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THESIS NO.: M-121-MSESPM-2017-2020

Optimal Allocation of Capacitor Bank in Radial Distribution System for Loss Minimization and Voltage Profile Improvement

by

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A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENERGY SYSTEM PLANNING AND MANAGEMENT

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

JULY, 2020

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CERTIFICATE OF APPROVAL

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Optimal Allocation of Capacitor Bank in Radial Distribution System for Loss Minimization and Voltage Profile Improvement**", submitted by Milan Silwal in partial fulfillment of the requirement for the degree of Masters of Science Engineering in Energy System Planning and Management.

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ABSTRACT

Distribution system links the consumer with the power system. Distribution system in Nepal is mainly radial in nature because of its simple design and low capital cost. In radial distribution system, voltage decreases along the feeder due to which voltage of the terminal nodes attains lower values which is below statutory voltage limit. Load of distribution system is mostly inductive in nature so reactive power compensation is required. Power is generated at generating stations and is transported to the load centers. However, reactive power is generally locally produced near to the load centers. Capacitor banks in distribution system helps to improve power factor of the system thereby minimize the system loss, increase the power transfer capacity and improve the voltage profile.

This study presents MATLAB based particle swarm optimization (PSO) technique to determine the optimal location and size of the capacitor bank in distribution system. First of all, load flow was carried out using backward forward sweep algorithm. The voltage profile, current flowing through the line and system losses was calculated from the load flow. Using Loss sensitivity index (LSI), the candidate nodes for the location of capacitor bank was determined. The buses with high value of LSI was sorted in descending order and top fifty percentage of bus with high LSI value has been considered as the variable for the location of capacitor bank. Two types of variables have been considered for the optimization problem. One is the location and another is the size of capacitor bank. LSI was used to determine the candidate node for capacitor bank installation while particle swarm optimization was used to optimize the size and location of the capacitor bank. The location and size of capacitor bank which gives in minimum annual loss has been considered the optimum solution. The proposed procedure was applied to IEEE 34 and 69 bus system and on a real distribution system, i.e. Parsa feeder, Chitwan. The result of IEEE 34 and 69 bus system was compared with previous publications. After compensation using capacitor bank, the peak power loss of IEEE 34 bus, IEEE 69 bus and Parsa feeder decreased by 29.9%,42.48% and 45.41% respectively. Simulation results showed improved voltage profile and remarkable savings can be obtained after installation of capacitor bank in radial distribution system.

ACKNOWLEDGEMENT

LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
AI	Artificial Intelligence
DG	Distributed Generation
IEEE	Institute of Electrical and Electronics Engineers
KCL	Kirchhoff's Current Law
KVL	Kirchhoff's Voltage Law
kVA	Kilo Volt Ampere
kVAr	Kilo Volt Ampere Reactive
kW	Kilowatt
kWh	Kilowatt Hour
LF	Load Factor
LLF	Load Loss Factor
LSI	Loss Sensitivity Index
MINLP	Mixed Integer Non-Linear Programming
MVA	Mega Volt Ampere
NEA	Nepal Electricity Authority
NLP	Non-Linear Programming
PSO	Particle Swam Optimization
PSOA	Particle Swam Optimization Algorithm
pu	Per Unit

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CHAPTER ONE: INTRODUCTION

1.1 Background

Power system comprises electrical network which delivers the power generated from the generating station to the consumers. Power generated in a generating station is at low voltage level which is stepped up by the means of step-up transformers and then transmitted at higher voltages. The power is then lowered down at the substation which is further stepped down while distributing to the consumers. Therefore, power system comprises three systems in it, called as

- Generation- where energy is produced at lower voltage level,
- Transmission- the generated power is then transmitted to other place at higher voltages,
- Distribution system- where the energy is delivered to the end consumers in useable for at lower voltages.

From generation process at generating stations, to the transmission and the distribution of the energy, there incurs loss in the power. The percentage of power loss at generation and transmission systems is lower compared to the distribution losses. Distribution system loss in Nepal was 11.28% in fiscal year 7075/76 which is better than that of 2074/75 accounting 14.82%. The overall system loss of Nepal Electricity Authority (NEA) in fiscal year 2075/76 was15.32% (NEA,2019).

It is always beneficial to reduce the system losses. Distribution system losses are broadly categorized into two major categories which are technical and nontechnical losses. Non-technical losses refer losses such as loss due to theft, meter error or billing irregularity which can be controller through effective management and regular supervision.

Technical loss can be classified as load loss or no-load loss. Losses occurred due to current flowing the conductor is the load loss. This depends upon the current of the system. i.e, I^2R loss. No load losses are also called the iron loss which occurs in transformers. Loss occurred in transformer even though transformer is not connected to the load is the no load loss. Load loss is directly proportional to the square of current flowing through the line so load loss becomes much higher during time of peak load.

Technical losses can be minimized with the placement of proper conductor, reconfiguration of feeder, optimal placement of capacitor bank, distributed generating units, or combination of these using other methods.

1.2 Problem statement

Radial distribution system is most popular in Nepal because of its simple design and low capital cost. However, due to lengthy radial feeder, the voltage at the terminal node becomes very low due to voltage drop along the path of current flow. Due to the rapid urbanization and growth in economic activities, electrical demand is increasing more than ever.

Annual growth in demand of electrical energy is around 10 % in Nepal. Distribution system planned years ago are still in operation with minimal or no improvement. So, losses in the distribution system is increasing. Load on the distribution system is mostly inductive in nature so reactive power compensation is required.

Use of capacitor bank in radial distribution system helps to improve the power factor of the system which helps to minimize the system losses and improve the voltage profile. Capacitor bank in distribution system can be a cost-effective technique to improve the system loss but optimal allocation of capacitor bank is required to have better results.

1.3 Objectives

The primary objective of this research is to study the improvement in voltage profile and net savings obtained after optimal allocation of capacitor bank. The specific objectives to meet the main objectives are as follows:

- To determine the bus voltage and losses in line using load flow using backward forward sweep algorithm
- To determine the node for capacitor bank in radial distribution system using LSI
- To determine the sitting and sizing of the capacitor bank
- To study the savings and improvement in bus voltage after capacitor bank placement

1.4 Assumptions and limitations

Distribution network is vast and consists of complex parameters. The scopes for different studies related to this power system are defined as per the field of concern and requirements without violating the basic principles of power system. Feeder under study is assumed

balanced but in reality, all the three phases may not be balanced. A balanced three phase radial feeder is assumed. The peak load is considered as system load. Similarly, cost of capacitor bank cost is assumed same for all banks irrespective of the size of the capacitor bank. This study is limited to IEEE 34 bus, IEEE 69 bus and 53 bus Parsa feeder.

CHAPTER TWO: LITERATURE REVIEW

2.1 Distribution system

The distribution system is the part of the electric power system that provides the energy to the costumers at the readily form to use. The distribution system is the terminal part of power system which holds its place after generation and transmission system. Since power is fed to the costumer via distribution system, reliability and power quality of distribution system carries much significance. The primary components of a distribution system are:

• Distribution substation

• Primary feeder

• Distribution transformer

 • Secondaries and services.

The distribution substation receives electrical power at a high voltage which is than fed to the primary feeder. In Nepalese context, Primary distribution feeder is the feeder line which originates from distribution substation at a voltage such as 11 kV or 33 kV. These primary feeder carries large current at a rated voltage which is then stepped down via distribution transformer. Secondary distribution means the lower voltage distribution network such as three phase 400 V or single phase 230 V. The service mains refer to the cable which connects consumer with the distribution system.

Primary distribution includes three basic types: radial, loop and interconnected systems. In radial distribution system, unique feeders radiate out from substation and fed the distributers at one end only. The radial system is often used and simple. This is economical and widely used in low load density areas. For the system where higher reliability is desired ring main system is used. Two feeders form a closed loop with a point open in common so that load can be transferred from one feeder to another in case of fault at any feeder. Whenever the fault occurs, it can be repaired with the minimum number of customer interruptions. As the loop system requires a greater number of switches and conductors, the investment cost is more than for radial distribution but the resultant reliability of the system pays off the cost invested.

The interconnected system comprises of a grid interconnection which is supplied via number of substations. It provides better service quality and is more reliable than the radial or loop system. However, interconnected network system is the most complicated among three. Since this system employs interconnection of number of substation and switches, it is more reliable. Although the system is expensive one, it is preferred in urban areas with concentrated loads.

According to Electricity Regulation,1993, the standard low voltage single phase distribution is 230V and 400V for three phase. Similarly, high voltage distribution system comprises 3.3kV,6.6Kv,11kV,22kV and 33kV. The fluctuation is not be allowed for more than five percent in standard volt while the level of power factor of the electricity supplied to the consumer should not be allowed not less than 0.8 lagging and not more than one unit leading. The standard frequency is set 50 hertz with fluctuations not exceeding 2.5 percentage of the set value.

2.2 Load flow of distribution System

The flow of power in an electrical network is called power flow and is commonly referred as load flow. The load flow study shows how power is flowing along the network. By performing load flow, the steady state characteristics such as bus voltage, current flowing in the feeder, active and reactive power demand can be found out. Gauss seidel, Netwon - Rapshon method, backward forward sweep algorithm are the techniques generally required to carry out load flow study.

Load flow study is carried out to study short-circuit conditions for any interconnected power system. They are also required for the planning and operation of the systems under the existing condition, its improvement and future expansion. The demand in the distribution network is ever growing. To meet the increasing demand, different planning strategies have been proposed to continue the quality and reliable power supply to the consumers. Load flow is required during planning of electrical network or during operational phase such as for:

- Network reconfiguration: load balancing, service restoration, loss reduction
- Volt-VAR control: Voltage profile improvement, Volt-VAR optimization

- DG and Capacitor Placement: Loss reduction, renewable integration, reactive power management
- Regulator placement and control settings

2.3 Optimization techniques

Optimization is the selection of best choice based on some criteria from the set of available alternatives. The optimization problem has three parameters which are the decision variables, objective functions and constraints. Decision is made based on the decision variables. Decision variables may be continuous, semi continuous, discrete or sets. The objective function consists of equations related to the decision variable which are to be minimized or maximized. The constraints are the restrictions or boundary of the problem in the search space.

Based on the type and nature of the objective function, different optimization methods have been formulated. General methods of optimization can be categorized as

- Mathematical programming techniques
- Metaheuristics techniques

Mathematical programming techniques is based on the geometric properties of the problem. Some of the techniques are simplex algorithm, Netwon's method.

Metaheuristics techniques are nature inspired algorithms to solve the optimization problem. Some of the metaheuristics technique are genetic algorithm, artificial bee colony optimization, differential evolution, particle swarm optimization cuckoo search algorithm, flower pollination algorithm many more. This algorithm mimics the natural behavior of organism. For example, particle swarm optimization imitates the intelligence of swarm of birds or flock of fish to reach a destination or the search of food. In PSO, in successive iteration particle velocity and position is updated to reach the optimum solution. Analogy to this is birds move collectively in population to seek food or shelter through their collective intelligence. Genetic algorithm is based on the selection of fittest. After each iteration, new generation is produced based on the biological process of mutation, crossover and selection. This is analogous the new solution produced from the successive iterations. The input parameters are the population size, elite count and crossover fraction.

Abdelaziz et al. (2014) studied the optimal sizing of the capacitor bank in radial distribution system using flower pollination optimization algorithm and power loss index. The algorithm was tested in 15 bus,69 bus and 118 bus radial feeder and the result was validated using other techniques from earlier publications.

Ali et al. (2015) studied the optimal capacitor allocation in radial distribution network using loss sensitivity index and cuckoo search algorithm. The methodology was implemented in 24 bus,85 bus and EDN distribution network, Egypt. The result showed better voltage profile and loss reduction was possible using capacitor bank in the radial distribution network.

Abdelrahaman et al, (2014) studied the loss reduction and voltage enhancement in distribution system using the distributed generation. Sensitivity based technique was implemented to determine the candidate location of distributed generators. The results obtained was better voltage profile and reduction in losses.

Pradeepa et al. (2015) studied the optimal allocation of combined distributed generator and capacitor units for voltage stability enhancement. Optimization was done using Genetic algorithm. This was tested in 33 bus radial feeder which showed loss reduction and voltage profile improvement can be obtained after the DG and capacitor unit placement.

Babu and singh (2016) presented optimal capacitor allocation in radial distribution system using loss sensitivity factor and analytical technique with the objective to minimize the system loss. The algorithm was tested in 15 bus,34 bus and 69 bus system which was also compared with other methods. The result obtained was improvement in loss reduction compared with other methods.

Devababbaji and kumar (2015) presented the harmony search-based optimization technique to determine the size and the location of the capacitor bank. The result was tested in IEE 34 bus test system. The objective function was to minimize the aggregate voltage deviation. The result showed better performance using this method than that of previous publications. Similarly, Analytical technique has been used by Casheng and Hashem in 2004 for distributed generation (DG) units placement in radial feeder. They found savings can be increased by employing DG units.

Chopde and Biledash (2011) studied capacitor placement technique using ETAP and genetic algorithm. Load flow was carried out using ETAP and optimization of problem via genetic algorithm. The algorithm was tested in IEEE 34 bus system. Nonlinear load was considered the system load. The research showed that harmonic component affected the capacitor placement.

Liu et al. (2017) presented the network reconfiguration method in smart distribution network considering uncertainty in demand in power system. The objective function was to minimize the loss cost, minimum switch operating cost and minimum expected energy not supplied. Optimization tool used was harmony search algorithm. The result showed that the proposed algorithm is feasible.

Gou et al (1999) studied the optimal capacitor allocation technique using mixed integer nonlinear programming approach. They also studied the harmonic distortion brought after connecting capacitor bank in radial distribution system. Nonlinear loads have been represented by harmonic current injections. The location and size of capacitor bank was suggested to minimize the effect of harmonics.

2.3.1.1 Particle swarm optimization

Particle swarm optimization is the optimization technique based on the swarm intelligence. It was proposed by Kennedy and Eberhart in 1995 and is one of the most optimization tool till date. Suppose particle is in its current position X_k^i.Each particle tries to update its position based upon the following parameters:

- The velocity of the particle (V_k^i)
- The difference between the particle's best position and particle' current position   (p_k^i-X_k^i)
- The difference between the best position attained by swarm and particle' current position (p_k^i-X_k^i)

Considering the swarm of p particles in search space, each particle represents the possible solution for the problem. Kennedy and Eberhart (1995) originally proposed the idea of PSO and the equation determining the PSO was defined as follows:

$$X^i_{k+1} = X^i_k + V^i_{k+1}$$ Equation 2.1

$$V^i_{k+1} = V^i_k + c_1 * r_1 * (p^i_k - X^i_k) + c_2 * r_2 * (p^g_k - X^i_k)$$ Equation 2.2

The subscript k, denotes iteration count. The term p^i_k represents the best attained by the particle at the kth iteration, while p^g_k is the global best position attained by the particle in the kth iteration. To make the function stochastic two random numbers r_1 and r_2 are selected which lies in the range 0 to 1. c1 and c2 represents the acceleration coefficients of the particles. C1 attracts the particles towards the personal best while c2 attracts the particle towards the global best. If c1 is greater than c2 particle gets attracted towards the local best while if c2 is greater than c1, particle gets attracted to the global best but there is chance that particle miss the local minima. If both c1 and c2 have same value than the particle converges to the global optima without skipping the local minima. Shi and Eberhart in 1998 modified the velocity equation presented in equation 2.2 by placing the parameter inertial weight(w) in the velocity equation as shown in the equation 2.3. Inertial weight defines the momentum of particle. To constrict the velocity, linearly decreasing inertial weight in each iteration is selected.

$$V^i_{k+1} = w * V^i_k + c_1 * r_1 * (p^i_k - X^i_k) + c_2 * r_2 * (p^g_k - X^i_k)$$ Equation 2.3

2.4 Load curve

Load curve or chronological curve is plot of electrical demand against time. Generally, load is expressed in kW or MW. Load curve may be daily, monthly or annual. Time is
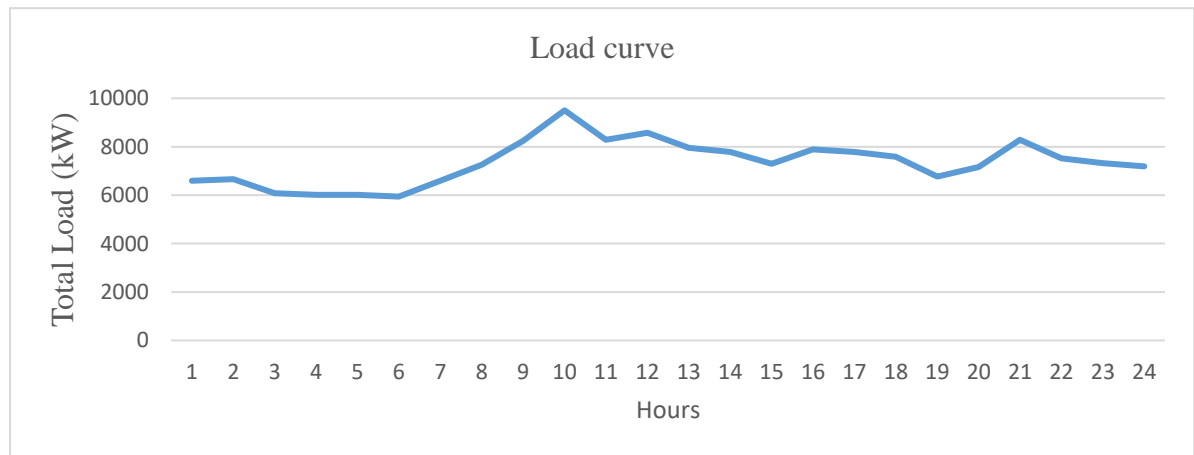
Figure 2.1 Load curve

presented in the X-axis while the load is expressed in the Y-axis. The figure represents daily load curve. Here load variation according to hour of day is presented. The Figure 2.2 shows the typical load curve at Parsa feeder of Chitwan district in 16th June,2019.

The peak load occurs at 10 AM which is due to energy consumed by fan and other accessories both for the commercial and industrial purpose. However, in winter season, the peak load occurs during evening time.

2.5 Load duration curve

Load curve represents the load in descending order versus the numbers of hour. The peak load is plotted in the left most part of curve while the lowest load is presented in the rightmost part of plot. It shows the number of hours at which the load is present. The figure below shows the load duration curve of Parsa feeder, Chitwan in 18th October, 2019. Here, the peak load is 7524 kW which occurred for 1 hour while the lowest demand is 3564 kW which occurred throughout the day. i.e. for 24 hours.
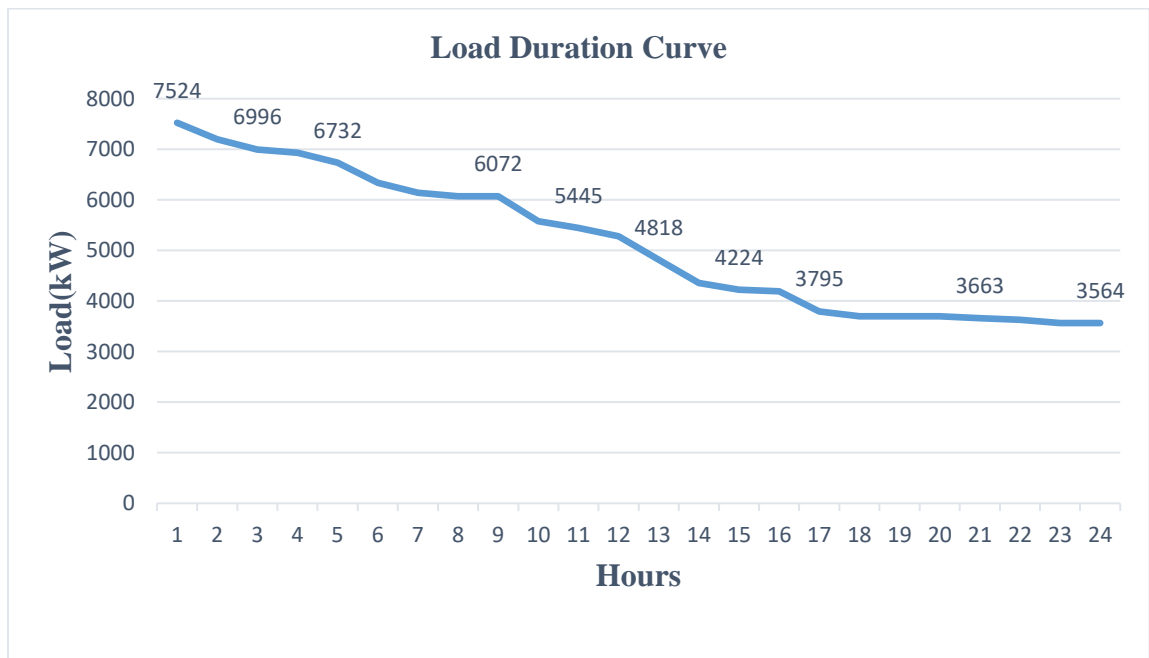
Figure 2.2 Load duration curve

2.7 Load factor

Load factor can be defined as the fraction of the average load of the system to the maximum load over that period.

$$Load\ Factor = \frac{Average\ load}{Peak\ load} \qquad \text{Equation 2.4}$$

Load factor shows how efficiently we are utilizing the energy. Generally, demand surges during the peak demand time such as evening or morning time while the load is nominal during off peak time such as nigh time. In system with high load factor, there is less gap between the peak demand and base demand. If load factor means 1 then demand is equal throughout the period of that system.

2.6 Load loss factor

Load Loss Factor (LLF) is a factor which when multiplied with the peak power loss gives the average loss of the system. There are two methods to determine the loss load factor of the system which are the exact technique and approximate technique.

2.6.1 Approximate technique

LLF can be formulated as

LLF = α * Annual Load Factor + (1 – α) * (Annual Load Factor)^2 Equation 2.5

According to Baitch (2004), the value of α is 0.2 for medium voltage feeder and distribution substation while that for transmission system is 0.3. To determine the peak power loss, load flow is carried out with the load data under peak load conditions. So, the average system loss is obtained by multiplying the peak loss with the load loss factor.

Annual Total Loss Cost = LLF * peak power loss * energy price per unit * hours

Equation 2.6

Bhattarai and Shakya (2017), studied the technical and non-technical losses in Industrial feeder of Nepal in Kawasoti distribution feeder and the LLF calculated was 0.365 while the load factor (LF) was calculated 0.539.

2.6.2 Exact technique

Exact method uses the load profile of the system. Ekwue (2015) presented the exact method to calculate the LLF which is:

$$LLF = \frac{Sum\ of\ hourly\ demand}{(Maximum\ demand)^2 * 8760} \qquad \text{Equation 2.7}$$

Number of days in a year is 365 and with 24 hours a day gives 8,760 hours annually.

The equation is further simplified by Malmedal, and Sen (2008). They defined LLF which was defined as follows:

$$LLF=\frac{(I)^2avg*R}{(I)^2peak*R}$$ Equation 2.8

Where,

$(I)^2_{avg}$ is square of average of current of the system

$(I)^2_{peak}$ is the square of peak current of the system

R is the between two bus.

Since the system voltage is already defined for any system, total load is obtained from the load curve. The current at any time can be obtained by dividing the total load at that time by the system voltage.

CHAPTER THREE: RESEARCH METHODOLOGY

The methodological approach followed during the research is presented in figure 3.1.

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│              Problem formulation              │
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┌─────────────────────────────────────────────┐
│      Literature review and data collection    │
└─────────────────────────────────────────────┘
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                      ▼
┌─────────────────────────────────────────────┐
│  Perform load flow and calculate the voltage profile and │
│                   losses feeder               │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│      Calculate the loss sensitive Index (LSI)  │
└─────────────────────────────────────────────┘
                      │
                      ▼
┌─────────────────────────────────────────────┐
│   Optimal allocation of capacitor in feeder line using │
│        particle swarm optimization (PSO)       │
└─────────────────────────────────────────────┘
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                      ▼
┌─────────────────────────────────────────────┐
│       Perform load flow again after optimization │
└─────────────────────────────────────────────┘
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┌─────────────────────────────────────────────┐
│   Calculate the net savings after capacitor placement │
└─────────────────────────────────────────────┘
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┌─────────────────────────────────────────────┐
│             Discussion and conclusion          │
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┌─────────────────────────────────────────────┐
│          Report writing and presentation       │
└─────────────────────────────────────────────┘
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Figure 3.1 Research methodology

An algorithm was modeled compute the load flow, determine the loss sensitivity index and particle swarm optimization for determining the optimal size and location of capacitor bank. Load flow study computes the voltage profile, current and phase angle of the system. LSI was computed and the buses were ranked according to the values of loss sensitivity index. Similarly, particle swarm optimization (PSO) has been used to determine optimum

position and size of the capacitor bank. All the algorithm was simultaneously run so that optimum result is obtained.

For this study, load data and line data of feeder, load factor, load loss factor of the feeder is required. In this study, for IEEE 34 and IEE 69 bus system, load and line data was taken from previous publications. For 53 bus Pasa feeder load profile, load and line data was collected from Parsa substation.

Annual net benefit was calculated which is equal to annual value of electricity saved after the installation of capacitor bank subtracted from annual cost of capacitor bank. The result of IEEE 34 bus and IEEE 69 bus was compared with the previous literature.

3.1 Load flow computation

Consider a radial distribution system as shown in the figure 3.2. The load flow was carried out in following steps:
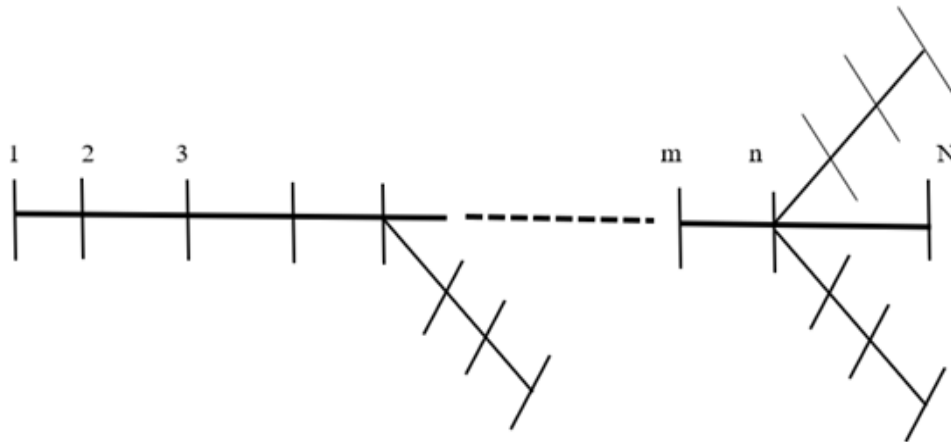
Figure 3.2 Typical radial distribution system

Step 1: Initialization of node voltages

In this step, initialize voltage at each bus to $V_s \angle 0^0$. The voltage at source bus or reference bus $V_s \angle 0^0$ remains constant and V_j at zeroth iteration will be equal to $V_s \angle 0^0$, where j is starting from 2, 3, ..., N.

Step 2: Iteration count Initialization

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Initialize iteration count k, for first iteration k is set 1.

Step 3: Load current computation

Calculate load current (I_j) at Z^{th} bus during k^{th} iteration. The equation for current calculation is given by

$$I_j^{(k)} = \left(\frac{P_{Lj}+jQ_{Lj}}{V_j^{k-1}}\right)^*$$
Equation 3.1

 In this equation, voltage will be of $(k-1)^{th}$ iteration.

Step 4: Backward Sweep

In backward sweep, calculate the branch current (I_{mn}) from nodes m to n at k^{th} iteration. The branch current includes load current at nth bus and summation of all the branch currents emanated from bus n.

$$I_{mn}^{(k)} = I_n^{(k)}+\sum \text{ all the currents of branches emanated from bus n}$$
Equation 3.2

Step 5: Forward Sweep

In forward sweep, the voltage at each bus is calculated. For example, the voltage on the nth bus will be the voltage at the mth bus minus voltage drop in the m-n line. Line drop is calculated by multiplication of impedance and current of that line, whereas the mth bus voltage is calculated prior to n^{th} bus voltage calculation. The equation for bus voltage is given by

$$V_n^{(k)} = V_m^k - Z_{mn}I_{mn}^{(k)} \text{ for all n=2,3......N}$$
Equation 3.3

Step 6: Calculation of error

After the calculation of voltage at each bus by forward sweep process, calculation of error provides deviation in bus voltage at k^{th} iteration with respect to $(k-1)^{th}$ iteration. For example, error at bus m will be bus voltage at k^{th} iteration minus $(k-1)^{th}$ iteration. This process repeated from second bus to n^{th} bus.

$$e_j^{(k)} = \left| V_j^{(k)} - V_j^{(k-1)} \right| \quad \text{for all } j=1,2,3\ldots\ldots\ldots..N \qquad \text{Equation 3.4}$$

Step 7: Calculation of maximum Error

In this step, calculate maximum error (e_{max}) among all the error, calculated between two consecutive iterations at each bus.

$$e_{max}^{(k)} = \max\ (e_2^{(k)}, e_3^{(k)}, e_4^{(k)} \ldots \ldots \ldots \ldots e_N^{(k)}) \qquad \text{Equation 3.5}$$

Step 8: Tolerance

In this step, the maximum error with respect to tolerance value was compared. The tolerance values is user define value. The tolerance value was considered 10^{-5}. The condition for converge is, if the maximum error becomes less than or equals to tolerance. Otherwise, proceed for next iteration $(k+1)^{th}$ i.e., go to step 3 and repeat the same process. Once the maximum error satisfies the convergence criteria then print the result.

3.2 Loss sensitive index (LSI)

Loss sensitive index have been used to determine the candidate bus for the installation of capacitor and reduce the search space. Consider two nodes distribution system shown in figure 3.3, where bus p is the sending end bus while q is the receiving end buses, respectively.

The active power flowing through the line is given by:

$$P_{lossk} = I_K^2 * R_k = \left(\frac{P_{eff}^2 + Q_{eff}^2}{|Vq|^2} \right) * R_k \qquad \text{Equation 3.6}$$

The reactive power flowing through the line is given by:

$$Q_{lossk} = I_K^2 * X_k = \left(\frac{P_{eff}^2 + Q_{eff}^2}{|Vq|^2} \right) * X_k \qquad \text{Equation 3.7}$$

Where, P_{eff} is the effective real power beyond node P while Q_{eff} is the total effective reactive power loads beyond node q respectively. Effective reactive power is the sum of reactive power demand at that node and sum of reactive power demand up to that node up to the root node.
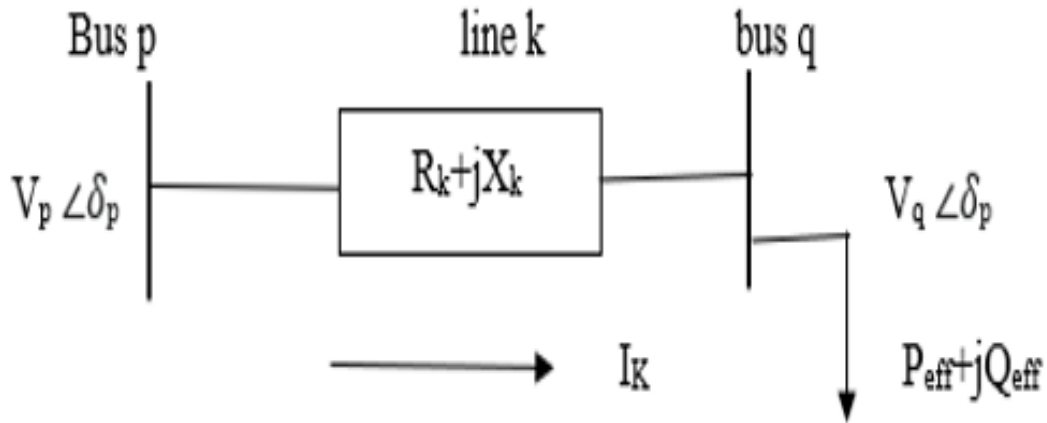
Figure 3.3 Two node radial distribution system

The loss sensitivity index (LSI) is formulated as follows:

$$\text{LSI} = \frac{\partial \text{PLossk}}{\partial \text{Qeff}} = \frac{2 * \text{Qeff} * \text{Rk.}}{Vq^2}$$
Equation 3.8

The value of LSI is not much significance in this optimization problem. However, the ranking of these buses is important. Firstly, LSI is calculated for each bus and buses are sorted in descending order based on the value of LSI. Fifty percent of the buses starting from the indexed top position was selected as the variable of the optimal allocation of the capacitor bank. This formula for loss sensitivity LSI has been considered from Reddy (2013).

To calculate the value of LSI, the value of effective reactive power, resistance of the line and voltage magnitude is required. The value of voltage magnitude was determined from the load flow study. Resistance of the line was obtained from the network data. Another parameter is the effective reactive power, this is the sum of effective power beyond the node and loss at that node. In this study, all the values are calculated in per unit. Per unit effective reactive power loss was obtained by dividing the effective reactive loss by the base power, per unit resistance was obtained by dividing the resistance by base impedance. The per unit voltage was has been obtained by dividing the node voltage by the base voltage.

3.3 Capacitor sizing and placement problem using PSO

The flowchart of particle swarm optimization is shown in the figure 3.4 below.
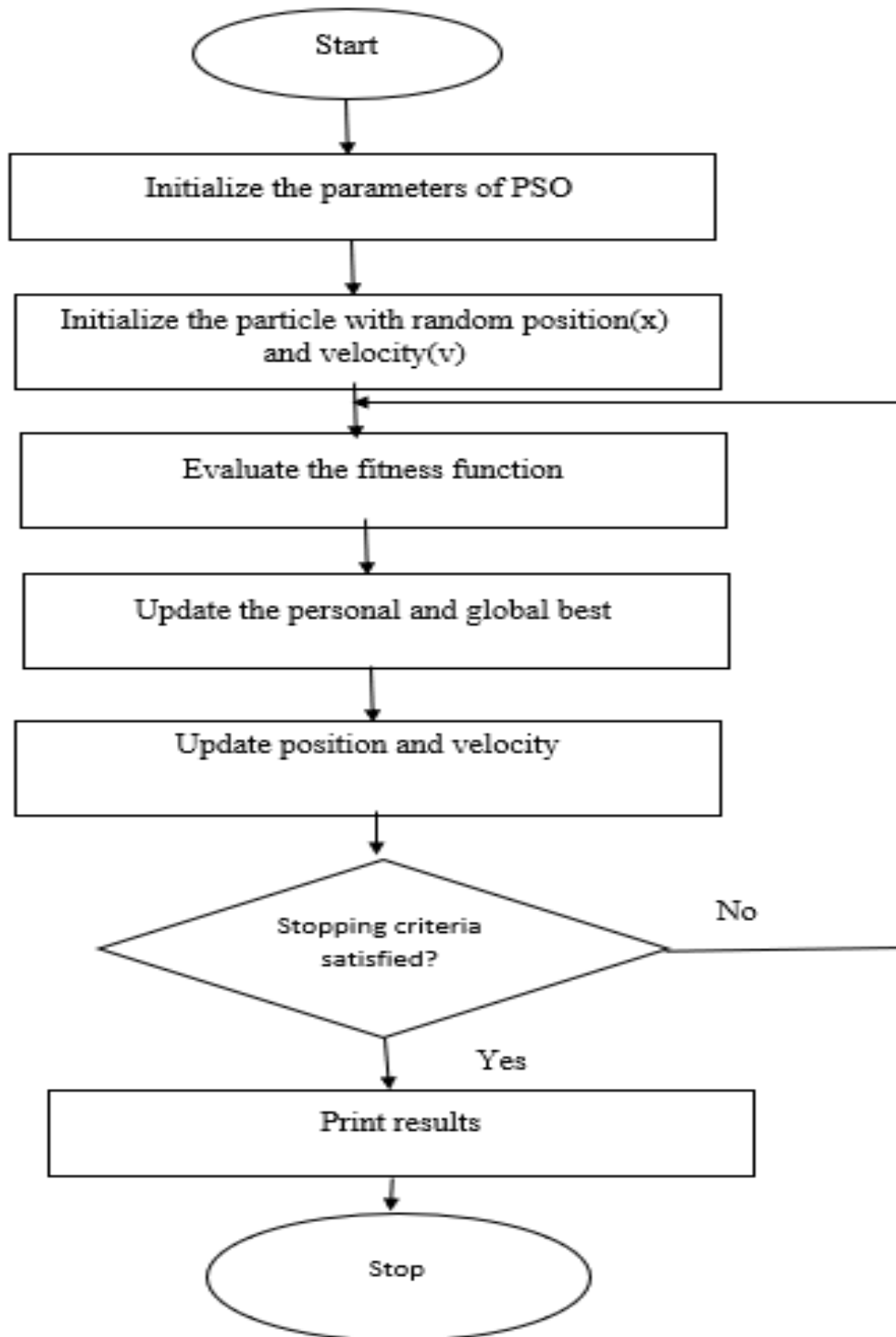
Figure 3.4 PSO flowchart

After load flow simulation is carried out, the voltage profile and system loss were determined. Similarly, candidate node for optimal capacitor bank allocation was obtained from loss sensitive index. Now to optimize the size and the location of the capacitor bank particle swarm optimization has been used.

The first step is to define the parameters of PSO. The value of inertial weight(w) was considered linearly decreasing with successive iterations. The initial value of w was assumed 0.9 and lowest value was assumed 0.4. Linearly decreasing the velocity helps in limit the velocity thereby abrupt changing the velocity.

$W=W_{max}-(W_{max}-W_{min})/(\text{maximum iteration})*\text{iteration number}$ Equation 3.8

Similarly, both the value of acceleration coefficients, c1 and c2 was set 2.0. This gives equal chance of exploration and exploitation. In other words, equal value of c1 and c2 helps to converge the solution to global minima without skipping local minima. (Rezaei and Jasni,2013). Similarly, maximum iteration count was set 1000 while population size of 200 was selected. Having high iteration and population count slows the result but better convergence can be obtained.

The constraints considered was the size of capacitor bank and the allowable voltage range. The capacitor bank with the step size of 150 kVAr between the range 150 kVAr to 1200 kVAr was selected. The allowable voltage range was assumed from 0.9 pu to 1.1 pu.

Two types of variables were required to be optimized, one is the position and another is the size of the capacitor bank. The variables for position was obtained from LSI. Another variable is the size of the capacitor bank. Capacitor bank of the size 150kVAr to 1200kVAr has been considered but for making the algorithm simple, the lower and the upper bound of the size of the variable has been considered 0 to 1 and capacitor bank of the corresponding size was selected corresponding the range as mentioned in the table 3.1

Now the main loop of PSO is started where for the first iteration velocity and position of the particle is randomly generated. In the successive iteration, the particles move to their best position to find the best value of fitness function. Fitness function in this problem is to minimize the total annual cost so, the location and size of the capacitor bank which gives the minimum annual loss is the optimum solution.

Table 3.1 Capacitor bank sizing methodology

Lower range	Upper range	Value of capacitor bank(kVAr)
0	0.125	150
0.125	0.25	300
0.25	0.375	450
0.375	0.5	600
0.5	0.625	750
0.625	0.75	900
0.75	0.875	1050
0.875	1	1200

3.4 Financial calculation

The objective function is to minimize the total cost which includes energy loss cost and capacitor bank purchase cost. Since the cost is calculated on annual basis, the optimized salutation gives the minimum capacitor size and the capacitor size. The active power loss is simply obtained by multiplying the square of current flowing through the line with the

corresponding resistance. i.e., $P = I^2R$. The total power loss of all the branches can be evaluated by adding all the line losses, i.e.

Total power loss $= \sum_{i=1}^{b} P_i$　　　　　　　　　　　　　　　　　Equation 3.9

Where, b represents the count of branches.

Power loss multiplied by the time gives the total energy. Total time period considered is one year so the time is 8760 hrs. Multiplying the peak power loss with LLF gives the average power loss throughout the year. Only LLF of Parsa feeder has ben calculated because load curve of other buses is unknown.

Annual energy loss cost = LLF * peak power loss* energy cost per unit * 8760

Equation 3.10

The sum of individual capacitor bank at each node gives the total size of the capacitor bank.

The annual loss of capacitor bank in distribution system is

Annual Capacitor Cost = $(k_c * Q_{VAr})$/ (Life expectancy of capacitor bank)

Equation 3.11

Where, k_c is the per kVAr cost of the capacitor bank expressed in United States dollar, $/kVAr,

Q_{VAr} is cumulative size of capacitor bank expressed in kVAr.

For this research, the value of unit cost of capacitor was taken $5/kVAr while life expectancy was considered 10 years. (Abou et al,2016)

3.5 Fitness function

Fitness function is the objective function of the optimization problem.

Minimize F= annual cost of energy loss + Annual cost of the capacitor bank

Equation 3.12

The solution which gives the minimum loss is the optimized solution.

3.6 Case study

3.6.1 IEEE 34 bus system
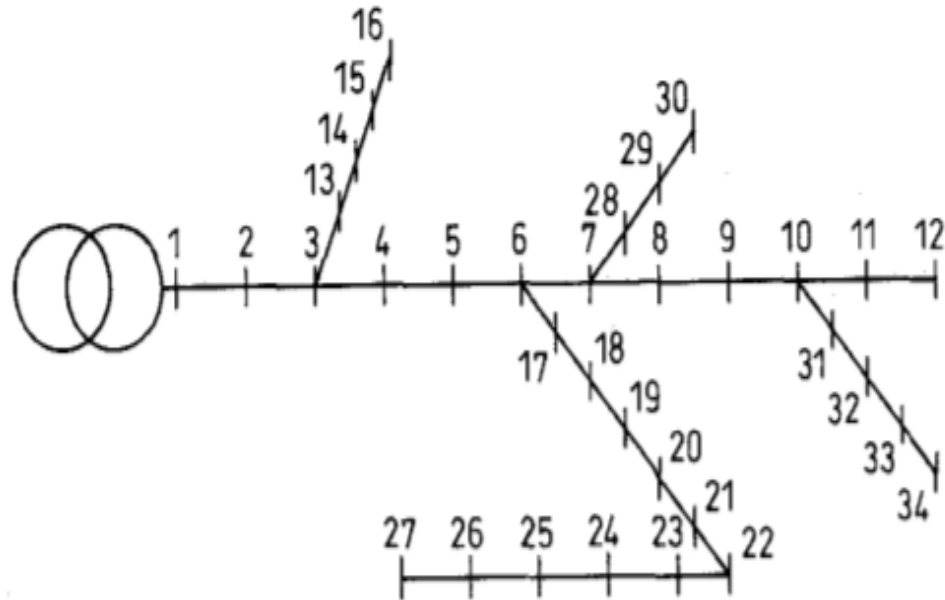
Figure 3.5 IEEE 34 bus system

(Source: Chis et al,1997)

Single line diagram of IEEE 34 bus radial distribution system has been illustrated in Figure 3.5. The system has four laterals and branching occurs at node 3,6,7 and 10. The rated system voltage is 11 kV and base of 100 MVA. The load data and line data of the bus is taken from Prakash and Lakshminarayana,(2017) .Bus 1 is considered slack bus where the voltage is assumed to be 1.00 pu. The total active power demand is 4636.5 kW while the reactive power demand is 2872.5 kVAr. Load data and line data of the system is presented in Appendix. Network data of these bus has been presented in appendix I.

3.6.2 IEEE 69 bus system

The single line diagram of the system is illustrated in figure 3.6. Branching occurs at nodes 3,4,8,9 and 11. The system voltage is 12.66 kV and base power has been assumed 100 MVA. The load data and the line data for this system was obtained from Das,2007. The

active power demand is 1896 kW while the reactive power is 1347 kVAr. Network data of the system is shown in the appendix I.
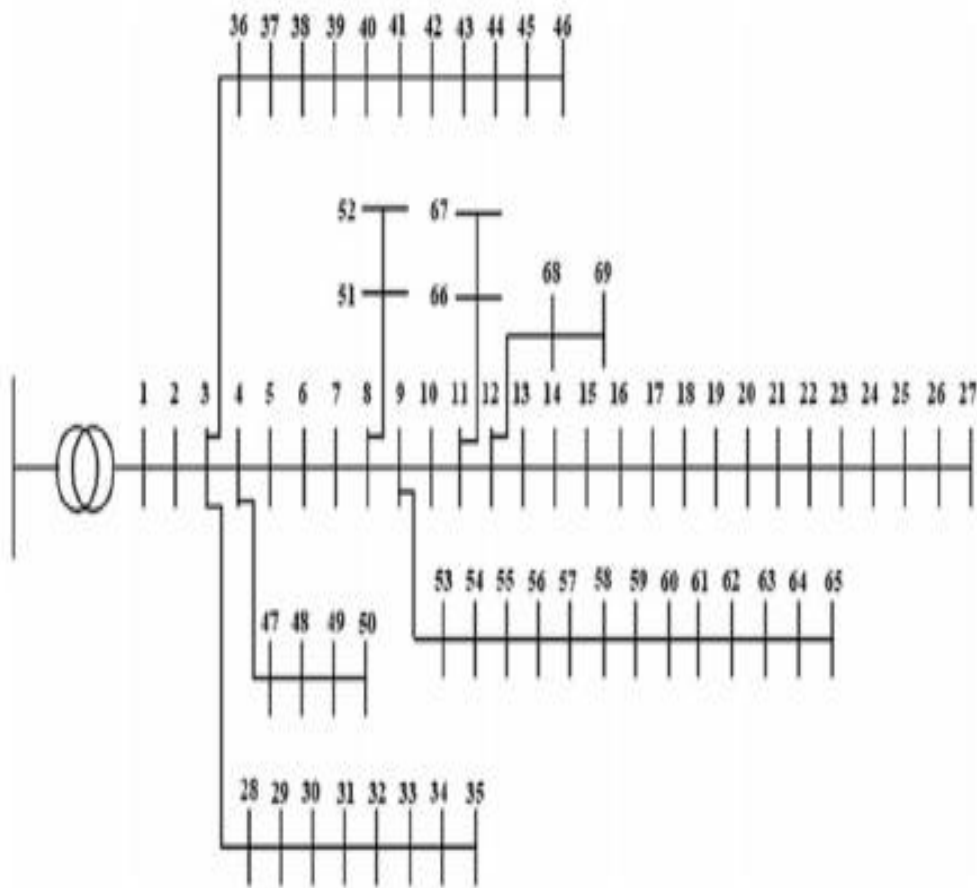
Figure 3.6 IEEE 69 bus system

(Source: Roy,2015)

3.6.3 53 bus Parsa feeder

Parsa feeder is a 53-bus radial feeder which originates from Parsa substation. The system comprises of 72 transformers connected into 11 kV primary distribution system. This system has been modified to 53 bus system after load on transformer located within 100-meter distance lumped to the single node. The total installed capacity of transformer is 9500 kVA and the substation operate at 0.8 lag power factor. The peak load of the system in 2019 was 9504 kW on July 16. Mostly high load occurs in summer season while in winter the load is comparatively low. The average load of the system is 4805.51 kW.

Altogether there are 10 branches in the feeder. Dog conductor has been used in the main feeder while rabbit conductor was used in the lateral feeder. Main feeder comprises bus number 1 to 23 which can be seen in the single line diagram below. Bus 1 is the substation while other buses are the load bus.

The single line diagram of 53 bus Parsa feeder is shown in figure 3.7. Load data and line data of the feeder has been presented in appendix I

.
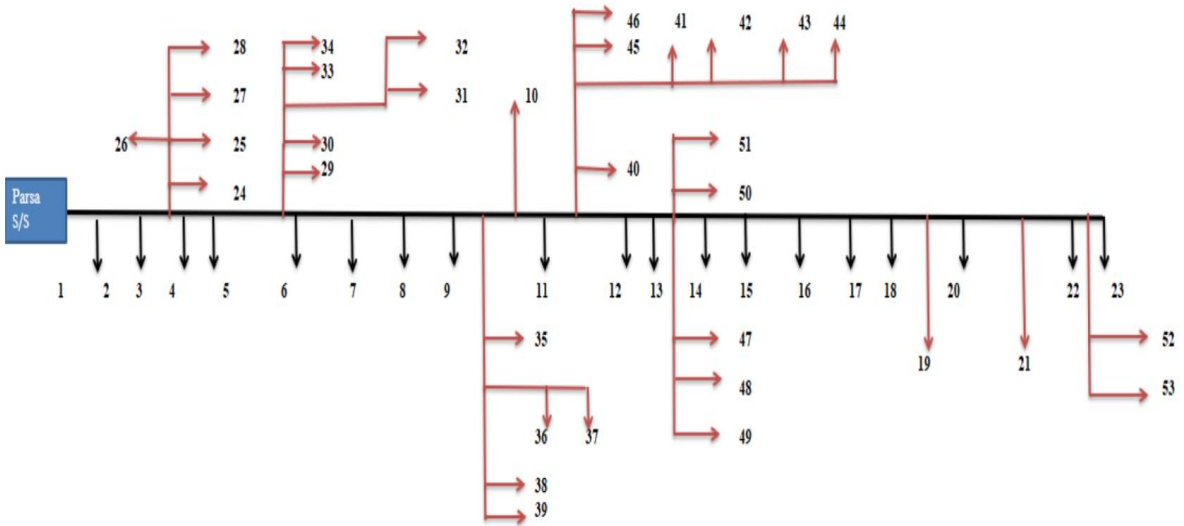
 Figure 3.7 Single line diagram of Parsa feeder

CHAPTER FOUR: RESULTS AND DISCUSSION

The proposed algorithm has been implemented by coding on MATLAB (Matrix Laboratory), multi-paradigm numerical computing environment and eighth-generation programming language and executed on Intel Core i-7, 1.8 Giga Hertz (GHz) personal computer with 12 Giga Byte (GB) RAM. The algorithm was tested in the IEEE standard 34 bus, IEEE 69 bus and 53 bus Parsa feeder radial distribution system. Different size and complexity of bus has been used to test the effectiveness of system.

4.1 IEEE-34 bus

4.1.1 Load flow of IEEE-34 Bus radial distribution system

The load flow of the system was carried out using backward/forward sweep algorithm. The voltage profile of the system has been represented in the figure 4.1.
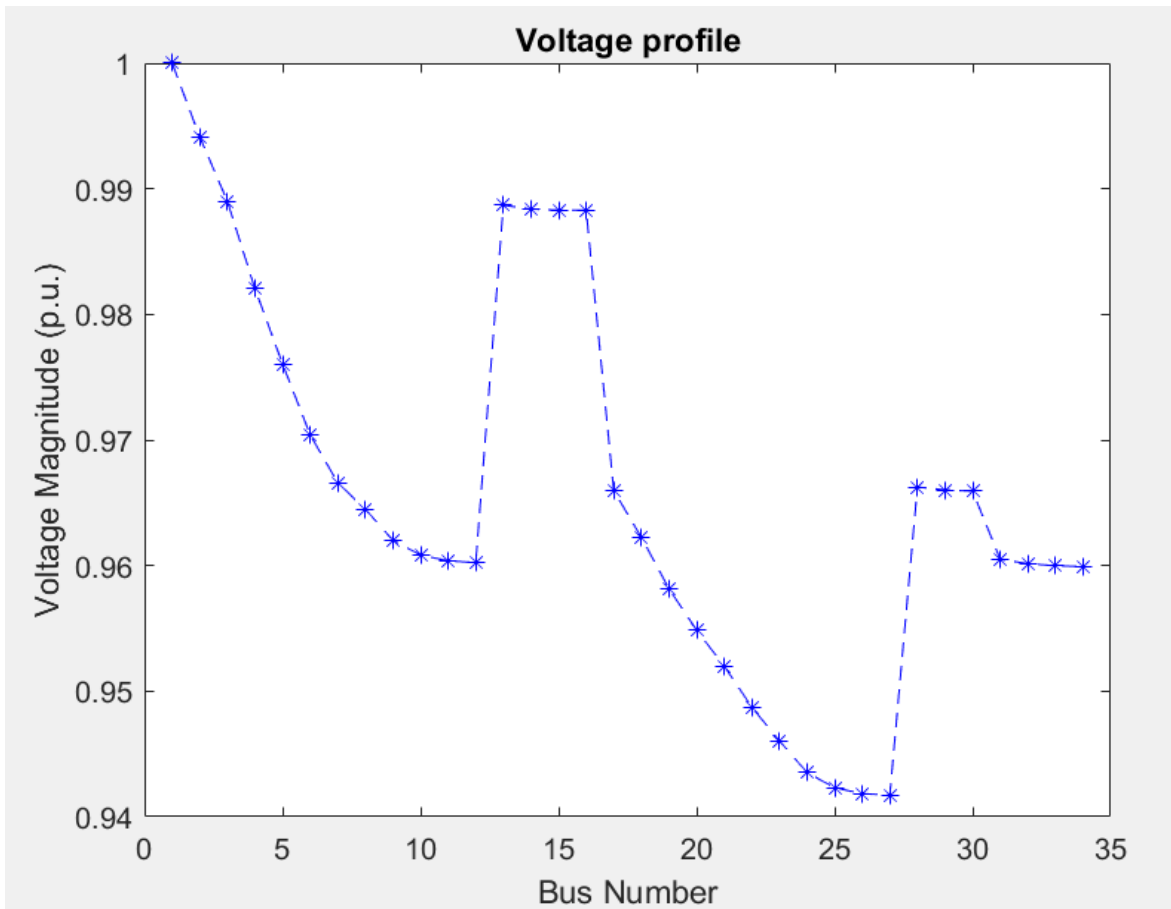
Figure 4.1 IEEE-34 Bus System voltage profile

The value of voltage is 1pu at the first node because first node is defined as the slack bus. The least value of voltage was at bus number 27 which is 0.94171 pu. In the uncompensated system, the annual power loss was obtained 221.6772 kW. The voltage profile gradually decreases from bus 1 to bus 12 because bus 12 is the terminal node of the main feeder but voltage at bus number 13 is comparable than that of node 3 because node 13 branches out from node 3.In the same way, voltage at bus number 17 is comparable bus number 6 because node number 17 branches out from node number 6.The voltage decreases gradually from node 17 to 27 due to voltage drop in each successive node. However, there was increase in voltage at node 28 when compared with node 27. This was because branching occurred from node 7 to 28 which extended up to node 30. Voltage profile decreased from node 30 to 31 because bus number 31 is connected to node 10.

4.1.2 Loss sensitive index of IEEE 34 bus

The loss sensitivity index of IEEE 34 bus system is presented in the table 4.1. First column of the table is the bus number. This table has been kept in ascending order according to the bus number. Second column is the reactive power demand in per unit (p.u) of the nodes from 2 to 34.This value was obtained by dividing the reactive power of the node by the base MVA .Here base power was considered 10^5 kVA, so the reactive power demand at the first node which value was 142.5 kVAr, the per unit value became 0.001425.The third column refers to the reactive power loss at that node. It is also presented in per unit system. Total reactive power loss in the uncompensated system is 65.1007 kVAr. Fourth column corresponds to the total effective reactive power. This is the sum of total reactive power demand beyond the node whose LSI is to be calculated .For example, the total reactive power demand beyond node 2 is 2872.5 kVAr and the reactive power loss at node 2 is 12.8 kVAr so the total effective reactive power beyond node 2 is 2885.3 kVAr whose value in pu is 0.028853.In the same manner, fourth column refers to the per unit resistance. Resistance of the line was obtained from the network data which has also been presented in the Appendix I. With the base voltage of 11kV and base power of 10^5 kVA the base impedance value of 1.21p.u. The value of resistance when divided by the base resistance gives the value of per unit resistance. The per unit voltage was already calculated in power flow computation. The square of the value of per unit voltage has been represented in the

column numbered 6. Finally, the value of LSI was calculated using the formula mentioned in the equation 3.8.

Table 4.1 Loss sensitivity index for IEEE 34 bus system

Bus number	Reactive power demand (pu)	Reactive power loss in (pu)	Total effective reactive power (pu)	Resistance in (pu)	Square of Voltage (pu)	LSI
2	0.001425	0.000128	0.028853	0.096694	0.988314	0.005648
3	0.000000	0.000106	0.027416	0.088636	0.978161	0.004969
4	0.001425	0.000099	0.025984	0.135909	0.964422	0.007324
5	0.001425	0.000081	0.024541	0.123554	0.952693	0.006365
6	0.000000	0.000072	0.023107	0.123554	0.941696	0.006063
7	0.000000	0.000011	0.007946	0.259835	0.934296	0.004420
8	0.001425	0.000005	0.006500	0.173223	0.930222	0.002421
9	0.001425	0.000005	0.005075	0.259835	0.925482	0.002849
10	0.000000	0.000002	0.003647	0.173223	0.923194	0.001368
11	0.001425	0.000000	0.002265	0.108264	0.922311	0.000532
12	0.000840	0.000000	0.000840	0.086612	0.922061	0.000158
13	0.000450	0.000000	0.001425	0.129917	0.977508	0.000379
14	0.000450	0.000000	0.000975	0.173223	0.976895	0.000346
15	0.000450	0.000000	0.000525	0.086612	0.976737	0.000093
16	0.000075	0.000000	0.000075	0.043306	0.976717	0.000007
17	0.001425	0.000037	0.015137	0.148264	0.933059	0.004811
18	0.001425	0.000028	0.013703	0.135909	0.925925	0.004023
19	0.001425	0.000024	0.012274	0.171818	0.918051	0.004594
20	0.001425	0.000017	0.010842	0.156198	0.911758	0.003715
21	0.001425	0.000013	0.009413	0.156198	0.906304	0.003244
22	0.001425	0.000010	0.007985	0.216529	0.900089	0.003842
23	0.001425	0.000006	0.006556	0.216529	0.894992	0.003172
24	0.001425	0.000005	0.005130	0.259835	0.890230	0.002994

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Bus number	Reactive power demand (pu)	Reactive power loss (pu)	Total effective reactive power (pu)	Resistance (pu)	Square of voltage (pu)	LSI
25	0.001425	0.000002	0.003702	0.173223	0.887948	0.001444
26	0.001425	0.000000	0.002275	0.108264	0.887081	0.000555
27	0.000850	0.000000	0.000850	0.086612	0.886818	0.000166
28	0.000480	0.000000	0.001440	0.129917	0.933639	0.000401
29	0.000480	0.000000	0.000960	0.129917	0.933214	0.000267
30	0.000480	0.000000	0.000480	0.129917	0.933001	0.000134
31	0.000345	0.000000	0.001380	0.129917	0.922541	0.000389
32	0.000345	0.000000	0.001035	0.173223	0.921888	0.000389
33	0.000345	0.000000	0.000690	0.999350	0.921562	0.001497
34	0.000345	0.000000	0.000345	0.999010	0.921466	0.000748

The next step is to sort the bus according the value of LSI in descending order. The bus with the highest value of LSI is indexed in the top position while that having lowest value has been indexed in the bottom position. Out of 34 bus, 17 bus whose LSI value is high has been selected as the candidate node for the optimal allocation of capacitor bank. Bus having high value of LSI are more prone to loss than that having lower value. Another advantage of using LSI is it reduce the search space for thee optimization problem.

As seen in the table 4.2, the value of LSI was found highest in the bus number 4. This is mainly because of high value of resistance, total effective reactive power and slightly lower value of voltage compared at the buses 2 and 3. On the other hand, the value of LSI was obtained lowest at the bus number 16.Bus number 16 is the terminal node of the branch so it has lower value of effective reactive power demand, relatively lower value of voltage resistance and slightly higher value of voltage than the terminal node. As mentioned in the

formula, the value of LSI is directly proportional to the effective reactive power and resistance but inversely proportional to the square of the voltage.

Table 4.2 Sorting IEEE 34 bus according to LSI

Rank	Bus number	LSI
1	4	0.007324
2	5	0.006365
3	6	0.006063
4	2	0.005648
5	3	0.004969
6	17	0.004811
7	19	0.004594
8	7	0.00442
9	18	0.004023
10	22	0.003842
11	20	0.003715
12	21	0.003244
13	23	0.003172

Rank	Bus Number	LSI
14	24	0.002994
15	9	0.002849
16	8	0.002421
17	33	0.001497
18	25	0.001444
19	10	0.001368
20	34	0.000748
21	26	0.000555
22	11	0.000532
23	28	0.000401
24	32	0.000389
25	31	0.000389
26	13	0.000379
27	14	0.000346

Rank	Bus Number	LSI
28	29	0.000267
29	27	0.000166
30	12	0.000158
31	30	0.000134
32	15	9.31E-05
33	16	6.65E-06

4.1.3 Optimal allocation of capacitor bank in IEEE 34 bus system

After the value of LSI was calculated and sorted in descending order, the top ranked 17 buses has been selected as the candidate node for the optimal placement of the capacitor bank in the system. The candidate nodes are buses 4,5,6,2,3,17,19,7,18,22,20,21,23,24,9,8 and 33.

After simulation in MATLAB, the optimal location of capacitor bank was found at nodes 18,22,24 and 9. A total of 2550kVAr capacitor bank was suggested after simulation. The active power loss decreased to 159.86kW after compensation which corresponds to 29.9% loss reduction. Also, the minimum voltage of the system rose to 0.95062 at bus 27.

Table 4.3 Size and location of capacitor bank in IEEE 34 bus system

Bus number	Size of the capacitor bank(kVAr)
18	600
22	600
4	750
9	750
Total size	2550

The comparison of the voltage profile of the compensated and uncompensated IEEE 34 bus system has been represented the figure 4.2. Number of iterations was performed before getting the lowest value of annual loss cost. The simulation result with the lowest value of annual loss cost is the optimum solution. As seen from the figure 4.2, capacitor bank was installed in the location where voltage profile is low, there is significant improvement in voltage profile
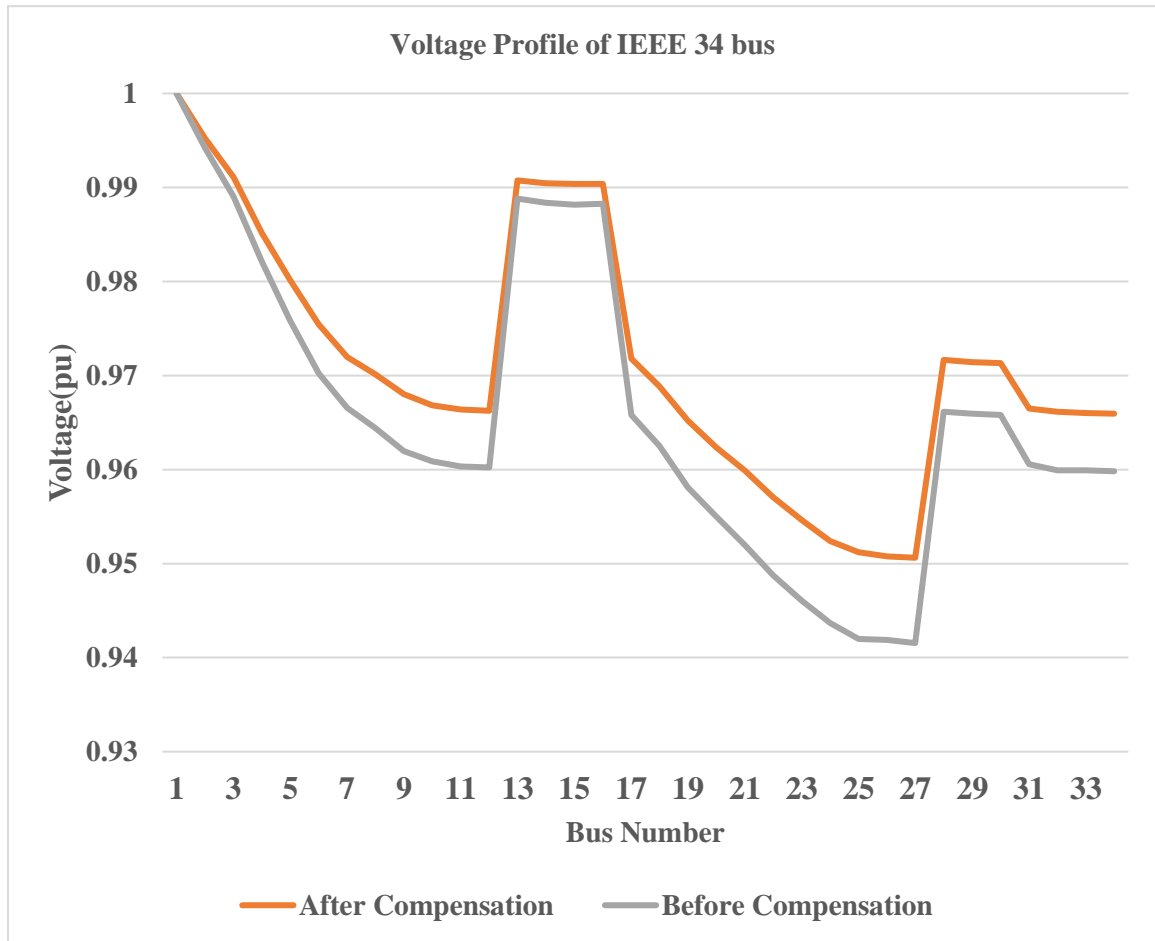
Figure 4.2 Voltage profile of IEEE 34 bus system after compensation

4.1.4 Result validation and cost benefit analysis

Comparing the results with earlier publications, it was found that the proposed method provided better results. Active power loss was minimum using this method. Total loss using mixed integer nonlinear programming method was 162.9 kW while that using bacterial foraging optimization algorithm loss was 160.6 kW.

Table 4.4 IEEE 34 bus system result validation

Parameters	Uncompensated	Mixed integer nonlinear programming approach, (Nojavan et al.,2014)	Bacterial foraging optimization algorithm, (Devabalaji and Kothari,2015)	Particle swarm optimization
Total losses (kW)	221.6772	162.9	160.6	159.8648
Optimal location	-	4,10,14,18,22,27	10,20,25	18,22,24,9
Optimal size in kvar	-	2800	2175	2550
Vmin (pu) at	0.94171 at 27	0.9521 at 27	0.9499 at 27	0.9502 at 27

Cost and benefit after capacitor bank installation was calculated after the result which shows that net annual savings of $9710 was obtained after capacitor bank installation in 34

bus system. The table below shows the financial cost and benefits before and after capacitor bank installation in the IEEE 34 radial bus system.

Table 4.5 IEEE 34 bus system cost and benefits calculation

Parameters	Before compensation	After compensation
Minimum voltage in pu	0.94171, # 27	0.95062 # 27
Maximum voltage in pu	0.99414, # 2	0.99504, # 2
Active power loss (kW)	221.6772 kW	159.86
Total power saved (KW)	-	61.8172
Price of electricity (KW-year) in $	168	168
Annual savings of Electricity compared to base case ($)	-	10,385
Total size of capacitor bank(kVAr)	-	2550
Capacitor price per year ($)	0	1275
Net annual savings ($)		9710

4.2 IEEE-69 bus bus

4.2.1 Load flow

The load flow of the system was carried out using backward/forward sweep algorithm. The voltage profile of the system after load flow has been illustrated in the figure 4.3.
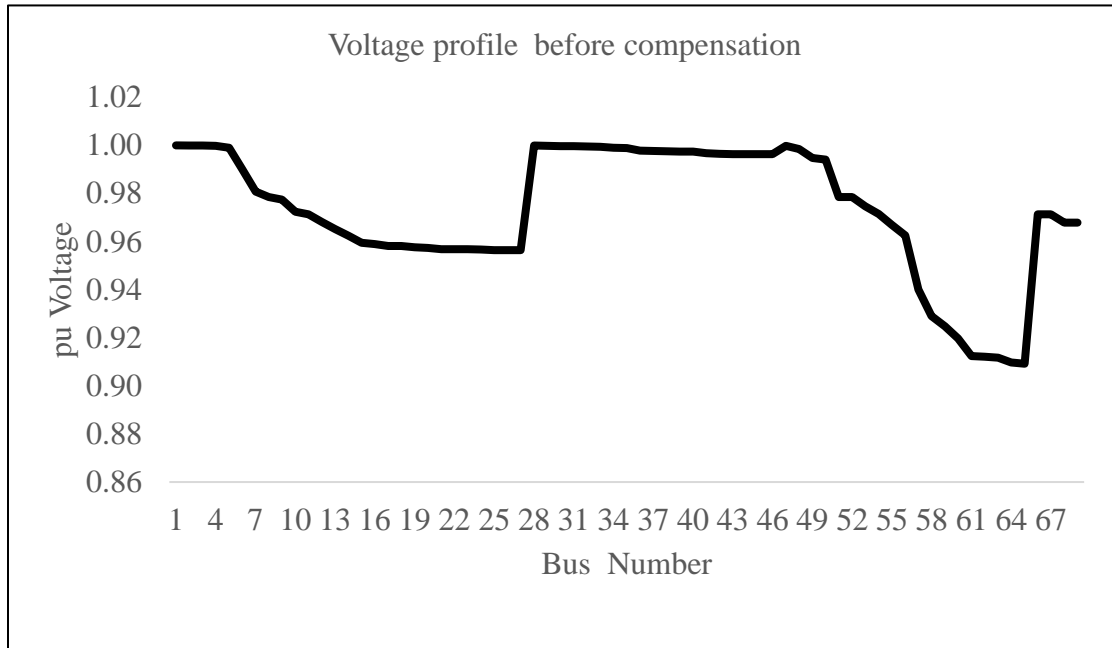
Figure 4.3 Voltage profile of IEEE 69 bus system before compensation

The value of voltage was least at bus number 65 which is 0.90921 pu. In this uncompensated system, the power loss was 225.338 kW. The voltage profile of bus 3 and 36,3 and 28,9 and 53,8 and 51,11 and 66 was similar because of branching which can be seen clearly from the single line diagram of 69 bus system.

The voltage profile of the uncompensated system is portrayed in figure. The voltage at first bus in 1 pu because first bus is considered as the slack bus of the system. As seen from the figure of voltage profile, voltage gradually decreases from bus 1 to 27. This is because of drop in voltage at each node. Voltage drop is caused by impedance of the system. On the other hand, the voltage abruptly increased from bus 3 to 28. This was because voltage branching occurred from node 3 to 28. Furthermore, voltage profile from node 28 to 50, was nearly constant. This occurred because of branching and very nominal nodes among these nodes.
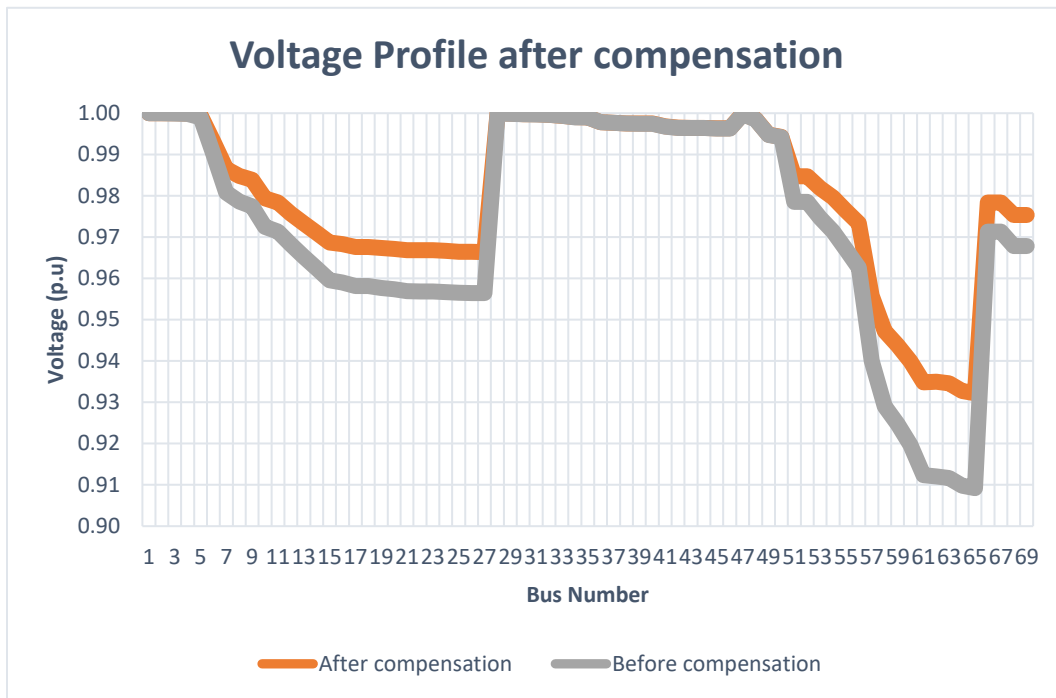
Figure 4.4 Voltage profile of IEEE 69 bus system after compensation

Branching occurred from node 3 to 28 and 36. In the same manner, there was branching from node 4 to 47. In the similar pattern, the voltage decreased abruptly from node 50 to 65. The voltage is least at node 65. The decrease in voltage is caused by long linear node 53 to 65. The voltage however increased from node 66 to 69. This was because branching occurred from node 11 to 66 which further extends to 67. Similarly, branching occurred from node 12 to 68 which extends further up to 69.

4.2.2 Loss sensitivity index of IEEE 69 bus system.

Loss sensitivity index (LSI) is used to determine the candidate node for the optimal allocation of the capacitor bank. Column 1 is the bus number. Here, buses are sorted in descending order. Second column is the per unit reactive power. Reactive power demand at various nodes is presented in the appendix. Dividing the reactive power at node by base power gives the per unit reactive power at that node. Reactive power loss at each node is calculated by simple formula $I^2 * X$, where I is the current flowing through the node and X is the reactance at the node. The value of X was obtained from the network data and value of current after performing the load flow. In column 3, effective reactive power demand beyond that node has been presented. In case of second bus, the effective reactive power is

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the total reactive power demand of the system because all other nodes originate form the second node. Similarly, the value of effective reactive power demand at the terminal nodes is the reactive power demand at that node only because there is no branching at the terminal node. Column number 6 is the summation of the effective reactive power demand at each node and reactive power loss at each node. i.e., summation of values of third and fifth column values. Computation has been done in per unit values so these values can be added.

Table 4.6 Effective reactive power computation in IEEE 69 bus

Receiving node	Reactive power (pu)	Effective reactive power demand (pu)	Reactive power loss in kVAr	Reactive power loss (pu)	Total effective reactive power(pu)
2	0	0.026936	0.179925834	1.79926E-06	0.026938
3	0	0.026936	0.179925351	1.79925E-06	0.026938
4	0	0.024994	0.467676548	4.67677E-06	0.024999
5	0	0.01894	2.267072516	2.26707E-05	0.018963
6	0.000022	0.01894	14.37355273	0.000143736	0.019084
7	0.0003	0.018918	14.93812364	0.000149381	0.019067
8	0.00054	0.018618	3.512205164	3.51221E-05	0.018653
9	0.00022	0.017768	1.717002121	1.717E-05	0.017785
10	0.00019	0.005281	1.575038614	1.57504E-05	0.005297
11	0.00104	0.005091	0.334619239	3.34619E-06	0.005094
12	0.00104	0.003791	0.721890212	7.2189E-06	0.003798
13	0.00005	0.002351	0.422474149	4.22474E-06	0.002355
14	0.00005	0.002301	0.404156919	4.04157E-06	0.002305
15	0	0.002251	0.397093929	3.97094E-06	0.002255
16	0.0003	0.002251	0.07372077	7.37208E-07	0.002252
17	0.00035	0.001951	0.105787426	1.05787E-06	0.001952
18	0.00035	0.001601	0.000727001	7.27001E-09	0.001601
19	0	0.001251	0.034248373	3.42484E-07	0.001251
20	0.000006	0.001251	0.02172298	2.1723E-07	0.001251
21	0.00081	0.001245	0.03523764	3.52376E-07	0.001245

Receiving node	Reactive power(pu)	Effective reactive power demand (pu)	Reactive power loss (kVAr)	Reactive power loss (pu)	Total effective reactive power(pu)
23	0	0.0004	0.001565282	1.56528E-08	0.0004
24	0.0002	0.0004	0.003545011	3.54501E-08	0.0004
25	0	0.0002	0.001901324	1.90132E-08	0.0002
26	0.0001	0.0002	0.000691691	6.91691E-09	0.0002
27	0.0001	0.0001	4.58649E-05	4.58649E-10	0.0001
28	0.000186	0.000652	0.000851332	8.51332E-09	0.000652
29	0.000186	0.000466	0.00631697	6.31697E-08	0.000466
30	0	0.00028	0.001926743	1.92674E-08	0.00028
31	0	0.00028	0.000339923	3.39923E-09	0.00028
32	0	0.00028	0.001699634	1.69963E-08	0.00028
33	0.0001	0.00028	0.004126014	4.12601E-08	0.00028
34	0.00014	0.00018	0.003438855	3.43885E-08	0.00018
35	0.00004	0.00004	0.000158432	1.58432E-09	4E-05
36	0.000186	0.00129	0.156305462	1.56305E-06	0.001292
37	0.000186	0.0011045	0.037026921	3.70269E-07	0.001105
38	0	0.000919	0.020320016	2.032E-07	0.000919
39	0.00017	0.000919	0.005864673	5.86467E-08	0.000919
40	0.00017	0.000749	0.000232537	2.32537E-09	0.000749
41	0.00001	0.000579	0.057154417	5.71544E-07	0.00058
42	0	0.000569	0.023609512	2.36095E-07	0.000569
43	0.000043	0.000569	0.003114813	3.11481E-08	0.000569
44	0	0.000526	0.000650205	6.50205E-09	0.000526
45	0.000263	0.000526	0.007697485	7.69748E-08	0.000526
46	0.000263	0.000263	1.6683E-05	1.6683E-10	0.000263
47	0	0.006054	0.057527409	5.75274E-07	0.006055
48	0.000564	0.006054	1.426557274	1.42656E-05	0.006068

Receiving node	Reactive power(pu)	Effective reactive power demand(pu)	Reactive power loss (kVAr)	Reactive power loss(pu)	Total effective reactive power(pu)
49	0.002745	0.00549	3.99696054	3.99696E-05	0.00553
50	0.002745	0.002745	0.283538212	2.83538E-06	0.002748
51	0.000283	0.00031	0.000892628	8.92628E-09	0.00031
52	0.000027	0.000027	1.48201E-05	1.48201E-10	2.7E-05
53	0.000035	0.012267	2.943523345	2.94352E-05	0.012296
54	0.00019	0.012232	3.418198672	3.4182E-05	0.012266
55	0.000172	0.012042	4.64538067	4.64538E-05	0.012088
56	0	0.01187	4.477303657	4.4773E-05	0.011915
57	0	0.01187	16.67621675	0.000166762	0.012037
58	0	0.01187	8.217421185	8.21742E-05	0.011952
59	0.00072	0.01187	3.14269586	3.1427E-05	0.011901
60	0	0.01115	3.238185224	3.23819E-05	0.011182
61	0.00888	0.01115	7.142209716	7.14221E-05	0.011221
62	0.00023	0.00227	0.056514874	5.65149E-07	0.002271
63	0	0.00204	0.068071566	6.80716E-07	0.002041
64	0.00162	0.00204	0.335990407	3.3599E-06	0.002043
65	0.00042	0.00042	0.020775024	2.0775E-07	0.00042
66	0.00013	0.00026	0.000793228	7.93228E-09	0.00026
67	0.00013	0.00013	2.52204E-06	2.52204E-11	0.00013
68	0.0002	0.0004	0.007700649	7.70065E-08	0.0004
69	0.0002	0.0002	7.44316E-06	7.44316E-11	0.0002

LSI values for all the bus starting from bus number 2 was calculated which is shown in the table 4.7. Generally, higher value of LSI means the bus is loss prone. The resistance when divided by base impedance gives the values of per unit impedance. The value of base impedance was calculated 1.6028. The voltage profile was determined from the load flow study. The per unit value of voltage is squared which is displayed in column 4. Finally, the value of LSI was calculated which is shown in the column 5.

Table 4.7 LSI calculation in 69 bus system

Receiving node	Total effective reactive power (pu)	Resistance(pu)	Square of node voltage(pu)	LSI
2	0.026937799	0.000311963	0.9999400	0.000016808
3	0.026937799	0.000311963	0.9998600	0.000016810
4	0.024998677	0.000935888	0.9996800	0.000046807
5	0.018962671	0.015660525	0.9980410	0.000595097
6	0.019083736	0.228356656	0.9802782	0.008891145
7	0.019067381	0.237715535	0.9619686	0.009423618
8	0.018653122	0.057525912	0.9576188	0.002241054
9	0.01778517	0.030759517	0.9554085	0.001145192
10	0.00529675	0.510994811	0.9456785	0.005724170
11	0.005094346	0.116798814	0.9435402	0.001261236
12	0.003798219	0.44386045	0.9374112	0.003596883
13	0.002355225	0.642643047	0.9317655	0.003248819
14	0.002305042	0.651378001	0.9262138	0.003242131
15	0.002254971	0.660112955	0.9207170	0.003233427
16	0.002251737	0.122663712	0.9196810	0.000600657
17	0.001952058	0.233597628	0.9179939	0.000993462
18	0.001601007	0.002932449	0.9179939	0.000010229
19	0.001251342	0.204397925	0.9170935	0.000557788
20	0.001251217	0.131398666	0.9165382	0.000358759
21	0.001245352	0.213132879	0.9156193	0.000579773
22	0.000435001	0.008734954	0.9156002	0.000008300
23	0.000400016	0.099266513	0.9154662	0.000086750
24	0.000400035	0.216065327	0.9151792	0.000188889
25	0.000200019	0.467195256	0.9148731	0.000204286
26	0.000200007	0.192730522	0.9147392	0.000084281
27	0.0001	0.10806386	0.9147201	0.000023628

Receiving node	Total effective power(pu)	Resistance in per unit(pu)	Square of node voltage(pu)	LSI
28	0.000652009	0.002745271	0.9998600	0.000003580
29	0.000466063	0.039931218	0.9997000	0.000037232
30	0.000280019	0.24819748	0.9994601	0.000139075
31	0.000280003	0.043799555	0.9994201	0.000024542
32	0.000280017	0.218997776	0.9992202	0.000122742
33	0.000280041	0.523473317	0.9987004	0.000293570
34	0.000180034	1.065664393	0.9980210	0.000384473
35	4.00016E-05	0.919665876	0.9979011	0.000073731
36	0.001291563	0.002745271	0.9956647	0.000007122
37	0.00110487	0.039931218	0.9953255	0.000088652
38	0.000919203	0.065699333	0.9950063	0.000121388
39	0.000919059	0.018967329	0.9949065	0.000035043
40	0.000749002	0.001123066	0.9949065	0.000001691
41	0.000579572	0.454404788	0.9935106	0.000530161
42	0.000569236	0.193416839	0.9929325	0.000221767
43	0.000569031	0.025580937	0.9928528	0.000029322
44	0.000526007	0.005740113	0.9928329	0.000006082
45	0.000526077	0.067945464	0.9926336	0.000072020
46	0.000263	0.000561533	0.9926336	0.000000298
47	0.006054575	0.002121346	0.9995800	0.000025698
48	0.006068266	0.053096042	0.9970821	0.000646288
49	0.00552997	0.180813549	0.9894281	0.002021154
50	0.002747835	0.051286659	0.9883342	0.000285181
51	0.000310009	0.057900267	0.9575601	0.000037490
52	2.70001E-05	0.207080803	0.9575405	0.000011678
53	0.012296435	0.108563	0.9499816	0.002810450

Receiving Node	Total effective reactive power(pu)	Resistance in per unit(pu)	Square of node voltage(pu)	LSI
54	0.012266182	0.126656834	0.9436568	0.003292714
55	0.012088454	0.177319567	0.9349923	0.004585106
56	0.011914773	0.175510184	0.9265603	0.004513822
57	0.012036762	0.992041209	0.8838068	0.027021661
58	0.011952174	0.488970249	0.8631339	0.013541949
59	0.011901427	0.189798073	0.8551996	0.005282669
60	0.011182382	0.240897554	0.8459401	0.006368793
61	0.011221422	0.316642084	0.8323825	0.008537360
62	0.002270565	0.060770323	0.8318534	0.000331748
63	0.002040681	0.090469167	0.8311604	0.000444243
64	0.00204336	0.443298918	0.8276996	0.002188763
65	0.000420208	0.649506226	0.8266628	0.000660312
66	0.000260008	0.125533768	0.9434237	0.000069194
67	0.00013	0.002932449	0.9434237	0.000000808
68	0.000400077	0.461330358	0.9367723	0.000394050
69	0.0002	0.002932449	0.9367723	0.000001252

Now the buses are sorted in descending order according to LSI. The top ranked bus are 57,58,7,6,61,60,10,59,55,56,12,54,13,14,15,53,8,64,49,11,9,17,65,48,16,5,21,19,41,63,68,34,20,62.Top 34 buses are are selected for the optimal allocation of the capacitor bank.

4.2.3 Optimal allocation of capacitor bank in IEEE 69 bus system

After simulation it was found that, the optimal location of capacitor bank was found at nodes 7,21 and 62. The optimal sizes in this location was obtained after optimization using PSO. At bus number 7,21 and 62, 300kVAr,150kVAr and 750kVAr capacitor bank was allocated respectively whose cumulative sum was 1200 kVAr. The active power loss decreased from 225.338 kW to 146.8644 kW after compensation which corresponds to 42.48% loss reduction. Similarly, there was significant improvement in the lowest value of

voltage which rose from 0.90921 pu before compensation to 0.93219 pu after compensation. The minimum system voltage occurred at bus number 65. The voltage profile of the compensated and uncompensated IEEE 69 bus system is illustrated in the figure 4.4

4.2.4 Result validation and cost benefit analysis

The result obtained after the simulation was further compared with other papers. It was found PSO provided superior performance in terms of loss reduction and voltage profile improvement.

Table 4.8 IEEE 69 bus system result validation

Parameters	Uncompensated	Fuzzy GA (Das,2007)	cuckoo search algorithm El-Fergany and Almoataz(2007)	hybrid evolutionary approach Muthukumar and S Jayalalitha (2018)	Proposed method-PSO
Total losses (kW)	225.338	156.64	148	147.74	146.864
Optimal location #Bus No. Size	-	#61 700 #64 800 #59 100	#62 250 #21 1450	#61 1150 #18 250	#7 300 #21 150 # 62 750

Parameters	Uncompensated	Fuzzy GA (Das,2007)	cuckoo search algorithm El-Fergany and Almoataz(2007)	hybrid evolutionary approach Muthukumar and S Jayalalitha (2018)	Proposed method-PSO
Optimal size in kVAr	-	1600	1700	1400	1200
Vmin (pu) at	0.90921, at 65	0.9369 at 65	0.93 at 65	0.9288 at 27	0.9321 at 65

The table shows the cost and benefits obtained before and after the installation of capacitor bank in the IEEE 69 bus radial distribution system. The net savings of 78.7436 kW was obtained after the capacitor bank installation. Similarly, the price of electricity was $168 kW-year (Abou,2016). The net annual savings obtained after installation of capacitor was $12583.

Table 4.9 IEEE 69 bus system cost and benefit analysis after compensation

Parameters	Before compensation	After compensation
Minimum voltage in pu	0.90921 # 27	0.93219 # 27

Parameters	Before compensation	After compensation
Active power loss (kW)	225.338	146.8644
Total power saved (kW)	-	78.4736
Price of electricity (kW-year) in $	168	168
Annual savings of Electricity compared to base case ($)	-	13,183
Total size of capacitor bank(kVAr)	-	1200
Capacitor price per year ($)	0	600
Net annual savings ($)		12,583

4.3 53 Bus Parsa feeder

4.3.1 Calculation of price of electricity

Considering the price of electricity in Nepal be Rs 10/kWh and exchange rate of $1=Nrs.115 and hours in year=8760, The price of electricity is

=$ 10/115*8760

=$761.734 kW-Year

4.3.2 Calculation of LLF

The graph of the load profile is shown in the figure below. Since this feeder lies in Terai region, energy demand is much higher during summer season than the winter. The peak load is 9504 kW which occurred in 10AM in Ashad,2076. This peak demand is caused by

energy demand both from the commercial and domestic consumers. As seen from the figure 4.5 the load profile of summer month is much higher than the winter season. The average load of the system is 4784.6 kW and the load factor is 0.5434.
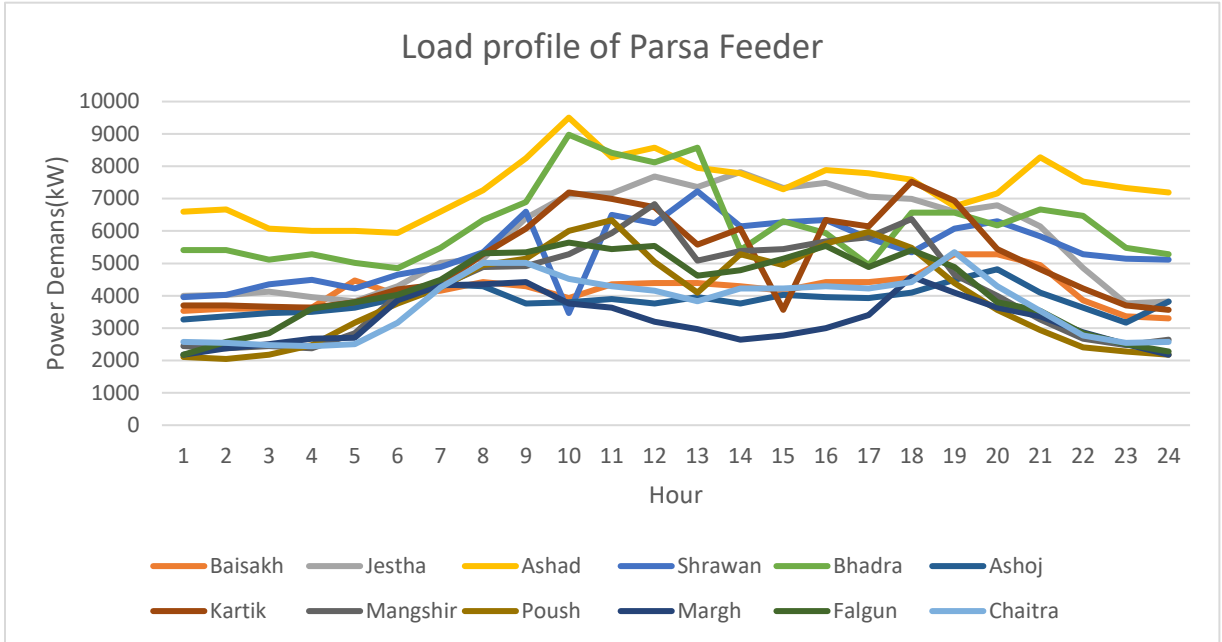
Figure 4.5 Parsa feeder load profile

The monthly load profile of the system in the year 2076 B.S. is shown in the table below. The load data of the month corresponds to the first day of that month.

Table 4.10 Monthly load profile of Parsa feeder

Hours	Baisakh	Jestha	Ashad	Shrawan	Bhadra	Ashoj	Kartik	Mangshir	Poush	Margh	Falgun	Chaitra
1	3531	3993	6600	3960	5412	3267	3696	2442	2112	2178	2178	2574
2	3597	4026	6666	4026	5412	3366	3696	2376	2046	2376	2574	2541
3	3597	4125	6072	4356	5115	3465	3663	2442	2178	2508	2838	2475
4	3630	3960	6006	4488	5280	3498	3630	2376	2475	2673	3597	2442
5	6468	3828	6006	4224	5016	3630	3795	2838	3168	2706	3795	2508
6	4026	4290	5940	4653	4851	3927	4191	4026	3762	3861	4026	3168
7	4158	5016	6600	4884	5478	4356	4356	4290	4257	4323	4488	4257
8	4422	5148	7260	5346	6336	4290	5280	4884	4950	4356	5313	5016
9	4290	6402	8250	6600	6897	3762	6072	4917	5148	4422	5346	5016
10	3927	7128	9504	3465	8976	3795	7194	5280	6006	3762	5643	4521
11	4356	7161	8283	6501	8415	3894	6996	5940	6336	3630	5445	4290

Hours	Baisakh	Jestha	Ashad	Shrawan	Bhadra	Ashoj	Kartik	Mangshir	Poush	Margh	Falgun	Chaitra
12	4389	7689	8580	6237	8118	3762	6732	6831	5049	3201	5544	4158
13	4389	7359	7953	7227	8580	3960	5577	5082	4092	2970	4620	3828
14	4290	7821	7788	6138	5412	3762	6072	5379	5280	2640	4785	4224
15	4158	7326	7293	6270	6303	4026	3564	5445	4950	2772	5148	4224
16	4422	7491	7887	6336	5940	3960	6336	5676	5610	3003	5544	4290
17	4422	7062	7788	5775	4950	3927	6138	5808	5973	3399	4884	4224
18	4554	6996	7590	5346	6567	4092	7524	6369	5478	4587	5412	4422
19	5280	6600	6765	6072	6567	4488	6930	4653	4389	4092	4884	5346
20	5280	6798	7161	6303	6171	4818	5445	3993	3564	3630	3795	4290
21	4950	6138	8283	5841	6666	4092	4818	3267	2937	3366	3531	3531
22	3861	4861	7524	5280	6468	3630	4224	2673	2409	2871	2838	2772
23	3366	3762	7326	5148	5478	3168	3696	2475	2277	2508	2508	2541
24	3300	3821	7194	5115	5280	3818	3564	2640	2178	2178	2277	2574

Here,

Peak load=9504 kW

Average load=4784.67 kW

Since the system is 11kV the peak current and average current can be calculated as follows:

Peak current (I_{max})=9504/11=864A

Average current (I_{avg})= 4784.67 kW/11=4351=435A

LLF= (I_{avg}/ I_{max}) ^2

$\quad$ = (435/864) ^2

$\quad$ =0.2534.

Load factor which is the ratio of average load to the maximum load was calculated =0.5034

LLF is related to Annual Load Factor (LF) as:

LLF = α * Annual Load Factor + $(1 - \alpha)$ * (Annual Load Factor)^2

The value of α is 0.2 for medium voltage feeders and distribution substations Baitch(2004)

LLF=0.2*0.5043+(1-0.2) *0.5034^2

LLF=0.2534

The result shows that same value of LLF was obtained from exact and approximate technique.

4.3.3 Load flow of 53 Bus Parsa feeder

The load flow of the system is carried out using backward/forward sweep algorithm. The voltage profile of the system a represented in the figure 4.6.

The value of voltage is least at bus number 53 which is 0.7421 pu. As seen from the graph of the system, the voltage profile is in decreasing pattern from bus 1 to 23 which is the main bus of the system. Voltage profile is in decreasing pattern in main bus because voltage at bus number 1 is 1 p.u and due to impedance, voltage decreases. Voltage at bus number 24 rises and nearly equal to bus number 3 which is 0.96 p.u. This is because branching occurs at bus number 3 which is connected to bus number 24.Similarly voltage at bus number 22 is 0.743 p.u which is nearly equal to bus number 52 because branching occurred
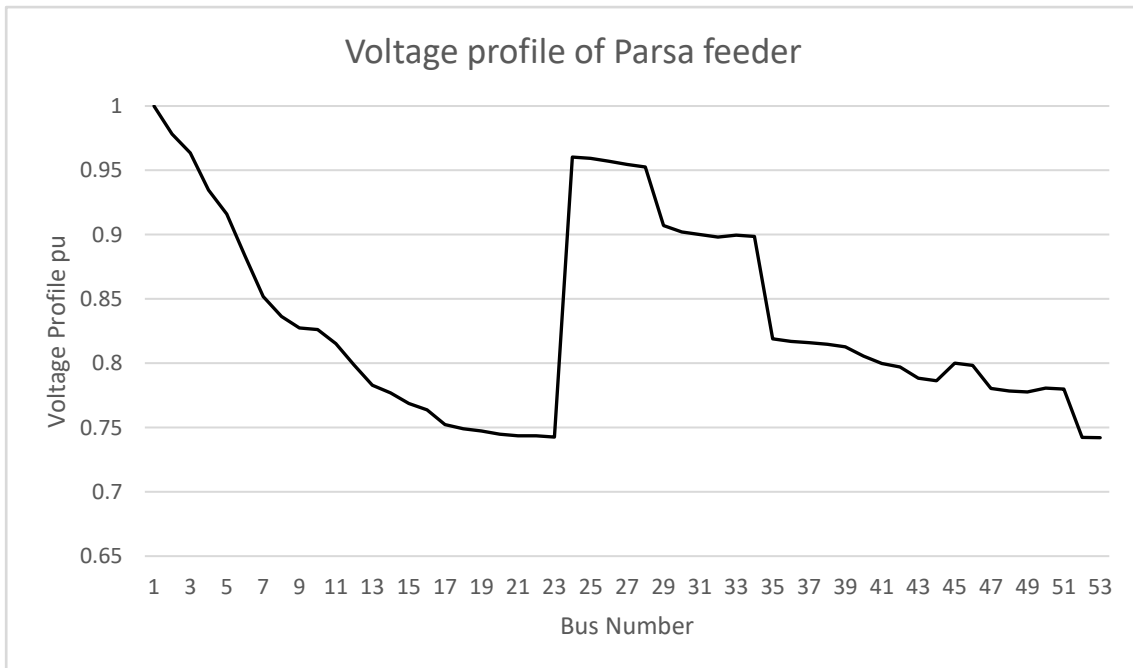
Figure 4.6 Voltage profile of 53 bus Parsa feeder

from node 22 to 52.In the similar fashion, branching occurred from node 5 to node 29 so that these two node voltage was nearly equal.

4.3.4 Loss sensitive index and capacitor sizing

The value effective reactive power in per unit, per unit resistance and per unit voltage at each node was computes and LSI was obtained. The value of LSI was high for bus 4 because of high value of resistance and nearly equal voltage compared to the other initial nodes i.e. bus 2 and 3. In the same manner, the value of LSI for the terminal nodes was indexed in the bottom of the list. The value of LSI was sorted in descending order and presented in the table shown below. Out of 53 bus,26 buses with high value of LSI has been used as variable for the optimization problem.

Table 4.11 LSI values for 53 bus Parsa feeder

Bus number	LSI
4	0.77873
6	0.75768
7	0.74693
2	0.63239
5	0.48724
3	0.4096
8	0.33459
11	0.3099
12	0.22441
9	0.18719
13	0.16826
17	0.10129
15	0.070777
14	0.051251
16	0.049309
40	0.028401

Bus Number	LSI
29	0.022901
36	0.02064
20	0.011296
30	0.010739
45	0.0093972
41	0.0084181
26	0.0082276
43	0.0074841
27	0.0074231
24	0.0066439
22	0.0051558
47	0.0040954
50	0.0039867
33	0.003906
42	0.0033248
38	0.0029905
31	0.0028536
35	0.0023152
28	0.0020564
23	0.0020208
48	0.0019719
10	0.0019321
32	0.0018551
19	0.001725
46	0.0016679
44	0.0016131
39	0.0014795
21	0.0014067
52	0.0013583

Bus number	LSI
34	0.00085123
25	0.00075404
49	0.00071532
51	0.00058802
53	0.00027849

Loss sensitive index (LSI) of all the node was calculated and out of 52 buses, the 26 bus whose LSI value was higher was selected for the optimal allocation of the capacitor bank. Bus 4 , 6, 7 , 2 ,5 , 3 , 8 ,11 ,12 ,13 ,9 , 17, 15 ,14 ,29 , 40 ,16, 36 ,20 ,30 ,18 , 24 45 , 41, 43, 26 was selected as the variable of for the optimal allocation of the capacitor bank. After simulation using PSO, following result was obtained

Table 4.12 Capacitor bank sizing and LSI

Bus no.	Size allocated	Actual size (kVAr)
4	0.625	900
6	0	0
7	0.375	600
2	0	0
5	0	0
3	0	0
8	0	0
11	0	0
12	1	1200
13	0	0
9	0	0
17	0.875	1200
15	0	0
14	0	0
40	0	0
16	0	0

Bus no.	Size allocated	Actual size (kVAr)
20	0	0
30	0.125	300
18	0	0
24	0	0
45	0	0
41	0.125	300
43	0	0
26	0.125	300

4.3.5 Optimal allocation of capacitor bank in 53 bus system

Total capacitor bank of size 4950kVAr is obtained in 8 different location shown in the table below. Four capacitor banks at node 4,7,12,17 was selected for the main feeder while other banks were selected for the laterals. There was sharp gradient of voltage from bus number 2 to 23 which has been compensated by capacitor bank at node 4,7,12 and 17. Capacitor bank size at nodes 36,30,41 and 26 are lesser than those installed at the main feeder because these are supplying the laterals and reactive power demand is lesser at the laterals than the initial nodes of the main feeder.

Table 4.13 Bus Number and capacitor size

S. no	Bus number	Capacitor size(kVAr)
1	4	900
2	7	600
3	12	1200
4	17	1200
5	36	150
6	30	300
7	41	300
8	26	300
Total		4950

The comparitive voltage profile of the feeder before and after compensation has been presented in the figure 4.7.
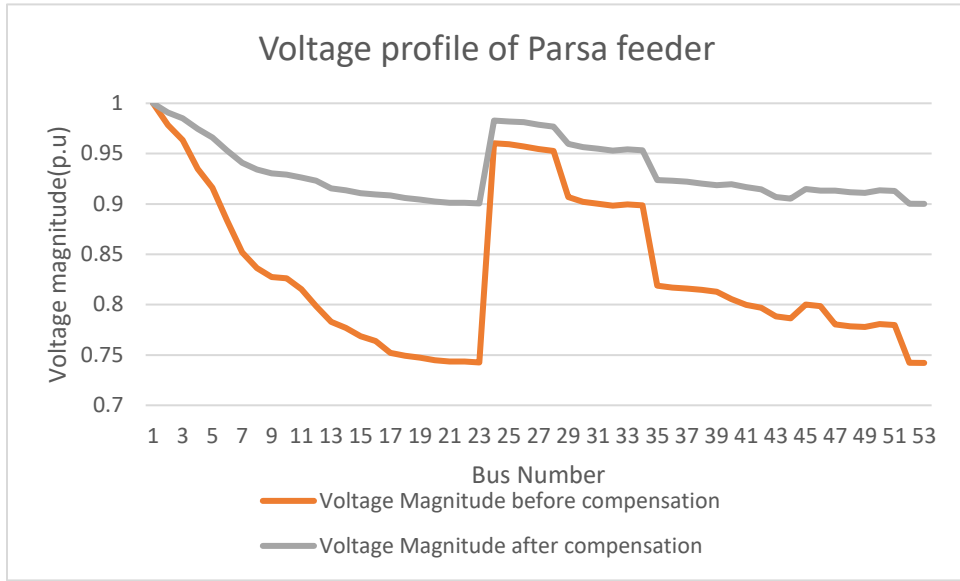
Figure 4.7 Voltage profile of Parsa feeder after compensation

After compensation the voltage profile increased significantly as shown in the table below.

Table 4.14 Voltage profile of Parsa feeder before and after compensation

Bus no	Voltage magnitude before compensation(pu)	Voltage magnitude after compensation(pu)
1	1	1
2	0.97825	0.99081
3	0.96357	0.98503
4	0.93478	0.97452
5	0.916	0.96608
6	0.88344	0.95289
7	0.85176	0.94091
8	0.83636	0.93408
9	0.82753	0.93038
12	0.79858	0.92313

Bus no	Voltage magnitude before compensation(pu)	Voltage magnitude after compensation(pu)
14	0.77698	0.9134
15	0.76861	0.91065
17	0.75219	0.90844
18	0.74909	0.90588
19	0.74727	0.90438
20	0.74477	0.90232
21	0.74356	0.90132
22	0.74351	0.90128
23	0.7425	0.90045
24	0.96024	0.98283
25	0.9593	0.98191
26	0.95707	0.98115
27	0.95453	0.97867
28	0.95262	0.97681
29	0.90692	0.95968
30	0.90204	0.95653
31	0.90019	0.95478
32	0.89817	0.95287
33	0.89952	0.95414
34	0.89851	0.95319
35	0.8189	0.92386
36	0.81698	0.92313
37	0.81587	0.92214
38	0.81472	0.92016
39	0.81286	0.91851
41	0.7997	0.91672
42	0.79702	0.91439
43	0.78836	0.90687

Bus no	Voltage magnitude before compensation(pu)	Voltage magnitude after compensation(pu)
45	0.80012	0.91481
47	0.78028	0.9133
48	0.77853	0.91181
49	0.77776	0.91115
50	0.78068	0.91364
51	0.77981	0.91289
52	0.74229	0.90027
53	0.7421	0.90011

4.3.6 Calculation of cost and benefits of capacitor bank installation

After the installation of capacitor bank the total loss reduced to 804.147 kW from 1473kW.There was net savings of 669kW of electricity. This corresponds to loss reduction by 45.41% Similarly, there was increase in voltage profile of the system. Load loss factor was calculated 0.2534 and cost of the electricity was $761.734 kW-year. Total size of capacitor bank obtained after the simulation was 4950 kVAr. The price per kVAr of the capacitor bank was $5 while the life of capacitor bank was assumed 10 years so the annual cost of capacitor bank was $2475.The annual savings considering LLF which was $129136.The net annual savings obtained after installation of capacitor bank was $124,186.

Table 4.15 Parsa feeder cost and benefits after capacitor bank installation

Parameters	Before compensation	After compensation
Minimum voltage in pu	0.7421 # 53	0.90011 # 53
Power loss	1473	804.147
Total power saved (kW)	-	669.02
Annual savings of Electricity compared to base case ($)	-	509615
Load loss factor (LLF)		0.2534
Annual savings considering LLF		129136
Total size of capacitor bank(kVAr)	-	4950

Parameters	Before compensation	After compensation
Net annual savings ($)		124,186

4.3.7 Convergence of PSO
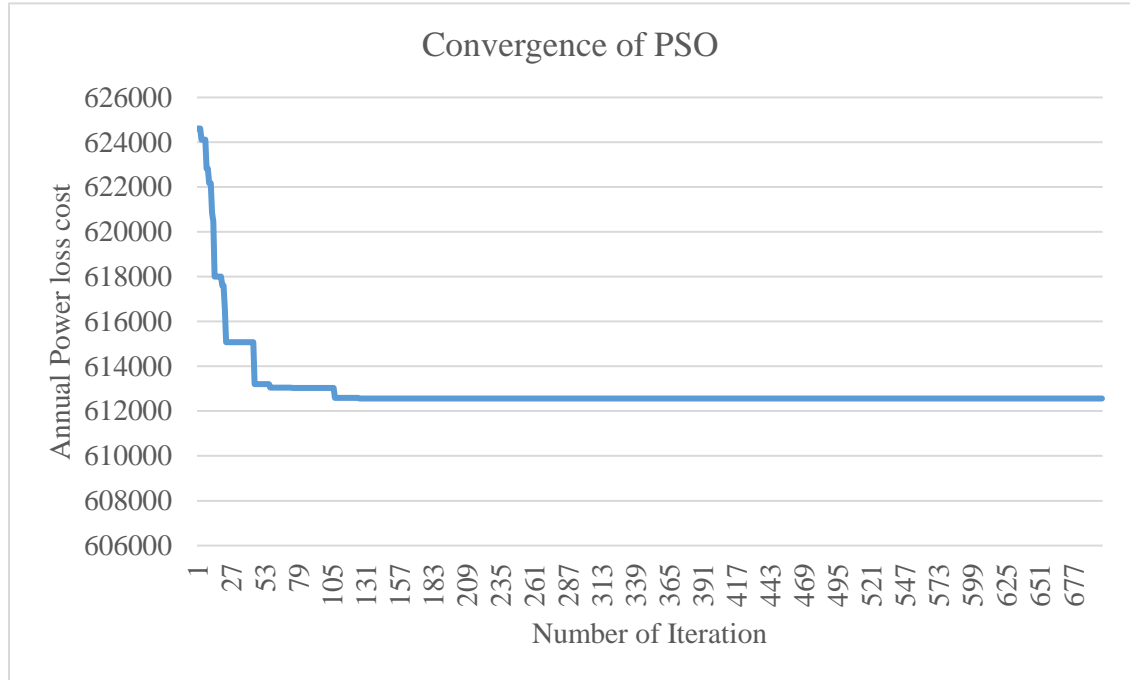
Figure 4.8 Convergence of PSO

The minimum power loss obtained was 804.182kW obtained after 127th iterations. The corresponding power loss cost is \$612563. This is the global best value of optimization problem. Results obtained after simulation has been presented in the Appendix II. since this is optimization problem, optimum value of solution may not be obtained at single iteration. So, algorithm should run number of times before actual value of solution is obtained. The value of five iterations summary is presented in the Appendix III.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Losses in radial distribution system and voltage dip was found very high in radial distribution system. More losses and high voltage deviation was found when the system is operating in its peak load conditions. High loss occurred in the line was due to its lengthy feeders and high electrical loads. Radial distribution system could be a better for short length feeder with light loads. It was also observed that, if distribution system operated near unity power factor, loss would be minimum.

After compensation using capacitor bank, the peak power loss of IEEE 34 bus, IEEE 69 bus and Parsa feeder decreased by 29.9%,42.48% and 45.41% respectively. Therefore, installation of capacitor bank presents the possible tool to reduce the losses. Comparing the results with the earlier publication, it was found that this method provides superior results which proves superiority of particle swarm optimization.

The result shows significant voltage profile improvement can be obtained after the placement of capacitor bank in radial distribution system. The lowest voltage rose from 0.94171 pu to 0.95062 in IEEE 34 bus,0.90921 pu to 0.9321 pu in IEEE 69 bus,0.7421 pu to 0.90011 pu in Parsa feeder. There was significant drop in voltage in case of uncompensated 53 bus Parsa feeder because of high load and long radial feeder which shows lengthy radial distribution system increases losses and decreases the voltage profile of the system. Furthermore, it was found significant loss reduction can be obtained by operating the distribution system near to unity power factor. Therefore, the algorithm represented a potential tool to study the system loss reduction and improve power quality of the utilities.

5.2 Recommendations

Power demand is increasing on daily basis with the increase in prosperity of the country. Electrical utilities should work regularly for improving the performance of the overall power system to reduce the system operating cost and increase the power quality of the system. Use of capacitor bank in radial distribution can be cost effective technique for loss reduction and voltage profile improvement that can be implemented within short period of time. However, switching transients of the capacitor bank should be thoroughly studied

and proper switchgear and protection system is required before implementing capacitor bank in the system. Further study can be done to design the switchgear and protection system for capacitor bank installation, effect of harmonics in the Parsa feeder after capacitor installation.

REFERENCES

Nepal Electricity Authority (2019), A year in review fiscal year 2018/19. NEA, 2019.

Bhattarai Trilochan and Shakya Shree Raj, (2017)," Estimation of Technical and Non-Technical Losses of an 11kV Industrial Feeder: A Case Study in Kawasoti Distribution Centre", Volume 5, Proceedings of IOE Graduate Conference.

Prakash, D. B., & Lakshminarayana, C. (2017). Optimal siting of capacitors in radial distribution network using whale optimization algorithm. Alexandria Engineering Journal, 56(4), 499-509.

Ghosh, S., & Das, D. (1999). Method for load-flow solution of radial distribution networks. IEE Proceedings-Generation, Transmission and Distribution, 146(6), 641-648.

Bhujel, D., Adhikary, B., & Mishra, A. K. (2012, September). A load flow algorithm for radial distribution system with distributed generation. In 2012 IEEE Third International Conference on Sustainable Energy Technologies (ICSET) (pp. 375-380). IEEE.

Sunisith, S., & Meena, K. (2014). Backward/Forward sweep-based distribution load flow method. International electrical engineering journal (IEEJ), 5(9), 1539-1544.

ÖZGÖNENEL, O., & KARAGÖL, S. (2017). A novel generation and capacitor integration technique for today's distribution systems. Turkish Journal of Electrical Engineering & Computer Sciences, 25(3), 2434-2443.

Sirjani, R., Mohamed, A., & Shareef, H. (2010). System using Harmony Search Algorithm. Journal of Applied Sciences, 10(23), 2998-3006.

Reddy, P., & Prasad, D. (2013). Application of loss sensitivity factor and genetic algorithm for capacitor placement for minimum loss in radial distribution system. International Journal of Engineering Sciences & Research Technology, 9, 2400-2403.

Murthy, K. R., Raju, M. R., Rao, G. G., & Rao, K. N. (2010, December). Comparison of loss sensitivity factor & Index vector methods in determining optimal capacitor locations

in agricultural distribution. In Proc. 16th National Power System Conference (No. 6, pp. 26-30).

Gou, B., & Abur, A. (1999, July). Optimal capacitor placement for improving power quality. In 1999 IEEE Power Engineering Society Summer Meeting. Conference Proceedings (Cat. No. 99CH36364) (Vol. 1, pp. 488-492). IEEE.

M. J. Tahir, Badri. A. Bakar, M. Alam , M. S. Mazlihum,(2019), "Optimal capacitor placement in a distribution system using ETAP software", Indonesian Journal of Electrical Engineering and Computer Science, Vol. 15, No. 2, pp. 650~660.

Avinash Khatri KC, Tikaram Regmi,"(2018),"Optimal Allocation of Capacitor Bank for Loss Minimization and Voltage Improvement Using Analytical Method" SCITECH Nepal, Vol. 14, No. 1

 Rezaee Jordehi, A., & Jasni, J. (2013). Parameter selection in particle swarm optimisation: a survey. Journal of Experimental & Theoretical Artificial Intelligence, 25(4), 527-542.

Abou El-Ela, A. A., El-Sehiemy, R. A., Kinawy, A. M., & Mouwafi, M. T. (2016). Optimal capacitor placement in distribution systems for power loss reduction and voltage profile improvement. IET Generation, Transmission & Distribution, 10(5), 1209-1221.

El-Shorbagy, M. A., & Hassanien, A. E. (2018). Particle swarm optimization from theory to applications. International Journal of Rough Sets and Data Analysis (IJRSDA), 5(2), 1-24.

Baitch, A., (2004). Distribution Loss Factor Calculation Methodology. Tasmania: Aurora Energy BES Pty. Ltd.

Malmedal, K. and Sen, P.K., (2008), A better understanding of load and loss factors. In 2008 IEEE Industry Applications Society Annual Meeting (pp. 1-6). IEEE.

APPENDIX I: Network data

Table 1-Load data and Line date of IEEE 34 Bus System

Sending node	Receiving node	Resistance- R(Ω)	Reactance - X(Ω)	Active power - P(kW)	Reactive power Q(kVAr)
1	2	0.117	0.048	230	142.5
2	3	0.1073	0.044	0	0
3	4	0.1645	0.0457	230	142.5
4	5	0.1495	0.0415	230	142.5
5	6	0.1495	0.0415	0	0
6	7	0.3144	0.054	0	0
7	8	0.2096	0.036	230	142.5
8	9	0.3144	0.054	230	142.5
9	10	0.2096	0.036	0	0
10	11	0.131	0.0225	230	142.5
11	12	0.1048	0.018	137	84
3	13	0.1572	0.027	72	45
13	14	0.2096	0.036	72	45
14	15	0.1048	0.018	72	45
15	16	0.0524	0.009	13.5	7.5
6	17	0.1794	0.0498	230	142.5
17	18	0.1645	0.0457	230	142.5
18	19	0.2079	0.0473	230	142.5
19	20	0.189	0.043	230	142.5
20	21	0.189	0.043	230	142.5
21	22	0.262	0.045	230	142.5
22	23	0.262	0.045	230	142.5
23	24	0.3144	0.054	230	142.5
24	25	0.2096	0.036	230	142.5
25	26	0.131	0.0225	230	142.5
26	27	0.1048	0.018	137	85

Sending node	Receiving node	Resistance - R(Ω)	Reactance- X(Ω)	Active power - P(kW)	Reactive power Q(kVAr)
7	28	0.1572	0.027	75	48
28	29	0.1572	0.027	75	48
29	30	0.1572	0.027	75	48
10	31	0.1572	0.027	57	34.5
31	32	0.2096	0.036	57	34.5
32	33	0.1572	0.027	57	34.5
33	34	0.1048	0.018	57	34.5

Table 2. IEEE 69 Bus System Data

Sending node	Receiving Node	Resistance -R(Ω)	Reactance- X(Ω)	Active power -P(kW)	Reactive power Q(kVAr)
1	2	0.0005	0.0012	0	0
2	3	0.0005	0.0012	0	0
3	4	0.0015	0.0036	0	0
4	5	0.0251	0.0294	0	0
5	6	0.366	0.1864	2.6	2.2
6	7	0.381	0.1941	40.4	30
7	8	0.0922	0.047	75	54
8	9	0.0493	0.0251	30	22
9	10	0.819	0.2707	28	19
10	11	0.1872	0.0619	145	104
11	12	0.7114	0.2351	145	104
12	13	1.03	0.34	8	5
13	14	1.044	0.34	8	5
14	15	1.058	0.3496	0	0
15	16	0.1966	0.065	45	30

Sending node	Receiving node	Resistance -R(Ω)	Reactance- X(Ω)	Active power -P(kW)	Reactive power Q(kVAr)
16	17	0.3744	0.1238	60	35
17	18	0.0047	0.0016	60	35
18	19	0.3276	0.1083	0	0
19	20	0.2106	0.069	1	0.6
20	21	0.3416	0.1129	114	81
21	22	0.014	0.0046	5	3.5
22	23	0.1591	0.0526	0	0
23	24	0.3463	0.1145	28	20
24	25	0.7488	0.2475	0	0
25	26	0.3089	0.1021	14	10
26	27	0.1732	0.0572	14	10
3	28	0.0044	0.0108	26	18.6
28	29	0.064	0.1565	26	18.6
29	30	0.3978	0.1315	0	0
30	31	0.0702	0.0232	0	0
31	32	0.351	0.116	0	0
32	33	0.839	0.2816	14	10
33	34	1.708	0.5646	19.5	14
34	35	1.474	0.4873	6	4
3	36	0.0044	0.0108	26	18.55
36	37	0.064	0.1565	26	18.55
37	38	0.1053	0.123	0	0
38	39	0.0304	0.0355	24	17
39	40	0.0018	0.0021	24	17
40	41	0.7283	0.8509	1.2	1
41	42	0.31	0.3623	0	0
42	43	0.041	0.0478	6	4.3
43	44	0.0092	0.0116	0	0

Sending node	Receiving node	Resistance -R(Ω)	Reactance- X(Ω)	Active power -P(kW)	Reactive power Q(kVAr)
44	45	0.1089	0.1373	39.22	26.3
45	46	0.0009	0.0012	39.22	26.3
4	47	0.0034	0.0084	0	0
47	48	0.0851	0.2083	79	56.4
48	49	0.2898	0.7091	384.7	274.5
49	50	0.0822	0.2011	384.7	274.5
8	51	0.0928	0.0473	40.5	28.3
51	52	0.3319	0.114	3.6	2.7
9	53	0.174	0.0886	4.35	3.5
53	54	0.203	0.1034	26.4	19
54	55	0.2842	0.1447	24	17.2
55	56	0.2813	0.1433	0	0
56	57	1.59	0.5337	0	0
57	58	0.7837	0.263	0	0
58	59	0.3042	0.1006	100	72
59	60	0.3861	0.1172	0	0
60	61	0.5075	0.2585	1244	888
61	62	0.0974	0.0496	32	23
62	63	0.145	0.0738	0	0
63	64	0.7105	0.3619	227	162
64	65	1.041	0.5302	59	42
11	66	0.2012	0.0611	18	13
66	67	0.0047	0.0014	18	13
12	68	0.7394	0.2444	28	20
68	69	0.0047	0.0016	28	20

Table 3.53 Bus Parsa Feeder

Sending node	Receiving node	Resistance -(Ω)	Reactance -(Ω)	Apparent power(kVA)	Active power - P(kW)	Reactive power Q(kVAr)
1	2	0.16745	0.1575	400	320	240
2	3	0.11722	0.11025	200	160	120
3	4	0.25118	0.23625	200	160	120
4	5	0.16745	0.1575	300	240	180
5	6	0.3349	0.315	200	160	120
6	7	0.3349	0.315	200	160	120
7	8	0.16745	0.1575	300	240	180
8	9	0.10047	0.0945	100	80	60
9	10	0.6648	0.335	200	160	120
9	11	0.16745	0.1575	650	520	390
11	12	0.3349	0.315	200	160	120
12	13	0.3349	0.315	250	200	150
13	14	0.16745	0.1575	100	80	60
14	15	0.25118	0.23625	300	240	180
15	16	0.16745	0.1575	400	320	240
16	17	0.50235	0.4725	300	240	180
17	18	0.16745	0.1575	225	180	135
18	19	0.9972	0.5025	150	120	90
18	20	0.3349	0.315	200	160	120
20	21	0.6648	0.335	150	120	90
20	22	0.16745	0.1575	150	120	90
22	23	0.3349	0.315	200	160	120
3	24	0.4986	0.25125	100	80	60
24	25	0.9972	0.5025	100	80	60
24	26	0.6648	0.335	100	80	60
26	27	0.6648	0.335	200	160	120
27	28	0.9972	0.5025	200	160	120

Sending node	Receiving node	Resistance -(Ω)	Reactance -(Ω)	Apparent power(kVA)	Active power - P(kW)	Reactive power Q(kVAr)
5	29	0.9972	0.5025	175	140	105
29	30	0.6648	0.335	200	160	120
30	31	0.6648	0.335	125	100	75
31	32	1.3296	0.67	150	120	90
30	33	0.9972	0.5025	150	120	90
33	34	0.9972	0.5025	100	80	60
9	35	0.86424	0.4355	200	160	120
35	36	0.9972	0.5025	100	80	60
36	37	0.9972	0.5025	100	80	60
35	38	0.9972	0.5025	250	200	150
38	39	1.3296	0.67	125	100	75
11	40	0.86424	0.4355	150	120	90
40	41	0.9972	0.5025	150	120	90
41	42	0.6648	0.335	125	100	75
42	43	3.324	1.675	100	80	60
43	44	1.3296	0.67	125	100	75
40	45	1.3296	0.67	200	160	120
45	46	0.9972	0.5025	150	120	90
13	47	0.6648	0.335	100	80	60
47	48	0.6648	0.335	125	100	75
48	49	0.6648	0.335	100	80	60
13	50	0.6648	0.335	200	160	120
50	51	0.9972	0.5025	75	60	45
22	52	0.6648	0.335	100	80	60
52	53	0.3324	0.1675	50	40	30

APPENDIX II: Simulation result in MATLAB

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t = 245 BEST =612564.5942

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t = 254 BEST =612564.4636

t = 255 BEST =612564.4636

t = 256 BEST =612564.4636

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t = 258 BEST =612564.4636

t = 259 BEST =612564.4636

t = 260 BEST =612564.4636

t = 261 BEST =612564.4636

t = 285 BEST =612563.9155

t = 286 BEST =612563.8924

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t = 662 BEST =612563.6747

t = 663 BEST =612563.6747

t = 664 BEST =612563.6747

t = 665 BEST =612563.6747

t = 666 BEST =612563.6747

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t = 689 BEST =612563.6747

t = 690 BEST =612563.6747

t = 691 BEST =612563.6747

t = 692 BEST =612563.6747

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t = 694 BEST =612563.6747

t = 695 BEST =612563.6747

t = 696 BEST =612563.6747

t = 697 BEST =612563.6747

t = 698 BEST =612563.6747

t = 699 BEST =612563.6747

t = 700 BEST =612563.6747

APPENDIX III: Simulation summary in MATLAB

1.Simulation summary of IEEE 34 bus system

Simulation count	Power loss	Bus number Size(kVAr)				Total size of capacitor bank(kVAr)
1	160.2674 kW	18	21	8	24	
		600	450	900	600	2550
2	161.9199 kW	18	23	9	25	
		1200	300	600	450	2550
3	160.4199 kW	21	7	9	25	
		750	900	150	600	2400
4	160.7778 kW	2	19	7	25	
		1200	750	900	750	3600
5	159.8648 kW	18	22	4	9	
		600	600	750	750	2700

2.Simulation summary of IEEE 69 bus system

Simulation count	Power loss	Bus number Size (kVAr)			Total size of capacitor bank(kVAr)
1	148.7944 kW	59	11	63	
		150	450	600	1200
2	146.7147 kW	12	15	62	
		150	150	750	1050
3	147.1317 kW	8	17	62	
		150	150	750	1050
4	146.8644 kW	7	21	62	
		300	150	750	1200
5	147.7122 kW	8	21	63	
		150	450	750	1350

3.Simulation summary of 53 bus Parsa feeder

Simulation count	Power loss(kW)	Bus number								Total Size of bank (kVAr)
		Size of bank (kVAr)								
1	808.4571	7	6	11	15	40	18	20	30	
		1200	150	1200	900	600	600	1050	450	6150
2	804.147	4	7	12	17	36	30	41	26	
		900	600	1200	1200	150	300	300	300	4950
3	805.8065	3	8	11	17	14	20	29	41	
		1200	1200	1200	450	300	1200	300	450	6300
4	806.8843	5	8	13	18	20	30	35	41	
		1200	1200	1200	450	600	150	300	300	5400
5	837.4292	5	8	17	16	18	29	43	45	
		1200	1200	1200	150	450	1200	450	150	6000