Radial Distribution System

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CANDIDATE'S DECLARATION

I, MOHD FARMAN, Roll No. 2K19/PSY/11, a student of M. Tech (Electrical Engineering), hereby declare that the report titled "Radial distribution system" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi, in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or another similar title of recognition.

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I hereby certify that the report titled "radial distribution system" which is submitted by MOHD FARMAN, 2K19/PSY/11, Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master ofTechnology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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Date: 30th June, 2020 **SUPERVISOR**

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ABSTRACT

Radial distribution system is always a part of interest for the researcher because the radial distribution are of different types and every type have its own specialty in the flow of power from supplying end to receiver end further, it always attracts the researchers with the new challenges such as minimizing the loss in radial distribution system and maximizing power flow from sending end to receiving end because it is the end product that the receiver gets and it should be as maximum as possible The main motive of this thesis is to understand about the IEEE-33 bus and IEEE-69 bus radial distribution system. This thesis comprises of determination of the losses of the IEEE-33 bus as well as IEEE-69 bus system by applying the general voltage profile and further disciplinary study has been done to investigate what will happen if the industrial and commercial voltage profile is applied on both IEEE-33 and IEEE-69 bus system and the losses are calculated for both the voltage profile on each of the system.

A disciplinary study has been done to understand the Teaching learning based optimization technique such that the losses of distribution system could be minimized by determining optimal locations for placement of bank of capacitor on both IEEE-33 and IEEE-69 bus system respectively. And discussion over the results is also covered followed by the conclusion and future scope.

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CHAPTER 1

1.1 Introduction

A large amount of power is being generated at the generating station and there is a continuous increase of demand leads to the installation of bigger size of alternators in order to cater the demand of the consumer to some extent. The power station site also depends on type of power system. Such as a new thermal power station is being constructed in such a way that the power plant must be near to the coal mines so that the cost of transportation of coal from mines to power station should be as low as possible. The location of the Hydro power station is governed by the easy availability of water facilities. And the nuclear power plant should be located away from the main consumption site due to various safety reasons. This leads to the problem for the transferring of bulk of power through the longer distance. And this bulk of power is only transferable by using high voltage transmission system.

Basic structure of the AC power systems

Electrical energy that is generated at generating station is aimed to be transported to various consumers but we have various levels of voltages between the station of generating and the consumer and these are as follows

1. Transmission
2. Sub transmission
3. Distribution.

1.1.1 DISTRIBUTION SYSTEM

The components that are connecting all consumer in a particular area to source of bulk power is known as the distribution system. These bulk power sources are connected to their respective generating stations through the transmission lines and provide power in bulk to the number of substations that are generally located at various points near to load centers. And substations further distribute power according to the type of demands such as domestic, commercial, agricultural, industrial and other small consumer etc. The consumer that demands big amount of power generally get their supply from the sub transmission or else transmission levels because a large amount of power is first supplied to these latter levels. And it is to be noted that sub transmission system is somewhat similar to the distribution system but it only has higher voltage level and supplies to big consumers only whereas the distribution system only supplies to various number of loads. Whereas for transmission level the voltage level is higher than the sub transmission level and it supplies bulk of power to the very big consumers it also interconnects the two neighboring generating stations. But our main objective is to focus on the distribution system and a particular power distribution system is generally classified with respect to the feeder connected to it and these are as under:

- Radial distribution system.
- Parallel distribution system.
- Ring main distribution system.

There are different type of feeder system and our primary focus will be on the radial distribution system and we will study about the radial distribution system only.

Radial distribution system is underutilization only if the generating station and substation are surrounded by the various consumers. The distribution system gets it supply from the various substation and it further feed the input to the various consumers which leads to flow of power in one direction only. However, it looks as simple as that but the radial distribution system is not highly reliable that means if the fault occurs before the radial distribution system, then the feeder will not be able to fulfill the demand of the consumers that are connected to that particular feeder.

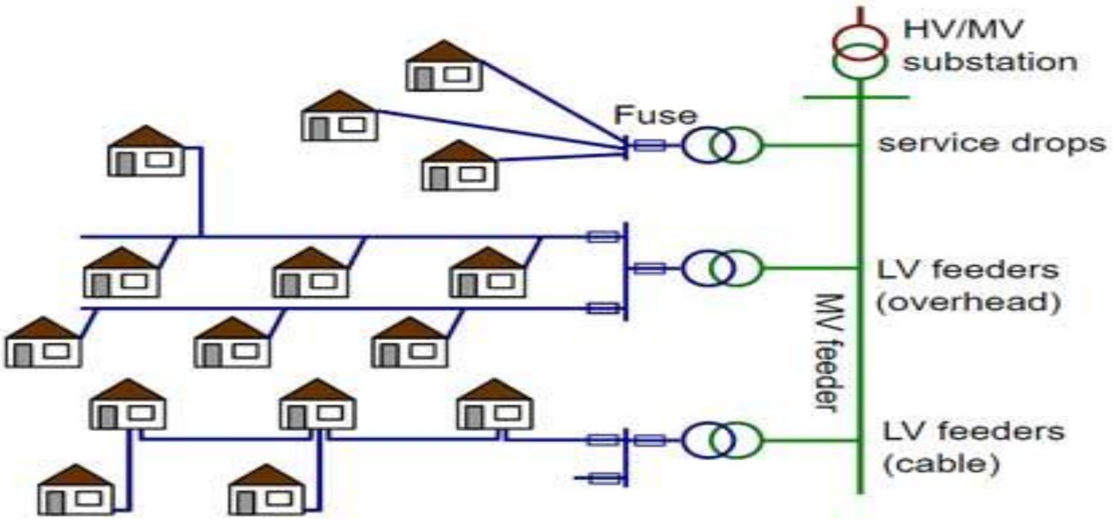

Figure 1.1An illustration of the radial distribution system[Wikipedia]

1.2 Objectives of Thesis

1. To understand the radial distribution system and determination or evaluation of the losses associated with the IEEE-33 bus and IEEE-69 bus system.

2. To understand the radial distribution system and evaluate losses of IEEE-33 and IEEE-69 bus system by applying the industrial and commercial load on both the bus system separately.

3. To understand the teaching learning-based optimization technique so that losses of IEEE-33 as well as IEEE-69 bus system could be reduced to some extent.

4. Application of Teaching learning-based optimization technique to determine optimum location to place the capacitor on IEEE-33 and IEEE-69 bus system to minimize losses of the whole system.

1.3 Methodology adopted.

- Backward sweep.

Backward sweep method is done in order to determine the current flowing through each branch of IEEE-33 and IEEE-69 bus system and voltage are taken as unity in PU only for first iteration. It is to be noted that backward sweep is done under the full load condition and further we have to perform the backward sweep first then only we can proceed for the forward sweep technique. To illustrate the backward a figure is shown below.

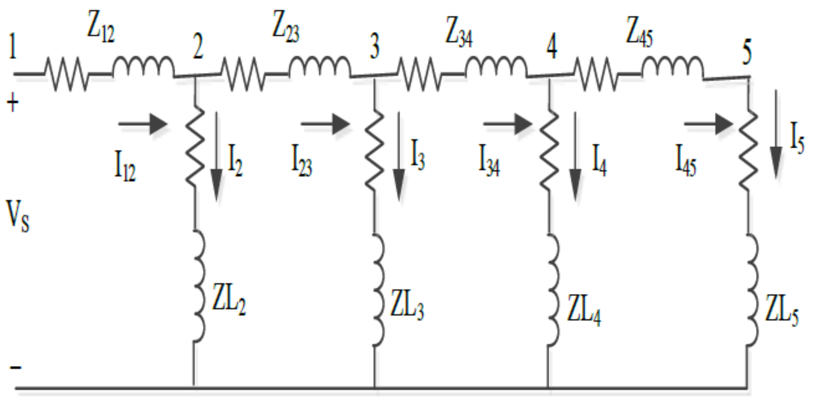

Figure 1.2 An illustration of backward sweep methodology[6]

- Forward sweep

The forward sweep method is done in radial power system to determine voltage at each bus of IEEE-33 and IEEE-69 system. In this technique the voltage is obtained by using the Kirchhoff's voltage law and this process of determining the voltage of every bus starts from source end and moves towards load end whereas the backward sweep technique starts determining the current in each branch from the load end and proceeds toward the source end. An illustration of forward sweep is shown below

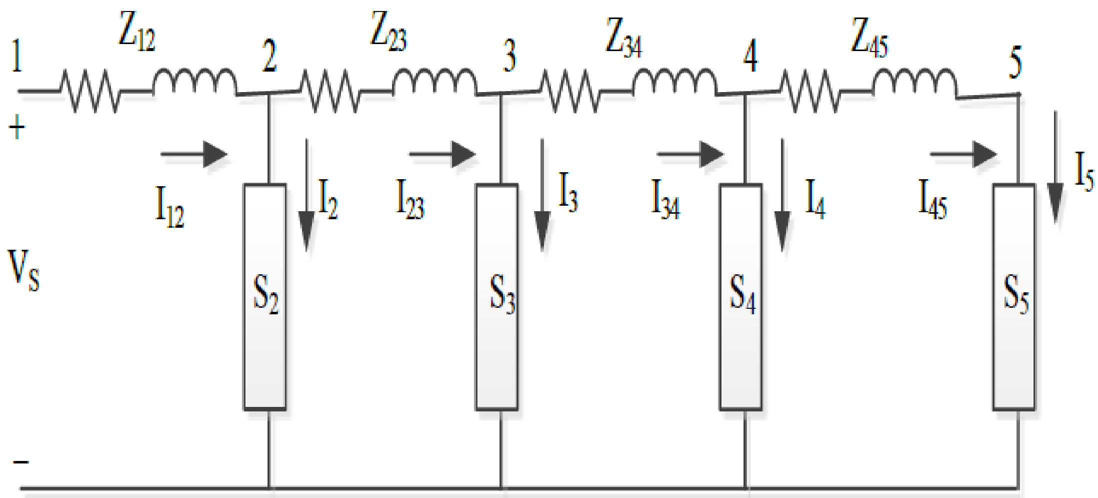

Figure 1.3. A ladder view for the forward sweep.[6]

- Convergence criteria.

The modified technique as mentioned above is aimed to perform forward sweep which evaluate voltages magnitude at every node by using the values of the current flowing in that line which is obtained by using the backward sweep, whereas the latter is performed prior to the forward sweep. Furthermore, the new backward sweep will be utilizing the previously performed forward sweep magnitude voltage.

However, this modified technique will need more iteration but it will be going to use less time for the convergence. In the above advanced version of technique convergence is determined by evaluating ratio of difference between voltage at $(n-1)\ th$ and nth iteration to the nominal line to neutral voltage. The convergence will be attained when the magnitude of voltage at each node satisfies.

$$\frac{|V^{nth}|-|V^{(n-1)th}|}{Vnominal} \leq specified\ tolerance. \qquad [1.1]$$

CHAPTER 2

2.1 Literature Review

The radial distribution system always grabs the attention of researchers towards itself because it is very easy to understand and its robust construction. However, its reliability is the main issue. There are different types of distribution system but this thesis will primarily focus on the IEEE-33 and IEEE-69 bus system. And disciplinary study will be done on IEEE-33 and IEEE-69 bus system.

The original version of both IEEE-33 and IEEE-69 bus test distribution system was first proposed by Baran and Wu. For IEEE-33 bus system as shown below in figure 2.1 it consists of 33 buses and 32 buses are fixed and it also provide 3 switchable lines with no reactive power compensation point on the bus system. For IEEE-69 bus system as shown below in figure 2.2 it comprises of 69 bus and 68 are fixed and it also provide 7 switchable lines but with no point for compensate reactive power loss. The voltage limit for both the distribution system ranges from 0.9 to 1.1 and we have taken the voltage limit from 0.95 to 1.05. Since distribution system is radial distribution type therefore both IEEE-33 and IEEE-69 bus test system will gets it input supply voltage from the bus number 1 only.

There are various methods adopted to reduce reactive power of entire system such as synchronous phase modifier, on load and Off load tap changing transformer (OLTC), series compensator, shunt compensator and many more.

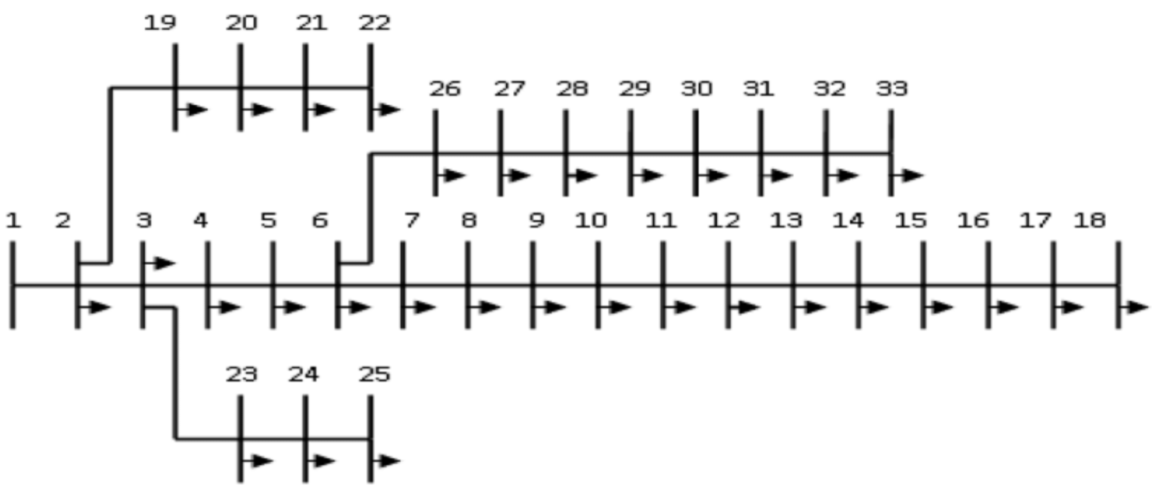

Figure 2.1 Single line diagram of IEEE-33 bus system[14]

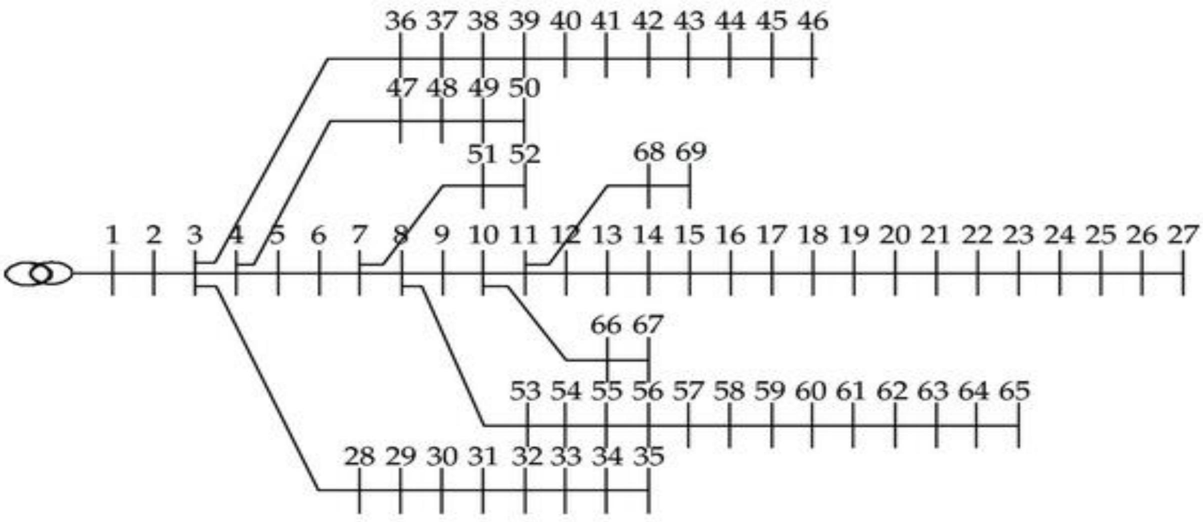

Figure 2.2. Single line diagram of IEEE-69 bus system[14]

Loading on System

There are different types of loads on the power system these loads are categorized according to the demand of the consumer. And these types of loads are as under

- Domestic
- Commercial
- Industrial
- Agricultural

The different types of loads are differentiated according to the need of the consumer for an instance for domestic consumer the appliance such as fans, ac and other appliance may operate for hardly three to four hours in a day and whereas for commercial consumer such as a small shop having appliances such as fans, ac and other appliances may operate continuously for six to eight hours and further more if we take on industrial load a particular industry having small and large machines may operate for 12 to 24 hours continuously. So, this is how the different type of loading on the distribution system is categorized with respect to the requirement of the consumers.

The industrial and commercial type of load profile will be applied on the IEEE-33 and IEEE-69 bus radial distribution system one by one and the losses of the distribution system will be evaluated simultaneously. And voltage, current and power flow outline will be examined briefly with respect to applied load profile on power system.

For efficient functioning of distribution system, it is important that regular maintenance and planning should be done to provide high quality services to the consumer. And for this the quality of power is the main problem as the power quality is the final service that is received by the consumer. The supply voltage should be maintained in a prescribed limits by regulatory body so as to assure that there should be no interference. There are many other methods for reduction of the power loss, and one most common method to reduce power loss is done by installing or placement of bank of capacitors. And this planning and the installation of capacitor bank is to give the absolute results by decrement in the loss of power of the distribution system.

Nowadays there are too many methods are in use for the planning and installation of bank capacitors at optimal location or point such as genetic algorithm (GA), shark smell optimization (SSO), plant grow simulation algorithm (PGSA), Cook search algorithm (CSA), Artificial bee colony (ABC). Generally, the solution can be trapped in at its best during the determination of size and optimum location of capacitor this is because the calculation is done on a predetermined location

Teaching learning-based optimization technique

The Teaching and learning based optimization technique were first introduced by Rao et al. This technique is inspired on the effect of the teacher on its student in class. This technique somewhat copies the capability of teaching and learning of the teacher and capability of learners in class. Therefore, the teacher as well as learner are the two basic aspects of this algorithm. This algorithm primarily focuses on the two basic phases that is teaching phase and learning phase. Then the outcome for TLBO technique is considered in the form of result or grades attained by the learner which completely depends on the merits of teaching by the teacher. Furthermore, the learner also tries to learn through the interaction with other learners which may or may not improve the results of the learner itself.

TLBO technique is a population-based technique. In this technique the teacher will be providing the group of solution of a particular problem to the group of learners and the optimal results is considered to be solved by the teacher itself now the student has to perform the solution by themselves and if the solution of any student becomes better solution than the teacher itself then that solution will be considered as the best solution according to the greedy solution

Algorithm of Teaching learning base optimization (TLBO) technique and following step are followed

Teacher phase

Step1. Initializing the number of learner or student (population).

Step2. Calculating the best of each of the variable.

Step3. Identifying the optimal results and considering it as the teacher solution.

Step4. Changing the solution with respect to the best solution. Step5. Checking whether the updated solution is better than the previous solution. If yes then considered it as the best solution and go to step 6 and if not then stop and the solution of the teacher is the best solution.

Student Phase or Learner phase

Step6. Select any two random solution and name as P and (teacher solution) Q.

Step7. Is solution P being better than Q if yes, the go to step8 or else go to step 9.

Step8. If solution P is better than Q then use equation below for finding the new fitness function (Xnew).

$Xnew = P1 + rand * (P1 - P0)$.

Step9. If solution Q is better than P then use equation below for finding the new fitness function (Xnew).

$Xnew = P1 - rand * (P1 - P0)$.

Where

Xnew = new fitness function.

rand = random number between 1and 2 generated randomly during the running of the program.

P0 = value of solution chosen randomly at 0th iteration. P1 = value of solution chosen randomly at 1st iteration.

Step10. Now checking that whether the newly updated solution is better than the existing one if yes then goes to step 11 or else the existing solution is the best solution.

Step11. Now check whether the new solution satisfied the termination criteria if yes then print the final solution or else remove the duplicate solution.

CHAPTER 3

3.1 Load flow analysis of IEEE-33 and IEEE-69 bus system

Load flow analysis also known as the power flow analysis isthe process to calculate the line current, voltage, active power and reactive volt amperes at various points on the power system which are considered to be operating under the normal stable or steady state or static condition. Main objective of power flow analysis is to plan a system to operate at its best stable condition and also to control the latter and also to plan for future expansion to keep flow of power in the stable state with the increase of the applied load of the power system [1]. The power flow study helps us to find or ascertain the effect of new load when applied and also new generating station, newlines, new interconnection before they may be practically installed in to power system. This knowledge in advance helps us to reduce the system loss and facilitate a check on stable condition of the power system. An ideal mathematical model for the given network is firstly considered which will further provide the relationships between the voltage at each bus, active power and reactive volt amperes is formulated. At each bus the powers, volt amperes and voltages will be providing or specified. And Numerical solution of the problem is obtained with respect to the data provided or specified the power flow and volt amperes are obtained in all the lines of network of power system [2].

Therefore from the above discussion the power flow analysis plays its significant role by providing the data such voltages at each buses and active power and reactive volt amperes and also provide variations occurring in these quantities with the application of new load or new equipment .So overall the power flow analysis acts like a bird eye on the power system and if there is any changes in the power system network then the power flow analysis will be providing that which quantity have changed when and why [3].

3.2 PROBLEM FORMULATION

In the load flow programs the input data can be either in per unit or in the actual values it depends on the design of the program. But in most of the programs the values are specified in per unit and for converting the data into per unit the base values such as base MVA, base voltage, base impedance and base current as well. These values are specified by the programmer in the program itself.

The reactive power as we all know is the power which is utilized or engaged in doing advantageous work in circuit it is measured in watts or in megawatts whereas reactive power is that power oscillates between source and the load end and is useless that is this power is not going to do a useful work in the circuit and is generally measured in Var.

For evaluation of the active and reactive volt amperes we need resistance and reactance which are taken in per unit and formula used for evaluation of active power and reactive power is as under.

$$active\ power = [(I)^2 * Rpu] \tag{3.1}$$

$$reactive\ power = [(I)^2 * Xpu] \tag{3.2}$$

where I is branch current and Rpu and Xpu are resistance and reactance of line respectively.

3.3 Applied methodology

3.3.1Backward sweep.

The backward sweep method is the technique that is used to determine the current at each branch under the full load condition. The backward sweep method starts by determining the load current from the load end and moves towards the source end. The load current is evaluated by simply applying the Kirchhoff's current law (KCL). Figure.1. shown below will help us to understand the backward sweep

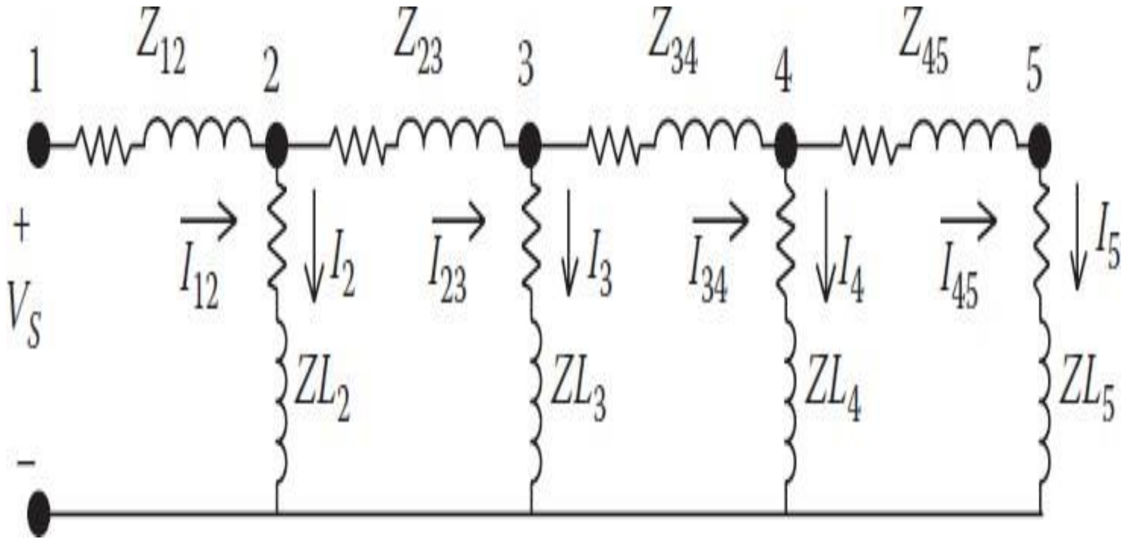

Figure3.1. ladder network for backward sweep method.[6]

$$I45 = 15. \tag{3.3}$$

$$I34 = I4 + I45.$$

$$I34 = I4 + I5. \tag{3.4}$$

$$I23 = I3 + I34.$$

$$I23 = I3 + I4 + I5. \tag{3.5}$$

$$I12 = I2 + I23.$$

$$I12 = I2 + I3 + I4 + I5. \tag{3.6}$$

3.3.2 Forward sweep.

Forward sweep method is the process of determining the voltage at every bus. It starts from source end and gets completed at load end. The voltages are calculated under the no load condition. It is also assumed that line and load impedance of the network are given or known along with voltage at the source end that is Vs. The voltages are obtained by simply applying the Kirchhoff's voltage law (KVL) (4].

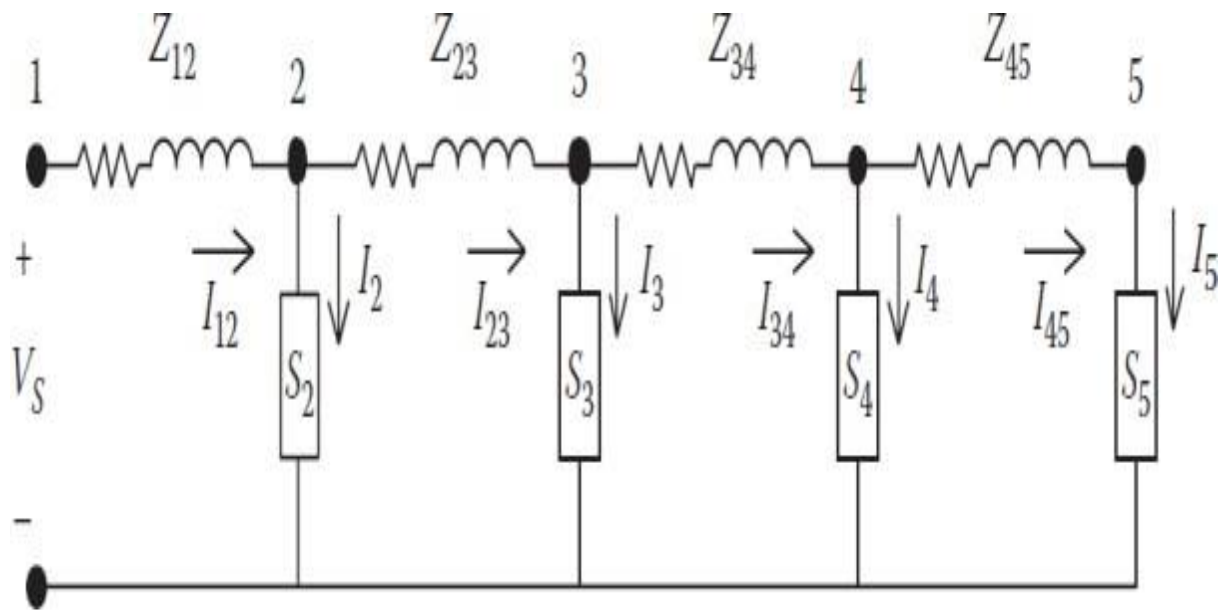

Figure 3.2 nonlinear network for forward sweep.[6]

$$V1 = Vs \tag{3.7}$$

$$V2 = Vs - Z12 * I12.$$

$$V2 = Vs - Z12 * (I2 + I3 + I4 + I5). \tag{3.8}$$

$$V3 = V2 - Z23 * I23$$

$$V3 = V2 - Z23 * (I23 + I4 + I5). \tag{3.9}$$

$$V4 = V3 - Z34 * I34$$

$$V4 = V3 - Z34 * (I4 + I5). \tag{3.10}$$

$$V5 = V4 - Z45 * I45$$

$$V5 = V4 - Z45 * I5 \tag{3.11}$$

Where V2,V3,V4V,V5 are voltage across the S1,S2,S3,S4,S5 respectively of the figure 2 given above. And values of I12,I23,I34,I45 are taken from equation 4,3,2,1 respectively.

3.4 ALGORITHM FOR LOAD FLOW ANALYSIS IN RADIAL DISTRIBUTION SYSTEM

Following are the steps of the algorithm that are followed strictly to get the results for IEEE-33 and IEEE-69bus system.

Step1 Initialization of voltages

$V^0 j = V\angle 0.$ For j = 2,3,4,5……………………N

Step2 Iteration count initialization k=1

Step3 Load current calculations.

$I^k j = \left[\frac{PLj+QLj}{Vj^{(k-1)}}\right]^*$ for j = 2,3,4…N where k is the iteration count.

Step 4 Backward sweep.

$I^k mn = I^k n + \sum$ of all the currents of branches emanated from bus n and m

where k is theiteration count.

Step 5 Forward sweep.

$V^k n = V^k m - Zmn * I^k mn.$

for all branch from n = 2,3,4,5………..N where k is the iteration count

Step 6 Calculation of error (E)

$E^k j = |V^k j - V^{(k-1)} j|$ for j= 2,3,4,5……….N where k is the iteration count.

Step 7 Maximum error Emax

$E^k \max = max(E^k 2, E^k 3, E^k 4 \ldots \ldots \ldots \ldots \ldots E^k n)$ where k is the iteration count.

Step 8 . If $E^k max$ is less than equal to tolerance print the result else update iteration count k = k+1 and goto step 3

3.5 CONVERGENCE CRITERIA

The mismatching of the maximum voltage at the nodes of each network is utilized as a convergence criterion. At iteration Kth current injection at each node is evaluated and voltages at each node are also calculated at (K-1) th iteration.

The voltages at each node at Kth iteration and voltages at each node at (K-1) th iteration are compared. And if the error between the two voltages comes under the limits of the tolerance, then the procedure is going to be stopped and final result will be printed otherwise the iteration count will get updated by one and the whole procedure will repeat again.

$$(||V^{nth}| - |V^{(n-1)\,th}||)\,/Vnomin \leq specified\ tolerance \tag{3.12}$$

3.6 RESULT AND OUTCOMES

Proposed method presented for this chapter takes advantage of the classical forward and backward sweep method in which Kirchhoff's voltage law (KVL) as well as Kirchhoff's current law (KCL) is used which is the most basic part power system engineering.

The proposed method is successfully programmed using MATLAB codes that are coded in such a way that they strictly follow the algorithm mentioned in this paper. The results obtained proves that the method used by MATLAB codes shows that forward and backward sweep method is very efficient and satisfies the requirement of the algorithm mentioned. The total power loss for 33 and 69 bus system given below are the final result which are verified with the various papers for 33 bus system total active power loss evaluated is 201.9620 kilo watt which is approximately correct when compared with the various papers and for 69 bus system total active power loss evaluated is 225.8983kilo watt which again approximately correct.

3.6.1 VOLTAGE PROFILES OBSERVATIONS

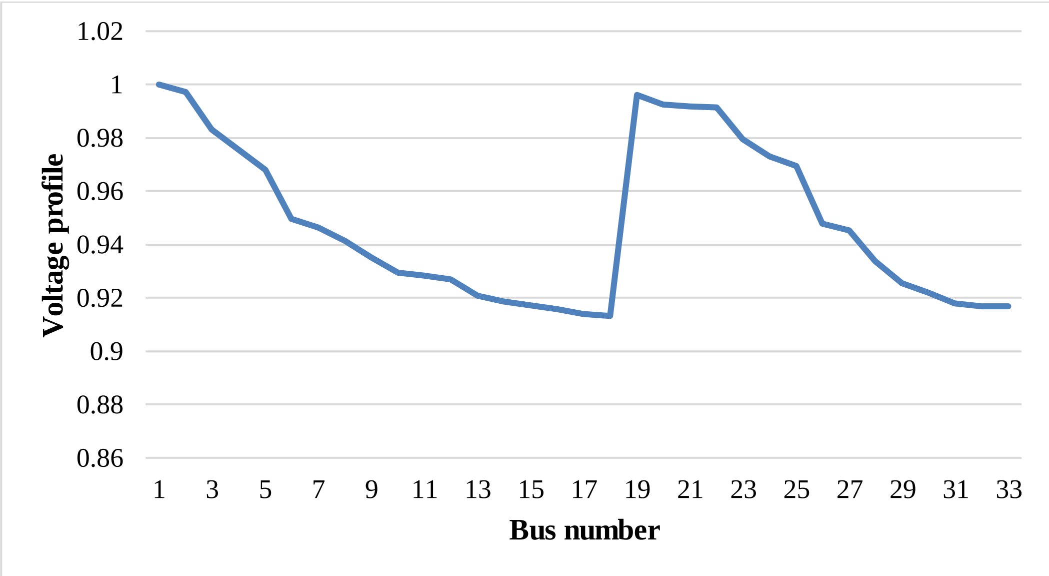

Figure 3.3. The voltage profile graph for IEEE-33 bus system

Voltage profile of IEEE-33 bus system as shown in the figure3 and we can see from the sending end that the voltage magnitude (in PU) goes on decreasing as we move towards the receiving end and this pattern is also followed by IEEE-69 bus system also as shown in figure 4 also there is a sudden increment or decrement in the voltages in PU in the graphs is nothing but the line termination occurs at 18,22 and 25 buses for IEEE-33 bus system and line terminates at 27,35,46,50,52,65 and 67 for IEEE-69 bus system.

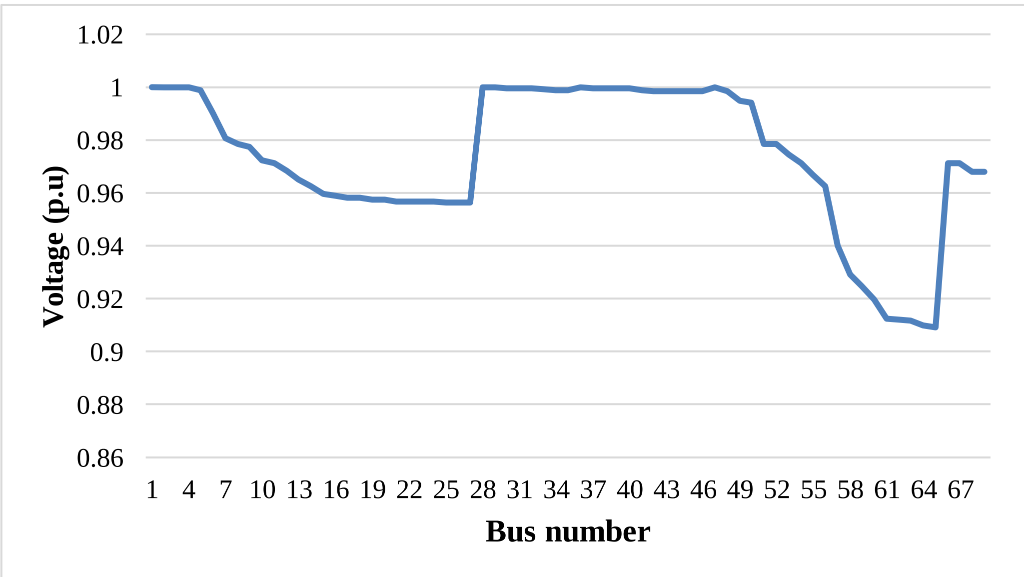

Figure 3.4. The Voltage profile graph for IEEE-69 bus system

3.6.2 LOAD FLOW PROFILES OBSERVATIONS

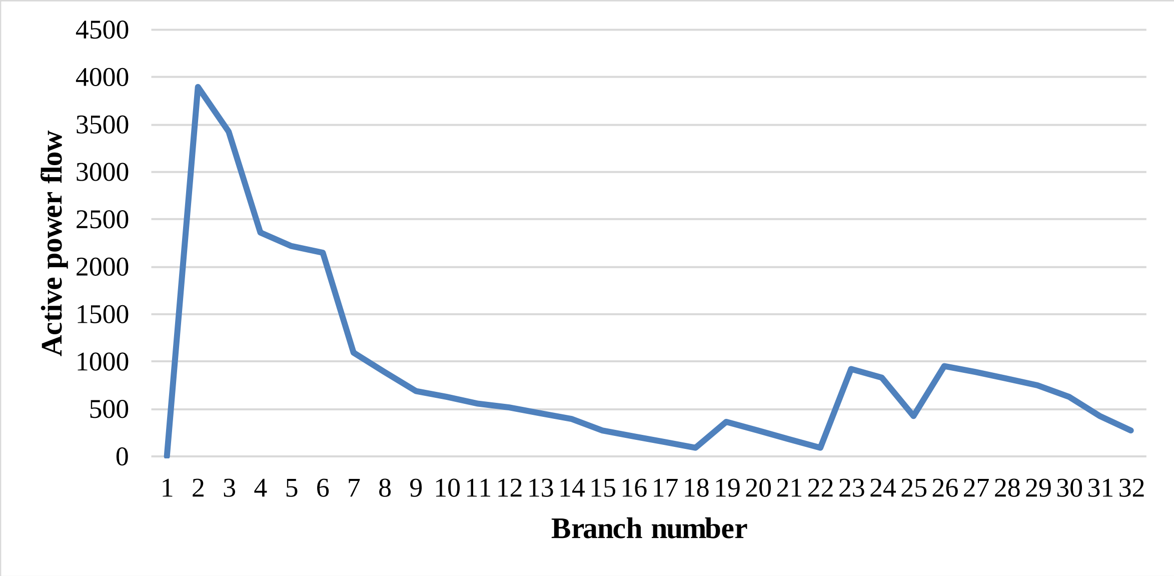

Figure 3.5 Power flow plot for IEEE-33 bus system.

From power flow plot of IEEE-33 bus system figure5 and IEEE-69 bus system figure6 it can be seen that the flow of power from the sending end goes on decreasing as we move from source or sending end to towards load end. Further, there is sudden increment or decrement of flow of power this is nothing but again the line terminates at 18,22 and 25 buses for IEEE-33 bus system and line terminates at 27,35,46,50,52,65 and 67 for IEEE-69 bus system.

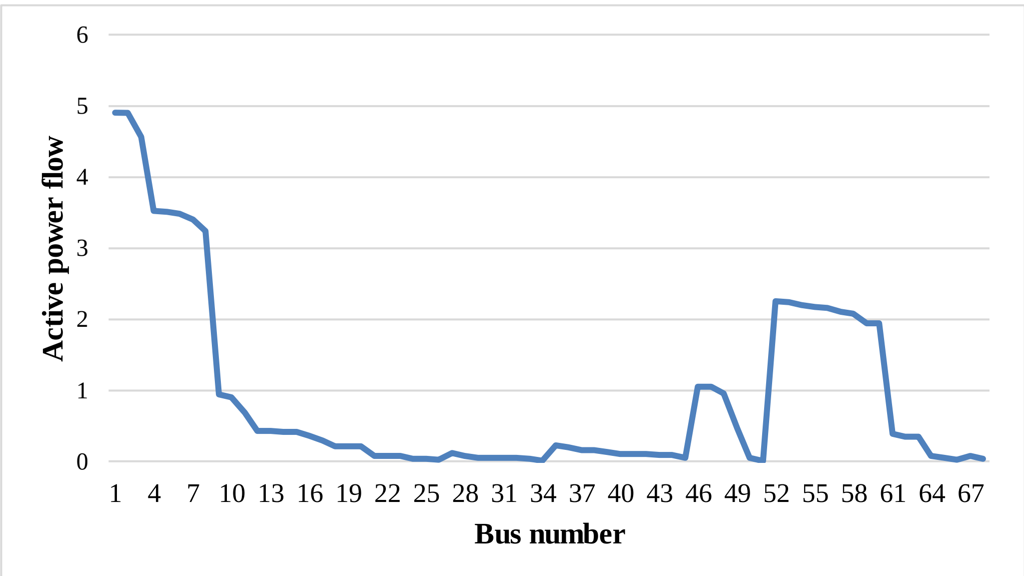

Figure 3.6. Power flow plot for IEEE-69 bus system

CHAPTER 4

Application of industrial and commercial load on radial distribution system.

4.1 Introduction

Load on power systems is classified by the time duration for which the electrical equipment is to be operated. For domestic load the electrical equipment such fans, bulb, air conditioners etc. are used for 4 to 5 hours this domestic load is for our house in which we use the electrical equipment for short duration and for commercial load the electrical loads such as fans ,bulbs , air conditioners etc. are inthe running condition for 8 to 10 hours this is because in our offices or buildings of school and college we use these electrical equipment such as fans ,bulb, air conditioners etc. only for whole day not for night this is the basic difference between the domestic and whereas for industries these electrical equipment such fan bulbs and also big machines are in the running condition for complete 24 hours therefore the comes under the industrial load.

These industrial sectors and commercial sectors cover the reasonable part of energy consumption which leads to greater than 60% oftotal energy used around the world [1]. And demand response is also improved widely for these sectors since 1970 and now a day it has been observed that it is changing with the efficient technology and improved devices [2]. And especially wholesale energy and ancillary services markets can incentivize the participation of demand response in markets [3]. Further progress of technology in equipment and devices and also in telecommunications enables faster and better management of demand response [4].

The load flow analysis is important tool to determine the power flow from sending end to load end or receiving end. There are various methods or technique used to determine power flow of transmission line and distribution system such as Newton Raphson method, Gauss Seidel method, Fast decoupled method and so on. The power flow analysis study of a distribution system is very advantageous for preplanning of the transfer of load.

Due to radial nature of distribution system, they have very high ratio of R/X which leads to the complications of load flow evaluation and therefore the Newton Raphson and Fast decoupled method becomes difficult to evaluation or determination of flow of power for large distribution system. [5,6]

Therefore, the new technique is proposed i.e., backward sweep and forward sweep method which is very easy to perform both in manual mathematical calculation and by using programming codes also. By using this technique, the voltage magnitude at every bus of distribution system is evaluated.

4.2 FORMULATION OF PROBLEM

For the power flow analysis, the input data such as impedance, resistance, reactance, voltages at each bus can be either described or specified in actual values or it may be specified in per unit form it totally depends on the user but in most of the cases the user specifies the values in per unit or else convert the actual values in per unit by considering the base values because in per unit it become easy for the calculation rather by writing the unit of each of the values. And conversion of actual value into the per unit values is not a difficult task to perform as we all know the per unit is defined as ratio of any arbitrary value of particular dimension to base value of same dimension and due to the same dimension, there is no unit for the per unit values. The main objective is to evaluate active power and reactive power for IEEE-33 and IEEE-69 bus distribution system by applying the voltage profiles of commercial loads and industrial loads. And reactive power is useful power which is engaged in doing useful work in circuit and having a measured value in watts or in megawatts. And for reactive power it is the power that is useless power which does nothing useful in the circuit but it keeps reflecting from the source end and the load end and also having the measured value in volt amperes Var

And the formula used for calculating these powers are as follows

$$active\ power = [(I)^2 * Rpu] \tag{4.1}$$

$$reactive\ power = [(I)^2 * Xpu] \tag{4.2}$$

where I am branch current and Rpu and Xpu are the resistance and reactance of the line respectively.

4.3 APPLIED METHODOLOGY

The backward sweep and forward sweep are one of the most common technique that is used to determine the power flow of a distribution system. Further this technique is simple, fast, easy convergence and occupies less memory for the processing with efficiencies and solution accuracy computational. A modified "ladder" network theory for linear system gives the robust and simple iteration technique for the power flow analysis of the distribution system [2]

4.3.1 BACKWARD SWEEP

First of all, this method occurs at full load condition for the first iteration. In this method our main objective is to determine the current across each load or buss and it is assumed that the voltages at each bus are equal (for 1stiteration) i.e., Vs
And now we apply the Kirchhoff's current law at nodes5, 4, 3, 2 to determine the current at each node. Referring to the figure1 and applying KCL to node 5 we get that I45 is equal to I5 and further applying KCL at node 4 we get that I34 is equal to sum of I4 and I45 whereas I45 is equal to I5 thereforewe get and similarly we get the following equations given below.

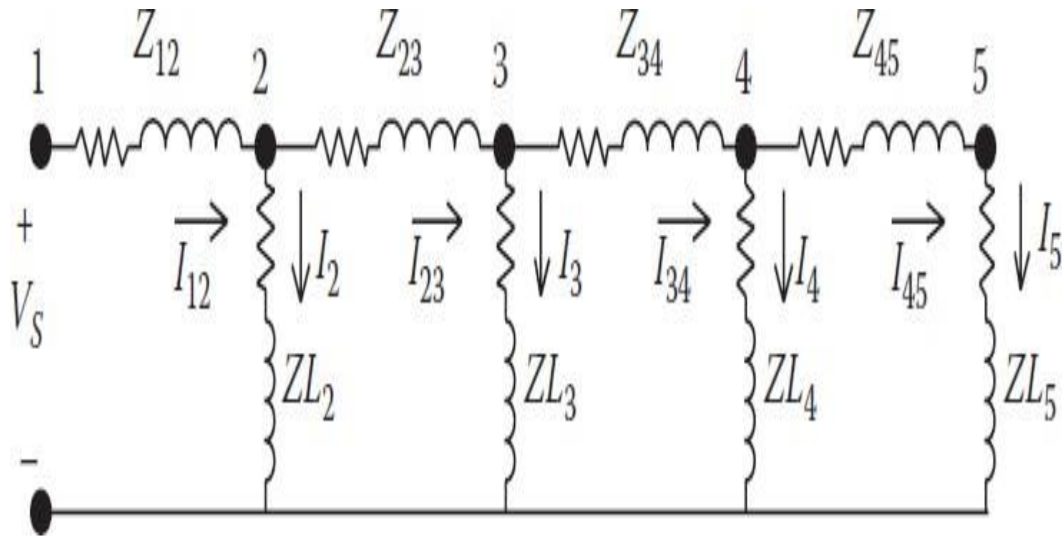

FIGURE 4.1 ladder network for backward sweep method [11]

$I45 = 15.$ (4.1)

and similarly we get

$I34 = I4 + I45.$

$\boldsymbol{I34 = I4 + I5}$ (4.2)

$\boldsymbol{I23 = I3 + I34}$

$\boldsymbol{I23 = I3 + I4 + I5}.$ (4.3)

$I12 = I2 + I23.$

$\boldsymbol{I12 = I2 + I3 + I4 + I5}$ (4.4)

4.3.2 FORWARD SWEEP

The forward sweep method is the technique that is used to determine the magnitude of voltage at each node of the circuit by using the Kirchhoff's voltage law (KVL). The determination of voltage starts from the sending end and then move towards the load end or source end and during the evaluation of voltages at each node the value of currents is taken from the backward sweep method.

Consider the Figure 2 and applying the Kirchhoff's voltage law in the circuit shown below will give the voltages at each node and during the evaluation of voltages the current will be replaced from the backward sweep method as mentioned.

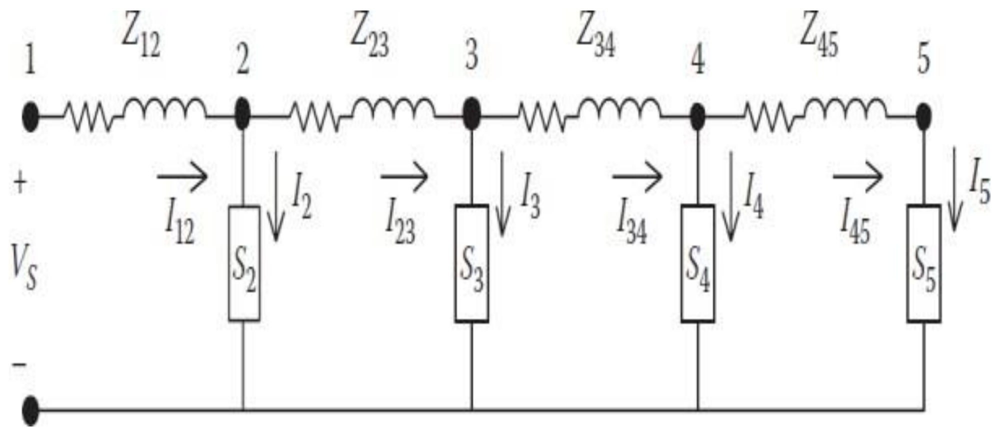

FIGURE 4.2 nonlinear network for forward sweep.[11]

$V1 = Vs$ (4.5)

$V2 = Vs - Z12 * I12.$

$V2 = Vs - Z12 * (I2 + I3 + I4 + I5).$ (4.6)

$V3 = V2 - Z23 * I23$

$V3 = V2 - Z23 * (I23 + I4 + I5).$ (4.7)

$V4 = V3 - Z34 * I34$

$V4 = V3 - Z34 * (I4 + I5).$ (4.8)

$V5 = V4 - Z45 * I45$

$V5 = V4 - Z45 * I5$ (4.9)

4.4 ALGORITHM FOLLOWED FOR LOAD FLOW ANALYSIS IN RADIAL DISTRIBUTION SYSTEM

For the 0^{th} iteration an initial flat voltage is supplied at each of the bus junction and each bus terminal in the power systemand it is given in the step 1.

Step1 Initialization of voltages

$V^0 j = V\angle 0.$ where j goes from 2,3,4,5……………………N

Step2 Iteration count initialization k=1

Step3 Load current calculations.

$I^k j = \left[\frac{PLj+QLj}{Vj^{(k-1)}}\right]^*$ where j goes from 2,3,4…N and where k is the iteration count.

Step 4 Backward sweep.

$I^k mn = I^k n + \sum$ of all the currents of branches emanated from bus n and m

where k is theiteration count.

Step 5 Forward sweep.

$V^k n = V^k m - Zmn * I^k mn.$

for all branch from and n goes from 2,3,4,5……….N where k is the iteration count.

Step 6 Calculation of error (E)

$E^k j = |V^k j - V^{(k-1)} j|$ where j goes from 2,3,4,5……….N and where k is the iteration count.

Step 7 Maximum error Emax

$E^k \max = max[E^k 2, E^k 3, E^k 4 \dots \dots \dots \dots \dots E^k n]$ where k is the iteration count.

Step 8 Setting the convergence criteria

$$Emax = 0.00001 \; or \; 0.0001 \; and \; \Delta Vmax = 0.00001 \; or \; 0.0001.$$

Step 8 If $E^k max$ is less than equal to tolerance print the result else update the iteration count k = k+1 and goto step 3

4.4 CONVERGENCE CRITERIA

The mismatching of the maximum voltage at the nodes of each network is utilized as a convergence criterion. At iteration Kth the current injection at each node is calculated and voltages at each node are also calculated at (K-1) th iteration.

The voltages at each node at Kth iteration and voltages at each node at (K-1) the iteration is compared. And if the error between the two voltages comes under the limits of the tolerance, then the procedure is going to be stopped and final result will be printed otherwise the iteration count will get updated by one and the whole procedure will repeat again.

$$(||V_{nth}| - |V_{(n-1)\,th}||) \,/Vnomin \leq specified\ tolerance \tag{4.10}$$

4.6 OBSERAVTION AND DISCUSSION ON RESULTSand OUTCOMES

4.6.1 Voltage profile for IEEE-33 bus distribution system

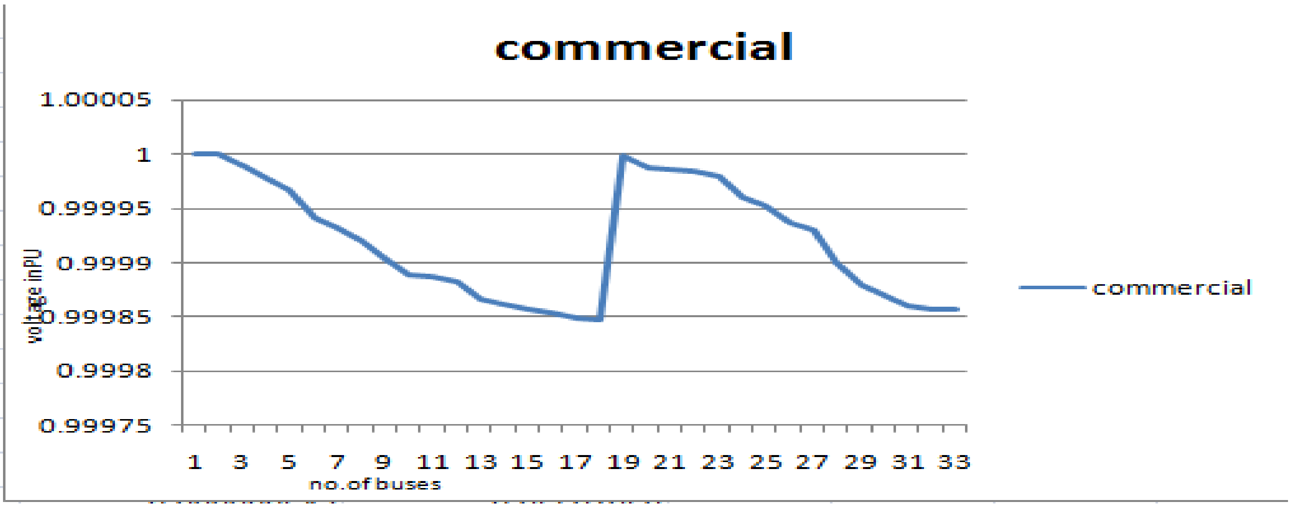

Fig.4.3. Bus voltage profile commercial load for 33-bus test distribution network

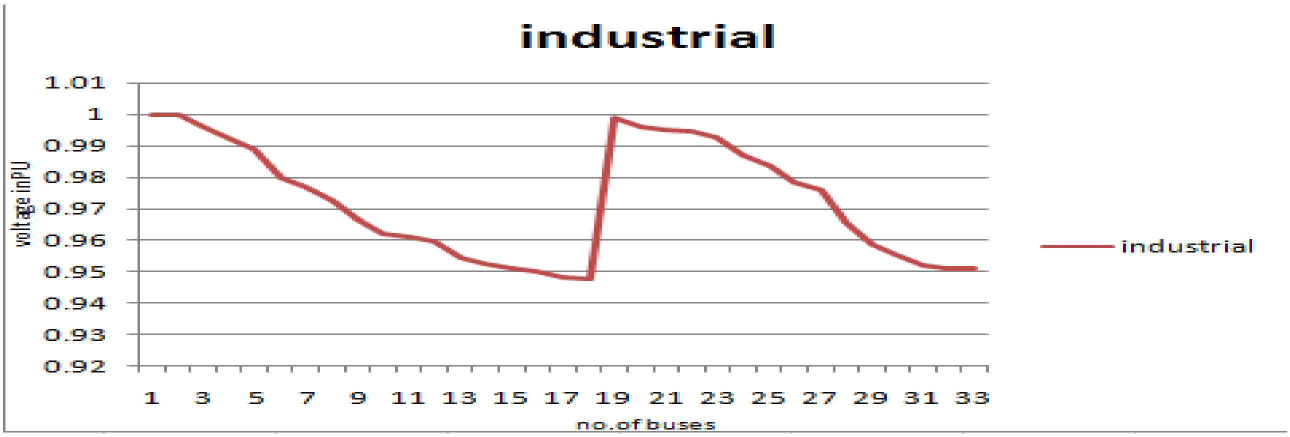

Fig.4.4. Bus voltage profile industrial load for 33-bus test distribution network

The voltage profile for IEEE-33 buses distribution system for both commercial and industrial load is shown above in figure3.And it can be observed that there is almost identical shape is formed by both the type of load. Although there is a sudden increase in the voltage at bus number 19 this is because at bus number 18 the line terminates and bus 19 getsits supply from bus number 2.

4.6.2 Voltage Profile for 69-bus test distribution network

The voltage profile for IEEE-69 bus system is shown for both industrial and commercial load the voltage profile as can be seen in identical irrespective of the voltage applied to the type of load the voltage across each bus is not actually at unity but it is less than or to say close to the unity.

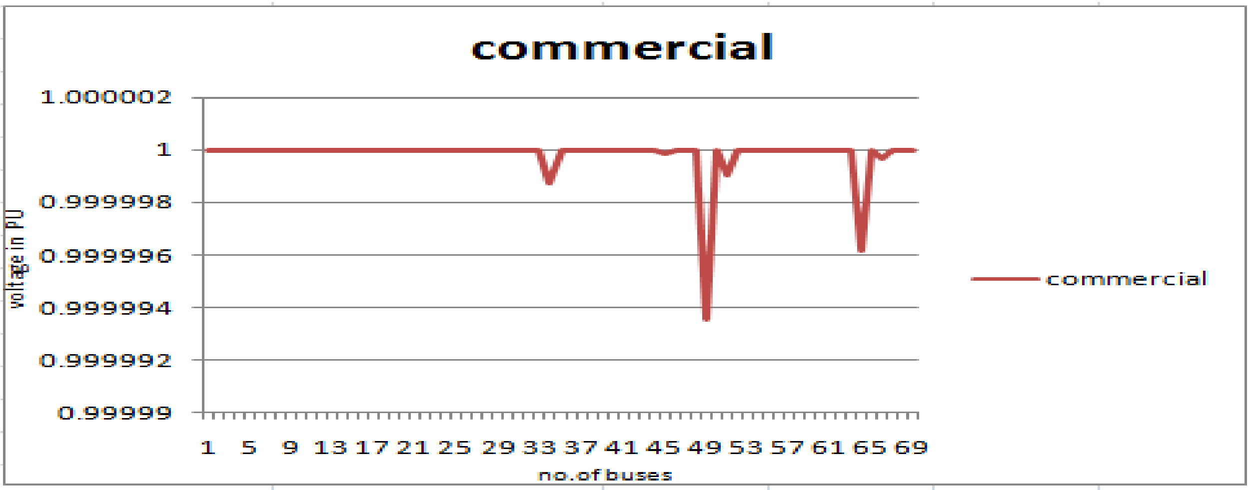

Fig. 4.5. Bus voltage profile for commercial load of 69- bus test radial distribution system

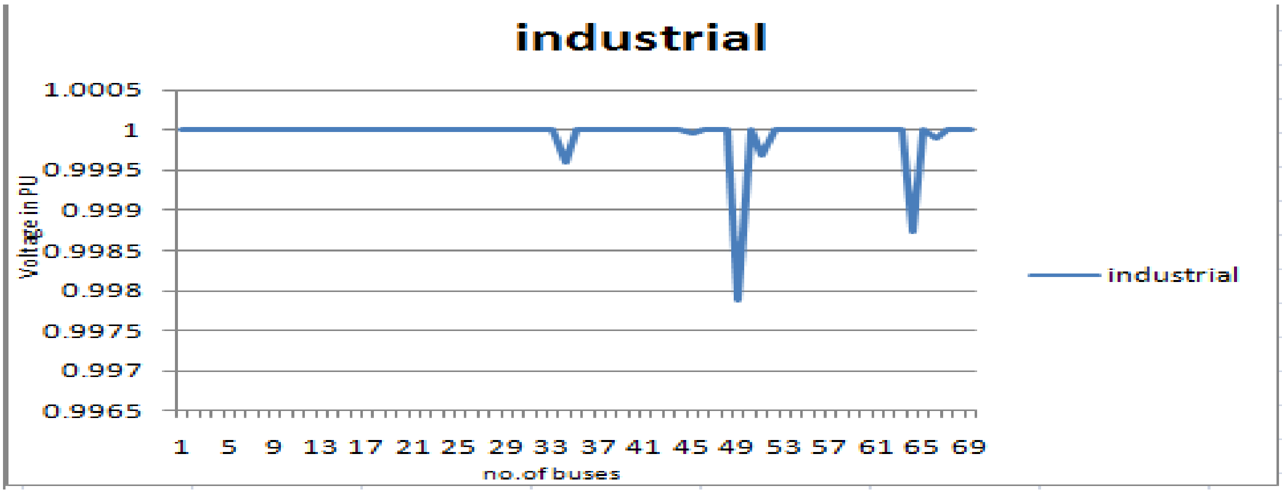

Fig. 4.6. Voltage profile at different buses of 69- bus test radial distribution system for industrial load

4.6.3 Profile of Current for 33-bus test Radial Distribution Network

From Fig. 6 and Fig. 7 are showing the current profile for 33-bus test radial distribution system in different branches for commercial and industrial load respectively. From these figures it is observed that the current profile in different branches for both loads it is almost similar. It is also noticed from these figures that there is sudden increment and decrement in current profile in those branches which are connecting terminal nodes.

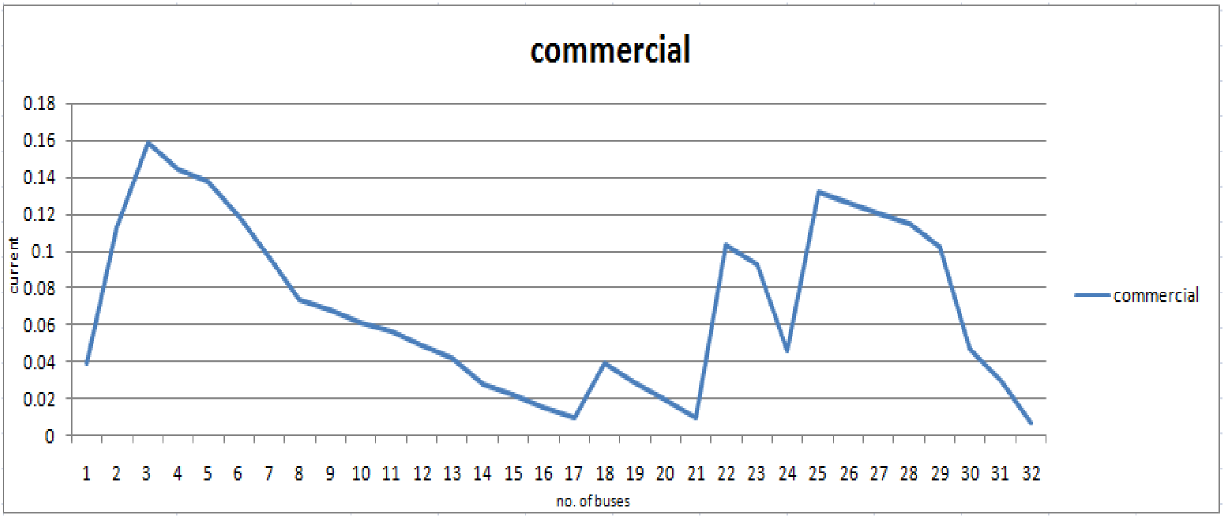

Fig.4.7. Profile of current of IEEE-33-bus radial distribution system for commercial load

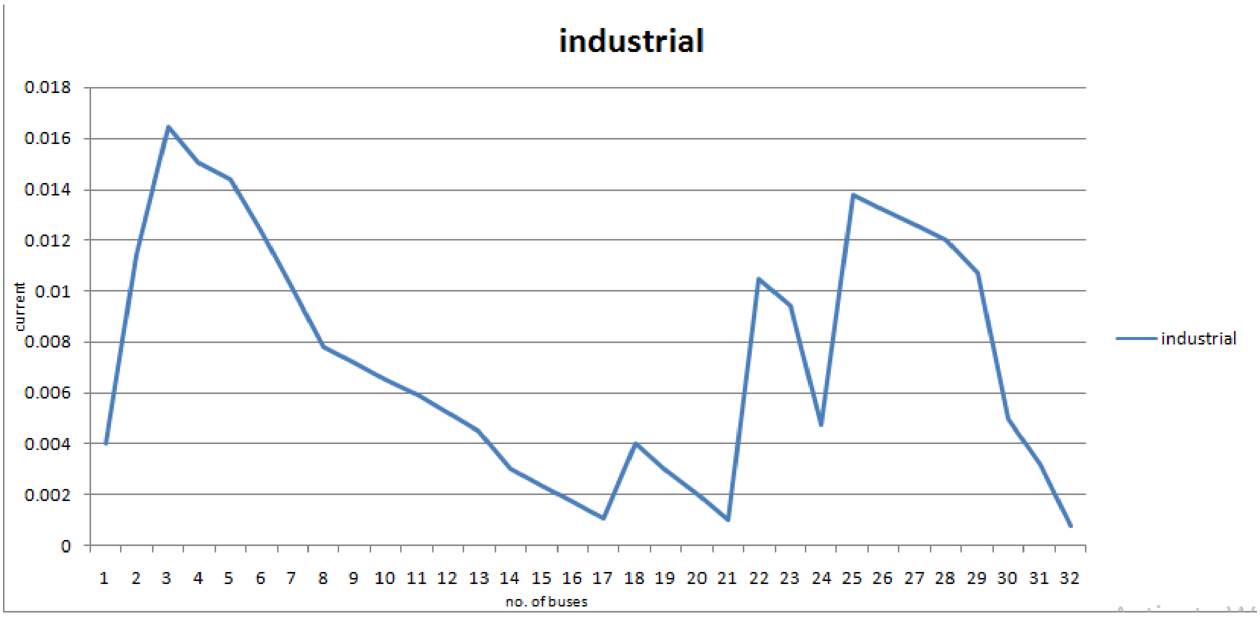

Fig. 4.8. Profile of current of IEEE-33-bus test radial distribution system for commercial load

3.6.3 Current profile for IEEE-69 buses distribution system

From Fig. 8 and Fig. 9 are showing the current profile for 69-bus test radial distribution system in different branches for commercial and industrial load respectively. From these figures it is observed that the current profile in different branches for both loads it is almost similar. It is also noticed from these figures that there is sudden increment and decrement in current profile in those branches which are connecting terminal nodes. It is also noticed from these figures that for commercial load in both cases that is for industrial and commercial load and shows that both are independent on the applied of voltage to the distribution system and again there is sudden increment or decrement of the magnitude of current this is nothing but it occurs due to the termination of the line or bus and new connection with the bus.

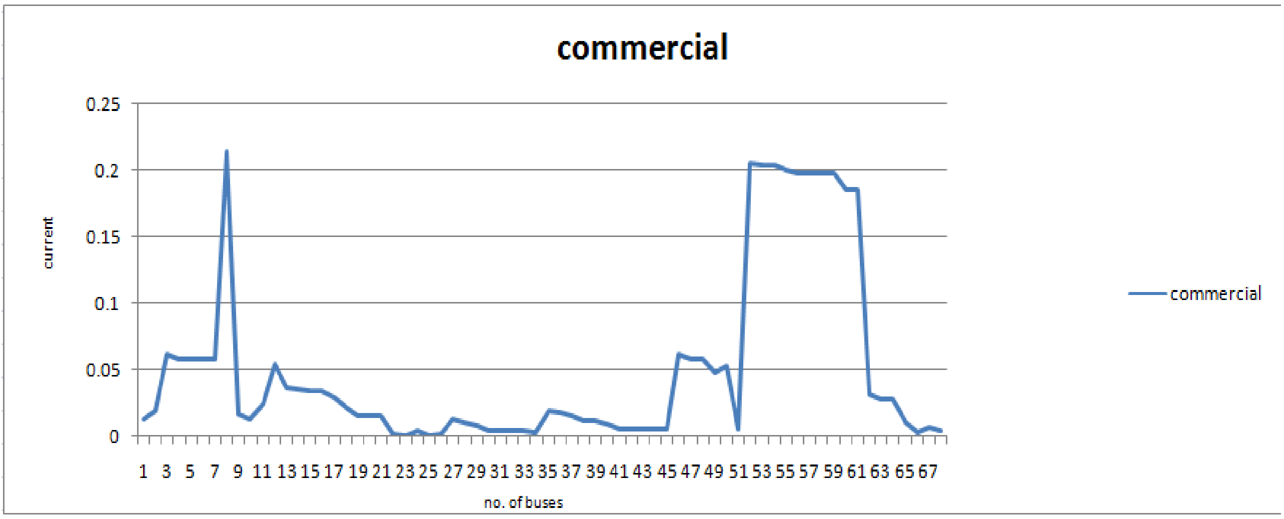

Fig.4.9. Profile of current for 69-bus test radial distribution network for commercial load

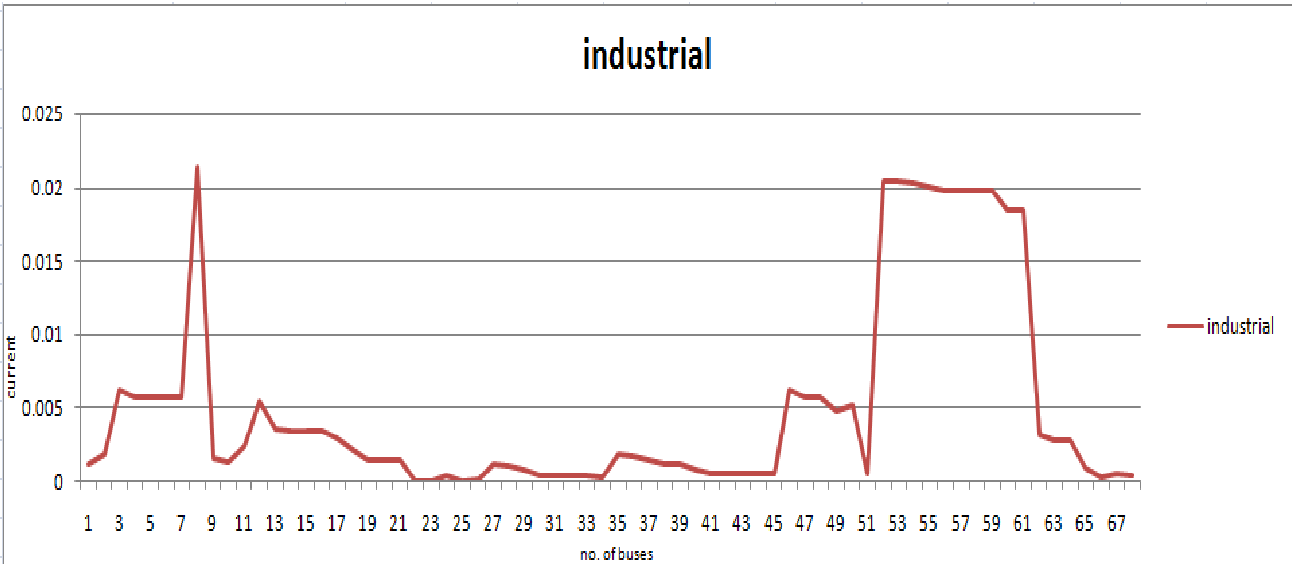

Fig. 4.10 Profile of current for 69-bus test radial distribution network for commercial load

4.7. Final observation on the results

The proposed method as described in this paper takes the advantage as granted for the forward sweep and backward sweep and it is simple and it uses the basic laws of electrical engineering that are Kirchhoff's current law and Kirchhoff's voltage law.

The described methodology is programmed successfully using the MATLAB codes that are designed or coded in a manner that they completely obey the algorithm as described in this paper. The result obtained using MATLAB codes proves the methodology applied that describes forward sweep and backward sweep shows a very good efficacy of the MATLAB codes.

The total power loss for IEEE-33 buses distribution system for both industrial and commercial load are 3.811Kwatt and 135.4152Kwatt respectively whereas the total power loss for IEEE-69 buses distribution system for both industrial and commercial load are 4.7426Kwatt and 156.8449Kwatt respectively.

CHAPTER 5

Optimal Capacitor Placement for Radial Distribution System by using Teaching Learning Based Optimization

5.1 Introduction

For the efficient functioning of distribution system, it is generally very important that regular maintenance and planning should be done to provide high quality services to the consumer. And for this the quality of power is the main problem as the power quality is the final service that is received by the consumer. The supply voltage should be maintained in a prescribed limits by the regulatory body so as to assure that no interference may occur [1]. There are many

other method for the reduction of the power loss, and one of the most common method to reduce the power loss is done by installing or placement of bank of capacitors. And this planning and the installation of capacitor bank is to give the absolute results by decrement in the loss of power of the distribution system.

Nowadays there are too many methods are in use for the planning and installation of bank capacitors at optimal location or point such as genetic algorithm (GA) [1],[2],[3],[4], shark smell optimization (SSO) [5], plant grow simulation algorithm (PGSA) [6],[7], Cokoo search algorithm (CSA) [8], Artificial bee colony (ABC). Generally, the solution can be trapped in at its best during the determination of the size and optimum location of capacitors this is because the calculation is done on a predetermined location

Particle swarm optimization technique and other technique as mentioned above are commonly used in determining optimum locations and size of capacitors that is to be installed in the distribution system. However, all the latter mentioned techniques utilizes the optimization algorithm that depends on algorithm parameters that are controlled which results in the decreasing robustness in the final results and further reduces the convergence rates. Therefore, we require a much more robust and quicker optimization technique and that is teaching and learning based optimization technique. And it is also demonstrated that TLBO is robust method and does not depend on the algorithm controlling parameters as compared to many common heuristic optimization techniques. And proportioning to widely implemented particles swarm optimization technique with the TLBO technique it is proven that TLBO uses approximately 20 times less iteration as compared to PSO for the convergence and the results of the TLBO are more robust than PSO

5.2. Formulation of the Problem.

The formulae of current and power loss are as under. Current flowing across the branch (p, q) connecting buses p and q is given as;

$$Ipq = \frac{[Ppq - Qpq]}{Vi} \tag{5.1}$$

Where

Ipq = current flowing through the branch (p, q).

Ppq= Active flowing into the branch (p, q).

Qpq = Reactive power flowing into the branch (p, q).

Vi = Voltage at node i.

The total loss of power across the branch (p, q) for a transmission line can be written as

$$Pl = \sum_{pq=1}^{n} I^2pq * Rpq \tag{5.2}$$

n = current flowing through the branch (p, q).

Rpq = Resistance of the branch (p, q).

The two component of branch current is the reactive power and active power and the total loss (TL) that is the sum of reactive power and active power can be written as.

$$TL = Active\ Power + Reactive\ Power. \tag{5.3}$$

Therefore, Total Power loss can also be written as.

$$TL = \sum_{pq}^{n} I^2pq * Rpq + \sum_{pq}^{n} I^2pq * Xpq \tag{5.4}$$

The capacitor for a radial distribution system will compensate for the reactive or inductive current but it is not going to affect the active or resistive current which will result in the reduction of the reactive power and active power as well.

5.3. Sizing of capacitor constraints and the total reactive power constraints.

The size of the capacitor can be expressed as.

$$Qc = Vc * Ic \tag{5.5}$$

Where

Qc = size of the capacitor (kVar).

Vc = Voltage magnitude of bus where capacitor is placed (V). Ic = capacitor current (A).

Limiting the capacitor size

The injecting of reactive power is maintained under the feasible maximum and minimum limit.

$$Qcmin \leq Qc \leq Qcmax \tag{5.6}$$

The injection of the total reactive power Qc^{total}should be chosen in such a manner that it must be less than or equal to the reactive power $QL^{toatl}$and can be expressed as

$$Qc\hat{}total \leq Ql^{total} \tag{5.7}$$

5.4. Teaching and learning based optimization algorithm

The Teaching and learning based optimization technique were first introduced by Rao et al [10], [11]. This technique is inspired on the effect of the teacher on its student in a class. This technique somewhat copies the capability of teaching and learning of the teacher and capability of learners in a class. Therefore, the teacher and learner are the two basic aspects of this algorithm. This algorithm primarily focuses on the two basic phases that is the teaching phase and the learning phase. Then the outcome for TLBO technique is considered in the form of result or grades attained by the learner which completely depends on the merits of teaching by the teacher. Furthermore, the learner also tries to learn through the interaction with other learners which may or may not improve the results of the learner itself.

TLBO technique is a population-based technique. In this technique the teacher will be providing the group of solution of a particular problem to the group of learners and the optimal results is considered to be solved by the teacher itself now the student has to perform the solution by themselves and if the solution of any student becomes better solution than the teacher itself then that solution will be considered as the best solution according to the greedy solution

5.5. Algorithm of Teaching learning base optimization (TLBO) technique and following step are followed

Teacher phase

Step1. Initializing the number of learner or student (population).

Step2. Calculating the best of each of the variable.

Step3. Identifying the optimal results and considering it as the teacher solution.

Step4. Changing the solution with respect to the best solution. Step5. Checking whether the updated solution is better than the previous solution. If yes then considered it as the best solution and go to step 6 and if not then stop and the solution of the teacher is the best solution.

Student Phase or Learner phase

Step6. Select any two random solution and name as P and (teacher solution) Q.

Step7. Is solution P being better than Q if yes, the go to step8 or else go to step 9.

Step8. If solution P is better than Q then use equation below for finding the new fitness function (Xnew).

$$Xnew = P1 + rand * (P1 - P0). \quad (5.8)$$

Step9. If solution Q is better than P then use equation below for finding the new fitness function (Xnew).

$$Xnew = P1 - rand * (P1 - P0). \quad (5.9)$$

Where

Xnew = new fitness function.

rand = random number between 1and 2 generated randomly during the running of the program.

P0 = value of solution chosen randomly at 0th iteration. P1 = value of solution chosen randomly at 1st iteration.

Step10. Now checking that whether the newly updated solution is better than the existing one if yes then goes to step 11 or else the existing solution is the best solution.

Step11. Now check whether the new solution satisfied the termination criteria if yes then print the final solution or else remove the duplicate solution.

The backward sweep method is the technique that is used to evaluate the current at each branch under the full load condition. The backward sweep method starts by determining the load current from load end and moves towards the source end. The load current evaluation is done by simply application of the Kirchhoff's current law (KCL). Figure.1. shown below will help us to understand the backward sweep method [4].

5.6. APPLICATION OF METHODOLOGY.

The most common and basic methodology is used for the determination flow of power for the distribution system of IEEE-33 bus system and IEEE-69 bus system. The forward and backward sweep method is the most simple and robust and easy to understand and can be easily program able.

Moreover, this technique is fast, easy convergence and requires less memory and provides solution with maximum accuracy. The network theory modified for linear system take the advantage of simple methodology used for power flow analysis of distribution system for IEEE-33 and IEEE-69 bus radial system.

5.6.1 BACKWARD SWEEP

Backward sweep method is done in order to determine the current flowing through each branch of IEEE-33 bus system and IEEE-69 bus system and voltage are taken as unity in PU only for first iteration. It is to be noted that backward sweep is done under the full load condition and further we have to perform the backward sweep then only we can proceed for the for the forward sweep.

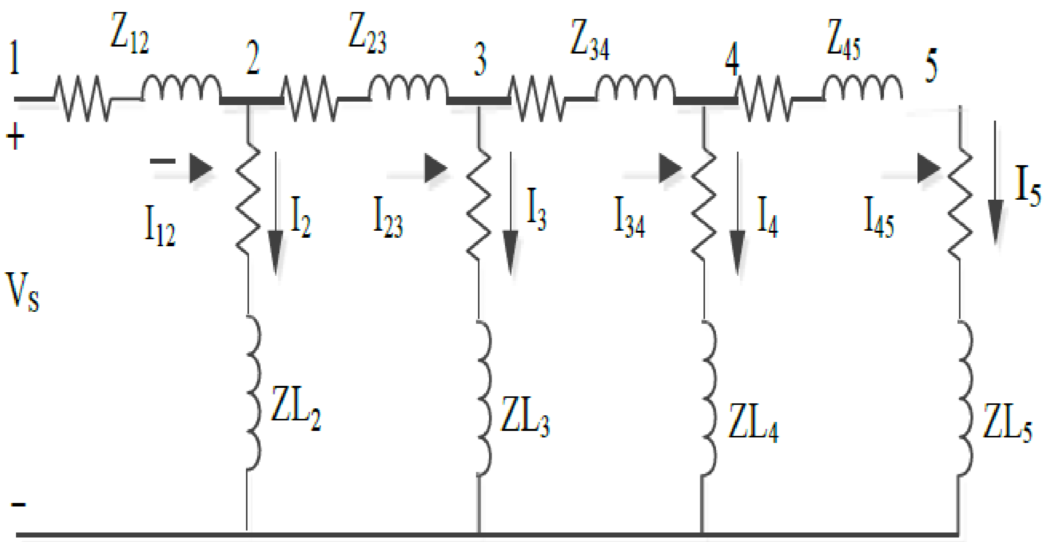

Figure5.1. Backward sweep ladder network.[12]

Now consider figure1 applying Kirchhoff's current law at nodes5, 4, 3, and 2 from the right-hand side to left hand side in order to determine the current at each node. And following relationships are obtained using the KCL.

$$I45 = I5. \quad (5.10)$$

$$I34 = I4 + I45.$$

$$I34 = I4 + I5. \quad (5.11)$$

$$I23 = I3 + I34.$$

$$I23 = I3 + I4 + I5. \quad (5.12)$$

$$I12 = I2 + I23.$$

$$I12 = I2 + I3 + I4 + I5. \quad (5.13)$$

5.6.2 FORWARD SWEEP.

The forward sweep method is done in the radial power system to determine voltage at each bus of IEEE-33 and IEEE-69 bus system. In this technique the voltage is obtained by using the Kirchhoff's voltage law and this process of determining the voltage of each bus starts from the source end and moves towards the load end whereas the backward sweep technique starts determining the current in each branch from the load end and proceeds toward the source end.

Considering the figure2 as shown below for the application of Kirchhoff's voltage law for determination of voltage at each bus by replacing the values of current from the backward sweep technique and that means that firstly we have to perform the backward sweep then only we can proceed for the next step that is forward sweep. And by using the circuit below the voltage at each bus is as under.

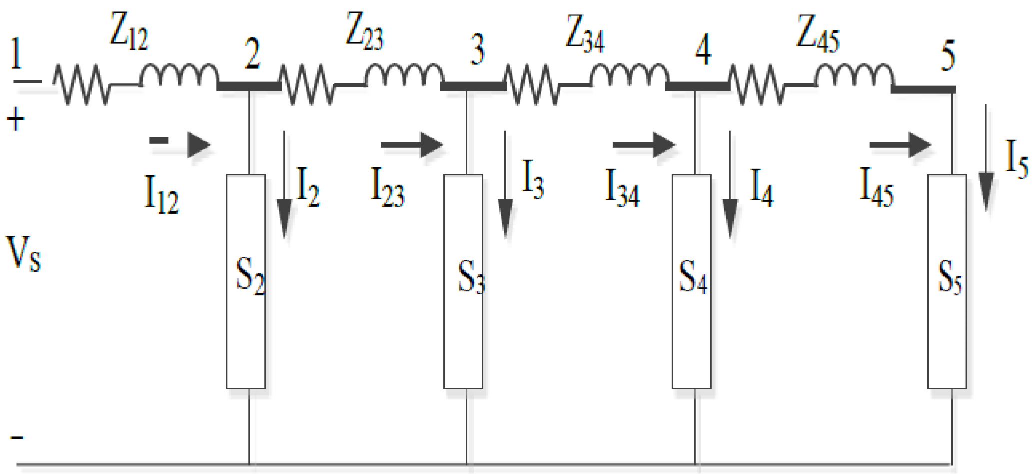

Figure5.2 Forward sweep ladder network.[12]

$$V1 = Vs \tag{5.14}$$

$$V2 = Vs - Z12 * I12.$$

$$V2 = Vs - Z12 * (I2 + I3 + I4 + I5). \tag{5.15}$$

$$V3 = V2 - Z23 * I23$$

$$V3 = V2 - Z23 * (I23 + I4 + I5). \tag{5.16}$$

$$V4 = V3 - Z34 * I34$$

$$V4 = V3 - Z34 * (I4 + I5). \tag{5.17}$$

$$V5 = V4 - Z45 * I45$$

$$V5 = V4 - Z45 * I5 \tag{5.18}$$

Where V2,V3,V4V,V5 are voltage across the S1,S2,S3,S4,S5 respectively of the figure 2 given above. And values of I12,I23,I34,I45 are taken from equation 8,9,10,11 respectively.

5.7 CONVERGENCE CRITERIA

The modified technique as mentioned above is aimed to perform the forward sweep which evaluate the voltages magnitude at every node by using the values of the current flowing in that line which is obtained by using the backward sweep, whereas the latter is performed prior to the forward sweep. Furthermore the new backward sweep will be utilizing the previously performed forward sweep magnitude voltage.

However this modified technique will need more iteration but it will be going to use less time for the convergence. In the above modified version of technique, the convergence is determined by evaluating the ratio of difference between the voltage at $(n-1)^{th}$ and n^{th} iteration and the nominal line to neutral voltage. The convergence is attained when the magnitude of voltage at each node satisfies.

$$(||V^{nth}| - |V^{(n-1)\,th}||)\ /Vnomin \leq specified\ tolerance \qquad (5.19)$$

5.8. ALGORITHM FOLLOWED FOR LOAD FLOW ANALYSIS IN RADIAL DISTRIBUTION SYSTEM

For the 0^{th} iteration an initial flat voltage is supplied at each of the bus junction and each bus terminal in the power system and it is given in the step 1.

Step1 Initialization of voltages

$V^0 j = V\angle 0.$ where j goes from 2,3,4,5……………………N

Step2 Iteration count initialization k=1

Step3 Load current calculations.

$I^k j = \left[\frac{PLj+QLj}{Vj^{(k-1)}}\right]^*$ where j goes from 2,3,4…N and where k is the iteration count.

Step 4 Backward sweep.

$I^k mn = I^k n + \sum$ of all the currents of branches emanated from bus n and m

where k is the iteration count.

Step 5 Forward sweep.

$V^k n = V^k m - Zmn * I^k mn.$

for all branch from and n goes from 2,3,4,5………. N where k is the iteration count.

Step 6 Calculation of error (E)

$E^k j = |V^k j - V^{(k-1)} j|$ where j goes from 2,3,4,5………. N and where k is the iteration count.

Step 7 Maximum error Emax

$$E^k \max = max[E^k 2, E^k 3, E^k 4 \dots\dots\dots\dots\dots E^k n]$$ where k is the iteration count.

Step 8 Setting the convergence criteria

$$Emax = 0.00001\ or\ 0.0001\ and\ \Delta Vmax = 0.00001\ or\ 0.0001.$$

Step 8 If $E^k max$ is less than equal to tolerance print the result else update the iteration count k = k+1 and goto step 3

5.9. Observation on the final results and the various voltage profiles.

5.9.1 Examining Voltage outline for IEEE-33bus radial system.

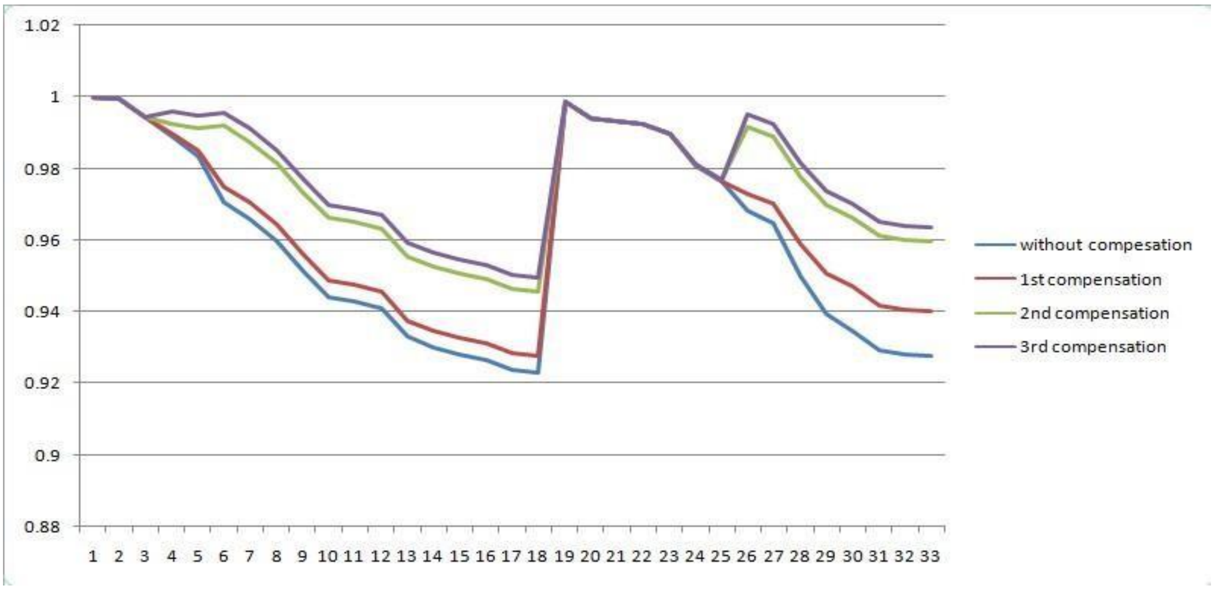

Figure5.3. Voltage outline for IEEE-33 bus system

The figure3.as seen above is the voltage outline for IEEE-33 bus system. It has been observed that the magnitude of voltage is raised accordingly as we continue to place the capacitor one by one. And furthermore, it also reduces the magnitude of the reactive current which results in the deduction of the overall power loss for IEEE-33 bus system.

5.9.2 Examining the voltage outline for IEEE-69 bus system

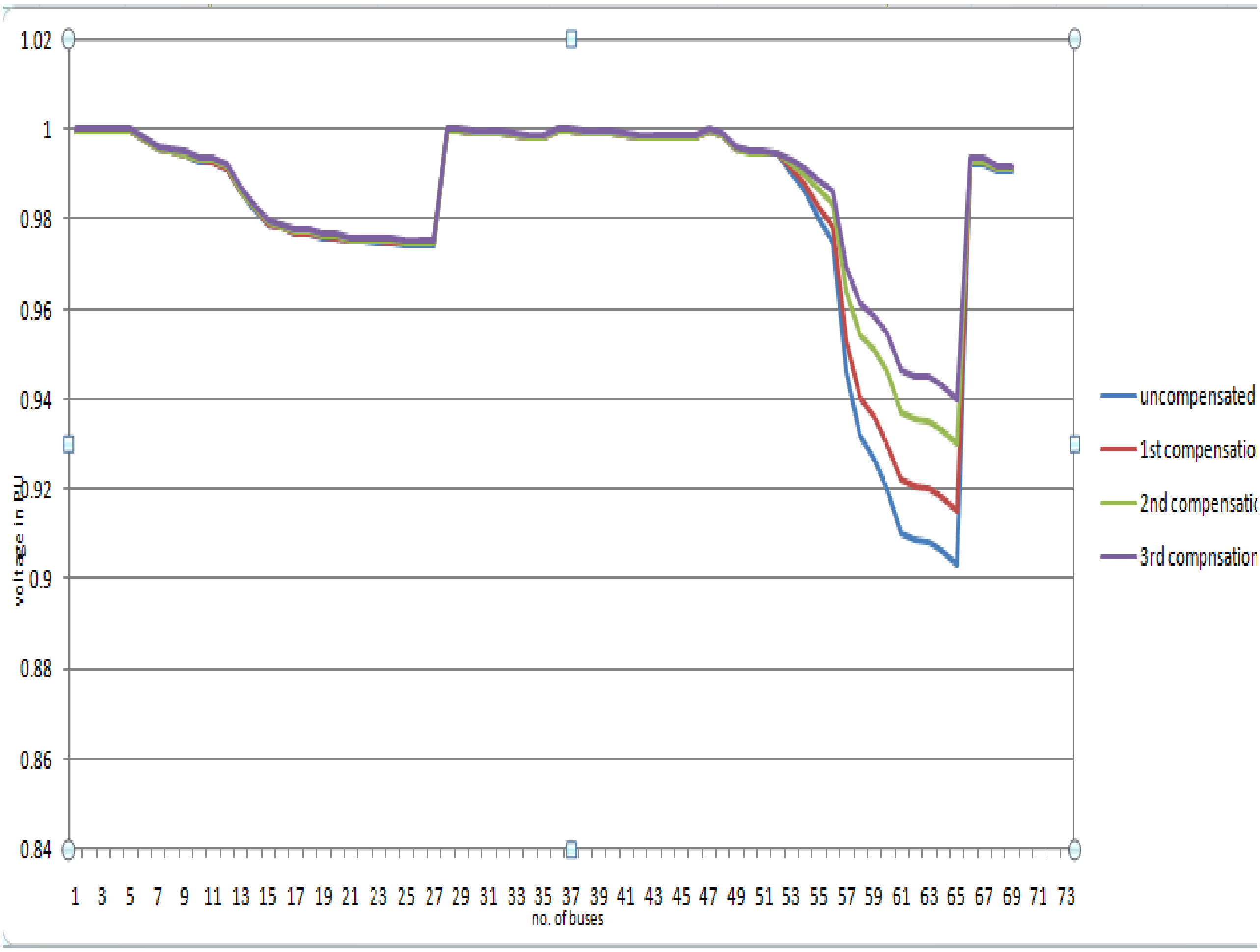

Figure5.4. Voltage outline for IEEE-69 bus system

The figure5.4 above shown is the voltage profile for IEEE-69 bus system. In this case also a similar behavior has been observed, i.e., there is a boost up of voltage level because of the placement of the capacitor. This further results in the decrement of the magnitude of the reactive current which over all helps in the reduction of total power loss of distribution system.

5.10 Observation over final results.

On the basis of the applied TLBO algorithm technique the optimal location of capacitor for IEEE-33 bus system the various locations can be found but there may be chances that sometimes the teaching phase solution is more effective than the student phase or vice versa. The optimal location for capacitor placement for IEEE-33 bus system is 3, 25, and29 and the total losses corresponds to these locations are 139.4416KW, 133.1564KW and 115.3223 respectively and the figure5.5. representing the proposed result is given below.

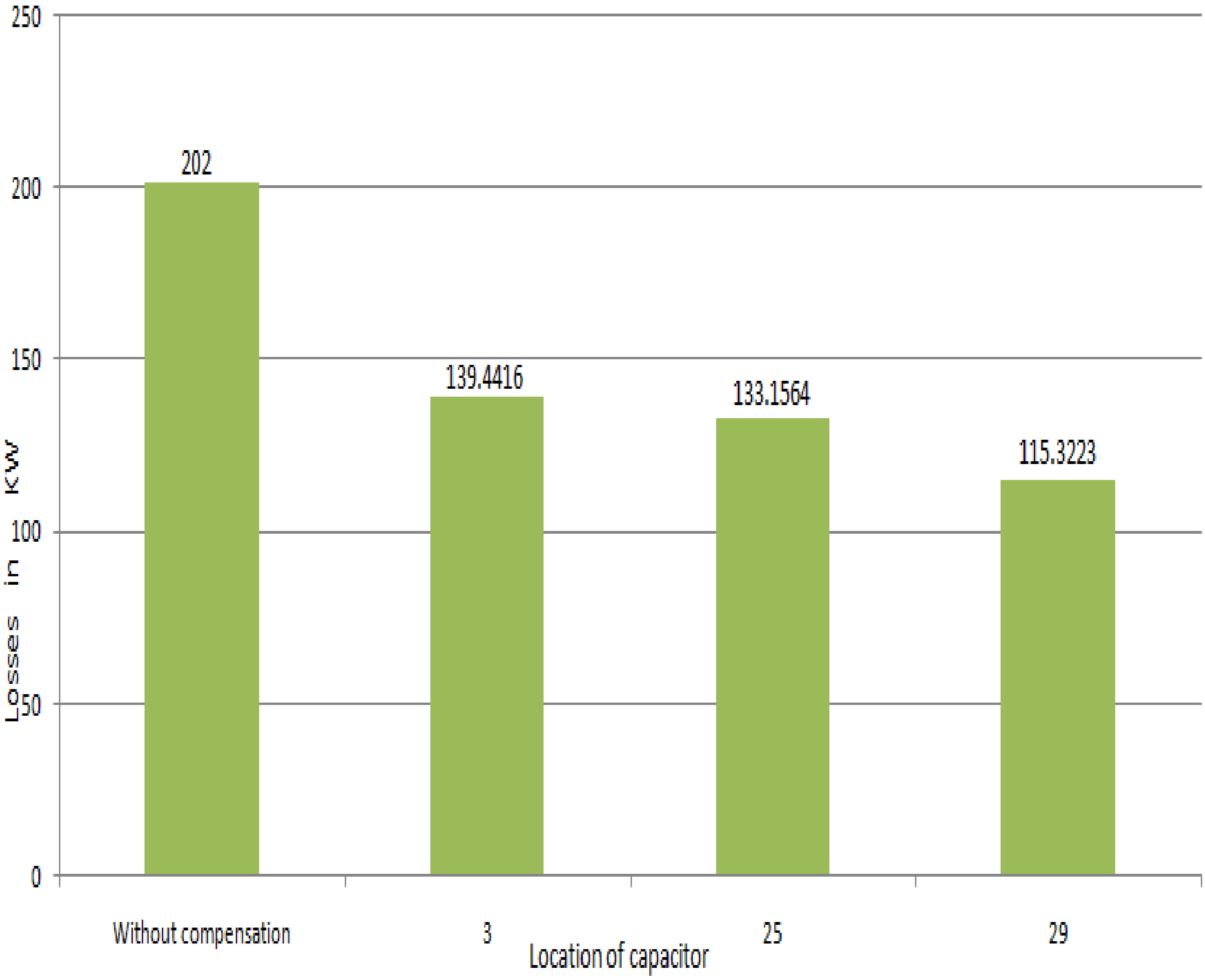

Figure5.5. Loss reduction for IEEE-33 bus system

And for IEEE-69 bus system 2, 59, 61 and the total losses corresponds to these locations are 175.1749KW, 167.6405KW and 130.9781KW respectively. It has been observed from the results obtained that higher value of the capacitor must be placed near to the sending end and this will lead to the maximum reduction of the total. And lower value of capacitor bank should be placed accordingly. The figure shown below is the representation of the proposed result for IEEE-69 bus system.

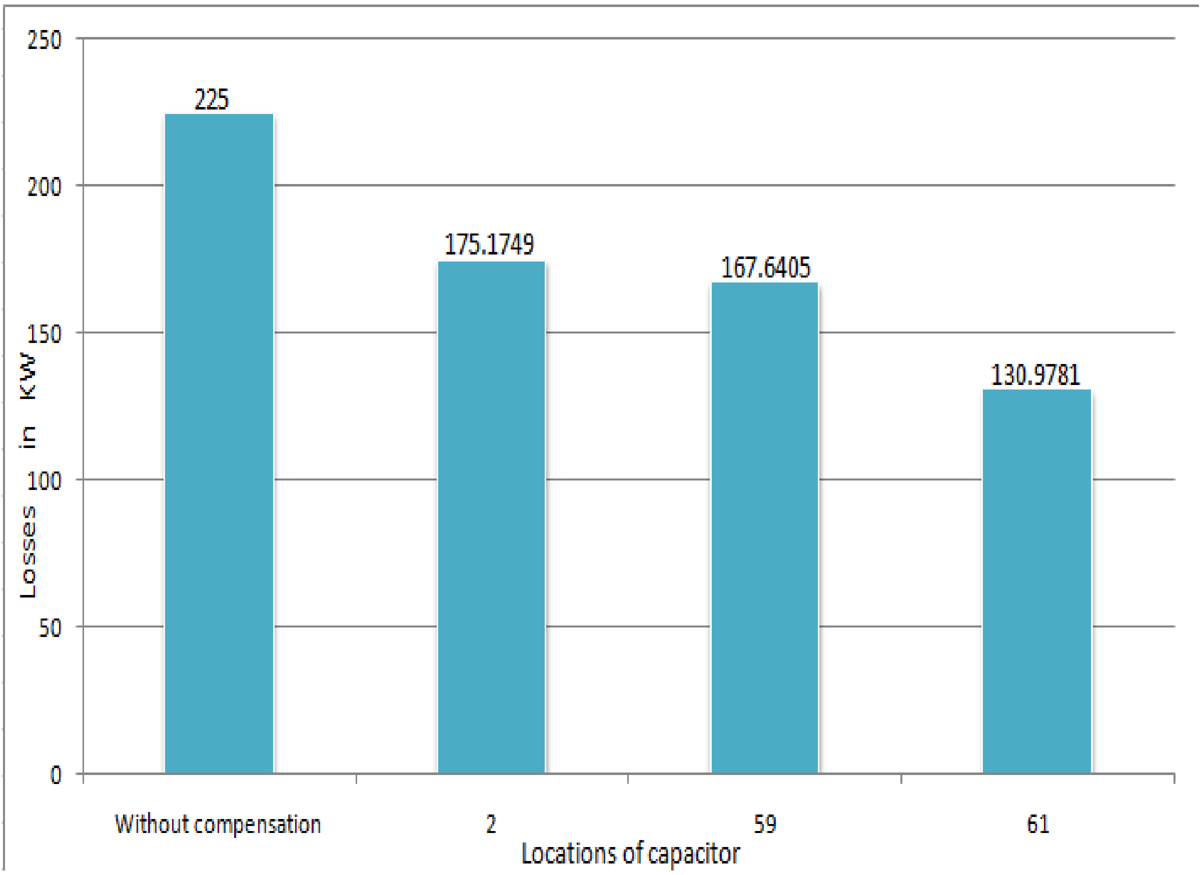

Figure 5.6. Representation of loss reduction for IEEE-69 bus system

CHAPTER 6

6.1 Discussion over the results obtained

The proposed method presented in chapter 3 takes the advantage of the classical forward and backward sweep method in which Kirchhoff's voltage law (KVL) and Kirchhoff's current law (KCL) is used which is the most basic part of the power system engineering. The proposed method is successfully programmed by using MATLAB codes that are coded in such a way that they strictly follow the algorithm mentioned in this paper. The results obtained proves that the method used by MATLAB codes shows that forward and backward sweep method is very efficient and satisfies the requirement of the algorithm mentioned.

The total power loss for 33 and 69 bus system given below are the final result which are verified with the various papers for 33 bus system total active power loss obtained is 201.9620 kilo watt which is approximately correct when compared with the various papers and for 69 bus system total active power loss obtained is 225.8983kilo watt which again approximately correct.

The proposed method as described in chapter 4 takes the advantage as granted for the forward sweep and backward sweep and it is simple and it uses the basic laws of electrical engineering that are Kirchhoff's current law and Kirchhoff's voltage law.

The described methodology is programmed successfully using the MATLAB codes that are designed or coded in a manner that they completely obey the algorithm as described in this paper. The result obtained using MATLAB codes proves the methodology applied that describes forward sweep and backward sweep shows a very good efficacy of the MATLAB codes.

The total power loss for IEEE-33 busses distribution system for both industrial and commercial load are 3.811Kwatt and 135.4152Kwatt respectively whereas the total power loss for IEEE-69 buses distribution system for both industrial and commercial load are 4.7426Kwatt and 156.8449Kwatt respectively.

On the basis of the applied TLBO algorithm technique the optimal location of capacitor for IEEE-33 bus system the various locations can be found but there may be chances that sometimes the teaching phase solution is more effective than the student phase or vice versa. The optimal location for capacitor placement for IEEE-33 bus system is 3, 25, and29 and the total losses corresponds to these locations are 139.4416KW, 133.1564KW and 115.3223 respectively.

CHAPTER 7

7.1Conclusion

Various applications especially in the automation of distribution system and economic operation of the power system. A load flow analysis for a particular power system is required to examine for every second and considering this it is very important that the solution of the load flow problem should be very efficiently available exactly on or before the solution is required. For the further improvement of the loadflow analysis, we need to confront the radial network. It must be taken as advantage that is granted for various fields of engineers that a technique that asses the actual performance of the power system is the load flow analysis. The load flow can be used to conduct the conceptual design and also in determining the size of the various equipment that are installed in the transmission line and at the substation.

The effect of industrial load and commercial load on IEEE-33 and IEEE-69 bus distribution system is studied and the impact of electrical equipment or electrical load leadsto the differentiation of the two types of loads. The advanced electrical equipment when used on either of the load shows the identical behavior as observed on the various current and voltage profile but as compared to the electrical equipment which when used previous 10 years before shows that the losses in flow of power from the sending end to the receiving end. Also, the applied methodology further helps toobtained the results very easily. For future the advanced electrical equipment should be developed by keeping in mindin order to take the losses as low as possible.

A disciplinary study is done for the optimization of losses of IEEE-33 and IEEE-69 bus radial distribution system by using the method of Teaching learning-based optimization technique and optimum positions of capacitor bank is determined using the MATLAB software. These techniques do not use the parameter that are controlled by the algorithm itself, robust to programming, easy and fast convergence rate also makes it different from the various other optimization technique. The effect of controlling parameters of the proposed algorithm is also examined and these controlling parameters must be tuned so that these parameters can provide better solution. It is also observed that the optimum positions of capacitor banks results in commendable operation of the radial distribution system.

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