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Load flow analysis using Forward and Backward sweep, and minimising power losses using Genetic Algorithm.

Tanish Deosaria, Srijan Choudhary, Tajender Meena

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ABSTRACT
This thesis presents a Backward/Forward Sweep Method to analyse the load flow in radial distribution system. The R/X ratios of distribution system having radial structure are high. So the Newton-Raphson and fast decoupled methods are failed with distribution system. On the other hand, the proposed method is one of the most effective methods for the load-flow analysis of the radial distribution system and it is easy to implement and there is no need of any complex renumbering of branches and nodes, or any matrix calculation. This method uses only the linear equations based on Kirchhoff's formulation and is used to determine power losses for each bus branch and voltage magnitudes for each node.
After analysis load flow analysis by forward and backward sweep method we observe there is some power losses that occur in our distributed system. So to optimized our system we introduce genetic algorithm for optimal capacitor placement.
The placement of shunt capacitor banks at optimal locations in the distribution network and their sizing can effectively reduce the losses in the utility network. It also helps in the maximum active power flow through the existing distribution lines which. This also increases the power transfer capacity of feeders and improves the voltage profile of the feeders which leads to reduced investment of transmission network. This paper presents a method for optimal placement and sizing of the capacitors in radial distribution feeder using Genetic algorithm (GA) with an objective of loss reduction and voltage profile improvement. The results have been validated using MATLAB programming. An IEEE 33-bus distribution test feeder is employed for testing the proposed algorithm. The optimal sizing of the capacitors has been suggested in terms of thekVAr.
Keywords: Backward/Forward sweepmethod, Distribution system, Load-flow Analysis.

I. INTRODUCTION

In general, the definition of an electric power system includes generating, transmission and distribution system. Among these the economic importance of the Distribution System is very high. The amount of investment involved in distribution system dictates careful planning, design, construction and operation. It holds a very specific position in the power system since it is the main link between bulk power and consumers. It is important to plan distribution network effectively to meet the present growing domestic, industrial and commercial load day-by-day. Distribution networks have attained an overwhelming research interest in the academics as well as in the industries community nearly from last 30 years.

1.1DISTRIBUTION SYTEM

An electric power distribution system transmits electricity from transmission system to individual consumers. It is the final phase in the delivery of electric power. It provides power to individual customer premises. The objective of distribution system planning is to assure that the growing demand for electricity in terms of accelerating growth rates and high load densities are often satisfied in an optimum way by additional distribution Systems from the secondary conductors through the majority power substations, which are both technically adequate and fairly economical.

Distribution transformers again decrease the voltage to lower level to the utilization voltage of household appliances and typically feed several customers through secondary distribution lines at this voltage. The distribution of electric power to consumers is done with a much lower voltage level as compared to that of the transmission of power over long distances. It generally consists of feeders, circuit breakers and the service mains. Fig. 1.1

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shows the single line diagram of a typical low tension distribution system.

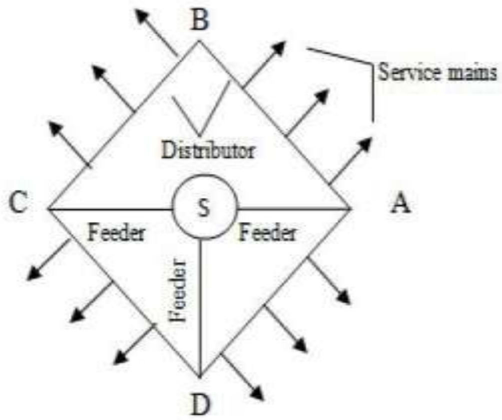

Fig. 1.1 Elements of Distribution System

1.2TYPES OF DISTRIBUTION SYSTEM

Distribution networks are divided into two types:

a) Radial Distribution System

b) Ring Main Distribution System

The ring main system is generally more expensive than the radial system because more switches and conductors are required in ring main system leading to high construction cost and it is not preferred to choose ring main system when the generation is at low voltage. Due to these reasons, radial system is used in distribution system.

1.3RADIAL DISTRIBUTION SYSTEM

Separate feeders are radiated from one substation and feed the distributors at only one end. This is termed as radial system. Radial distribution is the power distribution system in which the power is delivered from the main branch to the sub branches then it split out from the sub branches again as shown in Fig. 1.2, where power is transferred from the node and it splits at L1.There are no loops in the radial distribution network and each bus is connected to the source via exactly one path. This network configuration is the cheapest and least reliable. The Radial Distribution System is generally used in sparsely populated areas.

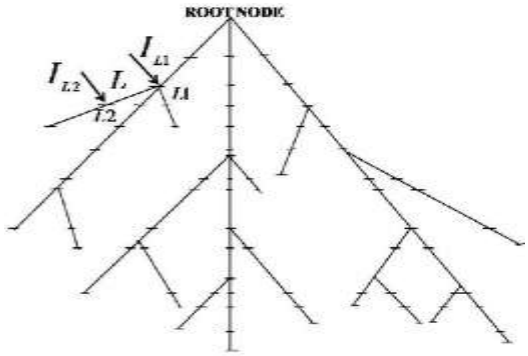

Fig. 1.2 Radial Distribution Network

Criteria assumed for node and line numbering in the network is as follows:

1. The nodes are numbered sequentially in ascending order proceeding from layer to layer, in such a way that any path from the root node to a terminal node encounters nodes numbered in the ascending order.
2. Each branch starts from the sending bus (root side) and is identified by the number of its (unique) ending bus.

The main advantage of radial network is that its construction is simple, low initial cost, can be used when generation is at low voltage. It is preferred when the substation is located at the centre of the load.

1.4FEATURES OF RADIAL DISTRIBUTION NETWORK

The conductors which are used in distribution systems are characterized by:

- High R/X ratios
- Uncertainties and imperfections
- Radial structure
- Large number of nodes and branches
- Distributed generation and topology configurations
- Dynamic change in imposed load

1.5LOAD FLOW STUDIES

Load-flow studies are used to make sure that the electrical power transmission, through the grid system, from generators to consumers is stable, reliable and economic. The increasing presence of distributed alternative energy sources, frequently in geographically remote locations, complicates load flow studies and has triggered a resurgence of interest in the topic. In a three phase AC power system, active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called flow or load flow. Power flow studies provide a systematic mathematical approach for computation of various bus voltages, their phase angle, active and reactive power flow through different branches, generators and loads under steady state condition.

II. THEORY:

Load-flow analysis is a extensively used tool in transmission system in several applications such as power generating scheduling and very useful for many applications in distribution system such as network analysis, load control, network reorganization, integration of generation and integration of electric vehicle. To understand the nature of the installed network, Load-flow studies are performed on power systems. Load-flow is used to discover the static performance of the system and usually uses simplified notation such as a one-line diagram and per-unit system. It focuses on various forms of AC power (voltages, voltage angles, real power and reactive power). It examines the power systems in normalsteady-state operation.

Due to radial or weakly meshed networks, high R/X ratios, multi-phase, unbalanced operation, unbalanced distributed load and distributed generation, transmission grid load flow methods or the Jacobian-based methods such as Newton-Raphson, Gauss-Seidel and fast decoupled methods are failed with distribution systems. Many approaches have been developed in the past for distribution system load-flow analysis. Due to computational efficiencies and solution accuracies, the ladder network theory and the backward/forward sweep methods are the commonly used approaches for distribution system load flow analysis.

In this thesis, standard backward/forward sweep method is used for radial distribution load flow analysis. An initial calculation is made from the large data to organize the radial distribution information into a main line and its derivations. After the organization into a suitable model, voltages of all other nodes are set to nominal voltage and then an iterative process is carried out by calculating currents in derivative lines and then the branch current in the main line is computed in a backward sweep using KCL. The node voltages are computed in a forward sweep using the voltage drop calculation. This backward and forward sweep technique is repeated until voltage magnitudes in each node in the current iteration and the preceding iterations are lower than the tolerance limit.

2.1LOAD FLOW ANALYSIS

Analysis of Load-flow requires two inputs, Line data and Load data, to provide electrical network characteristics.

In Load data, active power injections and the consumptions of the active/reactive power at each node are collected to establish it. The network information can be assembled in one table, as shown in Table 2.1.

Node	kVA	kVAr
……..	……..	……..
……..	……..	……..
……..	……..	……..

Table 2.1: Load Data Table

Line data represents network conductor characteristics; in utilities, line data are grouped in the GIS, or by knowing the electrical characteristics of conductors used, it can be brought together manually, the laying mode and the year of the conductor laying. The network information can be assembled in one table, as shown in Table 2.2.

Sending node	Receiving node	R (Ohm)	X (Ohm)
……..	……..	……..	……..
……..	……..	……..	……..
……..	……..	……..	……..

Table 2.2: Line Data Table

However, the network topology can be changed for maintenance activities, emergency operations, or network configurations.

2.2 FORMULATION OF THE PROBLEM

In a distribution system, the power flows are enumerated by the following set of simplified recursive equations derived from the single-line diagram, as shown in Fig

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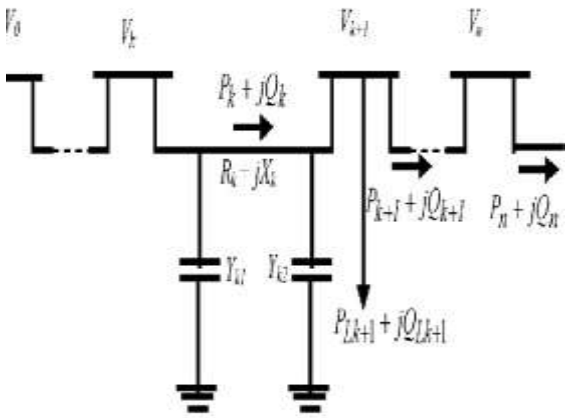
SENDING END

RECEIVING END



Single Line Diagram

The power flow can be used to obtain the voltage magnitude, power losses of the radial distribution network. The objective function is to find the power flow.

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1} \quad (2.1)$$

$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{Lk+1} \quad (2.2)$$

where,

P_k – Real power flowing out of bus

Q_k– Reactive power flowing out of bus

P_{Lk+1} – Real load power at bus k+1

Q_{Lk+1} - Reactive load power at bus k+1

The power loss in the line section connecting buses k and k+1 can be computed by the formulas given below.

$$P_{loss}(k,k+1) = R_k \frac{P_k^2+Q_k^2}{V_k^2} \quad (2.3)$$

$$Q_{loss}(k,k+1) = X_k \frac{P_k^2+Q_k^2}{V_k^2} \quad (2.4)$$

where,

P_{loss}(k,k+1) – Real power loss in the line section connecting buses k and k+1

Q_{loss}(k,k+1) – Reactive power loss in the line section connecting buses k and k+1

The total power loss of the feeder, $P_{T,LOSS}$ may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{T,loss}(k,k+1) = \sum_{k=1}^{n} P_{loss}(k,k+1) \quad (2.5)$$

$$Q_{T,loss}(k,k+1) = \sum_{k=1}^{n} Q_{loss}(k,k+1) \quad (2.6)$$

where,

$P_{T,loss}$(k,k+1) – Total Real power loss in the line section

$Q_{T,loss}$(k,k+1) – Total Reactive power loss in the line section

2.3 PROPOSED LOAD FLOW ANALYSIS METHOD

Let us consider a radial network, the Backward/Forward Sweep technique for the computation of load-flow is an iterative method within which, at every iteration two processes are performed, Backward sweep and Forward sweep. The load flow of one source network will be resolved iteratively from two sets of algorithmic equations. The first set of equations for calculations of the load flow through the branches initiating from the last branch and continuing in the backward direction towards the root node. The other set of equations are for calculating the voltage magnitude and the angle of each node initiating from the root node and continuing in the forward direction towards the last node.

In Fig. 2.2, the diagram of the general principle of the proposed load flow method is given.

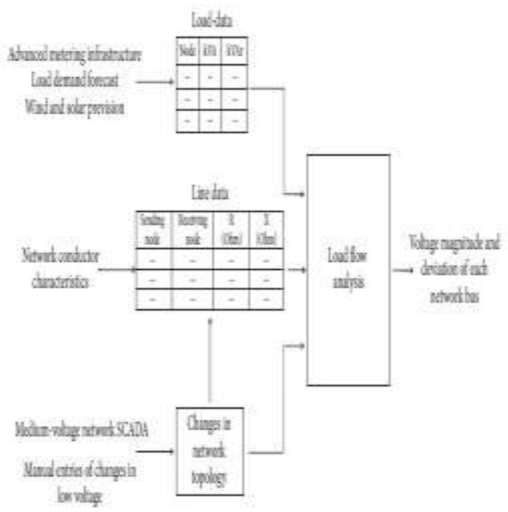


Fig. 2.2 Diagram of the Proposed Load Flow Analysis

BACKWARD SWEEP: It is a current or load flow solution with possible voltage updates. Branch current and load flows are updated beginning from the branches in the last layer and moving towards the branches connected to the root node. The updated effective load flows in each branch are calculated in the backward propagation computation considering the node voltages of previous iteration. This indicates that the voltage values calculated in the forward method are held constant during the backward propagation and

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updated power loads in each branch are transmitted backward along the feeder using backward method. This means that the backward propagation begin at the extreme end node and proceeds towards the source node.

FORWARD SWEEP: It is basically a voltage-drop calculation with possible current and power flow updates. In a forward sweep, Nodal voltages are updated initiating from branches in the first layer towards those in the last. The aim of the forwards propagation is to calculate the voltages at each node beginning from the feeder source node. The voltage of feeder substation is set at its actual value. During the forward propagation the effective power in each branch is held fixed to the value calculated in backward propagation.

The Backward/Forward sweep algorithm includes two steps: the backward sweep and the forward sweep. Voltage and currents are computed in backward sweep using Kirchhoff's Voltage Law and Kirchhoff's Current Law from the End node to the Source node. In Forward sweep, the downstream voltage is computed starting from the source node. The input data of this algorithm is given by node-branch aligned data. Basic data required are the active and reactive powers and classification for sending and receiving nodes.

Given below are the major steps of the proposed algorithm with appropriate equations.

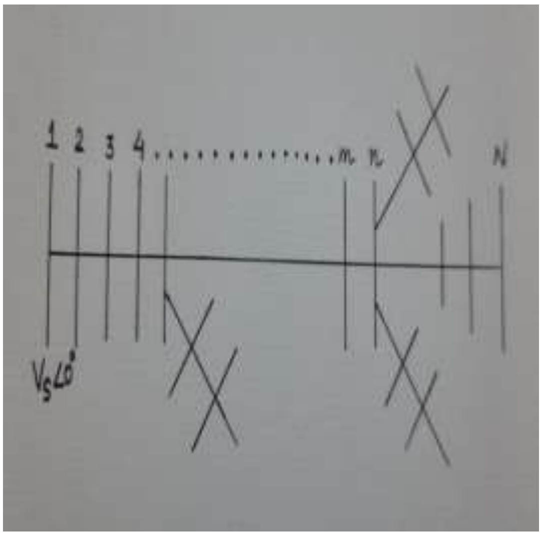


Fig. 2.3 Bus Network for the load flow calculation using Backward/Forward sweep method

Let us assume the radial distribution bus network given in Fig. 2.3 where **N** is the total number nodes.

Step 1: Initialization of Voltages

$$\mathbf{Vj^{(0)} = V_s\angle 0} \quad \text{for } j = 2, 3,\ldots,N \qquad (2.7)$$

Step 2: Iteration Count Initialization, **K = 1**

Step 3: Load Current computation

$$\mathbf{Ij^{(k)} = conj}\left(\frac{PLj + j\,QLj}{Vj^{\wedge}(k-1)}\right) \text{for } j = 2, 3, \ldots N \qquad (2.8)$$

Step 4: Backward Sweep

$$\mathbf{I_{mn}}^{(k)} = I_n^{(k)} + \sum \begin{matrix} \text{summation of all the currents of branches} \\ \text{emanated from bus } n \text{ for } mn \text{ branches} \end{matrix} \qquad (2.9)$$

Step 5: Forward Sweep

$$\mathbf{V_n^{(k)} = V_m^{(k)} + Z_{mn}.I_{mn}^{(k)}} \quad \text{for all } n = 2, 3,\ldots,N \qquad (2.10)$$

Step 6: Error

$$\mathbf{Ej^{(k)} = |Vj^{(k)} - Vj^{(k-1)}|} \quad \text{for } j = 2, 3,\ldots,N \qquad (2.11)$$

Step 7: Maximum Error

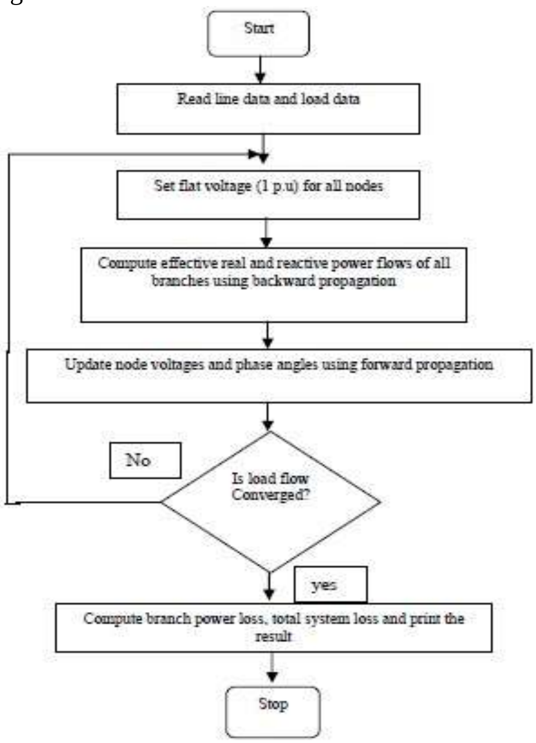
$$\mathbf{Emax(k) = max\ (E2(k), E3(k), E4(k),\ldots, En(k))}$$

Step 8: If $E_{max}^{(k)}$ is less than or equal to tolerance (ε), then the load flow is converging.

Else update the iteration count to k=k+1 and go to step 3 and repeat the steps.

In the proposed load flow method, power summation is done in the backward direction and voltages are calculated in the forward direction.

Figgives the detailed operation of the load flow calculation using backward forward sweep algorithm.



FigOperation of the Load Flow calculation using Backward/forward sweep method

PROBLEM FORMULATION:

Main objective of capacitor placement is to minimize the losses and improve voltage profile in the power system network. To achieve this objective, an objective function is formulated. Main goal of this objective function is to minimize the losses of the active and reactive powers along with the improvement of voltage profile. The section details related to the load and capacitor model, constraints formulation, objective function and power loss calculations are described in the followingsubsections.

A. Load and capacitormodel

The loads and capacitors are modeled as impedance. The impedance model of loads and capacitors are given by Eq. (1) and Eq. (2) respectively.

$$Z_{Load_i} = R_{Load_i} + jX_{Load_i} \quad (1)$$

$i = 1,2,3, \ldots ,NL$

Where NL = loadnumbers

Z_{Load_i} = impedance of i^{th} load

R_{Load_i} = resistance of i^{th} load

X_{Load_i} = reactance of i^{th} load

$k = 1,2,3, \ldots ,NC$

Where NC = capacitorsnumbers

Z_{C_k} = impedance of k^{th} capacitor

X_{C_k} = reactance of k^{th} capacitor

In the power network, the capacitive impedance cancels out the effect of inductive reactance and helps in minimization of the losses and improvement in the voltage profile. Excessive capacitive reactive power will results to the leading power factor which is an undesirable phenomenon in the power system as this condition produces the heating losses in the end user equipments. Hence, optimal sizing as well as placement of shunt capacitor banks is a key aspect for the powersystem.

Objective function

The proposed objective function considers the balanced three-phase system with time invariant loads. Mathematically, the proposed objective function of the problem is based on the minimization of the loss in power network and deviation in the voltages from their pre-defined standard values. The definition of the objective function is given below.

$$F = W_1 P_{loss} + W_2 Q_{loss} + W_3 \sum_i (1 - v_i)^2 \quad (3)$$

where W_1, W_2 and W_3 are weights utilized in the objective function corresponding to active power loss, reactive power loss and voltage deviation. P_{loss} is total active power loss and Q_{loss} is total reactive power loss in distribution network. v_i is voltage magnitude at i^{th} bus of the test system.

C. Constraints

The constraints are another significant part of the optimization model along with the objective function. These are required to be defined in terms of the maximum and minimum limits. The constraints considered in this research are of inequality type. The main constraints for the voltage are considered in the proposed research. The limits of voltage magnitude at each bus are defined by the following expression.

D. Calculation of Power Loss

The complex power at the i^{th} bus is given by the relation

$$P_i - jQ_i = V_i^* I_i$$

Where,

P_i : Load active power

Q_i : Load reactive power

V_i : Voltage at i^{th} bus

I_i : Load current at i^{th} bus

The Gauss-Seidel iterative method is used to calculate the bus voltage and line losses

$$v_i^{(k+1)} = \frac{1}{Y_{ii}}\left(\frac{P_i - jQ_i}{V_i^{*(k)}} - \sum_{\substack{n=1 \\ n\neq i}}^{m} Y_{in}V_n\right) \quad (6)$$

Where,

$V_i^{(k)}$: Voltage on i[th] bus at the k[th] iteration

P_i, Q_i : Active and reactive power of bus i

$Y_{im} = y_{im}$ for $i \neq y$

and $Y_{ii} = y_{i,m-1} + y_{i,m+1} + y_{ci}$ for i = m

The loss of power loss in the line segment between buses i and i+1, at power frequency can be computed by:

$$P_{loss(i,i+1)} = R_{i,i+1}\left[\left|V_{i+1} - V_i\right|, \left|y_{i,i+1}\right|\right]^2 \quad (7)$$

Where

$Y_{i,i+1} = \frac{1}{(R_{i,i+1} + x_{i,i+1})}$: Admittance of the line section between buses i and i+1.

$R_{i,i+1}$: Resistance of the line segment connecting bus i and i+1.

$X_{i,i+1}$: Reactance of the line segment connecting bus i and i+1.

The total power loss is calculated by the relation:

$$P_{loss} = \sum_{i=0} P_{loss(i,i+1)} \quad (8)$$

GENETIC ALGORITHM:

This section details the theoretical concepts of the genetic algorithm. The foundations for genetic algorithms were first introduced by John Holland [28] and then elaborated in detail using the tutorials by David Goldberg [29]. The genetic algorithm is a global search technique that can be utilized to solvethe optimizationproblems.Thisisbasedonthetheoryof natural selection and biological evolution process. GAconsists of population of binary string, which searches many peaks in parallel [30]. The important terminologies utilized related to the GA are detailed below[31].

Individual: The point for whichan objective function is implemented can be treated as an individual. This is a set of values of variables for which function is to be optimized. The value of objective function for an individual is called its score. The vector entries related to the genes of a genome are considered asindividuals.

Population: Population is an array of individuals. If we consider the size of population as 100 and number of variables in the objective function as 3, then population can be represented by a matrix of the size 100x3 in which each row corresponds to anindividual.

Generation: At each iteration, the genetic operators are used to perform a series of computations on the current population to produce a new population. The successive populations produced are known as newgeneration.

Parents and children: To create the next generation, the GA selects a number of individuals in the existing population which is called parents. This generation is used to create individuals in the next generation known aschildren.

The following genetic operators are applied on parents to form children for next generation:

Reproduction: This selects the fittest individuals in the current population to be used in generating the next population. These children are known as Elitechildren.

Crossover: This causes pairs of individuals to exchange genetic information between each other. These children are known as crossoverchildren.

Mutation: This causes individual genetic representations required to be changed following a set of some probabilistic rules. These children are called mutation children.

IMPLEMENTATION OF GA FOR CAPACITOR PLACEMENT

The objective function formulated for the optimal placement and sizing of the capacitors is minimized with the help of an optimization tool based on GA. The application of GA is iterated number of times taking different values of W_1, W_2 and W_3 to obtain optimum results. The detailed procedure of the genetic algorithm utilized for implementation of capacitors in test network for minimization of loss and voltage profile improvement.

Generate randomly constructed solutions (strings) as initial population of capacitors of given values which are to be placed at random nodes in the power distribution feeder i.e. IEEE 13 bus testsystem.

The crossover and mutation operators are used to obtain new solutions (capacitor values) using the initial population during geneticcycle.

The objective function values (power loss) are estimated for each new solution and decoded accordingly. The better solution can be obtained with the help of selectionprocedure.

The worst solution is discarded and the better solution joins the newpopulation.

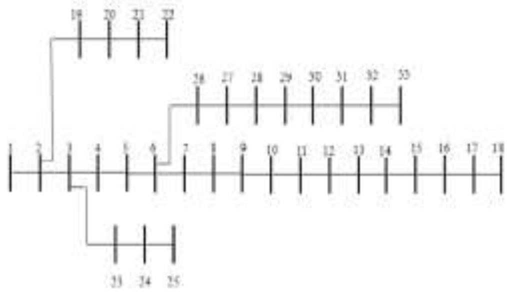
Individuals in the initial population with higher ranking in view of fitness value are used to replenish the shrunkenpopulation.

A new genetic cycle is started in each iteration till the termination criterion is achieved which is themaximum number ofgenerations.

The step-by-step procedure for capacitor allocation using the proposed algorithm is described in the flow chart of the Fig. 1. The size of capacitor at a particular bus location of the test system is used as decision variable. The encoding strategy of each individual is used which forms a possible solution.

III. RESULTS AND DISCUSSION

The proposed **Backward/Forward sweep algorithm** is tested on IEEE 33–bus radial distribution system using MATLAB coding. IEEE 33 bus radial distribution network consists of 33 nodes and 32 branches as shown in Fig. 3.1. The base voltage for this system is 11 kV and base MVA is 100.

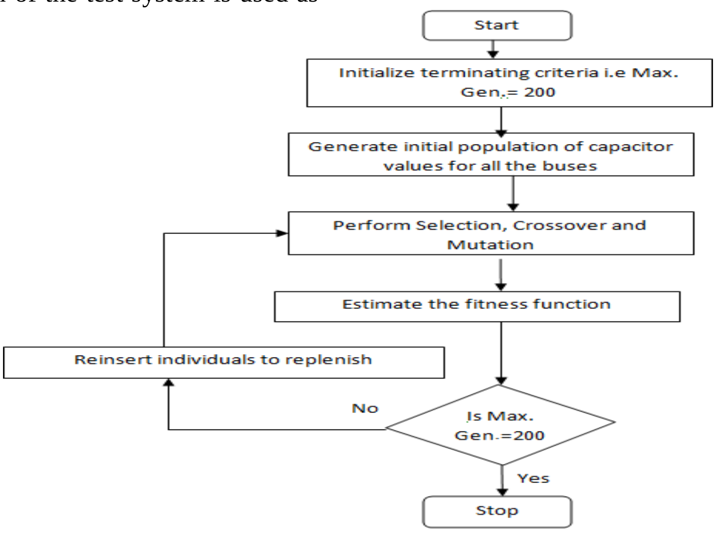


IEEE 33-bus Radial Distribution Network

The tolerance is 10^{-5}p.u. and the total number of iterations required is 2. The Voltage Magnitude (p.u.), Phase Angle (degrees), Real (kW) and Reactive (kVAR) Line losses in each branch is given in Table 3.1. Voltage profile of this system is shown in Fig. The Total Real power loss is $2.066303e^{02}$ KW.

The Total Reactive power loss is $1.378083e^{02}$ KW.

The proposed genetic algorithm-based solution methodology for the optimal placement of capacitors in the power distribution network has been implemented on 33-bus IEEE test feeder. The candidate places for capacitor placement and quantity of reactive compensation



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are decided by GA and tested for losses of the active and reactive powers by load flow analysis based on Gauss-Seidel method. The losses of the active and reactive powers in the test network without reactive power compensation and optimal reactive power compensation using genetic algorithm are provided in Table 4. The active power losses decrease by 66.51% and reactive power losses decreases by 60.81% of original values.

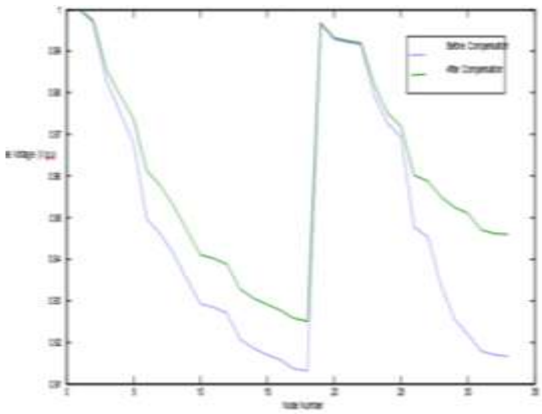
TABLE IV. RESULTS RELATED TO LOSSES OF ACTIVE AND REACTIVE POWERS

	Loss of active power	Loss of reactive power
Before Optimization	206.73	137.90
After optimization by GA	141.842	96.4364

The size of shunt capacitors is taken as discrete values of the capacity 50 kVAr which is generally used in the 11 kV distribution systems. The calculated values of reactive power compensation are converted in to nearest capacity as integral multiple of minimum available capacity. The bus voltages before and after compensation as well as capacity of capacitor units at candidate buses are provided in the Table 5. All voltages after optimal capacitor placement are found to be within permissible limits as specified.

RESULTS OF BUS VOLTAGES AND REACTIVE COMPENSATION

Bus No.	Bus Voltages without Reactive compensation	Bus voltages after optimal reactive compensation using GA
0	1.0000	1.0000
1	0.9960	0.9975
2	0.9770	0.9860
3	0.9668	0.9805
4	0.9568	0.9805
5	0.9318	0.9752
6	0.9271	0.9641
7	0.9205	0.9625
8	0.9119	0.9529
9	0.9040	0.9490
10	0.9028	0.9456
11	0.9008	0.9449
12	0.8924	0.9438
13	0.8894	0.9378
14	0.8874	0.9356
15	0.8856	0.9342
16	0.8828	0.9329
17	0.8820	0.9309
18	0.9953	0.9303
19	0.9906	0.9969
20	0.9896	0.9934
21	0.9888	0.9927
22	0.9722	0.9920
23	0.9632	0.9825
24	0.9588	0.9758
25	0.9292	0.9725
26	0.9257	0.9629
27	0.9101	0.9615
28	0.8989	0.9568
29	0.8941	0.9537
30	0.8884	0.9521
31	0.8871	0.9481
32	0.8867	0.9472



Voltage Profile graph for 33-node VDLF system before and after compensation

IV. CONCLUSIONS:

A new method for solving the load flow problem for radial distribution feeders without using conventional load flow methods like Gauss Seidel, Newton-Raphson, Fast Decoupled methods is presented in this thesis. This algorithm uses simple algebraic equations to calculate repeatedly the outgoing powers and voltage magnitudes of different nodes and discrepancy at the last nodes of main feeder and laterals and depending upon this discrepancy the substation injection is corrected cautiously, and this process is repeated until convergence. This makes the algorithm very strong and numerically efficient for convergence for wide alternation of distribution network. The results for IEEE 33-bus test system have been tabulated in Table 3.1and voltage profile is shown in Fig.3.2 and it was found that the proposed load flow method is suitable for fast convergence characteristics, high R/X ratios and radial structure.

This paper proposes a solution for placement of shunt capacitor banks in the power distribution network which can be easily implemented in the practical power system networks. The proposed method is based on the genetic algorithm. The algorithm is implemented on 33-bus IEEE distribution test system. The optimal location and sizes of shunt capacitors is obtained for minimum loss in the network and optimal voltage profile. The results have been validated in the MATLAB. The developed algorithm can also be applied on real network of large electricity utilitynetwork.

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