Independent System Operator
OCP	Optimal Capacitor Placement
OPF	Optimal Power Flow
ORPF	Optimal Reactive Power Flow
PF	Power Factor
PSO	Particle Swarm optimization
SG	Smart Grid

CHAPTER ONE

Introduction

1.1 Background

The main roles of power utilities are to maintain the voltage within required level and a minimum power loss of the system for high quality services delivery. Electric power loads vary from hour to hour and also voltage varies by change of the power load. The change of load causes variation in the reactive power requirement. Newton approach, interior point methods and dynamic programming have been developed to solve ORPF problem. Generally these techniques suffer due to algorithmic complexity, insecure convergence, and sensitivity to initial search point. The soft computing techniques fuzzy logic, fuzzy linear programming and evolutionary programming (EV) are used for setting optimal reactive power limits the problem of supporting its own real power transmission and the other for supplying reactive demand. At the minimization of the voltage deviations, the more optimum result was taken as the cost function. The total reactive cost was separated into generators duty and loadings duty. Have generalized the problem of reactive power control viewed from two aspects: load compensation and voltage support.

Operators in control center handle various equipment such as generators, transformers, static condenser and shunt reactor. Then the operators can inject reactive power and control voltage directly in target power systems. Voltage stability constrained reactive power dispatching in deregulated power networks is a difficult task facing an independent system operator (ISO) that is mandated to provide equitable additional services. Optimal reactive power flow (ORPF) is an important tool for power system in planning, operating stages and avoids instability. The power systems acquire reactive power for magnetizing purposes at no load conditions.

The most important methods in loss reduction and controlling the voltages of distribution systems are the utilization of optimal capacitors placement.

Distribution networks are subsystem of the electrical power network and deliver to the last user consumers. Distribution networks are fed from substation through distribution transmission lines. The high voltage comes from substation reduced by distribution transformer to supply consumers connected at distribution layer.

It is essential to understand distribution networks equipment’s, components and arrangements for its analysis. Power flow studies basically needs topology of the distribution network and its manipulation is based on the components such as switches and power lines.

1.2 Statement of the Problem

- Because of high real power loss in feeder 7 distribution system

- Voltage drop is high
- power factor is poor and
- Then reactive power demand increase.

Low power factor causes heavier current to flow and voltage to drop in power distribution lines in order to deliver a given number of kilowatts to an electrical load.

In Ethiopia from generated electric power 23% are losses as both technical and nontechnical losses. The major share (13%) is attributable to the distribution network[1].

Due to this high amount of losses in the distribution system Ethiopian Electric Utility faces the flowing problems:

- Increasing of over load of the distribution system equipment
- Reduce equipment life such as: cables, transformer, due to temperature rise /high heat generation
- Very low voltage profiles at the end connection (bus) of the load
- Transmission and distribution lines voltage drop is high due to poor voltage profile in the system.
- Ethiopian Electric Utility will not earn as expected (economical loss) because of high real power loss in the network.
- Ethiopian Electric Utility is forced to expand the existing distribution system or to construct new distribution system for high quality customer's service.

Therefore, a method is design to minimize the real power losses and voltage profile improvement in the distribution network avoids the mentioned problems. In this thesis this problem is resolved by optimal reactive power compensation.

1.3 Objective

1.3.1 General objective

The objective of this thesis is to improve power loss, voltage profile and power factor by optimal location and size of capacitor bank of Hawassa distribution feeder 7

1.3.2 Specific Objective

- To model Hawassa distribution feeder 7 in ETAP
- To calculate voltage drop, power factor and power loss of base case of Hawassa distribution feeder 7 using N-R load flow
- Optimal capacitor placement is carried out using GA with respect of minimum cost

1.4 Significance of the thesis

Feeder 7 distribution network optimal capacitor placement has significant role in Ethiopian Electric Utility (EEU), distribution network operating equipment and consumers, such as

- Minimize real power loss and improve voltage profile of the feeder 5 network.
- Distribution transformer and transmission line damage due to over load (temperature rise) will be avoid and
- Ethiopian Electric Utility income will increase

1.4 Scope of the thesis

This thesis mainly focuses on power loss reduction and voltage profile, power factor improvement of feeder 7 outgoing line. These reductions and voltage profile improvement achieved by optimization techniques for allocation and sizing of capacitor in the feeder network.

1.5 Research Methodology

This thesis has been started from investigating the problem and review literatures related to the power loss and under voltage problem distribution network. Recent, and important information and data like (line data and energy tariff and electric power sales of the country, peak and hourly recorded load data of the feeders) have been collected from Ethiopian Electric Utility (EEU) for the power distribution system under study (feeder 7 distribution network).

Review literatures to carry out the analysis in ETAP on the system for compensation. One line diagram of 40 buses power system with certain rated values of components as suggested by the tool is used [2].
Single line of feeder 7 is modeled by using Electrical Transient Analyzer Program (ETAP) software tool. The software tool is then used to model system parameters like transformers, lines and loads. Power loss on the lines and voltage profile on buses are obtained from the base case Power flow result using the ETAP tool. The results of the power flow are used to analysis and determine the optimum candidate location and size of the capacitor using genetic algorism (GA). Then the selected capacitor has been located in the candidate buses of feeder 7. Finally the power flows for new selected optimal capacitor size on optimal location are done using the same software tool. The automatic switch capacitor controller is done using ABB CQ930.

Therefore from the results, recorded all the data regarding the voltage profile, power factor at each bus’s, the losses on the lines and the size of the optimal capacitor at the optimal location with cost saving are determined.

1.6 Organization of the thesis

This thesis is organized into five chapters and briefly summarized as flow. Chapter one presents the introduction including background, statement of the problem, objective, significance of the thesis, scope of the thesis and research methodology. The second chapter discuss on background and literature review including optimal capacitor placement, economic advantage and benefits of capacitor placement, capacitor bank in distribution system, methods to determine capacitor size and location, load flow analysis and literature review. In chapter three, modeling and analysis of feeder 7 distribution network under this introduction, data collection, Newton-Rapson, cost calculation, objective function of OCP, genetic algorithm technique, GA for optimal capacitor placement and three most important aspects of using GA are included. Chapter four deals with simulation result of optimal capacitor placement and result of power flow for both with and without of optimal capacitor placement, economic analysis with cost benefit for optimal capacitor placement.

The final chapter which is chapter five presents the conclusion, recommendations and future works are discussed.

Chapter two

Background and Literature Review

2.1 Background

In this thesis work, power loss reduction and voltage profile improvement are a very important and subjective issue, since it defines the final power product supply to consumers. Voltages must be maintained within the limits specified by regulatory agencies, without introducing harmonics, and the service should not suffer any fluctuation. The maintenance of power quality regarding the voltage profile is taken into effect by using several measures, including preventive, corrective and emergency tools. Substation

transformers equipped with tap-changing control can limit voltage variations within a certain range, thus reducing voltage deviations. However, with the load increase (for instance, at peak hours), tap position adjustments may happen to be insufficient for maintaining the voltage within the desired range, resulting in low voltages at the secondary windings of distribution transformers. Installing capacitor banks can be an important method for decreasing reactive power flows through the network, thus improving voltage profile, power factor correction and reduce real power losses. Several other benefits can be obtained with the appropriate placement of capacitor banks, such as released feeder capacity, released distribution substation capacity, and financial improvement due to voltage improvement and loss reduction. The majority of power systems operate at a lagging power factor due to inductive loads and delivery apparatus like lines and transformers[3]. Power systems are inductive in nature, and require additional reactive power flow from the power grid. But excessive reactive power demands in distribution network result in reduced system capacity, increased losses, and decreased voltage, as well as higher operating costs. Shunt capacitor banks are able to compensate for Var requirements, but bank size, location, the capacitor control method, and cost considerations are important issues that need to be optimized during the design phase. An ideal solution would be a capacitor placement tool able to weigh all these factors and that considers load levels. This solution should also be able to place capacitors for voltage support and power factor correction, while minimizing the total cost of installation and operation[4].

Table 2.1 Purposes and benefits of capacitor application

PURPOSES	BENEFITS
Voltage control	Yields a primary benefit for both transmission and distribution systems
System power loss reduction	Yields a secondary benefit for transmission systems and a primary benefit for

	distribution systems
System capacity increase	Yields a secondary benefit for transmission systems and a primary benefit for distribution systems
Var support	Yields a primary benefit for transmission systems and a secondary benefit for distribution systems
Billing charge reduction	Does not apply to transmission systems, but yields a primary benefit for distribution systems

- to allocate shunt capacitor it is important
  - Determine connection location
  - Determine bank size in kVAr
  - Determine a control method
  - Determine a connection type (wye or delta)

The capacitor size and the appropriate location for voltage support and power factor correction can be determined in different ways. A common method applies “rules of thumb” techniques, and then runs multiple load flow studies to fine-tune the size and location. Unfortunately, this method may not yield the optimal solution. And it can also be very time consuming and impractical for large systems.

It is also important to minimize cost, while mathematically determining the capacitor size and location. Because this is an optimization issue, an optimization approach should be employed. This is where the ETAP OCP module excels. It is an extremely powerful simulation tool specifically designed for this application. The OCP module allows you to place capacitors for voltage support and power factor correction while minimizing total cost. The advanced graphic interface provides the flexibility to control the capacitor placement process, while allowing you to view the results instantly. The precise calculation approach automatically determines the best location and bank sizes. In addition, it reports the branch capacity release and savings during the planning period due to Var loss reduction. The capabilities of the OCP module are summarized below:

2.2 CAPACITOR PLACEMENT

Capacitors are used to provide reactive power compensation in distribution networks to reduce power losses and to maintain a voltage profile within acceptable limits. The ultimate goal in radial distribution systems is to determine the optimal location and size of the capacitors to maximize loss reduction and to minimize the total cost. The problem is determining the best capacitor size and location in a radial distribution system by minimizing the costs incurred due to power loss and capacitor installation[5].

Optimal capacitor placement OCP seeks the optimal locations and sizes of capacitors to be placed on a radial distribution feeder in order to maximize the net economic savings resulting from reductions in power loss and energy loss, less the investment and installation costs of the capacitor banks. An OCP solution must satisfy physical, engineering, and operating constraints to be a feasible solution, and thus OCP is said be a constrained optimization problem[4].

The equality constraints required the network be able to supply the active and reactive power to the load demand, as well as the power losses of the feeder segments. This requirement is given in terms of the active and reactive power flow equations at each node. The inequality constraints prescribe that voltages along the feeder must remain within lower and upper limitation from nominal voltage of the feeder. The sites and sizes of the capacitor banks are subject to financial and physical constraints, which include the minimum number of capacitor banks that can be placed at buses to achievement the required options of the whole system[6].

The lagging current demanded by reactive load components can be effectively canceled by the leading current provided by the capacitor. When the reactive load of distribution systems canceled by a capacitor placed at the center of reactive load, the entire power delivery system will be relieved of KVAR, originally supplied from the power supplier's generator. This makes the full capacity of the generators available to serve active power loads. the connection of the capacitor banks to distribution system either too far beyond or too far ahead of inductive load center, the capacitor still provides the loading with reactive power relative, but the system will not obtained the full advantages of voltage improvement and loss reductions which would be afforded by proper capacitor placement[4].

The installation of shunt capacitors bank have capital intensive requirement, therefore the capacitors should be placed in a way that it results in minimum capital investment of installation, maximum savings in power losses and better node voltage profile.

In general, capacitors are installed in power systems for voltage support, power factor correction, reactive power control, loss reduction, system capacity increase, and billing charge reduction. This process involves determining capacitor size, location, and control method. The main effort usually is to determine capacitor size and location for voltage support.

2.3 Economic advantage and benefit of capacitor placement

Most of power systems operate at a lagging power factor due to inductive loads and delivery equipment (lines and transformers). In nature, power systems are naturally inductive and require additional reactive power flow from the power grid. But excessive reactive power demands result in reduced system capacity, increased losses, and decreased voltage, as well as higher operating costs[7]. Reactive power compensation in power system, reduce reactive current transfer of power to a distribution system. That will reduce system power losses.

Economic benefits will be installed capacitors in the distribution system. To study the economic feasibility for capacitor placement issues such as reducing energy losses, dumping equipment capacity, reduce losses and profits of the capacitor express. In return, the cost of purchase, installation and maintenance of control equipment capacitance as investment costs are raised [8]. The loss reduction benefits possible with capacitor use can be significant enough to economically justify feeder metering or a large share of Supervisory Control and Data Acquisition (SCADA) system costs[9].

2.4 Capacitor Bank in Distribution System

In earlier years, shunt capacitor banks have been more commonly installed at distribution and lower sub transmission levels. However, there has been a recent multiplication of new capacitor banks at transmission levels.

Distribution systems have high R/X ratio, significant voltage drop that could cause power loss in the feeders. Totally 13% of the generated power is consumed as loss at the distribution level[9]. By placing shunt capacitors optimally we can thereby do power flow control, improve system stability, PF correction, voltage profile management, and thereby reduction in active energy losses.

2.5 Methods for determining capacitor size and location.

1. the most common method (intuitive) is based on rules of thumb followed by running multiple load flow studies for fine-tuning the size and location. This method may not yield the optimal solution and can be very time consuming and impractical for large systems[10].
2. The second method is to use the ETAP Optimal Power Flow (OPF) program to optimize the capacitor sizes based on the candidate locations selected by the engineer. This method requires per-selected locations, since OPF can optimize the capacitor sizes but not the locations[11].
3. the most effective method is to use the Optimal Capacitor Placement (OCP) program to optimize capacitor sizes and locations with cost considerations. OCP employs a genetic algorithm, which is an optimization technique based on the theory of nature selection. OCP uses the “Present Worth Method” to do alternative comparisons[12]. It considers initial installation and operating costs, which includes maintenance, depreciation, and interest rate.

2.6 Distribution Network Reconfiguration

The electric power distribution network is fundamental component of the power distribution system. So it requires particular attention for the most significant challenges for both design and operational-wise, breakout at this level. In electric power distribution system finding feasible solutions for power loss reduction is one particular area for power engineering work[13]. Distribution real power loss consequently causes an increase in operational costs of the system.

Introduction of the smart grid (SG) concept that aims at supporting the transition into a safe, efficient and sustainable power system requires the use of computational intelligence methods to meet the aforementioned objectives. Distribution network reconfiguration (DNR) has been shown to be a feasible approach, often involving computational intelligence algorithms to optimize power delivery by reducing power losses, balancing loads, increasing power quality and improve reliability[14]. The radial distribution systems often feature sectionalizing switches and tie switches mainly used for fault isolation, power supply recovery and system reconfiguration. The radial network topology analysis may be a complex task by itself. Due to a large number of possible network architectures (increasing exponentially with the size of the system), as well as multi-modal nature of the problem (i.e., the presence of many local optima), DNR is a highly complex combinatorial problem. Its practical solution requires implementation of efficient optimization algorithms with global search capability.

2.7 Load Flow Analysis

The ETAP Load Flow Analysis module calculates the bus voltages, branch power factors, currents, and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with multiple power grids and generator connections. It is capable of performing analysis on both radial and loop systems. ETAP allows you to select from several different methods in order to achieve the best calculation efficiency.

The Load Flow Toolbar section explains how you can launch a load flow calculation, open and view an output report, or select display options[15]. The Load Flow Study Case Editor section explains how you can create a new study case, what parameters are required to specify a study case, and how to set them. The Display Options section explains what options are available for displaying some key system parameters and the output results on the one-line diagram, and how to set them. The Load Flow Calculation Methods section shows formulations of different load flow calculation methods. Comparisons on their rate of convergence, improving convergence based on different system parameters and configurations, and some tips on selecting an appropriate calculation method are also found in this section. The Required Data for Calculations section describes what data is necessary to perform load flow calculations and where to enter them. The Load Flow Study Output Report section illustrates and explains output reports and their format. Finally, the Load Flow Result Analyzer allows you to view the results of various studies in one screen so you can analyze and compare the different results[10].

2.8 Literature review

Distribution network reconfiguration and capacitor placement are two main optimization means in electric power distribution automation network. Under the normal operating conditions, network structure can be reconfigured by changing the closed/open status of some tie switches and sectionalizing to reduce real power losses and improve voltage profiles of the network[16]. Capacitor placement also be used to improve voltage profile and minimized real power loss of the network. To reduce losses and to improve voltage profiles, network reconfiguration achieves voltage profile improvement and real power loss minimization by optimize active power flow in the network while capacitor allocation achieves this goal by optimizing reactive power flow in the network.

It is clear that these two means have different properties and limitations, but more importantly that these properties will strengthen each other in the combination of capacitor placement and network reconfiguration for better optimization results in distribution network[3].

Baran and Wu [17, 18] stated the capacitor placement problem as a mixed integer programming problem, and a two-phase solution algorithm was designed to solve optimal capacitor placement on radial distribution systems. The multiple capacitor placements are determined by minimizing loss saving equation with respect to capacitor current while capacitor location was determined by using a singly located capacitor[19]. To pre-identify the optimal location of capacitor bank Loss Sensitivity Factor (LSF) was proposed and an effective biologically inspired algorithm (Bat Algorithm) was proposed for capacitor size search [20] while tabu search was proposed in [21] and genetic algorithm was proposed in [22]. In tabu search and sensitivity hybrid analysis was proposed to optimal capacitor placement[23]. For load balancing network reconfiguration and power loss minimization by branch exchange type heuristic algorithm was proposed by[13, 24].

Combining network reconfiguration and capacitor control was proposed for loss reduction in distribution systems[3, 16]. To achieve high performance and high efficiency an improved adaptive genetic algorithm (IAGA) was developed to optimize capacitor switching, and a simplified branch exchange algorithm was developed to find the optimal network structure for each genetic instance at each iteration capacitor optimization algorithm [17]. In for distribution network reconfiguration optimal flow pattern algorithm was presented [25].

Capacitor placement in radial distribution system by non-dominated sorting genetic algorithm was presented in [26]. Non-dominated sorting genetic algorithm presented to solve optimal capacitor placement in radial distribution system for reactive power compensation and for capacitor allocation to minimize power loss plant growth algorithm was proposed [27]. In order to reduce power loss in radial distribution network hybrid SA and heuristics method for solving optimal capacitor placement was presented [12, 28].

Bacterial Foraging Optimization algorithm also used to find the optimal size and location of the capacitor for power loss minimization in distribution system[29]. Most of all the authors had tried to minimize the power losses, but failed to minimize the number of compensated location.

An integrated real power loss minimization with optimized power flow tracing method which is fuzzy logic controller technique was used to determine the real power loss for corresponding generator reactive power operating limit [30].

There was three different FACTS devices were presented to place in suitable location to improve voltage profile and reduce peal power loss of the system [31]. Under the normal and abnormal condition of the network to control the power flow of the helps the system to reduce load flow in heavy loaded lines, minimize system real power loss and improve voltage profile of the system without generating rescheduling or topological changes in the network [32]. Because FACTS devices are expensive it is very important to find out the optimal location for placement of these devices to improve voltage stability and enhance network security [31, 33]. FACTS devices can regulate the reactive, active power and also adaptive to voltage magnitude control simultaneously by their fast control capability and their continuous compensation characteristics as well as reduce heavy loaded flow on transmission lines and maintain voltages in desired level. Placement of these devices in appropriate location can lead to control in line power flow and maintain bus voltages in desired level and also improve voltage stability margins [31, 32].

There are different previous works on capacitor allocation of radial distribution network using ETAP software. Capacitor provides leading current to the system which minimizes the lagging current impact of the load in the system. As a result, system power factor improves, voltage profile enhanced and power losses minimized [34]. These factors can be controlled and improved by optimally placing the capacitors in the power system. Significant research has been done in this manner which provide health outcomes in the form of cost saving for power suppliers and customers at a same time [35].

In this thesis ETAP software is used to optimally allocate the capacitor and its size in the distribution network, blow literature related to ETAP is discussed.

Reference [36] presented an OCP problem for an IEEE 69 bus system. Their research is based upon two stages the first stage they determine the optimal location for capacitor by dimension reducing load flow method then on the second stage they use GA algorithm for optimal capacitor size in the network. They used ETAP software for the voltage profile improvement and power losses minimization of the IEEE system.

Active and reactive power is every power system components. Capacitor is a common source which is used to reduce reactive element of power system. Roy billinton test system (RBTS) 60 bus distribution system is considered in[37] for the capacitor allocation and sizing. The objective is to minimize the voltage drop and power losses of the system.

In [34] they proposed a solution methodology for capacitor placement at Tehran Metro line-2 power system with the objective function of enhancement of voltage profile, improvement of power factor and system power loss reduction. For real time implementation of power system they used ETAP software. Interconnected distorted power system considered for the optimal capacitor placement and sizing with voltage, number of capacitor banks and total harmonic distortion constraints. The objective

function is to reduce the energy supply cost with the minimum number of capacitors. For the problem solution and evaluation IEEE 30 bus system is selected [38].
To show the effectiveness of the proposed technique local 22KV distribution station is modelled and evaluated for the allocation and sizing of capacitors bank under the short circuit interruption conditions[39]. They concluded that by proper allocating and sizing the capacitors in the distribution network short circuit interruption incident can be reduced and system maintenance cost can be minimized.

In [40] Southern California Edison power system operating on 12.47KV is modeled using ETAP and openDSS software. Capacitor placement for the reactive power compensation and losses reduction is done in the presence of distorted photo voltaic generation. A comparative study is presented for objective function of capacitor placement problem with cost reduction under existing load curves.

Local 132KV operating grid station is modelled and grid is modelled for the Radial, loop and interconnected configuration and tested over the ETAP software. To demonstrate the efficiency of proposed algorithm for the minimization of objective function a comparative analysis is done between radial, loop and interconnected power system and results conclude that loop and interconnected system performs better as compare to radial network for linear loads after installing capacitor banks [9].

Reference [41] exhibited the problem formulation for reactive compensating device placement and rating for a IEEE 10 bus radial distribution network. They modelled the system by ETAP using data and implies genetic algorithm for capacitor placement in the distribution network, objective function is to achieve cost effective system having improved voltage and minimum power losses.

Chapter Three
Modeling and Analysis

3.1 Introduction

This chapter discussed the modeling and analysis of the study area utilized in this work.

3.2 Modeling and Analysis of feeder 7 Distribution network

Energy is always transferred from source to distribution via transmission and consuming active and reactive power losses. Major Losses are as a result of power losses and can be controlled by an improved reactive power management. To avoid the reactive power loss, local reactive power compensation by placing appropriate capacitor that is most strong method employed in the world. Capacitors can provide for reactive loads, reduce losses, improve voltage profile and power factor (PF), hence optimum capacitor placement is a necessity in today complex integrated network [42].

3.3 Data Collection

The necessary data for this thesis work has been collected from Hawassa substation in Ethiopian Electric Power side and distribution feeders from Ethiopian Electric Utility side. The data have been collected from, past recorded feeders loading during peak load and each hour load data of the substation and distribution feeder roots, from Ethiopian Electric Utility (EEU) and Ethiopian Electric Power (EEP). From EEU and EEP, the AutoCAD drawing of the feeders, the type and impedance of the conductors, loading status of the feeder, bus and line data of the feeders have been collected.

The collected data have been used to model the distribution feeder network by Electrical transient analyzer program (ETAP) [34].

3.4 Load Flow Analysis

ETAP load flow analysis module calculates branch power factor, bus voltage, power flow of the distribution network system. ETAP allows connection for unregulated power sources, swing, voltage regulator with generator and multiple power grids. It can analysis both radial and loop distribution system. In order to achieve the best calculation efficiency ETAP have different methods of option [3].

3.5 Load Flow Calculation Methods

ETAP provides four load flow calculation methods: these are Accelerated Gauss-Seidel, Newton-Raphson, Adaptive Newton-Raphson and Fast-Decoupled. These methods have different convergent characteristics due to this one is more favorable than another in terms of best performance achievement [4].

3.6 Newton-Raphson

Newton-Raphson method formulates and solves iteration with the following load flow equation.

$$\begin{matrix} \Delta P \\ \Delta Q \end{matrix} = \begin{matrix} J1 & J2 \\ J3 & J4 \end{matrix} * \begin{matrix} \Delta\delta \\ \Delta V \end{matrix} \qquad \ldots\ldots (1)$$

Where: ΔP = bus real power and ΔQ=reactive power mismatch vectors between specified value and calculated value, respectively.

Where: ΔV =bus voltage and Δδ represents angle vectors in an incremental form; and J1 through J4 are called Jacobian matrices. The Newton-Raphson method retains a unique quadratic convergence characteristic. It usually has a very fast convergence speed compared to other load flow calculation methods. It also has the advantage that the convergence criteria are specified to ensure convergence for bus real power and reactive power mismatches[34].

The main target of this thesis is to enhance voltage profile, improve power factor and reduce power loss of distribution network by determining OCP. Current flow in a branch i,k can be expressed as relation between branch active power and reactive power with respect to the bus voltage.

The branch current (I_{ik}) connecting buses i and k is given by

$$Iik = \frac{Pik-Qik}{vi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

I_{ik} =the current through branch (i, k).

P_{ik} =real power flow in branch (i,k).

Q_{ik} =reactive power flow in branch (i,k).

V_i =voltage at node i

The feeder net real power loss can be express as:

$$TPL = \sum^{n}{}_{ik=1}|I_{ik}|^2 R_{ik} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where

n=current through branch

R_{ik}=resistance of branch.

The total power loss (active and reactive) stated as:

$TPL = TPL^{a} + TPL^{r}$ ……………....(4)

$TPL = \sum^{n}{}_{ik=1}|I_{ik}{}^{a}|^{2}R_{ik} + \sum^{n}{}_{ik=1}|I_{ik}{}^{r}|^{2}R_{ik}$ …………(5)

Now active power is supplied by the substation to root bus, so active component of loss (TPL^{a}) can’t be reduced for a radial bus system, but reactive power compensation locally can reduce the loss TPL^{a} associated with their active parts. For a radial distribution system if the reactive current drawn is for a branch set changes only the reactive component of current. Obviously the currents of other branches is almost unaffected by the capacitor bank[37]. Loading current be draw by capacitor which have effect on branch (i, k) then the new current be

$I_{rik}{}^{new} = I_{ik}{}^{r} + D_{ik}I_{ik}{}^{c}$ …………………………(6)

Where {$D_{ik=1 \text{ if branch}}$ (i,k) $\epsilon\alpha$: $D_{ik=0}$,otherwise

$I_{ik}{}^{r}$ is the reactive current of branch obtained from the load flow solution. The loss associated with the reactive component of branch current in the compensated system (system with capacitor) can be expressed as:

$TPL_{r}{}^{T} = \sum^{n}{}_{ik=1}|I_{ik}{}^{r} + D_{ik}I_{c}|^{2}R_{ik}$ ……………………(7)

$I_{ik}{}^{r}$ is the reactive current of branch obtained from the load flow solution. The loss associated with the reactive component of branch current in the reactive power compensated system (system with capacitor placement) can stated as:

$TLS = \sum^{n}{}_{ik=1}(2D_{ik}I_{ik}{}^{r} + D_{ik}I_{c}{}^{2})\, R_{ik}$ …………(8)

The maximum saving current drawn by the capacitor can be expressed as:

$0 = \sum^{n}{}_{ik=1}(D_{ik}I_{ik}{}^{r} + D_{ik}I_{c})\, R_{ik}$ ……………….(9)

For the maximum cost saving the capacitor current can finalized as:

$I_{c} = (-\sum^{n}{}_{ik\epsilon\alpha}(\ )\, R_{ik}) / (\sum^{n}{}_{ik\epsilon\alpha} R_{ik})$ …..............(10)

While sizing the capacitors it is very important to meet system reactive power constraints, for this corresponding capacitor size for relevant bus can stated as:

$Q_{c} = V_{i}I_{c}$ ……………………….(11)

Where

Q_c= Capacitor size in KVAR
V_i= Voltage magnitude of bus ‘i’ in volts
I_c= Capacitor current in amps

The reactive power injected to the system by the capacitor can be limited by:

$Q_{cj}{}^{min} \le Q_{cj} \le Q_{cj}{}^{max}$ …………..(12)

The injected reactive power should be less than load reactive power of the system.

$Q_c{}^{Total} \leq Q_L{}^{Total}$ ………(13)

3.7 Cost calculation method

ETAP currently utilizes the genetic algorithm for optimal capacitor placement. A genetic algorithm an optimizations technique based on the theory of natural selection. The genetic algorithm starts with a generation of solutions with wide diversity to represent characteristics of the whole search space. By mutation and crossover good characteristics are selected and carried to the next generation. The optimal solution can be reached through repeated generations[43].

Optimal capacitor placement (OCP) uses the present worth method to perform alternative comparisons. It considers initial installation and operating costs, which include loss reduction savings, maintenance and depreciation.

3.8 Objective function of OCP

The objective of optimal capacitor placement is to minimize the cost of the system. This cost is measured in four ways:

I. Capacitor installation cost
II. Capacitor purchase cost
III. Capacitor bank operating cost (CQ930 Capacitor Controller)
IV. Cost of real power losses

Mathematical representation of cost stated as:

Min cost function = $\sum^{N_{bus}}_{i=1}(X_iC_{0i}+Q_{ci}C_{1i}+B_iC_{2i}T) + C_2\sum^{N_{load}}_{l=1}(T_lP_L{}^l)$ …….(14)

N_{bus} = Number of candidate buses

X_i = 0/1, 0 no capacitor installed in bus i

C_{0i} = installation cost

C_{1i} = per kvar cost of capacitor bnks

Q_{ci} = capacitor bank size

B_i = number of capacitor bank

C_{2i} = operating cost of per bank, per year

T = planning period (years)

C_2 =cost of each kwh loss, in \$/kwh

l = load levels, minimum, average and maximum

T_i = time duration of load level l

p^l_L = total system loss at load level l

Voltage constraint and power factor constraint can be represented mathematically as:

Voltage constraint for all PQ buses

$$V_{min} \leq V \leq V_{max} \qquad \text{……..(15)}$$

Power factor constraint for all PQ buses

$$PF_{min} \leq PF \leq PF_{max} \qquad \text{……(16)}$$

The technique that proposed used for selecting candidate buses to last capacitor placement and also repeatedly employed for more optimization of cost of energy by indicating the sequence of nodes to be compensated for further loss reduction by optimal capacitor placement.

3.10 Pole mount capacitor bank

Pole mount capacitor bank is an economical solution for reactive power compensation on overhead distribution system. It is the most effective way to compensate reactive power and keep the voltage with in the allowable limit. This pole mount capacitor banks are installed over feeders, close to inductive loads. Compensating the reactive power close to the load likely significantly progress the system performance diminishing the load over the upstream feeder[44].

In addition to inductive loads, factors such as expanding the lines length or the presence of distributed generation disturb power factor and increase voltage drop. Pole mount capacitor bank offers a simple and reliable of improvement on voltage profile, correction on power factor, real power loss minimization and increase in system capacity[45].

3.11 Pole mount capacitor bank system have different benefits

- Power factor correction close to the consumer loads
- Cost effective
- Reduce the electricity cost (Demand Cost)
- Voltage profile improvement
- Increase electrical system capacity
- Reduce line loss
- Cost saving from minimized power loss
- Harmonic Suppression
- Allows size reduction in cables , switchgear and transformers
- Allows expansion without additional electrical enhancement
- Reduce in transformer and distribution equipment losses
- Improve in electrical energy efficiency.

3.12 Automatic Capacitor Bank Controller

Automatic power capacitor banks are equipped with various types of controllers to automatically turn power capacitor bank/stages on and off based on VAr flow, watt flow, voltage level, current-flow, time-to-day, or day-of-week [46]. The controllers work hand in hand with the protection and control system to automatically turn on/off the power capacitor bank. The selection of controller is dependent on capacitor bank act [47] requirements, consumer preference experience with its act, easy and reliability of use [12]. Capacitor bank controller allows a utility to optimize operational plan and track to 3-phase power quality reducing system downtime and to monitor [48].

3.12.1 CQ930 Capacitor Bank Controller

To meet the growing demand of utility customers' higher data resolution and great control, the CQ930 rang of capacitor bank controller supplies a low cost and reliable method of monitoring and switching three phase pole-mounted capacitors. CQ930 is designed specifically for real time 3-phase monitoring and measurement a fully featured controller. It has an ability to operate the capacitor bank switches in traditional gang or individually operation, CQ930 is equally adequate automatic or via remote master SCADA controls. CQ930 is designed for easy setup, monitoring and configuration with the use of large back-lit LCD screen and keypad, or by using the supplied computer software [47]. The CQ930 controller consist of a range of control modes including remote, manual and automatic control, designed to bargain consumers true value through smart controlling of their electrical systems [49].

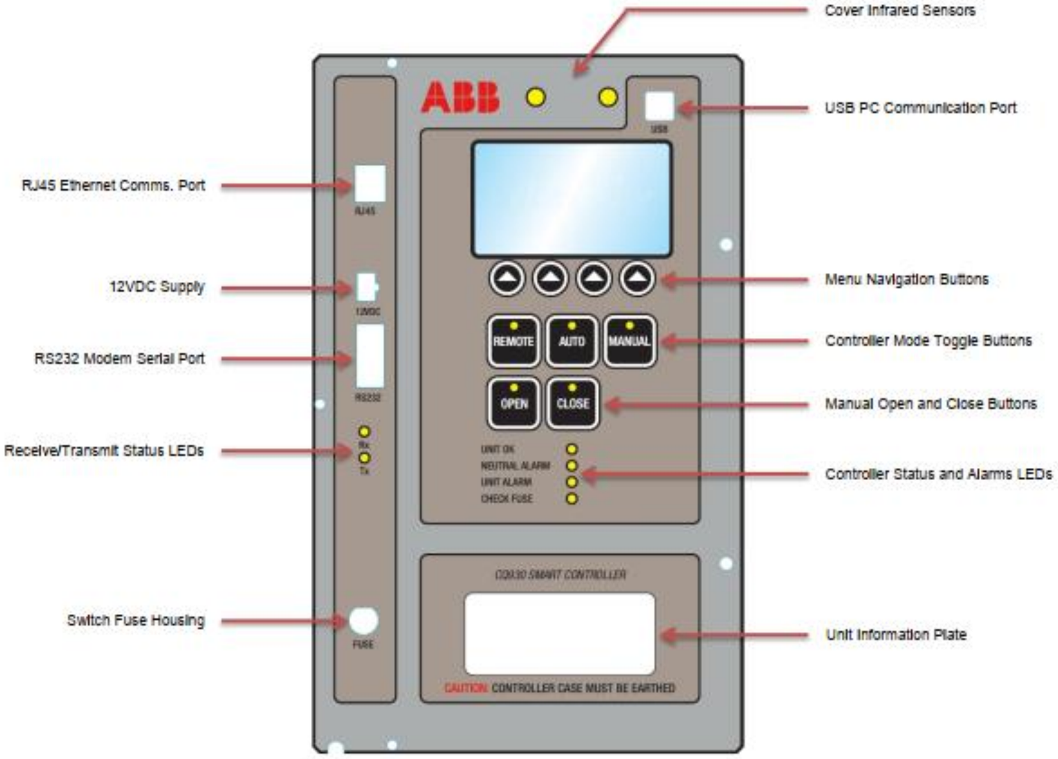


Figure 3.1 AAB CQ930 Capacitor bank controller

3.12.2 CQ930 capacitor controller Control modes

- Remote (control or monitor only)
- Automatic (local)
- Manual (local)

3.12.3 3-Phase Measurement and Monitoring

Network conditions for real time RMS measurements can be displayed, caught and recorded. Which includes current and voltage harmonic evaluation with global system values and THD, until 19th harmonic[50]. Also average system values are calculated. Rate for kvar, Kva, KW and power factor also calculated on phase by phase basis. The control unit can correspondingly set with Auto-Switching Control including the following modes:

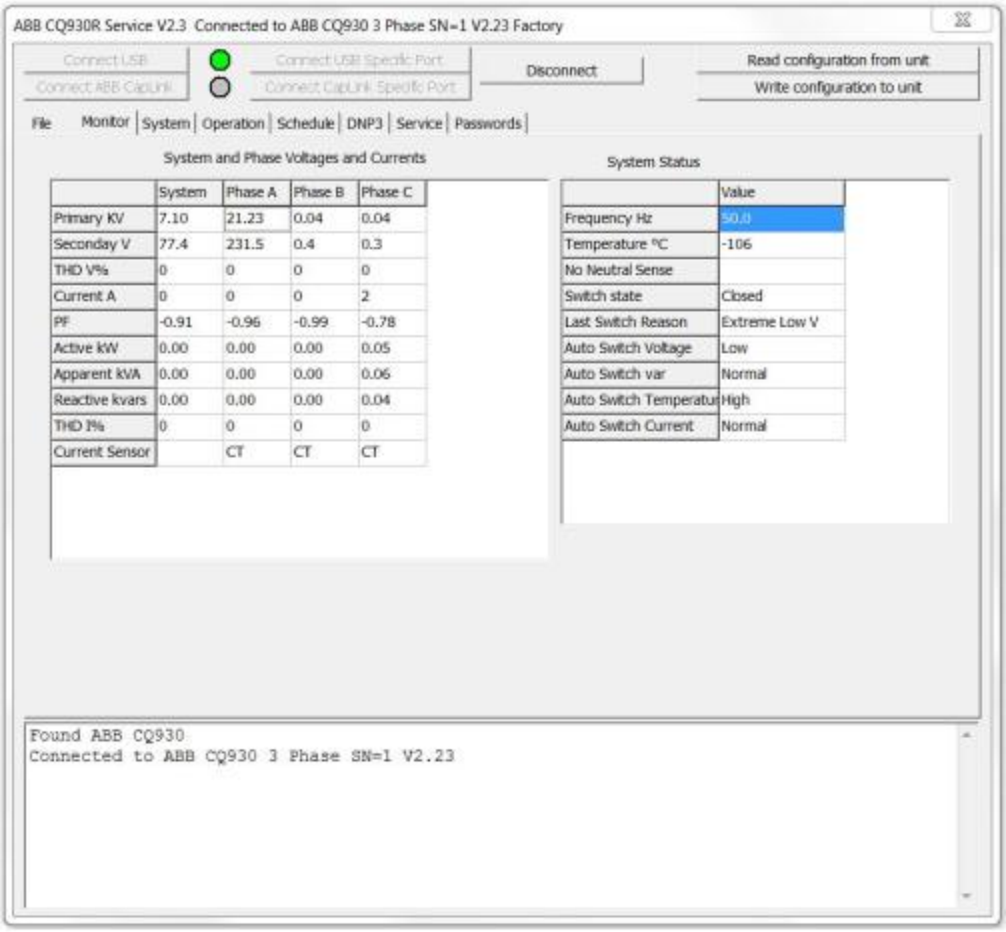
- Voltage
- Current
- VAR
- Schedule and
- Temperature

3.12.4 Modes of CQ930 Operation

The CQ930 has capability to work either an automatically controller device or manual controlled device, and also switches the capacitor bank on/off base on wide range of standard mention in the above control modes. Consenting abundant flexibility, any grouping of three of the above control mode can be used in concurrence, with chain of command of control being selected by the user[51]. The threshold values and time-outs for each control modes are fully programmable by the user, either through the unit face plat or provided computer/ PC utility software.

3.12.5 CQ930 Automatic Control Modes Switching ON Ranges

- **Switch on temperature rage:**
  -40^0c to $+50^0$c
- **Switch on voltage range:**
  360V to 430V
- **Switch on VAR range:**
  -10Mvar to +10Mvar
- **Open/Close time delay:**
  5s to 10 min separate open and close time
- **Maximum operations:**
  1 to 30 daily operations
  Logging periods 30s to 60 min



	System	Phase A	Phase B	Phase C
Primary KV	7.10	21.23	0.04	0.04
Seconday V	77.4	231.5	0.4	0.3
THD V%	0	0	0	0
Current A	0	0	0	2
PF	-0.91	-0.96	-0.99	-0.78
Active kW	0.00	0.00	0.00	0.05
Apparent kVA	0.00	0.00	0.00	0.06
Reactive kvars	0.00	0.00	0.00	0.04
THD I%	0	0	0	0
Current Sensor		CT	CT	CT

	Value
Frequency Hz	50.0
Temperature °C	-106
No Neutral Sense	
Switch state	Closed
Last Switch Reason	Extreme Low V
Auto Switch Voltage	Low
Auto Switch var	Normal
Auto Switch Temperatu	High
Auto Switch Current	Normal

```
Found ABB CQ930
Connected to ABB CQ930 3 Phase SN=1 V2.23
```

Figure 3.2Monitor tab on CQ930 utility software

3.13 Genetic Algorithm (GA) Optimization Technique

Most traditional optimization methods move from one point in the decision hyperspace to another using some deterministic rule. The problem with this is that it is likely to get stuck at a local optimum. GA starts with a diverse set (population) of potential solutions (hyperspace vectors). This allows for exploration of many optimums in parallel, lowering the probability of getting stuck at a local optimum [43, 52].

3.13.1 GENETIC ALGORISM FOR OCP

Genetic Algorism (GA) is a search and optimization technique inspired by the theory of biological evolution algorithm based on of natural selection technique. Basically, a GA makes a population that evolves through time using reproduction and mutation process. Only individuals representing good solutions of the capacitor placement problem will survive longer, and their genetic information will be present in the next generation. At the end, after several generations, the interaction between these high quality individuals will produce a final population which represent the best solutions set of the problem.

3.13.2 Three most important aspects of using GA

- Definition of objective function

- Definition and implementation of genetic representation
- Definition and representation of genetic operators

Real parameters of the problem must be represented in genetic algorithm language before the procedure of genetic algorism. The representation chosen for this application is a chromosome divided in two parts. First part indexes location of the capacitors. The second part indicates the size of the capacitors used. In reproduction process, first we randomly select a pair of chromosomes, with the same structure. In the next step, chromosomes are treated separately; one for binary part and another for integer part. In binary part, for a given position, if two parents share value, the chromosome produced by reproduction will keep it. If values are different, the result for new chromosome is selected at random. In integer part, for a given position, result will be the average of values found in the parents. If result is not an integer value, it will be approximated until closer value at random.

Chromosome structure is modified during mutation process. This change is performed at random, but there is a difference between binary and integer part. The GA was able to improve the quality of the randomly generated population very fast, and created good solutions in a very short time. In the selection of individuals for recombination, selection of a leader uniformly at random is required. The next step is to choose which one of the three supporters will take part in the recombination. This choice is also uniformly at random. Following this selection strategy, any pair of parents will belong to the same cluster. That makes the population act similarly to a multiple-population approach with a high migration rate. After the parents were selected, following the criterion described before, they are utilized as input parameters in the recombination operator. The recombination returns a new individual the offspring. Since the chromosome is composed of two distinct parts, they should be treated separately during the recombination process. The mutation operator aims to add diversity to the population of individuals. Similarly to the crossover, the mutation is divided into two parts. The first modifies the binary portion of the chromosome by choosing a position of the individual at random. The second part acts on the integer values by adding or subtracting a unity from its value. The choice of whether to add or subtract is also decided at random. Mutation is applied to 10% of the offspring. In general, higher mutation rates may slow down evaluation speed and hence should be avoided[42]. GA submits all or some of the new mutation individuals to a local search procedure for the purpose of improving their fitness function. This local search acts at the first part of the chromosome. Which mean it try to improve capacitor location. If a specific location already has a capacitor, the local search tests the possibility of dropping that capacitor (‘drop’). In case of deterioration of the solution, the position returns to the original value and the local search proceeds to the next one. This local search acts on the second part of the chromosome. It adjusts the sizes of the capacitors already present in the solution, trying to find the best size for each location. Only the sizes immediately above and below the present capacitor’s size are tested. Such tries are executed in a similar manner to the drop/add procedure, in one capacitor at a time;

accepting any change that improves the fitness. The fitness function quantifies the quality of the individual. Therefore, it will keep a close relation with the objective function of the problem. The first factor to be observed is the cost of the power losses, which takes into account the maximum voltage deviation observed in the distribution network's nodes for a given solution. Calculation of the power losses requires the execution of a load-flow algorithm. The objective of optimal capacitor placement is to minimize the cost of the system.

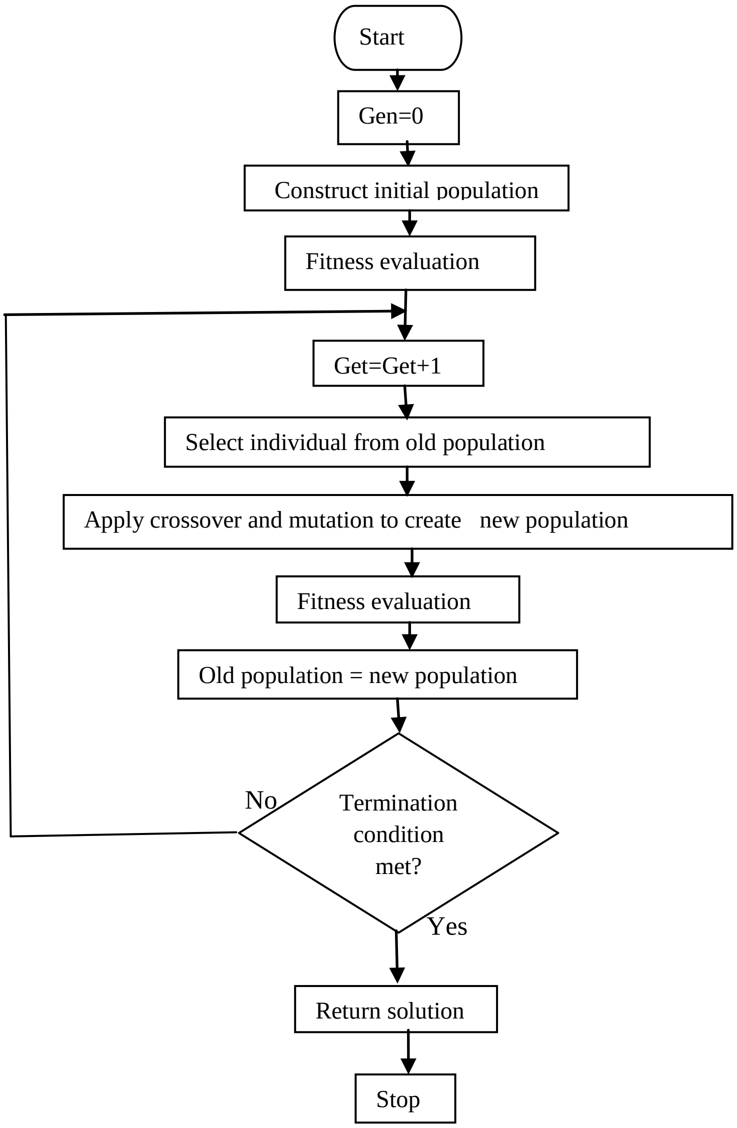


Figure 3.3 Genetic Algorism Flow Chart

3.13.3 Benefit of Using GA's

Even though GA is probabilistic, it is not strictly random search. The stochastic operators used in the operations on the population direct the search toward regions of the hyperspace that are likely to have higher fitness values.

GA is a general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms considered in natural systems and populations of living beings. Their basic principle is the reparation of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time.

Within this population new solutions are obtained during the genetic cycle using crossover and mutation operators. GA uses a ‘‘Chromosomal’’ representation which requires the solution to be coded as a finite length string. Figure 3.3 presents the flow chart of a typical GA that is used in this simulation.

Chapter Four

Simulation Studies and Analysis of Results

4.1 Introduction

In this chapter the simulation results obtained from ETAP performed by GA algorithms are presented. Power flow analysis is carried out to investigate the power loss, power factor, voltage profile and optimal cost with and without the optimal capacitor placement of capacitors.

The optimization procedure was implemented in Electrical Transient Analyzer Program (ETAP) Software tested on balanced 40 buses radial distribution feeder 7.

The solution used genetic algorithm methodology to optimal capacitor placement using ETAP 16.0.0 software. So from the overall result, the researcher reviewed that the optimization method for optimal capacitor allocation caused the power losses reduction on the lines and voltages profile improvement, power factor correction on buses of the real feeder 7 15KV Hawassa distribution feeder network with good investment and cost saving.

Hawassa has 9 outgoing 15kv feeders with different type of customer. Feeder 7 supplies its 65% power for of Hawassa industrial load. Table 4.1 shows different load type loaded to 15KV out going feeders.

Table 4.1 Feeders load type

Hawassa substation Feeders	Industrial load (%)	Commercial load (%)	Residential load (%)
Feeder 1	5	25	70
Feeder 2	11	9	80
Feeder 3	60	11	29
Feeder 4	12	14	74
Feeder 5	60	6	34
Feeder 6	8	32	40
Feeder 7	65	25	10
Feeder 8	10	41	49
Feeder 9	4	40	56

4.2 ETAP simulation study

This thesis work is based on Genetic Algorithm optimal capacitor placement and sizing. ETAP software 16.0.0 is used to evaluate the capacitor size and place in the system network. Feeder 7 which has 40 bus system is selected as test system for OCP using ETAP software. It is observed that capacitor placement in this feeder improves voltage profile attain the marginal power factor and reduces active and reactive power losses.

In this simulation the required data have been set as follow for implementation

- Objective function: Voltage Support & PF Correction
- Load flow method: Adaptive Newton-Raphson Method
- Maximum iteration: 99
- Precision of solution: 0.0001
- General parameter: average energy cost
- Energy cost: 0.06$/kwh
- Planning period: 5 years
- System frequency: 50.00Hz
- Unit system: Matric
- Minimum voltages limit =0.95
- Maximum voltage limit = 1.05
- Number of buses = 40
- Number of lines = 39
- Slack bus no = 1
- Base voltage = 15kv
- Base MVA = 25 MVA

4.3 Feeder 7 network system

The power losses of feeder 7 system is being evaluated and modelled based on AG using ETAP software. This feeder consists of 40 bus system of utility deliver operating at 15kv which is supplying power towards the load by 23 transmission lines, 16 distribution transformer and 39 load.

The load demand is 3.854 MVA and all the feeder elements are interconnected with each other by 40 bus-bars. Using load flow method optimal capacitor placement problem is evaluated. By this method it is identified the bus with high voltage drop and voltage constraints violation. So buses with this case are nominated for capacitor placement. Single line diagram of feeder 7 shown in Figure 4.1 below.

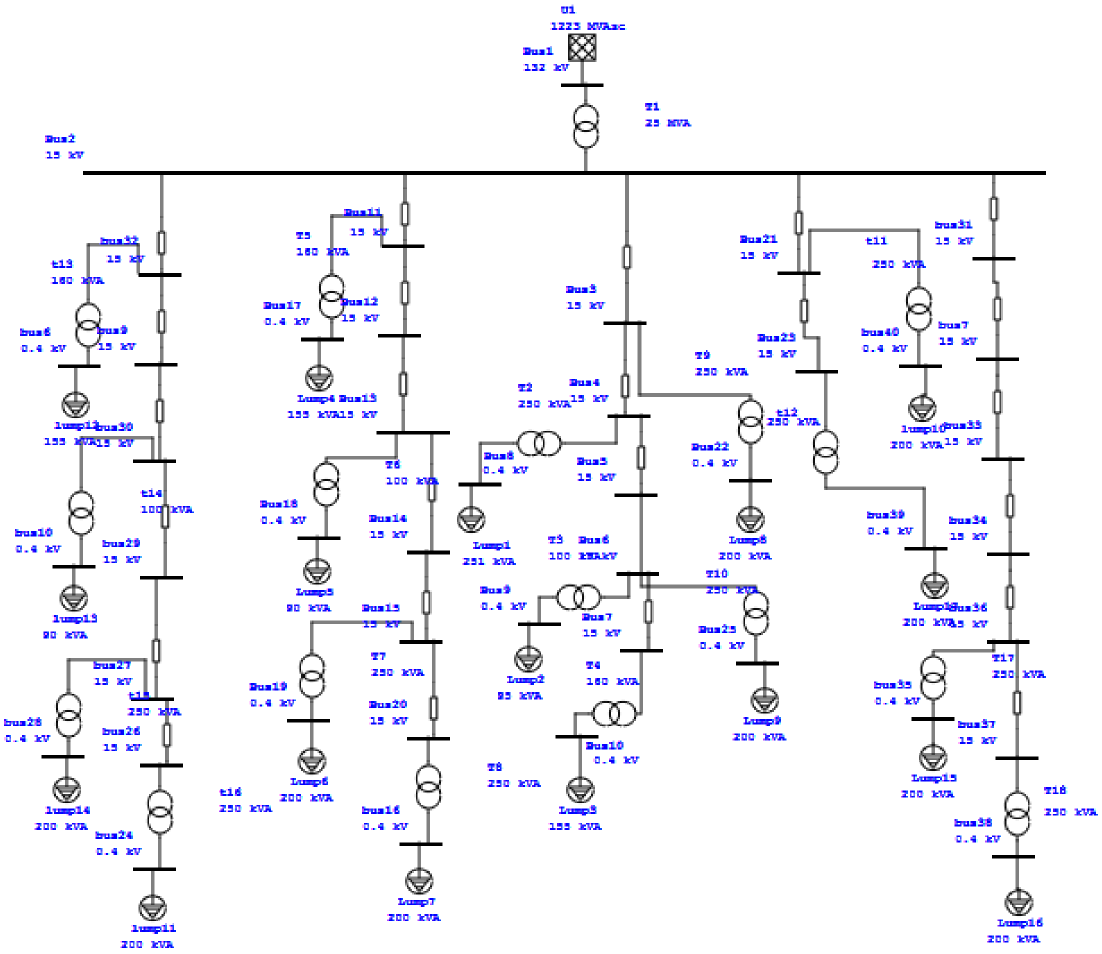


Figure 4.1 Single Line Diagram of 40 bus system feeder 7

4.4 Result will be discussed in the following steps

- The design has been done according to the following steps:
- **Step 1:** Analyze load flow without capacitor placement in to distribution feeder line buses.
- **Step 2:** Run the installing optimal capacitor size in optimal location of buses.
- **Step 3:** Comparing case1 & case2 and analyze the conclusion.
- **Step 4:** compare case 3 with PSO algorithm

4.5 Load flow analysis without capacitor placement

Load flow result obtained from ETAP simulation of feeder 7 distribution network presented in table 4.3. Base case active and reactive power loss also discussed in this table 4.2.

Table 4.2 Load flow report

Buses	Voltage			Load		Buses	Load Flow			
ID	KV	%Mag.	Ang.	MW	Mvar	ID	MW	Mvar	Amp.	PF%
Bus1	132	100	0	2.282	1.272	Bus2	2.282	1.272	11.4	87.3
Bus2	15	99.450	-0.5	0	0	Bus3	0.542	0.312	24.2	86.7
						Bus11	0.535	0.279	23.4	88.6
						Bus21	0.335	0.192	14.9	86.6
						Bus32	0.536	0.312	24.0	86.4
						Bus31	0.332	0.149	91.2	91.2
						Bus1	3.344	1.851	87.5	87.8
Bus3	15	97.563	-1.0	0	0	Bus2	-0.54	-0.32	24.6	85.9
						Bus4	0.37	0.214	16.9	86.6
						Bus22	0.165	0.105	7.7	84.3
Bus4	15	96.612	-1.2	0	0	Bus3	-0.37	-0.22	17.1	85.5
						Bus5	0.163	0.09	7.4	87.2
						Bus8	0.204	0.132	9.7	84.1
Bus5	15	96.154	-1.4	0	0	Bus4	-0.16	-0.10	7.7	84.3
						Bus25	0.162	0.104	7.7	84.3
Bus6	0.4	94.646	-1.9	0.125	0.077	Bus32	-0.13	-0.08	224.1	85.0
Bus7	15	98.033	-1.0	0	0	Bus31	-0.33	-0.17	14.5	89.0
						Bus33	0.329	0.168	14.5	89.0
Bus8	0.4	92.934	-2.2	0.199	0.123	Bus4	-0.2	-0.12	18.3	86.4
Bus9	15	97.02	-1.2	0	0	Bus32	-0.4	-0.23	18.3	86.4
						Bus30	-0.4	0.232	18.3	86.4
Bus10	0.4	92.535	-2.4	0.071	0.044	Bus30	-0.07	-0.04	130.3	85.0
Bus11	15	97.821	-1.1	0	0	Bus2	-0.53	-0.28	23.5	88.5
						Bus12	0.401	0.196	17.6	89.8
						Bus17	0.128	0.082	6.0	84.1
Bus12	15	96.714	-1.4	0	0	Bus11	-0.4	-0.23	17.8	88.8
						Bus13	0.398	0.206	17.8	88.8
Bus13	15	95.578	-1.8	0	0	Bus12	-0.4	-0.22	18.1	87.7
						Bus14	0.322	0.169	14.6	88.5
						Bus18	0.073	0.047	3.5	84.2
Bus14	15	94.64	-2.1	0	0	Bus13	-0.32	-0.18	14.9	87.2
						Bus15	0.319	0.18	14.9	87.2
Bus15	15	93.672	-2.3	0	0	Bus14	-0.32	-0.19	15.2	85.8
						Bus20	0.158	0.088	7.5	87.3
						Bus19	0.159	-0.1	7.7	84.2
Bus16	0.4	90.244	-3.3	0.154	0.095	Bus20	-0.15	0.1	290.2	85
Bus17	0.4	94.276	-2.1	0.124	0.077	Bus11	-0.12	-0.8	224.1	85.0
Bus18	0.4	92.28	-2.7	0.071	0.044	Bus13	-0.71	-0.04	130.3	85.0
Bus19	0.4	90.737	-3.1	0.155	0.096	Bus15	-0.65	-0.10	290.0	84.2
Bus20	15	93.18	-2.4	0	0	Bus15	-0.16	-0.10	7.7	84.2
						Bus16	0.158	0.101	7.7	84.2
Bus21	15	98.674	-0.7	0	0	Bus2	-0.33	-0.20	15.2	85.6
						Bus23	0.166	0.095	7.5	86.9
						Bus40	-0.16	0.106	7.7	84.3
Bus22	0.4	94.638	-1.8	0.161	0.10	Bus3	-0.17	-0.10	289.1	85.0

Bus23	15	98.281	-0.8	0	0	Bus21	-0.16	-0.11	7.7	84.3
						Bus39	0.17	0.106	7.7	84.3
Bus24	0.4	91.093	-2.8	0.156	0.096	Bus26	-0.16	-0.10	289.9	85.0
Bus25	0.4	93.226	-2.2	0.159	0.098	Bus5	-0.16	-0.10	289.4	85.0
Bus26	15	94.026	-2.0	0	0	Bus27	-0.16	-0.10	7.7	84.2
						Bus24	0.159	0.102	7.7	84.2
Bus27	15	94.523	-1.9	0	0	Bus29	-0.32	-0.20	15.3	85.2
						Bus26	0.160	0.094	7.6	86.1
Bus28	0.4	91.591	-2.7	0.156	0.097	Bus27	-0.16	-0.10	289.8	85.0
Bus29	15	95.508	-1.6	0	0	Bus30	-0.32	-0.20	15.1	86.0
						Bus27	0.322	0.191	15.1	86.0
Bus30	15	95.832	-1.6	0.155	0.096	Bus9	-0.40	-0.24	18.5	85.9
						Bus29	0.323	0.138	15.0	86.3
						Bus10	0.073	0.047	3.5	84.2
Bus31	15	98.752	-0.7	0	0	Bus2	-0.53	-0.16	14.3	90.1
						Bus7	0.331	0.159	14.3	90.1
Bus32	15	98.191	-0.9	0	0	Bus2	-0.53	-0.31	24.1	86.3
						Bus9	0.403	0.228	18.1	87.0
						Bus6	0.128	0.082	6.0	84.3
Bus33	15	97.295	-1.2	0	0	Bus7	-0.33	-0.18	14.7	87.9
						Bus34	0.327	-0.18	14.7	87.9
Bus34	15	96.537	-1.4	0	0	Bus33	-0.33	-0.19	15.0	86.9
						Bus36	-0.16	0.187	15.0	86.8
Bus35	0.4	92.765	-2.4	0.158	0.098	Bus36	-0.33	-0.10	189.5	86.8
Bus36	15	95.694	-1.6	0	0	Bus34	-0.16	-0.20	15.2	85.0
						Bus37	0.162	0.096	7.5	85.5
						Bus35	0.161	0.103	7.7	86.8
Bus37	15	95.299	-1.7	0	0	Bus36	-0.16	-0.10	7.7	84.3
						Bus38	0.161	0.103	7.7	84.3
Bus38	0.4	92.37	-2.5	0.157	0.098	Bus37	-0.16	-0.10	289.6	85.0
Bus39	0.4	95.357	-21.6	0.162	0.101	Bus23	-0.16	-0.10	289.0	85.0
Bus40	0.4	95.751	-1.5	0.163	0.101	Bus21	-0.16	-0.10	288.9	85.0

Load flow simulation for feeder 7 result illustrated in figure 4.2. The loaded bus are marked with red color and the loaded transformer it colored by violet.

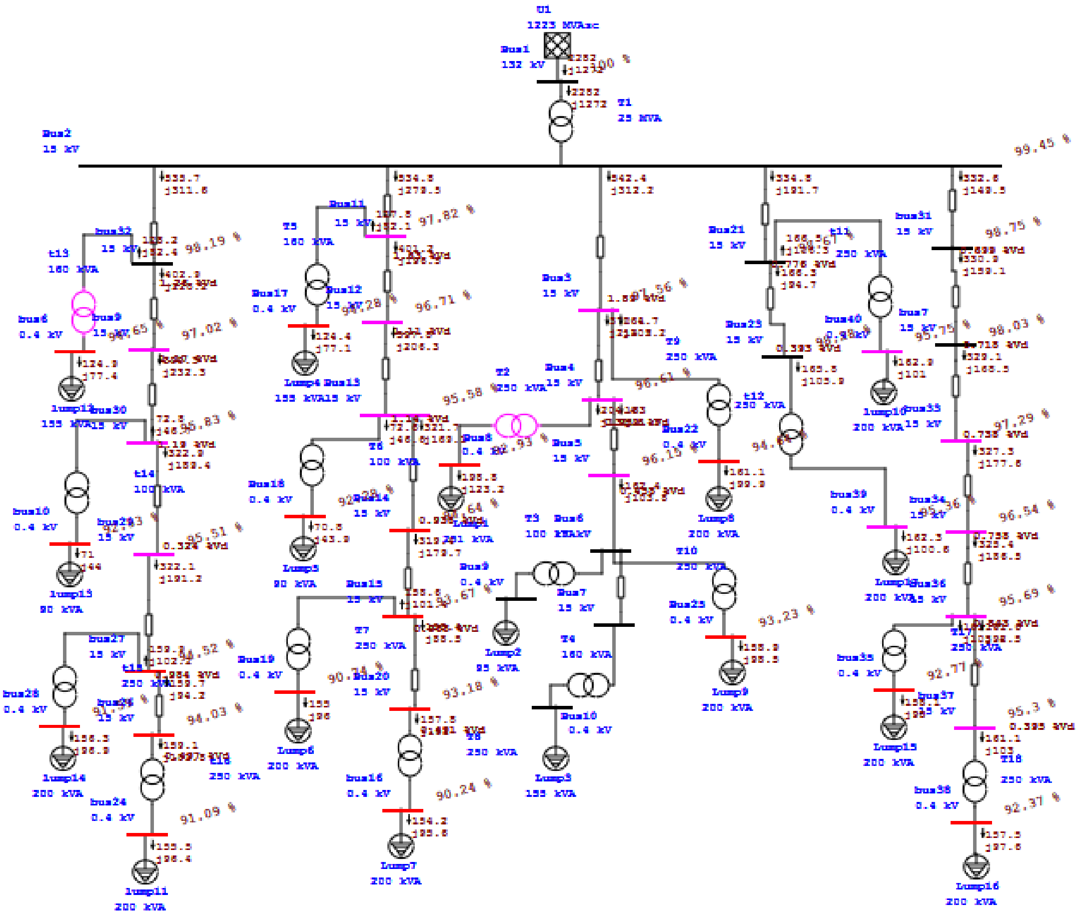


Figure 4.2 Feeder 7 Load Flow Simulation Result

4.6 Network Representation

Load flow result determines the voltage angle and voltage magnitude of the buses, the real power and reactive power flow on branches. System buses are represented by specifying two of these four quantities. Buses are classified depending on quantities specified as[3]:

4.6.1 PV buses

Constant active power and voltage magnitude are specified. This type of bus is used to represent generators whose active power and voltage magnitude are controlled and synchronous condensers. In order to consider equipment limits under atypical conditions (as mentioned in the previous section), reactive power limits for the corresponding network components are also used as input information.

4.6.2 PQ buses

Real powers and reactive powers are specified. This type of buses are used to characterize loads and generators with fixed dispatch. Loads can also be set to change (from their original Po and Qo values at nominal voltage) as a purpose of the voltage of the bus to which the load itself is linked.

4.6.3 Slack bus

Voltage magnitudes and voltage angles are stable. In traditional load flow calculations the slack bus (associated with a synchronous generator or an external network) carries out the balancing of power in the network. Special nodes used to signify devices such as HVDC converters, SVSs, etc., with specific control conditions (for example the control of active power flow at a certain MW threshold in a HVDC converter). In contrast to other power system calculation programs, Power factory does not directly define the node characteristic of each bus bar. Instead, more realistic control conditions for the network elements connected to these nodes are defined.

4.7 Before capacitor placement branch loss report

Table 4.3 Base case branch loss

Branch	From-To bus flow		To-From bus flow		Loss(kW)	Loss(kVar)	% bus voltage		Vd in mag
T1	3.347	1.91	-3.344	-1.851	10.08	59.3	100	99.2	0.82
Line 1	0.746	0.431	-0.732	-0.428	18.5	2.6	99.2	96.6	2.6
Line 6	0.533	0.279	-0.528	-0.278	13.9	0.9	99.2	97.5	1.63
Line 12	0.664	0.369	-0.657	-0.371	15.6	1.4	99.2	97.7	1.51
Line 18	0.534	0.311	-0.53	-0.31	11.6	1.1	99.2	97.9	1.26
Line 24	0.332	0.149	-0.33	-0.159	5.78	9.6	99.2	98.5	0.7
Line 30	0.534	0.311	-0.53	-0.31	11.6	1.1	99.2	97.9	1.26
Line 2	0.569	0.324	-0.562	-0.327	13.5	3.3	96.6	95.1	1.46
T9	0.163	0.104	-0.16	-0.099	10.7	5.3	96.6	93.7	2.93
Line 3	0.361	0.198	-0.358	-0.206	9.9	8.9	95.1	94.1	1
T2	0.202	0.13	-0.196	-0.121	12.7	8.5	95.1	91.4	3.68
Line 4	0.199	0.105	-0.198	-0.117	8.1	12.2	94.1	93.5	0.59
T10	0.159	0.102	-0.561	-0.096	10.7	5.4	94.1	91.2	2.93
Line 5	0.123	0.068	-0.122	-0.079	7.7	10.3	93.5	93.2	0.3

T3	0.075	0.048	-0.073	-0.045	9.1	3	93.5	90	3.49
T4	0.122	0.079	-0.119	-0.074	10.4	5.1	93.2	89.7	3.56
Line 7	0.4	0.196	-0.397	-0.206	10.4	9.7	97.5	96.4	1.11
T5	0.127	0.082	-0.124	-0.077	10.4	5	97.5	94	3.55
Line 8	0.397	0.206	-0.397	-0.215	10.5	9.3	96.4	95.3	1.14
Line 9	0.321	0.619	-0.319	-0.179	9.3	10.5	95.3	94.4	0.94
T6	0.072	0.046	-0.071	-0.044	9.8	2.7	95.3	92	3.3
Line 10	0.319	0.179	-0.316	-0.189	9.5	10.1	94.4	93.4	0.97
Line 11	0.158	0.088	-0.157	-0.101	7.6	12.4	93.4	92.9	0.49
T7	0.158	0.101	-0.155	-0.096	10.6	5.4	93.4	90.5	2.94
T8	0.154	0.095	0.157	-0.101	10.7	5.4	90	92.9	2.94
Line 13	0.492	0.266	0.488	-0.271	11.2	5.7	97.7	96.5	1.13
T20	0.165	0.105	0.161	-0.1	10.6	5.3	97.7	94.7	2.92
Line 14	0.324	0.167	0.323	-0.176	8.9	8.8	96.5	95.8	0.74
T19	0.163	0.104	0.159	-0.099	10.6	5.3	96.5	93.6	2.93
Line 15	0.323	0.176	0.321	-0.184	8.9	8.5	95.8	95	0.76
Line 16	0.321	0.184	0.319	-0.193	9.2	8.9	95	94.2	0.85
Line 17	0.159	0.091	0.159	-0.102	7.5	10.1	94.2	93.8	0.4
T11	0.159	0.102	0.156	-0.097	10.6	5.4	94.2	91.3	2.93
T12	0.159	0.102	0.155	-0.096	10.6	5.4	93.8	90.9	2.93

Line 25	0.33	0.159	0.328	-0.168	8.9	9.3	98.5	97.8	0.72
Line 19	0.402	0.228	0.398	-0.232	10.6	4.1	97.9	96.7	1.17
T13	0.128	0.082	0.125	-0.077	10.3	5	97.9	94.4	3.54
Line 26	0.326	0.177	0.328	-0.168	8.9	9.1	97	97.8	0.74
Line 27	0.325	0.177	0.325	-0.186	8.9	8.8	97	96.3	0.76
Line 28	0.325	0.186	0.322	-0.195	9.1	9.3	96.3	95.4	0.84
T17	0.158	0.098	0.161	-0.103	10.6	5.4	92.5	95.4	2.93
Line 29	0.161	0.092	0.161	-0.103	7.5	10.4	95.4	95	0.39
T18	0.161	0.103	0.157	-0.097	10.6	5.4	95	92.1	2.93
Line 20	0.398	0.232	0.395	-0.236	10.6	3.8	96.7	95.6	1.19
T14	0.071	0.044	0.073	-0.047	8.9	2.7	92.3	95.6	3.3
Line 21	0.322	0.189	0.321	-0.191	7.9	1.8	95.6	95.2	0.32
Line 22	0.321	0.191	0.319	-0.196	9.5	5.1	95.2	94.2	0.98
T15	0.156	0.097	0.159	-0.102	10.6	5.4	91.3	94.2	2.93
Line 23	0.159	0.094	0.159	-0.102	7.7	7.6	94.2	93.9	0.5
T16	0.159	0.102	0.155	-0.096	10.6	5.4	93.8	90.8	2.93

4.8 Optimal Capacitor Placement Power Flow Analysis

Base cases load flow simulation result which is step 1 network power loss, voltage profile and power factor are analyzed. After optimal capacitor placements this parameters are significantly improved. The optimization is carried out by both particle swarm optimization and genetic algorism.

4.8.1 Particle Swarm Optimization Technique

After PS optimization technique active power loss is minimized from 0.472MW to 0.305MW, reactive power is minimized from 0.07Mvar to 0.048Mvar. Which is 35.4% and 31.4% active and reactive power reduction respectively are recorded using particle swarm optimization. Saving from minimized power loss is $7176.06 with payback period of eighteen months.

4.8.2 Genetic Algorism Technique

A result for base case load flow, genetic algorism (the proposed algorism) and particle swarm optimization are compared. ETAP 16.0.0 OCP genetic algorism improved real power loss from base case of 0.472MW to 0.275MW reactive power loss from 0.07MVar to 0.03MVar. It mean that 41.51% and 44.29% active and reactive power losses are reduced respectively from base case. . Over all network power factor is improved from 87.35% to 95.49% and a minimum voltage magnitude improved from 90.244% to 95.622% while maximum voltage magnitude increase from 93.18% to 98.897%. Finally feeder 7 distribution network system capacity increase from 2.612Mva to 3.152MVA. Saving from reduced power loss by GA is $9654.25 per year. The profit during 5 years of plan period is $39334.02 with ten months of payback period. Table 4.4 shows the comparison in between base cases, PSO and GA. Then the result indicates that the proposed method which is GA better than PSO.

Table 4.4 Proposed method GA and PSO method analysis comparison

Parameters	**Base Case**	**PSO method**						**Proposed method (GA)**			
Bus		8	10	16	19	20	39	16	19	24	28
OCP size (MVAR)		0.75	0.86	1.6	3.1	0.49	1.14	1.6	2.4	0.97	0.81
Bus	16	22						20			
min V Mag. %	90.244	92.47						95.622			
Bus	15	39						31			
max V Mag. %	93.18	96.91						98.897			
P Loss (PL) KW	471.69	318.8						275.9			
PL reduction %	-	33.4						41.51			
Investment cost ($)	-	88,980						63,200			
Net saving/year ($)	-	18,621.02						39,707.22			
Payback period	-	13 months						7 months			

EEU revised energy average tariff which is 0.06$/kWh used to calculate power loss cost of F7 network. Base case power loss is 471.69KW and after placement of capacitor is 275.9KW. Therefore the power loss reduction due to capacitor placement is 195.79KW

- ➢ Power loss reduction due to OCP
    - ✓ 471.69KW-275.9KW = 195.79KW
- ➢ OCP total energy/year saved
    - ✓ 195.79KW*8760h = 1,715,120.4Kwh
- ➢ OCP saving cost
    - ✓ (1,715,120.4Kwh*0.06$)/Kwh = 102,907.224$

- ➢ Total purchase cost for OCP = 38,000$
- ➢ Installation cost for OCP = 4,000$

- ➢ Total purchase cost for CQ930 = 18,000$
- ➢ Total installation cost for CQ930 = 3,200$

- ➢ Total investments cost = 63,200$

- ➢ Then the payback period will be

    - ✓ Total investments cost/(OCP) $= \frac{\text{Total investments cost}}{OCP\ saving\ cost/year}$
    - ✓ $\frac{63{,}200\$}{102{,}907.224\$/year} =$ 0.614 year (about 7months)
- ➢ Yearly net saving is = 39,707.22$

Optimal capacitor size and location ETAP simulation result is illustrated in fig.4.4. The candidate buses are 16, 19, 24 and 28 with the capacitor size of 1.6Mvar, 2.4Mvar, 0.97Mvar and 0.81Mvar respectively.

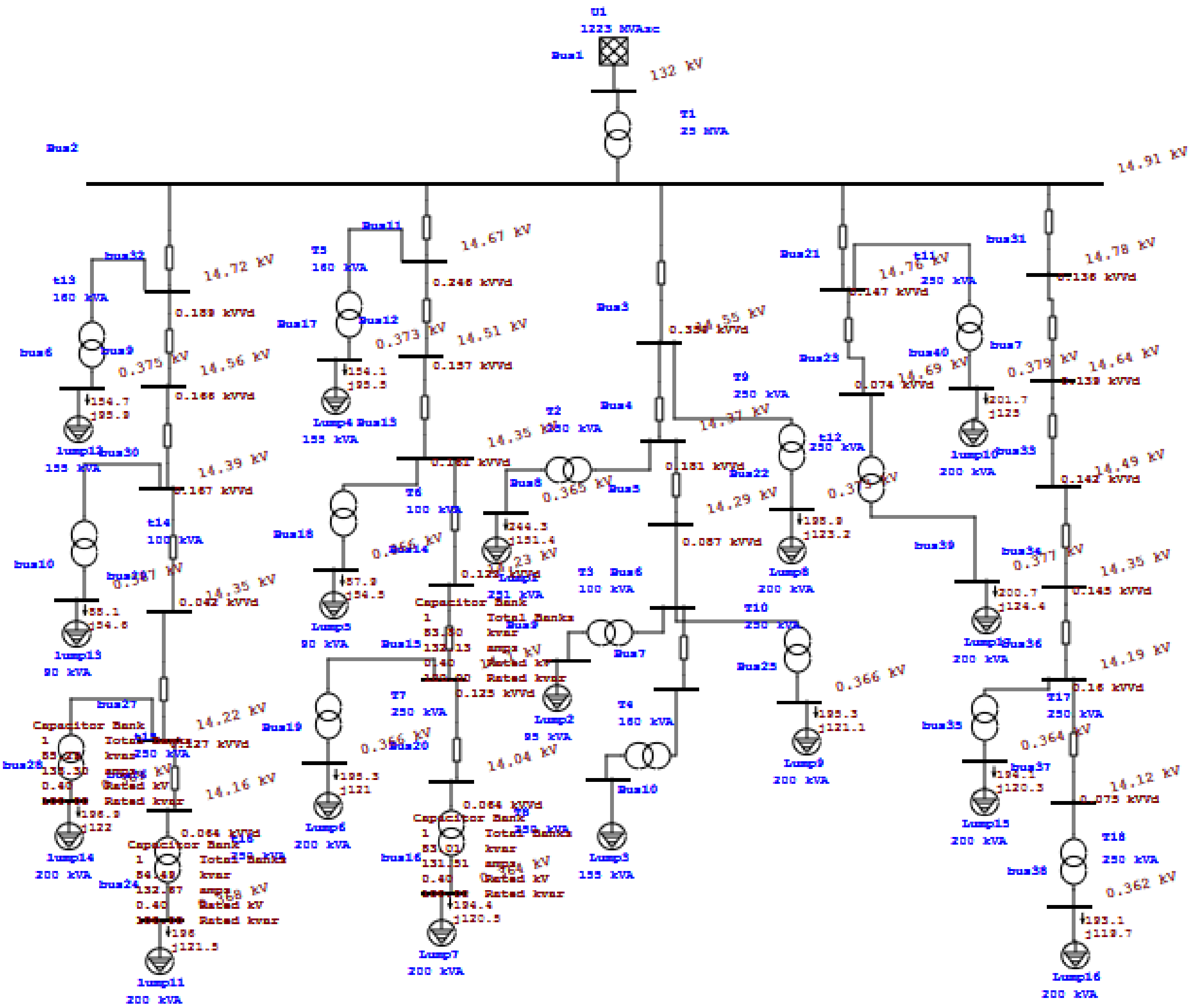


Figure 4.3 ETAP Optimal capacitor placement simulation result

4.9 Optimization of Capacitor Location and Size

Different size of capacitor is optimally placed in different buses. The optimal size and location are determined from ETAP 16.0.0 software by genetic algorism OCP. This locations are in bus number 16, 19, 24 and 28 of 40 buses of feeder 7 radial distribution network.in Tabe.4x the capacitor size and location are motioned.

Table 4.5 Optimal capacitor size and location

No.	Bus no.	Optimal capacitor size (Mvar)	Capacitor purchase Cost ($)	CQ930 purchase cost ($)
1	16	1.6	9745	4500
2	19	2.4	10,170	4500
3	24	0.97	9100	4500

4	28	0.81	8985	4500
5	-	5.78	38,000	18,000

Table 4.6 shows cost of capacitor, CQ930, installation and loss reduction in $. The yearly profit and accumulative profit of 5 year are stated briefly

Table4.6 Optimal capacitor cost summary

Years	Cost ($)		Saving ($)		
	Capacitor/Ins.	CQ930/Ins.	Loss Reduction	Profit/year	Accumulative Profit
1	42,000	21,200.00	102,907.22	39,707.22	39,707.22
2	0.00	0.00	39,707.22	39,707.22	79,414.44
3	0.00	0.00	39,707.22	39,707.22	119,121.66
4	0.00	0.00	39,707.22	39,707.22	158,828.88
5	0.00	0.00	39,707.22	39,707.22	198,536.1

CHAPTER FIVE

Conclusions, Recommendations and Future work

5.1 Introduction

In this chapter conclusion, recommendation and suggestion for future work are included in the thesis in title Power Loss Reduction and Voltage Profile Improvement of Distribution Feeder Using Capacitor Banks (Case Study: Hawassa Substation Distribution Feeder 7).

5.2 Conclusion

This thesis work is initiated from the objective of power loss reduction and voltage profile improvement Hawassa substation distribution feeder. The chosen feeder which is feeder 7 has high power loss and voltage drop compared with the rest of 15KV feeders from load flow analysis result. By the help of ETAP and based on collected data the base case simulation is carried out. ETAP genetic algorism base optimal capacitor placement showed a real power loss minimization from 471.69KW to 275.9KW with maximum voltage profile improvement from 90.24% to 95.62%. From the results, it can be concluded that by introducing optimal capacitor bank placement in the network, improved voltage profile, power factor, system loading capacity and minimize real power loss. Thus the capacitors allocated at optimal bus significantly improved the network of Feeder 7 Hawassa distribution system. During system load variation the reactive power can be managed by CQ930 capacitor controller so that voltage will remain within allowable range.

5.3 Recommendations

- EEU should consider to allocate optimal capacitor bank in Feeder 7 of Hawassa distribution network.
- Further research is recommended on the rest of Hawassa distribution feeders and even nationwide distribution system.
- Those consumers who demand reactive power should consider optimal capacitor placement
- It is recommended to integrate CQ930 capacitor controller with capacitor bank for reactive power compensation operation.

5.4 Suggestion for Future Work

In this thesis, the loss reduction and voltage profile, power factor correction improvement of the Hawassa feeder 7 distribution system has been done by considering optimal capacitor allocation and size in the network. However, impacts harmonics and phase unbalance load on power loss and under voltage of distribution systems have not been considered. Loss reduction and voltage profile improvement of the distribution network considering phase unbalance load and harmonics is suggested as a future work. Furthermore future work on reactive power compensator like SVC, FACT and AVR are suggested.

Reference

[1] M. A. H. Mondal, E. Bryan, C. Ringler, and M. Rosegrant, "Ethiopian power sector development: Renewable based universal electricity access and export strategies," *Renewable and Sustainable Energy Reviews,* vol. 75, pp. 11-20, 2017.

[2] G. Levitin, A. Kalyuzhny, A. Shenkman, and M. Chertkov, "Optimal capacitor allocation in distribution systems using a genetic algorithm and a fast energy loss computation technique," *IEEE Transactions on Power Delivery,* vol. 15, pp. 623-628, 2000.

[3] D. Zhang, Z. Fu, and L. Zhang, "Joint optimization for power loss reduction in distribution systems," *IEEE Transactions on Power Systems,* vol. 23, pp. 161-169, 2008.

[4] Q. K. Mohsin, X. Lin, F. F. Flaih, S. M. Dawoud, and M. Kdair, "Optimal placement and capacity of capacitor bank in radial distribution system," in *2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS),* 2016, pp. 416-423.

[5] A. A. Eajal and M. El-Hawary, "Optimal capacitor placement and sizing in unbalanced distribution systems with harmonics consideration using particle swarm optimization," *IEEE Transactions on Power Delivery,* vol. 25, pp. 1734-1741, 2010.

[6] P. M. Hogan, J. D. Rettkowski, and J. Bala, "Optimal capacitor placement using branch and bound," in *Proceedings of the 37th Annual North American Power Symposium, 2005.,* 2005, pp. 84-89.

[7] E. U. I. NNANEDU, D. ATUCHUKWU, and D. J. ILOH, "Reactive Power Compensation for Reduction of Losses in Nigeria 330kV Network Using Static Compensator (STATCOM)," 2019.

[8] F. Mahmoodianfard, H. A. Abyaneh, A. Vahabzadeh, and H. Salehi, "Optimal capacitor placement for loss reduction," in *2010 Modern Electric Power Systems*, 2010, pp. 1-5.

[9] P. Chopade and M. Bikdash, "Minimizing cost and power loss by optimal placement of capacitor using ETAP," in *2011 IEEE 43rd Southeastern Symposium on System Theory*, 2011, pp. 24-29.

[10] O. A. Afolabi, W. H. Ali, P. Cofie, J. Fuller, P. Obiomon, and E. S. Kolawole, "Analysis of the load flow problem in power system planning studies," *Energy and Power Engineering,* vol. 7, p. 509, 2015.

[11] W. A. Bukhsh, A. Grothey, K. I. McKinnon, and P. A. Trodden, "Local solutions of the optimal power flow problem," *IEEE Transactions on Power Systems,* vol. 28, pp. 4780-4788, 2013.

[12] M. Chis, M. Salama, and S. Jayaram, "Capacitor placement in distribution systems using heuristic search strategies," *IEE Proceedings-Generation, Transmission and Distribution*, vol. 144, pp. 225-230, 1997.

[13] S. Civanlar, J. Grainger, H. Yin, and S. Lee, "Distribution feeder reconfiguration for loss reduction," *IEEE Transactions on Power Delivery,* vol. 3, pp. 1217-1223, 1988.

[14] R. Rajaram, K. S. Kumar, and N. Rajasekar, "Power system reconfiguration in a radial distribution network for reducing losses and to improve voltage profile using modified plant growth simulation algorithm with Distributed Generation (DG)," *Energy Reports,* vol. 1, pp. 116-122, 2015.

[15] A. Dubey, "Load Flow Analysis of Power Systems," *International Journal of Scientific & Engineering Research,* vol. 7, 2016.

[16] C.-T. Su and C.-S. Lee, "Feeder reconfiguration and capacitor setting for loss reduction of distribution systems," *Electric power systems research,* vol. 58, pp. 97-102, 2001.

[17] M. Baran and F. F. Wu, "Optimal sizing of capacitors placed on a radial distribution system," *IEEE Transactions on power Delivery,* vol. 4, pp. 735-743, 1989.

[18] M. E. Baran and F. F. Wu, "Optimal capacitor placement on radial distribution systems," *IEEE Transactions on power Delivery,* vol. 4, pp. 725-734, 1989.

[19] M. Haque, "Capacitor placement in radial distribution systems for loss reduction," *IEE Proceedings-Generation, Transmission and Distribution,* vol. 146, pp. 501-505, 1999.

[20] K. Devabalaji, A. M. Imran, T. Yuvaraj, and K. Ravi, "Power loss minimization in radial distribution system," *Energy Procedia,* vol. 79, pp. 917-923, 2015.

[21] Y.-C. Huang, H.-T. Yang, and C.-L. Huang, "Solving the capacitor placement problem in a radial distribution system using tabu search approach," *IEEE Transactions on power Systems,* vol. 11, pp. 1868-1873, 1996.

[22] S. Sundhararajan and A. Pahwa, "Optimal selection of capacitors for radial distribution systems using a genetic algorithm," *IEEE Transactions on Power Systems,* vol. 9, pp. 1499-1507, 1994.

[23] R. A. Gallego, A. J. Monticelli, and R. Romero, "Optimal capacitor placement in radial distribution networks," *IEEE Transactions on Power Systems,* vol. 16, pp. 630-637, 2001.

[24] J.-Y. Fan, L. Zhang, and J. D. McDonald, "Distribution network reconfiguration: single loop optimization," *IEEE transactions on Power Systems,* vol. 11, pp. 1643-1647, 1996.

[25] S. K. Goswami and S. K. Basu, "A new algorithm for the reconfiguration of distribution feeders for loss minimization," *IEEE Transactions on Power Delivery,* vol. 7, pp. 1484-1491, 1992.

[26] C. H. Antunes, D. F. Pires, C. Barrico, Á. Gomes, and A. G. Martins, "A multi-objective evolutionary algorithm for reactive power compensation in distribution networks," *Applied Energy,* vol. 86, pp. 977-984, 2009.

[27] R. S. Rao, S. Narasimham, and M. Ramalingaraju, "Optimal capacitor placement in a radial distribution system using plant growth simulation algorithm," *International journal of electrical power & energy systems,* vol. 33, pp. 1133-1139, 2011.

[28] T. Ghose and S. Goswami, "Effects of unbalances and harmonics on optimal capacitor placement in distribution system," *Electric Power Systems Research,* vol. 68, pp. 167-173, 2004.

[29] K. R. Devabalaji, K. Ravi, and D. Kothari, "Optimal location and sizing of capacitor placement in radial distribution system using bacterial foraging optimization algorithm," *International Journal of Electrical Power & Energy Systems,* vol. 71, pp. 383-390, 2015.

[30] T. Hariharan, S. Raja, and S. Hareesh, "Real Power Loss Minimization using Fuzzy logic Controller," *International Journal of Emerging Trends in Electrical and Electronics (IJETEE-ISSN: 2320-9569),* vol. 6, pp. 46-49, 2013.

[31] C. Rambabu, Y. Cbulesu, and C. Saibabu, "Improvement of voltage profile and reduce power system losses by using multi type facts devices," *International Journal of Computer Application,* vol. 13, 2011.

[32] F. Galiana, K. Almeida, M. Toussaint, J. Griffin, D. Atanackovic, B. Ooi, *et al.*, "Assessment and control of the impact of FACTS devices on power system performance," *IEEE Transactions on power systems,* vol. 11, pp. 1931-1936, 1996.

[33] S.-H. Song, J.-U. Lim, and S.-I. Moon, "FACTS operation scheme for enhancement of power system security," in *2003 IEEE Bologna Power Tech Conference Proceedings,* 2003, pp. 36-41.

[34] M. Ghiasi and J. Olamaei, "Optimal capacitor placement to minimizing cost and power loss in Tehran metro power distribution system using ETAP (A case study)," *Complexity,* vol. 21, pp. 483-493, 2016.

[35] M. Tahir, B. A. Bakar, M. Alam, and M. Mazlihum, "Optimal capacitor placement in a distribution system using ETAP software," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS),* vol. 15, pp. 650-660, 2019.

[36] S. Neelima and P. Subramanyam, "OPTIMAL CAPACITORS PLACEMENT IN DISTRIBUTION NETWORKS USING GENETIC ALGORITHM: A DIMENSION REDUCING APPROACH," *Journal of Theoretical & Applied Information Technology,* vol. 30, 2011.

[37] P. Sarkar, S. Chatterjee, and S. Ray, "Optimal placement of capacitor for voltage support and minimizing overall cost in radial distribution system," *International Journal of Computer Applications,* vol. 65, 2013.

[38] A. G. Sayed and H. K. Youssef, "Optimal sizing of fixed capacitor banks placed on a distorted interconnected distribution networks by genetic algorithms," in *2008 IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering*, 2008, pp. 180-185.

[39] M. Pranitha and K. V. Chandrakala, "Optimal capacitor placement based improved reliability assessment of a distribution system," in *2017 International Conference on Intelligent Computing and Control (I2C2)*, 2017, pp. 1-6.

[40] C. B. Ferreira and D. Gebbran, "Simulation and Analysis of Reactive Power Compensation Methods in Presence of Solar Distributed Generation and Development of Optimal Capacitor Placement and Sizing," UC Irvine, 2017.

[41] A. Kumar and R. Bhatia, "Optimal capacitor placement in radial distribution system," in *2014 IEEE 6th India International Conference on Power Electronics (IICPE),* 2014, pp. 1-6.

[42] D. Watpade and P. Sonwane, "Optimal capacitor placement for ieee 14 bus system using genetic algorithm," *Int. J. Innov. Res. Adv. Eng,* vol. 3, pp. 43-53, 2016.

[43] L. D. Chambers, *Practical Handbook of Genetic Algorithms: Complex Coding Systems, Volume III* vol. 3: CRC press, 2019.

[44] C. Jones, "Deliverable 3.4. 3 “Report on the Carbon Impact Implications of the Smart Street Method at ENWL and Great Britain Scale”," 2018.

[45] E. D. Ruano Vega, "Ubicación óptima de un banco de capacitores, basado en algoritmos de lógica difusa," 2017.

[46] I. Roytelman and V. Ganesan, "Modeling of local controllers in distribution network applications," *IEEE transactions on power delivery,* vol. 15, pp. 1232-1237, 2000.

[47] D. Coury, C. Dos Santos, and M. Tavares, "Transient analysis resulting from shunt capacitor switching in an actual electrical distribution system," in *8th*

International Conference on Harmonics and Quality of Power. Proceedings (Cat. No. 98EX227), 1998, pp. 292-297.

[48] P. E. Engineer, A. Chee, P. Engineer, and M. Manjarekar, "Implementation of a Switched Capacitor Control Scheme using User-Defined Dynamic Load Models."

[49] C. Roberts, A. Scaglione, M. Jamei, R. Gentz, S. Peisert, E. M. Stewart, *et al.*, "Learning behavior of distribution system discrete control devices for cyber-physical security," *IEEE Transactions on Smart Grid,* vol. 11, pp. 749-761, 2019.

[50] M. El-Moursi and A. Sharaf, "Novel reactive power controllers for the STATCOM and SSSC," *Electric Power Systems Research,* vol. 76, pp. 228-241, 2006.

[51] J. M. Ramirez and M. E. Torres, "An electronic load controller for self-excited induction generators," in *2007 IEEE Power Engineering Society General Meeting*, 2007, pp. 1-8.

[52] D. E. Goldberg, "Genetic algorithms in search," *Optimization, and MachineLearning,* 1989.

Appendix: A Branch Connection

Branch Connections

CKT/Branch		Connected Bus ID		% Impedance, Pos. Seq., 100 MVA Base			
ID	Type	From Bus	To Bus	R	X	Z	Y
T1	2W XFMR	Bus1	Bus2	2.00	39.95	40.00	
T2	2W XFMR	Bus4	Bus8	887.52	1331.28	1600.00	
T5	2W XFMR	Bus11	Bus17	1386.75	2080.13	2500.00	
T6	2W XFMR	Bus13	Bus18	2218.80	3328.20	4000.00	
T7	2W XFMR	Bus15	Bus19	887.52	1331.28	1600.00	
T8	2W XFMR	Bus20	bus16	887.52	1331.28	1600.00	
T9	2W XFMR	Bus3	Bus22	887.52	1331.28	1600.00	
T10	2W XFMR	Bus5	Bus25	887.52	1331.28	1600.00	
t11	2W XFMR	Bus21	bus40	887.52	1331.28	1600.00	
t12	2W XFMR	Bus23	bus39	887.52	1331.28	1600.00	
t13	2W XFMR	bus32	bus6	1386.75	2080.13	2500.00	
t14	2W XFMR	bus30	bus10	2218.80	3328.20	4000.00	
t15	2W XFMR	bus27	bus28	887.52	1331.28	1600.00	
t16	2W XFMR	bus26	bus24	887.52	1331.28	1600.00	
T17	2W XFMR	bus36	bus35	887.52	1331.28	1600.00	
T18	2W XFMR	bus37	bus38	887.52	1331.28	1600.00	
Line1	Line	Bus2	Bus3	190.05	264.40	325.62	0.0183789
Line2	Line	Bus3	Bus4	137.26	190.96	235.17	0.0132737
Line3	Line	Bus4	Bus5	147.82	205.64	253.26	0.0142947
line4	Line	bus36	bus37	126.70	176.27	217.08	0.0122526
Line6	Line	Bus2	Bus11	158.37	274.13	316.59	0.0095390
Line7	Line	Bus11	Bus12	158.37	220.33	271.35	0.0153158
Line8	Line	Bus12	Bus13	158.37	220.33	271.35	0.0153158
Line9	Line	Bus13	Bus14	158.37	220.33	271.35	0.0153158
Line10	Line	Bus14	Bus15	158.37	220.33	271.35	0.0153158
Line11	Line	Bus15	Bus20	158.37	220.33	271.35	0.0153158
Line12	Line	Bus2	Bus21	126.70	176.27	217.08	0.0122526
Line13	Line	Bus21	Bus23	126.70	176.27	217.08	0.0122526
line14	Line	bus34	bus36	137.26	190.96	235.17	0.0132737
line15	Line	bus33	bus34	126.70	176.27	217.08	0.0122526
line16	Line	bus7	bus33	126.70	176.27	217.08	0.0122526
line17	Line	bus31	bus7	126.70	176.27	217.08	0.0122526
line18	Line	Bus2	bus32	116.14	201.03	232.17	0.0069953
line19	Line	bus32	bus9	158.37	220.33	271.35	0.0095390
line20	Line	bus9	bus30	158.37	220.33	271.35	0.0095390
line21	Line	bus30	bus29	52.79	73.44	90.45	0.0031797

CKT/Branch		**Connected Bus ID**		**% Impedance, Pos. Seq., 100 MVA Base**			
ID	Type	From Bus	To Bus	R	X	Z	Y
line22	Line	bus29	bus27	158.37	220.33	271.35	0.0095390
line23	Line	bus27	bus26	158.37	220.33	271.35	0.0095390
Line24	Line	Bus2	bus31	126.70	176.27	217.08	0.0122526

Appendix: A Bus Input Data

Bus Input Data

Bus			Initial Voltage		Load							
					Constant kVA		Constant Z		Constant I		Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
Bus1	132.000	1	100.0	0.0								
Bus2	15.000	1	100.0	0.0								
Bus3	15.000	1	100.0	0.0								
Bus4	15.000	1	100.0	0.0								
Bus5	15.000	1	100.0	0.0								
bus6	0.400	1	100.0	0.0	0.066	0.041	0.066	0.041				
bus7	15.000	1	100.0	0.0								
Bus8	0.400	1	100.0	0.0	0.107	0.066	0.107	0.066				
bus9	15.000	1	100.0	0.0								
bus10	0.400	1	100.0	0.0	0.038	0.024	0.038	0.024				
Bus11	15.000	1	100.0	0.0								
Bus12	15.000	1	100.0	0.0								
Bus13	15.000	1	100.0	0.0								
Bus14	15.000	1	100.0	0.0								
Bus15	15.000	1	100.0	0.0								
bus16	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
Bus17	0.400	1	100.0	0.0	0.066	0.041	0.066	0.041				
Bus18	0.400	1	100.0	0.0	0.038	0.024	0.038	0.024				
Bus19	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
Bus20	15.000	1	100.0	0.0								
Bus21	15.000	1	100.0	0.0								
Bus22	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
Bus23	15.000	1	100.0	0.0								
bus24	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
Bus25	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
bus26	15.000	1	100.0	0.0								
bus27	15.000	1	100.0	0.0								
bus28	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
bus29	15.000	1	100.0	0.0								
bus30	15.000	1	100.0	0.0								
bus31	15.000	1	100.0	0.0								
bus32	15.000	1	100.0	0.0								
bus33	15.000	1	100.0	0.0								

Bus			**Initial Voltage**		**Load**							
					Constant kVA		Constant Z		Constant I		Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
bus34	15.000	1	100.0	0.0								
bus35	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
bus36	15.000	1	100.0	0.0								
				34.4	800.0	0.0	1	75	0.237560	0.330500	0.0000045	
bus37	15.000	1	100.0	0.0								
bus38	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
bus39	0.400	1	100.0	0.0	0.085	0.053	0.085	0.053				
bus40	0.400	1	100.0	0.0	0.085	0.053	0.085					

Appendix: C Cable Input Data

Line/Cable Input Data

Ohms per Conductor (Cable) or per Phase (Line)

	Line/Cable				Length						
ID	ID	MVA	Library	Size	Adj. (m)	% Tol.	#/Phase	T (°C)	R	X	Y
Line1				34.4	800.0	0.0	1	75	0.237560	0.330500	0.0000045
Line2				34.4	300.0	0.0	1	75	0.237560	0.330500	0.0000045
Line3				34.4	400.0	0.0	1	75	0.237560	0.330500	0.0000045
line4				34.4	200.0	0.0	1	75	0.237560	0.330500	0.0000045
Line6				34.4	500.0	0.0	1	75	0.237560	0.411200	0.0000028
Line7				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000045
Line8				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000045
Line9				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000045
Line10				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000045
Line11				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000045
Line12				34.4	200.0	0.0	1	75	0.237560	0.330500	0.0000045
Line13				34.4	200.0	0.0	1	75	0.237560	0.330500	0.0000045
line14				34.4	300.0	0.0	1	75	0.237560	0.330500	0.0000045
line15				34.4	200.0	0.0	1	75	0.237560	0.330500	0.0000045
line16				34.4	200.0	0.0	1	75	0.237560	0.330500	0.0000045
line17				34.4	200.0	0.0	1	75	0.237560	0.330500	0.0000045
line18				34.4	100.0	0.0	1	75	0.237560	0.411200	0.0000028
line19				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000028
line20				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000028
line21				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000028
line22				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000028
line23				34.4	500.0	0.0	1	75	0.237560	0.330500	0.0000028
Line24				34.4	200.0	0.0	1	75	0.237560	0.330500	0.0000045

Line / Cable resistances are listed at the specified temperatures.

Appendix: D Transformer Input Data

2-Winding Transformer Input Data

Transformer		Rating					Z Variation			% Tap Setting		Adjusted	Phase Shift	
ID	Phase	MVA	Prim. kV	Sec. kV	% Z1	X1/R1	+ 5%	- 5%	% Tol.	Prim.	Sec.	% Z	Type	Angle
T1	3-Phase	25.000	132.000	15.000	10.00	20.00	0	0	0	0	0	10.0000	Dyn	0.000
T2	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T5	3-Phase	0.160	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T6	3-Phase	0.100	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T7	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T8	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T9	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T10	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
t11	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
t12	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
t13	3-Phase	0.160	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
t14	3-Phase	0.100	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
t15	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
t16	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T17	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000
T18	3-Phase	0.250	15.000	0.400	4.00	1.50	0	0	0	0	0	4.0000	Dyn	0.000

Appendix: E Load Flow

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
* Bus1	132.000	100.000	0.0	2.282	1.272	0	0	Bus2	2.282	1.272	11.4	87.3	
Bus2	15.000	99.450	-0.5	0	0	0	0	Bus3	0.542	0.312	24.2	86.7	
								Bus11	0.535	0.279	23.4	88.6	
								Bus21	0.335	0.192	14.9	86.8	
								bus32	0.536	0.312	24.0	86.4	
								bus31	0.333	0.149	14.1	81.2	
								Bus1	-2.280	-1.244	100.5	87.8	
Bus3	15.000	97.563	-1.0	0	0	0	0	Bus2	-0.535	-0.319	24.6	85.9	
								Bus4	0.370	0.214	16.9	86.6	
								Bus22	0.165	0.105	7.7	84.3	
Bus4	15.000	96.612	-1.2	0	0	0	0	Bus3	-0.367	-0.223	17.1	85.5	
								Bus5	0.163	0.091	7.4	87.2	
								Bus8	0.204	0.132	9.7	84.1	
Bus5	15.000	96.154	-1.4	0	0	0	0	Bus4	-0.162	-0.104	7.7	84.3	
								Bus25	0.162	0.104	7.7	84.3	
bus6	0.400	94.646	-1.9	0	0	0.125	0.077	bus32	-0.125	-0.077	224.1	85.0	
bus7	15.000	98.033	-1.0	0	0	0	0	bus33	0.329	0.168	14.5	89.0	
								bus31	-0.329	-0.168	14.5	89.0	
Bus8	0.400	92.934	-2.2	0	0	0.199	0.123	Bus4	-0.199	-0.123	363.3	85.0	
bus9	15.000	97.020	-1.2	0	0	0	0	bus32	-0.399	-0.232	18.3	86.4	
								bus30	0.399	0.232	18.3	86.4	
bus10	0.400	92.535	-2.4	0	0	0.071	0.044	bus30	-0.071	-0.044	130.3	85.0	
Bus11	15.000	97.821	-1.1	0	0	0	0	Bus2	-0.529	-0.279	23.5	88.5	
								Bus12	0.401	0.196	17.6	89.8	
								Bus17	0.128	0.082	6.0	84.1	
Bus12	15.000	96.714	-1.4	0	0	0	0	Bus11	-0.398	-0.206	17.8	88.8	
								Bus13	0.398	0.206	17.8	88.8	
Bus13	15.000	95.578	-1.8	0	0	0	0	Bus12	-0.394	-0.216	18.1	87.7	
								Bus14	0.322	0.169	14.6	88.5	
								Bus18	0.073	0.047	3.5	84.2	
Bus14	15.000	94.640	-2.1	0	0	0	0	Bus13	-0.319	-0.180	14.9	87.2	
								Bus15	0.319	0.180	14.9	87.2	
Bus15	15.000	93.672	-2.3	0	0	0	0	Bus14	-0.317	-0.190	15.2	85.8	
								Bus20	0.158	0.088	7.5	87.3	
								Bus19	0.159	0.101	7.7	84.2	
bus16	0.400	90.244	-3.3	0	0	0.154	0.096	Bus20	-0.154	-0.096	290.2	85.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bus17	0.400	94.276	-2.1	0	0	0.124	0.077	Bus11	-0.124	-0.077	224.1	85.0	
Bus18	0.400	92.280	-2.7	0	0	0.071	0.044	Bus13	-0.071	-0.044	130.3	85.0	
Bus19	0.400	90.737	-3.1	0	0	0.155	0.096	Bus15	-0.155	-0.096	290.0	85.0	
Bus20	15.000	93.180	-2.4	0	0	0	0	Bus15	-0.158	-0.101	7.7	84.2	
								bus16	0.158	0.101	7.7	84.2	
Bus21	15.000	98.674	-0.7	0	0	0	0	Bus2	-0.333	-0.201	15.2	85.6	
								Bus23	0.166	0.095	7.5	86.9	
								bus40	0.166	0.106	7.7	84.3	
Bus22	0.400	94.638	-1.8	0	0	0.161	0.100	Bus3	-0.161	-0.100	289.1	85.0	
Bus23	15.000	98.281	-0.8	0	0	0	0	Bus21	-0.166	-0.106	7.7	84.3	
								bus39	0.166	0.106	7.7	84.3	
bus24	0.400	91.093	-2.8	0	0	0.156	0.096	bus26	-0.156	-0.096	289.9	85.0	
Bus25	0.400	93.226	-2.2	0	0	0.159	0.098	Bus5	-0.159	-0.098	289.4	85.0	
bus26	15.000	94.026	-2.0	0	0	0	0	bus27	-0.159	-0.102	7.7	84.2	
								bus24	0.159	0.102	7.7	84.2	
bus27	15.000	94.523	-1.9	0	0	0	0	bus29	-0.320	-0.196	15.3	85.2	
								bus26	0.160	0.094	7.6	86.1	
								bus28	0.160	0.102	7.7	84.2	
bus28	0.400	91.591	-2.7	0	0	0.156	0.097	bus27	-0.156	-0.097	289.8	85.0	
bus29	15.000	95.508	-1.6	0	0	0	0	bus30	-0.322	-0.191	15.1	86.0	
								bus27	0.322	0.191	15.1	86.0	
bus30	15.000	95.832	-1.6	0	0	0	0	bus9	-0.396	-0.236	18.5	85.9	
								bus29	0.323	0.189	15.0	86.3	
								bus10	0.073	0.047	3.5	84.2	
bus31	15.000	98.752	-0.7	0	0	0	0	bus7	0.331	0.159	14.3	90.1	
								Bus2	-0.331	-0.159	14.3	90.1	
bus32	15.000	98.191	-0.9	0	0	0	0	Bus2	-0.531	-0.311	24.1	86.3	
								bus9	0.403	0.228	18.1	87.0	
								bus6	0.128	0.082	6.0	84.1	
bus33	15.000	97.295	-1.2	0	0	0	0	bus34	0.327	0.178	14.7	87.9	
								bus7	-0.327	-0.178	14.7	87.9	
bus34	15.000	96.537	-1.4	0	0	0	0	bus36	0.325	0.187	15.0	86.8	
								bus33	-0.325	-0.187	15.0	86.8	
bus35	0.400	92.765	-2.4	0	0	0.158	0.098	bus36	-0.158	-0.098	289.5	85.0	
bus36	15.000	95.694	-1.6	0	0	0	0	bus37	0.162	0.092	7.5	86.8	
								bus34	-0.323	-0.196	15.2	85.5	
								bus35	0.162	0.103	7.7	84.3	
bus37	15.000	95.299	-1.7	0	0	0	0	bus36	-0.161	-0.103	7.7	84.3	
								bus38	0.161	0.103	7.7	84.3	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
bus38	0.400	92.370	-2.5	0	0	0.158	0.098	bus37	-0.158	-0.098	289.6	85.0	
bus39	0.400	95.357	-1.6	0	0	0.162	0.101	Bus23	-0.162	-0.101	289.0	85.0	
bus40	0.400	95.751	-1.5	0	0	0.163	0.101	Bus21	-0.163	-0.101	288.9	85.0	

Appendix : F Alert Summary

Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

Critical Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
bus10	Bus	Under Voltage	0.400	kV	0.370	92.5	3-Phase
Bus14	Bus	Under Voltage	15.000	kV	14.20	94.6	3-Phase
Bus15	Bus	Under Voltage	15.000	kV	14.05	93.7	3-Phase
bus16	Bus	Under Voltage	0.400	kV	0.36	90.2	3-Phase
Bus17	Bus	Under Voltage	0.400	kV	0.38	94.3	3-Phase
Bus18	Bus	Under Voltage	0.400	kV	0.37	92.3	3-Phase
Bus19	Bus	Under Voltage	0.400	kV	0.36	90.7	3-Phase
Bus20	Bus	Under Voltage	15.000	kV	13.98	93.2	3-Phase
Bus22	Bus	Under Voltage	0.400	kV	0.38	94.6	3-Phase
bus24	Bus	Under Voltage	0.400	kV	0.36	91.1	3-Phase
Bus25	Bus	Under Voltage	0.400	kV	0.37	93.2	3-Phase
bus26	Bus	Under Voltage	15.000	kV	14.10	94.0	3-Phase
bus27	Bus	Under Voltage	15.000	kV	14.18	94.5	3-Phase
bus28	Bus	Under Voltage	0.400	kV	0.37	91.6	3-Phase
bus35	Bus	Under Voltage	0.400	kV	0.37	92.8	3-Phase

Critical Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
bus38	Bus	Under Voltage	0.400	kV	0.369	92.4	3-Phase
bus6	Bus	Under Voltage	0.400	kV	0.38	94.6	3-Phase
Bus8	Bus	Under Voltage	0.400	kV	0.37	92.9	3-Phase

Marginal Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus11	Bus	Under Voltage	15.000	kV	14.673	97.8	3-Phase
Bus12	Bus	Under Voltage	15.000	kV	14.51	96.7	3-Phase
Bus13	Bus	Under Voltage	15.000	kV	14.34	95.6	3-Phase
bus29	Bus	Under Voltage	15.000	kV	14.33	95.5	3-Phase
Bus3	Bus	Under Voltage	15.000	kV	14.63	97.6	3-Phase
bus30	Bus	Under Voltage	15.000	kV	14.37	95.8	3-Phase
bus33	Bus	Under Voltage	15.000	kV	14.59	97.3	3-Phase
bus34	Bus	Under Voltage	15.000	kV	14.48	96.5	3-Phase
bus36	Bus	Under Voltage	15.000	kV	14.35	95.7	3-Phase
bus37	Bus	Under Voltage	15.000	kV	14.29	95.3	3-Phase
bus39	Bus	Under Voltage	0.400	kV	0.38	95.4	3-Phase
Bus4	Bus	Under Voltage	15.000	kV	14.49	96.6	3-Phase
bus40	Bus	Under Voltage	0.400	kV	0.38	95.8	3-Phase
Bus5	Bus	Under Voltage	15.000	kV	14.42	96.2	3-Phase
bus9	Bus	Under Voltage	15.000	kV	14.55	97.0	3-Phase
t13	Transformer	Overload	0.160	MVA	0.15	95.3	3-Phase
T2	Transformer	Overload	0.250	MVA	0.24	97.3	3-Phase

Project:	**ETAP**	Page:	1
Location:	16.0.0C	Date:	15-09-2021
Contract:		SN:	4359168
Engineer:	Study Case: LF	Revision:	Base
Filename: tg 3		Config.:	Normal

Branch Losses Summary Report

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
T1	2.282	1.272	-2.280	-1.244	10.7	-27.3	100.0	99.5	0.55
Line1	0.542	0.312	-0.535	-0.319	16.9	-7.2	99.5	97.6	1.89
Line6	0.535	0.279	-0.529	-0.279	15.2	0.9	99.5	97.8	1.63
Line12	0.335	0.192	-0.333	-0.201	11.2	-9.3	99.5	98.7	0.78
line18	0.536	0.312	-0.531	-0.311	13.8	1.0	99.5	98.2	1.26
Line24	0.333	0.149	-0.331	-0.159	11.1	-19.6	99.5	98.8	0.70
Line2	0.370	0.214	-0.367	-0.223	12.1	-8.8	97.6	96.6	0.95
T9	0.165	0.105	-0.161	-0.100	12.9	5.3	97.6	94.6	2.92
Line3	0.163	0.091	-0.162	-0.104	9.9	-12.5	96.6	96.2	0.46
T2	0.204	0.132	-0.199	-0.123	14.9	-18.4	96.6	92.9	3.68
T10	0.162	0.104	-0.159	-0.098	12.9	5.4	96.2	93.2	2.93
t13	-0.125	-0.077	0.128	0.082	12.1	-15.0	94.6	98.2	3.54
line16	0.329	0.168	-0.327	-0.178	11.1	-9.1	98.0	97.3	0.74
line17	-0.329	-0.168	0.331	0.159	11.1	-9.4	98.0	98.8	0.72
line19	-0.399	-0.232	0.403	0.228	12.9	-14.1	97.0	98.2	1.17
line20	0.399	0.232	-0.396	-0.236	12.9	-13.8	97.0	95.8	1.19
t14	-0.071	-0.044	0.073	0.047	11.1	2.7	92.5	95.8	3.30
Line7	0.401	0.196	-0.398	-0.206	12.7	-19.8	97.8	96.7	1.11
T5	0.128	0.082	-0.124	-0.077	12.6	5.0	97.8	94.3	3.54
Line8	0.398	0.206	-0.394	-0.216	12.8	-19.4	96.7	95.6	1.14
Line9	0.322	0.169	-0.319	-0.180	11.9	-10.6	95.6	94.6	0.94
T6	0.073	0.047	-0.071	-0.044	11.1	2.7	95.6	92.3	3.30
Line10	0.319	0.180	-0.317	-0.190	9.7	-10.2	94.6	93.7	0.97
Line11	0.158	0.088	-0.158	-0.101	9.9	-12.5	93.7	93.2	0.49
T7	0.159	0.101	-0.155	-0.096	12.9	5.4	93.7	90.7	2.93
T8	-0.154	-0.096	0.158	0.101	12.9	5.4	90.2	93.2	2.94
Line13	0.166	0.095	-0.166	-0.106	9.8	-11.2	98.7	98.3	0.39
t11	0.166	0.106	-0.163	-0.101	12.9	5.3	98.7	95.8	2.92
t12	0.166	0.106	-0.162	-0.101	12.9	5.3	98.3	95.4	2.92
t16	-0.156	-0.096	0.159	0.102	12.9	5.4	91.1	94.0	2.93
line23	-0.159	-0.102	0.160	0.094	9.9	-17.6	94.0	94.5	0.50
line22	-0.320	-0.196	0.322	0.191	11.8	-15.2	94.5	95.5	0.98
t15	0.160	0.102	-0.156	-0.097	11.9	5.4	94.5	91.6	2.93
line21	-0.322	-0.191	0.323	0.189	10.1	-11.8	95.5	95.8	0.32
line15	0.327	0.178	-0.325	-0.187	10.9	-18.9	97.3	96.5	0.76

Branch ID	**From-To Bus Flow** MW	Mvar	**To-From Bus Flow** MW	Mvar	**Losses** kW	kvar	**% Bus Voltage** From	To	Vd % Drop in Vmag
line14	0.325	0.187	-0.323	-0.196	11.4	-19.3	96.5	95.7	0.84
T17	-0.158	-0.098	0.162	0.103	11.9	15.4	92.8	95.7	2.93
line4	0.162	0.092	-0.161	-0.103	9.8	-10.5	95.7	95.3	0.39
T18	0.161	0.103	-0.158	-0.098	12.6	15.4	95.3	92.4	2.93
					471.69	-157.3			

Appendix: G Bus constraints

Bus Constraints

	% Voltage		% PF	
Bus ID	Min.	Max.	Min.	Max.
Bus2	90	110	85	
Bus3	90	110	85	
Bus4	90	110	85	
Bus5	90	110	85	
Bus8	90	110	85	
Bus11	90	110	85	
Bus12	90	110	85	
Bus13	90	110	85	
Bus14	90	110	85	
Bus15	90	110	85	
Bus17	90	110	85	
Bus18	90	110	85	
Bus19	90	110	85	
Bus20	90	110	85	
bus16	90	110	85	
Bus21	90	110	85	
Bus22	90	110	85	
Bus23	90	110	85	
Bus25	90	110	85	
bus31	90	110	85	
bus7	90	110	85	
bus33	90	110	85	
bus34	90	110	85	
bus35	90	110	85	
bus36	90	110	85	
bus37	90	110	85	
bus38	90	110	85	
bus39	90	110	85	
bus40	90	110	85	
bus6	90	110	85	
bus32	90	110	85	
bus9	90	110	85	
bus10	90	110	85	
bus30	90	110	85	
bus29	90	110	85	

Bus ID	% Voltage		% PF	
	Min.	Max.	Min.	Max.
bus28	90	110	85	
bus27	90	110	85	
bus26	90	110	85	
bus24	90	110	85	
Global Constraints	90	110	90	

Allow Over Compensation for PF Correction: Yes

Appendix: H Average Load Flow

AVERAGE LOADING-LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
* Bus1	132.000	100.000	0.0	2.297	0.909	0	0	Bus2	2.297	0.909	10.8	93.0	
Bus2	15.000	99.595	-0.5	0	0	0	0	Bus3	0.543	0.313	24.2	86.7	
								Bus11	0.542	0.100	21.3	98.3	
								Bus21	0.335	0.192	14.9	86.8	
								bus32	0.542	0.131	21.5	97.2	
								bus31	0.333	0.150	14.1	91.2	
								Bus1	-2.296	-0.885	95.1	93.3	
Bus3	15.000	97.708	-1.0	0	0	0	0	Bus2	-0.536	-0.320	24.6	85.9	
								Bus4	0.371	0.214	16.9	86.6	
								Bus22	0.165	0.105	7.7	84.3	
Bus4	15.000	96.757	-1.2	0	0	0	0	Bus3	-0.368	-0.223	17.1	85.5	
								Bus5	0.163	0.091	7.4	87.2	
								Bus8	0.205	0.132	9.7	84.1	
Bus5	15.000	96.299	-1.4	0	0	0	0	Bus4	-0.163	-0.104	7.7	84.3	
								Bus25	0.163	0.104	7.7	84.3	
bus6	0.400	95.154	-2.0	0	0	0.126	0.078	bus32	-0.126	-0.078	224.0	85.0	
bus7	15.000	98.178	-1.0	0	0	0	0	bus33	0.330	0.169	14.5	89.0	
								bus31	-0.330	-0.169	14.5	89.0	
Bus8	0.400	93.079	-2.2	0	0	0.199	0.123	Bus4	-0.199	-0.123	363.2	85.0	
bus9	15.000	97.925	-1.5	0	0	0	0	bus32	-0.407	-0.054	16.1	99.1	
								bus30	0.407	0.054	16.1	99.1	
bus10	0.400	93.846	-2.9	0	0	0.072	0.045	bus30	-0.072	-0.045	130.2	85.0	
Bus11	15.000	98.454	-1.3	0	0	0	0	Bus2	-0.537	-0.101	21.4	98.3	
								Bus12	0.409	0.018	16.0	99.9	
								Bus17	0.129	0.083	6.0	84.1	
Bus12	15.000	97.743	-1.8	0	0	0	0	Bus11	-0.406	-0.029	16.0	99.7	
								Bus13	0.406	0.029	16.0	99.7	
Bus13	15.000	97.006	-2.3	0	0	0	0	Bus12	-0.403	-0.040	16.1	99.5	
								Bus14	0.330	-0.007	13.1	-100.0	
								Bus18	0.074	0.047	3.5	84.2	
Bus14	15.000	96.471	-2.8	0	0	0	0	Bus13	-0.328	-0.004	13.1	100.0	
								Bus15	0.328	0.004	13.1	100.0	
Bus15	15.000	95.910	-3.2	0	0	0	0	Bus14	-0.326	-0.016	13.1	99.9	
								Bus20	0.163	0.001	6.5	100.0	
								Bus19	0.163	0.015	6.6	99.6	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
bus16	0.400	93.931	-4.7	0	0	0.160	0.011	Bus20	-0.160	-0.011	246.4	99.8	
Bus17	0.400	94.910	-2.2	0	0	0.125	0.078	Bus11	-0.125	-0.078	224.0	85.0	
Bus18	0.400	93.713	-3.2	0	0	0.072	0.045	Bus13	-0.072	-0.045	130.2	85.0	
Bus19	0.400	94.223	-4.5	0	0	0.160	0.011	Bus15	-0.160	-0.011	246.4	99.8	
Bus20	15.000	95.622	-3.4	0	0	0	0	Bus15	-0.163	-0.015	6.6	99.6	
								bus16	0.163	0.015	6.6	99.6	
Bus21	15.000	98.819	-0.7	0	0	0	0	Bus2	-0.333	-0.201	15.2	85.6	
								Bus23	0.167	0.095	7.5	86.9	
								bus40	0.167	0.106	7.7	84.3	
Bus22	0.400	94.784	-1.8	0	0	0.161	0.100	Bus3	-0.161	-0.100	289.1	85.0	
Bus23	15.000	98.426	-0.8	0	0	0	0	Bus21	-0.166	-0.106	7.7	84.3	
								bus39	0.166	0.106	7.7	84.3	
bus24	0.400	94.396	-4.1	0	0	0.161	0.011	bus26	-0.161	-0.011	246.3	99.8	
Bus25	0.400	93.372	-2.2	0	0	0.159	0.099	Bus5	-0.159	-0.099	289.4	85.0	
bus26	15.000	96.080	-2.8	0	0	0	0	bus27	-0.163	-0.014	6.6	99.6	
								bus24	0.163	0.014	6.6	99.6	
bus27	15.000	96.373	-2.6	0	0	0	0	bus29	-0.328	-0.020	13.1	99.8	
								bus26	0.164	0.006	6.5	99.9	
								bus28	0.164	0.014	6.6	99.6	
bus28	0.400	94.693	-3.9	0	0	0.161	0.010	bus27	-0.161	-0.010	246.2	99.8	
bus29	15.000	96.950	-2.2	0	0	0	0	bus30	-0.329	-0.014	13.1	99.9	
								bus27	0.329	0.014	13.1	99.9	
bus30	15.000	97.139	-2.0	0	0	0	0	bus9	-0.404	-0.059	16.2	98.9	
								bus29	0.330	0.012	13.1	99.9	
								bus10	0.074	0.047	3.5	84.2	
bus31	15.000	98.897	-0.7	0	0	0	0	bus7	0.331	0.159	14.3	90.1	
								Bus2	-0.331	-0.159	14.3	90.1	
bus32	15.000	98.697	-1.1	0	0	0	0	Bus2	-0.538	-0.131	21.6	97.1	
								bus9	0.409	0.049	16.1	99.3	
								bus6	0.129	0.083	6.0	84.1	
bus33	15.000	97.440	-1.2	0	0	0	0	bus34	0.328	0.178	14.7	87.9	
								bus7	-0.328	-0.178	14.7	87.9	
bus34	15.000	96.683	-1.4	0	0	0	0	bus36	0.326	0.187	15.0	86.8	
								bus33	-0.326	-0.187	15.0	86.8	
bus35	0.400	92.911	-2.4	0	0	0.158	0.098	bus36	-0.158	-0.098	289.5	85.0	
bus36	15.000	95.840	-1.6	0	0	0	0	bus37	0.162	0.093	7.5	86.8	
								bus34	-0.324	-0.196	15.2	85.5	

	Voltage			Generation		Load		Load Flow					XFMR
	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
								bus35	0.162	0.104	7.7	84.3	
bus37	15.000	95.445	-1.7	0	0	0	0	bus36	-0.161	-0.103	7.7	84.3	
	132.000	100.000	0.0	2.852	1.342	0	0	bus38	0.161	0.103	7.7	84.3	
bus38	0.400	92.516	-2.5	0	0	0.158	0.098	bus37	-0.158	-0.098	289.5	85.0	
bus39	0.400	95.502	-1.6	0	0	0.163	0.101	Bus23	-0.163	-0.101	289.0	85.0	
bus40	0.400	95.896	-1.5	0	0	0.163	0.101	Bus21	-0.163	-0.101	288.9	85.0	
								bus32	0.672	0.233	27.5	94.5	
								bus31	0.414	0.209	18.0		
								Bus1	-2.850	-1.302	121.3	91.0	

Appendix: I Maximum Load Flow

MAXIMUM LOADING-LOAD FLOW REPORT

Bus		**Voltage**		**Generation**		**Load**		**Load Flow**					**XFMR**
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
* Bus1	132.000	100.000	0.0	2.852	1.342	0	0	Bus2	2.852	1.342	13.8	90.5	
Bus2	15.000	99.413	-0.6	0	0	0	0	Bus3	0.676	0.407	30.5	85.7	
								Bus11	0.671	0.206	27.2	95.6	
								Bus21	0.417	0.248	18.8	86.0	
								bus32	0.672	0.233	27.5	94.5	
								bus31	0.414	0.209	18.0	89.3	
								Bus1	-2.850	-1.302	121.3	91.0	
Bus3	15.000	97.021	-1.2	0	0	0	0	Bus2	-0.664	-0.407	30.9	85.2	
								Bus4	0.459	0.276	21.2	85.7	
								Bus22	0.204	0.132	9.6	84.1	
Bus4	15.000	95.818	-1.5	0	0	0	0	Bus3	-0.455	-0.282	21.5	85.0	
								Bus5	0.202	0.118	9.4	86.4	
								Bus8	0.253	0.165	12.1	83.8	
Bus5	15.000	95.240	-1.7	0	0	0	0	Bus4	-0.201	-0.129	9.7	84.1	
								Bus25	0.201	0.129	9.7	84.1	
bus6	0.400	93.719	-2.4	0	0	0.155	0.096	bus32	-0.155	-0.096	280.2	85.0	
bus7	15.000	97.578	-1.2	0	0	0	0	bus33	0.408	0.225	18.4	87.6	
								bus31	-0.408	-0.225	18.4	87.6	
Bus8	0.400	91.209	-2.8	0	0	0.244	0.151	Bus4	-0.244	-0.151	454.8	85.0	
bus9	15.000	97.051	-1.8	0	0	0	0	bus32	-0.501	-0.129	20.5	96.9	
								bus30	0.501	0.129	20.5	96.9	
bus10	0.400	91.807	-3.5	0	0	0.088	0.055	bus30	-0.088	-0.055	163.0	85.0	
Bus11	15.000	97.776	-1.5	0	0	0	0	Bus2	-0.664	-0.201	27.3	95.7	
								Bus12	0.504	0.098	20.2	98.2	
								Bus17	0.159	0.103	7.5	83.9	
Bus12	15.000	96.727	-2.1	0	0	0	0	Bus11	-0.500	-0.106	20.3	97.8	
								Bus13	0.500	0.106	20.3	97.8	
Bus13	15.000	95.655	-2.7	0	0	0	0	Bus12	-0.495	-0.114	20.5	97.4	
								Bus14	0.405	0.055	16.4	99.1	
								Bus18	0.091	0.059	4.3	84.0	
Bus14	15.000	94.845	-3.2	0	0	0	0	Bus13	-0.402	-0.065	16.5	98.7	
								Bus15	0.402	0.065	16.5	98.7	
Bus15	15.000	94.010	-3.7	0	0	0	0	Bus14	-0.399	-0.075	16.6	98.3	
								Bus20	0.199	0.031	8.3	98.8	
								Bus19	0.199	0.044	8.4	97.7	
bus16	0.400	91.111	-5.4	0	0	0.194	0.037	Bus20	-0.194	-0.037	313.7	98.2	
Bus17	0.400	93.337	-2.7	0	0	0.154	0.095	Bus11	-0.154	-0.095	280.3	85.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
Bus18	0.400	91.527	-3.8	0	0	0.088	0.054	Bus13	-0.088	-0.054	163.0	85.0	
Bus19	0.400	91.542	-5.2	0	0	0.195	0.037	Bus15	-0.195	-0.037	313.5	98.2	
Bus20	15.000	93.586	-3.9	0	0	0	0	Bus15	-0.199	-0.044	8.4	97.7	
								bus16	0.199	0.044	8.4	97.7	
Bus21	15.000	98.433	-0.9	0	0	0	0	Bus2	-0.414	-0.255	19.0	85.1	
								Bus23	0.207	0.122	9.4	86.2	
								bus40	0.207	0.133	9.6	84.1	
Bus22	0.400	93.359	-2.2	0	0	0.199	0.123	Bus3	-0.199	-0.123	361.7	85.0	
Bus23	15.000	97.937	-1.0	0	0	0	0	Bus21	-0.206	-0.133	9.6	84.1	
								bus39	0.206	0.133	9.6	84.1	
bus24	0.400	91.918	-4.8	0	0	0.196	0.037	bus26	-0.196	-0.037	313.2	98.3	
Bus25	0.400	91.572	-2.7	0	0	0.195	0.121	Bus5	-0.195	-0.121	362.2	85.0	
bus26	15.000	94.379	-3.3	0	0	0	0	bus27	-0.200	-0.043	8.4	97.7	
								bus24	0.200	0.043	8.4	97.7	
bus27	15.000	94.807	-3.0	0	0	0	0	bus29	-0.402	-0.079	16.6	98.1	
								bus26	0.201	0.036	8.3	98.5	
								bus28	0.201	0.043	8.3	97.8	
bus28	0.400	92.353	-4.5	0	0	0.197	0.037	bus27	-0.197	-0.037	313.0	98.3	
bus29	15.000	95.655	-2.5	0	0	0	0	bus30	-0.405	-0.074	16.6	98.4	
								bus27	0.405	0.074	16.6	98.4	
bus30	15.000	95.934	-2.4	0	0	0	0	bus9	-0.497	-0.131	20.6	96.7	
								bus29	0.406	0.073	16.5	98.4	
								bus10	0.091	0.059	4.3	84.0	
bus31	15.000	98.505	-0.9	0	0	0	0	bus7	0.411	0.217	18.2	88.4	
								Bus2	-0.411	-0.217	18.2	88.4	
bus32	15.000	98.156	-1.3	0	0	0	0	Bus2	-0.666	-0.230	27.6	94.5	
								bus9	0.506	0.126	20.4	97.0	
								bus6	0.160	0.104	7.5	83.9	
bus33	15.000	96.632	-1.4	0	0	0	0	bus34	0.406	0.232	18.6	86.8	
								bus7	-0.406	-0.232	18.6	86.8	
bus34	15.000	95.666	-1.7	0	0	0	0	bus36	0.403	0.240	18.8	85.9	
								bus33	-0.403	-0.240	18.8	85.9	
bus35	0.400	90.929	-3.0	0	0	0.194	0.120	bus36	-0.194	-0.120	362.5	85.0	
bus36	15.000	94.600	-2.0	0	0	0	0	bus37	0.200	0.118	9.4	86.0	
								bus34	-0.399	-0.247	19.1	85.0	
								bus35	0.200	0.129	9.7	84.1	
bus37	15.000	94.102	-2.1	0	0	0	0	bus36	-0.199	-0.128	9.7	84.1	
								bus38	0.199	0.128	9.7	84.1	
bus38	0.400	90.429	-3.1	0	0	0.193	0.120	bus37	-0.193	-0.120	362.7	85.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
bus39	0.400	94.278	-2.0	0	0	0.201	0.124	Bus23	-0.201	-0.124	361.5	85.0	
bus40	0.400	94.774	-1.9	0	0	0.202	0.125	Bus21	-0.202	-0.125	361.4	85.0	

Project:	**ETAP**	Page:	1
Location:	16.0.0C	Date:	15-09-2021
Contract:		SN:	4359168
Engineer:	Study Case: OCP	Revision:	Base
		Config:	Normal

Appendix: J Minimum Load Flow

MINIMUM LOADING-LOAD FLOW REPORT

Bus		**Voltage**		**Generation**		**Load**		**Load Flow**					**XFMR**
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
* Bus1	132.000	100.000	0.0	1.849	0.572	0	0	Bus2	1.849	0.572	8.5	95.5	
Bus2	15.000	99.473	-0.6	0	0	0	0	Bus3	0.676	0.409	30.3	85.7	
								Bus11	0.678	0.006	26.9	99.9	
								Bus21	0.269	0.148	18.8	86.0	
								bus32	0.672	0.030	27.0	99.3	
								bus31	0.268	0.109	18.0	89.3	
								Bus1	-1.840	-0.507	174.3	95.0	
Bus3	15.000	98.021	-0.8	0	0	0	0	Bus2	-0.664	-0.407	30.9	86.3	
								Bus4	0.499	0.266	23.4	85.5	
								Bus22	0.204	0.084	9.8	84.4	
Bus4	15.000	95.808	-1.0	0	0	0	0	Bus3	-0.495	-0.286	23.6	86.0	
								Bus5	0.202	0.078	9.9	88.4	
								Bus8	0.263	0.106	12.7	83.8	
Bus5	15.000	95.240	-1.7	0	0	0	0	Bus4	-0.201	-0.089	9.7	84.4	
								Bus25	0.201	0.089	9.7	84.4	
bus6	0.400	96.799	-2.6	0	0	0.105	0.066	bus32	-0.105	-0.066	180.2	85.0	
bus7	15.000	98.658	-0.8	0	0	0	0	bus33	0.206	0.124	18.4	90.6	
								bus31	-0.206	-0.124	18.4	90.6	
Bus8	0.400	94.309	-2.8	0	0	0.264	0.160	Bus4	-0.264	-0.160	490.8	85.0	
bus9	15.000	98.055	-1.8	0	0	0	0	bus32	-0.309	-0.006	10.8	-100.0	
								bus30	0.309	-0.000	10.8	-100.0	
bus10	0.400	95.807	-3.5	0	0	0.088	0.036	bus30	-0.088	-0.036	164.0	85.0	
Bus11	15.000	98.986	-1.5	0	0	0	0	Bus2	-0.665	-0.001	26.9	99.9	
								Bus12	0.304	-0.098	20.0	-98.2	
								Bus17	0.109	0.068	4.8	83.9	
Bus12	15.000	96.525	-2.6	0	0	0	0	Bus11	-0.300	-0.006	20.9	-97.8	
								Bus13	0.300	-0.006	20.9	-97.8	
Bus13	15.000	98.054	-2.0	0	0	0	0	Bus12	-0.398	-0.020	20.9	-97.8	
								Bus14	0.208	-0.058	10.8	-97.7	
								Bus18	0.090	0.039	4.8	84.0	
Bus14	15.000	97.845	-3.2	0	0	0	0	Bus13	-0.202	-0.065	10.5	-98.6	
								Bus15	0.202	-0.065	10.5	-98.6	
Bus15	15.000	97.010	-3.8	0	0	0	0	Bus14	-0.390	-0.032	10.6	-98.3	
								Bus20	0.199	-0.031	8.3	-98.8	
								Bus19	0.199	-0.009	8.4	-97.8	
bus16	0.400	96.162	-4.4	0	0	0.194	-0.037	Bus20	-0.194	-0.037	393.2	-98.8	
Bus17	0.400	98.138	-2.8	0	0	0.104	0.063	Bus11	-0.104	-0.063	180.3	85.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
Bus18	0.400	95.443	-2.7	0	0	0.058	0.036	Bus13	-0.058	-0.036	104.0	85.0	
Bus19	0.400	96.345	-3.9	0	0	0.131	-0.012	Bus15	-0.131	0.012	197.2	-99.6	
Bus20	15.000	97.232	-3.0	0	0	0	0	Bus15	-0.133	0.009	5.3	-99.8	
								bus16	0.133	-0.009	5.3	-99.8	
Bus21	15.000	99.124	-0.6	0	0	0	0	Bus2	-0.268	-0.158	12.1	86.1	
								Bus23	0.134	0.073	5.9	87.7	
								bus40	0.134	0.085	6.2	84.4	
Bus22	0.400	95.915	-1.4	0	0	0.131	0.081	Bus3	-0.131	-0.081	231.1	85.0	
Bus23	15.000	98.812	-0.7	0	0	0	0	Bus21	-0.134	-0.085	6.2	84.4	
								bus39	0.134	0.085	6.2	84.4	
bus24	0.400	96.360	-3.6	0	0	0.131	-0.012	bus26	-0.131	0.012	197.2	-99.6	
Bus25	0.400	94.800	-1.7	0	0	0.129	0.080	Bus5	-0.129	-0.080	231.3	85.0	
bus26	15.000	97.426	-2.5	0	0	0	0	bus27	-0.133	0.009	5.3	-99.8	
								bus24	0.133	-0.009	5.3	-99.8	
bus27	15.000	97.612	-2.3	0	0	0	0	bus29	-0.266	0.027	10.5	-99.5	
								bus26	0.133	-0.018	5.3	-99.1	
								bus28	0.133	-0.009	5.3	-99.8	
bus28	0.400	96.548	-3.4	0	0	0.131	-0.012	bus27	-0.131	0.012	197.2	-99.6	
bus29	15.000	97.975	-1.9	0	0	0	0	bus30	-0.267	0.035	10.6	-99.2	
								bus27	0.267	-0.035	10.6	-99.2	
bus30	15.000	98.092	-1.8	0	0	0	0	bus9	-0.327	-0.001	12.8	100.0	
								bus29	0.268	-0.037	10.6	-99.1	
								bus10	0.060	0.038	2.8	84.4	
bus31	15.000	99.205	-0.6	0	0	0	0	bus7	0.267	0.114	11.2	92.0	
								Bus2	-0.267	-0.114	11.2	92.0	
bus32	15.000	99.123	-0.9	0	0	0	0	Bus2	-0.435	-0.053	17.0	99.3	
								bus9	0.331	-0.013	12.9	-99.9	
								bus6	0.104	0.066	4.8	84.3	
bus33	15.000	98.080	-1.0	0	0	0	0	bus34	0.264	0.134	11.6	89.2	
								bus7	-0.264	-0.134	11.6	89.2	
bus34	15.000	97.486	-1.1	0	0	0	0	bus36	0.263	0.144	11.9	87.7	
								bus33	-0.263	-0.144	11.9	87.7	
bus35	0.400	94.482	-2.0	0	0	0.129	0.080	bus36	-0.129	-0.080	231.3	85.0	
bus36	15.000	96.821	-1.3	0	0	0	0	bus37	0.131	0.072	5.9	87.6	
								bus34	-0.262	-0.155	12.1	86.0	
								bus35	0.131	0.083	6.2	84.4	
bus37	15.000	96.508	-1.4	0	0	0	0	bus36	-0.131	-0.083	6.2	84.4	
								bus38	0.131	0.083	6.2	84.4	
bus38	0.400	94.169	-2.0	0	0	0.128	0.080	bus37	-0.128	-0.080	231.4	85.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	% PF	% Tap
bus39	0.400	96.475	-1.3	0	0	0.131	0.081	Bus23	-0.131	-0.081	231.1	85.0	
bus40	0.400	96.788	-1.2	0		0.132	0.082	Bus21	-0.132	-0.082	231.1	85.0	

Appendix: K Max. Branch Loading

Branch Loading Summary Report (Max. Loading)

CKT / Branch		Cable & Reactor			Transformer				
						Loading (input)		Loading (output)	
ID	Type	Ampacity (Amp)	Loading Amp	%	Capability (MVA)	MVA	%	MVA	%
T1	Transformer				25.000	3.152	12.6	3.134	12.5
* T2	Transformer				0.250	0.302	120.8	0.287	115.0
* T5	Transformer				0.160	0.190	118.7	0.181	113.3
* T6	Transformer				0.100	0.108	108.0	0.103	103.4
T7	Transformer				0.250	0.204	81.7	0.199	79.5
T8	Transformer				0.250	0.203	81.4	0.198	79.2
T9	Transformer				0.250	0.243	97.3	0.234	93.6
T10	Transformer				0.250	0.239	95.6	0.230	91.9
t11	Transformer				0.250	0.246	98.6	0.237	94.9
t12	Transformer				0.250	0.245	98.1	0.236	94.4
* t13	Transformer				0.160	0.191	119.1	0.182	113.7
* t14	Transformer				0.100	0.108	108.3	0.104	103.7
t15	Transformer				0.250	0.206	82.2	0.200	80.1
t16	Transformer				0.250	0.205	81.9	0.199	79.8
T17	Transformer				0.250	0.238	95.0	0.228	91.3
T18	Transformer				0.250	0.236	94.6	0.227	90.9

* Indicates a branch with operating load exceeding the branch capability.

Bus Loading Summary Report (Max. Loading)

Appendix: L Max. Bus Loading

Bus			Bus Total Load					
ID	kV	Rated Amp	MW	Mvar	MVA	% PF	Amp	% Loading
Bus1	132.000		2.852	1.342	3.152	90.5	13.8	
Bus2	15.000		2.850	1.302	3.134	91.0	121.3	
Bus3	15.000		0.664	0.407	0.779	85.2	30.9	
Bus4	15.000		0.455	0.282	0.535	85.0	21.5	
Bus5	15.000		0.201	0.129	0.239	84.1	9.7	
bus6	0.400		0.155	0.096	0.182	85.0	280.2	
bus7	15.000		0.408	0.225	0.466	87.6	18.4	
Bus8	0.400		0.244	0.151	0.287	85.0	454.8	
bus9	15.000		0.501	0.129	0.518	96.9	20.5	
bus10	0.400		0.088	0.055	0.104	85.0	163.0	
Bus11	15.000		0.664	0.201	0.693	95.7	27.3	
Bus12	15.000		0.500	0.106	0.511	97.8	20.3	
Bus13	15.000		0.495	0.114	0.508	97.4	20.5	
Bus14	15.000		0.402	0.065	0.407	98.7	16.5	
Bus15	15.000		0.399	0.075	0.406	98.3	16.6	
bus16	0.400		0.194	0.121	0.229	85.0	362.4	
Bus17	0.400		0.154	0.095	0.181	85.0	280.3	
Bus18	0.400		0.088	0.054	0.103	85.0	163.0	
Bus19	0.400		0.195	0.121	0.230	85.0	362.3	
Bus20	15.000		0.199	0.044	0.203	97.7	8.4	
Bus21	15.000		0.414	0.255	0.487	85.1	19.0	
Bus22	0.400		0.199	0.123	0.234	85.0	361.7	
Bus23	15.000		0.206	0.133	0.245	84.1	9.6	
bus24	0.400		0.196	0.121	0.231	85.0	362.1	
Bus25	0.400		0.195	0.121	0.230	85.0	362.2	
bus26	15.000		0.200	0.043	0.205	97.7	8.4	
bus27	15.000		0.402	0.079	0.410	98.1	16.6	
bus28	0.400		0.197	0.122	0.232	85.0	362.0	
bus29	15.000		0.405	0.074	0.412	98.4	16.6	
bus30	15.000		0.497	0.131	0.514	96.7	20.6	
bus31	15.000		0.411	0.217	0.465	88.4	18.2	
bus32	15.000		0.666	0.230	0.704	94.5	27.6	
bus33	15.000		0.406	0.232	0.467	86.8	18.6	
bus34	15.000		0.403	0.240	0.468	85.9	18.8	
bus35	0.400		0.194	0.120	0.228	85.0	362.5	

Appendix: M Branch Losses

Branch Losses Summary Report (Max. Loading)

CKT / Branch	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop in Vmag
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	
T1	2.852	1.342	-2.850	-1.302	2.0	39.7	100.0	99.4	0.59
Line1	0.676	0.407	-0.664	-0.407	12.1	-10.9	99.4	97.0	2.39
Line6	0.671	0.206	-0.664	-0.201	10.9	14.5	99.4	97.8	1.64
Line12	0.417	0.248	-0.414	-0.255	6.1	-7.7	99.4	98.4	0.98
line18	0.672	0.233	-0.666	-0.230	9.0	13.5	99.4	98.2	1.26
Line24	0.414	0.209	-0.411	-0.217	5.8	-18.1	99.4	98.5	0.91
Line2	0.459	0.276	-0.455	-0.282	7.2	-16.4	97.0	95.8	1.20
T9	0.204	0.132	-0.199	-0.123	8.6	18.4	97.0	93.4	3.66
Line3	0.202	0.118	-0.201	-0.129	3.9	-11.8	95.8	95.2	0.58
T2	0.253	0.165	-0.244	-0.151	11.8	13.2	95.8	91.2	4.61
T10	0.201	0.129	-0.195	-0.121	8.6	18.4	95.2	91.6	3.67
t13	-0.155	-0.096	0.160	0.104	8.2	17.8	93.7	98.2	4.44
line16	0.408	0.225	-0.406	-0.232	5.9	-17.5	97.6	96.6	0.95
line17	-0.408	-0.225	0.411	0.217	5.9	-17.8	97.6	98.5	0.93
line19	-0.501	-0.129	0.506	0.126	7.5	-12.8	97.1	98.2	1.11
line20	0.501	0.129	-0.497	-0.131	7.5	-12.6	97.1	95.9	1.12
t14	-0.088	-0.055	0.091	0.059	5.8	14.2	91.8	95.9	4.13
Line7	0.504	0.098	-0.500	-0.106	7.4	-18.4	97.8	96.7	1.05
T5	0.159	0.103	-0.154	-0.095	8.2	17.8	97.8	93.3	4.44
Line8	0.500	0.106	-0.495	-0.114	7.4	-18.0	96.7	95.7	1.07
Line9	0.405	0.055	-0.402	-0.065	5.9	-19.9	95.7	94.8	0.81
T6	0.091	0.059	-0.088	-0.054	5.8	14.2	95.7	91.5	4.13
Line10	0.402	0.065	-0.399	-0.075	5.9	-19.6	94.8	94.0	0.84
Line11	0.199	0.031	-0.199	-0.044	3.7	-12.4	94.0	93.6	0.42
T7	0.199	0.044	-0.195	-0.037	7.2	16.3	94.0	91.5	2.47
T8	-0.194	-0.037	0.199	0.044	7.2	16.3	91.1	93.6	2.47
Line13	0.207	0.122	-0.206	-0.133	3.8	-10.7	98.4	97.9	0.50
t11	0.207	0.133	-0.202	-0.125	8.6	18.3	98.4	94.8	3.66
t12	0.206	0.133	-0.201	-0.124	8.6	18.3	97.9	94.3	3.66
t16	-0.196	-0.037	0.200	0.043	7.2	16.3	91.9	94.4	2.46
line23	-0.200	-0.043	0.201	0.036	3.7	-7.5	94.4	94.8	0.43
line22	-0.402	-0.079	0.405	0.074	5.9	-4.6	94.8	95.7	0.85
t15	0.201	0.043	-0.197	-0.037	7.2	16.3	94.8	92.4	2.45
line21	-0.405	-0.074	0.406	0.073	4.0	-11.6	95.7	95.9	0.28
line15	0.406	0.232	-0.403	-0.240	6.0	-7.2	96.6	95.7	0.97

CKT / Branch	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
line14	0.403	0.240	-0.399	-0.247	8.3	-7.4	95.7	94.6	1.07
T17	-0.194	-0.120	0.200	0.129	8.6	18.4	90.9	94.6	3.67
line4	0.200	0.118	-0.199	-0.128	9.8	-9.8	94.6	94.1	0.50
T18	0.199	0.128	-0.193	-0.120	11.6	18.4	94.1	90.4	3.67
					274.9	73.7			

Appendix: N Cost Summary

Optimal Capacitor Placement Cost Summary

	Cost ($)		Saving ($)		
Year	**Installation**	**CQ930Op.**	**Loss Reduction**	**Yearly Profit**	**Accumulative Profit**
1	42000.00	21200.00	102907.22	39707.22	39707.22
2	0.00	0.00	39707.22	39707.22	79414.44
3	0.00	0.00	39707.22	39707.22	119121.66
4	0.00	0.00	39707.22	39707.22	158828.88
5	0.00	0.00	39707.22	39707.22	198536.1