SELECTION OF OPTIMAL SIZE AND LOCATION OF DGs AND DSTATCOM USING TEACHING LEARNING BASED OPTIMIZATION IN RADIAL DISTRIBUTION SYSTEMS

DISSERTATION

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Submitted by:

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CERTIFICATE

This is to certify that the dissertation entitled **"SELECTION OF OPTIMAL SIZE AND LOCATION OF DGs AND DSTATCOM USING TEACHING LEARNING BASED OPTIMIZATION IN RADIAL DISTRIBUTION SYSTEMS"** submitted by **PUNIT SAINI (2K15/PSY/10)** in the partial fulfillment of the requirement for the reward of the degree of Master of Technology in Electrical Engineering, Delhi Technological University (Formerly Delhi College of Engineering) is an authentic record of the candidate's own work carried out by him under my constant guidance. The information and data contained in this project is original and has not been submitted anywhere else for the award of any other degree.

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DECLARATION

I, Punit Saini, Roll No. 2K15/PSY/10 and a student of M. Tech. Electrical Engineering (Power Systems), hereby declare that the dissertation titled "SELECTION OF OPTIMAL SIZE AND LOCATION OF DGs AND DSTATCOM USING TEACHING LEARNING BASED OPTIMIZATION IN RADIAL DISTRIBUTION SYSTEMS" under the supervision of Dr. S. Bhowmick, Professor, Department of Electrical Engineering, Delhi Technological University, in partial fulfillment of the requirement for the award of the degree of Master of Technology, has not been submitted elsewhere for the award of any Degree, and is true to my knowledge.

Place: Delhi

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Date:

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ABSTRACT

This thesis proposes an approach to determine the optimal location and sizing of Distributed Generation (DG) and Distribution STATCOM (DSTATCOM) simultaneously to improve the node voltage and power losses in radial distribution systems.The objective is to minimize active power losses while keeping the voltage profiles in the network within specified limits. Power-flow studies is carried out using forward/backward algorithm using BIBC and BCBV matrices. Teaching learning based optimization (TLBO) technique is used to find the optimal locations and sizes of DG and DSTATCOM.

A 33-bus and a 69-bus radial distribution system are used to demonstrate the effectiveness of the method. The simulation results show that the reduction of power loss in distribution systems is possible if DG and DSTATCOM are optimally placed in the distribution system. The superiority of the approach has been shown by comparing the results with PSO and BFO (Bacterial Foraging Optimization) methods in the two systems.

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LIST OF ABBREVIATIONS AND SYMBOLS

RDN	radial distribution system
P_{loss}	Power loss of the network
R_i	The resistance of *i-th* branch.
S_i	The complex power at *i-th* node.
P_i	The real power at *i-th* node.
Q_i	The reactive power at i-*th* node.
V_i	*I-th* node voltage.
I_i	*I-th* node equivalent current injection
V_i^k	The node voltage at the *k-th* iteration for *i-th* node.
I_i^k	The equivalent current injection at the *k-th* iteration for *i-th* node.
I_i^r	the real parts of the equivalent current injection at the *k-th* iteration for *i-th* node.
I_i^i	the imaginary parts of the equivalent current injection at the *k-th* iteration for *i-th* node.
$P_{D\_i}^{without\_dg}$	active power demand without DG
$P_{Di}^{with\_dg}$	active power demand with DG
$Q_{D\_i}^{without\_DST}$	reactive power demand withot DSTATCOM
$Q_{D\_i}^{with\_DST}$	reactive power demand withot DSTATCOM

CHAPTER-1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Now a day with increased loading and demand in existing power systems, distributionnetworks are constantly facing increased burden and reduced bus voltages.The voltage at nodes decreasesin distribution network if the location of substation is at a distant from network. This voltage decrement is mainly due to the insufficientreactive power.At certain nodes,increase in loading may even lead to disintegrate voltage.To maintain voltage profile and to get rid of system failure we need reactive power compensation. This distribution system has high R/X ratio than the transmission network, this is the reason the losses in distribution network is much more than transmission network. These losses have significant effect on distribution equipment's.That is why we need to reduce these losses for overall performance. Shunt capacitor and reconfiguration of network can be used for minimization of these losses, Distributed generation (DG) placement etc. These DG's are for active power which help in minimizing MVA, current, energy losses.Peak demand losses and it also improves voltage profile,stability and power factor.

DG's play key role in smart grid. DG technologyare in two categories: renewable energy sources (RES)& nonrenewablebased energy sources. Non-conventional energy sources come in RES based DG'swhile conventional energy sources come in nonrenewable build DG's. Other environmental and economic factors play big role in DG's development. The demand is now rising as after Kyoto agreement on climate change.

To increase system performance, FACTS (Flexible AC Transmission System) devices are installed at specific locations. D-STATCOM (Distribution STATCOM), shunt connected voltage source converter is one of the device used here to increase the accuracy and ability of distribution systems.Its advantages are lower harmonic distortion and losses, auto operation, and immune to resonance effect etc. In both steady state and dynamic conditions these devices play key role in maintaining voltage profile and to reduce losses

A lot of research is going on to find ideal location and size of these devices.Addition of FACTS devices with DGs will improve system performance more efficiently.

1.2 Objective of the work

The work presented in this dissertation is divided into two parts. The first part involves study of DG and DSTATCOM and the second one involves sizing and siting of DG(s) and DSTATCOM(s) using teaching learning based optimization (TLBO) technique. For validation, the Forward/Backward power-flow method using BIBC and BCBV matrices have been used in radial distribution systems. The objective function is to minimize the network power loss and the node voltage variation(s). Teaching learning based optimization (TLBO) is used for computing the optimum size and locationof the DGs. Previous research focused mainly on the optimization of either DG or DSTATCOM placements. However it is necessary to integrate both DG and DSTATCOM in the distribution system with an objective of minimizing power loss, operational costs and the voltage profile enhancement of the system. TLBO is used for the solution strategy.

1.3 LITERATURE REVIEW

Power-flow studies

Power-flowisessential for the steady-state analysis of distribution networks, The power-flow for distribution systems is different from that of transmission systems.There are several techniques used by the researchers. Teng et al. [1] have proposed thepower-flow of radial distribution networks using node-injection to branch-current (BIBC)and branch-current to node-voltage (BCBV) matrices. Dharmasa et al.[2] have presented a non-iterative power-flow solution for voltage improvement in radial distribution systems.

Augugliaro et.al[3] have proposed a new backward/forward methodology for the analysis of distribution systems with constant power loads. In the proposed method, the loads are considered as constant impedances.

Araujo[4] have presented performance comparisons between the well-known Backward-forward sweep and a Newton power-flow algorithm when applied to large scale, three-phase distribution systems. The Three-Phase Current Injection Method – TCIM applies the full Newton method to solve the nonlinear current injection equations which are derived using phase coordinates, and the complex variables are written in rectangular form.

DG placement

Acharya *et al.*[5] have proposed an analytical expression to compute theoptimum size and also suggested an effective methodology for corresponding optimum location of DGs in distribution systems to minimize both active and reactive power losses. The proposed analytical expression is based on the exact loss formula.

Gozel and Hocaoglu [6] have developed an analytical method based on sensitivity factors for the determination of the optimal size and location of distributed generation in distribution systems to minimize total power losses. This method works without the use of admittance matrix, inverse of admittance matrix or Jacobian matrix. In this research paper the loss sensitivity factor was formulated based on the equivalent current injection and it is employed for the determination of optimal size and location of DG unit(s) to be placed in distribution systems to minimize losses.

Hedayati *et al.* [7] have suggested a method for the optimal placement of DG units in distribution systems which was based on continuation power-flow method. It also computes the most sensitive buses for voltage collapse. The improvement of voltage profile, reduction of power losses and enhancement of power transfer capacity were carried out by thesuggested method.

Ghosh *et al.* [8]have developed a simple method for the optimal sizing and optimal placement of generators. A simple conventional iterative search technique along with Newton Raphson power-flow method had been implemented on three different systems. Both the cost and the losses are effectively reduced.

Wang and Nehrir [9] have suggested an analytical method to compute the optimal location to place a DG unit in radial as well as meshed distribution networks to minimize the power losses. This method was developed for the optimal placement of DG units in a networked system based on the bus admittance matrix, generation information and load distribution of the system.

Kim et al. [10] have presented a Fuzzy-GA based approach for the optimal placement of DGs in a distribution system. The objective of this method was the reduction of power loss costs with considering the number or size of DG and the deviation of bus voltage as a constraint.

Hung et al. [11] have successfully developed an analytical expressionbased on the exact loss formula for finding the optimal size and power factor of four types of DG units. The proposed analytical expressions were based on an improvement to the existing method that was limited to DG Type-I, which was capable of delivering real power only

Shukla et al. [12] have presented a multi-location distributed generation problem to reduce the active power losses of the radial distribution system using genetic algorithm (GA) based solution. The loss sensitivity to the change in active power injection was used to select the optimal node for DG placement.

Moradi and Abedini [13] have proposed a novel GA / particle swarm optimization (PSO) to find the optimal size and location of DG units in a distribution system. The objective of this method was to minimize the network power losses, better voltage regulation and improve the voltage stability within a certain specified frame-work of system operation and system constraints in radial distribution systems.

Mistry and Roy [14] have applied a PSObased technique with constriction factor to determine the optimal sizes and locations of multiple DG units. A predetermined load growth with voltage regulation for five year was considered as the constraints in this research paper. The results proved that by the incorporation of multiple DG units in distribution system reduced the real power loss, reactive power loss, purchase cost of energy and voltage deviation in the distribution system

Khyati Mistry [15]have presented three different optimization techniques namely PSO, Craziness based particle swarm optimization (CRPSO) and Teaching-learning based optimization (TLBO) algorithm for optimal placement of DGs.The main objective of this paper is to minimize the active power loss and to improve the voltage profile of the overall system by optimal sizing and siting of DGs.

Sulatna and Roy[16] have presented a novel quasi-oppositional teaching learning based optimization (QOTLBO) methodology in order to find the optimal location of DGs to simultaneously optimize power loss, voltage stability index and voltage deviation of radial distribution networks.

Neeraj Kanwar *et.al*[17] have presented an improved variant of the Teaching Learning Based Optimization (TLBO) method to efficiently and effectively deal with the problem of simultaneous allocation of distributed resources in radial distribution networks

Sajjadi et al. [18] have presented the simultaneous placement of DGs and capacitors for reducing active and reactive power loss reduction in a radial distribution network. Voltage stability was also considered as an objective function.

DSTATCOM placement

Abhinav Jain et.al[19] have presented an effective method for the DSTATCOM placement for the minimization of power losses and improvement of voltage profile in radial distribution systems.

A. R. Gupta[20] have proposed D-STATCOM Placement in Radial Distribution System Based on Power Loss Index Approach.

Atma Ram Gupta[21] presents Energy savings using D-STATCOM placement in radial distribution system

Gupta and Ashwini [20] have determined the optimal location and size for D-STATCOM for radial distribution networks under reconfigured network to reduce the power loss.

Combined DG and DSTATCOM placement

K.R. Devabalaji et.al [22] have presented an approach to carry out optimal sizing and siting of multiple DGs and DSTATCOMs in radial distribution systems using Bacterial Foraging Optimization Algorithm (BFOA).

S.Devi[23] have used PSO for both DG and DSTATCOM placement in radial distribution systems.

1.4 OUTLINE OF THE THESIS:-

The work carried out in this Report has been concluded in six chapters.

Chapter-2 represents the overview of DISTRIBUTION GENERATION (DG) and DSTATCOM. In this chapter, the advantages and disadvantages associated with DG as well as DSTATCOM connection to the grid is addressed.

Chapter-3 presents the power-flow analysis of radial distribution networks using Forward/Backward sweep power-flow technique.

Chapter-4 presents the details of TLBO, its flow chart, and the implementation of TLBO in DG and DSTATCOM in distribution system.

Chapter-5 discusses the case studies corresponding to incorporation of both DG and STATCOM in distribution systems using TLBO technique and its comparison with other optimization techniques like PSO.

Chapter-6 presents the conclusion and the scope of further work.

CHAPTER 2

DISTRIBUTED GENERATION (DG) AND D-STATCOM

2.1 INTRODUCTION

In current scenario, power networks Loss Minimization has understood greater importance.In literature it shows that In distribution network 70% of total power loss are happening while in transmission system it is only 30 %of total power loss. For improving the overall efficiency of the power system power utilities have to decrease the loss, mainly at the distribution level.The following methods are used for minimization of distribution networks power losses.

- DG placement
- Reactive power compensation
- Feeder reconfiguration
- Reinforcement of the feeders.
- High voltage distribution networks
- Grading of conductor

To meet the load demand of the radial distribution network, a large number of DG will be required in the distribution network.This large number of DG plays a key role in improving the system consistency, security, and quality of electric system by providing active power and reactive power support for regulating the voltage. Distributed generation(DG) refers to a selection of technology that generate electricity at or near wherein it will likely be used, including solar panals which is combination of haet and power. DG may supply a single unit, such as a home or business,or it may be part of a major industrial facility. When related to connection of electrical supply to lower voltage, distributed generation can supply clean and reliable power to customer end and decrease power losses in transmission and distribution network.One of the characteristics of future electricity system under smart grid idea is to have an cost efficient transmission and distribution network that will minimize the line losses.

2.2 DISTRIBUTED GENERATION

Distributed Generation (DG) is defined as small-scale technologies to produce electricity close to the end users of power. With people, attention to sustainable improvement and environmental pollutants, DG generation with its particular environment and economic system raises increasingly more subject. In recent years, distributed generation technologies are developing swiftly, becoming an significant area of energy research direction.The speedy development of DG induced its large capacity distributed power integrated into the grid, and the addition of distributed power in the nearby grid is gradually high.

2.3 Types of Distributed Generation

The different types of renewable and non renewable DGs are classified on the basis of real and reactive power delivering capability.In this thesis four types of DG are considered for comparative studies which are described as follows:

Type1: DG is capable of delivering only active power such as micro turbines, photovoltaic, fuel cells, which are incorporated to the main grid with the help of converters/inverters.

Type2: This type of DG is capable of delivering only reactive power. Synchronous compensators such as gas turbines are the example of this type and operate at zpf (zero power factor)

Type3: This type of DG is capable of delivering both active and reactive power. DG units based on synchronous machines (gas turbine) come under this type.

Type4: This type of DG is capable of delivering active power but consuming reactive power. Mainly induction generators, which are used in wind farms, come under this category.

2.4 BENEFITS AND PROBLEMS OF DG INCORPORATED INTO THE DISTRIBUTION NETWORK

Distributed Generation(DG) provides flexible power supply support in distribution power system as a new form of clean energy generation it has a positive meaning for improving electric power quality and power system stability,so an increasing number of interest is attracted all over the world. But DG capacity normally is smaller, lower voltage levels, and it is integrated into electric power system at distribution network side.Therefore, DG included into electric power system has added many problems;DG has a poor impact on power system quality and stability, power system control and protection of distribution network.

2.4.1 DISTRIBUTED GENERATION BENEFITS

The major benefits of the integrations of DG into electric power networks are as follows:

- DG units are usually installed near the load site on the radial distribution networks. Thus,part of the transmission power is replaced by the injected DG power, causing a reduction in transmission and distribution line losses, which minimizes costs related to loss.
- Injecting active and reactive power by DG units improves system voltage profiles and the load factor, which minimizes the number of required voltage regulators, capacitors and their ratings and maintenance costs. However, the amount of improvement depends on the size and location of the DG unit.
- Increases in power demands as a result of load growth can be covered by DG units without needin to increase existing traditional generation capacity; it also reduces or delay the need for building new T&D lines, upgrades the present power systems and reduces T&D network capacity during the planning phase.
- DGs are flexible devices that can be installed at load centres rather than at substations, where difficulties due geographical constraints or scarcity of land availability may occur.
- DG technology is available in a wide capacity range (i.e., from ten kW up to 15 MW), so it can be installed on medium and/or low voltage distribution networks, giving it flexibility for sizing and sitting.
- DG technologies produce electric power with few emissions(and sometimes zero emissions). This feature makes them more environmentally friendly compared to traditional power plants.
- DGs can help in system service continuity and reliability, as there are many generation spots, not just one large centralized generation site.

2.4.2 Problems with DGs connected to the grid

DG connected to the grid at the distribution side will necessarily have an impact on power system stability. When the large number of DG is connected to the grid, it will critically affect the distribution system control, design, operation and protection, affect security and reliability of system.This requires planning methods of traditional distribution network make approp-riate modifications. DG is usually connected to the grid at the distribution side, there are mainly two aspects of DG connected to the grid control and power regulation. How to connected to the grid and to minimize the impact on power system.There are following problem associated with DG placement in distribution network:-

- Effect on system voltage
- The impact on protection
- The impact on combined power system grid stability
- The impact on grid scheduling

2.4.3 The Basic Technical Requirements of DG Connected To Grid

Distributed generation connected to the distribution network will affect the operation mode and performance of distribution network. In order to ensure the safe operation of distribution network and the power supply quality of users, the connection of distributed generation to grid must meet the following basic requirements:

- It must ensure that the voltage deviation caused by DG connection to the grid does not exceed the limit.
- The normal operation current and thermal stability current should not exceed the allowable range.
- Short circuit capacity should not exceed the permissible limit for distribution network such as circuit breaker,cable etc.
- The power produced by DG should be qualified for power quality, voltage sag, swell, flicker and harmonic.There value should not exceed the permissible value.

2.7 Voltage stability

Modern electric power utilities are facing many challenges due to ever increasing complexity in their operation and structure. In recent years, one problem has that received wide attention is voltage instability The lack of new generation and transmission facilities,and overexploitation of existing facilities together with the increase in load demand make these problems more likely in modern power systems.

Voltage stability is the ability of a power system to maintain adequate voltage magnitude so that when the system nominal load is increased,the actual power transferred to that load will increase. The main cause of voltage instability is the inability of the power system to meet the demand for reactive power. Voltage instability is the cause of system voltage collapse, in which the system voltage decays to a level from which it is unable to recover. Voltage collapse may lead to partial or full power interruption in the system.

Providing adequat reactive power support at the appropriate location solves voltage instability problems. There are many reactive compensation devices used by the utilities for this purpose, each of which has its own characteristics and limitations. However, the utility would like to achieve this with the most beneficial compensation device. Hence, this thesis report compares the advantages and disadvantages of the currently available and most commonly used shunt-compensation devices.

2.7.1 Static voltage stability

Static voltage instability is mainly associated with reactive power imbalance.Thus,the loadability of a bus in a system depends on the reactive power support that the bus can receive from the system. As the system approaches the maximum loading point or voltage collapse point,both the real and reactive power losses increase rapidly.Therefore, the reactive power supports have to be locally adequate.With static voltage stability,slowly developing changes in the power system occur that eventually lead to a shortage of reactive power and declining voltage. This phenomenon can be seen from a plot of power transferred versus voltage at the receiving end. These plots are popularly referred to as P–V curves. As power transfer increases, the voltage at the receiving end decreases. Eventually, a critical(nose) point, the point at which the system reactive power is out of usage, is reached where any further increase in active power transfer will lead to very rapid decrease in voltage magnitude. Before reaching the critical point, a large voltage drop due to heavy reactive power losses is observed. The only way to save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse.

2.8 Shunt capacitor, SVC and STATCOM

2.8.1 Shunt capacitor

Shunt capacitors are relatively inexpensive to install and maintain. Installing shunt capacitors in the load area or at the point that they are needed will increase the voltage stability. However, shunt capacitors have the problem of poor voltage regulation and, beyond a certain level of compensation,a stable operating point is unattainable.Furthermore, the reactive power delivered by the shunt capacitor is proportional to the square of the terminal voltage,during low voltage conditions Var support drops, thus compounding the problem. The characteristic of the shunt capacitor is shown in Fig. 1

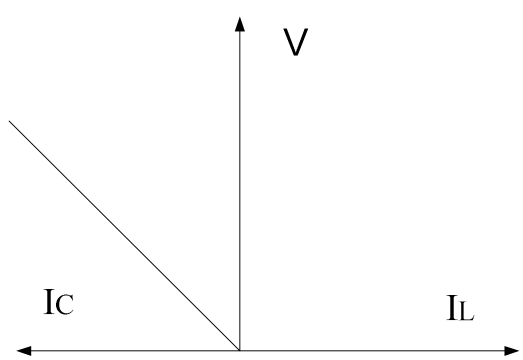
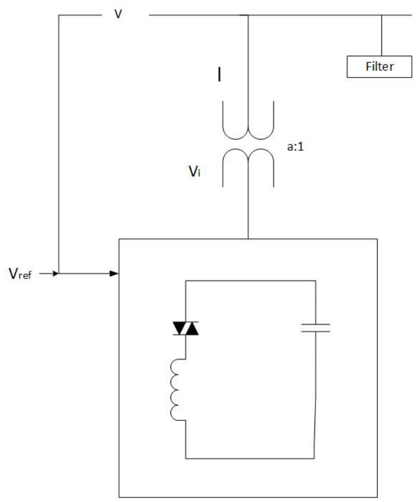


Fig 1: Terminal characteristic of shunt capacitor.

2.8.2 Static Var compensator (SVC)

SVC is a shunt connected static Var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variable. Typically, the power system control variable is the terminal bus voltage.There are two popular configurations of SVC. One is a fixed capacitor (FC) and thyristor controlled reactor (TCR) configuration and the other one is a thyristor switched capacitor (TSC) and TCR configuration. In the limit of minimum or maximum susceptance, SVC behaves like a fixed capacitor or an inductor.Choosing appropriate size is one of the important issues in SVC applications in voltage stability enhancement.Figures 2.2 and 2.3 show the basic structure and terminal characteristic of a SVC,respectively.



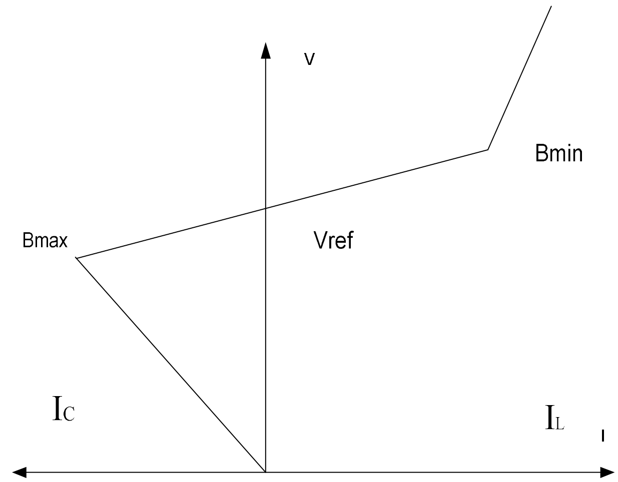
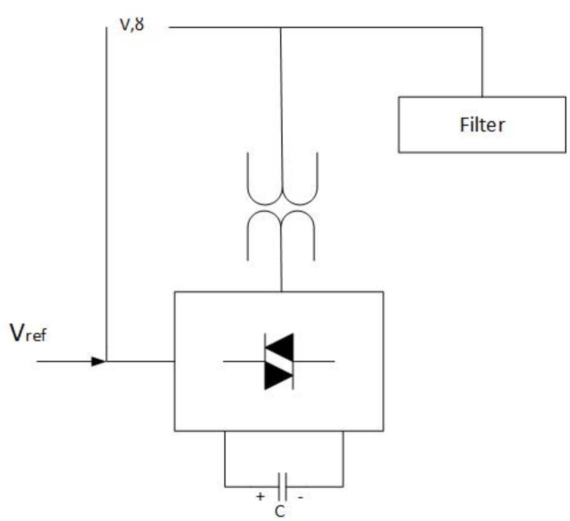


Fig 2.2:basic structure of svc

Fig 2.3: Terminal characteristic of SVC

2.8.3 Static synchronous compensator (STATCOM)

STATCOM is a voltage source converter based device, which converts a DC input voltage into an AC output voltage in order to compensate the active and reactive needs of the system. STATCOM has better characteristics than SVC; when the system voltage drops sufficiently to force the STATCOM output to its ceiling, its maximum reactive power output will not be affected by the voltage magnitude. Therefore, it exhibits constant current characteristics when the voltage is low under the limit. A schematic diagram and STATCOM characteristic are shown in Figs. 2.4 and 2.5, respectively.



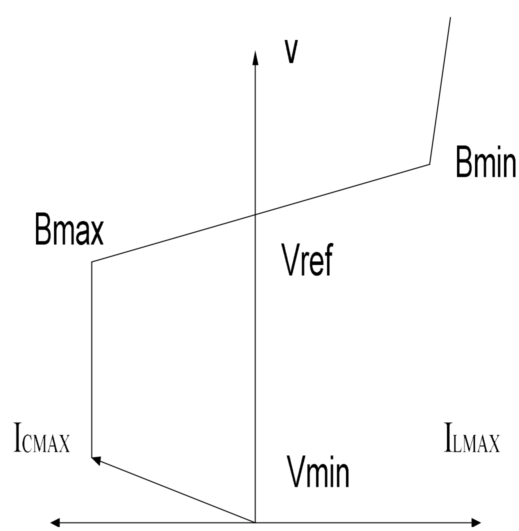


Fig 2.4: Basic structure of STATCOM.

Fig 2.5: Terminal characteristic of STATCOM

2.6 DSTATCOM

The alternative of the fixed or the switched capacitors are the FACTS devices.The devices are originally developed for the transmission system but now they have been in use in the distribution system for the same purpose.They provide the reactive power compensation according to the system needs. They acts like is capacitor when the system requires reactive power and acts like inductor when system has more reactive power. To compensate the reactive power devices are used such as DVR,DSTATCOM and UPQC. These power devices are provide a fast efficient and reliable control over the distribution parameters like voltage, phase angle and line impedance between sending and receiving end node.It has been observed that amongst all, the D-STATCOM serves all the purposes with the required reactive power compensation.

D-STATCOM is a shunt connected voltage source converter based static compensator that is used for the improvement of bus voltage profile. It is connected in shunt to the distribution system through a standard power distribution transformer.The DSTATCOM is capable of generating continuously variable reactive power at a level up its maximum MVA rating. The D-STATCOM constantly checks the line waveform with respect to a reference ac signal, and hence, it can offer the precise quantity of leading or lagging reactive current compensation to minimize the amount of voltage variations. The main components of a D-STATCOM are a dc capacitor, an ac filter, one or more inverter modules, a PWM control strategy and a transformer to match the inverter output to the line voltage. D-STATCOM has been utilized to increase the reliability and efficiency of distribution systems due to its various advantages such as low harmonic distortion,small size, low losses, automatic operation, no resonance problems, continuous operations etc.These devices play an important role in improving voltage regulation,voltage balancing and reducing power losses etc of distribution systems under both steady state and dynamic conditions.

CHAPTER-3

POWER-FLOW STUDIES IN DISTRIBUTION SYSTEMS

3.1 INTRODUCTION

The power flow of a power network provides the steady state solution through which various parameters of interest like currents,voltages, losses etc can be calculated. The load flow is important for the analysis of distribution system, to investigate the issues related to planning, design and the operation and control.Some applications like optimal DG and dstatcom placement in distribution system, requires repeated power-flow solution. Many methods such Gauss-Seidel, Newton-Raphson are well reported to carry the power-flow of transmission system.The use of these methods for distribution systems may not be advantageous because they are mostly based on the general meshed topology of a typical transmission system whereas most distribution systems have a radial or tree structure. Further distribution system posses high R/X ratio, which cause the distribution systems to be ill conditioned for conventional load flow methods.

Some other inherent characteristics of electric distribution systems are

(i) Radial or weakly meshed structure

(ii) unbalanced operation and unbalanced distributed loads

(iii) large number of buses and branches

(iv) has wide range of resistance and reactance values

(v) Distribution system has multiphase operation.

The effectiveness of the optimization problem of distribution networks relies on upon the load flow algorithm on the grounds that load flow result need to run for ordinarily.The load flow result of distribution networks ought to have time proficient qualities.A technique which can discover the load flow result of radial distribution networks specifically by utilizing topological normal for distribution system is utilized. In this strategy, the plan of tedious Jacobian matrix or admittance matrix, which are needed in customary techniques, is stayed away from.This system is illustrated in a nutshell

3.2 POWER-FLOW IN RADIAL DISTRIBUTION NETWORKS

A feeder brings power from substation to load points/nodes in radial distribution networks . Single or multiple radial feeders are used in this planning approach. Basically,the RDN total power losses can be minimized by minimizing the branch power flow or transported electrical power from transmission networks (i.e. some percentage of load are locally meeting by local DG). To determine the total power loss of the network or each feeder branch and the maximum voltage deviation are determined by performing power-flow.The Forward/Backward Sweep Power-flow technique is used in this case.The impedance of a feeder branch is computed by the specified resistance and reactance of the conductors used in the branch construction. The Forward/Backward Sweep Power-flow method consist two steps (i) backward sweep and (ii) forward sweep.

Backward sweep*:* In this step, the load current of each node of a distribution network having*N* number of nodes is determined as:

$$\bar{I}_L(m)=\left(\frac{P_L(m)-jQ_L(m)}{V*(m)}\right) \tag{3.1}$$

where, $P_L(m)$ and $Q_L(m)$ represent the active and reactive power demand at node *m* and the overbar notation ($\bar{x}$) indicates the phasor quantities,such as $\bar{I}_L$, $\bar{V}^*$. Then,the current in each branch of the network is computed as:

$$\bar{I}(mn) = \bar{I}_L(n) + \sum_{m\in T} \bar{I}_L(m) \tag{3.2}$$

where, the set Γ consists of all nodes which are located beyond the node n

Forward sweep: This step is used after the backward sweep so as to determine the voltage at each node of a distribution network as follows

$$\bar{V}(n) = \bar{V}(m) - \bar{I}(mn)Z(mn) \tag{3.3}$$

where, nodes n and m represent the receiving and sending end nodes, respectively for the branch mn and Z(mn) is the impedance of the branch In this work the estimation methodology utilized within the forward/backward power-flow is based on (i) equivalent current injections (ECI), (ii) the node-injection to branch- current matrix (BIBC) and (ii) the branch-current to node-voltage matrix (BCBV). In this area,the advancement methodology will be depicted in subtle element.Load flow for distribution networks under balanced operating condition with constant power load model can be under remained through the accompanying focuses

3.2.1 Equivalent Current Injection

The technique is based on the equivalent current injection of a node in distribution networks, the equivalent-current-injection model is more practical. For any node of distribution networks, the complex load S_i is expressed by

$$S_i = P_i + jQ_i \tag{3.4}$$

Now, the equivalent current injection is expressed as

$$I_i = I_i^r(Vi) + jI_i^i(Vi) = \left(\frac{Pi + jQi}{Vi}\right)^* \tag{3.5}$$

For the power-flow solution equivalent current injection (ECI) at the *k-th* iteration at *i-th* node is computed as

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{Pi + jQi}{Vi}\right)^* \tag{3.6}$$

3.2.2Formation of BIBC Matrix

The power injections at every node might be transformed into the equivalent current injections using the eq. (3.6) and applying Kirchhoff's Current Law (KCL) at each and every node a set of comparisons could be composed. Now each and every branch currents of the network can be shaped as a function of the equivalent current injections (ECI).As shown in Figure 3.1, the branch currents IB5, IB4, IB3, IB2 and IB1 can be expressed as:

$$IB_5 = I_6 \tag{3.7}$$

$$IB_4 = I_5 \tag{3.8}$$

$$IB_3 = I_4 + I_5 \tag{3.9}$$

$$IB_2 = I_6 + I_3 + I_4 + I_5 \tag{3.10}$$

$$IB_1 = I_2 + I_3 + I_4 + I_5 + I_6 \tag{3.11}$$

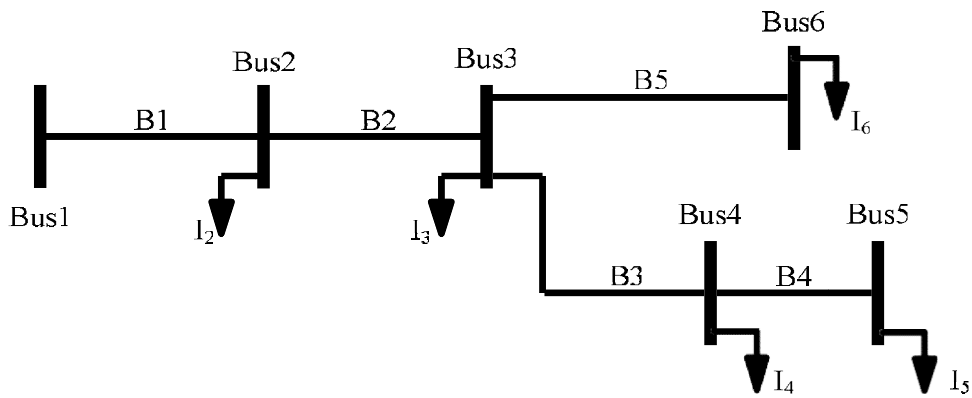


Figure 3.1. Simple distribution system

$$\begin{bmatrix} IB1 \\ IB2 \\ IB3 \\ IB4 \\ IB5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2 \\ I3 \\ I4 \\ I5 \\ I6 \end{bmatrix} \tag{3.12}$$

he general form as of eq. (3.12) can be expressed as:

$$[IB] = [BIBC][I] \tag{3.13}$$

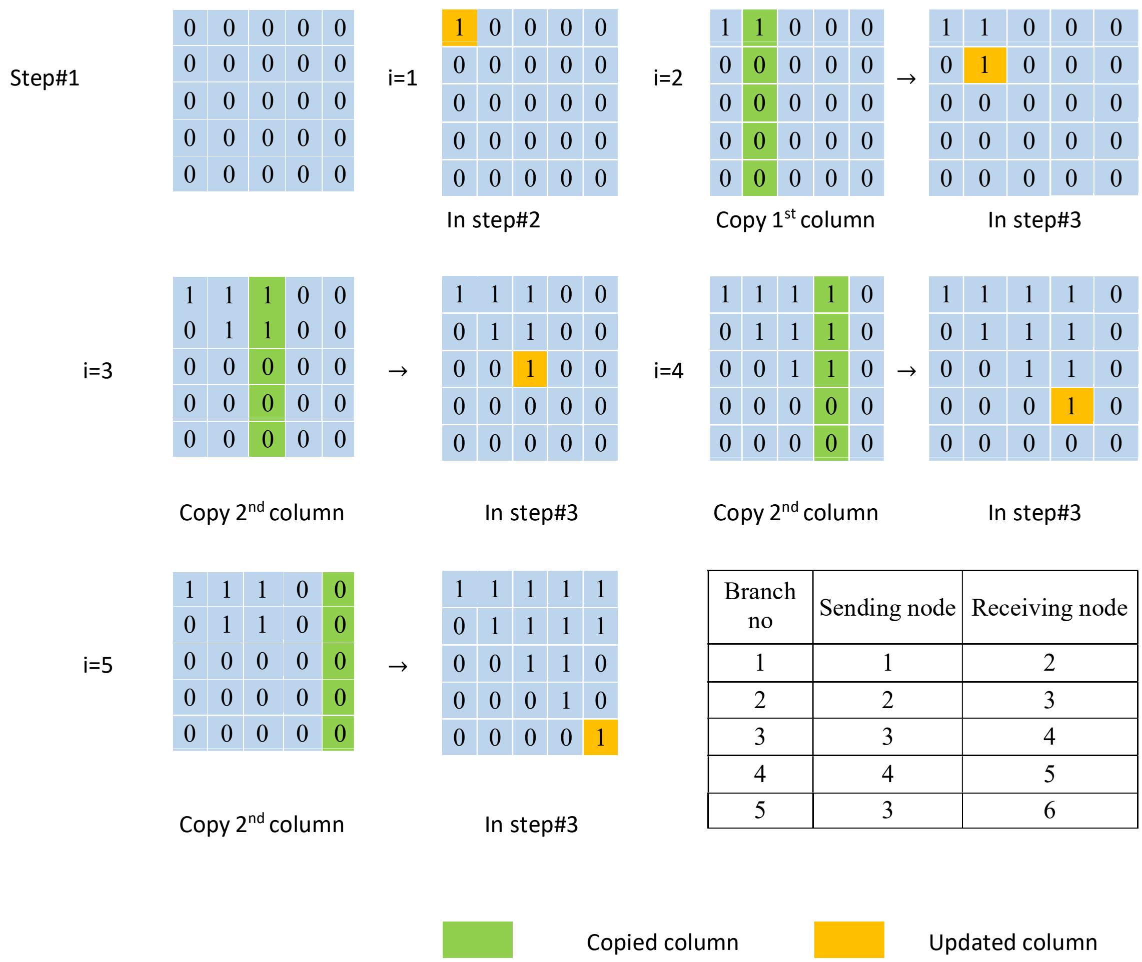
The detailing of BIBC matrix for distribution networks demonstrated in Figure 3.1 is given in eq. (3.13). For general network,the BIBC matrix might be shaped through the accompanying steps and the example is done by the help of Figure 3.1:

Step 1: Make an initial null BIBC matrix with a dimension of (m × (n − 1)). Where m and n are the number of branches and nodes available in the network.

Step 2: initially set i=1 and read the IBi (i=1, 2, 3…m) branch data (i.e. sending end and receiving end node)from line-data matrix. If a line section IBi is located between Node 'x' and Node 'y'. Check,that the IBi branch section of the network is belongs to the first node of the network or not. If it is, then make the *(y-1, y-1)-th* bit of BIBC matrix by '+1'.Increment 'i' by one or go to the step#3.

Step 3: If the in step#2 the IBi branch section is not belongs to the first node of the network. Then copy the column segment of the *'(x-1)-th'* node of BIBC matrix to the column segment of *'(y-1)-th'* node and fill *(y-1, y-1)-th* bit of the BIBC matrix by '+1'. Increment 'i' by one and go to the step#2.This is explained in fig 3.2

Step 4: Repeat step#2 and step#3 until all the branches of the network included in to the BIBC matrix



Branch no	Sending node	Receiving node
1	1	2
2	2	3
3	3	4
4	4	5
5	3	6

Figure 3.2. The formation of BIBC matrix

3.2.3 Formation of BCBV matrix

The Branch Current to Node voltage (BCBV) matrix summarizes the relation between branch current and node voltages. The relations between the branch currents and node voltages can be obtained easily by applying Kirchhoff's Voltage Law (KVL). As shown in Figure 3.1, the voltages of Node 2, 3, and 4 are expressed as:

$$V_2 = V_1 - IB_1 Z_{12} \tag{3.14}$$

$$V_3 = V_2 - IB_2 Z_{23} \tag{3.15}$$

$$V_4 = V_3 - IB_3 Z_{34} \tag{3.16}$$

Substituting equations (3.14) and (3.15) into eqn. (3.16), the voltage of Node 4 can be rewritten as:

$$V_4 = V_1 - IB_1Z_{12} - IB_2Z_{23} - IB_3Z_{34} \qquad (3.17)$$

From equation it can be seen that the node voltage of the network can be expressed as a function of the branch currents,line parameters and main substation voltage.Similar approach can be employed for other nodes,and the Branch-Current to Node-Voltage (BCBV) matrix can be derived as:

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{56} \end{bmatrix} \begin{bmatrix} IB_1 \\ IB_2 \\ IB_3 \\ IB_4 \\ IB_5 \end{bmatrix}$$

The general form of eq. (3.18) can be expressed as:

$$\text{Or, } [\Delta V] = [BCBV][IB] \qquad (3.19)$$

The formulation of BCBV matrix for distribution networks shown in Figure 3.1 is given eq. (3.18) and eq. (3.19).For universal network, the BCBV matrix can be formed through the following steps:

Step 1: Make an initial null BVBC matrix with a dimension of $((n - 1) \times m)$.Where m and n are the number of branches and nodes available in the network.

Step 2: initially set i=1 and read the IB_i (i=1, 2, 3…m) branch data (i.e. sending end and receiving end node) from line-data matrix. If a line section IB_i is located between Node 'x' and Node 'y'. Check,that the IB_i branch section of the network is belongs to the first node of the network or not. If it is,then make the *(y-1, y-1)-th* bit of BVBC matrix by the corresponding branch impedance(Z_{xy}). Increment 'i' by one or go to the step#3.

Step 3: If the in step#2 the IB_i branch section is not belongs to the first node of the network.Then copy the row segment of the *'(x-1)-th'* node of BVBC matrix to the row segment of *'(y-1)-th'* node and fill *(y-1, y-1)-th* bit of the BVBC matrix by the corresponding branch impedance (Z_{xy}).Increment 'i' by one and go to the step#2.This is explained in Figure 3.2.

Step 4: Repeat step#2 and step#3 until all the branches of the network included in the BVBC matrix.

From Figure (3.2) and Figure (3.3), it can be seen that the algorithms for the both BIBC and BCBV matrices are virtually identical. Basic formation difference of BIBC matrix and BCBV matrix is that, in BIBC matrix *(x-1)-th* node column is copied to the column of the *(y-1)-th* node and fill with +1 in the *(x-1)-th* row and the *(y-1)-th* node column,while in BCBV matrix row of the *(x-1)-th* node is copied to the row of the *(y-1)-th* node and fill the line impedance (Zxy) in the position of the *(y-1)-th* node row and the *i-th* column.

$$[BCBV]=\begin{bmatrix}1&0&0&0&0\\1&1&0&0&0\\1&1&1&0&0\\1&1&1&1&0\\1&1&0&0&1\end{bmatrix}\begin{bmatrix}Z_{12}&0&0&0&0\\0&Z_{23}&0&0&0\\0&0&Z_{34}&0&0\\0&0&0&Z_{45}&0\\0&0&0&0&Z_{56}\end{bmatrix}$$

$$[BCBV]=\begin{bmatrix}1&1&1&1&1\\0&1&1&1&0\\0&0&1&1&0\\0&0&1&1&0\\0&0&0&0&1\end{bmatrix}\begin{bmatrix}Z_{12}&0&0&0&0\\0&Z_{23}&0&0&0\\0&0&Z_{34}&0&0\\0&0&0&Z_{45}&0\\0&0&0&0&Z_{56}\end{bmatrix}$$

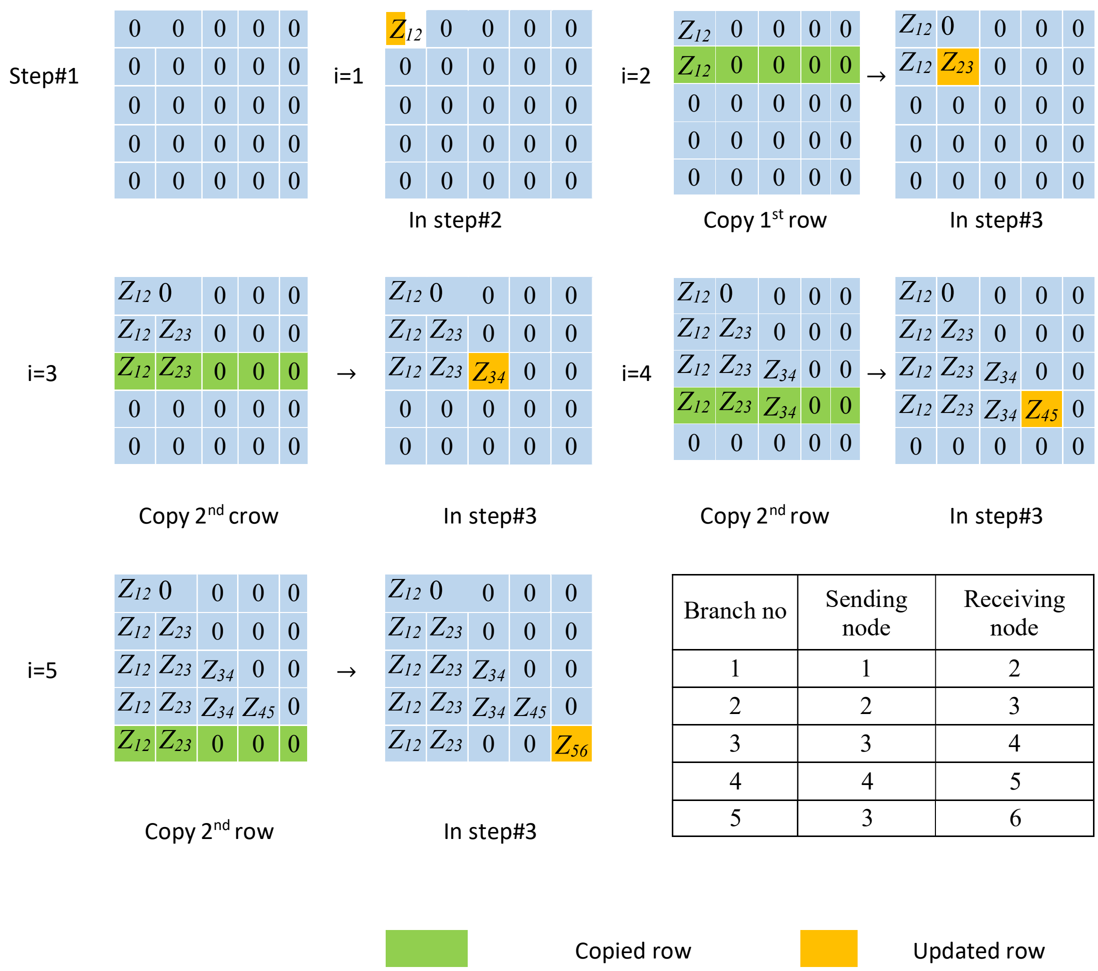
$$[BCBV] = [BIBC][ZD]$$

$$\begin{bmatrix}V_1\\V_1\\V_1\\V_1\\V_1\end{bmatrix}-\begin{bmatrix}V_2\\V_3\\V_4\\V_1\\V_1\end{bmatrix}=\begin{bmatrix}1&0&0&0&0\\1&1&0&0&0\\1&1&1&0&0\\1&1&1&1&0\\1&1&0&0&1\end{bmatrix}\begin{bmatrix}Z_{12}&0&0&0&0\\0&Z_{23}&0&0&0\\0&0&Z_{34}&0&0\\0&0&0&Z_{45}&0\\0&0&0&0&Z_{56}\end{bmatrix}\begin{bmatrix}IB_1\\IB_2\\IB_3\\IB_4\\IB_5\end{bmatrix}$$

The general form of eq. (3.23) can be expressed as:

$$[\Delta V] = [BCBV][ZD][IB] \quad (3.24)$$

$$[\Delta V] = [BIBC]^T[ZD][IB] \quad (3.25)$$



Branch no	Sending node	Receiving node
1	1	2
2	2	3
3	3	4
4	4	5
5	3	6

Figure 3.3. The formation of BVBC matrix

3.2.4 Solution Methods

The development of BIBC and BCBV matrices is clarified in section 3.2.2 and 3.2.3.These matrices investigate the topological structure of distribution networks.Basically the BIBC matrix is making an easy relation between the node current injections and branch currents. These relation give a simple solution for branch currents variation,which is occurs due to the variation at the current injection nodes,these can be obtained directly by using BIBC matrix. The BCBV matrix build an effective relations between the branch currents and node voltages. The concern variation of the node voltages is produced by the variant of the branch currents. These could be discovered specifically by utilizing the BCBV matrix. Joining eqs. (3.13) and (3.19),the relations between the node current injections and node voltages could be communicated as:

$$[\Delta V] = [BCBV].[BIBC].[I] \quad (3.26)$$

Now $$[BCBV] = [BIBC]^T. [ZD] \quad (3.27)$$

∴ $$[\Delta V] = [BIBC]^T. [ZD]. [BIBC]. [I] \quad (3.28)$$

∴ $$[DLF] = [BCBV][BIBC] \quad (3.29)$$

∴ $$[DLF] = [BIBC]^T. [ZD]. [BIBC] \quad (3.30)$$

so $$[\Delta V] = [DLF].[I] \quad (3.31)$$

The iterative solution for the distribution system power-flow can be obtained by solving eqs. (3.32) and (3.33) which are specified below:

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{Pi + jQi}{Vi}\right)^* \quad (3.32)$$

$$[\Delta V^{k+1}] = [DLF].[I^k] \quad (3.33)$$

$$[V^{k+1}] = [V^0] + [\Delta V^{k+1}] \quad (3.33)$$

The new definition as illustrated uses just the DLF matrix to take care of power-flow problem.Subsequently this strategy is extremely time efficient, which is suitable for on-line operation and optimization problem of distribution networks.

3.3 ALGORITHM FOR DISTRIBUTION NETWORK POWER-FLOW

The algorithm steps for power-flow solution of distribution networks is given below:

Step 1: Read the distribution networks line data and bus data.

Step 2: Calculate the each node current or node current injection matrix.There relationship can be expressed as –

$$[I] = \left(\frac{S}{V}\right)^{*} = \left[\frac{P-jQ}{V^{*}}\right]$$

Step 3: Calculate the BIBC matrix by using steps given in section 3.2.2.

Step 4: Evaluate the branch current by using BIBC matrix and current injection matrix (ECI). The relationship can be expressed as -

[IB] = [BIBC][I]

Step 5: Form the BCBV matrix by using steps given in section 3.2.3.The relationship therefore can be expressed as -

[ΔV] = [BCBV][IB]

Step 6: Calculate the DLF matrix by using the eq. (3.30). The relationship will be -

[DLF] = [BCBV][BIBC]

[ΔV] = [DLF][I]

Step 7: Set Iteration k =0.

Step 8: Iteration k = k + 1.

Step 9: Update voltages by using eqs. (3.32), (3.33), (3.34)

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{Pi + jQi}{Vi}\right)^{*}$$

$$[\Delta V^{k+1}] = [DLF].\,[I^k]$$

$$[V^{k+1}] = [V^0] + [\Delta V^{k+1}]$$

Step 10: If max ((|V(k + 1)| − |V(k)|) > tolerance) go to step 6.

Step 11: Calculate branch currents, and losses from final nodevoltages.

Step 12: Display the node voltage magnitudes and angle,branch currents and losses.

Step 13: Stop

The above algorithm steps are shown in Flowchart given as Figure 3.4.

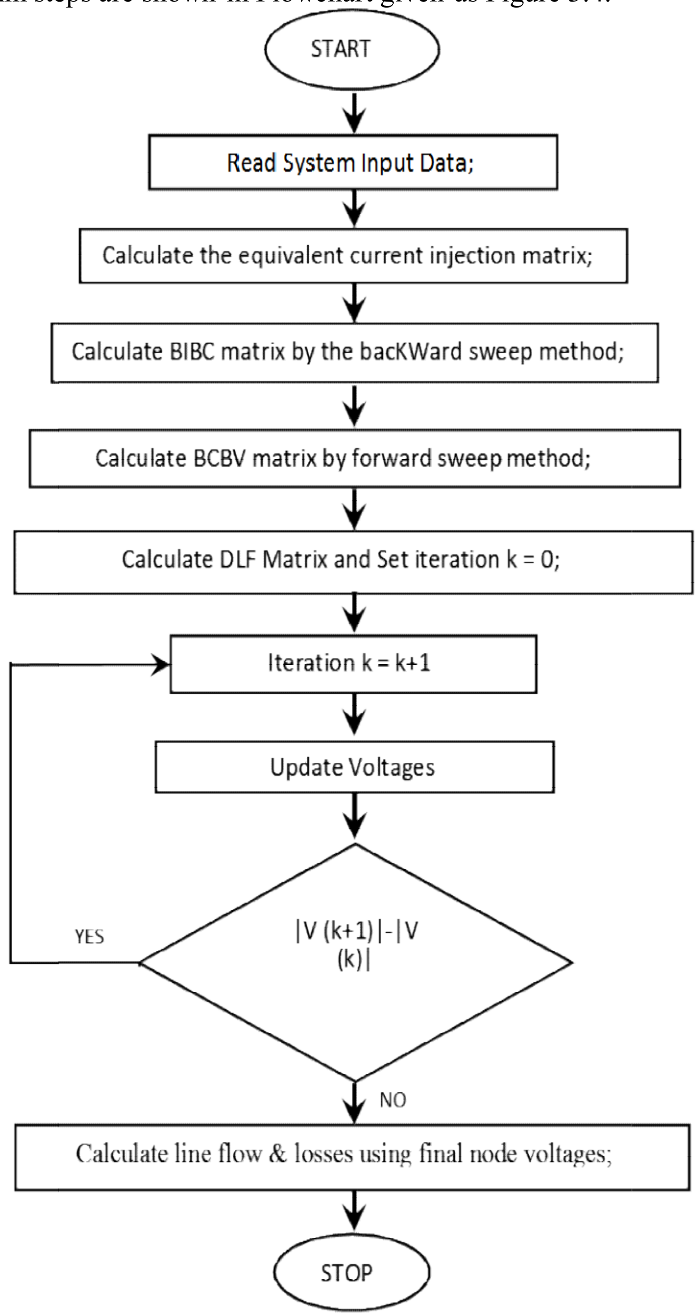


Fig 3.4:- Flowchart for load flow solution for distribution networks.

3.4 INCORPORATION OF DGs IN POWER-FLOW

Assume that a single source radial distribution networks with *NL* branches and a DG is to be placed at node *i* and α be a set of branches connected between the source and node *i* .It is known that the DG supplies active power to the power system but in case of reactive power it is depensd upon distribution generation (DG) and/or DSTATCOM, either it is supplies to the system or consume from the system. The current of other branches are unaffected by the DG.

Total Apparent Power at i^{th} node:

$$S = S_{D\_i} = \sum(P_i + jQ_i) \qquad i = 1, \ldots N_B \tag{3.34}$$

Current at i^{th} node:

$$I_D = I_{Di}^{witho\quad\_DG} = \left(\frac{S}{V}\right)^*$$

To incorporate the DG model, the active and reactive power demand at *i-th* node at which a DG unit is placed, is modified by:

$$P_{Di}^{with\_dg} = P_{D\_i}^{without\_dg} + P_{gi}^{DG} \tag{3.36}$$

$$Q_{Di}^{with\_dg} = Q_{D\_i}^{without\_dg} \mp Q_{gi}^{DG} \tag{3.37}$$

DG power at i^{th} node:

$$S_{DG\_i} = P_{G\_i}^{DG} \pm Q_{G\_i}^{DG}$$

Total new apparent power at i^{th} node:

$$S = S_{D\_i} - S_{DG\_i} \tag{3.39}$$

Now the updated network power can be expressed in matrix form

$$[S] = [S_{D\_i}] - [S_{DG\_i}] \tag{3.40}$$

3.5 INCORPORATION OF DSTATCOM IN POWER-FLOW

Assume that a single source radial distribution networks with N_B branches and DSTATOM is to be placed at node *i*.The DSTATCOM produces reactive power ($Q_{G\_i}^{DST}$)due to this a reactive current(I_{DSTi}^{i}) flow through the radial network branches which changes the reactive component of current of branch. To incorporate the DSTATCOM model, the reactive power demand at *i-th* node at which a DSTATCOM unit is placed, is modified by:

$$Q_{D\_i}^{with\_DST} = Q_{D\_i}^{witho\quad\_DST} \mp Q_{G\_i}^{DST} \tag{3.41}$$

$$[S] = [S_{D\_i}] - [S_{DST\_i}] \tag{3.42}$$

3.6 ALGORITHM FOR DISTRIBUTION NETWORK POWER-FLOW WITH BOTH DSTATCOM AND DG

The algorithm steps for power-flow solution of distribution networks is given below:

Step 1: Read the distribution networks line data and bus data.

Step 2: Calculate DG power and DSTATCOM power for each nodes and update the system bus data.

Step 3: Calculate the total power demand with DG or DSTATCOM or with both by the help of eq. (3.40) (3.42). The relationship can be expressed as –

$$[S] = [S_{D\_i}] - [S_{DG\_i}] - [S_{DST\_i}]$$

Step 4: Calculate the each node current or node current injection matrix. The relationship can be expressed as –

$$[I] = \left(\frac{S}{V}\right)^{*} = \left[\frac{P-jQ}{V^{*}}\right]$$

Step 5: Calculate the modified impedance matrix and modified current injection matrix

Step 6: Calculate the BIBC matrix by using steps given in section 3.2.2.

Step 7: Evaluate the branch current by using BIBC matrix and current injection matrix (ECI). The relationship can be expressed as -

[IB] = [BIBC][I]

Step 8:Form the BCBV matrix by using steps given in section 3.2.3.

[ΔV] = [BCBV][IB]

Step 9: Calculate the DLF matrix by using the eq. (3.30).The relationship will be –

$$[DLF] = [BCBV][BIBC]$$

$$[\Delta V] = [DLF][I]$$

Step 10: Set Iteration k = 0.

Step 11: Iteration k = k + 1.

Step 12: Update voltages by using eqs. (3.32), (3.33), (3.34),as

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{Pi \quad jQi}{Vi}\right)^*$$

$$[\Delta V^{k+1}] = [DLF].[I^k]$$

$$[V^{k+1}] = [V^0] + [\Delta V^{k+1}]$$

Step 13: If max((|V(k + 1)| − |V(k)|) > tolerance) go to step 6.

Step 14: Calculate branch currents, and losses from final node voltages.

Step 15: Display the node voltage magnitudes and angle, branch currents and losses.

Step 16: Stop

CHAPTER -4

OPTIMAL DG AND DSTATCOM ALLOCATION USING TLBO ALGORITHM

4.1 PROBLEM FORMULATION

Total power loss in a distribution network will be formulated using current injection method as

$$I_i = \left(\frac{Pi+ jQi}{Vi}\right)^* \tag{4.1}$$

Real and imaginary part of current I_i can be divided as following:

$$\mathrm{re}(I_i) = \frac{P_i \cos\theta_i + Q_i \sin\theta_i}{|V_i|} \qquad \mathrm{im}(I_i) = \frac{P_i \sin\theta_i - Q_i \cos\theta_i}{|V_i|} \tag{4.2}$$

than total power loss can be reperents as using BIBC matrix using eq(3.12):-

$$P_{loss} = \sum_{i=1}^{n} |IB_i|^2 * R_i = [R]^T |(BIBC).(I)|^2 \tag{4.3}$$

$$P_{loss} = [R]^T |(BIBC).(I)|^2 = [R]^T \left(\left((BIBC).[re(i)]^2\right) + \left((BIBC).[im(i)]^2\right)\right) \tag{4.4}$$

By substituting the equivalent bus injection expression

$$P_{loss} = [R]^T \left((BIBC).\left(\frac{\mathrm{P}\cos\theta + \mathrm{Q}\sin\theta}{V}\right)\right)^2 + [R]^T \left((BIBC).\left(\frac{\mathrm{P}\sin\theta - \mathrm{Q}\cos\theta}{V}\right)\right)^2 \tag{4.5}$$

Power loss at i^{th} branch:-

$$P_{loss} = R_j \left[\left(\sum_{i=2}^{n} BIBC(j, i-1).\left(\frac{P_i \cos\theta_i + Q_i \sin\theta_i}{|V_i|}\right)\right)^2 + \left(\sum_{i=2}^{n} BIBC(j, i-1).\frac{P_i \sin\theta_i - Q_i \cos\theta_i}{|V_i|}\right)^2\right] \tag{4.6}$$

Total power loss can be written as:-

$$\mathrm{P_{loss}} = \sum_{j=1}^{n} R_j \left[\left(\sum_{i=2}^{n} BIBC(j, i-1).\left(\frac{P_i \cos\theta_i + Q_i \sin\theta_i}{|V_i|}\right)\right)^2 + \left(\sum_{i=2}^{n} BIBC(j, i-1).\frac{P_i \sin\theta_i - Q_i \cos\theta_i}{|V_i|}\right)^2\right] \tag{4.7}$$

Minimization of this P_{loss} is our main constraint in distribution system network

4.2OPTIMIZATION TECHNIQUE

4.2.1 INTRODUCTION

Optimization is a process by which we try to find out the best solution from set of available alternative. In DG and DSTATCOM allocation problem, DG and DSTATCOM locations and sizes must be optimize in such a way that it give most economical, efficient,technically sound distribution system. In general distribution system have many nodes and it is very hard to find out the optimal DG and DSTATCOM location and size by hand. There are numerous optimization approaches used in the literature. All evolutionary and swarm intelligence based optimization algorithms require common control parameters like population size, number of generations,elite size, etc. Besides the common control parameters,different algorithms require their own algorithm-specific parameters. For example, GA uses mutation probability and crossover probability and selection operator;PSO uses inertia weight and social and cognitive parameters; ABC algorithm uses number of bees(scout, onlooker, and employed) and limit; and NSGA-II requires crossover probability, mutation probability, and distribution index.Proper tuning of these algorithm-specific parameters is a very crucial factor which affects the performance of the algorithms. The improper tuning of algorithm-specific parameters either increases the computational effort or yields a local optimal solution. In addition to the tuning of algorithm-specific parameters, the common control parameters also need to be tuned which further enhances the effort. Thus, there is a need to develop an algorithm which does not require any algorithm-specific parameters and teaching-learning-based optimization (TLBO) is such an algorithm.

4.2.2 TLBO ALGORITHM

The TLBO algorithm is a teaching-learning process inspired algorithm proposed by Rao et al[19] and Rao and Savsani [20] based on the effect of influence of a teacher on the output of learners in a class. The algorithm describes two basic modes of the learning: (i) through teacher (known as teacher phase) and (ii) through interaction with the other learners (known as learner phase). In this optimization algorithm, a group of learners is considered as population and different subjects offered to the learners are considered as different design variables of the optimization problem and a learner's result is analogous to the 'fitness'value of the optimization problem.The best solution in the entire population is considered as the teacher. The design variables are actually the parameters involved in the objective function of the given optimization problem and the best solution is the best value of the objective function. The working of TLBO is divided into two parts, 'Teacher phase'and 'Learner phase'. Working of both the phases is explained below.

4.2.2.1 TEACHER PHASE

It is the first part of the algorithm where learners learn through the teacher.During this phase, a teacher tries to increase the mean result of the class in the subject taught by him or her depending on his or her capability. At any iteration i, assume that there are 'm' number of subjects (i.e., design variables), 'n' number of learners (i.e., population size, k = 1, 2,…, n) and $M_{j,i}$ be the mean result of the learners in a particular subject 'j' (j = 1, 2,…, m) The best overall result $X_{total\text{-}kbest,i}$ considering all the subjects together obtained in the entire population of learners can be considered as the result of best learner k_{best}. However, as the teacher is usually considered as a highly learned person who trains learners so that they can have better results, the best learner identified is considered by the algorithm as the teacher. The difference between the existing mean result of each subject and the corresponding result of the teacher for each subject is given by

$$\text{Difference Mean}_{j;k;i}= r_i\ (X_{j,best,i}\text{-}T_F,M_{j,i}) \qquad (4.1)$$

where, $X_{j,kbest,i}$ is the result of the best learner in subject j. T_F is the teaching factor which decides the value of mean to be changed,and r_i is the random number in the range [0, 1].Value of T_F can be either 1 or 2. The value of T_F is decided randomly with equal probability as,

$$T_F\text{=round}[1 + rand(0,1)\{2 - 1\}] \qquad (4.2)$$

TF is not a parameter of the TLBO algorithm.The value of T_F is not given as an input to the algorithm and its value is randomly decided by the algorithm using Eq. (4.2). After conducting a number of experiments on many benchmark functions it is concluded that the algorithm performs better if the value of T_F is between 1 and 2. However,the algorithm is found to perform much better if the value of TF is either 1 or 2 and hence to simplify the algorithm, the teaching factor is suggested to take either 1 or 2 depending on the rounding up criteria given by Eq. (4.2). Based on the Difference_Mean$_{j,k,i}$, the existing solution is updated in the teacher phase according to the following expression.

$$X^{'}_{j,k,i} = X_{j,k,i} + \text{Difference\_}mean_{j,k,i}$$

where, $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$. $X'_{j,k,i}$ is accepted if it gives better function value. All the accepted function values at the end of the teacher phase are maintained and these values become the input to the learner phase. The learner phase depends upon the teacher phase.

4.2.2.2 Learner Phase

It is the second part of the algorithm where learners increase their knowledge by interacting among themselves. A learner interacts randomly with other learners for improving knowledge. A learner learns new things if the other learner has more knowledge than him or her. Considering a population size of 'n', the learning phenomenon of this phase is explained below.

Randomly select two learners P and Q such that $X'_{total-P,i} \neq X'_{total-Q,i}$ (where, $X'_{total-P,i}$ and $X'_{total-Q,i}$ are the updated function values of $X_{total-P,i}$ and $X_{total-Q,i}$ of P and Q, respectively, at the end of teacher phase)

$$X''_{j,p,i} = X^{i}_{j,p,i} + r_i(X'_{j,P,i} - X'_{j,Q,i}) \text{ ,if } X'_{total-Pi} < X'_{total-Qi} \quad (4.4)$$

$$X''_{j,p,i} = X^{i}_{j,p,i} + r_i(X'_{j,Q,i} - X'_{j,P,i}) \text{ ,if } X'_{total-Qi} < X'_{total-Pi} \quad (4.5)$$

$X''_{j,P,}$is accepted if it gives a better function value. The Eqs. (4.4) and (4.5) are for minimization problems. In the case of maximization problems, the Eqs. (4.6) and (4.7) are used

$$X''_{j,p,i} = X^{i}_{j,p,i} + r_i(X'_{j,P,i} - X'_{j,Q,i}) \text{ ,if } X'_{total-Qi} < X'_{total-Pi} \quad (4.6)$$

$$X''_{j,p,i} = X^{i}_{j,p,i} + r_i(X'_{j,Q,i} - X'_{j,P,i}) \text{ ,if } X'_{total-Pi} < X'_{total-Qi} \quad (4.7)$$

Teaching-learning-based optimisation (TLBO) is a population-based algorithm which simulates the teaching-learning process of the class room. This algorithm requires only the common control parameters such as the population size and the number of generations and does not require any algorithm-specific control parameters.

4.3 Implementation of TLBO technique for optimal DG and/or DSTATCOM placement problem

The stepwise procedure for the implementation of TLBO algorithm in solving the optimal placement of DG and DSTATCOM is given by following steps.

Step 1. Initialize the following optimization parameters: population size (NP), maximum number of iterations, number of design variables (ND) and limits of design variables to be installed in the distribution network.

Step 2. Randomly generate different locations for the placement of DG and DSTATCOM depending upon number of DG and DSTATCOM.

Step 3. Randomly generate different size of the DGs within their operating limits which are installed in the distribution network. The operating KW and KVAR of all the installed DGs and DSTATCOM comprise a vector which represents the grade of different subjects of a particular student and it also represents a candidate solution for the optimal DG and DSTATCOM placement problems

Step 4. Run the power-flow to find the power losses of the distribution network. Afterward, the objective functions are evaluated. Based on the objective value, sort the students from best to worst and the best solution obtained so far is assigned as the teacher of the class.

Step 5. Modify the grade point of each subject(KW/KVAr of DG/DSTATCOM)using the concept of teaching phase

Step 6. Update the grade point of each subject(KW/KVAr of DG/DSTATCOM) of all students using the concept of learning phase

Step 7. Check whether the updated KW/KVAR of the any installed DG and DSTATCOM violates the operating limits or not. If any value is less than the minimum value it is made equal to minimum limit and if it is greater than the maximum value it is made equal to the maximum limit.

Step 8. Check for the stopping criteria. If it is satisfied, then stop the iteration process and print the best solution else go to step no. 4 and repeat the whole process.

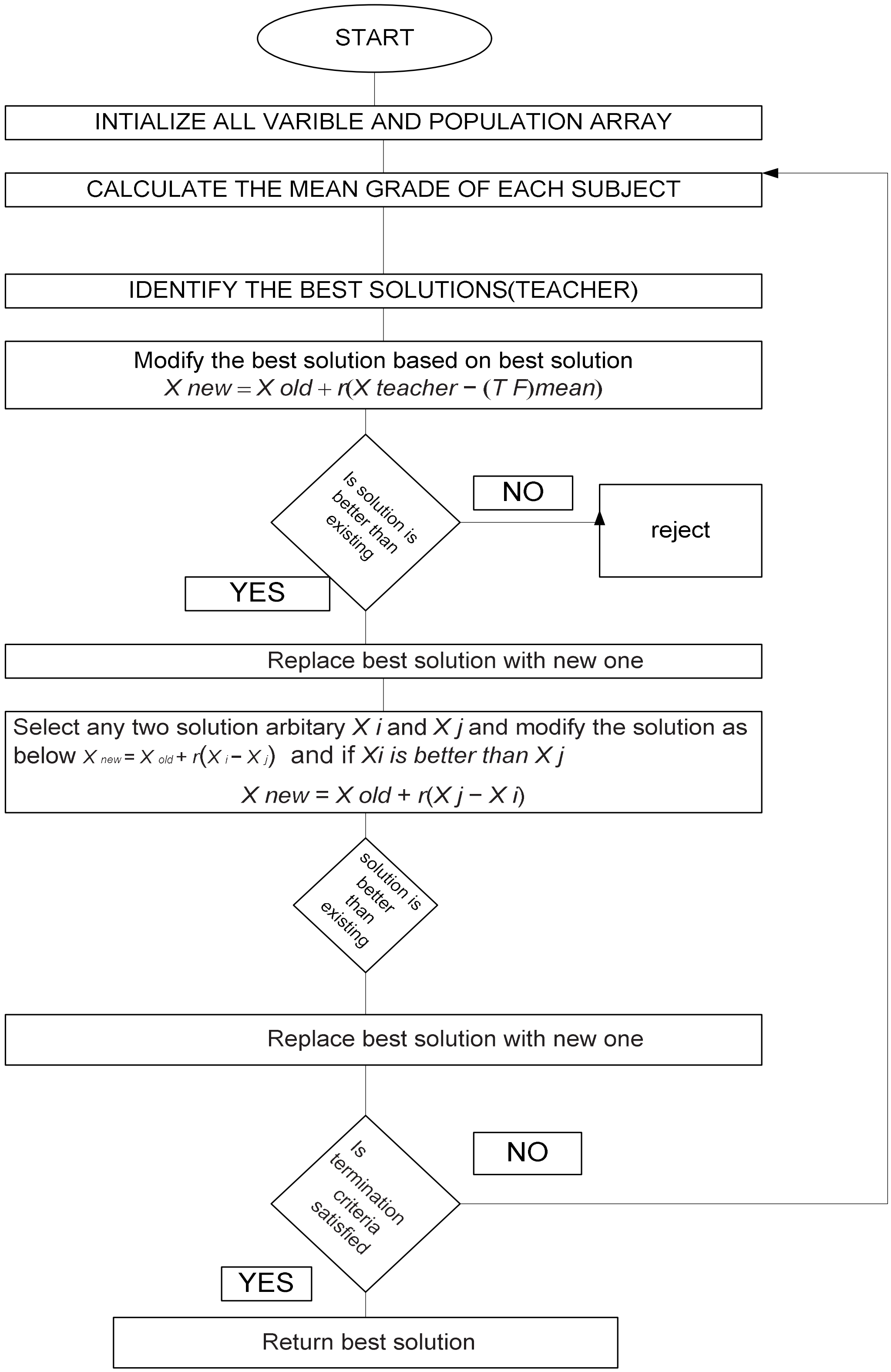


Fig :Flow chart for TLBO algorithm

CHAPTER 5

CASE STUDIES AND RESULTS

5.1 33 BUS RADIAL DISTRIBUTION SYSTEM:-

The IEEE 33-bus radial distribution system consists of 33 buses and 32 branches. The bus data and line data of this system are taken from The base values are 100 MVA and 12.66 kV and the total real and reactive power loads of this system are 3715 kW and 2300 kVAr. The schematic diagram of 33 bus distribution system is shown in figure,the first bus is considered as slack bus or feeder bus and remaining bus is considered as candidate location for DG and DSTATCOM placemant.Total real and reactive power loss for base case as 210.98 kW and 143.13 kVAr.

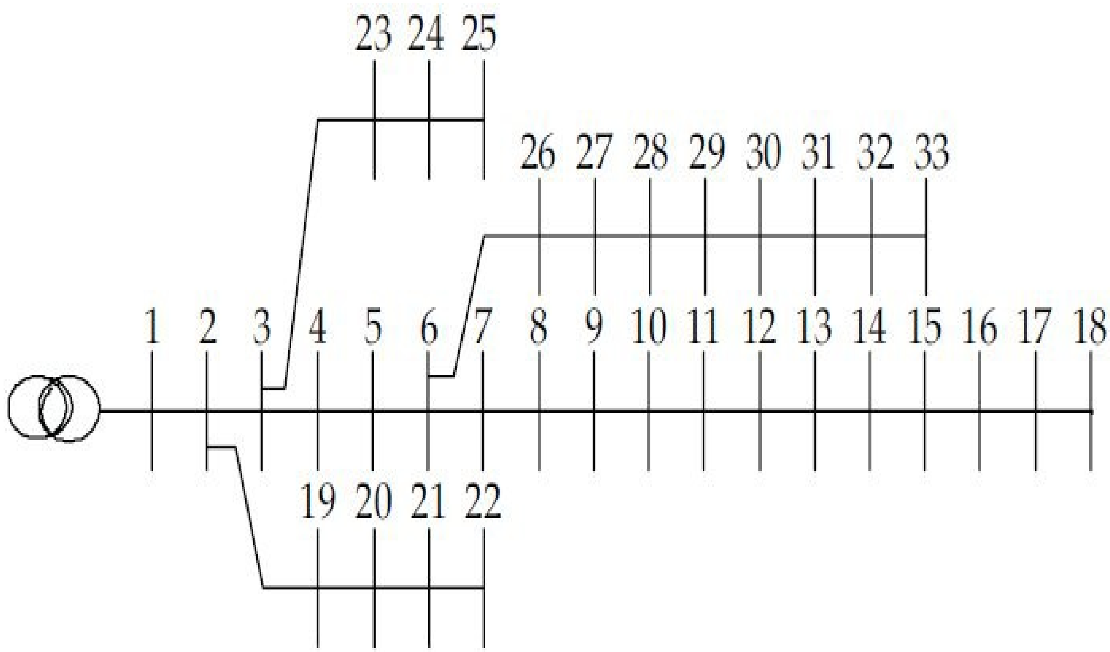


Fig 5.1:-33 bus radial distribution system

There are four different case studies is considered in this section, size and location of DG and DSTATCOM is shown in the result and compare with single and multiple DG and DSTATCOM conditions.

5.CASE STUDIEDS OF 33 BUS RADIAL DISTRIBUTION SYSTEM:-

CASE 1: ALLOCATION OF SINGLE AND MULITPLE **TYPE 1 DG** IN DISTRIBUTION SYSTEM:-

	Base case	No of DG =1	No of DG =2	No of DG =3
DG size in kw(bus)	_	2590.24(6)	851.50(13) 1157.63(30)	801.70(13) 1091.33(24) 1053.64(30)
P_{loss}(kw)	210.98	111.03	87.16	72.78
%loss reduction	_	47.37%	58.68%	65.50%

Table 1: single and multiple type 1 DG allocation in distribution system

Power loss reduces to 72.78 kw from 210.98kw as number of DG increases. DG sizing and location is showing in the table.

CASE 2 ALLOCATION OF SINGLE AND MULITPLE DSTATCOM IN DISTRIBUTION SYSTEM:-

	Base case	No of DSTATCOM =1	No of DSTATCOM =2	No of DSTATCOM =3
DSTATCOM size in kw(bus)	_	1257.99(30)	465.13(12) 1063.36(30)	387.91(13) 544.21(24) 1037.02(30)
P_{loss}(kw)	210.98	151.378	141.841	138.264
%loss reduction	210.98	28.25%	32.77%	34.46%

Table: single and multiple DSTATCOM allocation in distribution system

Power loss reduces to 138.264kw from 210.98 through reactive power compensation using DSTATCOM.As number of DG increases power loss also reduces to 34.46%.

CASE 3 ALLOCATION OF TYPE 3 DG IN DISTRIBUTION SYSTEM:-

	Base case	No of DG =1	No of DG =2	No of DG =3
DG size in KW/KVAr(bus)	_	2558.5/1761.35(6)	845.587/398.76(13) 1137.04/1064.31(30)	793.874/373.37(13) 1070.02/517.15(24) 1029.735/1011.51(30)
P_{loss}(kw)	210.98	67.86	28.50	11.74
%loss reduction	_	67.83%	86.49	94.43

Table 3:single and multiple type 3 DG allocation

As type 3 DG gives both active and reactive power compensation so power loss reduces efficiently.power loss reduces to 11.74kw from 210.98 using three type 3 DG in the system

CASE 4 ALLOCATION OF MULTIPLE DG AND DSTATCOM IN DISTRIBUTION SYSTEM:-

	Base case	No of DG =1	No of DG =2	No of DG =3
DG size in kw(bus)	_	2531.737(6)	846.15(13) 1137.53(30)	765.33(14) 1075.132(24) 1041.37(30)
DSTATCOM size in KVAr(bus)	_	1255.798(30)	446.554(12) 1043.719(30)	372.775(13) 517.264(24) 1011.766(30)
P_{loss}(kw)	210.98	58.456	28.49	11.72
%loss reduction	_	72.29%	86.49%	94.44%

Table 4:single and multiple DG & DSTATCOM in distribution system.

Simultaneous allocation of DG and DSTATCOM gives more efficient result in radial distribution system as power losses reduces to 94.44%

5.2 FOR 69 BUS RADIAL DISTRIBUTION SYSTEM

The total load of the networks is 4.660MW (3802.19 kW active power and 2694.6kVAR reactive power) and the slack node is delivering 4.902MW power. The distribution loss in the networks is 0.247 MW.The power loss due to active component of current is 224.995 KW and power loss due to reactive component of the current is 102.198 kVAR.All node voltages are within 0.90919 - 1 p.u.

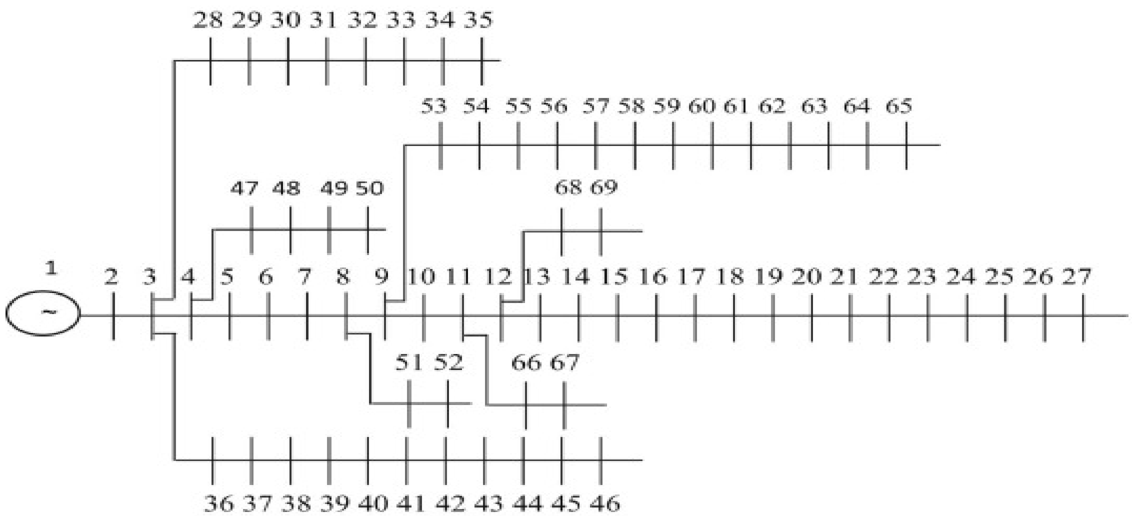


Fig 5.2:-69 bus radial distribution system

There are four different case studies is considered in this section, size and location of DG and DSTATCOM is shown in the result and compare with single and multiple DG and DSTATCOM conditions.

CASE STUDIEDS OF 69 BUS RADIAL DISTRIBUTION SYSTEM:-

CASE 1 ALLOCATION OF TYPE 1 DG IN DISTRIBUTION SYSTEM:-

	Base case	No of DG =1	No of DG =2	No of DG =3
DG size in kw(bus)	_	1872.70(61)	531.48(17) 1781.47(61)	526.84(11) 380.35(18) 1718.96(61)
P_{loss}(kw)	224.995	83.22	71.67	69.42
%loss reduction	_	63.01%	68.14%	69.14%

Table 5:single and multiple DG allocation in 66 bus distribution system

Power loss reduces to 69.42 kw from 225kw using three type 1 DG in the distribution system

CASE 2 ALLOCATION OF ONLY DSTATCOM IN DISTRIBUTION SYSTEM:-

	Base case	No of DG =1	No of DSTATCOM =2	No of DSTATCOM =3
DSTATCOM size in kw(bus)	_	1329.99(61)	361.06(17) 1275.05(61)	413.09(11) 230.61(18) 1232.41(61)
P_{loss}(kw)	224.995	152.03	146.43	145.11
%loss reduction	_	32.43%	34.91%	35.50%

Table 6:single and multiple DG allocation in 66 bus distribution system

As allocation of only DSTATCOM in the system is reduce losses to 145.11 kw from 225 kw.

CASE 3 ALLOCATION OF TYPE 3 DG IN DISTRIBUTION SYSTEM:-

	Base case	No of DG =1	No of DG =2	No of DG =3
DG size in KW/KVAr(bus)	_	1828.47/1300.69 (61)	522.345/353.43(17) 1734.676/1238.461 (61)	494.544/353.84(11) 379.07/251.53(18) 1674.32/1195.4(61)
P_{loss}(kw)	224.995	23.171	7.204	4.268
%loss reduction	_	89.70%	96.79	98.10%

Table 7:single and multiple type 3 DG allocation in 66 bus distribution system

Allocation of single and multiple type 3 DG gives better results,it reduces power loss to 4.268 from 225kw for three type 3 DG allocation.

CASE 4 ALLOCATION OF TYPE 1 DG and DSTATCOM IN DISTRIBUTION SYSTEM:-

	Base case	No of DG =1	No of DG&DSTATCOM =2	No of DG&STATCOM =3
DG size in kw(bus)	_	1828.475(61)	522.345(17) 1734.676(61)	494.646(11) 378.963(18) 1674.31(61)
DSTATCOM size in KVAr(bus)	_	1300.609(61)	353.43(17) 1238.461(61)	374.887(11) 230.459(21) 1195.455(61)
P_{loss}(kw)	224.995	23.71	7.204	4.255
%loss reduction	_	89.70%	96.79%	98.10%

Table 8: simultaneous DG and DSTATCOM allocation in 66 bus distribution system

COMPARISION WITH OTHER EXISTING TECHNIQUE:-For 33 bus distribution system

method	method	P_{loss}(kw)	%loss reduction	DG size in KW (location)	DSTATCOM SIZE KVAr (location)
Single DG	PSO[34] (TLBO)	203.98 111.03	3.33% 47.37%	1996(21) 2590.24(6)	_
Multiple DG(type 1)	BFOA[33] (TLBO)	75.53 72.78	65% 65.50%	779(14) 880(25) 1083(30) 801.70(13) 1091.33(24) 1053.64(30)	_
Single DG and DSTATCOM	PSO[34] (TLBO)	60.482 58.456	71.33% 72.29%	137.1(21), 2531.737(6)	163.4 (21) 1255.798(30)
multiple DG and DSTATCOM	BFOA[33] (TLBO)	15.07 11.72	92.85% 94.44%	850(12) 750(25) 860(30) 765.33(14) 1075.132(24) 1041.37(30)	400(12) 350(25) 850(30) 372.775(13) 517.264(24) 1011.766(30)

Table 9:-comprision with PSO and BFOA technique.

As result shown in the table proposed method is better than PSO [34](practical swan optimization technique) and for multiple DG and DSTATCOM allocation method is better than BFOA[33]technique.

For 69 bus distribution system:-

Table 10: comparison with PSO

method	method	P_{loss}(kw)	%loss reduction	DG size in KW (location)	DSTATCOM SIZE KVAr (location)
Single DG	PSO[34] Proposed method (TLBO)	83.22 83.21	63.01% 63.01%	1876.1(61) 1872.70(61)	_
Multiple DG(type 1)	PSO[33] (TLBO)	83.68 69.42	62.79% 69.14%	500(9) 521(33) 1929(62) 526.84(11) 380.34(18) 1718.56(61)	_
Single DG and DSTATCOM	PSO[34] (TLBO)	32.56 23.71	 89.70%	122.3(61), 1828.5(61)	0.1634 (21) 1300(30)

From above table we can stat that proposed method is better than existing PSO method as power loss reduces significantly.

From above table we can stat that proposed method is better than existing PSO method as power loss reduces significantly.

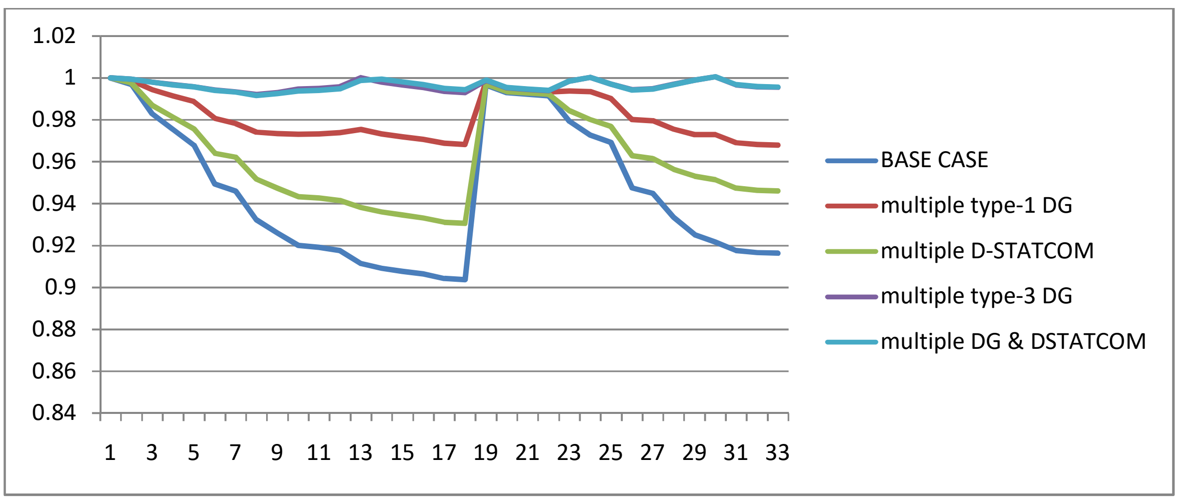


Fig 5.3:-comparison of voltage profile of various cases in 33 bus radial distribution system

Fig 5.1 shows the voltage profile of different nodes in 33 bus radial distribution system from figure it is very clear that voltage is maintain to 1 p.u. in multiple type-3 DG and multiple DG & DSTATCOM.

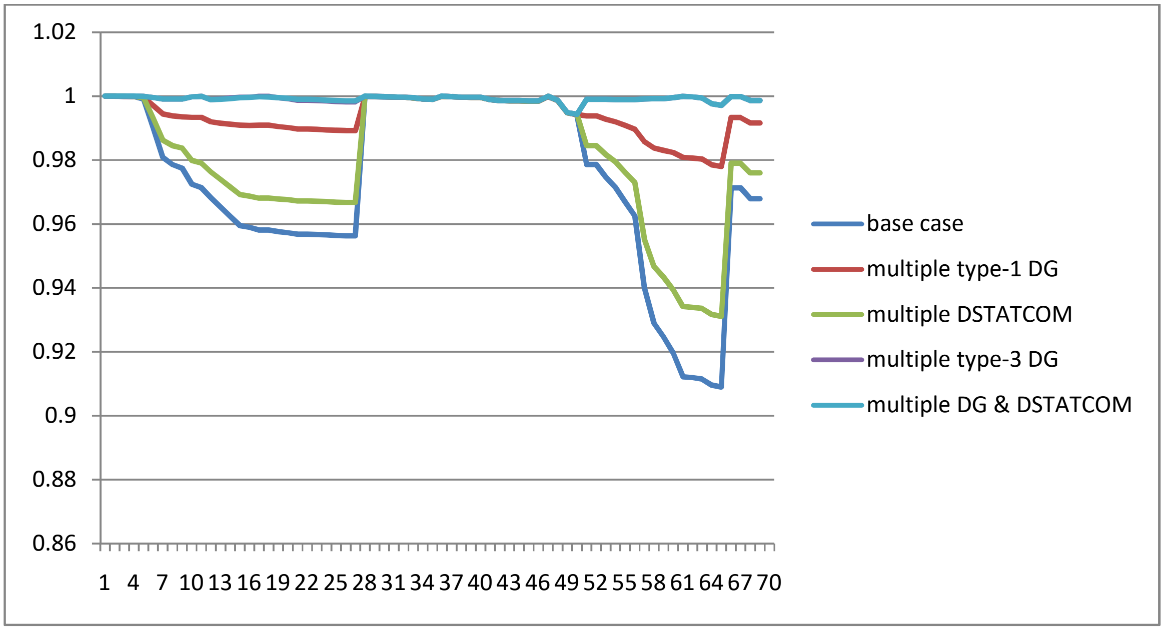


Fig 5.4:-comparison of voltage profile of various cases in 69 bus radial distribution system

Fig 5.4 shows the voltage profile or each node in 69 bus radial distribution system.In graph it shows the result for various cases it is very clear that voltage is maintain to 1p.u. in multiple type-3 DG and DSTATCOM case.

CHAPTER-6

CONCLUSIONS AND SCOPE FOR FUTURE WORK

6.1 CONCLUSIONS

DG and DSTATCOM installment in distribution network is more important nowadays. The benefits of DSTATCOM and DG's on distribution network are luring companies to adapt to this new system. The benefits that we are talking about are Reduced Power Loss, Good Voltage profile, Improved Power Quality and emission impacts. These benefits include, it is helping to prevent transmission and distribution network capacity in the planning stage only to avoid upgrading later.These benefits can only be achieved on the capacity and placing of DSTATCOM in the distribution network.

In this thesis,using forward/backward load flow, load flow problem was solved. Adaptive optimization technique has been used in to find the ideal location in distribution system and also presented that installation of DG with DSTATCOM in reduces power loss and improves system performances in distribution systems.The capability of this method is established on the IEEE 33-node and IEEE 69-node reliability test system.

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6.2 SCOPE FOR FUTURE WORK

These areas are identified for future work:

1. This same work can be continued on network with 119 nodes.

2. Optimization is done with basic adaptation scheme. There are several improved versions for the optimization which can be used for the same.

3. Balanced distribution network is considered here. The installation of DG's and DSTATCOM can be continued to unbalance networks too.

4. The extremity conditions (Rating, reactive power compensation)can be mutated and applied into these networks.

5. The DSTATCOMallotment problem can be continued for reactive power compensation devices(eg SVC,UPQC).

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APPENDIX

BUS DATA

Table-1: Bus Data for IEEE-33 Bus System
BASE KV= 12.66, BASE MVA= 100

Bus NO.	Bus Code	-------------------Load------------------	
		In kW	In Kvar
1	1	SLACK BUS	
2	0	100	60
3	0	90	40
4	0	120	80
5	0	60	30
6	0	60	20
7	0	200	100
8	0	200	100
9	0	60	20
10	0	60	20
11	0	45	30
12	0	60	35
13	0	60	35
14	0	120	80
15	0	60	10
16	0	60	20
17	0	60	20
18	0	90	40
19	0	90	40
20	0	90	40
21	0	90	40
22	0	90	40
23	0	90	50
24	0	420	200
25	0	420	200
26	0	60	25
27	0	60	25
28	0	60	20
29	0	120	70
30	0	200	600
31	0	150	70
32	0	210	100
33	0	60	40

Table-2: Line Data for IEEE-33 Bus System

Sending end Bus	Receiving end Bus	R(in ohm)	X(in ohm)
1	2	0.09220	0.04700
2	3	0.49300	0.25110
3	4	0.36600	0.18640
4	5	0.38110	0.19410
5	6	0.81900	0.70700
6	7	0.01872	0.61880
7	8	0.71140	0.23510
8	9	1.03000	0.74000
9	10	1.04400	0.74000
10	11	0.19660	0.06500
11	12	0.37440	0.12380
12	13	1.46800	1.15500
13	14	0.54160	0.71290
14	15	0.59100	0.52600
15	16	0.74630	.054500
16	17	1.28900	1.72100
17	18	0.73200	0.57400
2	19	0.16400	0.15650
19	20	1.50420	1.35540
20	21	0.40950	0.47840
21	22	0.70890	0.93730
3	23	.045120	0.30830
23	24	0.89800	0.70910
24	25	0.89600	0.70110
6	26	0.20300	0.10340
26	27	0.20420	0.14470
27	28	1.05900	0.93370
28	29	0.80420	0.70060
29	30	0.50750	0.25850
30	31	0.97440	0.96300
31	32	0.31050	0.36190
32	33	0.34100	0.53020

Table-3: Bus Data for IEEE-69 Bus System

BASE KV= 12.66, BASE MVA= 10

Bus NO.	Bus Code	-------------------Load------------------	
		In kW	In Kvar
1	1	SLACK BUS	
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	2.6	2.2
7	0	40.4	30
8	0	75	54
9	0	30	22
10	0	28	19
11	0	145	104
12	0	145	104
13	0	8	5.5
14	0	8	5.5
15	0	0	0
16	0	45.5	30
17	0	60	35
18	0	60	35
19	0	0	0
20	0	1	0.6
21	0	114	81
22	0	5.3	3.5
23	0	0	0
24	0	28	20
25	0	0	0
26	0	14	10
27	0	14	10
28	0	26	18.6
29	0	26	18.6
30	0	0	0
31	0	0	0
32	0	0	0
33	0	14	10
34	0	19.5	14
35	0	6	4
36	0	26	18.55
37	0	26	18.55
38	0	0	0
39	0	24	17
40	0	24	17

41	0	1.2	1
42	0	0	0
43	0	6	4.3
44	0	0	0
45	0	39.22	26.3
46	0	39.22	26.3
47	0	0	0
48	0	79	56.4
49	0	384.7	274.5
50	0	384.7	274.5
51	0	40.5	28.3
52	0	3.6	2.7
53	0	4.35	3.5
54	0	26.4	19
55	0	24	17.2
56	0	0	0
57	0	0	0
58	0	0	0
59	0	100	72
60	0	0	0
61	0	1244	888
62	0	32	23
63	0	0	0
64	0	227	162
65	0	59	42
66	0	18	13
67	0	18	13
68	0	28	20
69	0	28	20

Table-4: Line Data for IEEE-69 Bus System

Sending end Bus	Receiving end Bus	R(in ohm)	X(in ohm)
1	2	0.0005	0.0012
2	3	0.0005	0.0012
3	4	0.0015	0.0036
4	5	0.0251	0.0294
5	6	0.366	0.1864
6	7	0.3811	0.1941
7	8	0.0922	0.047
8	9	0.0493	0.0251
9	10	0.819	0.2707
10	11	0.1872	0.0691
11	12	0.7114	0.2351
12	13	1.03	0.34

13	14	1.044	0.345
14	15	1.058	0.3496
15	16	0.1966	0.065
16	17	0.3744	0.1238
17	18	0.0047	0.0016
18	19	0.3276	0.1083
19	20	0.2106	0.0696
20	21	0.3416	0.1129
21	22	0.014	0.0046
22	23	0.1591	0.0526
23	24	0.3463	0.1145
24	25	0.7488	0.2745
25	26	0.3089	0.1021
26	27	0.1732	0.0572
3	28	0.0044	0.0108
28	29	0.064	0.1565
29	30	0.3978	0.1315
30	31	0.0702	0.0232
31	32	0.351	0.116
32	33	0.839	0.2816
33	34	1.708	0.5646
34	35	1.474	0.4873
3	36	0.0044	0.0108
36	37	0.064	0.1565
37	38	0.1053	0.123
38	39	0.0304	0.0355
39	40	0.0018	0.0021
40	41	0.7283	0.8509
41	42	0.31	0.3623
42	43	0.041	0.0478
43	44	0.0092	0.0116
44	45	0.1089	0.1373
45	46	0.0009	0.0012
4	47	0.0034	0.0084
47	48	0.0851	0.2083
48	49	0.2898	0.7091
49	50	0.0822	0.2011
8	51	0.0928	0.0473
51	52	0.3319	0.1114
9	53	0.174	0.0886
53	54	0.203	0.1034
54	55	0.2842	0.1447
55	56	0.2813	0.1433
56	57	1.59	0.5337
57	58	0.7837	0.263

58	59	0.3042	0.1006
59	60	0.3861	0.1172
60	61	0.5075	0.2585
61	62	0.0974	0.0496
62	63	0.145	0.0738
63	64	0.7105	0.3619
64	65	1.041	0.5302
11	66	0.2012	0.0611
66	67	0.0047	0.0014
12	68	0.7394	0.2444
68	69	0.0047	0.0016