

# **LOSS MINIMIZATION IN HIGH VOLTAGE DISTRIBUTION SYSTEM BY CAPACITOR PLACEMENT USING GENETIC ALGORITHM**

*Thesis submitted in partial fulfillment of requirements for the award of degree of*

**Master of Engineering  
In  
Power systems & Electric Drives**



**Thapar University, Patiala**

Submitted By:  
**Amritpal Singh**  
(Regn. No. 800841003)

Under the esteemed Guidance of:

**Ms. Aabha**  
**Assistant Professor, EIED**

JULY, 2010  
**DEPARTMENT OF ELECTRICAL AND INSTRUMENTATION ENGINEERING  
THAPAR UNIVERSITY  
PATIALA - 147004**

### CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled "LOSSES MINIMIZATION IN HVDS BY CAPACITOR PLACEMENT USING GENETIC ALGORITHM", in partial fulfilment of the requirement of the award of degree of Master of Engineering in Power Systems & Electric Drives submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Ms.Aabha, Asstt. Prof, EIED.

The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

*Amritpal Singh*  
(AMRITPAL SINGH)

This is certify that the above statement made by candidate is correct and true to best of my knowledge.

*Aabha*  
25.6.2010  
(Ms.Aabha)

EIED

Thapar University,

Patiala.

Countersigned by

*S. Ghosh*  
12/7/10  
(Dr.S.Ghosh)

Professor & Head

EIED, Department

Thapar University,

Patiala.

*R.K.Sharma*  
13.7.10  
(Dr.R.K.Sharma)

Dean (Academic Affairs)

Thapar University,

Patiala.

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AMRITPAL SINGH

## **ABSTRACT**

Electricity distribution is the final stage in the delivery (before retail) of electricity to end users. A distribution system's network carries electricity from the transmission system and delivers it to consumers. Distribution networks are typically of two types, radial or interconnected. A radial network leaves the station and passes through the network area with no normal connection to any other supply. This is typical of long rural lines with isolated load areas. An interconnected network is generally found in more urban areas and will have multiple connections to other points of supply. These points of connection are normally open but allow various configurations by the operating utility by closing and opening switches. The benefit of the interconnected model is that in the event of a fault or required maintenance a small area of network can be isolated and the remainder kept on supply. In distribution systems, the voltages at buses reduces when moved away from the substation, also the losses are high. The reason for decrease in voltage and high losses is the insufficient amount of reactive power, which can be provided by the shunt capacitors. The work reported in this thesis is carried out with the objective of identifying the Optimal locations and sizes of shunt capacitors to be placed in radial distribution system to have overall economy considering the saving due to energy loss minimization and cost of capacitors. For the purpose two stage methodology is used. In first stage, the load flow of pre-compensated distribution system is carried out. On the basis of load flow solutions, loss sensitivity factors (LSF) indicating the potential locations for compensation are computed. From LSF, the candidate number of buses is identified. In the second stage, genetic algorithm is used to identify the sizes of the capacitor for minimizing the energy loss cost and capacitor cost. A coding scheme is implemented where the identification of location and size of capacitor is represented by one dimensional array. The developed algorithm is tested for distribution systems at 11 KV high voltage distribution system (HVDS) while taking the different sizes for capacitors.

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*Dedicated to my Parents and Friends.*

# **CHAPTER-1**

## **INTRODUCTION**

### **1.1 OVERVIEW**

The modern power distribution network is constantly being faced with an ever growing load demand, this increasing load is resulting into increased burden and reduced voltage. The distribution network also has a typical feature that the voltages at buses (nodes) reduces if moved away from substation. This decrease in voltage is mainly due to insufficient amount of reactive power. Even in certain industrial areas under critical loading, it may lead to voltage collapse. Thus to improve the voltage profile and to avoid voltage collapse reactive compensation is required. It is well known that losses in a distribution system are significantly high compared to that in a transmission system. The need of improving the overall efficiency of power delivery has forced the power utilities to reduce the losses at distribution level. Many arrangements can be worked out to reduce these losses like network reconfiguration, shunt capacitor placements etc. The shunt capacitors supply part of the reactive power demand, thereby reducing the current and MVA in lines. Installation of shunt capacitors on distribution network will help in reducing energy losses, peak demand losses and improvement in the system voltage profile, system stability and power factor of the system. However to achieve these objectives, keeping in mind the overall economy, the size and location of capacitors should be decided.

The literature on distribution system is very much diversified, the brief review is presented on the subject of capacitor placement in distribution systems.

## 1.2 LITERATURE REVIEW

Shunt capacitor Sizing for radial distribution feeders with distorted substation voltages is explained in reference [1]. The objective of this method is to present an algorithm for optimizing shunt capacitor sizes on radial distribution lines with nonsinusoidal substation voltages such that the rms voltages and their corresponding total harmonic distortion lie within prescribed values. A simple heuristic numerical algorithm that is based on the method of local variations is proposed to determine an optimal solution.

A new technique for loss reduction using compensating capacitors applied to distribution systems with varying load condition has been proposed in reference [2]. T.S.A Salam, A.Y Chikhap and R Hackam method allocates capacitors to certain nodes which are selected by first indentifying the branch which has the largest losses due to reactive power. Then the node which has the largest reactive power is selected .the capacitor is determine by differentiating the system losses with respect to load connected to that node. The compensating capacitors are placed at these optimal locations with appropriate VAR ratings to achieve maximum benefits in dollar savings. The variation of the load during the year is considered. The capital and installation costs of the capacitors are also taken into account.

Optimal Sizing of Capacitors placed on a radial distribution system is explained by M.e. Baran and F.F Wu the reference [3]. The capacitor-sizing problem is a special case of the general capacitor placement problem. The problem is to determine the optimal size of capacitors placed on the nodes of a radial distribution system so that the real power losses will be minimized for a given load profile. This problem is formulated as a nonlinear programming problem. The ac power flow model of the system, constraints on the node voltage magnitudes, and the cost of capacitors are explicitly incorporated in the formulation. This paper gives a new formulation of the power flow equations in a radial distribution network and a numerically robust, computationally efficient solution scheme.

Classification of Capacitor allocation Techniques has been dealt within in reference [4]. M. M. A. Salma and A. Y. Chikhani method describes the evolution of the research and provides an evaluation of the practicality and accuracy of the capacitor placement algorithms in the literature. The intent of this paper is not to provide a complete survey of all the literature in capacitor allocation, but to provide researchers and utility engineers further insight into the choices of available capacitor allocation techniques and their respective merits and shortcomings

A simplified Network approach to the VAR control problem for radial distribution system is considered in the reference [5]. According to this method proposed by M. M. A. Salma and A. Y. Chikhani, the capacitors are assumed to be located optimally at the feeder branches. The optimal compensation levels (capacitor size) are represented by dependent current sources located at the branch connected bus. The solution of the equivalent circuit for the distribution system yields the values of the voltage at any bus. The actual compensation level is then determined by substituting the bus voltage in the dependant current source formula. The method is simple and needs no sophisticated optimization technique. It can be used as on-line controller and as well as in the planning stage. It can be easily adapted in the expert system configuration.

This paper present a new technique [6] for placing fixed capacitors in radial distribution systems based on genetic algorithms (GA). Rojas L.; Garcia, R.; Roa, L. gives Current optimization models of capacitor placement only consider losses reduction and voltage profile simultaneously, but the compensation cost and the load changes are not taken into account as part of the objective function. Also, the result may be not the best choice because this is a very large optimization problem and there are too many combinations. We present a general approach for the optimal solution of this problem considering all the parameters of the distribution system involved: capacitor cost, voltage, angle and load changes. An exhaustive search through all possible solutions is needed. Therefore, GA is an ideal candidate to solve this situation. Working with this algorithm, a Microsoft Excel program has been developed in order to answer the capacitor placement problem

for any kind of radial distribution system.

Sundhararajan, S.; Pahwa, A, present, a new design methodology for determining the size, location, type and number of capacitors to be placed on a radial distribution system is presented [7]. The objective is to minimize the peak power losses and the energy losses in the distribution system considering the capacitor cost. A sensitivity analysis based method is used to select the candidate locations for the capacitors. A new optimization method using a Genetic Algorithm is proposed to determine the optimal selection of capacitors. Test results have been presented along with the discussion of the algorithm.

Power losses in distribution system have become the most concerned issue in power losses analysis in any power system. In the effort of reducing power losses within distribution system, reactive power compensation has become increasingly important as it affects the operational, economical and quality of service for electric power systems [10]. Nallagownden, P.; Thin, L.T; Guan, N.C.; Mahmud presents the application of genetic algorithm approach for reactive power loss reduction in radial distribution system. IEEE 34-bus Standard Test System is used together with the ERACS and MATLAB as powerful tools for the analysis and simulation work. ERACS is used to perform load flow analysis while MATLAB is used for the identification of capacitor current via GAtool, and algorithm for the calculation of loss savings, its particular capacitor size and Location. The result is then compared with the heuristic search strategies to evaluate the performance of genetic algorithm.

Cook [9] considered the effects of fixed capacitors on radial distribution network with distributed loads and considered the reduction in energy loss. A methodology has been used to determine the ratings and location of fixed capacitors on the radial feeder for periodic load cycle. Cook [10] considered fixed and switched capacitors and discussed the methodology to decide the timing for the operation of switched capacitors.

Maxwell [11] suggested there are several benefits of capacitor placement which include: (i) reduced kVA input to feeder (ii) reduced I<sup>2</sup>R loss and energy losses (iii) reduced I<sup>2</sup>X losses (iv) reduced regulation cost (v) increased revenue

as a result of increased voltage levels. Major benefits are due to the reduction in kVA input, kW demand and energy loss.

Schmill [12] considered feeders with uniformly distributed and randomly distributed loads. A simplified method for capacitor application has been developed. Bae [13] presented an analytical method for capacitor allocation, under the assumptions (i) capacitor banks optimally located for specific load levels (ii) voltage regulation is not considered (iii) loads are assumed to be uniformly distributed along the feeder with the size of capacitor banks assumed equivalent (iv) only losses due to reactive current component are considered. The equations to determine the best capacitor locations and the loss reduction under varying load conditions has also presented.

A number of methods have been proposed in the literature [14-20] for the distribution networks. Shirmohammadi *et al.* [14] has proposed a load flow method for distribution networks using a multi-port compensation technique and basic formulations of Kirchhoff's Laws. Rajicic [16] has modified the fast decoupled load flow method to suit high R/X ratio nature of distribution system. Various methods [14-19] have been reported for the load flow of radial distribution system. Ghosh and Das [17] have proposed a method for the load flow of radial distribution network using the evaluation based on algebraic expression of receiving end voltage. Teng [19,20] has proposed the load flow of radial distribution system employing bus-injection to branch-current (BIBC) and branch-current to bus-voltage (BCBV) matrices.

Neagle and Samson [21] considered loss reduction by one capacitor bank placed along the feeder by considering uniformly distributed loads, uniformly decreasing loads and equally distributed loads along the feeder. A general application curves for selecting location and size of single capacitors to minimize loss has been presented.

Genetic Algorithms offer a 'one size fits all' solution to problem solving involving search. Unlike other conventional search alternatives, GA's can be applied to most problems, only needing a good function specification to optimize and a good choice of representation and interpretation. This, coupled with the

exponentially increasing speed/cost ratio of computers, makes them a choice to consider for any search problem. Genetic algorithms are inspired by Darwin's theory of evolution. Problems are solved by an evolutionary process resulting in a best (fittest) solution (survivor) - in other words, the solution is evolved.

**Genetic Algorithms (GAs)** are adaptive heuristic search algorithms based on the evolutionary ideas of natural selection and natural genetics. A genetic algorithm is a heuristically guided random search technique that concurrently evaluates thousands of postulated solutions. Biased random selection and mixing of the evaluated searches is then carried out in order to progress towards better solutions. The coding and manipulation of search data is based upon the operation of genetic DNA and the selection process is derived from Darwin's survival of the fittest'. Search data are usually coded as binary strings called chromosomes, which collectively form populations. Evaluation is carried out over the whole population and involves the application of, often complex 'fitness' functions to the string of values (genes) within each chromosome. Typically, mixing involves recombining the data that are held in two chromosomes that are selected from the whole population.

Evolutionary computing was introduced in the 1960s by I. Rechenberg in his work "Evolution strategies". His idea was then developed by other researchers. Genetic Algorithms (GAs) were invented by John Holland at the University of Michigan. This led to Holland's book "Adaptation in Natural and Artificial Systems" published in 1975. The goals of their research have been two fold: (1) to abstract and rigorously explain the adaptive processes of natural systems and (2) to design artificial systems software that retains the important mechanisms of natural systems. The central theme of research on genetic algorithms has been robustness, the balance between efficiency and efficacy necessary for survival in many different environments. In 1992 John Koza has used genetic algorithm to evolve programs to perform certain tasks. He called this method "Genetic Programming" (GP)

GAs vs Conventional Algorithms: Genetic Algorithms are different from normal optimization and search methods in four ways:

1. GAs work with coding of the parameter set, not the parameters themselves.
2. GAs search from a population of points, not a single point.
3. GAs use payoff (objective function) information, not derivatives or other auxiliary knowledge.
4. GAs use probabilistic transition rules, not deterministic rules.

Biological Terminology: All living organisms consist of cells. Each cell of a living thing contains chromosomes. Each chromosome contains a set of genes - blocks of DNA. Each gene encodes a particular protein. Each gene determines some trait of the organism (like eye colour). Possible settings for a trait (e.g. blue, brown) are called alleles. Each gene has its own position in the chromosome. This position is called locus. Complete set of genetic material (all chromosomes) is called genome. A collection of genes is sometimes called a genotype. A collection of aspects (like eye colour) is called a phenotype such as eye color, intelligence etc.

The mechanics of simple genetic algorithm involves nothing more complex than copying strings and swapping partial strings. The strings of artificial genetic systems are analogous to chromosomes in biological systems. Total package of strings is called structure and is analogous to genotype. The structures decode to form a particular parameter set, solution alternative or point, which correspond to phenotype. Strings are composed of features or detectors, which take on different values. Features may be located at different positions on the string.

**GENETIC ALGORITHM DESCRIPTION:** The genetic algorithm is a search algorithm that iteratively transforms a set (called a population) of mathematical objects (typically fixed-length binary character strings), each with an associated fitness value, into a new population of offspring objects using the Darwinian principle of natural selection and using operations such as crossover (sexual recombination) and mutation[26].

Algorithm begins with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new

population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are then selected to form new solutions (offspring) are selected according to their fitness - the more suitable they are the more chances they have to reproduce. This is repeated until some condition is satisfied.

The space of all feasible solutions (the set of solutions among which the desired solution resides) is called search space (also state space). Each point in the search space represents one possible solution. Each possible solution can be "marked" by its value (or fitness) for the problem. With GA we look for the best solution among a number of possible solutions. The problem is that the search can be very complicated. One may not know where to look for a solution or where to start. There are many methods one can use for finding a suitable solution, but these methods do not necessarily provide the best solution.

A simple genetic algorithm that yields good results in many practical problems is composed of three operators:

1. **Reproduction:** This operator is an artificial version of natural selection based on Darwinian survival of the fittest among string creatures. Reproduction operator can be implemented in algorithmic form in a number of ways.
2. **Crossover:** It occurs after reproduction or selection. It creates two new population or strings from two existing ones by genetically recombining randomly chosen parts formed by randomly chosen crossover point.
3. **Mutation:** It is the occasional random alteration of the value of a string position. Mutation creates a new string by altering value of existing string.

Steps in Basic Genetic Algorithm

1. [Start] Generate random population of  $n$  chromosomes (suitable solutions for the problem)
2. [Fitness] Evaluate the fitness  $f(x)$  of each chromosome  $x$  in the population
3. [New population] Create a new population by repeating following steps until the new population is complete
  - a. [Selection] Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)

- b. [Crossover] With a crossover probability cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.
  - c. [Mutation] With a mutation probability mutate new offspring at each locus (position in chromosome).
  - d. [Accepting] Place new offspring in the new population
4. [Replace] Use new generated population for a further run of the algorithm
  5. [Test] If the end condition is satisfied, stop, and return the best solution in current population
  6. [Loop] Go to step 2

**Encoding of a Chromosome:**

In the applications of GAs to various problems, some special genetic codes and encoding methods have been developed. Encoding of chromosomes is the first question to ask when starting to solve a problem with GA. A chromosome should in some way contain information about solution that it represents. The most used way of encoding is a binary string. Each chromosome is represented by a binary string. Each bit in the string can represent some characteristics of the solution. Another possibility is that the whole string can represent a number. Of course, there are many other ways of encoding. The encoding depends mainly on the solved problem. For example, one can encode directly integer or real numbers, sometimes it is useful to encode some permutations and so on.

Binary encoding is the most common one, mainly because the first research of GA used this type of encoding and because of its relative simplicity. In binary encoding, every chromosome is a string of bits - 0 or 1.

Chromosome A

101100101100101011100101

Permutation encoding can be used in ordering problems, such as traveling salesman problem or task ordering problem. In permutation encoding, every chromosome is a string of numbers that represent a position in a sequence.

Chromosome A

1 5 3 2 6 4 7 9 8

Value Encoding: Direct value encoding can be used in problems where some more complicated values such as real numbers are used. Use of binary encoding for this type of problems would be difficult. In the value encoding, every chromosome is a sequence of some values. Values can be anything connected to the problem, such as (real) numbers, chars or any objects.

Tree encoding is used mainly for evolving programs or expressions, i.e. for genetic programming. In the tree encoding every chromosome is a tree of some objects, such as functions or commands in programming language.

Bias code: Bias-encoding technique is to encode the problem solution space in different member density. In some subspace, in which there exists big possibility of solution, more members should be encoded.

Uniform code: Uniform code will distribute the population members in a manner of uniform possibility.

Tri-sector Code: Tri-sector code is a special kind of Bias Code. According to definition of this code, the population will be encoded in three sectors, and in each sector the value of members are biased to some value.

Symmetric Codes: Symmetric codes include Horizontal Symmetric Code and Vertical Symmetric Code They are successfully applied into solving some problems with great algorithm complexity, such as robot dynamic control and path planning. At the same time, some new genetic strategies based on these special codes are proposed, such as Genetic Strategy with Change Function and Genetic Algorithm with Symmetric Codes

**Fitness function**: A typical genetic algorithm requires two things to be defined: (1) a genetic representation of solutions, (2) a fitness function to evaluate them. The fitness function is defined over the genetic representation and measures the quality of the represented solution. The fitness function is always problem dependent. Once we had the genetic representation and the fitness function defined, GA proceeds to initialize a population of solutions randomly, then improve it through repetitive application of mutation, crossover, and selection operators.

**Selection:** Chromosomes are selected from the population to be parents for crossover. The problem is how to select these chromosomes. According to Darwin's theory of evolution the best ones survive to create new offspring. There are many methods in selecting the best chromosomes. Examples are roulette wheel selection, rank selection, steady state selection and some others.

Roulette Wheel Selection: Parents are selected according to their fitness. The better the chromosomes are, the more chances to be selected they have. In this method all the chromosomes in the population are placed on the roulette wheel. The size of the section in the roulette wheel is proportional to the value of the fitness function of every chromosome - the bigger the value is, the larger the section is. A marble is thrown in the roulette wheel and the chromosome where it stops is selected. Clearly, the chromosomes with bigger fitness value will be selected more times.

This process can be described by the following algorithm:

1. [Sum] Calculate the sum of all chromosome fitnesses in population - sum S.
2. [Select] Generate random number from the interval (0,S) - r.
3. [Loop] Go through the population and sum the fitnesses from 0 - sum s. When the sum s is greater than r, stop and return the chromosome where you are.

Of course, the step 1 is performed only once for each population.

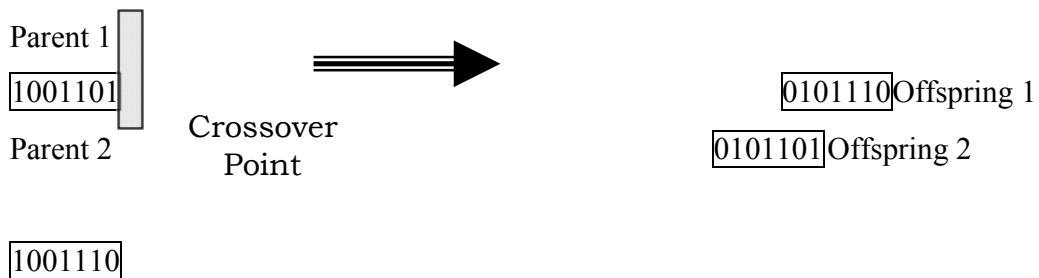
Rank Selection The previous type of selection will have problems when there are big differences between the fitness values. For example, if the best chromosome fitness is 90% of the sum of all fitness then the other chromosomes will have very few chances to be selected. Rank selection ranks the population first and then every chromosome receives fitness value determined by this ranking. The worst will have the fitness 1, the second worst 2 etc. and the best will have fitness N (number of chromosomes in population).

Now all the chromosomes have a chance to be selected. However this method can lead to slower convergence, because the best chromosomes do not differ so much from other ones.

Steady-State Selection: The main idea of this type of selecting to the new population is that a big part of chromosomes (with greater fitness) can survive to next generation. The steady-state selection GA works in the following way. In

every generation a few good chromosomes are selected for creating new offspring. Then some bad chromosomes are removed and the new offspring is placed in their place. The rest of population survives to new generation.

**Crossover**: Crossover takes place when proper encoding method has been decided. Crossover operates on selected genes from parent chromosomes and creates new offspring. The simplest way how to do that is to choose randomly some crossover point and copy everything before this point from the first parent and then copy everything after the crossover point from the other parent. There are other ways how to make crossover, for example we can choose more crossover points. Crossover can be quite complicated and depends mainly on the encoding of chromosomes. Specific crossover made for a specific problem can improve performance of the genetic algorithm.



**Mutation**: After a crossover is performed, mutation takes place. Mutation is intended to prevent falling of all solutions in the population into a local optimum of the solved problem. Mutation operation randomly changes the offspring resulted from crossover. In case of binary encoding we can switch a few randomly chosen bits from 1 to 0 or from 0 to 1. Mutation can be then illustrated as follows:

Chromosome A 101100101100101011100101  
 After Mutation 101000101100101011100101

The technique of mutation (as well as crossover) depends mainly on the encoding of chromosomes. For example when we are encoding permutations, mutation could be performed as an exchange of two genes.

**Parameters of GA:** There are two basic parameters of GA - crossover probability and mutation probability. Other parameters include population size etc.

**Crossover probability** is how often crossover will be performed. If there is no crossover, offspring are exact copies of parents. If there is crossover, offspring are made from parts of both parent's chromosome. If crossover probability is 100%, then all offspring are made by crossover. If it is 0%, whole new generation is made from exact copies of chromosomes from old population. Crossover is made in hope that new chromosomes will contain good parts of old chromosomes and therefore the new chromosomes will be better.

**Mutation probability** is how often parts of chromosome will be mutated. If there is no mutation, offspring are generated immediately after crossover (or directly copied) without any change. If mutation is performed, one or more parts of a chromosome are changed. If mutation probability is 100%, whole chromosome is changed, if it is 0%, nothing is changed. Mutation generally prevents the GA from falling into local extremes. Mutation should not occur very often, because then GA will in fact change to random search.

**Population size** is how many chromosomes are in population (in one generation). If there are too few chromosomes, GA have few possibilities to perform crossover and only a small part of search space is explored. On the other hand, if there are too many chromosomes, GA slows down.

**Elitism:** When creating a new population by crossover and mutation, there are chances that the best chromosome is lost. Elitism is the name of the method that first copies the best chromosome (or few best chromosomes) to the new population. The rest of the population is constructed according to GA. Elitism can rapidly increase the performance of GA, because it prevents a loss of the best found solution.

**Applications of GA:** Since GAs are mainly used in optimization and give outstanding performance, GAs are treated as function optimiser. But there are many other ways to view genetic algorithms in different areas such as:

- GAs as problem solvers
- GAs as challenging technical puzzle

- GAs as basis for competent machine learning
- GAs as computational model of innovation and creativity
- GAs as computational model of other innovating systems
- GAs as guiding philosophy

Genetic algorithms have been used for difficult problems (such as NP-hard problems), for machine learning and also for evolving simple programs. They have been also used for some art, for evolving pictures and music. Some of the applications of GAs are:

- Nonlinear dynamical systems - predicting, data analysis
- Designing neural networks, both architecture and weights
- Robot trajectory
- Evolving LISP programs (genetic programming)
- Strategy planning
- Game Playing
- Finding shape of protein molecules
- Signal Processing
- TSP and sequence scheduling
- Functions for creating images

## **1.2 OBJECTIVE OF THE WORK**

The objective of the present work is to identify the location and sizes of capacitors to be placed in radial distribution system have the overall economy using genetic algorithm. A recent load flow technique for a radial distribution using BIBC and BCBV has been used. The candidate buses for shunt capacitor placement have been identified using Loss Sensitivity Factors. The sizes of the capacitors have been found using Genetic Algorithm, while optimizing the overall economy calculated considering the energy loss cost and capacitor cost.

## **1.3 ORGANIZATION OF THE REPORT**

The work carried out in this Report has been summarized in five chapters. The Chapter 1 highlights the brief introduction, summary of work carried out by various researchers, and the outline of the thesis is also given in this chapter. The Chapter 3 explains the Load Flow technique of distribution system using BIBC and BCBV matrix. The Chapter 4 briefly describes Loss Sensitivity Factor to identify the candidate buses for shunt capacitor placement, objective function for overall economy and steps for Capacitor Allocation using Genetic Algorithm. The Chapter 5 details the results and discussion pertaining to various test cases. The conclusions and the scope of further work are detailed in Chapter 6.

## **CHAPTER 2:**

# **HIGH VOLTAGE DISTRIBUTION SYSTEM (HVDS)**

### **2.1 INTRODUCTION**

The existing rural distribution system in India consists of largely 3 phase 11 KV main distribution feeders with 3 phase spur lines and 11/0.4 KV three phase distribution transformers. The distribution system on low voltage side is done by 3 phase 4 wire, 3 phase 5 wire, single phase 3 wire, and single phase 2 wire LT lines. This system involves nearly 2:1 ratio of LV and HV line lengths. Large LT network results in high occurrence of LT faults leading to frequent interruptions in supply and high incidence of distribution transformer failures due to LT fault currents.

This system is unsuitable to cater certain areas like desert, tribal and forests, where the load density is very low and the development of load in these areas is slow[25]. Heavy capital investment on 3 phase 11 KV lines with higher rating 3 phase transformers is not economically justified.

To improve the quality of supply, one of the recommendations is the implementation of "Single phase HT distribution system with small capacity single phase transformers. Under this system HT line is extended up to or as near the load as possible and to erect small capacity distribution transformers i.e. 10 KVA, 16 KVA and to extend supply to the consumer through a short length of LT lines, preferably insulated overhead cable (Aerial Bunched Cables) system.

Due to use of smaller rating transformers, either 3 phase or single phase length of LT lines is considerably reduced and power is distributed mainly through HV (11 KV) lines. Distribution system employs a suitable mix of 11 KV 3 phase and single phase or 3 phase configuration for giving supply either to small rating lines. With the main line being 3 phase, the spur line comprises of either single phase or three phase configuration for giving supply to small rating single phase or three phase distribution transformers.

## **2.2 Types of HV Distribution System**

- I) Single phase and 1 Neutral (continuous neutral from Sub-station)
- II) 2 Phase 2 wire (Rigidly earthed natural system)
- III) 3 Phase small rating transformers with 3 phase HV system

In case of single phase transformer with phase to neutral system, a continuous earth wire is required to be drawn from 33/11 sub-station and earth wire is to be earthed at all the poles. The neutral of the distribution transformer is also earthed on HV and LV sides. The voltage on the secondary side of the transformer is 0-250 V. The single phase transformer can be oil filled or dry type (Resin encapsulated). The failure of single phase distribution transformers is reported to be less as compared to conventional distribution transformers. Only small group of connections with Aerial Bunch Cables (ABC) are given and no overloading of distribution transformers occurs.

### **Advantages of High Voltage Distribution System**

The HVDS offers the following direct advantages.

- 1) In single phase system only few numbers of consumers are connected to transformers and as a result chances of unauthorized connections and theft of energy are reduced.
- 2) Reduction of system faults because of low length of LV lines.
- 3) Distribution losses are reduced by 75% or more depending on the load factor
- 4) The HVDS is cost effective to electrify remote villages and hamlets where bringing of long 3 phase lines is costly due to low demand.
- 5) The single phase line can be upgraded to 2 phase or 3 phase circuits in future, if the load growth warrants it. The power utilities can keep the investment low and cut down the expenses during the initial period of low demand and electrifying remote rural areas.

- 6) In the event of failure of transformers, it will affect only a small number of consumers, whereas failure of large sized distribution transformers will affect large number of consumers.
- 7) In view of less LT system and usage of ABC, which has tough insulating cover, direct tapping by unscrupulous consumers is avoided.
- 8) Since losses are reduced considerably, power can be supplied to additional loads without any further investment on infrastructure.
- 9) No additional generation capacity is needed for giving new loads due to reduction in power drawl.
- 10) Single phase motor up to 5 HP can operate efficiently on single phase lines. The power factor of these motors is nearly unity. And thus the system efficiency also gets improved.

### **2.3 Merits and Demerits in comparison to 3 phase LV systems**

1. **Line Losses:** The losses in HVDS for distribution of same power are less than that of LV line. Thus, the losses in LV network are negligible bringing down the total energy losses considerably.
2. **Voltage Drop:** The voltage drop for distribution of same power is less than that of LVDS and thus ensures proper voltage profile at consumer points.
3. **System Power Factor:** The single phase motors have built in capacitors and PF is more than 0.95. This high PF causes low energy losses and better voltage profile.
4. **Failure of Distribution Transformers:** The failure of distribution transformers due to LV line faults is eliminated as the length of LT lines is minimized and usage of Aerial Bunched Cables (ABC) system. The over loading is prevented as each single phase
5. **Theft of Energy:** The LT lines are virtually eliminated and even short LT lines required will be with AB Cables. This makes direct tapping very difficult.

6. **End Use Equipment:** Due to better voltage profile, the efficiency of end use equipment is high, bringing in considerable benefit by way of energy conservation.
7. **Reliability of Supply:** The failure of transformer will affect only a small number of consumers served by it, thus the reliability of supply is high.
8. **Voltage Fluctuations:** The voltage drop on LV lines is negligible and voltage profile is very stable. Any voltage fluctuations occurring can be remedied by installations of Automatic Voltage Regulators on HV line.

## **CHAPTER-3**

### **DISTRIBUTION SYSTEM LOAD FLOW**

#### **3.1 INTRODUCTION**

The load 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 capacitor placement in distribution system and distribution automation system, requires repeated load flow solution. Many methods such Gauss-Seidel, Newton-Raphson are well reported to carry the load flow of transmission system. The use of these methods for distribution system may not be advantageous because they are mostly based on the general meshed topology of a typical transmission system where as 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 efficiency of the optimization problem of distribution system depends on the load flow algorithm because load flow solution has to run for many times. Therefore, the load flow solution of distribution system should have robust and time efficient characteristics. A method which can find the load flow solution of radial distribution system directly by using topological characteristic of distribution network [19,20] is used. In this method, the formulation of time consuming Jacobian matrix or admittance matrix, which are required in conventional methods,

is avoided. This method is explained in brief.

### 3.2 LOAD FLOW OF RADIAL DISTRIBUTION SYSTEM [19,20]

The method to carry out the load flow for distribution system under balanced operating condition employing constant power load model can be understood through the following points:

- \* Equivalent current injection.
- \* Formulation of BIBC matrix.
- \* Formulation of BCBV matrix.

#### 3.2.1 EQUIVALENT CURRENT INJECTION

The method is based on the equivalent current injection. At bus  $i$ , the complex power  $S_i$  is specified and the corresponding equivalent current injection at the  $k$ -th iteration of the solution is computed as

$$S_i = (P_i + j * Q_i) \quad i = 0, 1, 2, 3 \dots \dots \dots N \quad (3.1)$$

$$I_i^k = I_i^r(V_i^k) + j * I_i^i(V_i^k) = \left( \frac{P_i + j * Q_i}{V_i^k} \right) \quad (3.2)$$

where,

$S_i$  is the complex power at the  $i$ -th bus.

$P_i$  is the real power at the  $i$ -th bus.

$Q_i$  is the reactive power at the  $i$ -th bus.

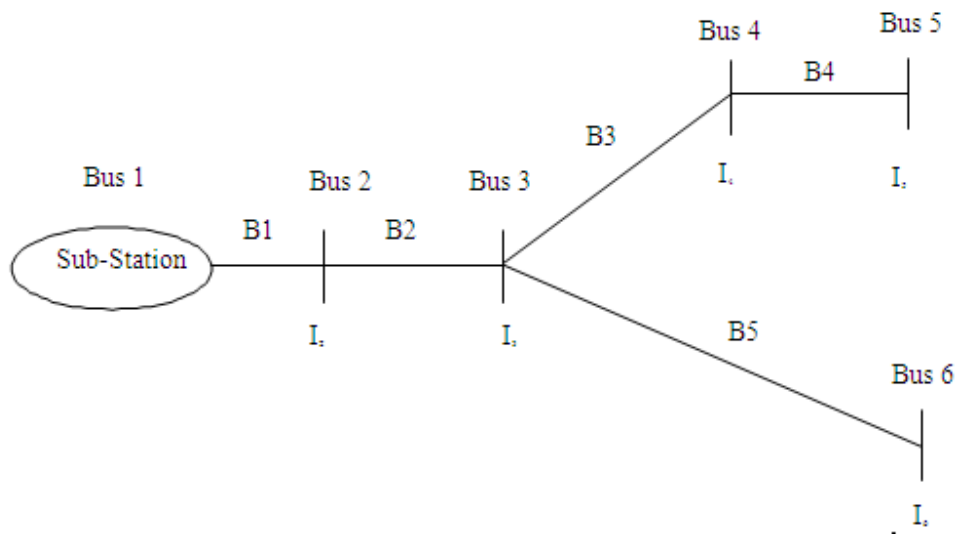
$V_i(k)$  is the bus voltage at the  $k$ -th iteration for  $i$ -th bus.

$I_i(k)$  is the equivalent current injection at the  $k$ -th iteration for  $i$ -th bus.

$I_i^r$  and  $I_i^i$  are the real and imaginary parts of the equivalent current injection at the  $k$  iteration for  $i$ -th bus.

### 3.2.2 FORMATION OF BIBC MATRIX

The formulation of Bus-injection to Branch-current (BIBC) matrix is explained with the help of simple distribution system shown in Fig. 3.1



**Figure 3.1: A typical distribution system**

The power injections at each bus can be converted into the equivalent current injections using eq. (3.2) and a set of equations can be written by applying Kirchhoff's Current Law (KCL) at each bus. Then, the branch currents can be formed as a function of the equivalent current injections. As shown in Fig. 3.1, the branch currents B5, B4, B3, B2 and B1 can be expressed as:

$$B_5 = I_6, \quad (3.3)$$

$$B_4 = I_5, \quad (3.4)$$

$$B_3 = I_4 + I_5, \quad (3.5)$$

$$B_2 = I_3 + I_4 + I_5 + I_6, \quad (3.6)$$

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6, \quad (3.7)$$

From the above equations the BIBC matrix can be obtained as:

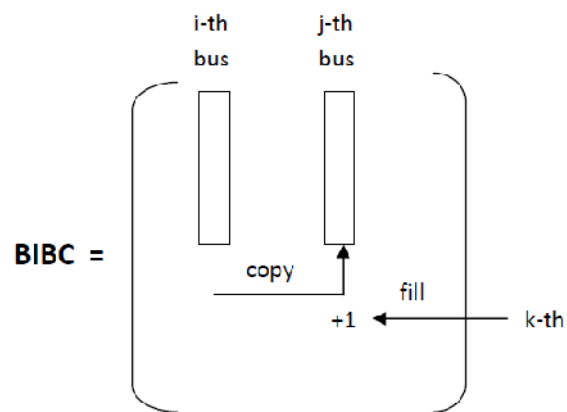
$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (3.8)$$

The general form as of eq. (3.8) can be expressed as:

$$[B] = [BIBC] [I] \quad (3.9)$$

The formulation of BIBC matrix for distribution system shown in Fig. 3.1 is given in eq. (3.8). For general network, the BIBC matrix can be formed through the following steps:

- Step 1:** For a system with  $m$  branch sections and an  $n$ -bus, the dimension of the BIBC matrix is  $m \times (n-1)$ .
- Step 2:** If a line section ( $B_k$ ) is located between Bus  $i$  and Bus  $j$ , copy the column of the  $i$ -th bus of BIBC matrix to the column of the  $j$ -th bus and fill a  $+1$  in the position of the  $k$ -th row and the  $j$ -th bus column. This is explained in Fig. 3.2.
- Step 3:** Repeat step (2) until all the line sections are included in the BIBC matrix.



**Figure 3.2: The formation of step (2) for BIBC matrix**

### 3.2.3 FORMATION OF BCBV MATRIX

The Branch-Current to Bus voltage (BCBV) matrix summarizes the relation between branch current and bus voltages. The relations between the branch currents and bus voltages can be obtained easily. As shown in Fig. 3.1, the voltages of Bus 2, 3, and 4 are expressed as:

$$V_2 = V_1 - B_1 Z_{12}, \quad (3.10)$$

$$V_3 = V_2 - B_2 Z_{23}, \quad (3.11)$$

$$V_4 = V_3 - B_3 Z_{34}, \quad (3.12)$$

Substituting eqs. (3.10) and (3.11) into eq. (3.12), the voltage of Bus 4 can be rewritten as:

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \quad (3.13)$$

From eq. it can be seen that the bus voltage can be expressed as a function of the branch currents, line parameters and substation voltage. Similar procedures can be utilized for other buses, and the Branch-Current to Bus-Voltage (BCBV) matrix can be derived as:

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (3.14)$$

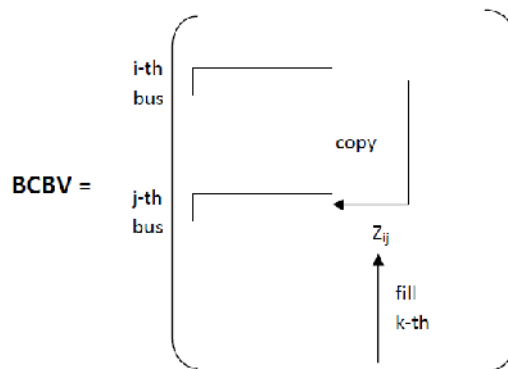
The general form of eq. (3.14) can be expressed as:

$$[\Delta V] = [BCBV] [B] \quad (3.15)$$

The formulation of BCBV matrix for distribution system shown in Fig. 3.1 is given

eq. (3.14) and eq.(3.15). For general network, the BCBV matrix can be formed through the following steps:

- Step 1:** For a system with  $m$  branch sections and an  $n$ -bus, the dimension of the BCBV matrix is  $(n - 1) \times m$ .
- Step 2:** If a line section ( $B_k$ ) is located between Bus  $i$  and Bus  $j$ , copy the row of the  $i$ -th bus of the BCBV matrix to the row of the  $j$ -th bus, and fill the line impedance ( $Z_{ij}$ ) in the position of  $j$ -th bus row and the  $k$ -th column. This is explained in Fig. 3.3.
- Step 3:** Repeat Step (2) until all the line sections are included in the BCBV matrix.



**Figure 3.3: The formation of step (2) for BCBV matrix**

From Fig. (3.2) and Fig. (3.3), it can be seen that the algorithms for the BIBC and BCBV matrices are almost similar. The only difference in the formation of BIBC matrix and BCBV matrix is that, in BIBC matrix  $i$ -th bus column is copied to the column of the  $j$ -th bus and fill with  $+1$  in the  $k$ -th row and the  $j$ -th bus column, while in BCBV matrix row of the  $i$ -th bus is copied to the row of the  $j$ -th bus and fill the line impedance ( $Z_{ij}$ ) in the position of the  $j$ -th bus row and the  $k$ -th column.

### 3.2.4 SOLUTION METHODOLOGY

The formation of BIBC and BCBV matrices is explained in section 3.2.2 and 3.2.3. These matrices explore the topological structure of distribution systems. The BIBC matrix is responsible for the relations between the bus current injections and branch currents. The corresponding variation of the branch currents, which is generated by the variation at the current injection buses, can be found directly by using the BIBC matrix. The BCBV matrix is responsible for the relations between the branch currents and bus voltages. The corresponding variation of the bus voltages, which is generated by the variation of the branch currents, can be found directly by using the BCBV matrix. Combining eqs. (3.9) and (3.15), the relations between the bus current injections and bus voltages can be expressed as:

$$[\Delta V] = [BCBV][BIBC][I] \quad (3.16)$$

$$[DLF] = [BCBV][BIBC] \quad (3.17)$$

Therefore 
$$[\Delta V] = [DLF][I] \quad (3.18)$$

The solution for the load flow can be obtained by solving eqs. (3.19) and (3.20) iteratively which are given below:

$$I_i^k = I_i^r(V_i^k) + j * I_i^i(V_i^k) = \left( \frac{P_i + j * Q_i}{V_i^k} \right) \quad (3.19)$$

$$[\Delta V^{k+1}] = [DLF][I^k] \quad (3.20)$$

$$[V^{k+1}] = [V^o] + [\Delta V^{k+1}] \quad (3.21)$$

The new formulation as explained uses only the DLF matrix to solve load flow problem. Therefore this method is very time efficient, which is suitable for on-line operation and optimization problem of distribution system.

### 3.3 ALGORITHM FOR DISTRIBUTION SYSTEM LOAD FLOW

The algorithm steps for load flow solution of distribution system is given below:

- Step 1:** Read the distribution system line data and load data.
- Step 2:** Form the BIBC matrix by using steps given in section 3.2.2. The relationship can be expressed as –  
 $[B] = [BIBC] [I]$
- Step 3:** Form the BCBV matrix by using steps given in section 3.2.3. The relationship therefore can be expressed as –  
 $[\Delta V] = [BCBV] [B]$
- Step 4:** Form the DLF matrix by using the eq. (3.17). The relationship will be –  
 $[DLF] = [BCBV][BIBC]$   
 $[\Delta V] = [DLF][I]$
- Step 5:** Set Iteration  $k = 0$ .
- Step 6:** Iteration  $k = k + 1$ .
- Step 7:** Update voltages by using eqs. (3.19), (3.20), (3.21), as –

$$I_i^k = I_i^r(V_i^k) + j * I_i^i(V_i^k) = \left( \frac{P_i + j * Q_i}{V_i^k} \right)$$

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

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

- Step 8:** If  $\max(|I_{(k+1)}| - |I(k)|) > \text{tolerance}$  go to step 6.
- Step 9:** Calculate line flows, and losses from final bus voltages.
- Step 10:** Print bus voltages, line flows and losses.
- Step 11:** Stop

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

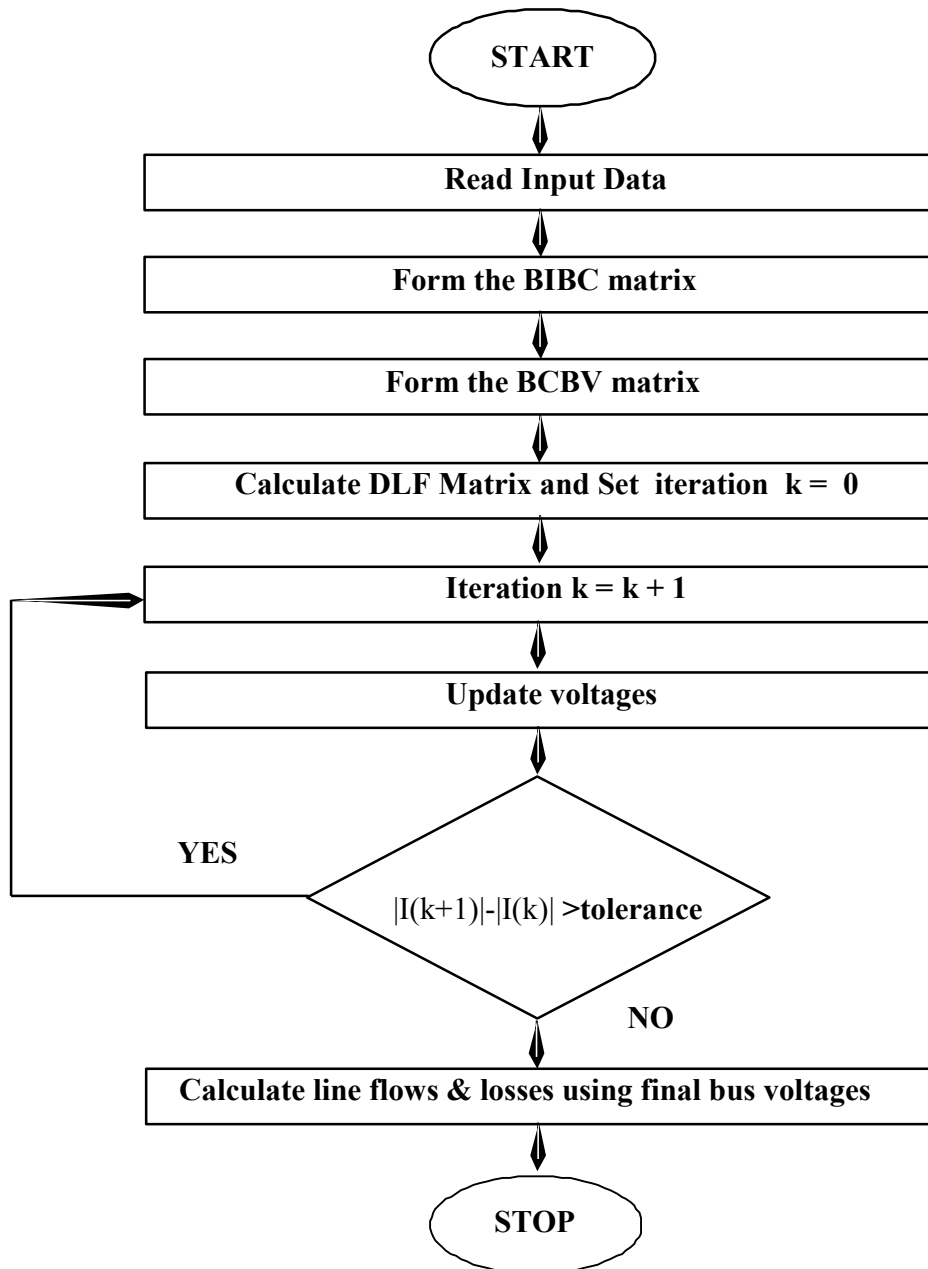


Figure 3.4: Flowchart for load flow solution for radial distribution system

### **3.4 CONCLUSION**

In this chapter, a direct approach algorithm for distribution load flow has been formulated. The Bus Injection to Branch Current (BIBC) matrix is responsible for the variation between the bus current injection and branch current and the Branch Current to Bus voltage (BCBV) matrix is responsible for the variation between the branch current and bus voltage. The load flow is based on these two matrices and their matrix multiplication. With the formulation of this load flow of radial distribution system, the much needed background has been prepared to work in the area of capacitor placement problem in radial distribution system.

# **CHAPTER-4**

## **CAPACITOR PLACEMENT IN DISTRIBUTION SYSTEM USING GENETIC ALGORITHM**

### **4.1 INTRODUCTION**

Loss Minimization in power system has assumed greater significance, because substantial amount of generated power is being wasted as losses. Studies have shown that 70% of the total system losses are occurring in the distribution system, while transmission lines account for only 30% of the total losses. The pressure of improving the overall efficiency of power delivery has forced the power utilities to reduce the loss, especially at the distribution level. The following methods are adopted for reduction of distribution system losses.

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

Among the above listed methods, the reactive power compensation is most commonly used method for loss reduction in distribution system. The distribution network is usually compensated by either series or shunt capacitors. Series capacitors increase the maximum power limit while shunt capacitors have several benefits. Some of the benefits [23] are:

(i) reduce real and reactive power loss in the system (ii) increase voltage level at the load and power factor of source (iii) improve voltage regulation (iv) improve stability (v) improve power factor of the system (vi) decrease KVA loading on source generators etc. However to achieve these objective(s), the optimal locations of capacitors and sizes should be find out. Certainly, the locations and

sizes of the capacitors will be influenced by the objective under consideration.

## 4.2 THE OBJECTIVE FUNCTION

The aim of the present work is to find out the location and sizes of the shunt capacitor so as to maximize the net saving by minimizing the energy loss cost for a given period of time and considering cost of shunt capacitors. Therefore, the objective function consists of two main terms: energy loss cost and capacitors cost. Mathematical formulation of the terms used in objective function is given below:

### Term 1: Energy loss Cost (ELS):

If  $I_i$  is the current of section- $i$  in time duration  $T$ , then energy loss in section- $i$  is given by:

$$EL_i = I_i^2 * R_i * T \quad (4.1)$$

The Energy loss (EL) in time  $T$  of a feeder with  $n$  sections can be calculated as:

$$EL = \sum_{i=1}^n EL_i \quad (4.2)$$

The Energy loss cost (ELC) can be calculated by multiplying eq. (3.2) with the energy rate ( $C_e$ )

$$ELC = C_e \times EL \quad (4.3)$$

EL is energy loss (kW) in section- $i$  in time duration  $T$ .

$I_i$  is the current of the section- $i$

$R_i$  is the resistance of section- $i$ .

$T$  is the time duration.

$C_e$  is the energy rate.

ELC is the energy loss

**Term 2: Capacitor Cost (CC):**

Capacitor cost is divided into two terms: constant installation cost and variable cost which is proportional to the rating of capacitors. Therefore capacitor cost is expressed as:

$$CC = C_{ci} + ( C_{cv} \times Q_{ck} ) \quad (4.4)$$

where,

$C_{ci}$  is the constant installation cost of capacitor.

$C_{cv}$  is the rate of capacitor per kVAr.

$Q_{ck}$  is the rating of capacitor on bus-k in kVAr.

The cost function is obtained by combining eqs. (4.3) and ( 4.4). This cost function is considered as the objective function to be minimized in the present work. The cost function 'S' is therefore expressed as:

Minimize

$$S = C_e \times \sum_{i=1}^n EL_i + \sum_{k=1}^{ncap} C_{ci} + ( C_{cv} \times Q_{ck} ) \quad (4.5)$$

where S is the cost function for minimization.

By minimizing the cost function, the net saving due to the reduction of energy losses for a given period of time including the cost of capacitors is given below:

$$\text{Net saving} = \text{BEL} - \text{CC} \quad (4.6)$$

where

$\text{BEL} = \text{ELC}_{(\text{without capacitor})} - \text{ELC}_{(\text{with capacitor})}$

BEL is benefit due to energy loss reduction.

$\text{ELC}_{(\text{without capacitor})}$  is energy loss cost without capacitor.

$\text{ELC}_{(\text{with capacitor})}$  is energy loss cost with capacitor.

CC is the total capacitors cost as expressed by eq. (3.4).

### 4.3 LOSS SENSITIVITY FACTOR AND CANDIDATE BUS SELECTION

The loss sensitivity factor and the criterion to select the candidate buses for compensation are summarized in this section.

#### 4.3.1 LOSS SENSITIVITY FACTOR

To identify the location for capacitor placement in distribution system Loss Sensitivity Factors have been used [22] . The loss sensitivity factor is able to predict which bus will have the biggest loss reduction when a capacitor is placed. Therefore these sensitive buses can serve as candidate buses for the capacitor placement. The estimation of these candidate buses basically helps in reduction of the search space for the optimization problem. As only few buses can be candidate buses for compensation, the installation cost on capacitors can also be reduced. Consider a distribution line with an impedance  $R + jX$  and a load of  $P_{\text{eff}} + jQ_{\text{eff}}$  connected between 'i' and 'j' buses as given below in Fig. 4.1.

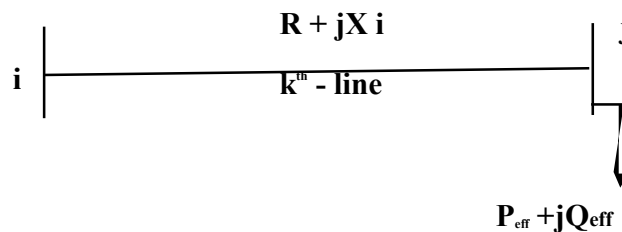


Figure 4.1: A distribution line with Impedance and load

Real power loss in the line of the above Fig. 4.1 is given by  $[I_k] * [R_k]$ , which can also be expressed as

$$P_{\text{line loss}}[j] = \frac{(P_{\text{eff}}^2[j] + Q_{\text{eff}}^2[j]) * R[k]}{(V[j])^2} \quad (4.7)$$

Similarly the reactive power loss in the  $k^{\text{th}}$  line is given by

$$Q_{\text{line loss}}[j] = \frac{(P_{\text{eff}}^2[j] + Q_{\text{eff}}^2[j]) * X[k]}{(V[j])^2} \quad (4.8)$$

where

$P_{\text{eff}}[j]$  = Total effective active power supplied beyond the bus 'j'

$Q_{\text{eff}}[j]$  = Total effective reactive power supplied beyond the bus 'j'

Now, the Loss Sensitivity Factors can be calculated as:

$$\frac{\partial P_{\text{line loss}}[j]}{\partial Q_{\text{eff}}[j]} = \frac{(2 * Q_{\text{eff}}[j]) * R[k]}{(V[j])^2} \quad (3.9)$$

$$\frac{\partial Q_{\text{line loss}}[j]}{\partial Q_{\text{eff}}[j]} = \frac{(2 * Q_{\text{eff}}[j]) * X[k]}{(V[j])^2} \quad (3.10)$$

### 4.3.2 CANDIDATE BUS SELECTION USING LOSS SENSITIVITY FACTOR

The Loss Sensitivity Factor as given in eq. (4.9) has been calculated from the base case Load flows. The values of loss sensitivity factors have been arranged in descending order and correspondingly the bus numbers are stored in bus position 'bpos[i]' vector. The descending order of (elements of 'bpos [i]' vector will decide the sequence in which the buses are to considered for compensation. At these buses of 'bpos [i]' vector, normalized voltage magnitudes are calculated by considering the base case voltage magnitudes given as below:

$$\text{norm}[i] = |V[i]|/0.95 \quad (4.11)$$

The 'norm[i]' decides whether the buses need reactive compensation or not. The buses whose norm[i] value is less than 1.01 can be selected as the candidate buses for capacitor placement. The following are the steps to be performed to find out the potential buses for capacitor placement:

- Step 1:** Calculate the Loss Sensitivity Factor at the buses of distribution system using Eq. (4.9).
- Step 2:** Arrange the value of Loss Sensitivity Factor in descending order. Also store the respective buses into bus position vector bpos[i].
- Step 3:** Calculate the normalized voltage magnitude norm[i] of the buses of bpos[i] using Eq. (4.11).
- Step 4:** The buses whose norm[i] is less than 1.01 are selected as candidate buses for capacitor placement.

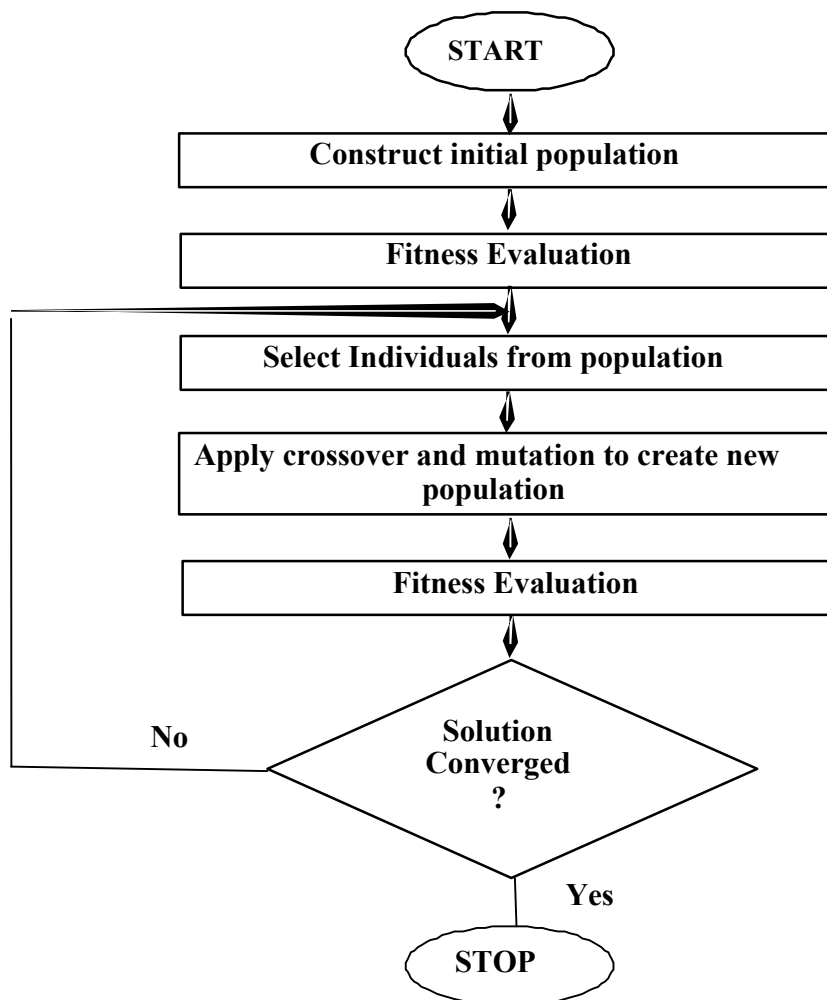
#### **4.4 CAPACITOR ALLOCATION USING GA**

The developed algorithm for identifying the sizing and location is based on Genetic Algorithm (GA). The development of algorithm is explained with a review on GA. A GA is an iterative procedure which begins with a randomly generated set of solutions referred as initial population. For each solution in set, objective function and fitness are calculated. On the basis of these fitness functions, pool of selected population is formed by selection operators, the solution in this pool has better average fitness than that of initial population. The crossover and mutation operator are used generate new solutions with the help of solution in the pool. The process is repeated iteratively while maintain fixed number of solutions in pool of selected population, as the iteration progress, the solution improves and optimal solution is obtained. During the selection process of the GA, good solutions are selected from the initial generated population for producing offspring. Good solutions are selected randomly from the initial generated population using a mechanism which favors the more fit individuals. Good individuals will probably be selected several times in a generation but poor solutions may not be selected at all.

The second GA operator is crossover. Crossover takes place when proper encoding method has been decided. Crossover operates on selected genes from parent chromosomes and creates new offspring. The simplest way how to do that is to choose randomly some crossover point and copy everything before this point from the first parent and then copy everything after the crossover point from the other parent. In the crossover two parents are selected randomly from the pool of selected/obtained population by the selection process. Crossover produces two off springs which has some basic properties of the parents. The mutation operator generates an offspring using a random solution from pool. Each new solution is evaluated i.e. objective function and fitness value calculated. These newly created off springs and the populations are combined. The combined population is put for selection by selection operator. With the above description, a simple Genetic Algorithm is given as follow:

- Step 1:** Randomly generate initial population strings.
- Step 2:** Calculate the fitness value for each string in the population.
- Step 3:** Create the pool after selection.
- Step 4:** Create off springs through crossover and mutation operation.
- Step5:** Evaluate the off springs and calculate the fitness value for each solution.
- Step 6:** If the search goal is achieved, or an allowable generation is attained, return the best chromosome as the solution; otherwise go to step 3.

The standard procedure of GA is depicted in Flowchart as shown in Fig. 4.2.



**Figure4.2:GeneticAlgorithmFlowchart**

#### 4.4.1 CODING SCHEME

The success of the GA structure will lie on the coding scheme, the coding scheme and the brief discussion of various operators with reference to the problem of interest is summarized as:

Here the coding scheme for 33-bus radial distribution system has been discussed. First steps to obtain the base case load flow solution for distribution system using the algorithm discussed in Chapter 3. Then identify the potential buses for capacitor placement by using loss sensitivity factor as discussed in section (4.3.2). Using the loss sensitivity factor, the potential buses for shunt capacitor placement are obtained and these potential buses should be preserved.

Let the number of Potential Buses = [24 7 30]

Having identified the potential buses, the sizing is attempted using GA. Let the capacitor allowable range is from 10 kVAr to 40 kVAr.

#### 4.4.2 INITIALIZATION AND FITNESS FUNCTION

Initialization is the generation of initial population. Here, the initial population is generated randomly which is the capacitors of different sizes (kVAr ratings) to be installed at the potential buses. The population size affects the efficiency and performance of the algorithm. It can be stated that string length is equal to the number of buses selected for the shunt capacitor placement problem.

After generating population of required size the corresponding load flow solution has to run to evaluate the objective function 'S' as stated in eq. 4.5 and the fitness function  $f(x)$  calculated as given below:

$$S = C_e \times \sum_{i=1}^n EL_i + \sum_{k=1}^{ncap} C_{ci} + (C_{cv} \times Q_{ck})$$

$$f(x) = \frac{1}{1 + S} \quad (4.12)$$

The load flow solution, evaluation of objective function and fitness function is repeated for all the strings in the population. The procedure to determine the fitness function ‘f(x)’ is very much application oriented. It is directly associated with the objective function value in the optimization problem. In the capacitor placement problem, the objective function is the minimization of cost function.

#### 4.4.3 REPRODUCTION

The first genetic algorithm operator is reproduction. This determines which strings in the current population will be used to create the next population or be part of pool of selected population. So, sometime this operator is also named as the selection operator. This is done by using a biased random - selection methodology. That is parents are randomly selected from the current population in such a way that the ‘best’ strings in the population have more chance of being selected. There are many ways to do this , such as by Roulette Wheel selection, Boltzman selection, tournament selection, rank selection etc. In the present work Roulette Wheel selection has been used[24]:

Reproduction is simply an operator where by an old solution is copied into a mating pool. The solution with a higher fitness value have higher probability of being selected into mating pool and contributing one or more offspring in the next generation. The following are the steps carried out for the roulette wheel selection process]:

- Step 1:** Sum the fitness of all the population members. Call it as total fitness.
- Step 2:** Generate a random number (r) between zero and the total fitness.
- Step 3:** Select a population member whose cumulative fitness obtained from adding its fitness to the fitness of the proceeding population members is greater than or equal to random number (r).

#### 4.4.4 CROSSOVER

Here the two selected parents is utilized in certain fashion to generate two children who bear some of the useful characteristics of parents and expected to be more fit than parents. The random selection technique is used to pick up two parents randomly from the existing population. After selecting the parents, crossover can be carried out using methods like Single Point Crossover, Multi-point Crossover or Uniform Crossover arrangements.

In the present work single point crossover has been used. This is illustrated in the following example. Let Parent1 and Parent2 be the two parents selected randomly for crossover. Assume the strings parent1 and parent2 as given below and, a crossover site is selected randomly as an integer between 1 and string length.

Parent1 = { 100 400 200 500 100 }

Parent2 = { 300 500 100 600 700 }

For illustration the string length is taken as 5, but in the thesis work string length depends upon the number of candidate buses for compensation. Let the crossover site is 3<sup>rd</sup> position. Then children Child1 and Child2 are generated as below.

Child1 = { 100 400 200 600 700 }

Child2 = { 300 500 100 500 100 }

It is seen that each crossover resulted in two children. In order to control crossover also there is a parameter called “Crossover Probability (Pe)”. This probability is used as a decision variable before performing the crossover. This probability is known as the crossover rate. Crossover probability lies in the range of 0.7-1 . The following steps are carried out to perform crossover.

- Step 1:** Select two parents by randomly selection method from the population.
- Step 2:** Generate random number between 0 and 1.
- Step 3:** Set a crossover probability 'Pc'.
- Step 4:** If the randomly generated number is greater than crossover probability 'Pc' Child1 and Child2 are directly selected as Parent1 and Parent2. This Step is equivalent to the case of crossover where crossover site is equal to the string length.
- Step 5:** If the randomly generated number is less than crossover probability 'Pc' than crossover takes place.

#### 4.4.5 MUTATION

This operator is capable of creation new genetic material in the population to maintain the population diversity. It is nothing but random alteration of capacitor size. The following

example illustrates the mutation operation.

Let Mutation site is at 4th position of the string.

Original String = { 400 100 500 200 800 }

String after mutation = { 400 100 500 950 800 }

In the above illustration after getting the mutation site, a random value is generated from 100 to 1100 is placed at the mutation site. Mutation is the process of random modification of the value of a string position with a small probability. The mutation probability 'Pm' lies in the range of 0.0001 to 0.01 .The following steps to be carried out to perform

the mutation:

- Step 1:** Generate random number between 0 and 1.
- Step 2:** Set a crossover probability 'Pc'.
- Step 3:** If the randomly generated number is less than mutation probability 'Pm' than mutation is performed on the off-springs generated by the crossover.

## 4.5 ALGORITHM FOR CAPACITOR ALLOCATION

The general outline of the Loss Sensitivity Factor and the Genetic algorithm for capacitor placement problem is discussed in the previous sections. The set of steps have been shown below to solve the capacitor placement problem:

- Step 1:** Read the distribution system branch impedance values and the bus real and reactive Power data.
- Step 2:** Run the Load Flow of Distribution System by using steps given in section 3.3, to find out voltage magnitudes at the buses and total power loss.
- Step 3:** Select the candidate buses by using steps given in section 4.3.2.
- Step 4:** Set  $GEN = 0$
- Step 5:** Form initial population of real numbers, which is randomly selected value of capacitors to be installed at the candidate buses for compensation.
- Step 6:** Update the reactive power at candidate buses.
- Step 7:** Run the Load Flow of Distribution System by using steps given in section 3.3, with updated reactive power at the candidate buses for each population. Also calculate total power loss for each population.
- Step 8:** Calculate the total Energy Loss Cost (ELC) and Capacitor Cost (CC) for population by using Eqs. (4.3) and (4.4)
- Step 9:** For each population, evaluate the objective function and the fitness value. The objective function for each population is the total energy loss cost and the cost of capacitors given in Eq. (4.5)
- Step 10:**  $GEN = GEN + 1$
- Step 11:** Select the solutions in pool from initial population by using Roulette Wheel Selection procedure given in section 4.4.3.
- Step 12:** Perform Crossover on the solutions selected randomly from the pool using procedure given in section 4.4.4 and generate two off springs.
- Step 13:** Perform Mutation on the offspring generated by the crossover operation using the procedure given in section 4.4.5 and generate the offspring.

- Step 14:** Calculate Energy Loss Cost (ELC) and capacitors cost (CC) Also evaluate objective function and Fitness Function of each offsprings.
- Step 15:** Combine the solutions of the pool and the offsprings and refer them as new population.
- Step 16:** Replace new population with initial population for next generation.
- Step 17:** Go to step 10, till the solution converges.
- Step 18:** STOP

The above set of steps for the Capacitor Placement in radial distribution system is depicted in Flowchart as shown in Fig.4.3.

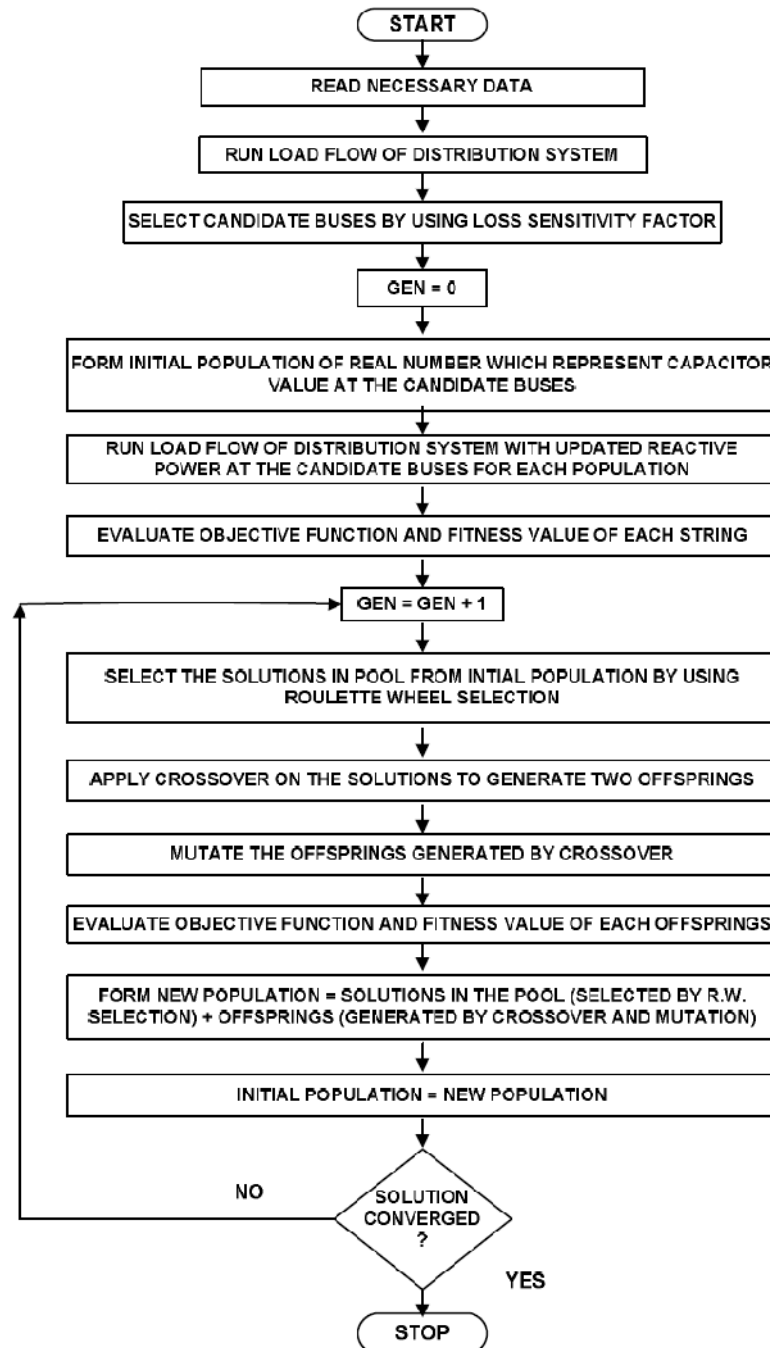


Figure 4.3: Flowchart for capacitor placement in distribution system

## **4.6 CONCLUSION**

In this chapter loss sensitivity factors and genetic algorithm for capacitor placement in the distribution system have been discussed. The loss sensitivity factors are used to determine the candidate buses for compensation and genetic algorithm is used to find the sizes of shunt capacitors to be installed at candidate buses.

## **CHAPTER-5**

### **RESULTS AND DISCUSSION**

In this chapter results have been presented after the implementation of the algorithm discussed in Chapter 4. The algorithm has been developed in MATLAB environment.

Loss Sensitivity Factor discussed in Chapter 4 has been used to find out the potential buses for capacitor placement. Among the total potential buses selected by loss sensitivity factor, different number of candidate buses are selected and the effectiveness of compensation is discussed for maximum annual saving after considering saving due to energy loss cost and capacitor cost. The effectiveness of the algorithm for above systems has been studied two cases.

In all simulations, the following parameters have been used :

1. population size = 100
2. maximum Generation = 100
3. Crossover probability ' $P_c$ '=1
4. Mutation Probability ' $P_m$ '=1
5. energy rate = US \$0.06/kWh.
6. capacitor installation cost ' $C_{ci}$ ' = US \$1000.
7. capacitor rate ' $C_{cv}$ ' = US \$3.0/kVAr.

#### **5.1 Optimal Capacitor Placement on 33-Bus RDS**

The 33-bus radial distribution system, as shown in Fig. (5.1), has following characteristics:

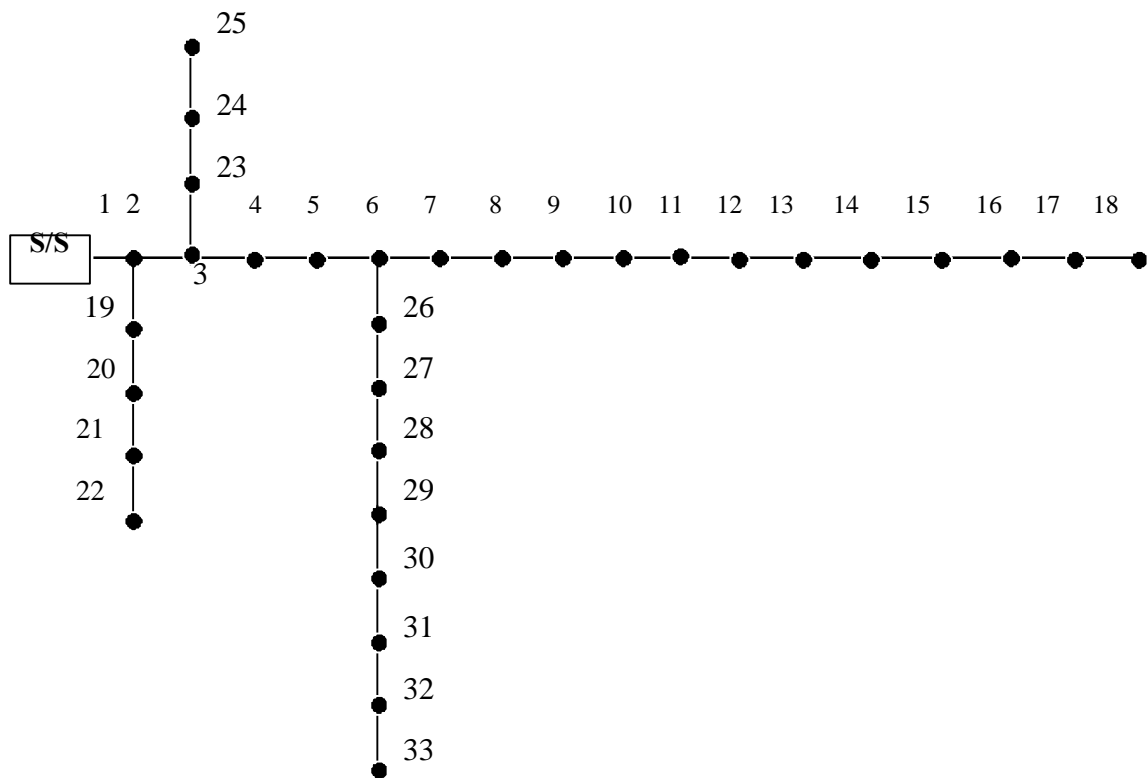
Number of buses = 33

Number of lines = 32

Slack Bus No =1

Base Voltage=12.66 KV

Base MVA=100 MVA



**Figure (5.1): 33-Bus Radial Distribution System**

The load flow of the distribution system is obtained using the algorithm discussed in Chapter 3.

Loss Sensitivity Factor method as discussed in Chapter 4 has been used to identify the potential buses for shunt capacitor placement. The buses have been ordered according to decreasing LSF. The potential buses comes to be **30,24,7**.

In this case capacitor value has been taken as a discrete variable. The capacitor allowable range is from 100 kVAr to 1100 kVAr with discrete step of 50 kVAr.

In this case first three buses, having highest loss sensitivity values are selected as candidate buses, these candidate buses are (i.e. buses 24, 7, 30 ) and the capacitor sizes have been determined by using GA.

Now to minimize the losses the capacitor is selected by genetic algorithm. The capacitor placement results in bus voltages and reduced power losses. A comparison is made between the losses of with capacitor and without capacitor.

**Case 1:**  $x(1)$ ,  $x(2)$ ,  $x(3)$ , are the capacitances to be put across the candidate buses. In the GA function above their value is varied from 10 to 40 ( $\mu$  farad) and for each combination the program calculates the value of fitness function i.e losses with capacitor in place and compares it with losses without capacitor. Those values are selected for which the losses are minimum.

**Case 2:**  $x(1)$ ,  $x(2)$ ,  $x(3)$ , are the capacitances to be put across the candidate buses. In the GA function above their value is varied from 12 to 42 ( $\mu$  farad) and for each combination the program calculates the value of fitness function i.e losses with capacitor in place and compares it with losses without capacitor. Those values are selected for which the losses are minimum.

**Table(5.1):Comparison of losses with and without capacitor**

**GA Output**

<b>X(1)</b>	<b>X(2)</b>	<b>X(3)</b>	<b>Loses with Capacitor</b>	<b>Loses without Capacitor</b>
10	10	10	1940437	2126508
34	39	39	2939791	2126508
37	30	11	2701258	2126508
14	11	23	2215874	2126508
37	35	21	2850875	2126508
29	38	33	2852382	2126508
13	30	34	2513182	2126508
18	33	16	2518541	2126508
26	32	25	2735071	2126508
39	22	23	2762481	2126508
39	30	29	2880473	2126508
15	15	31	2369746	2126508
39	31	33	2910492	2126508
39	11	18	2546615	2126508
25	18	30	2604834	2126508
34	11	30	2599109	2126508
14	13	15	2181645	2126508
23	35	14	2587924	2126508
37	31	25	2848412	2126508
34	20	39	2773662	2126508
10	10	10	1940437	2126508
14	13	15	2181645	2126508
29	38	21	2777108	2126508
15	15	10	2173004	2126508
26	15	31	2587258	2126508
10	10	16	2010115	2126508
14	30	15	2399328	2126508
39	11	29	2633868	2126508
37	31	18	2792724	2126508
14	11	39	2305375	2126508
34	13	15	2503052	2126508
34	10	10	2389077	2126508
37	31	11	2712613	2126508
10	10	10	1940437	2126508
18	33	16	2518541	2126508
25	30	30	2731255	2126508
38	30	11	2710044	2126508

13	13	15	2155386	2126508
38	23	24	2773036	2126508
15	11	23	2241235	2126508
10	10	10	1940437	2126508
10	10	10	1940437	2126508
34	10	10	2389077	2126508

From the above table we conclude that the best combination of capacitors that are used to minimize the losses is as given below.

### Optimal capacitor Result

X(1)	X(2)	X(3)	Losses with capacitor	Losses without capacitor
10	10	10	1940437	2126508

**Table (5.2): Comparison of losses with and without capacitor**

### GA Output

X(1)	X(2)	X(3)	Losses with capacitor	Losses without capacitor
12	12	12	2067792	2126508
36	41	41	2975093	2126508
39	32	13	2757209	2126508
16	13	25	2319737	2126508
39	37	23	2894766	2126508
31	40	35	2895041	2126508
15	32	36	2587873	2126508
20	35	18	2591755	2126508
28	34	27	2788436	2126508
41	24	25	2815534	2126508
41	32	31	2921895	2126508
17	17	33	2459149	2126508
41	33	35	2949107	2126508
41	13	20	2620233	2126508
27	20	32	2671373	2126508
36	13	32	2667301	2126508
16	15	17	2288511	2126508
25	37	16	2654024	2126508
39	33	27	2892578	2126508
36	22	41	2825236	2126508

12	12	12	2067792	2126508
16	15	17	2288511	2126508
31	40	23	2826823	2126508
17	17	12	2278611	2126508
28	17	33	2655915	2126508
12	12	18	2133079	2126508
16	32	17	2484116	2126508
41	13	31	2699431	2126508
39	33	20	2841936	2126508
16	13	41	2400660	2126508
36	15	17	2579952	2126508
36	12	12	2474021	2126508
39	33	13	2767457	2126508
12	12	12	2067792	2126508
20	35	18	2591755	2126508
27	32	32	2784849	2126508
40	32	13	2765324	2126508
15	15	17	2264874	2126508
40	25	26	2824824	2126508
17	13	25	2342567	2126508

From the above table we conclude that the best combination of capacitors that are used to minimize the losses is as given below.

**Optimal capacitor result**

<b>X(1)</b>	<b>X(2)</b>	<b>X(3)</b>	<b>Losses with capacitor</b>	<b>Losses without capacitor</b>
12	12	12	2067792	2126508

From above we see that Table (5.1) capacitor combination has minimum losses as compared to Table (5.2). So Table (5.1) gives the required optimal results for loss minimization in distribution system.

**Table (5.3)**  
**Base Case Load Flow Solution of 33-Bus RDS (without capacitor)**

Bus Number	Voltage Magnitude in p.u.	Angles in degrees
1	1.0000	0.0000
2	0.9980	0.0139
3	0.9835	0.0964
4	0.9760	0.1619
5	0.9685	0.2285
6	0.9560	0.1347
7	0.9465	-0.0963
8	0.9425	-0.2305
9	0.9323	-0.3243
10	0.9260	-0.3756
11	0.9205	-0.3821
12	0.9130	-0.3657
13	0.9116	-0.4566
14	0.9080	-0.4673
15	0.9075	-0.5430
16	0.9055	-0.6055
17	0.9036	-0.6845
18	0.9074	-0.6933
19	0.9920	-0.0025
20	0.9960	-0.0649
21	0.9932	-0.0822
22	0.9924	-0.1044
23	0.9768	-0.0632
24	0.9722	-0.0244
25	0.9686	-0.0654
26	0.9463	-0.1764
27	0.9447	-0.2309
28	0.9327	-0.3136
29	0.9254	-0.3922
30	0.9219	-0.4813
31	0.9169	-0.4133
32	0.9158	-0.3856
33	0.9152	-0.3756

Total power losses = 787.1413 KW  
 Minimum system voltage  $V_{17} = 0.9036$

**Table (5.4)**  
**Load Flow Solutions of 33 Bus RDS(with optimal capacitor at three candidate buses)**

Bus Number	Voltage magnitude in p.u	Angles in degrees	Capacitor Value 'Q' in kVAr.
1	0.0000	0.0000	0
2	0.9984	-0.0379	0
3	0.9392	-0.2346	0
4	0.9780	-0.3798	0
5	0.9687	-0.5360	0
6	0.9568	-1.1056	0
7	0.9570	-1.3691	10
8	0.9430	-1.6488	0
9	0.9327	-1.8007	0
10	0.9328	-1.9458	0
11	0.9292	-1.9547	0
12	0.9154	-1.9735	0
13	0.9140	-2.0619	0
14	0.9095	-2.1379	0
15	0.9089	-2.1744	0
16	0.9078	-2.1969	0
17	0.9069	-2.2715	0
18	0.9125	-2.2808	0
19	0.9982	-0.0487	0
20	0.9964	-0.1149	0
21	0.9937	-0.1357	0
22	0.9725	-0.1556	0
23	0.9684	-0.2654	0
24	0.9832	-0.3537	10
25	0.9684	-0.3974	0
26	0.9469	-1.1478	0
27	0.9452	-1.2035	0
28	0.9329	-1.5339	0
29	0.9259	-1.7435	0
30	0.9323	-1.7734	10
31	0.9172	-1.8546	0
32	0.9162	-1.8742	0
33	0.9158	-1.8811	0

Total power losses = 551.0162 KW

Minimum system voltage  $V_{17} = 0.9069$  p.u at bus 17

## **CHAPTER-6**

### **CONCLUSIONS AND SCOPE FOR FUTURE WORK**

#### **6.1 CONCLUSIONS**

The work has been carried out to find the optimal locations and sizes (kVAr) of capacitors to be placed in radial distribution system. The above problem has been solved by two step methodology, the candidate locations for compensation are found using loss sensitivity factor calculated from base case load flow. The sizing has been attempted using Genetic Algorithm. In GA, coding scheme is developed to carry out the allocation problem, which is identification of location and size by one dimensional array. The study has been carried out on 33-bus considering the capacitors step sizes of 10 to 40 kVAr and 12 to 42 kVAr. From the study the following conclusions are drawn.

- \* The compensation is yielding into increase in voltage profile, reduction in losses.
- \* The developed algorithm is effective in deciding the allocation of capacitors for different number of candidate buses and for different capacitor sizes.

#### **6.2 SCOPE FOR FUTURE WORK**

The completion of one research project opens the avenues for work in many other related areas. The following areas are identified for future work:

1. The same work can be extended to 69 bus system.
2. The study has been carried out on balanced distribution system. The capacitor allocation problem can be extended to unbalanced distribution system.

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## APPENDIX

**TABLE(A.1.1) Line data for 33-Bus Radial Distribution System**

Branch Number	Sending end Bus	Receiving end Bus	Branch resistance (ohm)	Branch resistance (ohm)
1	1	2	0.080214	0.044361
2	2	3	0.42891	0.233523
3	3	4	0.31842	0.173352
4	4	5	0.331557	0.180513
5	5	6	0.71253	0.65751
6	6	7	0.162864	0.575484
7	7	8	1.488918	1.148643
8	8	9	0.8961	0.6882
9	9	10	0.87348	0.6882
10	10	11	0.171042	0.06045
11	11	12	0.325728	0.115134
12	12	13	1.27716	1.07415
13	13	14	0.471192	0.662997
14	14	15	0.51417	0.48918
15	15	16	0.649281	0.50685
16	16	17	1.12143	1.60053
17	17	18	0.63684	0.53382
18	2	19	0.14268	0.145545
19	19	20	1.308654	1.260522
20	20	21	0.356265	0.444912
21	21	22	0.616743	0.871689
22	3	23	0.392544	0.286719
23	23	24	0.78126	0.659463
24	24	25	0.77952	0.652023
25	6	26	0.17661	0.096162
26	26	27	0.247254	0.134571
27	27	28	0.92133	0.868341
28	28	29	0.699654	0.651558
29	29	30	0.441525	0.240405
30	30	31	0.847728	0.89559
31	31	32	0.270135	0.336567
32	32	33	0.29667	0.493086

**Table (A.1.2): Load Data for 33-Bus Radial Distribution System**

<b>Bus number</b>	<b>P (KW)</b>	<b>Q(kVAr)</b>
1	0	0
2	200	120
3	180	80
4	240	160
5	120	60
6	120	40
7	400	200
8	400	200
9	120	40
10	120	40
11	90	60
12	120	70
13	120	70
14	240	160
15	120	20
16	120	40
17	120	40
18	180	80
19	180	80
20	180	80
21	180	80
22	180	80
23	180	100
24	840	400
25	840	400
26	120	50
27	120	50
28	120	40
29	240	140
30	400	1200
31	300	140
32	420	200
33	120	80

