

Load-flow and Stable Planning of Radial Distribution Networks using Distributed Generation

A THESIS

Submitted in the fulfilment of the requirement for the award of the degree of

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ELECTRICAL ENGINEERING
by

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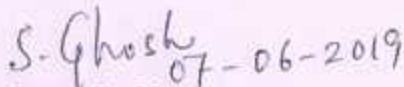
I hereby certify that the work, which is being presented in thesis entitled "*Load-flow and Stable Planning of Radial Distribution Networks using Distributed Generation*" to the Department of Electrical & Instrumentation Engineering, Thapar Institute of Engineering & Technology (Deemed to be university), Patiala in the partial fulfilment of the requirements for the award of degree of "Doctor of Philosophy", is an authentic record of my own research work carried out under the guidance of Dr. Smarajit Ghosh and refers other research works, which are duly listed in the reference section.

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


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(Suman Bhullar)

*Dedicated to My
Father*

ABSTRACT

The distribution networks execute perceptible evolution due to the wide range of load levels in daily routine as compared to transmission networks. In this thesis, it has been tried to discover the possibilities associated with the efficient operation of electric power distribution networks. A systematic load-flow is necessary for proper working as well as control, well-organized planning and cost effective optimization of distribution networks. The objective of this research work is to develop simple and efficient load-flow solution for radial distribution networks assumed to be of balanced nature, which is providing platform for the mechanism involved in the stable planning of distribution networks using distributed generation. In this work, an array based novel searching technique is used to solve the load-flow of radial distribution networks in an iterative method. The proposed technique is used to identify the nodes beyond the branch and hence helpful in calculation of node current and then branch current. Simple equations are used to relate the sending-end voltage, receiving-end voltage and voltage drops in each branch of the distribution system. A computer algorithm is developed to find out the respective parameters considering flat voltage profile by using backward/forward sweep. The angle of the receiving-end voltage is also computed along with the magnitude of the voltage. The comparison of proposed method with the other available methods reported in the literature has been verified on seven radial distribution networks including one practical Indian feeder to show its efficiency.

DG technologies developed for the distribution systems, which comprise of conservative as well as non-conservative types of energy sources for the generating power, are procuring thrust and playing leading role in the distribution system by providing substitute for distribution system planning option. The optimal allocation of DG in any distribution network reduces the loss of the system and increases the voltage profile and hence stability of the system. In power distribution network, losses occurring in the network are one of the important components, and effort should be done to reduce their value. In this work, hybrid Artificial Bee Colony and Cuckoo Search optimization technique is utilized for siting and sizing of DG for loss reduction. Instead of integrating a single large size DG, two or more than two small DGs (multi DGs) are usually placed. These DGs must be placed in appropriate buses/nodes with suitable size to ensure better performance of the system. The multi DGs are optimally placed by considering objectives

like power loss, penalty function (PE) and voltage profile (VP). The outcomes of two different types of radial distribution networks obtained by the suggested method for placement of multi DGs have been correlated to that obtained by using other optimization techniques. The proposed method has also been correlated with the other published methods to indicate its strength.

Whenever there is increase in load demand, the chances are more for voltage instability. In this work, an attempt has been made to propose a new suitable voltage stability index (VSI) for radial distribution networks. The VSIs available in literature are based on reduction of network and without considering the voltage angle. The proposed VSI has been derived without reduction of the network and without neglecting voltage angle. In the present work total seven different types radial distribution networks (RDNs) have been considered including one practical RDN. The results obtained by the proposed method have been compared with that of obtained by the other available methods.

An effective planned distribution network not only reduces the loss of the system, but also enhances the voltage profile and stability of the system. In this work, a technique is suggested for optimal planning of distribution networks using DG. The optimal location of the substation is found by genetic algorithm incorporating the proposed “voltage stability index” as the objective function. The node points are connected to the substation in optimum routes in such a way that the network becomes radial. The outcomes of the proposed planned network for single feeder case, double feeder case and triple feeder case have been compared with an existing planning system keeping the system data unaltered. The three feeder configuration suits to the utility. Next the three DG units are integrated to this network for three feeder case.

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List of Symbols

kk	Branch
BN	Branch number
Z_{kk}	Impedance of branch kk
R_{kk}	Resistance of branch kk
X_{kk}	Reactance of branch kk
$\delta(n1)$	Voltage angle of node $n1$
$\delta(n2)$	Voltage angle of node $n2$
$I(kk)$	Current passing through branch kk
$V(i)$	Voltage magnitude at i th node
V_k	Magnitude of voltage at k th bus
δ_k	Angle of V_k
V_k^{\min} and V_k^{\max}	Minimum and maximum value of V_k
r_{kl} and x_{kl}	Resistance and reactance of the segment between k th and l th bus
P_k and Q_k	Active and quadrature power injection at bus 'k'
P_{Gk} and P_{Dk}	Active power generation and demand at bus 'k'
Q_{Gk} and Q_{Dk}	Wattless power generation and demand at bus 'k'
P_{Gk}^{\min} and P_{Gk}^{\max}	Lower and upper value of active power generation at bus 'k'

Q_{Gk}^{\min} and Q_{Gk}^{\max}	Lower and upper value of quadrature power generation at bus 'k'
S_k^{\min} and S_k^{\max}	Lower and upper value of apparent power at bus 'k'
P_L	Real power loss of the system
PE	Penalty function
VP	Voltage profile
N_G	Number of generator
N_L	Number of lines/transformers
$I_{SC,DG}$	Short circuit current with DG
$I_{SC,no DG}$	Short circuit current without DG
IC_k	Percentage short circuit interrupting capacity at the k th bus
IC_k^{\max}	Percentage short circuit interrupting capacity limit at the k th bus
PCC	Point of common coupling
$IPCC_k$	Percentage short circuit at the k th PCC
$IPCC_k^{\max}$	Percentage short circuit limit at the k th PCC
K_v	Constant of PE of voltage
K_L	Constant of PE of line/transformers loading
K_{IC}	Constant of PE of short circuit interrupting capacity

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In the present eternities, electric power has developed into the elemental module of the substructure of prevailing civilization, for the majority of routine activeness with the postulation that the aspired electric power is straight away accessible for usage. In the prospective years, high reliability of electric supply for residential, academic, commercial and industrials sectors is presumed. Electricity is the one of the greatest endeavours, which has already transformed the living style of humankind. The community currently is intimately influenced by the electric power for accomplishing activities performed on daily basis. It means for endurance of humanity, electrical energy is obligatory. Proliferation of any nation is appraised by an index called per capita consumption of electricity. Higher the per capita consumption, the more prosperous is the country. Electricity has become an inevitable part of every field as well as infrastructure. Such an imperative electrical substructure means electrical power system.

The electric power system is a web of electrical modules established with a motive to provide generation, transmission, distribution and utilization of electrical energy allied with the prominent features of regulation of energy in an invulnerable, authoritative and affordable manner. The classification of power system is endorsed on the basis of voltage levels. Power system's behaviour becomes more significant as the load demand is escalating all over the world. This abrupt magnification in load demand intimidates power systems to operate near critical limits due to economic and environmental constraints.

The power system architecture is equitable like tree the foundations of which represent the generation system, the trunk represents transmission system, the branches represent distribution system and the leaves represent the consumers. The functioning of distribution system is largely affected by the category of consumers. The contemporary power distribution system is being encountered with consistently growing load usage. The highly

complex distribution system requires suitable design of new effective and reliable devices in the deregulated electric power industry for flexible power flow control and also uninterrupted power supply. The design and planning of power distribution networks are indispensable aspects for resolving the guidelines related to optimum expansion in order to cater to the elementary objectives of distribution systems i.e., to appease the consumers.

Distribution networks originate from distribution substations and terminate at consumer premises as shown in Figure 1.1. The distribution substation handovers power from transmission system to the distribution system of an area by stepping down the voltage levels, with the support of distribution transformer, appropriate for consumers. Feeders are designed with constant current capacity whereas distributors are designed from the point of view of constant voltage due to different tapings available for consumers. Distributors are linked through secondary of the transformer and electric power is conveyed to diverse consumers by means of service mains. Bulk consumers are directly connected to feeders.

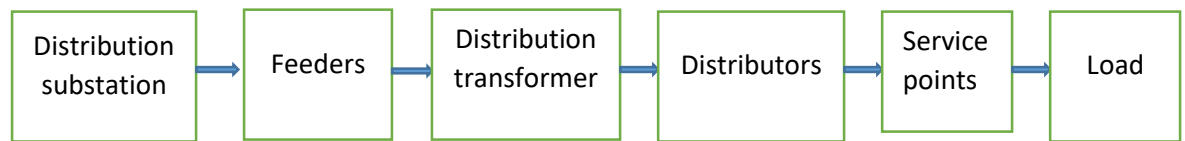


Figure 1.1: Block Diagram of Distribution System

The distribution networks are categorized predominantly on the basis of alignment of feeder's i.e., radial, ring main and interconnected networks. Feeders are designed considering constant voltage as main parameter. The radial distribution network shown in Figure 1.2 is the simplest and economical configuration of distribution networks.

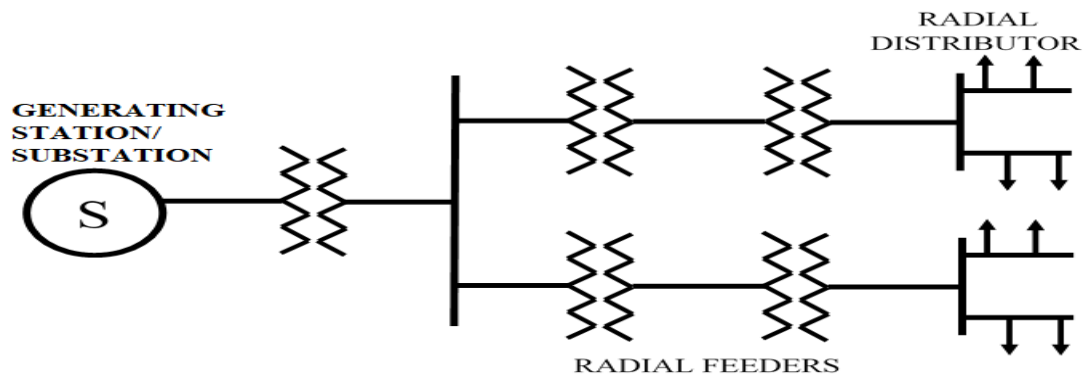


Figure 1.2: Configuration of Radial Distribution Network

Although ring mains feeders are more reliable than radial feeders, radial feeders are more common in practice in India. Reason being major portion of population lives in rural areas, radial feeders are more common in practice due to economics related to operational issues, simplex nature of load-flow, unproblematic fault detection etc.

1.2 LOAD-FLOW AND STABLE PLANNING OF DISTRIBUTION NETWORKS USING DG

As power flow is the power that flows through the transmission and distribution lines, load-flow phraseology is universally applied as a substitute of power flow. Load-flow gives complete information about the prime parameters of power system, which are closely associated with the efficient working. It is considered as pre requisite while renovating, expanding, planning and designing a power system. Load-flow provides guidelines to check the outage of transmission lines, distribution lines and main equipment with the estimation of under loading and over loading. Hence, the methods adopted for solving load-flow of distribution system are different from transmission system due to some factors such as network topology and resistance to reactance ratio.

The technologies of DGs are developed from the distribution systems where conventional as well as non-conventional energy sources are used for generating power. Hence DGs are getting popular momentum for an alternative option in the planning of distribution systems. There is an exemplar transformation in the field of the design and planning of distribution networks due to deregulation policies and expeditious dispersal of DG's. The procedures adopted for optimum siting and sizing of DG are having either deterministic or heuristic attributes. In deterministic approach, analytical expressions are used whereas while solving with the aid of heuristic methodology, optimization techniques are applied.

The distribution networks execute perceptible evolution due to wide range of load levels in routine as compared to the transmission networks. Hence, voltage stability phenomenon gets more appreciation in case of the distribution networks because the voltage levels at receiving-end fluctuate phenomenally. Voltage stability is elucidated as competence of a power network to cultivate substantial voltage at all nodes of the network after having undergone an interruption from an accustomed commencing executing mark.

Substation planning involves site selection, substation size and service area determination and equipment installation timing. Distribution substation planning is considered as one of the most important steps in power system planning process because it represents the main link between the transmission and distribution systems. The location of substation site depends upon voltage levels, voltage regulation, substation costs, primary feeders, distribution transformers etc. Substations usually set limits on the overall economy of distribution system planning although their cost represents a relatively small part of total cost of distribution system. The optimal location of substation to meet electrical power demands in an urban area can have a very strong effect on current and future operating costs.

Numerous confrontations are being endured by the power system planners in the planning of cost effective and stable distribution networks, executing functions proficiently and intensifying the reliability as well as availability of power supply.

The efficient optimal stable planning of the distribution systems needs the following:

- (i) Efficient load–flow
- (ii) DG placement
- (iii) Voltage Stability Index (VSI)
- (iv) Optimal location of substation using VSI

1.3 SCOPE OF THE RESEARCH

After the meticulous literature studies, the subsequent areas are pronounced as scope of further research.

- A comprehensive investigation of the consequences of the methodologies used to solve the load-flow in the reported studies, stipulated gaps such as manual coding to ascertain nodes of the feeder, lateral(s) and sublateral (s), longer execution time, high ohmic losses, and so on. These gaps are expected to be confronted for further enhancement of load-flow of RDN. In the proposed work, a novel search algorithm is proposed, which finds out the nodes in the feeder, lateral(s), and sublateral (s) from the accessible line data.
- An exhaustive research is going on in the field of DG placement. The optimum selection of distributed generation not only reduces the size of DGs but also

improves the voltage profile. In suggested work, a structure has been suggested for placement of multi DGs and their sizing based on multi-objective criteria with innovative objective function so that system's performance can be increased.

- The voltage stability indices derived in proclaimed literature are on the basis of equivalent networks and in a few cases, the magnitude of voltage of sending–end node and receiving–end node had been assumed to be equal. The proposed VSI has been derived without reduction of the network and without neglecting the voltage angle.
- The planning of distribution systems had been proposed without considering the stability criteria. In this work, while planning the distribution substation, voltage stability index will be used as an objective function. The optimal location of the substation reduces the feeder length and hence, the cost. Sometimes, the optimal location may not be used due to some unavoidable reasons. In that case, the location provided by the society is to be used.

1.4 OBJECTIVES OF THE RESEARCH:

To achieve efficient optimal stable planning of the distribution networks, the objectives of the research are presented below:

- To develop a search technique to solve load-flow of electric power radial distribution networks.
- To develop a method for optimal placement of DG sets in electric power radial distribution networks.
- To develop a new voltage stability index for electric power radial distribution networks.
- To develop a method for optimal substation planning.

1.5 ORGANIZATION OF THE RESEARCH

Chapter 1 includes the basic introduction of power system, distribution network, load-flow and stable planning of distribution networks, objectives of the research, scope of the research and organization of the research.

Chapter 2 provides the literature survey on load-flow, DG placement, voltage stability and planning of radial distribution networks.

Chapter 3 introduces a novel search technique to solve load-flow of radial distribution networks. The method is tested on seven radial distribution networks including one practical distribution network. The outcomes obtained by the suggested method are correlated with the other methods reported in the literature in order to check the supremacy of the suggested method. The suggested method takes lesser CPU times as well as iteration number and has converged for different load modelling.

Chapter 4 acquaints the hybrid optimization technique for multi DG placement in order to diminish power loss and to escalate the voltage profile of radial distribution networks. The suggested method provides better performance in all aspects than those obtained by using GA-PSO, PSO and GA in terms of minimum voltage, power loss, percentage loss reduction, DG cost and energy cost. The recommended technique has been correlated with other recommended techniques reported in literature to highlight its effectiveness.

Chapter 5 presents the formulation and computation of VSI for radial distribution networks without reducing the network and taking into account the voltage angle. VSI helps to identify the most critical node of the network, which is indispensable from the stability point of view. The results obtained by the proposed method have been compared with the other reported methods.

Chapter 6 proposes optimal distribution substation placement for radial distribution networks. The optimal location of substation has been obtained by using optimization technique using an objective function containing the proposed VSI. The load points are connected to the substation in optimum routes for single feeder, double feeder and triple feeder cases. The outcomes of the proposed planning for these three cases have been compared with the outcomes available in reported literature.

Chapter 7 highlights the main conclusions and future scope of the research.

References include the list of previous published research papers, reports, and books etc., which are reviewed for literature survey and also for completion of submitted work.

Appendix-A presents the system data of 13-node radial distribution network.

Appendix-B presents the system data of 24-node radial distribution network.

Appendix-C presents the system data of 28-node radial distribution network.

Appendix-D presents the system data of 33-node radial distribution network.

Appendix-E presents the system data of 34-node radial distribution network.

Appendix-F presents the system data of 69-node radial distribution network.

Appendix-G presents the system data of 85-node radial distribution network.

Appendix-H presents the system data of 30-node radial distribution network.

Appendix-I presents the system data of 141-node radial distribution network.

Appendix-J presents the co-ordinates and data of 53 load points.

CHAPTER 2

LITERATURE SURVEY

To accomplish the objectives of proposed work, extensive literature survey has been carried out in the following areas:

- (i) Load-flow of electric power radial distribution networks
- (ii) Optimal DG placement for loss reduction
- (iii) Voltage stability index for electric power radial distribution networks
- (iv) Optimal substation placement

2.1 LITERATURE SURVEY ON LOAD-FLOW OF RADIAL DISTRIBUTION NETWORKS

Ghosh and Das (1999) presented a straightforward and adequate method for solving load-flow of electric power distribution networks having radial configuration. Their method involved only the evaluation of a simple algebraic expression of receiving-end voltages. The method had fast convergence characteristics as compared to other existing methods.

Miu and Chiang (2000) numerically examined the steady state characteristics of power distribution system in working mode for unbalanced loading and for different transformer connections as well as for different phases. It was stated that for three phase distribution networks having radial topology with non-linear loads, if the load-flow solution prevailed, it would be uncommon.

Teng and Chang (2002) proposed a novel load-flow algorithm for unbalanced radial distribution systems. The proposed method used branch voltages as state variables and employed Newton-Raphson algorithm to solve the load-flow problem. The time consuming procedures, such as LU factorization of the Jacobian matrix did not exist in the load-flow problem.

Li *et al.* (2004) presented a technique for the reliability of complex radial distribution systems considering restoration sequence and network constraints. A distribution network was

represented using a tree data structure to dynamically respond the change of network topology induced by system reconfiguration. An improved branch-oriented load-flow method was embedded in the reliability evaluation technique to examine network constraints after network reconfiguration.

Ranjan *et al.* (2004) proposed a load-flow technique based on simple algebraic equations and had claimed that power convergence gave a satisfactory convergence for composite load modelling.

Jabr (2006) discussed that the load-flow for radial distribution networks could be formulated as a conic quadratic optimization problem. That could be solved efficiently by using interior point methods. Even ill-conditioned distribution networks were solved through the developed technique. It was extended to unbalanced three phase networks. The implications were three fold-solutions using interior point algorithm for ill-conditioned networks and conic formulation in radial system optimization.

Chang *et al.* (2007) presented an improved Backward (BW)/Forward (FW) sweep algorithm for load-flow analysis of three phase radial distribution systems. In BW sweep, KCL and KVL were used to compute voltage at each upstream bus. In FW sweep, linear proportional principle was employed to update the voltage at each bus. The procedure stopped after the mismatch of the computed and specified voltage at the substation was less than convergence tolerance.

Satyanarayana *et al.* (2007) introduced a novel method of load-flow for ill-conditioned systems with fast convergence characteristics and was applicable to load growth also. The proposed method was based on simple algebraic recursive equations of receiving-end voltage of radial distribution system. Simulation results demonstrated faster convergence characteristics as compared to those in other existing methods.

Smith *et al.* (2007) developed a new load-flow for three phase distribution networks, which employed mismatch constraints in both phase and sequence components. Power mismatches existed in phase components at PQ bus bars while at generator bus bars, all mismatches were in sequence components. The overall solution was for phase components system nodal voltages because most bus bars are PQ.

Ghosh and Sherpa (2008) suggested a new method based on simple equations for the load-flow solution of radial distribution networks with minimum data preparation. According to the authors, the sequential node and branch numbering were not required, as they were sequential in the case of other feasible techniques.

Dharmasa *et al.* (2008) formulated an algorithm in which input data were sorted to compute power injections, losses, currents flowing through the branch, and complex voltages. The developed technique was based on network graphical information in order to cater the needs of distribution automation.

Ghosh (2009) suggested an amended variant of the minimum data preparation technique to resolve load-flow of radial distribution network that needed lesser data arrangement. The author used the feeder, lateral(s), and sublateral(s) set of nodes for the developed algorithm.

Chen *et al.* (2010) suggested a load-flow method for three-phase distribution networks involving loop frame reference for unbalanced distribution systems instead of bus frame, which was earlier used by researchers frequently. A straight forward iterative approach was adopted by implementing impedance form along with graph theory and injection current approach.

Dilek *et al.* (2010) proposed a power flow algorithm applying Kirchhoff's equations for heavily loaded distribution systems of mesh type as well as loop type with radial subsystems. To interpret the load-flow, load stepping procedure was employed to deal with the hindrances faced by sweep techniques.

Abul'Wafa (2011) instigated an innovative mechanism based on heuristic search for most favourable reconfiguration of electric power radial distribution networks. That process resulted in minimal losses due to reduced switching combinations. Depth first search technique of graph theory had been used for path traversal of networks to solve the load-flow.

Hamouda *et al.* (2011) introduced a refined iterative method based on electric circuit laws to solve the power flow problems of balanced radial distribution networks with laterals. The method developed was simple based on Kirchhoff's laws and took less computational time to

execute as well as less number of iterations to converge while operating under divergent loading conditions

Singh and Ghosh (2011) pitched an effective and simple methodology based on the forward sweep method to solve the load-flow of radial distribution networks without any continuous node numbering. The consequences of charging capacitance were considered while deriving the equations for load-flow. Elementary equations were used to evaluate the parameters of radial distribution network.

Abul' Wafa (2012) extended a technique to solve the load-flow of radial distribution network based on network topology (Abul' Wafa (2011)) to fulfil the requirement of distribution automation. Depth first search technique of graph theory was employed to scrutinize the nodes beyond a particular branch.

Janecek *et al.* (2012) developed analytical probabilistic load-flow method that included the multi vibrato normal distribution in lieu of traditional numerical methods based on approximation. For execution, the authors used the backward/forward algorithm. The developed technique had shown momentous enhancement even in the presence of uncertainties and critical operating conditions.

Ruiz- Rodriguez *et al.* (2012) applied a novel analytical technique and compared it with Monte Carlo method to solve a probabilistic load-flow for radial distribution networks with photovoltaic generation. The results demonstrated that solutions were reached in lesser iterations with proposed technique.

Vicente *et al.* (2012) formulated and solved a novel analytical technique to solve a probabilistic load-flow for radial distribution networks using arithmetic laws and also methodologies were developed to determine the effects of DG (using renewable sources) in distribution network.

Singh and Ghose (2013) developed an efficient method for load-flow solutions of radial distribution networks exploiting features of network topology. The authors used matrix transformation technique, which made forward backward sweep based load-flow method more simple and effective.

Yuntao *et al.* (2014) proposed a method for handling PV nodes based on loop analysis incorporated in the FBS framework. Numerical simulations of the proposed method were carried out to check the performance.

Eltantawy *et al.* (2014) presented a novel algorithm for computing distribution load-flow for smart grids. The recommended approach utilized lumping technique, which compensated the system laterals by equivalent loads. The simulation results verified the authenticity of the developed method.

Nguyen *et al.* (2015) used multi-agent communication system to develop a technique to solve power flow of unbalanced radial distribution systems. The dispersed intelligent agents utilized backward/forward sweep approach to iteratively elucidate the load-flow of distribution networks.

Nikmehr *et al.* (2015) discussed that traditional power flow methods might not be useful for active distribution networks. The authors modelled the loads by the heuristic method taking into account the fragmentary performance of renewable energy resources.

Bolognani *et al.* (2016) suggested an unambiguous estimated explanation of the non-linear load-flow equations and grid topology of power distribution networks operating in balanced state and implemented eminence of the assessment through simulations.

Wang *et al.* (2017) propounded categorical appropriate computational environments to solve load-flow of distribution systems having positive sequence correspondents that resulted in the surety of actuality and distinctiveness of the developed technique.

Jabr *et al.* (2018) discussed that forward-backward sweep current injection methods could be used for solving load-flow of radial and meshed distribution networks respectively and also could be used for solving load-flow of micro-grid operating in grid connected mode. The developed method was a type of compensation approach applied to complex power.

2.2 LITERATURE SURVEY ON OPTIMAL DG PLACEMENT FOR LOSS REDUCTION

Chowdhury *et al.* (2003) presented a reliability model for determining the DG equivalence to a distribution facility for use in distribution system planning in the new competitive environment. The size, location and reliability of DG would be based on the comparable incremental reliability provided by the distribution system under consideration.

Hegazy *et al.* (2003) presented a Monte–Carlo based method for the adequacy assessment of distributed generation systems. The duty cycle of each DG represented the main source of the random operation of this DG. State duration sampling was implemented to assess the ability of system power capacity to meet the total demand.

EI–Khattam *et al.* (2006) proposed a novel algorithm to evaluate the performance of electric distribution networks including DG. The algorithm employed the Newton–Raphson method as a powerful power flow solution in conjunction with Monte–Carlo simulation technique to cover all possible operating conditions of the systems. The algorithm provided the hourly systems centralized power generation, the total DG penetration level, the reduction in centralized power generation, the system power loss saving, feeders flow and bus voltages.

Bae *et al.* (2007) presented an analytical technique using the load curve for evaluating the reliability of distribution systems, including DG. Impact factors and parameters were expressed as a function of time, so that precise evaluation of reliability was possible for distribution systems. Proposed model included the characteristics of DG such as peaking and stand by modes and their mixed operation mode.

Fletcher *et al.* (2007) described horizon distribution planning problem and optimal distribution system model formulation. The horizon planning model approach would enable determination of a complete set of optimal and minimal cost future designs.

Keane *et al.* (2007) presented a methodology, which maximized the amount of energy that might be reaped from a given area, while taking account of available energy sources, connection costs, losses, frequency of constraint breaches and other technical constraints. It had also been shown that there should be clear objective at the outset of DG planning process, as the results vary widely between different approaches.

Haffer *et al.* (2008) presented a model for use in the problem of multistage planning of energy distribution systems including distributed generation, which made it possible to consider the most common alteration to a distribution network such as (i) change in cross–section of already existing conductors, (ii) insertion of new branches with different cross–sections, (iii) installations of new substations, (iv) increasing the capacity of existing substations, (v) use of available capacity of DG and (vi) long–term planning horizon.

Haffer *et al.* (2008a) presented computer simulation of the multistage model for distribution expansion planning with DG as described in Part 1. The influence of additional constraints was analyzed in terms of the computational effort required to find the optimum solution of the problem.

Kumar *et al.* (2010) figured out the root cause of hindrances faced during cold load pick up condition that was deprivation from load diversity mainly. The authors recommended a method to preserve the diversity by implementing DG for swift re-establishment and saving of supplementary power demand resulted from the cold load pick up condition.

EI-Zonkoly (2011) developed a technique dealing with diversified intentions to evaluate the most favourable siting as well as sizing of multi DG units installed in a distribution network. The work was implemented with the particle swarm intelligence optimization technique and discussed the effects of different types of load modelling (power factor other than unity) for optimal selection of DG.

Li *et al.* (2013) used the game theory to optimize the multi-objective function to get the exact location and sizing of DG. They discussed the advantages of game theory for optimization i.e., “game optimization theory”. They tested the proposed method on an 8-bus network.

Hung and Mithulananthan (2013) proposed a method for multiple DG placement using an improved analytical method for loss reduction in distributed systems. They used the loss of the system as an objective function. They compared the optimal size of four different types of DG. They showed the effectiveness of improved analytical method compared to loss sensitivity factor (LSF) and effective load-flow methods using 16-node, 33-node and 69-node radial distribution networks.

Murthy and Kumar (2013) discussed that there is increasing interest in the field of renewable sources of energy. Hence integration of distributed resources had been rapidly increasing. When a DG is being installed at a customer sites, it increases utility. Authors explored and compared various methods exercised for optimal siting and sizing of DG in distribution networks.

Ameli *et al.* (2014) presented a multi-objective particle swarm optimization (PSO) algorithm to optimize sizing, and siting of DGs, as well as the contract price of their generated power.

The proposed method improved the voltage profile and stability, reduced power losses, and enhanced the supply reliability. They had used a 33-node radial distribution network.

Devi and Geethanjali (2014) used a modified bacterial foraging optimization algorithm (BFOA) for loss reduction as well as improvement of the voltage profile integrating multiple DGs in 12-node, 34-node, and 69-node radial distribution networks.

Jenkins *et al.* (2014) provided experienced outcomes related to academics as well as industry in the field of power generation. The content contained material, which would strengthen the knowledge of core electrical engineers and also, created an interest among non-core electrical engineers interested in the field of power generation.

Kaur *et al.* (2014) presented a mixed integer non-linear programming based technique to place multiple DG units (a maximum of three) in radial distribution networks using two examples. They compared their method with an improved analytical and PSO-based methods to prove its superiority.

Cataliotti *et al.* (2015) devised a contemporary arrangement for remote supervision and regulation of DG's and energy storage systems associated with low voltage distribution networks by virtue of interface protection systems. The assembly was tested in an island to point out its outstanding communication strategies as well as restraints.

Kabalci (2015) evolved a system with a view to perceive how the distribution system affected the parameters averse to drops, failures and utilization instantaneously. The recommended programming logic controller framework eradicated concerns such as unreliability, intervention, shading as well as fading of wireless systems.

Kansal *et al.* (2016) proposed a hybrid approach, which was a combination of an analytical method used for evaluating the size and a heuristic approach, to place optimally multiple DGs. They used 33-node and 69-node radial distribution networks and the performances obtained by the proposed method were also compared with the PSO and the method proposed by Hung *et al.* (2013). In scheduled method, loss reduction obtained by PSO was better than that obtained by their proposed hybrid method for one DG, two DGs and three DGs in both examples for Type-I DG. Their proposed hybrid method failed to give better loss reduction for one DG, two DG and three DG than that of Hung *et al.* (2013) for a 69-node radial distribution networks.

Adefarati and Kansal (2016) discussed the contemporary issues related in the field of distribution generation in distribution systems. Policies related to power system planning, energy regulation and energy management are gaining more benefits with the integration of DG into distribution networks. The authors extensively reviewed previous research publications related to DG integration in distribution systems considering technical, economic and environmental constraints.

Prodhan *et al.* (2016) suggested a hybrid power generation system for a hilly area based on fundamental and supplementary requisite intake statistics. The proposed technique was devised to design most favorable arrangement based on hourly basis for energy suitability and loads.

Vita (2017) described an established and an accurate arrangement based on decision making algorithms for better placement as well as sizing of DG and used an extended Newton-Raphson load-flow method. The proposed method was tested on a 33-node radial distribution network with a single DG system.

2.3 LITERATURE SURVEY ON VOLTAGE STABILITY INDEX OF ELECTRIC POWER RADIAL DISTRIBUTION NETWORKS

Vaahedi *et al.* (1999) derived two new techniques for voltage stability contingency screening and ranking; Reactive Support Index (RSI) and Iterative Filtering Method (IFM). The RSI method used the system normal nose points and ranked contingencies based on extra reactive injections required at dynamic reactive devices to get a load-flow solution. To ensure that no critical contingencies were misclassified, the Iterative Filtering Method was devised. Analytical algorithm was used to screen the contingencies down to the critical number required.

Kashem *et al.* (2000) presented an algorithm for enhancement of voltage stability index by network reconfiguration. They performed the network reconfiguration by altering the topological structure of distribution feeders by which voltage stability index could be maximized for a particular set of loads in distribution system.

Chakravorty and Das (2001) recommended a voltage stability index to recognize the node of the distribution network prone to voltage collapse. They handled the composite load using

power convergence and used the load-flow technique proposed by Das *et al.* (1995). They had shown that the critical burdening was maximum for a load type of constant current load, while it was minimum for constant power load.

Chen *et al.* (2003) presented a survey of most available approaches and made a comparison between them. They pointed out the possible consequences of not considering load dynamics, which at worst could be a complete voltage collapse. Based on this observation, modelling of load dynamics was considered and neural networks including recurrent neural networks were applied for load modelling.

Haque (2003) proposed a simple equivalent model of the power system to generate the voltage stability boundary involving very little computations without any repetitive load-flow simulations. Thus, various voltage stability margins of the critical bus or area in a large power system could be directly determined from the generated stability boundary for different initial operating conditions with a high potential for on-line application.

Ranjan and Das (2003) introduced unfamiliar voltage stability index to identify the most sensitive node i.e., node, which was on the edge of collapse. In developed index, the altered load-flow technique fused load modelling of different types and diversified load arrangement.

Ranjan *et al.* (2004a) suggested a novel VSI to determine the most susceptible bus of radial distribution networks. They used the load-flow proposed by Das *et al.* (1995) for satisfactory convergence of load modelling having composite nature and investigated the voltage convergence in load-flow. They assumed the equality of magnitude of voltage for sending-end node and receiving-end node of each branch while deriving the voltage stability index. They had also assumed that the load at any node was the sum of the loads of all nodes following it. They had shown that the critical burdening was maximum for constant impedance type of load while it was minimum for constant power load. They were silent about critical loading for composite load modelling.

Smon *et al.* (2006) simplified the determination of the Thevenin's parameters and enabled derivation of the new local voltage stability index using Tellegen's theorem and adjoint

networks, which required the voltage and current phasors measurements only, to compute the system's voltage stability at a bus.

Yu *et al.* (2008) suggested a new line loadability index based on the non-negative property of the discriminant of a voltage double–quadratic equation. The most sensitive node obtained by them was neither the end node nor the node having minimum voltage of 69–node radial distribution network.

Eminoglu and Hocaoglu (2009) developed the VSI that was based on the transferred active and reactive power equations of the distribution line. Network topology algorithm based on the bus-injection to branch-current (BIBC) matrix was used for implementation of the developed stability index of the radial distribution networks.

Eidiani (2011) presented a method for estimation of static voltage stability of power systems. The expanded 'Newton–Raphson–Seydel' (NRS) and 'Down-Hill' (DH) mathematical models were employed. Standard CPF and expanded NRS methods were compared with the developed method.

Goswami *et al.* (2011) reviewed that FACTS was developed for transmission networks primitively but extended to distribution networks later. It was recommended to incorporate FACTS devices in distribution networks in order to enhance voltage stability of networks.

Wang *et al.* (2011) acknowledged that due to diversity among loads in power system, Thevenin equivalent circuit poses problems for analysis of impedance matching. They presented technique of decoupling of networks so that the modified adaptations of impedance match theorem could be utilized practically for valuation of voltage stability boundary and determination of sluggish nodes.

Hazarika (2012) suggested a technique to auditor the status of voltage stability utilizing the assessment of active power, reactive power and voltage of specified bus for two successive time frames.

Mahmoud (2012) proposed a catastrophe theory to compute VSI to recognize the bus prone to voltage collapse in radial distribution networks and the voltage stability boundary of a distribution system.

Mousavi *et al.* (2013) recommended precautionary remedial measures to enhance the voltage stability limits through administering the reactive power as well as its backup in order to

magnify the effective generator reactive power reserve. Multi-stage optimization techniques were applied to exemplify the strength of the recommended approach.

Pérez-Londoño *et al.* (2014) introduced a novel assessment based simplified voltage stability to assess voltage stability limits for power systems. The affiliation of variables used for computation of electric networks for deriving VSI refined performance as well as reduced computational time.

Yu *et al.* (2014) introduced a novel method to analyze and detect the long term voltage instability related to transmission and distribution network with the help of branch equivalent. Even after the equivalence, the main parameters remained persistent and self-reliant from type of load also. The method identified the weak nodes where remedial measures could be applied in order to enhance the voltage stability.

Murty and Kumar (2105) proposed a distinct voltage stability index for most favorable DG placement and conferred the analogy of different techniques evaluating power stability, proposed VSI and power loss sensitivity indices used for siting and sizing of DG in radial distribution networks

Modarresi *et al.* (2016) investigated the voltage stability indices evaluated from distinct conditions based on ideas, presumptions, captious values and mathematical equations. The paper reported an exhaustive literature survey in the field of voltage stability that would help the researchers for future work.

2.4 LITERATURE SURVEY ON PLANNING OF ELECTRIC POWER RADIAL DISTRIBUTION NETWORKS

Boulaxi *et al.* (2002) proposed a new algorithm for optimal feeder routing problem of a medium voltage radial network including all practical issues such as cost parameters, technical constraints as well as physical routing constraints. Dispersed generation had also been taken into account. The developed algorithm had been effectively applied in realistic problems.

Ranjan *et al.* (2002) evolved a theorized mechanism for distribution system planning. The other suggested technique did not necessitate the preceding expertise of siting of aspirant substation. The suggested method based on heuristic rules claimed that it supported

computerized options from the main parameters utilized for planning of distribution systems gratifying restraints utilizing modified load-flow method incorporating load growth.

Khodr *et al.* (2003) presented probabilistic methodology to compute the perimeter of area, where the load centre had maximum likelihood to be found, taking into account the hourly load changes in load cycle in the planning process. Within the calculated perimeter, the final decision of location of substation was made.

Lin *et al.* (2003) proposed two interruption cost models including an average or aggregated model(AAM), and a probabilistic distribution model (PDM) by using radial basis function (RBF) neural network with orthogonal least squares learning method. AAM and PDM based on the RBF network could integrate different customer sectors data in the network, so that cost models could be used conveniently for reliability worth analysis. A Monte–Carlo time sequential simulation technique had been used.

Gomez *et al.* (2004) proposed an ant colony system (ACS) algorithm for the planning of electric distribution systems. ACS algorithm, an improved version of the ant system (AS) algorithm, which reproduced the technique used by ants to construct their food recollection routes from their nest, and where a set of artificial ants cooperated to find the best solution through the interchange of the information contained. The ACS methodology was coupled with a conventional distribution system load–flow algorithm and adapted to solve the primary distribution system planning problem.

Gupta *et al.* (2004) discussed the cold load pick up (CLPU) condition i.e., restoration of thermostatically controlled devices in distribution systems, after prolonged interruption might create a load significantly higher than the normal load. An approach was presented for distribution sub-station transformer and feeder system planning to ensure proper voltages, minimum customer interruption durations and acceptable transformer and feeder overload during CLPU conditions.

EI–Khattam *et al.* (2005) suggested a paradigm incorporating universal optimization and planner’s understanding to resolve siting and sizing of DG, which was enticing preference for the researchers at that time and still it worked. The proposed work was performed to minimize the total system cost, DG investment as well as operation and maintenance costs,

cost of purchasing power from DISCO from the main grid and the payments towards compensating for DISCO's power loss. DG added the opportunity to use existing DISCO's network for further load growth without the need for feeder up gradation.

Sepasian *et al.* (2006) proposed substation expansion planning (SEP) in which mathematically clustering technique was used to find a list of feasible candidates by observing the limitations on substation capacities, feeder capacities and voltage regulation. The GA was used to solve optimization problem.

Fletcher *et al.* (2007) described horizon distribution planning problem and optimal distribution system model formulation. The horizon planning model approach would enable determination of a complete set of optimal minimal cost future designs. The horizon planning model approach could lead to a more efficient utilization of distribution systems in the long term. In fact, the proposed model and optimization formulation provided a generalized horizon planning approach and introduced a fully functioning comprehensive horizon planning model using a perspective that encompassed all necessary parameters and constraints.

EI-Fouly *et al.* (2008) presented a planning optimization model for distribution substation siting, sizing and timing, which involved using linear functions to express the total cost functions and included different electrical constraints. The proposed problem was formulated as MILP problem to avoid non-linear programming.

Nahman *et al.* (2008) presented a method for optimal planning of radial distribution networks, which was based on combination of steepest descent and the simulated annealing approaches. The minimum capital cost oriented solution created by applying the steepest descent approach was used as initial solution for the optimization procedure that was further improved by simulated annealing to obtain the minimum total cost solution.

Navarroand *et al.* (2009) proposed the planning of large scale distribution systems by showing the simultaneous network selection and transformer optimization. But they did not consider the aspect of stability.

Najafi *et al.* (2009) presented the planning approach of substantial distribution network using network theory by pioneering loss characteristic matrix and the modified genetic algorithm handled working as well as optimization constraints successfully.

Martins and Borges (2011) recommended a model where traditional options used for expansion of distribution networks had an alliance with DG integration, which was considered to be a prime consideration for active distribution networks. A secure and cost effective system was designed by taking into account the uncertainties and load growth.

Naderi *et al.* (2012) conferred that updated technology and deregulated environment of the power system industry had led to innovations in distribution system planning (DSP). In their model, an optimal power flow (OPF) was proposed to reduce the initial costs involving up-gradation of network and operating costs as well as the cost associated with the losses for administering increase in the load demand for the planning perspective acknowledging the topology of the network.

Ganguly *et al.* (2013) deliberated and compared a dynamic programming based distinct optimization mechanism for multi-objective planning of distribution networks with existing methods to check the authenticity of the proposed algorithm. Optimization of cost and reliability using Pareto solutions were carried out simultaneously using optimal feeder routes and size of branch conductors as major parameters.

Zidan *et al.* (2013) suggested a continuing planning approach to magnify the perks of network reconfiguring as well as appropriation of DG in distribution systems. The developed technique managed enduring load elevation on annual basis. The investigation was carried out to characterize the corroboration with acceptable constraints while maintaining the quality ethics.

Popović *et al.* (2014) suggested a combinatorial approach for planning of active distribution networks. For reduction of overall development cost, mixed integer programming based model was developed. Further to govern the disintegration and key factor, simulated annealing mechanism was recommended. Solutions having immense standards for different radial distribution networks incorporating DG could be produced by recommended technique and also discussed significant consequences of collapsing DG while choosing optimal development strategy.

Georgilakis and Hatzargyriou (2015) discussed that how the mode of operation of distribution grids had changed the nature of grids from passive to active networks. The various methods utilized for planning of distribution networks had been scrutinized and segregated, which would help the present and future researchers in the field of power distribution planning.

Xing *et al.* (2016) presented a bulging planning model for enlargement of progressive distribution networks harmonizing ‘dispersed energy storage systems’ along with four prime executive strategies. With the aid of dist-flow mathematical statements and coercion mitigation, convoluted expansion problem was solved by changing the order of programming approach i.e., mixed integer non-linear model to second order cone programming.

Hasanvand *et al.* (2017) suggested a peculiar and exhaustive mechanism to resolve the complications suffered during the planning of distribution systems. Issues related to siting and sizing of DG as well as technologies related to DG, from the point of view of reliability assessment, were also deliberated using multi-objective adaptive fuzzy model.

Silva *et al.* (2018) suggested a technique based on artificial immunological systems for optimal placement of distribution substation. Substantial, scientific and working constraints were considered while evaluating the overall planning costs.

CHAPTER 3

LOAD-FLOW OF RADIAL DISTRIBUTION NETWORKS

3.1 INTRODUCTION

Load-flow is an inevitable mechanism to carry out the proper investigation of voltage, loading and losses in transmission and distribution networks. The load-flow approach imparts elemental reckoning mechanism to ascertain the attributes of power system under stable working conditions. Load-flow study is an integral part of planning as well as expansion of power system networks as it is required in the inception stages of various operations of networks. Hinged on an enumerated generating mode and network topology, load-flow analysis interprets the balanced state working with node voltage and branch power flow of system network. The load-flow has the most significant role in computing the node voltage of each node along with the losses of the distribution systems because voltages are required to be maintained within the specified limits for efficient operation of the system. Its improvement in the distribution system is an ongoing process. Distribution planners are always in the search of more effective, accurate load-flow solutions so that the planning of the distribution systems can be made efficiently. The distribution networks have a high range of resistance to reactance as compared to transmission networks. The long established methods used for load-flow analysis of transmission networks are rarely used for the analysis of distribution networks due to their distinct network topologies. The previously published methods of load-flow for transmission systems are amended for distribution systems. Moreover, these methods hardly converge when applied to distribution networks. The transformed version of these methods is used as full-fledged methodology in radial distribution networks (RDN).

3.2 PROBLEM FORMULATION

The load-flow revelation should be decisive, proficient, and consistent and should entail restricted memory space of the computer. Ultra-modern power systems necessitates the

evolution of sophisticated load-flow methods composed for distribution systems. The objective of the proposed work is to evolve a novel technique to solve load-flow solution of radial networks. The suggested method does not need any manual coding of the node from which the lateral and sublateral are emanating. An equation for evaluating the voltage of receiving-end node is procured along-with the computation of voltage angle.

3.2.1 Assumptions for Load-Flow

The load-flow problem is formulated assuming the distribution network to be linear, balanced and having lumped parameters. As the system is operating in balanced condition, the single line diagram is considered as substitute of network. A simplified diagram of a radial distribution network (RDN) is shown in Figure 3.1.

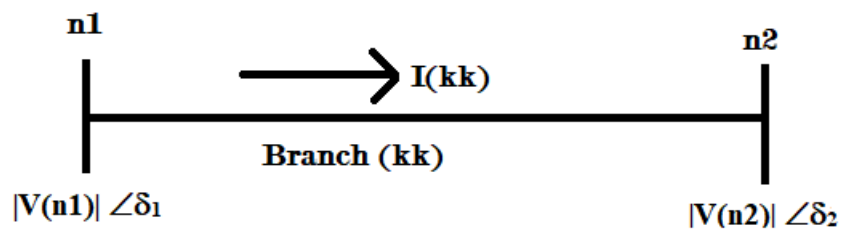


Figure 3.1: Mathematical Model of Radial Distribution Network

3.2.2 Backward and Forward Sweep for Load-flow

Backward and forward sweep method is an iterative technique having two computational stages. The paramount Kirchoff's current and voltage laws are practiced while interpreting load-flow explanation of a network having single source. The source voltage is set at fixed value, i.e., 1 p.u. Node currents are appraised using backward sweep i.e., starting from end node of the network and voltages are overhauled using forward sweep i.e., starting from first node (substation). In other words, nodal voltages are updated in forward propagation and nodal currents are updated in backward progression. The effective power in each branch during the forward sweep is apprehended as constant to the assessment obtained during backward sweep. The voltage values attained in the forward pathway are apprehended as persistent during the backward propagation. The rationalized power flows in each branch are conveyed backward along the feeder using backward sweep.

In view of this, backward and forward sweep method is favourable option among other methods solely designed for radial distribution systems due to enumeration adequacy and creditability of results.

3.2.3 Analytical Expression for Receiving-end Voltage

From Figure 3.1, the current and power can be computed using Equation (3.1) and Equation (3.2).

$$|I(kk)| = \frac{|V(n1)| \angle \delta(n1) - |V(n2)| \angle \delta(n2)}{Z(kk)} \quad (3.1)$$

$$P(n2) - jQ(n2) = V^*(n2) \times I(kk) \quad (3.2)$$

Where $Z(kk) = R(kk) + jX(kk)$ is the impedance of branch 'kk', $R(kk)$ and $X(kk)$ are resistance and reactance of branch kk, respectively. 'n1' and 'n2' are the corresponding source and sink nodes of branch kk.

'P (n2)' is the summation of active power loads of all the nodes beyond branch 'kk' plus the summation of the active power losses of all the branches beyond node 'n2'.

'Q (n2)' is the summation of reactive power loads of all the nodes beyond branch 'kk' plus the summation of the reactive power losses of all the branches beyond node 'n2'.

'I (kk)' is the current passing through the branch 'kk'.

'|V (i)|' is the voltage magnitude of the i th node,

' $\delta(n1)$ ' is the voltage angle of node 'n1',

' $\delta(n2)$ ' is the voltage angle of node 'n2',

From Equation (3.1),

$$\begin{aligned} |V(n1)| \angle \delta(n1) &= |V(n2)| \angle \delta(n2) + |I(kk)| |Z(kk)| \\ &= |V(n2)| \angle \delta(n2) + |I(kk)| \angle \theta |Z(kk)| \angle \phi \\ &= |V(n2)| \angle \delta(n2) + |I(kk)| |Z(kk)| \angle (\theta + \phi) \end{aligned}$$

Where $\theta = \tan^{-1} \frac{I_m(kk)}{I_r(kk)}$, $\phi = \tan^{-1} \frac{X(kk)}{R(kk)}$, $I(kk) = I_r(kk) + j I_m(kk) = |I(kk)| \angle \theta$,

$Z(kk) = R(kk) + jX(kk) = |Z(kk)|\angle\phi$ and $I_r(kk)$ and $I_m(kk)$ are the real and imaginary parts of $I(kk)$.

$$|V(n2)|\angle\delta(n2) = |V(n1)|\angle\delta(n1) - |I(kk)||Z(kk)|\angle(\theta + \phi)$$

$$\begin{aligned} |V(n2)|\cos\delta(n2) + j|V(n2)|\sin\delta(n2) &= |V(n1)|\cos\delta(n1) + j|V(n1)|\sin\delta(n1) \\ &\quad - |I(kk)||Z(kk)|\cos(\theta + \phi) - j|I(kk)||Z(kk)|\sin(\theta + \phi) \end{aligned}$$

$$|V(n2)|\cos\delta(n2) = |V(n1)|\cos\delta(n1) - |I(kk)||Z(kk)|\cos(\theta + \phi) \quad (3.3)$$

$$|V(n2)|\sin\delta(n2) = |V(n1)|\sin\delta(n1) - |I(kk)||Z(kk)|\sin(\theta + \phi) \quad (3.4)$$

From Equations (3.3) and Equation (3.4),

$$|V(n2)|^2 = |V(n1)|^2 - 2|V(n1)||I(kk)||Z(kk)|\cos\{\delta(n1) - \theta - \phi\} + |I(kk)|^2|Z(kk)|^2$$

$$|V(n2)| = \sqrt{\left\{ |V(n1)|^2 - 2|V(n1)||I(kk)||Z(kk)|\cos\{\delta(n1) - \theta - \phi\} + |I(kk)|^2|Z(kk)|^2 \right\}} \quad (3.5)$$

$$\delta(n2) = \tan^{-1} \left\{ \frac{|V(n1)|\sin\delta(n1) - |I(kk)||Z(kk)|\sin(\theta + \phi)}{|V(n1)|\cos\delta(n1) - |I(kk)||Z(kk)|\cos(\theta + \phi)} \right\} \quad (3.6)$$

The magnitude of voltage can be computed from Equation (3.5) and the angle of voltage can be computed from Equation (3.6).

The active and reactive power losses of the branch kk are expressed by Equation (3.7) and Equation (3.8), respectively.

$$PL(kk) = \frac{R(kk) \times [P^2(n2) + Q^2(n2)]}{|V(n2)|^2} \quad (3.7)$$

$$PQ(kk) = \frac{X(kk) \times [P^2(n2) + Q^2(n2)]}{|V(n2)|^2} \quad (3.8)$$

3.2.4 Load Modelling

The load modelling has consequential repercussion on the change of the active and reactive power of the network as rooted by voltage disparity. Hence, the type of load has remarkable outcome influencing load-flow solution. The load modelling proposed by Eminoglu *et al.* (2005) is used in the proposed work.

$$P = P_0 \left(\frac{V}{V_0} \right)^{n_p} \quad (3.9)$$

$$Q = Q_0 \left(\frac{V}{V_0} \right)^{n_q} \quad (3.10)$$

Where P and Q are active power and reactive power at receiving-end respectively. P₀ and Q₀ are nominal active power and reactive power respectively. V is the voltage at the receiving-end and V₀ is the nominal voltage taken as (1+j0) respectively. The values of n_p and n_q vary depending upon the nature of load as shown in Table 3.1.

Table 3.1: Exponential Values (n_p and n_q) for Static Load Modelling (Eminoglu *et al.* (2005))

Sr. no.	Type of Load	n _p	n _q
1.	Constant power	0	0
2.	Constant current	1	1
3.	Constant impedance	2	2
4.	Air conditioner	0.5	2.5
5.	Battery charge	2.59	4.69
6.	Fluorescent lamp	2.07	3.21
7.	Resistance space heater	2.00	0.00
8.	Pumps, fans and other motors	0.08	1.60
9.	Incandescent lamp	1.54	0.00
10.	CFL	1.00	0.35
11.	Small industrial motor	0.10	0.60
12.	Large industrial motor	0.05	0.50

3.2.5 Searching Technique for Identification of Nodes beyond Branch

The practice of recognizing a specific evidence is called Searching. Searching is maneuver that assists in discovering the abode of a certain element or significance in the list. Plenty of time is ordinarily exhausted in exploring for any appropriate element. If the statistics is retained accurately in categorized structure, probing becomes straight forward and dynamic. The customary searching modes that are being monitored in data structure, are linear search / sequential search and binary search. The proposed searching technique is based on the formation of arrays for feeders, laterals and sub laterals using linear search or sequential search technique.

Array is an immovable-stature arranged assembly of variables residing to the identical data descriptions. For accumulating values, the array has adjoining memory orientations to repertoire values. When a program endeavors with many unpredictable parameters, which embrace commensurate formation of data, then organizational and managerial impediment expeditiously succeed. If arrays are not being used, the tally of handled variables will increase i.e., usage of the array leads to reduction in the number of variables. Arrays are notably conducive for compiling input data, which report in haphazard manner.

3.2.5.1 Linear Search

Linear search is the intelligible method for searching. In this practice of searching, the element to be found during searching is searched successively in the list. This introductory process can be executed on an organized (sorted) or an unorganized (unsorted) list (usually arrays). During handling of a sorted list, searching starts from 0th element and endures until the constituent is initiated from the list or the constituent whose assessment is greater than (speculating that the organized list is in ascending order) the value being searched is attained. Unorganized list also commences from the 0th element and sustains as far as the element or the end of the list is attained.

3.2.5.2 Proposed Searching Technique

From Equation (3.5), it is clear that the perception of $I(kk)$, i.e., the current flowing through the branch kk , is required as the value of $Z(kk)$, i.e., the impedance of branch kk , is known to us. In order to compute the current of branch kk , the knowledge of initial voltage of each and every node is essential. Since the value of the voltage of each node except the substation is not known, a flat voltage start is considered in this technique. To compute the current in each branch, a search technique to arrange the nodes sequentially of each feeder, lateral, and sublateral is proposed. A radial distribution network (RDN) is shown in Figure 3.2. The bracketed terms indicate the branch number (BN). Sending –end node of any branch ‘ kk ’ is denoted by ‘SE’ ($n1$), whereas the receiving-end node of branch ‘ kk ’ is denoted by ‘RE’ ($n2$).

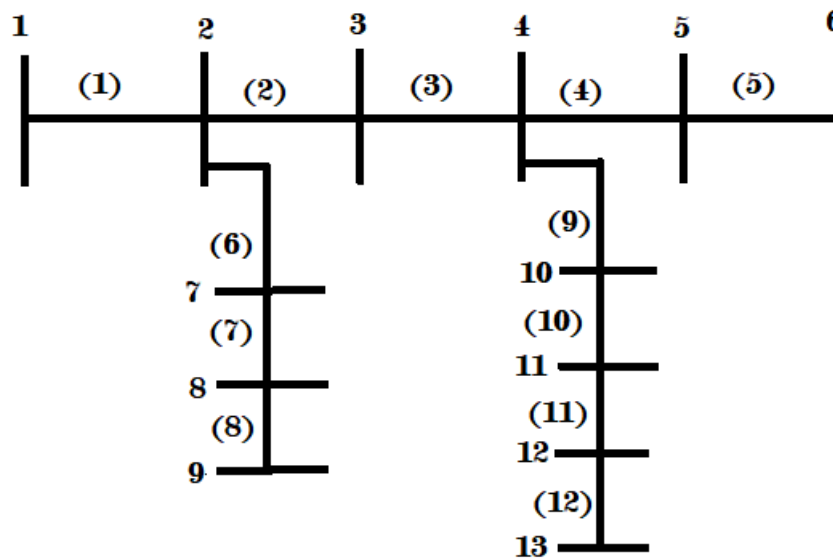


Figure 3.2: Sample Radial Distribution Network

Table 3.2 shows the BN, SE and RE of Figure 3.2.

Let the branch number, its source node, and sink node be stored in $BN[i]$, $SE[i]$ and $RE[i]$ respectively, where $i = 1$ to 12. Figure 3.2 has one feeder, and two laterals. Let the respective nodes of the feeder and laterals of Figure 3.2 be stored in $F[i]$, $LAT1 [i]$ and $LAT2 [i]$ respectively. $SE [1]$ is the source node of $BN [1]$, i.e., branch 1. The corresponding $RE [1]$ is 2, which is the receiving-end node of branch 1. $SE [1]$ is stored in $F [1]$ for $i =1$ and $RE [1]$ is stored in $F [2]$, i.e. $i = 1+1 =2$. $RE [1]$ is checked with all the source nodes of Table 3.2

for $kk= 2$ to $kk=12$. SE [2] and SE [6] are equal to RE [1]. Let us take a counter $k = 1$ and here $j1 = 2$ is taken. Here, at first, start with SE [2] for $j1 = 1$. For $j1 = 2$, SE [6] is marked. The respective RE [2] is stored in F [3], i.e., $i = 2 + 1 = 3$. RE [2] is checked with all the source nodes of Table 3.2 for $kk= 3$ to $kk=12$. RE [2] and SE [3] are only equal. The respective RE [3] is stored in F [4], i.e., $i = 3 + 1 = 4$. RE [3] is checked with all the source nodes of Table 3.2 for $kk= 4$ to $kk=12$. Here SE [4], SE [9] and RE [3] are identical and $j2=2$ is put and the counter is increased by one, i.e., $k = 1+1 =2$. The respective RE [4] is stored in F [5], i.e., $i = 4+1 = 5$ and SE [9] is marked referred to $j2 =2$. RE [4] is checked with all the source nodes of Table 3.2 for $kk= 5$ to $kk=12$. Here SE [5] and RE [4] are identical.

Table 3.2: BN, SE node, and RE node of Sample Radial Distribution Network

BN (kk)	SE- node (n1)	RE- node (n2)
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	2	7
7	7	8
8	8	9
9	4	10
10	10	11
11	11	12
12	12	13

The respective RE [5] is stored in F [6], i.e., $i = 5+1 = 6$. RE [5] is checked with all the source nodes of Table 3.2 for $kk= 6$ to $kk=12$ and no SE [kk] for $kk = 6$ to 12 is equal to RE [5]. The search is stopped for this feeder.

Let us consider $k = 1$. For $k =1$, $j1 = 2$. For $j1=2$, SE [6] will be considered. It is stored in LAT1 [1], i.e., $i =1$, which is starting value of this array. The respective RE [6] is checked with all SE [kk] for all $kk = 7$ to $kk = 12$. RE [6] and SE [7] are identical only. The respective

RE [7] is stored in LAT1 [2], i.e., 'i' is increased by 1, i.e., $i = 1+1 = 2$. RE [7] is checked with all SE [kk] for all $kk = 8$ to $kk = 12$. SE (8) = RE [7] only and the respective RE [8] is stored in LAT1 [3], i.e., 'i' is increased by one, i.e., $i = 2+1 = 3$. RE [8] is checked with all SE [kk] for all $kk = 9$ to $kk = 12$. Any SE (kk) for $kk = 9$ to 12 is not equal to RE [8]. Hence the search for $k = 1$ and $j_1 = 2$ is stopped.

Let us consider $k = 2$. For $k = 2$, $j_2 = 2$. For $j_2 = 2$, SE [9] will be considered. It is stored in LAT2 [1], i.e., $i = 1$, which is starting value of this array. The respective RE [9] is stored in LAT2 [2], i.e., $i = 1+1 = 2$ and RE [9] is checked with all SE [kk] for all $kk = 10$ to $kk = 12$. RE [9] and SE [10] are identical only. The respective RE [10] is stored in LAT2 [3], i.e., 'i' is increased by 1, i.e., $i = 2+1 = 3$. RE [10] is checked with all SE [kk] for all $kk = 11$ to $kk = 12$. SE [11] = RE [10] only and the respective RE [11] is stored in LAT1 [4], i.e., 'i' is increased by one, i.e., $i = 3+1 = 4$. RE [11] is checked with all SE [kk] for all $kk = 12$ to $kk = 12$. Any SE [12] = RE [11] and here RE [12] is stored in LAT2 [5], i.e., $i = 4+1 = 5$.

The above searching technique makes the process much simpler as compared to the method (Ghosh and Das (1999)) and other proposed methods. No manual pre-coding of nodes is required from which lateral or sublateral are emanated as proposed in the method (Das *et al.* (1995)). Only general data preparation is required.

The above search techniques produces the following:

$F [1] = 1, F [2] = 2, F [3] = 3, F [4] = 4, F [5] = 5, F [6] = 6$

$LAT1 [1] = 2, LAT1 [2] = 6, LAT1 [3] = 7, LAT1 [4] = 9$

$LAT2 [1] = 4, LAT2 [2] = 10, LAT2 [3] = 11, LAT2 [4] = 12, LAT2 [5] = 13$

LAT1 [1] is checked with F[i] for $i = 1$ to 5 and $LAT1 [1] = F [2]$ for $i = 2$.

LAT2 [1] is checked with F[i] for $i = 1$ to 5 and $LAT2 [1] = F [4]$ for $i = 4$.

An array K[i] is considered to map F[i]. The elements of K[i] for $i = 1, 3, 5$ are put to zero whereas K[i] for $i = 2, 4$ are put to one.

3.2.6 Algorithm for the Proposed Load-flow

The steps of the algorithm for the proposed load-flow solution are presented below.

Step-1	:	START
Step-2	:	Read the system data and the type of load modelling.
Step-3	:	Read base values of the system, convergence factor ($\text{esp}=0.000001$) and ITMAX (IT = 100).
Step-4	:	Convert the line data and load data into its per unit value
Step-5	:	Make $V(i) = 1 + j0$ for all $i=1, 2, 3 \dots NN$.
Step-6	:	Compute $VV(i) = V(i) $ and $VV1(i) = VV(i)$
Step-7	:	IT=1
Step-8	:	Use the proposed search technique to form the array of the feeder, lateral and sublateral and to link them.
Step-9	:	Compute the current in each branch
Step-10	:	Compute voltage magnitude $VV(i)$ of each and every node using Equation (3.5)
Step-11	:	Calculate the voltage angle of each and every node using Equation (3.6).
Step-12	:	Calculate $\Delta V(i) = VV(i) - VV1(i) $ for each and every node.
Step-13	:	Find the max value of $\Delta V(i)$.
Step-14	:	If $\Delta V(i) _{\text{max}} \leq \text{eps}$, GO TO Step-18.
Step-15	:	Make $VV1(i) = VV(i)$ for all 'i'.
Step-16	:	IT = IT+1
Step-17	:	If (IT \leq ITMAX), GO TO Step-9, Else Display Not Converged and GO TO Step-21.
Step-18	:	Compute active and reactive power losses of each and every branch using Equation (3.7) and Equation (3.8).
Step-19	:	Compute the total active and total reactive power losses of the system.
Step-20	:	Display all the RESULTS
Step-21	:	STOP

3.3 SIMULATION RESULTS AND DISCUSSIONS

In this work, a total of seven RDNs have been studied. These are 13-node, 24-node, 28-node, 33-node, 34-node, 69-node and 85-node. Out of these, 33-node and 69-node are the IEEE data bus and 24-node is the practical data bus (Jeevakona, India). The system data of 13-node and 34-node RDNs are accessible in Suharati *et al.* (2014). The line data and load data of 28-node RDN are available in Das *et al.* (1994) and 85-node RDN are accessible in Das *et al.* (1995). The system data of 33-node and 69-node distribution networks are accessible in Ghosh and Das (1999). The system data of 24-node RDN are accessible in Kumar *et al.* (2013).

3.3.1 Load-flow Results of 13-node RDN

Figure 3.3 shows the diagram of 13-node RDN having base values **11 kV and 100 MVA**. The system data of Figure 3.3 have been presented in **Appendix-A**.

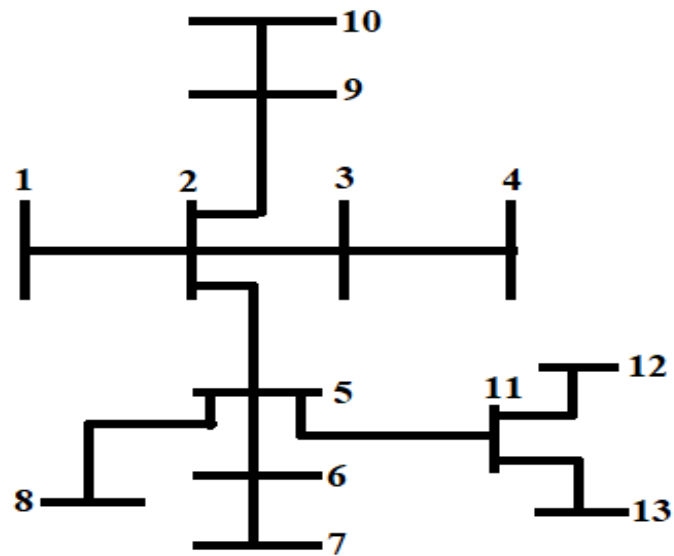


Figure 3.3: 13-node Radial Distribution Network

Load-flow results for 13-node RDN are given in Table 3.3. In 13-node RDN, the minimum voltage is observed at node 7. Real component of voltage is having the minimum value as compared to other nodes of the network and reactive component for the same node is having maximum value. The voltage angle (in radians) for node 7 is more as compared to other nodes of 13-node RDN.

Table 3.3: Real Part of the Voltage, Imaginary Part of the voltage, voltage magnitude (p.u.), and Voltage Angle (rad.) of 13-node RDN

Node number	Real part of the voltage (p.u.)	Imaginary part of the voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.997122	0.003838	0.997130	0.003849
3	0.996619	0.004621	0.996630	0.004637
4	0.996327	0.004871	0.996339	0.004889
5	0.995401	0.006669	0.995424	0.006700
6	0.994755	0.008153	0.994789	0.008196
7	0.994319	0.009958	0.994369	0.010014
8	0.995243	0.006802	0.995266	0.006835
9	0.996211	0.006294	0.996231	0.006318
10	0.995736	0.007691	0.995766	0.007724
11	0.994757	0.007820	0.994788	0.007861
12	0.994641	0.008069	0.994673	0.008112
13	0.994626	0.007837	0.994657	0.007879

3.3.2 Load-flow Results of 24-node RDN

Figure 3.4 shows diagram of 24-node RDN. Load-flow results for 24-node RDN are given in Table 3.4, which clearly shows that in 24-node RDN, the minimum voltage is observed at node 14. Real component of voltage is having the minimum value as compared to other nodes of the network and reactive component for the same node is having maximum value. The voltage angle (in radians) for node 14 is more as compared to other nodes of 24-node RDN.

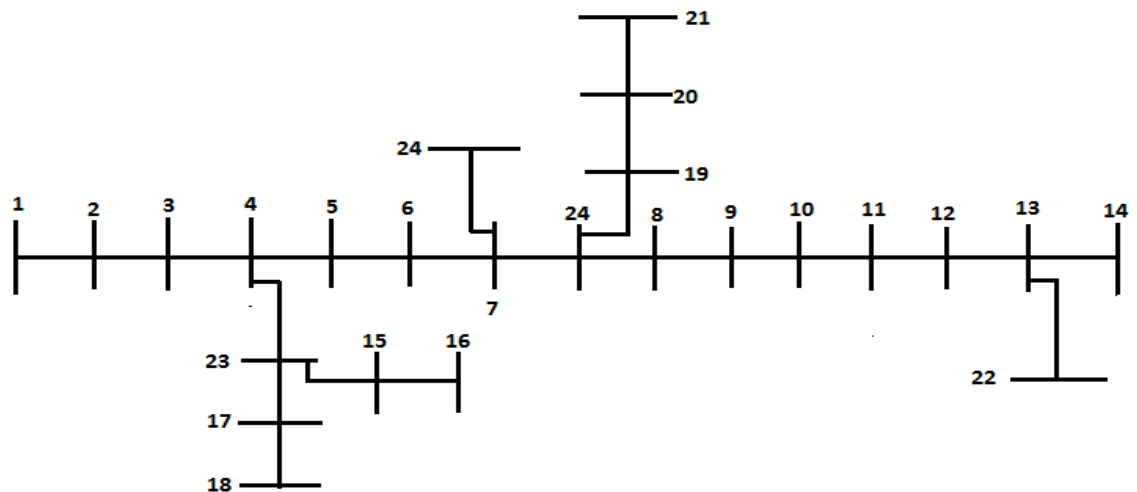


Figure 3.4: 24-node Radial Distribution Network

Table 3.4: Real Part of the Voltage, Imaginary Part of the Voltage, Voltage Magnitude (p.u.), and Voltage Angle (rad.) of 24-node RDN

Node number	Real part of voltage (p.u.)	Imaginary part of voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.996484	-0.000494	0.996484	-0.000496
3	0.991674	-0.001181	0.991674	-0.001191
4	0.989861	-0.001436	0.989862	-0.001451
5	0.987671	-0.001770	0.987672	-0.001792
6	0.986612	-0.001926	0.986614	-0.001952
7	0.985675	-0.002062	0.985677	-0.002092
8	0.983725	-0.002321	0.983728	-0.002359
9	0.982435	-0.002467	0.982438	-0.002511
10	0.981269	-0.002566	0.981272	-0.002615
11	0.979837	-0.002681	0.979840	-0.002736
12	0.979578	-0.002697	0.979582	-0.002754
13	0.978873	-0.002745	0.978877	-0.002805
14	0.978673	-0.002751	0.978677	-0.002811
15	0.989260	-0.001521	0.989262	-0.001537
16	0.989012	-0.001555	0.989013	-0.001573
17	0.989368	-0.001533	0.989370	-0.001550
18	0.989115	-0.001589	0.989116	-0.001607
19	0.983115	-0.002473	0.983119	-0.002515
20	0.982901	-0.002505	0.982904	-0.002549
21	0.982652	-0.002540	0.982656	-0.002585
22	0.978788	-0.002770	0.978792	-0.002830
23	0.989608	-0.001477	0.989609	-0.001492
24	0.984834	-0.002181	0.984837	-0.002214

3.3.3 Load-flow Results of 28-node RDN

Figure 3.5 shows the diagram of 28-node RDN having base values **11 kV and 100 MVA**. The system data of Figure 3.5 have been presented in **Appendix-C**.

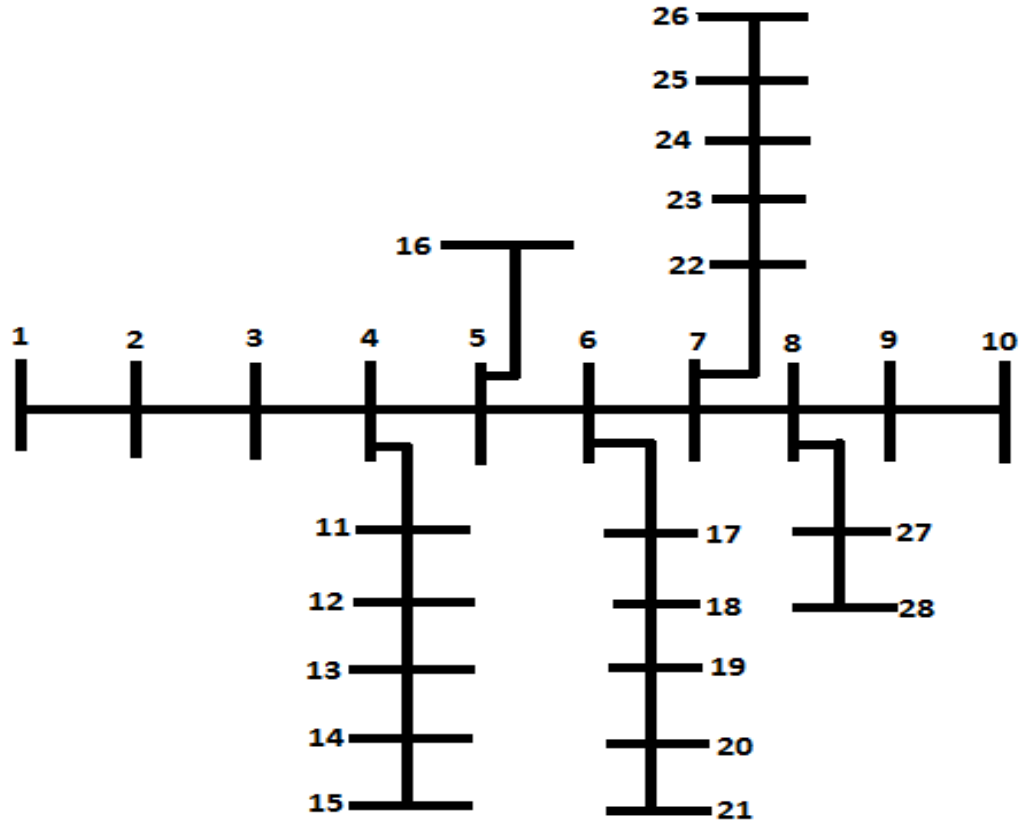


Figure 3.5: 28-node Radial Distribution Network

The load-flow results are given in Table 3.5. From Table 3.5, it is clear that the minimum voltage is observed at node 26. Real component of voltage is having the minimum value as compared to other nodes of the network and reactive component for the same node is having maximum value. The voltage angle (in radians) for node 26 is more as compared to other nodes of 28-node RDN.

Table 3.5: Real Part of the Voltage, Imaginary Part of the Voltage, Voltage Magnitude (p.u.), and Voltage Angle (rad.) of 28-node RDN

Node number	Real part of voltage (p.u.)	Imaginary part of voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.986217	0.002512	0.986220	0.002547
3	0.966435	0.006102	0.966454	0.006314
4	0.952317	0.008663	0.952356	0.009096
5	0.938126	0.011220	0.938193	0.011960
6	0.927569	0.013118	0.927662	0.014142
7	0.918372	0.014767	0.918490	0.016078
8	0.915907	0.015210	0.916034	0.016605
9	0.915626	0.015261	0.915753	0.016665
10	0.915380	0.015305	0.915508	0.016718
11	0.946099	0.011212	0.946166	0.011851
12	0.944321	0.011942	0.944397	0.012645
13	0.943258	0.012377	0.943339	0.013121
14	0.942977	0.012492	0.943060	0.013247
15	0.942735	0.012591	0.942819	0.013355
16	0.936990	0.011687	0.937063	0.012472
17	0.925773	0.013848	0.925877	0.014957
18	0.924790	0.014247	0.924900	0.015404
19	0.923110	0.014929	0.923231	0.016171
20	0.922245	0.015280	0.922372	0.016566
21	0.921606	0.015539	0.921737	0.016859
22	0.915470	0.015939	0.915609	0.017409
23	0.913922	0.016563	0.914072	0.018121
24	0.912737	0.017041	0.912896	0.018668
25	0.912475	0.017146	0.912636	0.018789
26	0.912308	0.017213	0.912471	0.018866
27	0.915409	0.015413	0.915539	0.016835
28	0.915285	0.015463	0.915415	0.016893

3.3.4 Load-flow results of 33-node RDN

Figure 3.6 shows the diagram of 33-node RDN having base values **12.66 kV and 100 MVA**. The system data of Figure 3.6 have been presented in **Appendix-D**.

The load-flow results are given in Table 3.6. In 33-node RDN, the minimum voltage is observed at node 18. Real component of voltage is having the minimum value as compared to other nodes of the network and reactive component for the same node is having maximum value. The voltage angle (in radians) for node 18 is more as compared to other nodes of 33-node RDN.

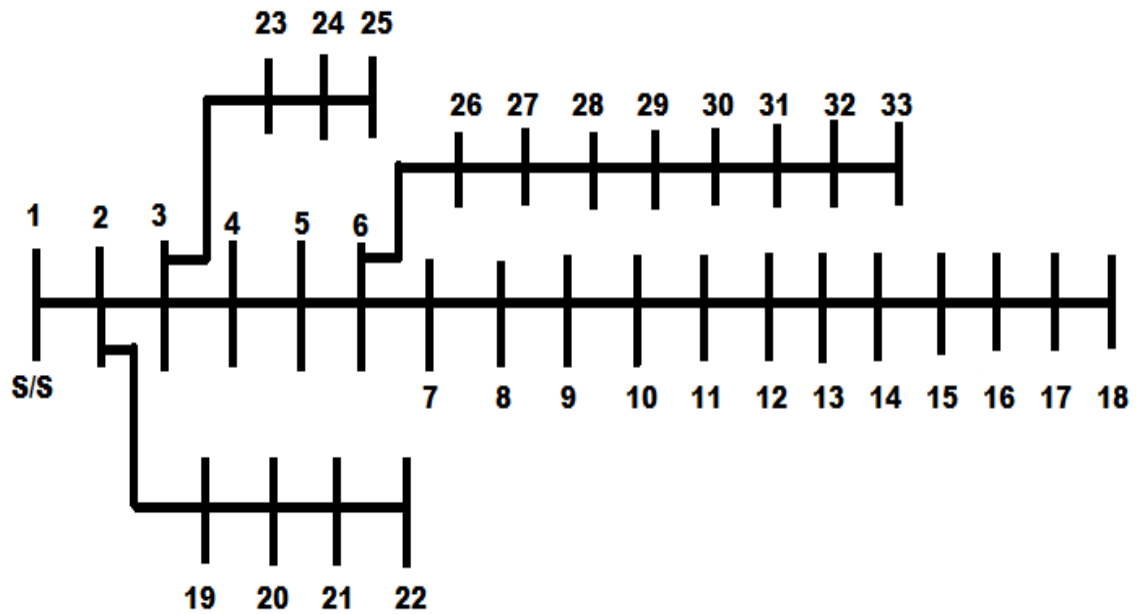


Figure 3.6: 33-node Radial Distribution Network

Table 3.6: Real Part of the Voltage, Imaginary Part of the Voltage, Voltage Magnitude (p.u.), and Voltage Angle (rad.) of 33-node RDN

Node number	Real part of voltage (p.u.)	Imaginary part of voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.997032	0.000252	0.997032	0.000253
3	0.982937	0.001648	0.982939	0.001676
4	0.975453	0.002752	0.975457	0.002822
5	0.968053	0.003858	0.968061	0.003985
6	0.949658	0.002220	0.949660	0.002337
7	0.946174	-0.001591	0.946175	-0.001682
8	0.941331	-0.000990	0.941332	-0.001052
9	0.935061	-0.002176	0.935063	-0.002327
10	0.929411	-0.003255	0.929416	-0.003503
11	0.928551	-0.003135	0.928556	-0.003376
12	0.927052	-0.002944	0.927057	-0.003176
13	0.920935	-0.004392	0.920945	-0.004769
14	0.918662	-0.005642	0.918679	-0.006142
15	0.917246	-0.006236	0.917267	-0.006799
16	0.915875	-0.006599	0.915899	-0.007205
17	0.913839	-0.007816	0.913872	-0.008553
18	0.913231	-0.007964	0.913265	-0.008720
19	0.996504	0.000064	0.996504	0.000064
20	0.992926	-0.001097	0.992926	-0.001105
21	0.992221	-0.001432	0.992222	-0.001443
22	0.991583	-0.001783	0.991584	-0.001798
23	0.979352	0.001113	0.979353	0.001136
24	0.972682	-0.000401	0.972682	-0.000413
25	0.969356	-0.001139	0.969357	-0.001175
26	0.947727	0.002868	0.947731	0.003026
27	0.945160	0.003786	0.945167	0.004006
28	0.933714	0.005092	0.933728	0.005454
29	0.925488	0.006306	0.925510	0.006813
30	0.921918	0.007976	0.921952	0.008651
31	0.917768	0.006587	0.917791	0.007178
32	0.916855	0.006212	0.916876	0.006775
33	0.916572	0.006087	0.916592	0.006641

3.3.5 Load-flow results of 34-node RDN

Figure 3.7 shows the diagram of 34-node RDN having base values **11 kV and 100 MVA**.

The system data of Figure 3.7 have been presented in **Appendix-E**.

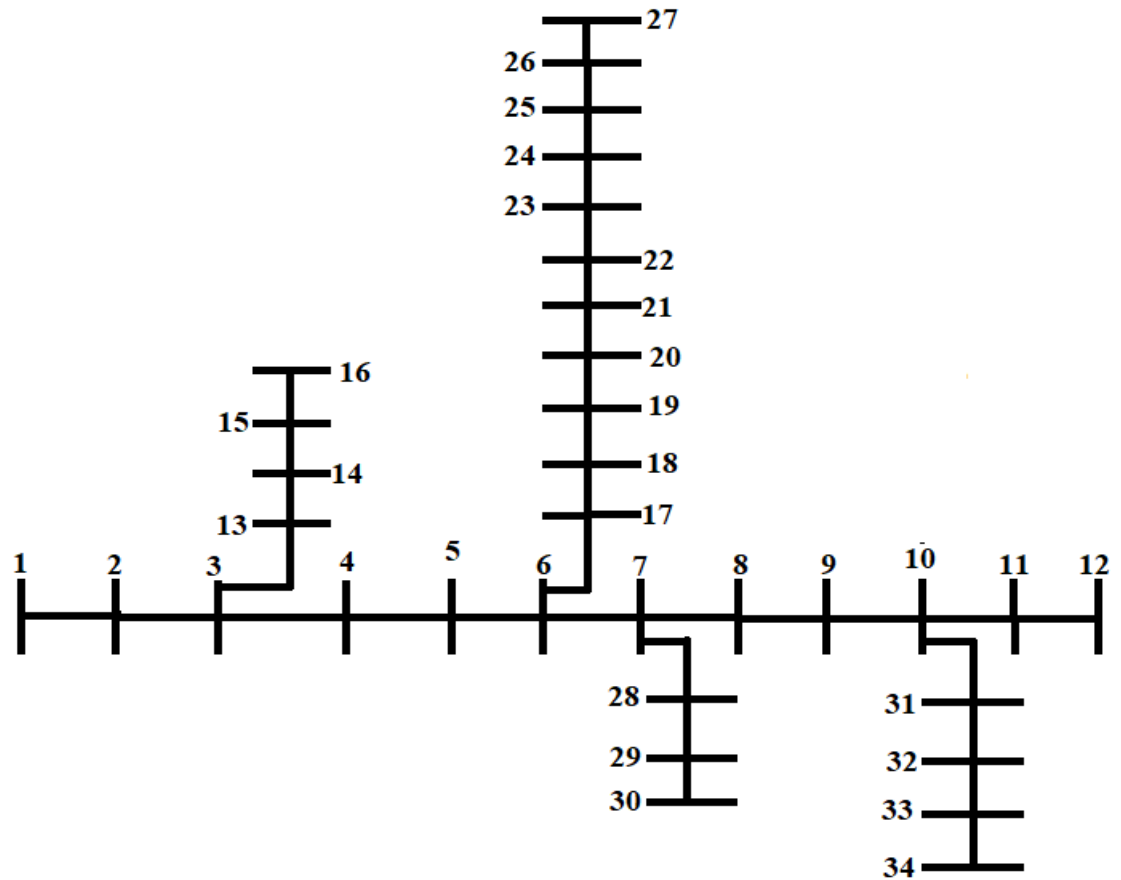


Figure 3.7: 34-node Radial Distribution Network

Table 3.7 shows the results of 34-node RDN. In 34-node RDN, the minimum voltage is observed at node 27. Real component of voltage is having the minimum value as compared to other nodes of the network and reactive component for the same node is having maximum value. The voltage angle (in radians) for node 27 is more as compared to other nodes of 34-node RDN.

Table 3.7: Real Part of the Voltage, Imaginary Part of the Voltage, Voltage Magnitude (p.u.), and Voltage Angle (rad.) of 34-node RDN

Node number	Real part of voltage (p.u.)	Imaginary part of voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.993782	0.001665	0.993784	0.001675
3	0.988367	0.003099	0.988372	0.003135
4	0.981029	0.006046	0.981047	0.006163
5	0.974711	0.008562	0.974748	0.008784
6	0.968754	0.010921	0.968816	0.011273
7	0.960929	0.007423	0.960957	0.007725
8	0.958754	0.008518	0.958791	0.008885
9	0.953701	0.006257	0.953722	0.006560
10	0.952483	0.006813	0.952508	0.007152
11	0.952010	0.007048	0.952036	0.007403
12	0.951871	0.007102	0.951898	0.007461
13	0.987745	0.002766	0.987749	0.002800
14	0.987438	0.002889	0.987442	0.002926
15	0.987355	0.002922	0.987359	0.002959
16	0.987349	0.002924	0.987353	0.002962
17	0.964044	0.012863	0.964130	0.013341
18	0.960106	0.014481	0.960215	0.015082
19	0.955802	0.016498	0.955945	0.017259
20	0.952338	0.018108	0.952510	0.019012
21	0.949325	0.019501	0.949526	0.020539
22	0.945908	0.021299	0.946148	0.022513
23	0.943100	0.022766	0.943374	0.024135
24	0.937738	0.020519	0.937962	0.021878
25	0.936469	0.021163	0.936708	0.022594
26	0.935983	0.021395	0.936227	0.022854
27	0.935841	0.021449	0.936087	0.022915
28	0.960702	0.007517	0.960732	0.007824
29	0.960551	0.007579	0.960581	0.007890
30	0.960439	0.007625	0.960469	0.007939
31	0.952139	0.006945	0.952165	0.007294
32	0.951794	0.007078	0.951820	0.007436
33	0.951622	0.007144	0.951649	0.007507
34	0.951564	0.007166	0.951591	0.007530

3.3.6 Load-flow results of 69-node RDN

Figure 3.8 shows the diagram of 69-node RDN having base values **12.66 kV and 100 MVA**. The system data of Figure 3.8 have been presented in **Appendix-F**.

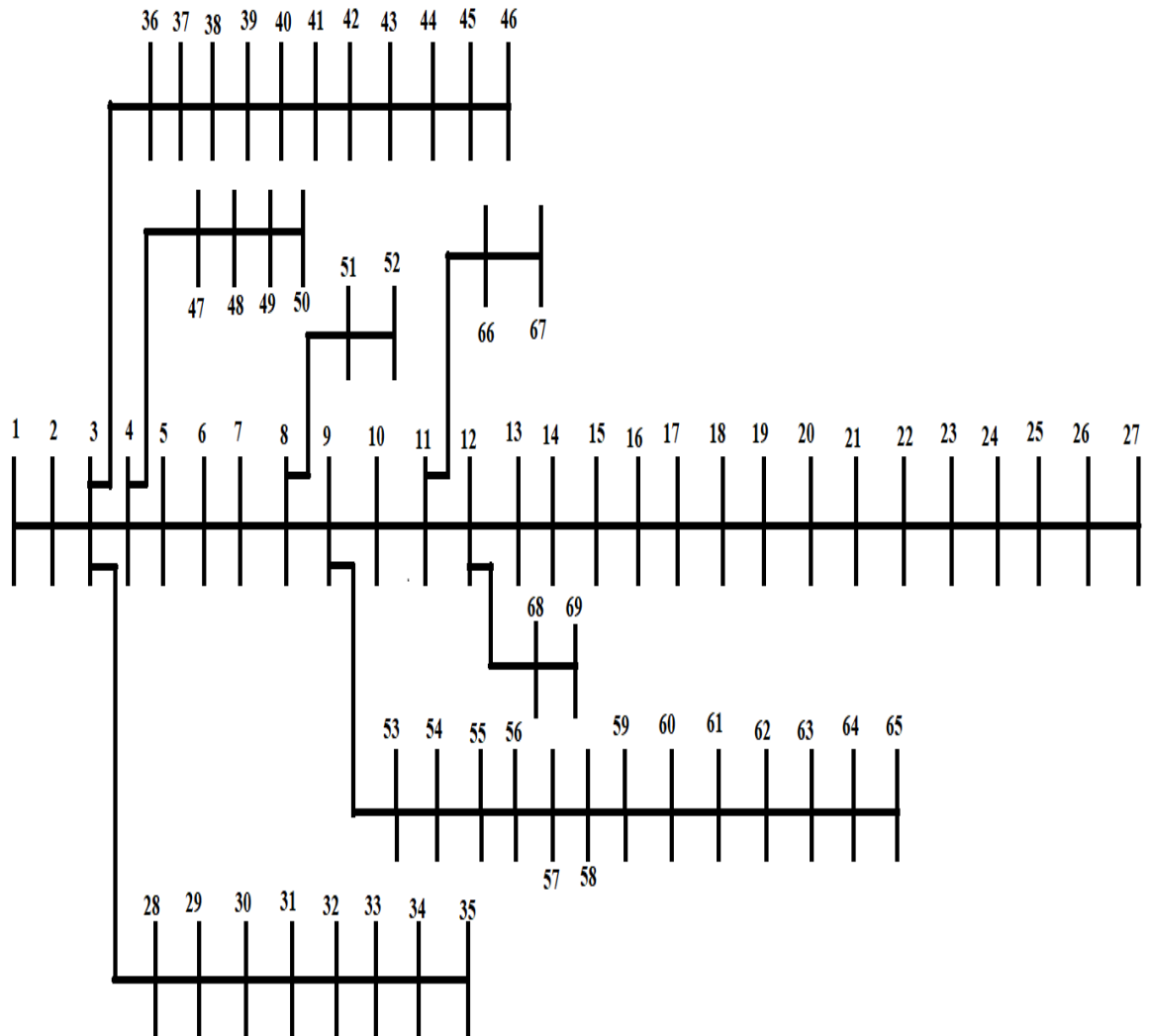


Figure 3.8: 69-node Radial Distribution Network

Load-flow results for 69-node RDN are given in Table 3.8. In 69-node RDN, the minimum voltage is observed at node 65. Real component of voltage is having the minimum value as compared to other nodes of the network and reactive component for the same node is having maximum value. The voltage angle (in radians) for node 65 is more as compared to other nodes of 69-node RDN.

Table 3.8: Real Part of the Voltage, Imaginary Part of the Voltage, Voltage Magnitude (p.u.), and Voltage Angle (rad.) of 69-node RDN

Node number	Real part of voltage (p.u.)	Imaginary part of voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.999967	-0.000021	0.999967	-0.000021
3	0.999933	-0.000043	0.999933	-0.000043
4	0.999839	-0.000103	0.999839	-0.000103
5	0.999020	-0.000323	0.999021	-0.000323
6	0.990087	0.000850	0.990087	0.000859
7	0.980793	0.002069	0.980796	0.002110
8	0.978577	0.002358	0.978580	0.002410
9	0.977444	0.002506	0.977447	0.002564
10	0.972442	0.003928	0.972450	0.004039
11	0.971340	0.004241	0.971349	0.004366
12	0.968177	0.005116	0.968191	0.005284
13	0.965251	0.005878	0.965269	0.006089
14	0.962350	0.006633	0.962373	0.006893
15	0.959477	0.007384	0.959505	0.007695
16	0.958943	0.007523	0.958972	0.007845
17	0.958061	0.007753	0.958093	0.008092
18	0.958052	0.007755	0.958084	0.008095
19	0.957587	0.007894	0.957619	0.008244
20	0.957288	0.007984	0.957321	0.008340
21	0.956805	0.008128	0.956840	0.008495
22	0.956798	0.008130	0.956833	0.008497
23	0.956726	0.008152	0.956761	0.008521
24	0.956569	0.008199	0.956604	0.008571
25	0.956400	0.008250	0.956435	0.008626
26	0.956330	0.008271	0.956366	0.008649
27	0.956310	0.008277	0.956346	0.008655

28	0.999926	-0.000047	0.999926	-0.000047
29	0.999854	-0.000093	0.999854	-0.000093
30	0.999733	-0.000056	0.999733	-0.000056
31	0.999712	-0.000049	0.999712	-0.000049
32	0.999605	-0.000016	0.999605	-0.000016
33	0.999349	0.000061	0.999349	0.000061
34	0.999013	0.000163	0.999013	0.000163
35	0.998946	0.000182	0.998946	0.000182
36	0.999919	-0.000052	0.999919	-0.000052
37	0.999747	-0.000164	0.999747	-0.000164
38	0.999589	-0.000206	0.999589	-0.000206
39	0.999543	-0.000218	0.999543	-0.000218
40	0.999541	-0.000219	0.999541	-0.000219
41	0.998843	-0.000410	0.998843	-0.000411
42	0.998551	-0.000491	0.998551	-0.000492
43	0.998512	-0.000501	0.998512	-0.000502
44	0.998504	-0.000504	0.998504	-0.000505
45	0.998405	-0.000536	0.998405	-0.000536
46	0.998405	-0.000536	0.998405	-0.000537
47	0.999789	-0.000134	0.999789	-0.000134
48	0.998545	-0.000916	0.998545	-0.000917
49	0.994699	-0.003329	0.994705	-0.003347
50	0.994153	-0.003671	0.994160	-0.003693
51	0.978542	0.002363	0.978544	0.002415
52	0.978532	0.002366	0.978535	0.002418
53	0.974656	0.002871	0.974660	0.002946
54	0.971412	0.003296	0.971417	0.003393
55	0.966936	0.003882	0.966944	0.004014
56	0.962565	0.004451	0.962575	0.004624
57	0.940039	0.010854	0.940102	0.011546
58	0.928936	0.014010	0.929042	0.015081

59	0.924639	0.015253	0.924764	0.016494
60	0.919586	0.016847	0.919740	0.018318
61	0.912169	0.017811	0.912343	0.019523
62	0.911879	0.017849	0.912053	0.019571
63	0.911490	0.017899	0.911665	0.019634
64	0.909584	0.018145	0.909765	0.019946
65	0.909008	0.018219	0.909191	0.020040
66	0.971283	0.004260	0.971292	0.004386
67	0.971282	0.004260	0.971292	0.004386
68	0.967847	0.005217	0.967861	0.005390
69	0.967846	0.005217	0.967860	0.005390

3.3.7 Load-flow results of 85-node RDN

Figure 3.9 shows the diagram of 85-node RDN having base values **11 kV and 100 MVA**. The system data of Figure 3.9 have been presented in **Appendix-G**. Load-flow results are given in Table 3.9. From Table 3.9, it is clear that the minimum voltage is observed at node 54. Real component of voltage is having the minimum value as compared to other nodes of the network and reactive component for the same node is having maximum value. The voltage angle (in radians) for node 54 is more as compared to other nodes of 85-node RDN.

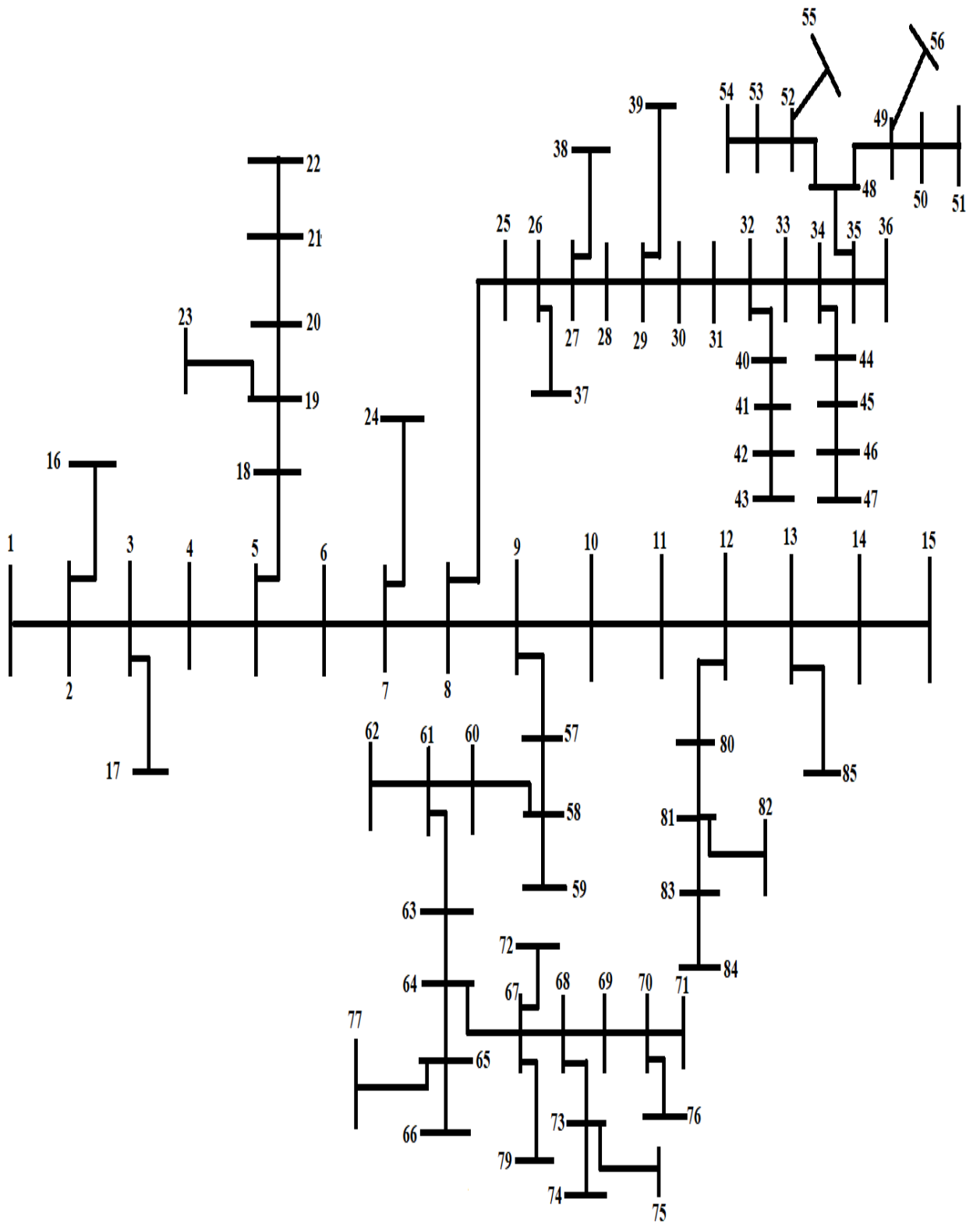


Figure 3.9: 85-node Radial Distribution Network

Table 3.9: Real Part of the Voltage, Imaginary Part of the Voltage, Voltage Magnitude (p.u.), and Voltage Angle (rad.) of 85-node RDN

Node number	Real part of voltage (p.u.)	Imaginary part of voltage (p.u.)	Voltage magnitude (p.u.)	Voltage angle (rad.)
1	1.000000	0.000000	1.000000	0.000000
2	0.995675	0.000729	0.995676	0.000732
3	0.989257	0.001841	0.989259	0.001861
4	0.981061	0.003257	0.981066	0.003320
5	0.977072	0.003949	0.977080	0.004042
6	0.962727	0.006407	0.962748	0.006655
7	0.953904	0.007924	0.953937	0.008307
8	0.915672	0.014454	0.915786	0.015784
9	0.913854	0.014770	0.913974	0.016161
10	0.910324	0.015398	0.910455	0.016914
11	0.907585	0.015885	0.907724	0.017501
12	0.905318	0.016287	0.905465	0.017989
13	0.904332	0.016463	0.904482	0.018203
14	0.904033	0.016517	0.904184	0.018268
15	0.903854	0.016549	0.904005	0.018307
16	0.995372	0.000857	0.995372	0.000861
17	0.988650	0.002097	0.988652	0.002121
18	0.974349	0.005088	0.974363	0.005222
19	0.972666	0.005792	0.972683	0.005955
20	0.972081	0.006036	0.972100	0.006210
21	0.971379	0.006329	0.971400	0.006516
22	0.970716	0.006606	0.970738	0.006806
23	0.972543	0.005844	0.972560	0.006009
24	0.953507	0.008089	0.953541	0.008483
25	0.910078	0.016637	0.910230	0.018279
26	0.905772	0.018317	0.905957	0.020220
27	0.900117	0.020520	0.900350	0.022793

28	0.897491	0.021540	0.897749	0.023996
29	0.892643	0.023421	0.892951	0.026232
30	0.888203	0.025140	0.888559	0.028297
31	0.886112	0.025950	0.886492	0.029276
32	0.884806	0.026457	0.885201	0.029892
33	0.883758	0.026863	0.884166	0.030386
34	0.879190	0.028618	0.879656	0.032538
35	0.876677	0.029583	0.877176	0.033732
36	0.876589	0.029617	0.877090	0.033774
37	0.905505	0.018424	0.905692	0.020344
38	0.899376	0.020814	0.899617	0.023139
39	0.892236	0.023582	0.892548	0.026424
40	0.884156	0.026710	0.884560	0.030200
41	0.883203	0.027081	0.883618	0.030652
42	0.883073	0.027131	0.883490	0.030714
43	0.882986	0.027165	0.883404	0.030755
44	0.877557	0.029247	0.878044	0.033316
45	0.876509	0.029652	0.877011	0.033816
46	0.875898	0.029887	0.876408	0.034108
47	0.875794	0.029927	0.876306	0.034158
48	0.874468	0.030431	0.874998	0.034786
49	0.874205	0.030533	0.874738	0.034913
50	0.873746	0.030709	0.874286	0.035132
51	0.873398	0.030843	0.873943	0.035299
52	0.871713	0.031486	0.872281	0.036104
53	0.871144	0.031704	0.871720	0.036377
54	0.870725	0.031864	0.871308	0.036579
55	0.871294	0.031647	0.871869	0.036305
56	0.874101	0.030573	0.874635	0.034963
57	0.911343	0.015768	0.911480	0.017301
58	0.904400	0.018515	0.904590	0.020469

59	0.904267	0.018568	0.904458	0.020531
60	0.900176	0.020188	0.900403	0.022423
61	0.899099	0.020617	0.899336	0.022927
62	0.898358	0.020913	0.898601	0.023275
63	0.899173	0.020586	0.899409	0.022891
64	0.895286	0.022117	0.895559	0.024699
65	0.895118	0.022184	0.895392	0.024778
66	0.894983	0.022238	0.895259	0.024842
67	0.893279	0.022905	0.893573	0.025636
68	0.890371	0.024045	0.890695	0.026999
69	0.888216	0.024891	0.888564	0.028016
70	0.887659	0.025109	0.888014	0.028279
71	0.887401	0.025210	0.887759	0.028402
72	0.893144	0.022959	0.893439	0.025700
73	0.888924	0.024614	0.889265	0.027682
74	0.888720	0.024694	0.889063	0.027779
75	0.888451	0.024799	0.888797	0.027906
76	0.887249	0.025270	0.887609	0.028474
77	0.895101	0.022191	0.895376	0.024787
78	0.909860	0.015587	0.909994	0.017129
79	0.893023	0.023007	0.893319	0.025757
80	0.903778	0.016909	0.903936	0.018707
81	0.903275	0.017111	0.903437	0.018941
82	0.903208	0.017139	0.903371	0.018973
83	0.902568	0.017396	0.902735	0.019271
84	0.902383	0.017470	0.902552	0.019358
85	0.903953	0.016616	0.904106	0.018379

3.3.8 Load-flow Convergence for Test Radial Distribution Networks for Constant Power Load Model

Table 3.10 presents value of $\Delta V|_{\max}$ iteration- wise for load-flow convergence of RDN.

Table 3.10: Value of $\Delta V|_{\max}$ Iteration- wise for Seven RDNs by the Proposed Technique for Constant Power Load Model

Iteration wise $\Delta V _{\max}$ values of Distribution Networks [convergence criteria $\Delta V _{\max} \leq 0.000001$]						
13-node	24-node	28-node	33-node	34-node	69-node	85-node
0.005519	0.020951	0.080540	0.080348	0.060149	0.082973	0.113750
0.000112	0.000365	0.006422	0.005896	0.003561	0.007141	0.013183
0.000000	0.000006	0.000519	0.000453	0.000192	0.000631	0.001539
	0.000000	0.000044	0.000035	0.000011	0.000059	0.000195
		0.000004	0.000003	0.000001	0.000005	0.000023
		0.000000	0.000000		0.000000	0.000003
						0.000000

Load-flow technique for 13-node RDN is converged in three iterations. For 24-node RDN, load-flow solution is converged in four iterations. For 28-node RDN, load-flow solution is converged in six iterations. For 33-node RDN, load-flow solution is converged in six iterations. For 34-node RDN, load-flow solution is converged in five iterations. For 69-node RDN, load-flow solution is converged in six iterations and for 85-node RDN, load-flow is converged in seven iterations. Since the initial $\Delta V|_{\max}$ of 34-node RDN is lower compared to that of 28-node RDN and 33-node RDN, that's why it takes less iteration number to converge compared to these two RDNs.

3.3.9 Load-flow Results of 24-node Radial Distribution Network for Different Load Modelling

Table 3.11 shows the load-flow results for 24-node RDN for various types of load modelling to ensure the convergence capacity of the proposed load-flow technique. Load-flow is converged in three or four iterations for different load modelling and minimum voltage is observed at same node, i.e., node number 14. Maximum voltage is observed in case of battery charge type of load modelling and minimum voltage is observed in case of large industrial motor type load modelling.

Table 3.11: Load-flow Results for 24-node RDN for Different Types of Load modelling

Load Modelling	Total Real power load (kW)	Total Reactive power load (kvar)	Total Real power loss (kW)	Total Reactive power loss (kvar)	Minimum voltage in p.u. (node number)	Total number of iteration
Battery charge	2854.27	1271.34	36.052	23.006	0.979697(14)	4
Fluorescent Lamps	2873.58	1285.42	36.675	23.404	0.979501(14)	4
Constant impedance	2875.93	1306.50	36.968	23.591	0.979390(14)	4
Fluorescent lighting	2915.11	1288.37	37.730	24.077	0.979203(14)	4
Air conditioner	2935.11	1296.89	38.324	24.457	0.979027(14)	3
Constant current	2914.82	1324.17	38.128	24.331	0.979042(14)	3
Resistance space heater	2875.37	1342.70	37.370	23.848	0.979229(14)	3
Pumps, fans and other motors	2952.27	1312.93	38.938	24.848	0.978836(14)	4
Incandescent lamps	2893.26	1342.70	37.809	24.128	0.979106(14)	3
Compact fluorescent lamps	2914.73	1336.16	38.264	24.418	0.978988(14)	3
Small industrial motors	2951.43	1331.41	39.129	24.970	0.978758(14)	4
Large industrial motors	2953.50	1333.27	39.203	25.017	0.978735(14)	4

3.3.10 Summary of Load-flow Results of Seven Test Radial Distribution Networks

Table 3.12 shows the total real power load, total reactive power load, total real power loss, total reactive power loss, minimum voltage magnitude (p.u.) along with the node number, and number of iterations to converge for the constant power load model for seven test radial distribution networks.

Table 3.12: Load-flow Results of Seven Test RDNs by the Proposed Techniques for Constant Power Load Model

Test RDN	Total Real Power Load (kW)	Total Reactive Power Load (kvar)	Total Real Power Loss (kW)	Total Reactive Power Loss (kvar)	Minimum Voltage in p.u. (Node Number)	Total number of iterations
13-node	1115.00	4430.00	38.236	12.744	0.994369 (7)	3
24-node	2955.59	1342.70	39.366	25.121	0.978677 (14)	4
28-node	761.04	776.41	68.81	46.04	0.912471(26)	6
33-node	3715.00	2300.00	202.522	135.128	0.913265(18)	6
34-node	4636.50	3633.50	262.702	98.315	0.936087(27)	5
69-node	3801.90	2692.60	224.936	102.130	0.909191(65)	6
85-node	2570.28	2622.21	316.13	198.61	0.871308 (54)	7

3.3.11 Comparison of Suggested Technique with Existing Techniques

Table 3.13 shows the comparison of the relative CPU time/Iteration number (IT no.)/ $\Delta V|_{\max}$ by the proposed technique and the available techniques Satyanarayana *et al.* (2007), Singh and Ghosh (2011) and Singh and Ghose (2013) under the same platform.

Table 3.13: Relative CPU time/ IT number/ $\Delta V|_{\max}$ of the Suggested Technique for Seven Test Distribution Networks with the Existing Techniques

Test Radial Distribution Network	Relative CPU Time/ IT Number/ $\Delta V _{\max}$			
	Proposed method	Satyanarayana <i>et al.</i> (2007)	Singh and Ghosh (2011)	Singh and Ghose (2013)
13-node	1/3/0.005519	1.27/3/0.005548	1.21/3/0.005537	1.31/3/0.005598
24-node	1/4/0.020951	1.39/4/0.020971	1.32/5/0.020972	1.45/5/0.021037
28-node	1/6/0.080540	1.43/6/0.080590	1.37/5/0.080593	1.51/6/0.080658
33-node	1/6/0.080348	1.51/6/0.080375	1.43/6/0.080368	1.57/6/0.080391
34-node	1/5/0.060149	1.56/5/0.060185	1.47/5/0.060176	1.64/6/0.060195
69-node	1/6/0.082973	1.83/6/0.083011	1.71/6/0.082988	1.92/7/0.083029
85-node	1/7/0.113750	1.97/8/0.113786	1.77/8/0.113768	2.10/9/0.113810

From above results, it can be observed that the proposed technique converges the load-flow of distribution networks efficiently. The suggested method takes lesser CPU time as well as iterations, in contrast to the methods of (Satyanarayana *et al.* (2007)), (Singh and Ghosh (2011)) and (Singh and Ghose (2013)) for the radial distribution networks .

3.4 CONCLUSIONS

A novel search technique is proposed to solve load-flow of RDNs. Voltage magnitudes of each node and its voltage angle are computed using the derived equations. The proposed search technique does not require to store the nodes beyond each branch and does not need repetitive search. The voltage convergence criteria are used and this method examined seven examples, including one practical Indian test feeder. The proposed technique takes lesser CPU time as compared to the three methods reported in the literature and has converged for different types of load modelling. The suggested technique is found to be superior to other available methods in terms of relative CPU time and iteration number.

CHAPTER 4

OPTIMAL DG PLACEMENT FOR LOSS REDUCTION

4.1 INTRODUCTION

Distribution system is that constituent of power systems, which is promptly encountering a robust metamorphosis exploiting both topology as well as technological features as compared to other constituents. The premier intention of distribution system is to impart electrical energy to clientele perpetually within admissible extremity. It entails more attentiveness as it directly deals with the end users having wide variations in load levels. Modern distribution systems are heavily burdened as expansion of distribution network is not up to mark as compared to generation and transmission infrastructure. In spite of the fact, it is often the utmost precarious module of power system in terms of its impacts on society. Deregulation has augmented compressions on electric power utilities to censor costs and has attentive prominence on availability, reliability and superiority of power supply. Regulators and utility users are repaying substantial consideration to trustworthiness and quality of electric service. So, it is key requisite that the distribution systems should not be built as well as operated in conventional manner.

Distribution generation (DG) is also known as dispersed generation. DG is an emerging perspective for imparting electrical energy to the clientele as analogized to stereotyped power systems. By amalgamating the DG module accessible to the end users, results in reduced transmission and distribution infrastructure as well as capacity. DG can be defined as small scale power generation situated closer to consumer side of the network i.e., enclosed by distribution networks. The belief behind the DG placement is not contemporary, but gained a momentum after a long gap. Earlier power systems were able to administer only small vicinity and that too for short distances. As generation of electricity is near load centre, losses involved in transmission and distribution of power can be avoided, which otherwise being bulky can reduce the efficiency of power system. Moreover, the instigation of DG's in

distribution systems has reoriented the originality of distribution networks from passive to active. DG is anticipated to execute an escalating contribution in emanating power systems.

Numerous elucidations for DG are interpreted by different associations such as IEEE and CIGRE. DG can be defined as, “*Electric generation that feeds into the distribution grid, rather than the bulk transmission grid, whether on the utility side of the meter or on the customer side.*” Another definition for DG is –“*Distributed generation is considered as an electrical source, connected to the power system, in a point very close to/or customer site, which is small enough compared with the centralized plants.*”

Advancement in technology and the demand of customers for cheap and reliable electric power has led to an increasing interest in DG. Since restricting concepts has already been introduced into existing power systems, DGs have attracted attention for their usage. DG is favourable option due to economical, technical and environmental benefits.

4.2 PROBLEM FORMULATION

The concerns interrelated to reliability and preservation have inhibited the diffusion of DG resources in distribution grids. However, DG placement impacts critically the operation of the distribution network. If the DG is being placed optimally, it will improve the system’s voltage profile and reduce system’s losses. Appropriate allocation of DG reduces the losses of any distribution grid and hence reduces the operating cost.

The real power loss of any system is expressed by Equation (4.1).

$$P_L = \sum_{k=1}^N \sum_{l=1}^N [\alpha_{kl} (P_k P_l + Q_k Q_l) + \beta_{kl} (Q_k P_l + P_k Q_l)] \quad (4.1)$$

$$\text{Where } \alpha_{kl} = \frac{r_{kl}}{V_k V_l} \cos(\delta_k - \delta_l), \beta_{kl} = \frac{r_{kl}}{V_k V_l} \sin(\delta_k - \delta_l)$$

The appropriate placement of DG with rated size not only reduces the net real power loss, but also enhances the node voltage. The following two functions represented by Equation (4.2) and Equation (4.3) are integrated in Equation (4.19) to get fitness function.

$$f_1 = \min[P_L + PE] \quad (4.2)$$

$$f_2 = \max [VP] = \max \left[\frac{|V_f - V_i|}{|V_i|} \right] \quad , i = 1, 2, 3, 4, \dots, N \quad (4.3)$$

PE can be computed from Equation (4.4)

$$PE = h(V) + h(S) + h(IC) + h(IPCC) \quad (4.4)$$

Where

$$h(V) = \sum_{i=1}^N h(V_i) = \begin{cases} K_V \times (V_i^{\min} - V_i)^2 & ; V_i < V_i^{\min} \\ 0 & ; V_i^{\min} \leq V_i \leq V_i^{\max} \\ K_V \times (V_i - V_i^{\max})^2 & ; V_i > V_i^{\max} \end{cases} \quad (4.5)$$

$$h(S) = \sum_{i=1}^{N_s} h(S_i) = \begin{cases} 0 & ; S_i \leq S_i^{\max} \\ K_S \times (S_i - S_i^{\max})^2 & ; S_i > S_i^{\max} \end{cases} \quad (4.6)$$

$$h(IC) = \sum_{i=1}^N h(IC_i) = \begin{cases} 0 & ; IC_i \leq IC_i^{\max} \\ K_{IC} \times (IC_i - IC_i^{\max})^2 & ; IC_i > IC_i^{\max} \end{cases} \quad (4.7)$$

Where

$$IC = \frac{I_{SC,DG}}{I_{SC,Rated}} \times 100 \quad (4.8)$$

$$h(IPCC) = \sum_{i=1}^N h(IPCC_i) = \begin{cases} 0 & ; IPCC_i \leq IPCC_i^{\max} \\ K_{IPCC} \times (IPCC_i - IPCC_i^{\max})^2 & ; IPCC_i > IPCC_i^{\max} \end{cases} \quad (4.9)$$

Where

$$IPCC = \frac{(I_{SC,DG} - I_{SC,noDG})}{I_{SC,noDG}} \times 100 \quad (4.10)$$

Provided the following constraints are satisfied.

$$P_{Gk} - P_{Dk} - \sum_{k=1}^N V_k V_l Y_{kl} \cos(\theta_{kl} - \delta_k + \delta_l) = 0 \quad (4.11)$$

$$Q_{Gk} - Q_{Dk} - \sum_{k=1}^N V_k V_l Y_{kl} \sin(\theta_{kl} - \delta_k + \delta_l) = 0 \quad (4.12)$$

Where $j = 2, \dots, N$

$$P_{G_k}^{\min} \leq P_{G_k} \leq P_{G_k}^{\max} ; \forall_k \in N_G \quad (4.13)$$

$$Q_{G_k}^{\min} \leq Q_{G_k} \leq Q_{G_k}^{\max} ; \forall_k \in N_G \quad (4.14)$$

$$P_{DG_k}^{\min} \leq P_{DG_k} \leq P_{DG_k}^{\max} ; \forall_k \in N_{DG} \quad (4.15)$$

$$Q_{DG_k}^{\min} \leq Q_{DG_k} \leq Q_{DG_k}^{\max} ; \forall_k \in N_{DG} \quad (4.16)$$

$$V_k^{\min} \leq V_k \leq V_k^{\max} ; \forall_k \in N \quad (4.17)$$

$$S_k^{\min} \leq S_k \leq S_k^{\max} ; \forall_k \in N_L \quad (4.18)$$

4.2.1 Proposed Multi DGs Placement and Sizing using Hybrid ABC-CS

In this work, a structure has been suggested for placement of multi DGs and their sizing based on multi objective so that the system's performance is increased. The suggested structure utilizes the hybrid Artificial Bee Colony and Cuckoo Search (ABC-CS) algorithm. ABC algorithm is categorized under swarm intelligence optimization technique, which perpetrates the given assignment by societal coordination. Three versions of bees – employed, onlooker and scout bees perform their specific functions in order to attain destination. The food sites as well as nectar present in food source provide a possible solution to the assigned problem and the fitness or quality of the solution, respectively. As the name suggests, the employed bees explore food sites and contribute guidance to onlooker bees. The scout bees are actually abandoned employed bees, which are searching new food sites. Cuckoo search is a nature inspired optimization algorithm, which is basically based on the method how cuckoos can increase their population instead of laying eggs in host birds. Some species remove other bird's eggs in order to increase hatching probability of their own eggs while others use brood parasitism method of reproduction.

The objectives considered in this proposed framework are to maximize voltage profile and minimize power loss. Based on the multi objective function, ABC-CS algorithm is employed for optimal location of multi DG with suitable size. The architecture of the suggested structure is shown in Figure 4.1.

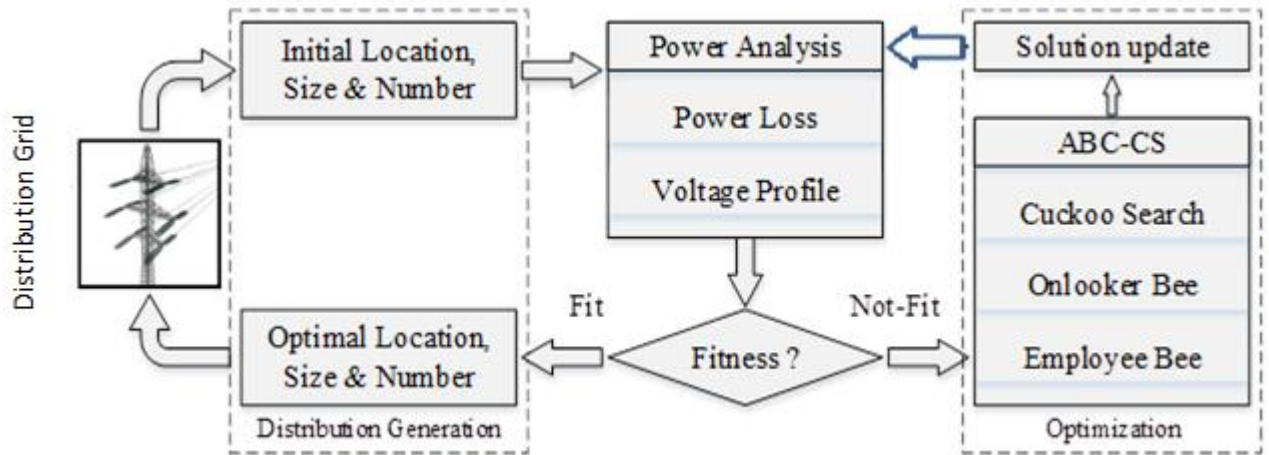


Figure 4.1: Architecture of the Suggested Structure

In the suggested structure, an artificial intelligence based technique is applied for the placement of multi DGs to enhance the functioning of any distribution grid. The detail description of the proposed technique is presented below:

4.2.1.1 Random initialization

In this phase the random initialization of distribution grid’s bus data or food sources is done. The random initial data contain the location, size and number of DG. The format of initial data is shown in Figure 4.2. The initial location is randomly initialized as $1 - B_{num}$ for ‘ B_{num} ’ bus system, size of DG is randomly initialized in the range of 0-2MW, and DG number is randomly initialized between $1 - d_{num}$ for placing ‘ d_{num} ’ DG (s).

Location	Size (0-2 MW)	DG Number
-----------------	----------------------	------------------

Figure 4.2: Format of Initial Data

4.2.1.2 Employed Bee Phase

In this phase for the corresponding initial data (arbitrary food sources) fitness value is computed and the formula to compute the fitness is shown in Equation (4.19). The fitness function ‘ F ’ is formed by combining Equation (4.2) and Equation (4.3).

$$F = \min \left[\frac{f_1}{f_2} \right] \quad (4.19)$$

After finding the fitness of the initial data, the iteration count is established as 1.

4.2.1.3 Onlooker Bee Phase

This phase is to select the best food origins of the obliged optimal location of DG and increases the food origins. The onlooker bee step comes under the cream solution of the suitable location at low power loss and high voltage profile, which enhances the velocity of the populations as expressed by Equation (4.20).

$$V_{m_o} = X_{m_o} + \Phi_{m_o} (X_{m_o} - X_{n_o}) \quad (4.20)$$

Where X_n is the candidate solution ($m \neq n$) that has been selected randomly, Φ_{m_o} represents a random number in the range $[-1, 1]$. A greedy selection is used only after the generation of new candidate solution (V_m).

4.2.1.4 Selection of Optimal Fitness

The optimal fitness of the modified solution can be realized with the help of selection in addition to determine this chance. The probability function is expressed by Equation (4.21).

$$Probability = \frac{fit_i}{\sum_{i=1}^n fit_i} \quad (4.21)$$

4.2.2. CS based Scout Bee Phase

When the onlooker bee step has not accomplished for better options, departs from the particular options and creates the random number of scout bee solution while using the Cuckoo Search (CS) Optimization.

Step 1: Initialization

At first the CS parameters are set. These parameters consist of the “number of nests (n)”, “the step size parameter (α)”, “discovering probability (P_a)” and the termination criteria, which is the maximum number of generation.

Step 2: Generate Initial Nests or Eggs of Host Birds

The initial positions of the nests are specified by the set of random values allocated to each variable presented by Equation (4.22).

$$D_{m,n}^{(0)} = \text{Round} \left(x_{n,\min} + \text{rand} \left(x_{n,\max} - x_{n,\min} \right) \right) \quad (4.22)$$

where ‘ $D_{m,n}^{(0)}$ ’ is the beginning value of the n th variable for the m th nest; $x_{n,\min}$ and $x_{n,\max}$ are the lower and the upper permitted values for the n th variable; ‘ rand ’ is “a random number in the interval $[0, 1]$ ”. Since the problem has discrete nature, the round function is achieved.

Step 3: Step Size Evaluation

In this step, the step sizes for individual parent weights obtained in step 3 are evaluated. The following expressions presented in Equation (4.23) are used to find out the step size.

$$S_z = \alpha S \left(D^t - D_{best}^t \right) r \quad (4.23)$$

Where ‘ S_z ’ is the step size, ‘ α ’ is step size parameter ($\alpha = 0.01$), ‘ D^t ’ is the current parent weight, ‘ D_{best}^t ’ is the foremost result so far, ‘ r ’ is a “random number from a standard normal distribution $[0,1]$ ” and ‘ S ’ is step. The step ‘ S ’ is found out by using the Mantegna’s algorithm, shown in Equation (4.24).

$$S = \frac{u}{|v|^{1/\beta}} \quad (4.24)$$

In Equation (4.24) ‘ β ’ is a parameter arising in the interval $[1, 2]$, which is taken as 1.5. ‘ u ’ and ‘ v ’ are normal distributions, which are estimated as Equation (4.25) and Equation (4.26).

$$u \sim N(0, \sigma_u^2), v \sim N(0, \sigma_v^2) \quad (4.25)$$

$$\sigma_u = \left\{ \frac{\Gamma(1+\beta) \sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left[\frac{(1+\beta)}{2}\right] \beta \cdot 2^{(\beta-1)/2}} \right\}^{1/\beta}, \sigma_v = 1 \quad (4.26)$$

Step 4: Generation of New Solution

In this step, the new optimized solutions or weights are generated for the corresponding parent weights based on the CS algorithm (Levy Flight). The new weights are generated by using the step size values obtained in the step 3. The new weights are generated by using the expression given in Equation (4.27).

$$D^{(t+1)} = D^t + S_z \quad (4.27)$$

Where ‘ $D^{(t+1)}$ ’ is the new weight, ‘ S_z ’ is the step size and ‘ D^t ’ is the current parent weight. From this step, another set of optimized weights are obtained.

Step 5: Ending of CS Process

The termination criteria is tested in this phase. If the process meets termination criterion, it is terminated else, step 3 is started for next iteration.

4.2.3 Termination Criteria

The process is repeated till the maximum number of iteration is attained. If the iteration number is maximum, the process is stopped and the current best solution is retained. Then DG is placed in that appropriate location. The proposed scheme for the optimal placement of multi DGs in RDNs using ABC-CS is described so far and the process flow diagram is presented in Figure 4.3. Initially, the bus data or the distribution grid data are initialized, then the random DG location, DG size and DG number are initialized for the ABC-CS. The fitness value for the corresponding initial value is computed in employee bee phase and based on this some solutions for further processing are selected. Then scout bee phase based on CS is processed to get the optimal DG location, DG size and DG number. The colony size and food number are taken as 20 and 10 respectively. The implementation and performance validation is done in the next section. The details of ABC and CS algorithms are available in

Karaboga *et al.* (2008) and Mohamad *et al.* (2014) respectively. The details of GA and PSO are available in Salama *et al.* (2013).

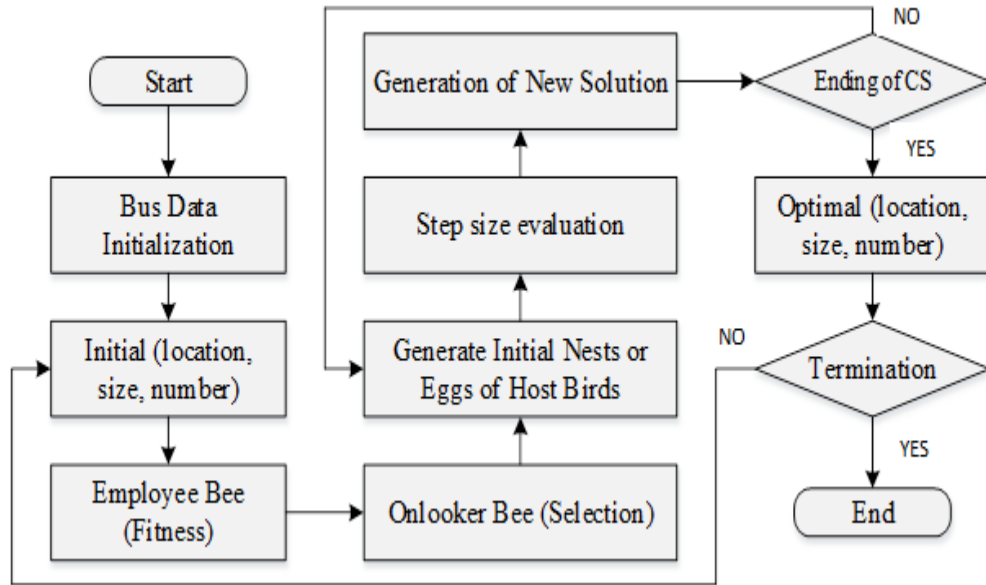


Figure 4.3: Process Flow of Proposed Technique

4.3 SIMULATION RESULTS AND DISCUSSIONS

The suggested technique of the optimal multi DGs placement using ABC-CS is implemented in the MATLAB platform. The proposed technique is tested in the standard two different types of radial distribution networks (30-node and 141-node RDNs). The formulae of the cost of energy loss per annum and DG cost are available in Murthy *et al.* (2013). The load-flow proposed in chapter 3 has been used in this work.

4.3.1 DG Siting and Sizing for 30-node Radial Distribution Network

The first distribution network is a 30-node RDN shown in Figure 4.4 and its system data presented in **Appendix-H** are available in Eminoglu *et al.* (2007) having **100 MVA and 11 kV** as base values. The net load on the system is $8.70 + j 5.37$ MVA. The voltage stability index “VSI” formula available in Eminoglu *et al.* (2007) has been used to detect the most sensitive node. The node having the minimum value of VSI is called the most sensitive node. Before placing DG, the values of minimum voltage and total real power loss were 0.8830

p.u. at node 27 and 0.874 MW, respectively. The energy cost (\$) was 459,374.4. The minimum value of VSI is 0.6071. The stability of the system has been enhanced when the number of DGs is five.

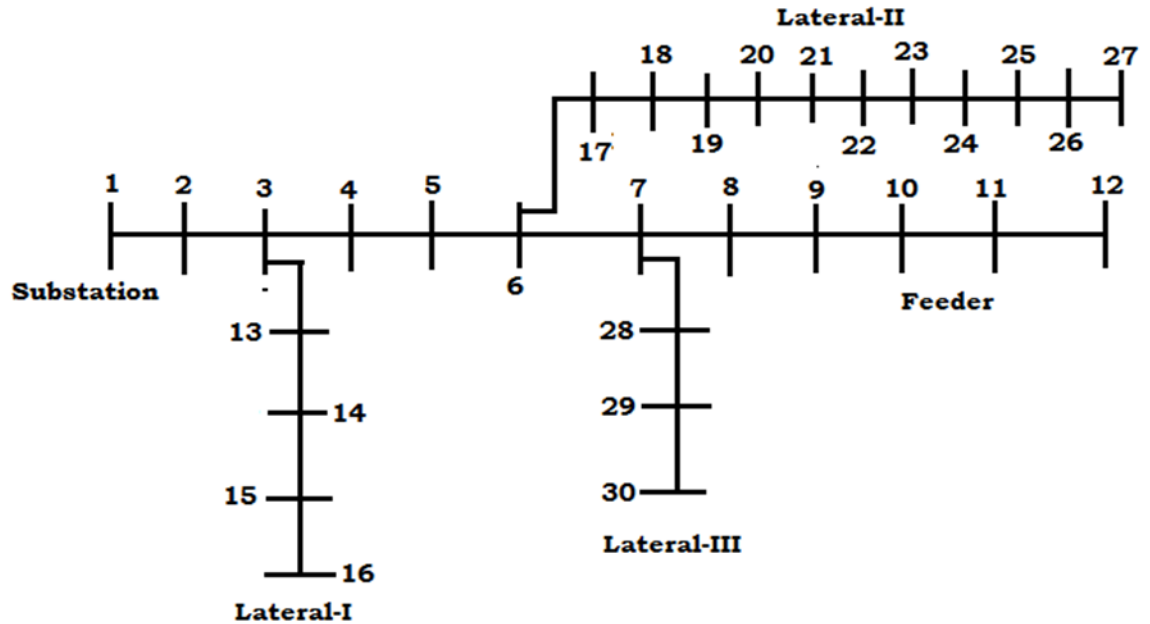


Figure 4.4: 30-node Radial Distribution Network

The performance measures obtained by the proposed ABC-CS technique for the placement of various numbers of DG have been shown in Table 4.1. The minimum voltage has been improved and power loss has been reduced for placing multiple DGs as compared to single DG placement. The energy cost has been reduced. Moreover, the loss reduction percentage is also high due to the placement of multiple DGs. Therefore, the multiple DGs placement enhances the performance of this system. Figure 4.5 shows the outcomes in terms of voltage magnitude (p.u.), VSI and loss of the system (MW) for five cases. Table 4.1 and Figure 4.5 show that the placement of DG not only increases the voltage profile and VSI but also reduces the loss of the system.

Table 4.1: Performance Obtained by Proposed Technique for 30-node RDN

No. of DG	Location (s)	Total DG Size (MW)	Min. Voltage Magnitude (p.u.)	VSI	Power Loss (MW)	% Loss Reduction	Energy Cost (\$)
1	30	1.8	0.8954	0.6213	0.6813	22.04	358,091.28
2	19,21	2.1	0.9387	0.6718	0.4902	43.91	257,649.12
3	7,15,17	2.4	0.9415	0.6825	0.3256	62.74	171,135.36
4	8,10,14,28	2.7	0.9786	0.7013	0.1975	77.40	103,806.00
5	3,11,15,19,28	2.96	0.9802	0.7217	0.0926	89.40	48,670.56

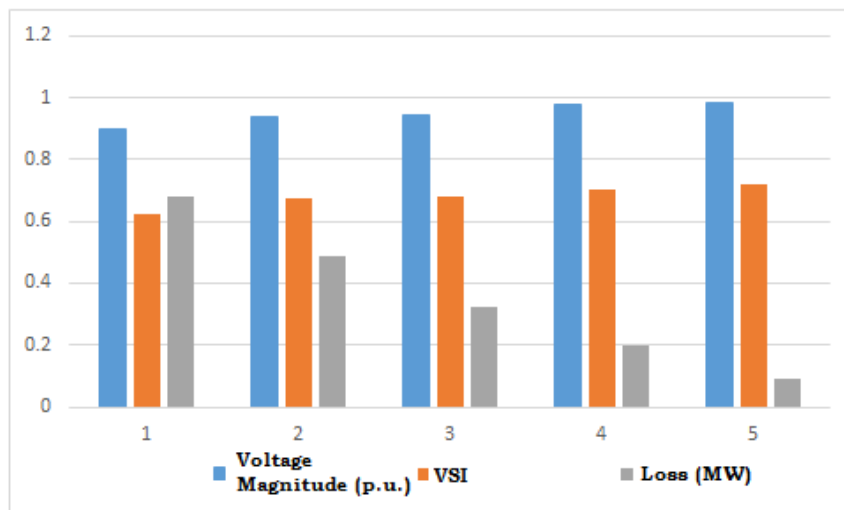
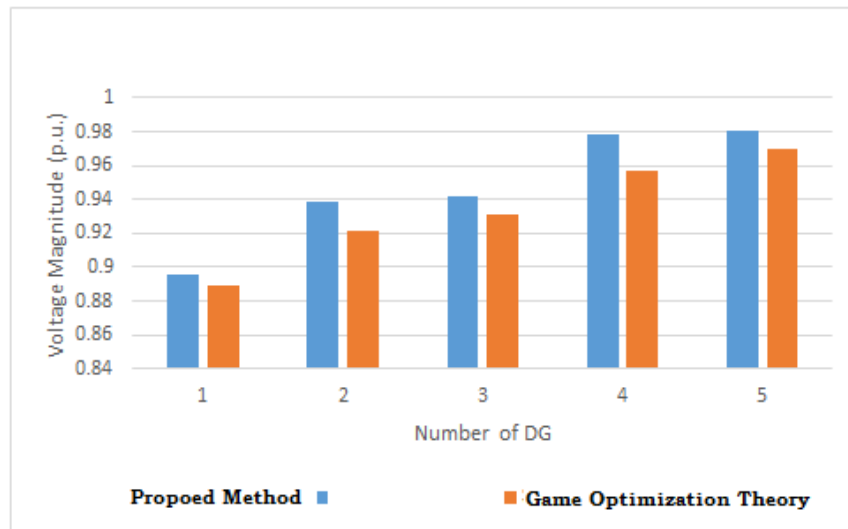


Figure 4.5: Outcomes Obtained by the Proposed Method

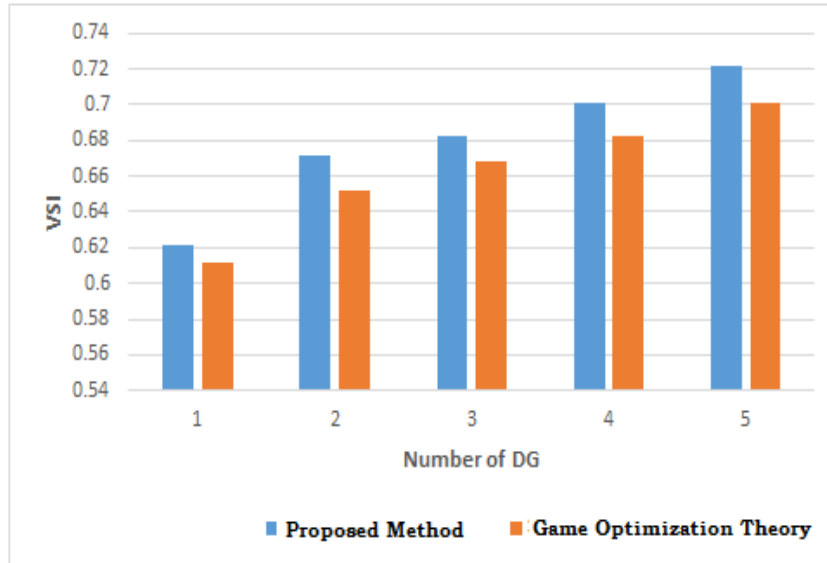
Table 4.2 shows the outcomes obtained by the game optimization theory using the proposed objective function. Figure 4.6 shows a comparison of voltage magnitude (p.u.), VSI and loss of the system (MW) for five cases obtained by the proposed method with that obtained by game optimization theory. The proposed method gives better results compared to that obtained by game optimization theory. Therefore, the appropriate placement and proper optimal sizing of DG can only ensure better loss reduction and improvement of voltage profile and VSI.

Table 4.2: Performance Obtained by Game Optimization Theory for 30-node RDN

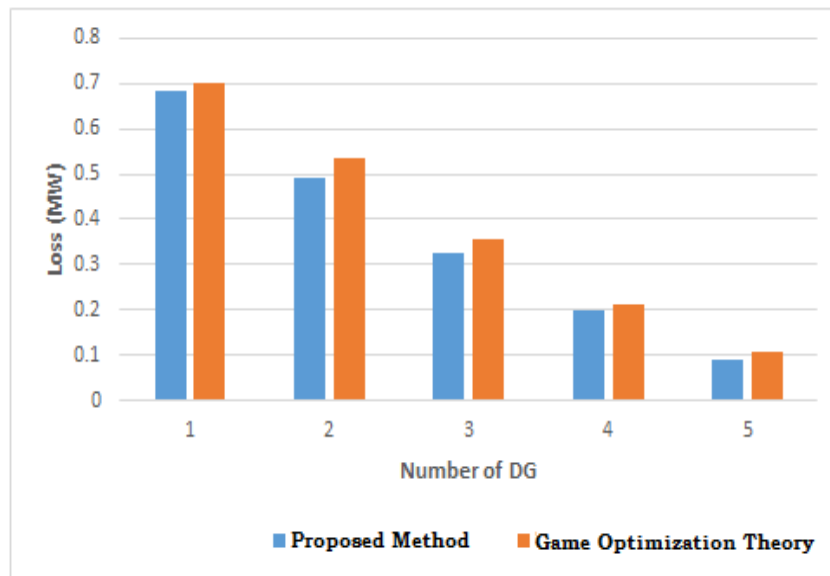
No. of DG	Location	Total DG Size (MW)	Min. Voltage (p.u.)	Voltage Stability Index	Power Loss (MW)
1	29	2.20	0.8891	0.6117	0.7013
2	17, 20	2.62	0.9213	0.6521	0.5328
3	6,8,13	3.00	0.9316	0.6682	0.3576
4	6,9,11,17	3.43	0.9568	0.6826	0.2143
5	4,10,13,16,23	3.78	0.9694	0.7012	0.1087



(a) Voltage Magnitude



(b) Voltage Stability Index



(c) Loss of the system (MW)

Figure 4.6: Comparison of Proposed Method with Game Optimization Theory

4.3.2 DG Siting and Sizing for 141-node Radial Distribution Network

The second distribution network is a 141-node RDN as shown in Figure 4.7 and its system data presented in **Appendix-I** are available in Khodr *et al.* (2008). The base kV is **12.47 kV** and base MVA is **100 MVA**. The net load of the system is (12.19 + j 6.289) MVA.

Before placing DG, the values of minimum voltage and total real power loss were 0.7752 p.u. at node 124 and 0.116 MW respectively. The energy cost was (\$) 60,969. In Table 4.3, the performance measures obtained by the proposed ABC-CS technique for the placement of various numbers of DG have been shown. The minimum voltage has been improved and power loss has been reduced for placing multiple DGs as compared to single DG placement. The energy cost has been reduced. Moreover, the loss reduction percentage is high due to placement of multiple DGs. Therefore, the placement of the multiple DGs enhances the performance of this distribution grid.

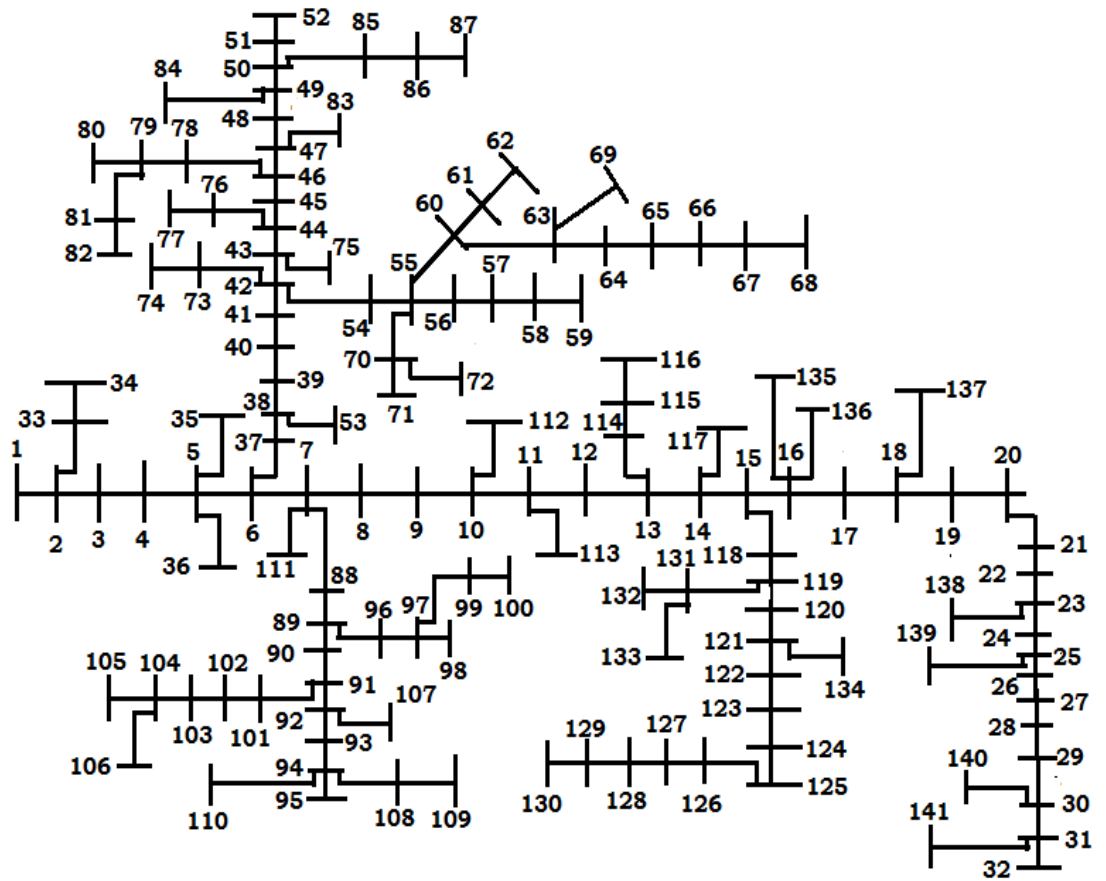


Figure 4.7: 141-node Radial Distribution Network

Table 4.3: Performance Obtained by Proposed Technique for 141-node RDN

No. of DG	Location	Total DG Size (MW)	Min. Voltage (p.u.)	Power Loss (MW)	% Loss Reduction	Energy Cost (\$)
1	65	1.97	0.9143	0.0754	35.00	39,630.24
2	48, 82	2.6	0.9278	0.0626	46.03	32,902.56
3	25,78,94	3.35	0.9658	0.0380	67.24	19,972.80
4	16,24,28,60	4.25	0.9711	0.0278	76.03	14,611.68
5	16,24,60,89,94	4.75	0.9786	0.02204	81.00	11,584.224

4.3.3 Performance Comparison

The performance measures of the proposed method are juxtaposed with the existing GA-PSO, PSO and GA for the placement of three DG as shown in Table 4.4 for the above two distribution grids using the same objective function. The overall performance of PSO is comparatively better than that of GA-based placement of DGs. The overall performance of GA-PSO is comparatively better than that of PSO-based placement of DGs, but the performance of the suggested method is better than the GA-PSO. Hence the proposed ABC-CS method to place DGs is better than these three techniques.

The real power loss reduction by the suggested method is higher than that obtained by GA-PSO, PSO and GA for the examples considered. The minimum voltage for each case have been improved by the suggested method as compared to GA-PSO, PSO and GA. The DG cost and energy cost achieved by the suggested method are lower than that achieved by GA-PSO, PSO and GA. The performance analysis clearly shows that the proposed method (ABC-CS) has better performance in all aspects of the placement of single or multiple DGs placement in RDNs.

Table 4.4: Performance Comparison of the Proposed Method (PM) with GA, PSO and GA-PSO with Three DGs

Networks →	30-node RDN				141-node RDN			
Parameters ↓	PM	GA-PSO	GA	PSO	PM	GA-PSO	PSO	GA
Location	7,15,17	8,12,21	13,15,20	8,15,25	25,78,94	25,98,132	37,98,121	25,69,99
Total DG Size (MW)	2.40	2.52	2.65	2.57	3.35	3.5	3.6	3.7
Minimum Voltage (p.u.)	0.9415	0.9376	0.9324	0.9358	0.9658	0.9513	0.9487	0.9410
Power Loss (MW)	0.3256	0.3572	0.3987	0.3734	0.038	0.0435	0.0464	0.0489
% Loss reduction	62.74	59.13	54.32	57.27	67.24	62.5	60.00	57.84
DG Cost (\$/h)	48.25	50.65	53.25	51.65	67.25	70.25	72.25	74.25
Energy Cost (\$)	171,135.3	187,744.3	209,556.7	196,364.1	19,972.8	22,863.6	24,387.84	37,212.48

4.3.4 Performance on Different Loads

In order to check the performance of the suggested method practical voltage dependent load models, i.e., residential, industrial, and commercial, have been considered as given in EI-Zonkoly (2011). The exponent values of the real power (α) and reactive power (β) for industrial, residential, and commercial loads are 0.18 and 6, 0.92 and 4.04; and 1.51 and 3.4, respectively.

Here a 30-node RDN is considered for load modelling. The size and location of DG for 30-node RDN are shown in Table 4.5.

Table 4.5: Results of 30-node RDN under Different Types of Load

Parameters	Load Type					
	Industrial Load		Residential Load		Commercial	
	Excluding DG	Including DG	Excluding DG	Including DG	Excluding DG	Including DG
DG Location	-	8,15,25	-	8,17,20	-	7,17,21
Total DG Size (MW)	-	1.80	-	2.04	-	2.43
Minimum Voltage (p.u.)	0.8953 (27)	0.9489 (24)	0.9100 (27)	0.9578 (26)	0.8969 (27)	0.9512 (25)
Power Loss (MW)	0.681	0.289	0.580	0.245	0.663	0.259
DG Cost (\$/h)	-	36.25	-	41.05	-	48.85
Energy Cost (\$)	357,933.6	151,898.4	304,848	128,772	348,472.8	136,130.4

4.3.5 DG Placement Comparison with Other Methods

The outcomes of 30-node RDN obtained by the suggested method have been correlated with the other existing methods Hung *et al.*(2013), Kaur *et al.*(2014) and Kansal *et al.*(2016) in terms of loss reduction, DG size, DG cost and energy cost as shown in Table 4.6. The proposed method gives lesser losses and less DG size as compared to the above mentioned methods.

Table 4.6: Comparison of Proposed Method for DG Placement with Available Methods for 30-node RDN

Method	Real Power Loss (MW)	DG Locations	Total DG Size (MW)	DG Cost (\$/h)	Energy Cost (\$)
Proposed Method	0.3256	7,15,17	2.40	48.25	171135.36
Hung <i>et al.</i> (2013)	0.3285	5,9,28	2.54	51.05	172659.60
Kaur <i>et al.</i> (2014)	0.3325	6,14,18	2.83	56.85	174762.00
Kansal <i>et al.</i> (2016)	0.3310	8,14,20	2.77	55.65	173973.60

4.4 CONCLUSIONS

Placement of multiple DGs is encouraged in RDNs to reduce power losses and improve voltage magnitude. Interconnecting a single large size DG in any RDN cannot give the expected loss reduction. Hence, multiple small sized DGs are placed in the distribution system to achieve the maximum loss reduction. In this work, a hybrid optimization technique based on the ABC and CS algorithms to place multiple DGs in distribution grids has been used. The suggested method provides better performance in all aspects than that obtained by using GA-PSO, PSO and GA in terms of minimum voltage, power loss, percentage loss reduction, DG cost and energy cost. The suggested method also reduces the loss to a minimum level when placing five DGs. The suggested method has been juxtaposed with other available methods reported in literature to show its effectiveness for a 30-node RDN.

CHAPTER 5

VOLTAGE STABILITY INDEX OF RADIAL DISTRIBUTION NETWORKS

5.1 INTRODUCTION

Reliability and stability are also important parameters for power systems and should be satisfied. By reliability, it is meant that the system has adequate reserves in the face of changing energy demand. By stability, it is meant that upon occurrence of a contingency, when the system could recover to its original state and supply the same quality service upon occurrence of a contingency. The attributes of all these objectives can be achieved by proper planning, operation and control of power generation, transmission and distribution systems. Power system stability is complicated term, which is strenuous to perceive and challenging to peruse.

Distribution systems under precise pivotal loading circumstances, practice voltage collapse followed by system devastation. A system is said to be voltage stable when after a perturbation, the resulting voltage is in the close proximity of the original one. Voltage stability of power systems propounds an intelligible interpretation of voltage instability, which is a pre-eminent complication that can expedite a comprehensive system disintegration. Voltage instability is due to inability of power system to maintain steady-state voltage at all buses following a disturbance, increased in load demand or change in final operating condition from a given initial operating condition. The main factor that causes voltage instability is inefficiency of distribution system to accommodate the reactive power demand. Voltage stability is occasionally also known as load stability. Hence, by analysing the load, the voltage stability of a distribution system can be determined.

Voltage stability problems are considered as one of the elemental problems that may occur in power system when there is an increase in load demand. In this case, some or all bus voltages decrease due to insufficient power delivered to loads and even serious blackouts may occur in a

considerable part of a system. In fact, several cases of voltage instability or voltage collapse were reported. When the necessity of electricity to industry and community in all fields of the life is considered, the importance of a blackout can be understood more easily. Therefore, special analysis should be performed in order to examine the voltage stability in power systems. The analysis of voltage stability for a given system state involves the examination of two aspects:

- Proximity: how close is the system to voltage instability?
- Mechanism: when, why and how voltage instability occurs? What are the key contributing factors? What are the voltage-weak points, and what areas are involved?

The following are the causes of voltage instability:

1. The load on distribution line is too high.
2. The voltage sources are too far from the load centers.
3. The source voltages are too low.
4. There is insufficient load reactive compensation.

Voltage stability analysis is currently one of the most significant fields of research in the power systems area. In the last few years, many contributions to a better knowledge of the various aspects of voltage problems have been reported in the literature, where the problem has been explored from many different points of view. Voltage collapse in addition, has been an active subject of research for years. The literature survey shows that the voltage stability analysis or detection of most sensitive node of the distribution network had been done using the reduced network and failed to incorporate to use the voltage angle. They had simplified the equation neglecting the voltage angle. The reported literature shows that it is an obligation for researchers for continuous improvement of voltage stability of electric power distribution systems.

The proposed work endeavors to derive a new expression of voltage stability index (VSI) and its applications in planning of power distribution system. The objectives are divided into the following:

- To derive a new expression of VSI to be computed for all nodes of the distribution networks.

- To identify the most sensitive nodes of distribution networks.

5.2 ASSUMPTIONS FOR DERIVING VOLTAGE STABILITY INDEX

Before deriving voltage stability index, the following assumptions are to be taken into account.

- The distribution system under consideration is assumed to be working in balanced mode
- Single line diagram can be used for analytical purposes

5.3 PROBLEM FORMULATION

In order to improve the efficiency of power system, voltage stability index is derived. Voltage stability is the major parameter to check the efficient working of network.

5.3.1 Analytical Expression for Voltage Stability Index

Figure 5.1 shows a two bus system of a distribution network.

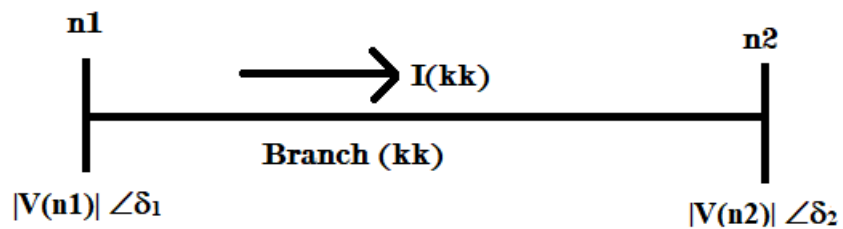


Figure 5.1: Two Bus System of Radial Distribution Network

From Figure 5.1, the current and power can be computed using Equation (5.1) and Equation (5.2).

$$I(kk) = \frac{|V(n1)| \angle \delta(n1) - |V(n2)| \angle \delta(n2)}{Z(kk)} \quad (5.1)$$

$$P(n2) - jQ(n2) = V^*(n2) \times I(kk) \quad (5.2)$$

Where $Z(kk) = R(kk) + j X(kk)$, ‘n1’ and ‘n2’ are the respective source and sink nodes of branch kk. ‘I(kk)’ is the current passing through the branch kk, ‘V(i)’ is the voltage magnitude of the ith node, ‘ $\delta(n1)$ ’ is the voltage angle of node n1, ‘ $\delta(n2)$ ’ is the voltage angle of node n2, ‘R(kk)’ and ‘X(kk)’ are the respective resistance and reactance of the branch kk.

From Equation (5.1),

$$\begin{aligned} |V(n1)| \angle \delta(n1) &= |V(n2)| \angle \delta(n2) + I(kk)Z(kk) \\ &= |V(n2)| \angle \delta(n2) + |I(kk)| \angle \theta |Z(kk)| \angle \phi \\ &= |V(n2)| \angle \delta(n2) + |I(kk)| |Z(kk)| \angle (\theta + \phi) \end{aligned}$$

$$\text{Where } \theta = \tan^{-1} \frac{I_m(kk)}{I_r(kk)} \text{ and } \phi = \tan^{-1} \frac{X(kk)}{R(kk)}$$

$I_m(kk)$ and $I_r(kk)$ are the imaginary and real parts of I(kk)

$$|V(n2)| \angle \delta(n2) = |V(n1)| \angle \delta(n1) - |I(kk)| |Z(kk)| \angle (\theta + \phi)$$

$$\begin{aligned} |V(n2)| \cos \delta(n2) + j |V(n2)| \sin \delta(n2) &= |V(n1)| \cos \delta(n1) + j |V(n1)| \sin \delta(n1) \\ &\quad - |I(kk)| |Z(kk)| \cos(\theta + \phi) - j |I(kk)| |Z(kk)| \sin(\theta + \phi) \end{aligned}$$

$$|V(n2)| \cos \delta(n2) = |V(n1)| \cos \delta(n1) - |I(kk)| |Z(kk)| \cos(\theta + \phi) \quad (5.3)$$

$$|V(n2)| \sin \delta(n2) = |V(n1)| \sin \delta(n1) - |I(kk)| |Z(kk)| \sin(\theta + \phi) \quad (5.4)$$

From Equation (5.3) and Equation (5.4)

$$|V(n2)|^2 = |V(n1)|^2 - 2 |V(n1)| |I(kk)| |Z(kk)| \cos\{\delta(n1) - \theta - \phi\} + |I(kk)|^2 |Z(kk)|^2$$

$$|V(n2)| = \sqrt{\left\{ |V(n1)|^2 - 2 |V(n1)| |I(kk)| |Z(kk)| \cos\{\delta(n1) - \theta - \phi\} + |I(kk)|^2 |Z(kk)|^2 \right\}} \quad (5.5)$$

$$\delta(n2) = \tan^{-1} \left\{ \frac{|V(n1)| \sin \delta(n1) - |I(kk)| |Z(kk)| \sin(\theta + \phi)}{|V(n1)| \cos \delta(n1) - |I(kk)| |Z(kk)| \cos(\theta + \phi)} \right\} \quad (5.6)$$

Here $|V(n2)| \geq 0$ in practice. Therefore,

$$|V(n1)|^2 - 2|V(n1)||I(kk)||Z(kk)|\cos\{\delta(n1) - \theta - \phi\} + |I(kk)|^2 |Z(kk)|^2 \geq 0 \quad (5.7)$$

Hence, voltage stability index (VSI) at receiving end node n2 is given by,

$$VSI(n2) = |V(n1)|^2 - 2|V(n1)||I(jj)||Z(jj)|\cos\{\delta(n1) - \theta - \phi\} + |I(jj)|^2 |Z(jj)|^2 \geq 0 \quad (5.8)$$

From Equation (5.8), the voltage stability index of any network can be determined.

The voltage stability index proposed by Das *et al.* (2001) [Method-1] is given by Equation (5.9).

$$VSI(n2) = \left[|V(n1)|^4 - 4.0\{P(n2)X(kk) - Q(n2)R(kk)\} \right]^2 - 2.0\{P(n2)R(kk) + Q(n2)X(kk)\}|V(n1)|^2 \quad (5.9)$$

The voltage stability index proposed by Ranjan and Das (2003) [Method-2] is given by Equation (5.10).

$$VSI(n2) = 0.5|V(n2)|^2 - P(n2)R(kk) - Q(n2)X(kk) \quad (5.10)$$

The voltage stability index proposed by Eminoglu and Hocaoglu (2009) [Method-3] is given by Equation (5.11).

$$VSI(n2) = 2|V(n1)|^2 |V(n2)|^2 - |V(n2)|^4 - 2|V(n2)|^2 [P(n2)R(kk) + Q(n2)X(kk)] - [R^2(kk) + X^2(kk)][P^2(n2) + Q^2(n2)] \quad (5.11)$$

The proposed voltage stability index given by Equation (5.8), incorporates the voltage angle of the sending- end node. Hence this one will give more exact results.

The active and reactive power losses of branch kk are given in Equation (5.12) and Equation (5.13) respectively.

$$LP(kk) = \frac{R(kk) \times [P^2(n2) + Q^2(n2)]}{V(n2)^2} \quad (5.12)$$

$$LQ(kk) = \frac{X(kk) \times [P^2(n2) + Q^2(n2)]}{V(n2)^2} \quad (5.13)$$

5.3.2 Proposed Algorithm to Compute Voltage Stability Index

The algorithm to compute the new voltage stability index is based on the proposed load-flow, which is discussed under Section 3.2 of Chapter 3.

The steps of algorithm used to compute VSI are presented below.

Step-1	:	START
Step-2	:	Read line data and load data of the system
Step-3	:	Read base values of the system, convergence factor ($\epsilon=0.000001$) and ITMAX.
Step-4	:	Convert the line data and load data into its per unit value
Step-5	:	Make $V(i) = 1 + j0$ for $i = 1, 2, 3 \dots NN$.
Step-6	:	Compute $VV(i) = V(i) $ and $VV1(i) = VV(i)$
Step-7	:	IT=1
Step-8	:	Use the search technique to form the array of feeder, lateral and sublateral and to link them.
Step-9	:	Compute the current for each branch
Step-10	:	Compute the voltage magnitude $VV(i)$ of each node using Equation (5.5)
Step-11	:	Compute the voltage angle of each node using Equation (5.6).
Step-12	:	Compute $\Delta V(i) = VV(i) - VV1(i) $ for each node.
Step-13	:	Find the max value of $\Delta V(i)$.
Step-14	:	If $\Delta V(i)_{\max} \leq \epsilon$, GO TO Step-18.
Step-15	:	Make $VV1(i) = VV(i)$ for all i .
Step-16	:	IT = IT+1
Step-17	:	If (IT \leq ITMAX), GO TO Step-9, Else Display Not Converged and GO TO Step-21.
Step-18	:	Compute the values of VSI (n_2) using Equation (5.8), Equation (5.9), Equation (5.10) and Equation (5.11). Also compute real and reactive power losses of each branch using Equation (5.12) and Equation (5.13).
Step-19	:	Compute the total real power loss and total reactive power loss of the system.
Step-20	:	Display the RESULTS
Step-21	:	STOP

5.3 SIMULATION RESULTS AND DISCUSSIONS

Total seven RDNs have been considered, which are 13-node, 24-node, 28-node, 33-node, 34-node, 69-node and 85-node. Here, 33-node and 69-node are the IEEE data bus.

5.3.1 VSI of 13-node RDN

Table 5.1 shows the VSI of each node of 13-node RDN obtained by the proposed method, Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan and Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)). The bold faced value is the minimum value of voltage stability index which symbolizes the most sensitive node of the network.

Table 5.1: VSI of 13-node RDN by the Proposed Method, Method-1, Method-2, and Method-3

Node Number	VSI values			
	Proposed method	Method-1	Method-2	Method-3
2	0.994268	0.999566	0.497025	0.999751
3	0.993272	0.987441	0.496353	0.988005
4	0.992691	0.985436	0.496056	0.986012
5	0.990868	0.988308	0.495369	0.988427
6	0.989605	0.980486	0.494466	0.981152
7	0.988769	0.977657	0.493968	0.978490
8	0.990554	0.981198	0.495120	0.981509
9	0.992476	0.987786	0.496041	0.988175
10	0.991549	0.983165	0.495312	0.984089
11	0.989603	0.980313	0.494422	0.981066
12	0.989375	0.978862	0.494573	0.979088
13	0.989343	0.978800	0.494542	0.979057

Node number (7) is having minimum value of VSI for proposed method, Method-1, Method-2 and Method-3. Hence, it is most sensitive node of 13-node RDN. Proposed method is having improved value of VSI for most sensitive node as compared to other three methods.

5.3.2 VSI of 24-node RDN

Table 5.2 shows the VSI of each node of 24-node RDN obtained by the proposed method, Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan and Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)). The bold faced value is the minimum value of voltage stability index which symbolizes the most sensitive node of the network.

Table 5.2: VSI of 24-node RDN by the Proposed Method, Method-1, Method-2, and Method-3

Node Number	VSI values			
	Proposed method	Method-1	Method-2	Method-3
2	0.992980	0.998766	0.496182	0.999338
3	0.983418	0.984915	0.491434	0.985376
4	0.979827	0.966353	0.489721	0.966720
5	0.975497	0.959775	0.487676	0.959900
6	0.973408	0.951128	0.486585	0.951357
7	0.971560	0.947154	0.485685	0.947335
8	0.967720	0.939761	0.483615	0.940233
9	0.965184	0.934904	0.482184	0.935689
10	0.962895	0.931502	0.481427	0.931536
11	0.960087	0.926642	0.479908	0.926897
12	0.959581	0.921679	0.479767	0.921723
13	0.958201	0.920594	0.479048	0.920693
14	0.957809	0.917398	0.478709	0.917773
15	0.978638	0.958696	0.489222	0.958887
16	0.978146	0.956771	0.488827	0.957252
17	0.978852	0.958888	0.489378	0.958983
18	0.978351	0.957171	0.488925	0.957662
19	0.966522	0.939060	0.482835	0.939877
20	0.966101	0.933824	0.482962	0.933994
21	0.965612	0.932407	0.482562	0.932879
22	0.958035	0.917830	0.478934	0.917989
23	0.979325	0.960060	0.489663	0.960060
24	0.969903	0.943929	0.484952	0.943926

Node number (14) is having minimum value of VSI for proposed method, Method-1, Method-2 and Method-3. Hence, it is most sensitive node of 24-node RDN. Proposed method is having improved value of VSI for most sensitive node as compared to other three methods.

5.3.3 VSI of 28-node RDN

Table 5.3 shows the VSI of each node of 28-node RDN obtained by the proposed method, Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan and Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)). The bold faced value is the minimum values of voltage stability index which symbolizes the most sensitive node of the network.

Table 5.3: VSI of 28-node RDN by the Proposed Method, Method-1, Method-2, and Method-3

Node Number	VSI			
	Proposed Method	Method-1	Method-2	Method-3
2	0.995965	0.999723	0.4979`13	0.999846
3	0.987514	0.991507	0.493647	0.991657
4	0.978354	0.974601	0.489029	0.974811
5	0.970459	0.956556	0.485071	0.956806
6	0.947948	0.940746	0.473705	0.940774
7	0.937083	0.897536	0.468259	0.897959
8	0.931389	0.877460	0.465518	0.877762
9	0.924452	0.866931	0.462077	0.867163
10	0.916472	0.853621	0.457968	0.854057
11	0.908632	0.838613	0.453960	0.839211
12	0.899680	0.822039	0.448857	0.823762
13	0.895855	0.807814	0.447480	0.808608
14	0.891677	0.800614	0.445296	0.801572
15	0.889618	0.794642	0.444684	0.794861
16	0.887582	0.790777	0.443610	0.791095
17	0.886387	0.786950	0.442954	0.787375
18	0.885793	0.784629	0.442599	0.785156
19	0.989184	0.988219	0.493657	0.990050
20	0.985155	0.974856	0.491661	0.976661
21	0.982190	0.967613	0.490355	0.969068
22	0.981296	0.962941	0.490201	0.963819
23	0.933885	0.876328	0.466463	0.877219
24	0.931338	0.870427	0.465210	0.871279
25	0.929040	0.865951	0.464134	0.866667
26	0.927124	0.859551	0.462606	0.861336
27	0.913775	0.842247	0.453545	0.848377
28	0.908992	0.826255	0.452108	0.830614

From Table 5.3, it is clear that node number (18) is having minimum value of VSI for proposed method, Method-1, Method-2 and Method-3. Hence, it is most sensitive node of 28-node RDN. Proposed method is having improved value of VSI for most sensitive node as compared to other three methods.

5.3.4 VSI of 33-node RDN

Table 5.4 shows the VSI of each node of 33-node RDN obtained by the proposed method and the Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan & Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)). The bold faced value is the minimum values of voltage stability index which symbolizes the most sensitive node of the network.

Table 5.4: VSI of 33-node RDN by the Proposed Method, Method-1, Method-2, and Method-3

Node Number	VSI			
	Proposed Method	Method-1	Method-2	Method-3
2	0.994074	0.999700	0.496962	0.999816
3	0.966168	0.986832	0.482745	0.986747
4	0.951517	0.932063	0.475391	0.932568
5	0.937141	0.904703	0.468392	0.904843
6	0.901855	0.876754	0.450533	0.876276
7	0.895247	0.811105	0.447004	0.812188
8	0.886105	0.797763	0.442018	0.799550
9	0.874344	0.783488	0.436694	0.784208
10	0.863815	0.762839	0.431439	0.763557
11	0.862217	0.745943	0.431041	0.746057
12	0.859435	0.742841	0.429550	0.743123
13	0.848140	0.735872	0.423268	0.737140
14	0.843971	0.716758	0.421224	0.718038
15	0.841378	0.711429	0.420435	0.711852
16	0.838871	0.706749	0.419088	0.707328
17	0.835163	0.701364	0.416884	0.702526
18	0.834054	0.695645	0.416473	0.696571
19	0.993020	0.987661	0.496379	0.987921
20	0.985903	0.981390	0.491768	0.983704
21	0.984504	0.970626	0.491903	0.971314
22	0.983240	0.966759	0.490988	0.968004
23	0.959132	0.932130	0.479216	0.932761

24	0.946110	0.907509	0.469817	0.913626
25	0.939652	0.882925	0.466603	0.889014
26	0.898194	0.813010	0.449005	0.813163
27	0.893342	0.806290	0.446542	0.806499
28	0.871848	0.796226	0.435411	0.796702
29	0.856568	0.756952	0.427376	0.758329
30	0.849996	0.728214	0.423397	0.730940
31	0.842341	0.717962	0.419838	0.720188
32	0.840661	0.707406	0.419698	0.708471
33	0.840141	0.705837	0.419811	0.706274

Node number (18) is having minimum value of VSI for proposed method, Method-1, Method-2 and Method-3. Hence, it is most sensitive node of 33-node RDN. Proposed method is having improved value of VSI for most sensitive node as compared to other three methods.

5.3.5 VSI of 34-node RDN

Table 5.5 shows the VSI of each node of 34-node RDN obtained by the proposed method and the Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan & Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)). The bold faced value is the minimum values of voltage stability index which symbolizes the most sensitive node of the network.

Table 5.5: VSI of 34-node RDN by the Proposed Method, Method-1, Method-2, and Method-3

Node Number	VSI			
	Proposed Method	Method-1	Method-2	Method-3
2	0.987606	0.998809	0.493505	0.999258
3	0.976880	0.975366	0.488440	0.975251
4	0.962454	0.952786	0.480841	0.953343
5	0.950134	0.924965	0.474716	0.925498
6	0.938604	0.902755	0.469302	0.902622
7	0.923439	0.880978	0.461719	0.880748
8	0.919281	0.851056	0.459185	0.851884
9	0.909585	0.839764	0.453348	0.842353
10	0.907271	0.827345	0.453636	0.827340
11	0.906372	0.822106	0.452901	0.822623
12	0.906109	0.821034	0.452923	0.821272
13	0.975647	0.953536	0.487630	0.953914
14	0.975042	0.951348	0.487383	0.951618

15	0.974878	0.950438	0.487370	0.950573
16	0.974866	0.950363	0.487427	0.950376
17	0.929546	0.879406	0.464354	0.880117
18	0.922013	0.862621	0.460621	0.863288
19	0.913830	0.848378	0.456446	0.849184
20	0.907275	0.833525	0.453211	0.834268
21	0.901599	0.821599	0.450373	0.822346
22	0.895196	0.810829	0.447029	0.811821
23	0.889955	0.799339	0.444409	0.800335
24	0.879773	0.786876	0.438442	0.789372
25	0.877421	0.772397	0.438255	0.773195
26	0.876522	0.768867	0.437976	0.769367
27	0.876258	0.767829	0.437998	0.768059
28	0.923005	0.852472	0.461430	0.852606
29	0.922716	0.851672	0.461286	0.851806
30	0.922500	0.851007	0.461142	0.851206
31	0.906618	0.822845	0.453227	0.822993
32	0.905962	0.821559	0.452872	0.821757
33	0.905635	0.820471	0.452736	0.820619
34	0.905526	0.819978	0.452709	0.820077

Node number (27) is having minimum value of VSI for proposed method, Method-1, and Method-3. For Method-2, it is node number 26. Hence, node number (27) is most sensitive node of 34-node RDN for all methods except Method-2. Proposed method is having improved value of VSI for most sensitive node as compared to other three methods.

5.3.6 VSI of 69-node RDN

Table 5.6 shows the VSI of each node of 69-node RDN obtained by the proposed method and the Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan and Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)). The bold faced value is the minimum values of voltage stability index which symbolizes the most sensitive node of the network.

Node number (65) is having minimum value of VSI for proposed method, Method-1, and Method-3. For Method-2, it is node number 61. Hence, node number (65) is most sensitive node of 69-node RDN for all the methods except Method-2. Proposed method is having improved value of VSI for most sensitive node as compared to other three methods.

Table 5.6: VSI of 69-node RDN by the Proposed Method, Method-1, Method-2, and Method-3

Node Number	VSI			
	Proposed Method	Method-1	Method-2	Method-3
2	0.999933	1.000000	0.499967	1.000000
3	0.999866	0.999866	0.499933	0.999866
4	0.999679	0.999732	0.499839	0.999732
5	0.998042	0.999358	0.499021	0.999355
6	0.980273	0.996054	0.490128	0.995755
7	0.961960	0.960415	0.480848	0.960344
8	0.957619	0.925140	0.478750	0.925235
9	0.955402	0.916985	0.477688	0.917004
10	0.945659	0.912124	0.472654	0.912367
11	0.943519	0.893478	0.471550	0.893871
12	0.937393	0.887224	0.467900	0.888698
13	0.931745	0.878473	0.465810	0.878558
14	0.926162	0.867914	0.463018	0.868000
15	0.920650	0.857777	0.460325	0.857746
16	0.919628	0.847347	0.459746	0.847471
17	0.917941	0.845101	0.458804	0.845406
18	0.917924	0.842609	0.458960	0.842613
19	0.917035	0.842585	0.458517	0.842584
20	0.916464	0.840947	0.458230	0.840950
21	0.915542	0.838806	0.457471	0.839355
22	0.915529	0.838215	0.457764	0.838216
23	0.915391	0.838193	0.457696	0.838193
24	0.915092	0.837667	0.457471	0.837804
25	0.914768	0.837393	0.457384	0.837393
26	0.914635	0.836679	0.457284	0.836740
27	0.914598	0.836489	0.457280	0.836523
28	0.999852	0.999724	0.499924	0.999728
29	0.999709	0.999590	0.499826	0.999647
30	0.999467	0.999418	0.499733	0.999418
31	0.999424	0.998933	0.499712	0.998933
32	0.999210	0.998848	0.499605	0.998848
33	0.998698	0.998058	0.499258	0.998239
34	0.998027	0.996370	0.498757	0.996884
35	0.997893	0.995790	0.498879	0.995924
36	0.999838	0.999724	0.499917	0.999728

37	0.999495	0.999563	0.499719	0.999620
38	0.999178	0.998990	0.499589	0.998990
39	0.999086	0.998323	0.499535	0.998340
40	0.999082	0.998172	0.499540	0.998173
41	0.997688	0.998122	0.498833	0.998141
42	0.997104	0.995381	0.498552	0.995380
43	0.997027	0.994204	0.498510	0.994210
44	0.997010	0.994062	0.498505	0.994062
45	0.996813	0.993833	0.498357	0.993931
46	0.996812	0.993635	0.498406	0.993636
47	0.999579	0.999358	0.499790	0.999358
48	0.997092	0.998697	0.498431	0.998922
49	0.989437	0.986577	0.492811	0.990353
50	0.988354	0.976844	0.493636	0.977915
51	0.957549	0.916912	0.478743	0.916973
52	0.957531	0.916865	0.478756	0.916883
53	0.949963	0.912768	0.474975	0.912751
54	0.943652	0.902256	0.471780	0.902303
55	0.934981	0.890260	0.467432	0.890295
56	0.926551	0.874189	0.463276	0.874118
57	0.883791	0.858497	0.441895	0.856669
58	0.863119	0.781086	0.431560	0.780659
59	0.855189	0.744163	0.427360	0.744510
60	0.845922	0.731349	0.422961	0.731263
61	0.832369	0.697406	0.410814	0.706428
62	0.831841	0.692751	0.415894	0.692794
63	0.831134	0.691960	0.415567	0.691959
64	0.827673	0.686222	0.412464	0.688498
65	0.826628	0.683314	0.412792	0.684178
66	0.943409	0.890125	0.471677	0.890177
67	0.943408	0.890018	0.471703	0.890020
68	0.936754	0.878107	0.468217	0.878406
69	0.936752	0.877505	0.468375	0.877507

5.3.7 VSI of 85-node RDN

Table 5.7 shows the VSI of each node of 85-node RDN obtained by the proposed method and the Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan and Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)). The bold faced value is the minimum values of voltage stability index which symbolizes the most sensitive node of the network.

Table 5.7: VSI of 85-node RDN by the Proposed Method, Method-1, Method-2, and Method-3

Node Number	VSI			
	Proposed Method	Method-1	Method-2	Method-3
2	0.994140	1.000000	0.497070	0.999925
3	0.985589	0.988314	0.492795	0.982652
4	0.974750	0.970906	0.487253	0.957133
5	0.969503	0.950138	0.484751	0.926328
6	0.950573	0.939936	0.475287	0.910251
7	0.938839	0.903589	0.469419	0.858830
8	0.888858	0.879831	0.444007	0.822009
9	0.886511	0.790069	0.443255	0.703345
10	0.881948	0.785901	0.440974	0.697765
11	0.878416	0.776756	0.438903	0.686391
12	0.875766	0.771615	0.437883	0.678898
13	0.874498	0.766966	0.437249	0.672178
14	0.874114	0.764411	0.436961	0.669046
15	0.873884	0.763673	0.436827	0.668121
16	0.993695	0.987429	0.496625	0.982215
17	0.984705	0.969644	0.491911	0.956549
18	0.966105	0.938392	0.482655	0.910369
19	0.964088	0.932165	0.481735	0.900523
20	0.963531	0.928929	0.481626	0.894772
21	0.963030	0.927427	0.481264	0.892341
22	0.993193	0.986432	0.496123	0.889202
23	0.963912	0.929125	0.481868	0.894904
24	0.938282	0.880373	0.468863	0.827405
25	0.881483	0.789574	0.440603	0.702940
26	0.875831	0.776390	0.437739	0.685989
27	0.868447	0.767080	0.434224	0.673541
28	0.865032	0.753740	0.432384	0.656811
29	0.858751	0.748280	0.429376	0.649488

30	0.853023	0.736881	0.426345	0.635366
31	0.850333	0.727364	0.425083	0.623177
32	0.848655	0.723067	0.424328	0.617583
33	0.847313	0.720141	0.423634	0.613949
34	0.841473	0.717939	0.420736	0.611070
35	0.838270	0.708076	0.419135	0.598739
36	0.838159	0.702510	0.419024	0.591917
37	0.875477	0.766460	0.437562	0.673249
38	0.867474	0.752510	0.433250	0.656052
39	0.858221	0.736544	0.428846	0.635211
40	0.847819	0.719743	0.423770	0.613702
41	0.846593	0.718798	0.423296	0.612219
42	0.846426	0.716437	0.423129	0.609442
43	0.846314	0.716248	0.423018	0.609324
44	0.839387	0.707045	0.419387	0.598108
45	0.838051	0.703636	0.418747	0.593798
46	0.837272	0.701395	0.418358	0.591006
47	0.837140	0.700803	0.418504	0.589826
48	0.835462	0.702696	0.417731	0.592019
49	0.835127	0.697997	0.417564	0.586175
50	0.834545	0.697055	0.417158	0.585241
51	0.834103	0.695728	0.416831	0.583812
52	0.831968	0.697997	0.415984	0.586153
53	0.831248	0.691708	0.415485	0.578642
54	0.830718	0.690092	0.415094	0.576896
55	0.831438	0.691289	0.415454	0.578383
56	0.834995	0.697217	0.417431	0.585342
57	0.883183	0.785432	0.441459	0.697487
58	0.874024	0.780012	0.437012	0.690064
59	0.873848	0.763610	0.436836	0.669391
60	0.868479	0.762992	0.433974	0.668947
61	0.867064	0.753027	0.433179	0.656495
62	0.866091	0.750114	0.432559	0.653097
63	0.867165	0.754179	0.433561	0.657223
64	0.862091	0.751976	0.431046	0.654329
65	0.861871	0.743201	0.430935	0.643247
66	0.861694	0.742517	0.430759	0.642575
67	0.859478	0.743201	0.429739	0.643234
68	0.855702	0.738703	0.427851	0.637532
69	0.852910	0.730411	0.425925	0.628234
70	0.852189	0.727455	0.426095	0.623383

71	0.851855	0.725657	0.425761	0.621483
72	0.859302	0.738399	0.429563	0.637367
73	0.853827	0.732225	0.426913	0.629379
74	0.853562	0.728567	0.426648	0.625068
75	0.853213	0.727973	0.426300	0.624695
76	0.851659	0.725323	0.425565	0.621273
77	0.861848	0.742783	0.430913	0.642743
78	0.881330	0.776742	0.440356	0.686425
79	0.859144	0.738129	0.429405	0.637196
80	0.873728	0.765728	0.436511	0.671390
81	0.873063	0.763401	0.436532	0.667651
82	0.872975	0.762086	0.436444	0.666081
83	0.872130	0.761073	0.435731	0.665438
84	0.871897	0.760205	0.435832	0.663844
85	0.873997	0.763870	0.436748	0.668710

Node number (54) is having minimum value of VSI for proposed method, Method-1, Method-2, and Method-3. Hence, node number (54) is most sensitive node of 69-node RDN for all the methods. Proposed method is having improved value of VSI for most sensitive node as compared to other three methods.

5.3.8 VSI of 24-node Radial Distribution Network for Different Load Modelling

Table 5.8 shows the minimum VSI of 24-node RDN using the proposed method and the Method-1 (Chakraborty and Das (2001)), Method-2 (Ranjan and Das (2004)) and Method-3 (Eminoglu and Hocaoglu (2009)) for different load modelling.

From Table 5.8, it is clear that node number (14) node is most sensitive node of 24-node RDN. The VSI obtained by different load modelling are arranged in decreasing order. From different types of load, constant power load is having minimum values of VSI by the proposed methods, Method-1, Method-2 and Method-3 among other types of loads. The proposed method is having improved values of VSI for different load modelling as compared to the methods mentioned above.

Table 5.8: Minimum VSI of 24-node RDN by the Proposed Method, Method-1, Method-2, and Method-3 for Different Load Modelling

Types of Load	VSI			
	Proposed Method	Method-1	Method-2	Method-3
Battery charge	0.959805(14)	0.921226(14)	0.479719(14)	0.921580(14)
Fluorescent Lamps	0.959422(14)	0.920491(14)	0.479525(14)	0.920849(14)
Constant Impedance	0.959204(14)	0.920072(14)	0.479414(14)	0.920433(14)
Fluorescent lighting	0.958839(14)	0.919372(14)	0.479230(14)	0.919736(14)
Air conditioner	0.958494(14)	0.918711(14)	0.479056(14)	0.919078(14)
Constant current	0.958524(14)	0.918768(14)	0.479070(14)	0.919136(14)
Resistance space heater	0.958889(14)	0.919468(14)	0.479254(14)	0.919832(14)
Pumps, fans, other motors	0.958120(14)	0.917994(14)	0.478866(14)	0.918366(14)
Incandescent lamps	0.958649(14)	0.919007(14)	0.479133(14)	0.919374(14)
Compact fluorescent lamps	0.958418(14)	0.918565(14)	0.479017(14)	0.918934(14)
Small industrial lamps	0.957966(14)	0.917699(14)	0.478788(14)	0.918073(14)
Large industrial motors	0.957922(14)	0.917614(14)	0.478766(14)	0.917988(14)
Constant Power	0.957809(14)	0.917398(14)	0.478709(14)	0.917773(14)

5.3.9 Summary of Minimum VSI of Eight Test Radial Distribution Networks for Constant Power

Table 5.9 shows the minimum VSI values of eight different types of RDN for constant power (CP) load modelling using the proposed method and the other three methods. With the help of Table 5.9, most sensitive node of seven test radial distribution networks along with the minimum value of VSI is summarized and compared with the existing three methods reported in literature.

The bold faced values are showing that in case of method-2, the most sensitive nodes are different in case of 34-node and 69-node networks as compared to proposed method as well as by method-1 and method-3 also. Proposed method is showing improvement as compared to other three methods.

Table 5.9: Comparison of Minimum VSI of Test Radial Distribution Networks for Constant Power Load Modelling

RDNs	VSI			
	Proposed Method	Method-1	Method-2	Method-3
13-node	0.9887690 (7)	0.9776570 (7)	0.4939680 (7)	0.9784900 (7)
24-node	0.957809 (14)	0.917398 (14)	0.478709 (14)	0.917773(14)
28-node	0.885793 (18)	0.784629 (18)	0.442599 (18)	0.785156 (18)
33-node	0.834054 (18)	0.695645 (18)	0.416473 (18)	0.696571 (18)
34-node	0.876258 (27)	0.767829 (27)	0.437976 (26)	0.768059 (27)
69-node	0.826628 (65)	0.683314 (65)	0.410814 (61)	0.684178 (65)
85-node	0.830718 (54)	0.690092 (54)	0.415094 (54)	0.690532 (54)

From above results, it can be observed that the proposed VSI gives better VSI values compared to that of obtained by Chakraborty and Das (2001), Ranjan and Das (2003), and Eminoglu and Hocaoglu (2009). Since the proposed equation has included the voltage angle and derived without reduction of the network, the VSI values have been improved compared to the other three methods. Method-1 and Method-3 gave the lower values of VSI for most sensitive node of 29-node radial distribution network as compared to Method-2. Method-2 gave lower values of VSI in other seven cases as compared to Method-1 and Method-3. The method-2 could not pick up the exact node as a sensitive node for 34-node and 69-node RDNs. The proposed method has given the better result for the cases of most sensitive nodes in all eight cases.

5.4 PROPOSED VSI FOR MULTI DG PLACEMENT

The proposed VSI is used in the objective function (Equation (4.19)) proposed in Chapter-4 for DG placement to get the proper size of multi-DG by ABC-CS algorithm and the results have been presented in Table 5.10. The results of multi-DG placement obtained using the proposed VSI and the VSI by Eminoglu and Hocaoglu (2009) for 30-node RDN are compared in Table 5.10 to check the effectiveness of proposed VSI.

Table 5.10: Comparison of the Results for Multi-DG Placement using Proposed VSI with available VSI for 30-node RDN

VSI	Real Power Loss (kW)	DG Locations	Total DG Size (MW)	DG Cost (\$/h)	Energy Cost (\$)
Proposed	32.56	7,15,17	2.40	48.25	17113.536
Eminoglu & Hocaoglu (2009)	33.56	8,13,22	2.65	53.25	17639.136

The proposed VSI gives better results as compared to the VSI proposed by Eminoglu and Hocaoglu (2009).

5.5 CONCLUSIONS

A VSI is proposed to find the VSI value of any RDN which has been derived without reduction of network. In the proposed VSI, the voltage angle has been incorporated. The proposed method has been tested with two IEEE RDN, one practical Indian RDN and other four RDNs. The VSIs proposed by Chakraborty and Das (2001), Ranjan and Das (2003) and Eminoglu and Hocaoglu (2009) have also been computed for the above seven RDNs using the load- flow technique discussed in Chapter-3. The proposed method and other three methods have been demonstrated for different types of practical load modelling of 24 node RDN. The proposed method in all cases gave the better results of VSI values compared to that of obtained by other three methods. The multi-DG placement using the proposed VSI gives the better results compared to the VSI proposed by Eminoglu and Hocaoglu (2009).

CHAPTER 6

OPTIMAL PLANNING OF RADIAL DISTRIBUTION NETWORKS USING DG

6.1 INTRODUCTION

An electrical substation is ancillary station of power system, where metamorphosis of voltage levels takes place. It is of three types-generation substation, transmission substation and distribution substation. It is actually the distribution substation that deals with consumers directly. It needs highly attention as distribution networks are heavily loaded due to poor planning. The distribution system consists of three components mainly which are distribution substation, primary distribution and secondary distribution. The main components of distribution substation are- supply line through which it is connected to sub transmission system, distribution transformers to step down the incoming voltage to be used for utilization, bus bars are used to distribute currents to multiple circuits within switchgear and protection circuitry, feeders carry power from bus bar to area to be electrified, distributors are conductors which supply to consumers through tapping, switchgear and protection equipment for switching and safety purposes, service mains which connect distributor to consumer premises etc.

An efficient distribution system planning should provide methodical evolution of the system to satisfy the consumer requirements in a prudently manner in the long run while abiding the operative constraints and safety measures. The long established distribution systems are modernized for the enhancement of reliability, stability as well as quality of service being given to customers in a cost effective way. Reliability, stability and quality of service are influential parameters while appraising the planning opportunities. The major ambiguities in case of distribution system planning are related to the load demand pattern, type of generating plant (centralized or decentralized), grid installation, network configuration, tariffs, sudden outages, environmental constraints, regulatory measures etc. Therefore, Distribution system planning is a convoluted mechanism which involves load forecasting, substation siting as well as sizing etc.

6.2 PROBLEM FORMULATION

This section defines the aim and restraints of the proposed work. The hope of the proposed methodology is to place the distribution generation in radial distribution system at the optimal location with maintaining the radial nature of the network. The placement is mainly done for the voltage stability improvement as well as for loss reduction of the system.

6.3 PROPOSED METHODOLOGY

The objective of the proposed plan is to boost the voltage profile and reduces the total power loss by placing the substation at optimal location. The load points are connected at shortest route so that the total length of the network is reduced. The radial structure of the network is maintained. For finding the optimal location of substation genetic algorithm is used. The DG is placed to enhance the performance of the system and its location is found out by using loss sensitivity factor. The improved bacterial foraging algorithm is used for the ideal selection of size of the DG. Figure 6.1 shows the functional block diagram for the proposed method.

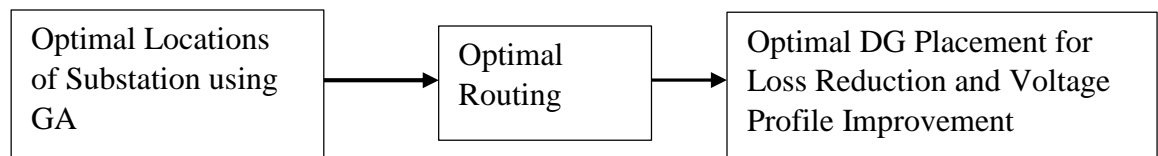


Figure 6.1: Block diagram for Proposed Method

From the initial load-flow analysis, the system parameters like voltage, current, and power losses of the system are measured. From the load -flow, it is identified that whether the system needs compensation or not.

6.3.1. Genetic Algorithm

Genetic algorithm is a global heuristic algorithm developed by Goldberg and Holland (1989). Genetic algorithm is based on Darwin’s evolutionary theory that is “the strongest species that survives” affected the survival of an organism. The genetic algorithm holds three processes known as reproduction, crossover and mutation. In the presented work, the genetic algorithm is used for the evaluation of optimal location of substation. The flow chart showing steps involved in genetic algorithm are shown in Figure 6.2.

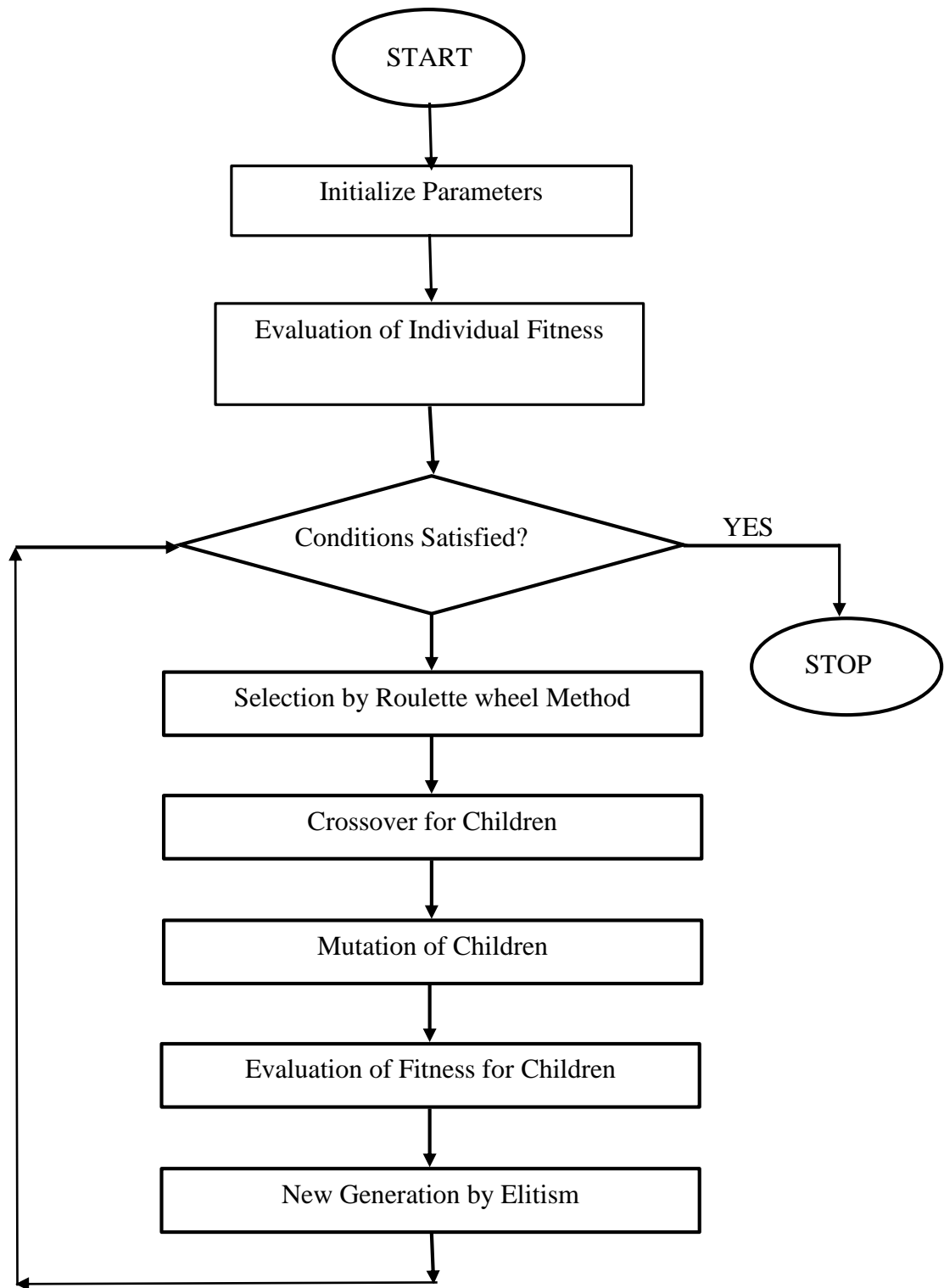


Figure 6.2: Flow Chart of Genetic Algorithm

The steps involved in genetic algorithm are discussed below:

Step 1: Initialization

The first step of the genetic algorithm is the initialization. Here, the parameters going to be initialized are number of chromosomes in the population and genes. The genes in every chromosome hold some values based on the objective function.

Step 2: Evaluation

The objective function is evaluated in the second step. The objective function is presented in Equation (6.1).

$$obj(f) = \min(VSI(r+1)) \quad (6.1)$$

The objective function value for each chromosome is evaluated. If the best objective is obtained in the evaluation, the process is stopped. Otherwise, the process is continued with selection process.

Step 3: Selection

Generally in the selection of the best chromosome, the roulette wheel method is used. The chromosome with the higher probability has been selected for the next generation. The fitness of the chromosome is found out by Equation (6.2).

$$fitness = \frac{1}{1 + obj(f)} \quad (6.2)$$

After the estimation of fitness for each chromosome, the values are summed. From the summed value of fitness, the probability is calculated.

Step 4: Crossover

The process of generation of new chromosome is generally defined as crossover. Crossover doesn't always occur. The probability of crossover occurring is usually about 60% to 70%. The pseudo code for crossover is described below,

```

Begin
   $k \leftarrow 0$ ;
  while( $k < \text{population}$ )do
     $R[k] \leftarrow \text{random}(0-1)$ ;
    if( $R[k] < \rho_c$ )then
      select Chromosome[ $k$ ]as parent;
    end;
     $k = k + 1$ ;
  end;
end;

```

Step 5: Mutation

After the process of selection and crossover, the new chromosomes are generated. The tally of chromosomes undergone crossover and mutation are generally ruled by crossover and mutation rate. After many iterations, the chromosomes are converged to a definite value. This is the supreme location for DG. The details of optimal sizing of DG has been presented in Chapter-4.

6.4 SIMULATION RESULTS AND DISCUSSIONS

The 53 load points shown in Figure 6.3, starting from node-2 to node-54 and node-1 is for substation location, (Ranjan *et al.* (2002)) are taken into consideration for the implementation of the substation planning. The detailed of the 53 load points have been presented in **Appendix-J**. The substation planning and distribution generation placement in optimally planned radial distribution network has been performed based on the evaluation of proposed voltage stability index and the loss sensitivity factor respectively of the each and every node of the distribution system. The optimal location for substation is $X = 9.33$ km and $Y = 10.99$ km. The optimum path is selected for power loss reduction. The optimal substation location has not been provided by Ranjan *et al.* (2002).

Table 6.1 displays the “branch number (BN), sending-end node (SEN), receiving-end node (REN) and conductor (CON)” of individual branch with 100% loads for single feeder, double feeder and triple feeder cases. Four types of conductors “1(SQUIRREL), 2(WEASEL), 3(RABBIT) and 4(RACCON)” have been reflected in proposed work and conductor of each branch has been selected based on rated value of current.

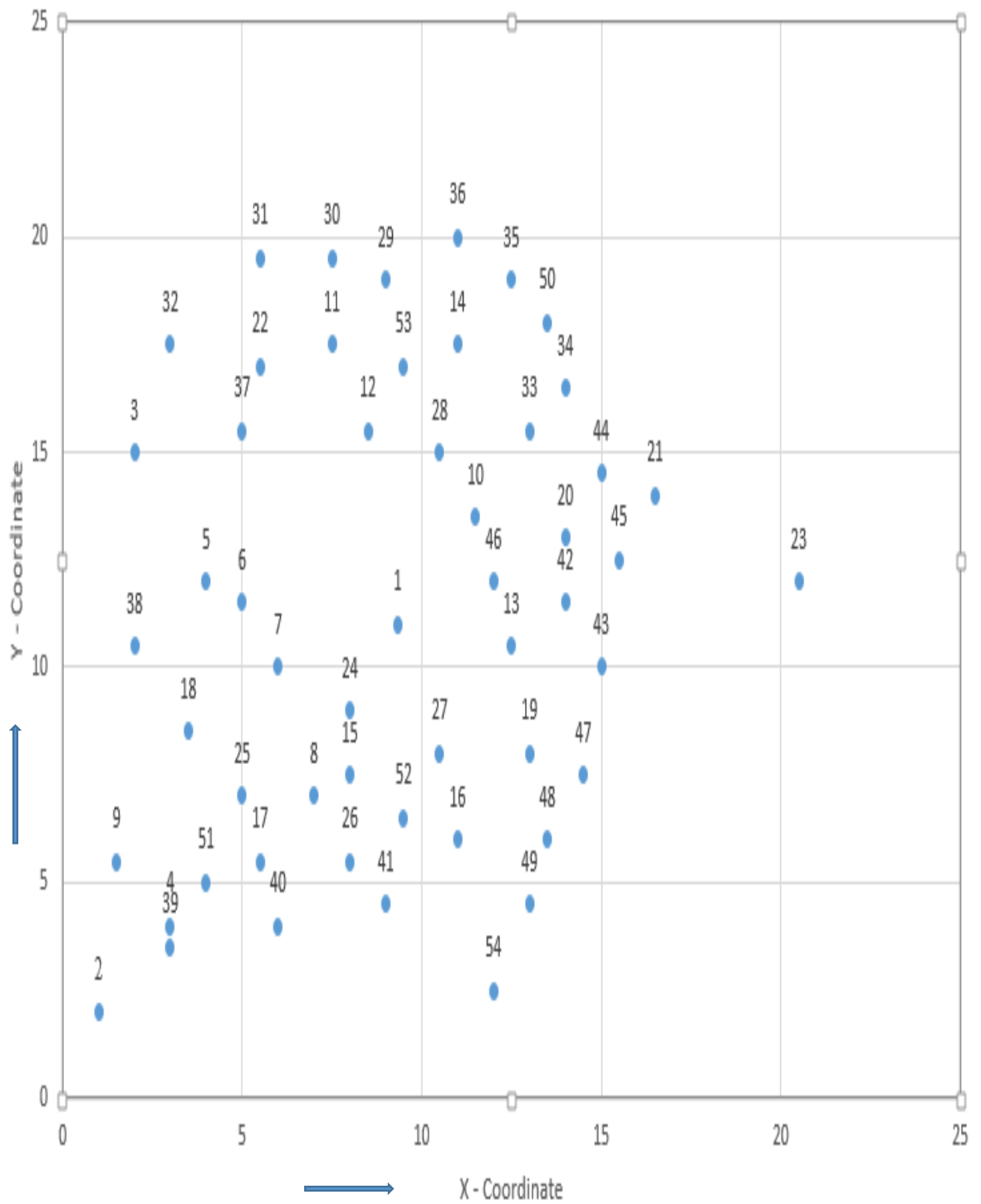


Figure 6.3: Coordinates of 53 Load Points

Table 6.1: BN, SEN, REN and CON of Each Branch for Single, Double and Triple Feeder Cases for 53 Load points

Node Number	Single feeder			Double feeder			Triple feeder		
	SEN	REN	CON	SEN	REN	CON	SEN	REN	CON
1	1	24	4	1	24	4	1	24	4
2	24	15	4	1	46	4	1	46	4
3	15	8	4	24	15	4	1	13	4
4	15	52	4	15	8	4	24	15	4
5	52	16	4	46	10	4	15	8	4
6	8	26	3	46	13	4	46	10	4
7	26	41	1	15	52	4	13	42	4
8	52	27	1	52	16	3	42	20	3
9	8	25	4	8	26	2	20	45	1
10	25	17	4	26	41	1	15	52	4
11	17	40	1	10	28	4	52	16	3
12	17	51	3	13	42	4	8	26	2
13	51	4	3	42	20	3	26	41	1
14	4	39	2	20	45	1	10	28	4
15	25	18	1	52	27	1	42	43	1
16	4	9	1	42	43	1	20	44	2
17	24	7	3	20	44	2	44	21	1
18	7	6	2	44	21	1	52	27	1
19	6	5	1	8	25	4	8	25	4
20	16	48	4	25	17	4	25	17	4
21	48	49	4	17	40	1	17	40	1
22	48	47	4	17	51	3	17	51	3
23	47	19	4	51	4	3	51	4	3
24	49	54	4	4	39	2	4	39	2
25	39	2	1	28	12	4	28	12	4
26	18	38	1	12	53	4	12	53	4
27	47	43	4	53	14	4	53	14	4
28	43	42	4	53	11	4	53	11	4
29	42	20	4	11	30	3	11	30	3
30	20	45	4	30	29	1	30	29	1
31	42	13	4	30	31	1	30	31	1
32	13	46	4	11	22	2	11	22	2
33	46	10	4	22	37	1	22	37	1
34	20	44	4	25	18	1	25	18	1
35	44	21	4	4	9	1	4	9	1
36	10	28	4	14	35	3	14	35	3
37	28	12	4	35	50	2	35	50	2

38	12	53	4	50	34	2	50	34	2
39	53	14	4	34	33	1	34	33	1
40	53	11	4	35	36	1	35	36	1
41	11	30	4	24	7	3	24	7	3
42	30	29	4	7	6	2	7	6	2
43	30	31	4	6	5	1	6	5	1
44	11	22	4	16	48	3	16	48	3
45	22	37	4	48	49	1	48	49	1
46	14	35	4	48	47	2	48	47	2
47	35	50	4	47	19	1	47	19	1
48	50	34	4	49	54	1	49	54	1
49	34	33	4	39	2	1	39	2	1
50	35	36	4	18	38	1	18	38	1
51	22	32	4	22	32	1	22	32	1
52	32	3	4	32	3	1	32	3	1
53	21	23	4	21	23	1	21	23	1

Figure 6.4, Figure 6.5 and Figure 6.6 show the connectivity diagrams for single feeder, double feeder and triple feeder cases.

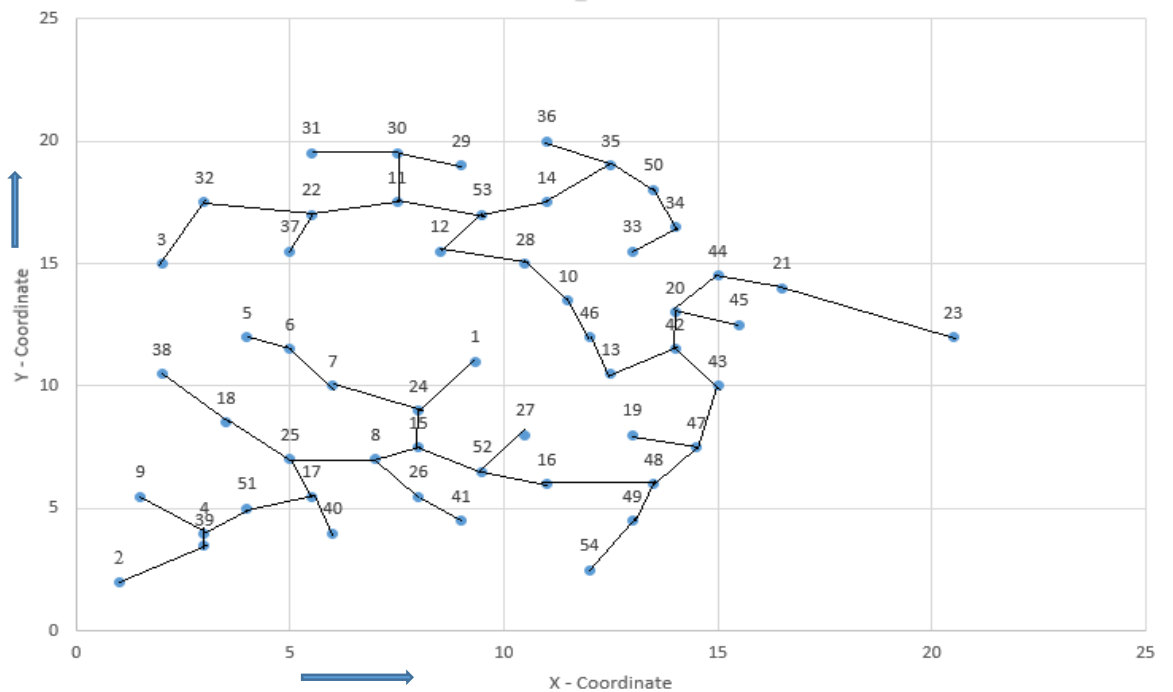


Figure 6.4: Connection Diagram of 53 Load Points for Single Feeder

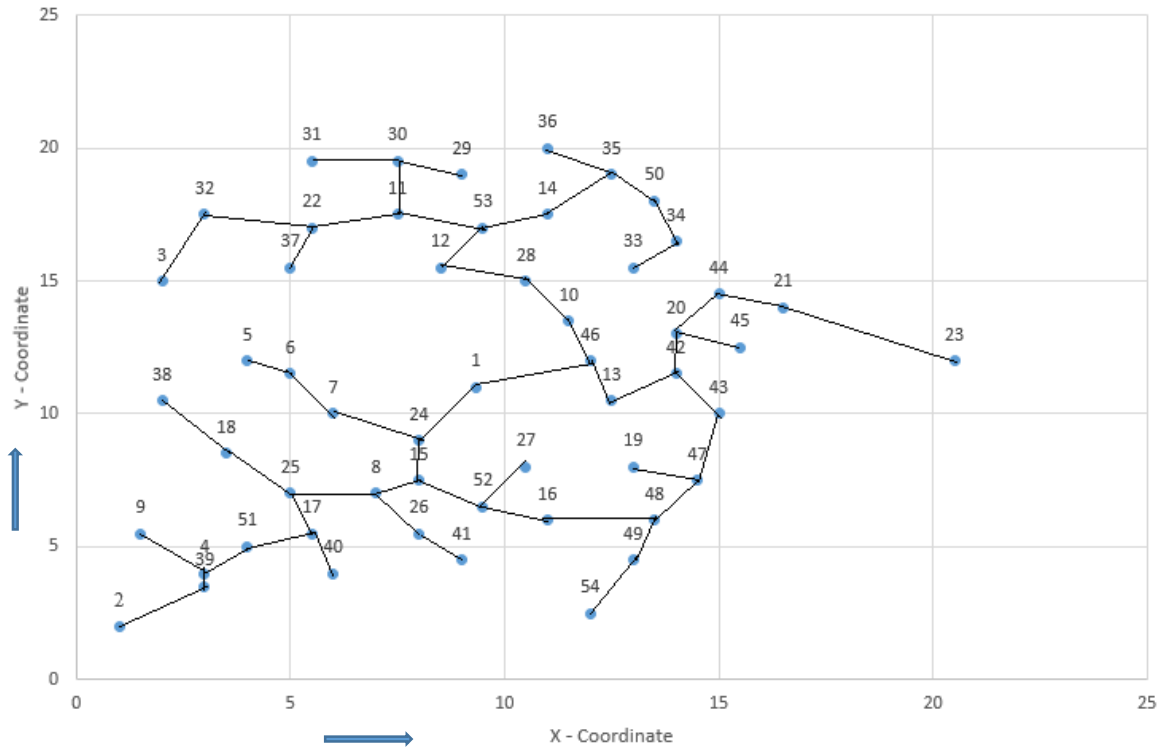


Figure 6.5: Connection Diagram of 53 Load Points for Double Feeder

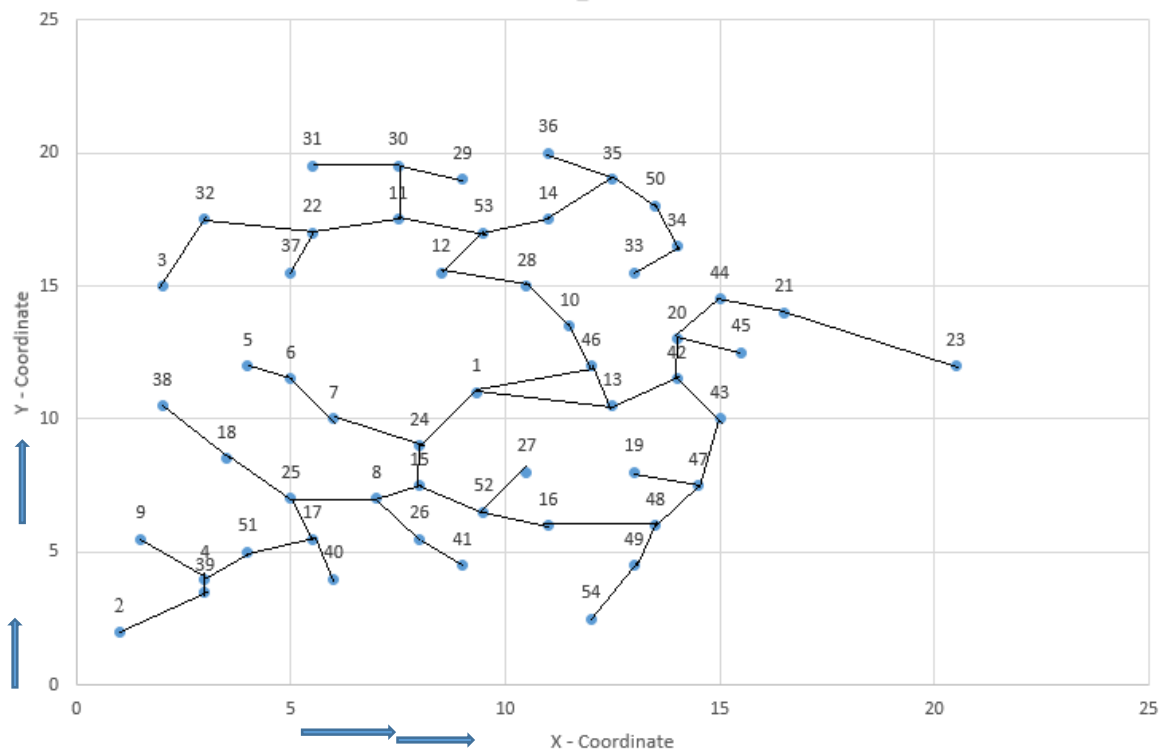


Figure 6.6: Connection Diagram of 53 Load Points for Triple Feeder

6.4.1 VSI for 53 Load Points RDN

Table 6.2, Table 6.3 and Table 6.4 show the voltage magnitude (p.u.), VSI by proposed method and VSI by Eminoglu and Hocaoglu (2009) for single feeder, double feeder and triple feeder respectively. The proposed VSI is better than VSI proposed by Eminoglu and Hocaoglu (2009).

Table 6.2: Voltage Magnitude (p.u.), VSI by Proposed Method (PM) and VSI by Eminoglu and Hocaoglu (2009) for Single Feeder

Node Number	Single feeder		
	Voltage Mag. (p.u.)	VSI by PM	VSI (Eminoglu and Hocaoglu (2009))
1	1.000000	-----	-----
2	0.951510	0.905371	0.819696
3	0.858116	0.736363	0.542231
4	0.952567	0.907384	0.826473
5	0.971448	0.943712	0.890591
6	0.972062	0.944904	0.895479
7	0.973680	0.948053	0.903985
8	0.959831	0.921276	0.857441
9	0.951973	0.906253	0.821294
10	0.879417	0.773375	0.611325
11	0.860342	0.740189	0.555044
12	0.868141	0.753668	0.582639
13	0.889772	0.791693	0.644366
14	0.861523	0.742223	0.554205
15	0.962525	0.926453	0.905352
16	0.941997	0.887358	0.818511
17	0.955126	0.912266	0.836832
18	0.954991	0.912007	0.835899
19	0.917682	0.842140	0.709199
20	0.895042	0.801099	0.644306
21	0.893628	0.798572	0.638785
22	0.859075	0.738009	0.547235
23	0.892570	0.796682	0.634700
24	0.975858	0.952299	0.995957
25	0.956556	0.914999	0.845637
26	0.958566	0.918848	0.845175
27	0.950330	0.903127	0.815637

28	0.873924	0.763743	0.596931
29	0.858662	0.737301	0.543613
30	0.858857	0.737635	0.546304
31	0.858237	0.736570	0.542535
32	0.858447	0.736932	0.543863
33	0.857858	0.735920	0.541578
34	0.858206	0.736517	0.543443
35	0.859791	0.739241	0.550230
36	0.859570	0.738861	0.545915
37	0.858686	0.737341	0.543672
38	0.953593	0.909340	0.826895
39	0.952210	0.906704	0.822463
40	0.954685	0.911423	0.830691
41	0.958172	0.918093	0.842896
42	0.896374	0.803486	0.669559
43	0.905001	0.819027	0.707745
44	0.894189	0.799574	0.641150
45	0.894855	0.800765	0.641225
46	0.884356	0.782086	0.625446
47	0.917798	0.842353	0.738398
48	0.927502	0.860261	0.786467
49	0.927027	0.859378	0.739680
50	0.858984	0.737854	0.546195
51	0.953670	0.909486	0.831453
52	0.951341	0.905050	0.857865
53	0.863303	0.745292	0.567442
54	0.926517	0.858434	0.736908

Table 6.3: Voltage Magnitude (p.u.), VSI by Proposed Method (PM) and VSI by Eminoglu and Hocaoglu (2009) for Double Feeder

Node Number	Double feeder		
	Voltage Mag. (p.u.)	VSI by PM	VSI (Eminoglu and Hocaoglu (2009))
1	1.000000	-----	-----
2	0.971751	0.944300	0.891701
3	0.961484	0.924452	0.854611
4	0.972786	0.946312	0.898768
5	0.983820	0.967902	0.936833
6	0.984426	0.969094	0.941847
7	0.986024	0.972244	0.950569
8	0.979899	0.960202	0.931044
9	0.972204	0.945181	0.893367
10	0.982718	0.965735	0.949063
11	0.965711	0.932598	0.878764
12	0.972664	0.946075	0.913356
13	0.984822	0.969875	0.948178
14	0.966764	0.934633	0.877709
15	0.982537	0.965378	0.951971
16	0.978801	0.958052	0.923442
17	0.975292	0.951194	0.909567
18	0.975159	0.950935	0.908594
19	0.975052	0.950727	0.903881
20	0.981035	0.962430	0.930175
21	0.978316	0.957102	0.919285
22	0.963644	0.928609	0.868255
23	0.975873	0.952328	0.906914
24	0.988174	0.976489	0.995957
25	0.976691	0.953926	0.918744
26	0.978120	0.956719	0.916641
27	0.979521	0.959462	0.920565

28	0.977820	0.956132	0.931174
29	0.963587	0.928500	0.862113
30	0.964025	0.929343	0.867210
31	0.962629	0.926655	0.858685
32	0.962231	0.925888	0.859791
33	0.961426	0.924340	0.854403
34	0.962210	0.925848	0.859460
35	0.964796	0.930832	0.872472
36	0.964298	0.929871	0.864659
37	0.962768	0.926923	0.859184
38	0.973790	0.948268	0.899207
39	0.972436	0.945633	0.894586
40	0.974859	0.950351	0.903166
41	0.977735	0.955965	0.913868
42	0.982585	0.965473	0.939180
43	0.981606	0.963551	0.928428
44	0.979610	0.959637	0.924932
45	0.980605	0.961587	0.924649
46	0.987123	0.974412	0.996962
47	0.975329	0.951266	0.905754
48	0.976456	0.953467	0.916576
49	0.975314	0.951238	0.908071
50	0.963479	0.928292	0.865797
51	0.973866	0.948414	0.903960
52	0.980502	0.961384	0.931485
53	0.968351	0.937703	0.894337
54	0.974091	0.948853	0.900318

Table 6.4: Voltage Magnitude (p.u.), VSI by Proposed Method (PM) and VSI by Eminoglu and Hocaoglu (2009) for Triple Feeder

Node Number	Triple feeder		
	Voltage Mag. (p.u.)	VSI by PM	VSI [Eminoglu and Hocaoglu (2009)]
1	1.000000	-----	-----
2	0.971751	0.944300	0.891701
3	0.965791	0.932752	0.870025
4	0.972786	0.946312	0.898768
5	0.983820	0.967902	0.936833
6	0.984426	0.969094	0.941847
7	0.986024	0.972244	0.950569
8	0.979899	0.960202	0.931044
9	0.972204	0.945181	0.893367
10	0.986931	0.974032	0.965294
11	0.969999	0.940898	0.894393
12	0.976921	0.954374	0.929285
13	0.995382	0.990785	0.997291
14	0.971047	0.942933	0.893328
15	0.982537	0.965378	0.951971
16	0.978801	0.958052	0.923442
17	0.975292	0.951194	0.909567
18	0.975159	0.950935	0.908594
19	0.975052	0.950727	0.903881
20	0.991635	0.983341	0.970947
21	0.988945	0.978012	0.959820
22	0.967940	0.936909	0.883791
23	0.986529	0.973238	0.947179
24	0.988174	0.976489	0.995957
25	0.976691	0.953926	0.918744
26	0.978120	0.956719	0.916641
27	0.979521	0.959462	0.920565
28	0.982054	0.964430	0.947255
29	0.967884	0.936800	0.877594
30	0.968320	0.937643	0.882737
31	0.966931	0.934955	0.874136
32	0.966534	0.934188	0.875252
33	0.965733	0.932639	0.869815
34	0.966513	0.934148	0.874918
35	0.969088	0.939131	0.888046

36	0.968592	0.938170	0.880163
37	0.967069	0.935223	0.874639
38	0.973790	0.948268	0.899207
39	0.972436	0.945633	0.894586
40	0.974859	0.950351	0.903166
41	0.977735	0.955965	0.913868
42	0.993169	0.986384	0.980146
43	0.992200	0.984461	0.969161
44	0.990226	0.980547	0.965590
45	0.991210	0.982498	0.965301
46	0.991316	0.982708	0.996962
47	0.975329	0.951266	0.905754
48	0.976456	0.953467	0.916576
49	0.975314	0.951238	0.908071
50	0.967777	0.936592	0.881311
51	0.973866	0.948414	0.903960
52	0.980502	0.961384	0.931485
53	0.972626	0.946002	0.910103
54	0.974091	0.948853	0.900318

6.4.2 Optimal Substation Planning

Table 6.5 describes the simulation results of newly developed radial distribution with optimal position of substation. The projected results have also been compared with the available results given by Ranjan *et al.* (2002) for single feeder, double feeder and triple feeder cases. The results provided in Ranjan *et al.* (2002) had been considered.

The length in single feeder case is slightly higher than that of Ranjan *et al.* (2002). But the loss in the proposed method is lower which entirely depends on the conductor selection. In double case, the losses and total length is lower than that of Ranjan *et al.* (2002). In triple feeder case, real power loss and total length is lower than that of Ranjan *et al.* (2002), but the reactive power loss is little bit higher than that of Ranjan *et al.* (2002). The performances of the proposed method in terms of the voltage profile is better compared to Ranjan *et al.* (2002). The proposed most sensitive node along with VSI value by proposed method and by Eminoglu and Hocaoglu (2009) in each case has been presented. The proposed VSI is better than that of available Eminoglu and Hocaoglu (2009), which had been used by most

researchers. The total losses of the system in triple feeder case are lower as compared to other feeder cases. Hence the triple feeder case is suggested.

Table 6.5: Comparison of the Proposed Planning Method with Existing Method

Parameters	Number of feeder originating from substation					
	Single		Double		Triple	
	Proposed Method	Ranjan <i>et al.</i> (2002)	Proposed Method	Ranjan <i>et al.</i> (2002)	Proposed Method	Ranjan <i>et al.</i> (2002)
P loss (kW)	146.89	173.50	40.34	56.18	35.42	50.13
Q loss (kVAr)	143.15	125.06	37.43	37.49	32.62	31.43
Vmin (p.u.) & node	0.857858 & 33	0.84916 & 33	0.961426 & 33	0.95282 & 33	0.965733 & 33	0.96081 & 33
Proposed VSI & node	0.735920 & 33	----	0.924340 & 33	----	0.932639 & 33	----
VSI (Eminoglu and Hocaoglu (2009) & node	0.541578 & 33	----	0.854403 & 33	----	0.869815 & 33	----
Length (km)	98.537	97.63	98.842	99.00	100.469	100.67
Coordinate of Substation (in km)	By Proposed Method			X = 9.33 Y =10.99	Ranjan <i>et al.</i> (2002)	Not available

Table 6.6 shows the simulation results after optimal position of 3 DGs in the planned radial distribution networks having triple feeder. Incorporation of 3 DGs significantly improves the voltage magnitude and voltage stability index when compared to base case. The maintenance of these parameters helps in the up-gradation of the stability of the system.

Table 6.6: Simulation Results of the Planned System for Optimal Location of Substation having Triple Feeder

Parameters	Base Case	After 3 DG placement
DG location & total DG size (kW)	-----	10,44,17 & 886
P loss (kW)	35.42	12.56
Q loss (kVAr)	32.62	09.78
Vmin (p.u.) & node	0.965733 & 33	0.98931 & 51
VSI & node [Proposed]	0.932639 & 33	0.94592 & 51
VSI & node (Eminoglu and Hocaoglu (2009))	0.869815 & 33	0.89757 & 51

If the location of substation is $X = 8.59$ km and $Y = 9.22$ km i.e., pre-fixed, then the optimal location of substation cannot be used. The optimum path is selected for power loss reduction.

Table 6.7 shows the base case results for single feeder, double feeder and triple feeder cases and triple DG placement in triple feeder case for 100% load. Once again the triple feeder gives the less loss of the system. Out of single, double and triple feeder case, triple feeder case is efficient as less active and reactive power losses are occurring. At the same time, voltage profile of three feeder case is improved as compared to other two feeders.

Further, when the triple feeder case was compared to triple feeder case with three DG, minimum active and reactive power losses are observed in case of triple feeder with three DG although the length of feeders in both cases is coming to be same.

Table 6.8 shows the comparisons of the substation locations obtained by GA, PSO and ABC algorithms using the same objective function. Table 6.8 also shows that the substation location obtained by GA gives the minimum loss of the system.

Table 6.7: Simulation Results for Single Feeder, Double Feeder, Triple Feeder along with three DG Placement in Triple Feeder Case

Parameters	Number of Feeders Emanating from Substation			Placement of Three DG in Triple Feeder Case
	Single	Double	Triple	
DG location & total DG size (kW)	-----	-----	-----	11,42,19 & 920
P loss (kW)	111.50	104.43	54.40	13.45
Q loss (kVAr)	108.46	101.54	51.88	11.67
Vmin (p.u.) & node	0.878440 & 33	0.882398 & 33	0.932652 & 33	0.9553 & 51
VSI & node (Proposed)	0.771656 & 33	0.778626 & 33	0.869840 & 33	0.9129 & 51
VSI & node (Eminoglu and Hocaoglu (2009))	0.595453 & 33	0.606258 & 33	0.756622 & 33	0.8045 & 51
Total Length (km)	96.773	97.092	97.555	97.555

Table 6.8: Comparison of the outcomes of substation locations obtained by GA, PSO and ABC algorithms.

Algorithm	Co-ordinate of Substation (X,Y) in km	Total loss (Single/Double/Triple cases) in kW
GA	X= 9.33 and Y=10.99	146.89 / 40.34 / 35.42
PSO	X = 9.47 and Y =11.14	149.67 / 42.97 / 38.23
ABC	X = 9.41 and Y =11.06	148.12 / 41.82 / 37.24

6.5 CONCLUSIONS

In this chapter, the optimal location of substation has been found out using the proposed VSI and genetic algorithm. The load points have been connected in optimal routes for single feeder, double feeder and triple feeder cases. The triple feeder case gave the best results as compared to single feeder and double feeder cases. Distributed generation has been placed in the planned system to further cut down the total losses of the system. If the optimal position of the substation can't be used due to objection by society, then the pre-fixed available location is to be used.

CHAPTER 7

MAIN CONCLUSIONS AND FUTURE SCOPE

The aim of this chapter is to give the main conclusions of the thesis and to discuss the future scope of work. In this chapter the results and findings of each chapter are to be discussed.

7.1 MAIN CONCLUSIONS

A brief introduction of power systems, distribution systems, radial distribution networks, load-flow and stable planning of radial distribution networks using DG, objectives of research, scope of research and organization of thesis are discussed in **Chapter 1**. The detailed literature survey on load-flow solution for distribution networks, DG placement for loss reduction, voltage stability index of radial distribution networks and planning of distribution networks is discussed in **Chapter 2**.

A novel search based technique to solve load-flow of radial distribution networks is presented in **Chapter 3**. The proposed search technique for load-flow does not require to store the nodes beyond each branch and does not need repetitive search. The proposed method examined eight examples, including one practical Indian test feeder. The suggested technique for load flow is found to be superior as compared to other available methods in terms of relative CPU time and iteration number.

In recent times, the number of studies in the field of incorporation of distributed resources to the power grid has been tremendously elevated due to expanding attention on inexhaustible resources. Multiple small sized DGs are placed in the distribution system to achieve the maximum loss reduction. A hybrid optimization technique based on the ABC and CS algorithms to place multiple DGs in distribution grids is suggested in **Chapter 4**. The technique proposed for multi DG placement provides better performance in all aspects than that obtained by using other optimization techniques in terms of minimum voltage, power loss, percentage loss reduction, DG cost and energy cost. The suggested method also reduces the loss to a minimum level when placing five DGs.

A VSI is proposed in **Chapter 5** to find the VSI value of any RDN which has been derived without reduction of network. The proposed method has been tested with two IEEE RDN, one practical Indian RDN and other five RDNs. The proposed method and other three methods have been demonstrated for different types of practical load modelling of 24 node RDN. The proposed method in all cases gave the better results of VSI values compared to that of obtained by other available three methods reported in literature.

The objectives of the planned work i.e. minimization of power loss and enhancement of voltage stability, are collectively attained through the optimal positioning of substation and DG in the existing and newly planned distribution networks in **Chapter 6** using genetic algorithm. DG siting and sizing are obtained from Chapter 4. VSI derived in chapter 5 is used as objective function for planning of distribution networks.

7.2 FUTURE SCOPE

After carrying out the research work, it is realized that the present work can be extended in following directions:

- While deriving the load-flow solution of distribution networks, the test distribution networks are of radial nature assumed to be operating in balanced mode. The proposed load-flow can be modified and extended to unbalanced radial distribution networks as well as weakly mesh distribution networks.
- Voltage stability can be investigated in the case of smart grids. Hence, DG placement and substation planning can be investigated in the environment of smart distribution systems.
- Possibilities of automation and remote technology can be explored in case of substation planning.

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Appendix A

Table A1: System Data of 13-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.117	0.048	100	30
2	2	3	0.107	0.044	20	730
3	3	4	0.165	0.046	150	225
4	4	5	0.15	0.042	50	10
5	5	6	0.15	0.042	120	540
6	6	7	0.314	0.054	40	700
7	5	8	0.21	0.036	75	90
8	2	9	0.314	0.054	50	150
9	9	10	0.21	0.036	125	825
10	5	11	0.131	0.023	210	800
11	11	12	0.105	0.0118	80	300
12	11	13	0.157	0.027	95	30

Appendix- B

Table B1: System Data of 24-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.110	0.070	259.17	125.52
2	2	3	0.165	0.105	159.53	66.51
3	3	4	0.066	0.042	256.44	152.16
4	4	5	0.110	0.070	67.5	19.69
5	5	6	0.055	0.035	207.16	86.37
6	6	7	0.055	0.035	164.88	68.74
7	7	24	0.055	0.035	0	0
8	24	8	0.110	0.070	212.89	88.75
9	8	9	0.165	0.105	236.19	98.47
10	9	10	0.220	0.140	10	2.03
11	10	11	0.275	0.175	48.6	17.64
12	11	12	0.055	0.035	36.93	21.91
13	12	13	0.165	0.105	32.4	9.45
14	13	14	0.055	0.035	312.45	185.4
15	4	23	0.055	0.035	0	0
16	23	15	0.110	0.070	80.78	41.39
17	15	16	0.110	0.070	209.58	95.49
18	23	17	0.165	0.105	30	8.75
19	17	18	0.220	0.140	111.87	40.6
20	24	19	0.330	0.210	126.74	46
21	19	20	0.055	0.035	153.41	63.96
22	20	21	0.110	0.070	208.25	94.88
23	13	22	0.275	0.175	30.82	8.99

Appendix- C

Table C1: System Data of 28-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.126	0.053	140	90
2	2	3	0.155	0.066	80	50
3	3	4	0.095	0.039	80	60
4	4	5	0.064	0.026	100	60
5	5	6	0.253	0.105	80	50
6	6	7	0.190	0.079	90	40
7	7	8	0.101	0.042	90	40
8	8	9	0.190	0.079	80	50
9	9	10	0.253	0.105	90	50
10	10	11	0.191	0.054	80	50
11	11	12	0.096	0.027	80	40
12	12	13	0.287	0.081	90	50
13	13	14	0.287	0.059	70	40
14	14	15	0.210	0.054	70	40
15	15	16	0.191	0.081	70	40
16	16	17	0.287	0.054	60	30
17	17	18	0.191	0.054	60	30
18	2	19	0.239	0.068	70	40
19	19	20	0.096	0.027	50	30
20	20	21	0.191	0.054	50	30
21	21	22	0.344	0.097	40	20
22	3	23	0.373	0.070	50	30
23	23	24	0.210	0.059	50	20
24	24	25	0.382	0.108	60	30
25	6	26	0.191	0.054	40	20
26	26	27	0.096	0.027	40	20
27	27	28	0.096	0.027	40	20

Appendix- D

Table D1: System Data of 33-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.092	0.047	100	60
2	2	3	0.493	0.251	90	40
3	3	4	0.366	0.186	120	80
4	4	5	0.381	0.194	60	30
5	4	6	0.819	0.707	60	20
6	6	7	0.187	0.618	200	100
7	7	8	0.711	0.235	200	100
8	8	9	1.030	0.740	60	20
9	9	10	1.044	0.740	60	20
10	10	11	0.196	0.065	45	30
11	11	12	0.374	0.123	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.541	0.712	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.746	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.156	90	40
19	19	20	1.504	1.355	90	40
20	20	21	0.409	0.478	90	40
21	21	22	0.708	0.937	90	40
22	3	23	0.451	0.308	90	50
23	23	24	0.898	0.709	420	200
24	24	25	0.896	0.709	420	200
25	6	26	0.203	0.103	60	25
26	26	27	0.284	0.144	60	25
27	27	28	1.059	0.933	60	20
28	28	29	0.804	0.700	120	70
29	29	30	0.507	0.258	200	600
30	30	31	0.974	0.963	150	70
31	31	32	0.310	0.361	210	100
32	32	33	0.341	0.530	60	40

Appendix- E

Table E1: System Data of 34-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.117	0.048	230	190
2	2	3	0.107	0.044	0	0
3	3	4	0.165	0.046	230	190
4	3	13	0.157	0.27	230	190
5	4	5	0.15	0.042	0	0
6	5	6	0.15	0.042	0	0
7	6	7	0.314	0.54	230	190
8	6	17	0.179	0.05	230	190
9	7	8	0.21	0.036	0	0
10	7	28	0.105	0.018	230	190
11	8	9	0.314	0.54	137	84
12	9	10	0.21	0.036	72	45
13	10	11	0.131	0.023	72	45
14	10	31	0.157	0.027	72	45
15	11	12	0.105	0.018	13.5	7.5
16	13	14	0.21	0.036	230	190
17	14	15	0.105	0.018	230	190
18	15	16	0.052	0.009	230	190
19	17	18	0.165	0.046	230	190
20	18	19	0.208	0.047	230	190
21	19	20	0.189	0.043	230	190
22	20	21	0.189	0.043	230	190
23	21	22	0.262	0.045	230	190
24	22	23	0.262	0.045	230	190
25	23	24	0.314	0.54	230	190
26	24	25	0.21	0.036	137	85
27	25	26	0.131	0.023	75	48
28	26	27	0.105	0.018	75	48
29	28	29	0.105	0.018	75	48
30	29	30	0.157	0.027	57	34.5
31	31	32	0.21	0.036	57	34.5
32	32	33	0.157	0.027	57	34.5
33	33	34	0.105	0.018	57	34.5

Appendix- F

Table F1: System Data of 69-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.0005	0.0012	0	0
2	2	3	0.0005	0.0012	0	0
3	3	4	0.0015	0.0036	0	0
4	4	5	0.0251	0.0294	0	0
5	5	6	0.366	0.1864	2.6	2.2
6	6	7	0.3811	0.1941	40.4	30
7	7	8	0.0922	0.047	75	54
8	8	9	0.0493	0.0251	30	22
9	9	10	0.819	0.2707	28	19
10	10	11	0.1872	0.0619	145	104
11	11	12	0.7114	0.2351	145	104
12	12	13	1.03	0.34	8	5
13	13	14	1.044	0.345	8	5.5
14	14	15	1.058	0.3496	0	0
15	15	16	0.1966	0.065	45.5	30
16	16	17	0.3744	0.1238	60	35
17	17	18	0.0047	0.0016	60	35
18	18	19	0.3276	0.1083	0	0
19	19	20	0.2106	0.069	1	0.6
20	20	21	0.3416	0.1129	114	81
21	21	22	0.014	0.0046	5	3.5
22	22	23	0.1591	0.0526	0	0
23	23	24	0.3463	0.1145	28	20
24	24	25	0.7488	0.2475	0	0
25	25	26	0.3089	0.1021	14	10
26	26	27	0.1732	0.0572	14	10
27	3	28	0.0044	0.0108	26	18.6
28	28	29	0.064	0.1565	26	18.6
29	29	30	0.3978	0.1315	0	0
30	30	31	0.0702	0.0232	0	0
31	31	32	0.351	0.116	0	0
32	32	33	0.839	0.2816	14	10
33	33	34	1.708	0.5646	9.5	14
34	34	35	1.474	0.4873	6	4

35	3	36	0.0044	0.0108	26	18.55
36	36	37	0.064	0.1565	26	18.55
37	37	38	0.1053	0.123	0	0
38	38	39	0.0304	0.0355	24	17
39	39	40	0.0018	0.0021	24	17
40	40	41	0.7283	0.8509	1.2	1
41	41	42	0.31	0.3623	0	0
42	42	43	0.041	0.0478	6	4.3
43	43	44	0.0092	0.0116	0	0
44	44	45	0.1089	0.1373	39.22	26.3
45	45	46	0.0009	0.0012	39.22	26.3
46	4	47	0.0034	0.0084	0	0
47	47	48	0.0851	0.2083	79	56.4
48	48	49	0.2898	0.7091	384.7	274.5
49	49	50	0.0822	0.2011	384.7	274.5
50	8	51	0.0928	0.0473	40.5	28.3
51	51	52	0.3319	0.1114	3.6	2.7
52	9	53	0.174	0.0886	4.35	3.5
53	53	54	0.203	0.1034	26.4	19
54	54	55	0.2842	0.1447	24	17.2
55	55	56	0.2813	0.1433	0	0
56	56	57	1.59	0.5337	0	0
57	57	58	0.7837	0.263	0	0
58	58	59	0.3042	0.1006	100	72
59	59	60	0.3861	0.1172	0	0
60	60	61	0.5075	0.2585	1244	888
61	61	62	0.0974	0.0496	32	23
62	62	63	0.145	0.0738	0	0
63	63	64	0.7105	0.3619	227	162
64	64	65	1.041	0.5302	59	42
65	11	66	0.2012	0.0611	18	13
66	66	67	0.0047	0.0014	18	13
67	12	68	0.7394	0.2444	28	20
68	68	69	0.0047	0.0016	28	20

Appendix- G

Table G1: System Data of 85-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.108	0.075	0	0.00
2	2	3	0.163	0.112	0	0.00
3	3	4	0.217	0.149	56	0.00
4	4	5	0.108	0.074	0	0.00
5	5	6	0.435	0.298	35.28	0.00
6	6	7	0.272	0.186	0	0.00
7	7	8	1.197	0.82	35.28	0.00
8	8	9	0.108	0.074	0	0.00
9	9	10	0.598	0.41	0	0.00
10	10	11	0.544	0.373	56	0.00
11	11	12	0.544	0.373	0	0.00
12	12	13	0.598	0.41	0	0.00
13	13	14	0.272	0.186	35.28	0.00
14	14	15	0.326	0.223	35.28	0.00
15	2	16	0.728	0.302	35.28	0.00
16	3	17	0.455	0.189	112	0.00
17	5	18	0.82	0.34	56	0.00
18	18	19	0.637	0.264	56	0.00
19	19	20	0.455	0.189	35.28	0.00
20	20	21	0.819	0.34	35.28	0.00
21	21	22	1.548	0.642	35.28	0.00
22	19	23	0.182	0.075	56	0.00
23	7	24	0.91	0.378	35.28	0.00
24	8	25	0.455	0.189	35.28	0.00
25	25	26	0.364	0.151	56	0.00
26	26	27	0.546	0.226	56	0.00
27	27	28	0.273	0.113	35.28	0.00
28	28	29	0.546	0.226	0	0.00
29	29	30	0.546	0.226	35.28	0.00
30	30	31	0.273	0.113	14	0.00
31	31	32	0.182	0.075	0	0.00
32	32	33	0.182	0.075	35.28	0.00
33	33	34	0.819	0.34	0	0.00
34	34	35	0.637	0.264	0	0.00

35	35	36	0.182	0.075	56	0.00
36	26	37	0.364	0.151	56	0.00
37	27	38	1.002	0.416	56	0.00
38	29	39	0.546	0.226	35.28	0.00
39	32	40	0.455	0.189	35.28	0.00
40	40	41	1.002	0.416	0	0.00
41	41	42	0.273	0.113	35.28	0.00
42	41	43	0.455	0.189	35.28	0.00
43	34	44	1.002	0.416	35.28	0.00
44	44	45	0.911	0.378	35.28	0.00
45	45	46	0.911	0.378	35.28	0.00
46	46	47	0.546	0.226	14	0.00
47	35	48	0.637	0.264	0	0.00
48	48	49	0.182	0.075	0	0.00
49	49	50	0.364	0.151	36.28	0.00
50	50	51	0.455	0.189	56	0.00
51	48	52	1.366	0.567	0	0.00
52	52	53	0.455	0.189	35.28	0.00
53	53	54	0.546	0.226	56	0.00
54	52	55	0.546	0.226	56	0.00
55	49	56	0.546	0.226	14	0.00
56	9	57	0.273	0.113	56	0.00
57	57	58	0.819	0.34	0	0.00
58	58	59	0.182	0.075	56	0.00
59	58	60	0.546	0.226	0	0.00
60	60	61	0.728	0.302	56	0.00
61	61	62	1.002	0.415	56	0.00
62	60	63	0.182	0.075	14	0.00
63	63	64	0.728	0.302	0	0.00
64	64	65	0.182	0.075	0	0.00
65	65	66	0.182	0.075	56	0.00
66	64	67	0.455	0.189	0	0.00
67	67	68	0.91	0.378	0	0.00
68	68	69	1.092	0.453	56	0.00
69	69	70	0.455	0.189	0	0.00
70	70	71	0.456	0.226	35.28	0.00
71	67	72	0.182	0.075	56	0.00
72	68	73	1.184	0.491	0	0.00
73	73	74	0.273	0.113	56	0.00
74	73	75	1.002	0.416	35.28	0.00

75	70	76	0.546	0.226	56	0.00
76	65	77	0.091	0.037	14	0.00
77	10	78	0.637	0.264	56	0.00
78	67	79	0.546	0.226	35.28	0.00
79	12	80	0.728	0.302	56	0.00
80	80	81	0.364	0.151	0	0.00
81	81	82	0.091	0.037	56	0.00
82	81	83	1.092	0.453	35.28	0.00
83	83	84	1.002	0.416	14	0.00
84	13	85	0.819	0.34	35.28	0.00

Appendix- H

Table H1: System Data of 30-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P (pu)	Q (pu)
1	1	2	0.096	0.039	0.0042	0.0026
2	2	3	0.088	0.036	0	0
3	3	4	0.135	0.037	0.0042	0.0026
4	4	5	0.123	0.034	0.0042	0.0026
5	5	6	0.123	0.034	0	0
6	6	7	0.259	0.0446	0	0
7	7	8	0.173	0.029	0.0042	0.0026
8	8	9	0.259	0.044	0.0042	0.0026
9	9	10	0.173	0.029	0.0041	0.0025
10	10	11	0.108	0.081	0.0042	0.0026
11	11	12	0.086	0.014	0.0025	0.0015
12	3	13	0.129	0.022	0.0011	0.0007
13	13	14	0.173	0.029	0.0011	0.0007
14	14	15	0.086	0.041	0.0011	0.0007
15	15	16	0.043	0.007	0.0002	0.0001
16	6	17	0.148	0.041	0.0044	0.0027
17	17	18	0.135	0.037	0.0044	0.0027
18	18	19	0.171	0.039	0.0044	0.0027
19	19	20	0.156	0.035	0.0044	0.0027
20	20	21	0.156	0.035	0.0044	0.0027
21	21	22	0.216	0.037	0.0044	0.0027
22	22	23	0.216	0.037	0.0044	0.0027
23	23	24	0.259	0.044	0.0044	0.0027
24	24	25	0.173	0.029	0.0044	0.0027
25	25	26	0.108	0.018	0.0044	0.0027
26	26	27	0.086	0.014	0.0026	0.0016
27	7	28	0.129	0.022	0.0017	0.0011
28	28	29	0.129	0.022	0.0017	0.0011
29	29	30	0.129	0.022	0.0017	0.0011

Appendix- I

Table II: System Data of 141-Node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q(kvar)
1	1	2	0.058	0.041	0	0
2	2	3	0.173	0.122	0	0
3	3	4	0.001	0.001	0	0
4	4	5	0.009	0.007	0	0
5	5	6	0.007	0.005	0	0
6	6	7	0.047	0.063	0	0
7	7	8	0.074	0.098	45.01	59.99
8	8	9	0.065	0.046	8.16	5.77
9	9	10	0.051	0.036	0	0
10	10	11	0.012	0.008	0	0
11	11	12	0.129	0.091	20.41	14.44
12	12	13	0.123	0.087	61.28	43.25
13	13	14	0.049	0.035	0	0
14	14	15	0.096	0.068	0	0
15	15	16	0.086	0.061	0	0
16	16	17	0.040	0.028	122.39	86.72
17	17	18	0.083	0.057	0	0
18	18	19	0.019	0.013	0	0
19	19	20	0.056	0.040	61.25	43.28
20	20	21	0.037	0.025	62.19	41.92
21	21	22	0.057	0.031	0	0
22	22	23	0.026	0.019	60.69	44.07
23	23	24	0.068	0.050	0	0
24	24	25	0.040	0.028	0	0
25	25	26	0.073	0.053	121.32	88.21
26	26	27	0.034	0.024	60.62	44.16
27	27	28	0.058	0.041	0	0
28	28	29	0.066	0.046	61.24	43.29
29	61	62	0.041	0.029	0	0
30	60	63	0.035	0.025	0	0
31	63	64	0.105	0.074	122.54	86.52
32	64	65	0.067	0.048	0	0
33	65	66	0.030	0.021	136.79	61.55
34	66	67	0.046	0.032	291.47	71.01

35	67	68	0.022	0.015	94.29	116.66
36	29	30	0.034	0.025	30.09	39.93
37	30	31	0.013	0.009	0	0
38	31	32	0.035	0.025	16.33	11.54
39	2	33	0.044	0.031	0	0
40	33	34	0.002	0.001	61.21	43.34
41	5	35	0.227	0.055	0	0
42	5	36	0.127	0.157	0	0
43	6	37	0.006	0.007	40.79	28.91
44	37	38	0.204	0.144	0	0
45	38	39	0.094	0.066	0	0
46	39	40	0.035	0.025	0	0
47	40	41	0.092	0.065	102.05	72.19
48	41	42	0.232	0.164	123.07	85.75
49	42	43	0.121	0.085	0	0
50	43	44	0.044	0.031	101.99	72.27
51	44	45	0.041	0.029	61.25	43.28
52	45	46	0.016	0.013	81.63	57.76
53	46	47	0.064	0.045	0	0
54	47	48	0.042	0.030	0	0
55	48	49	0.073	0.051	20.41	14.44
56	49	50	0.083	0.056	0	0
57	50	51	0.040	0.028	244.88	173.3
58	51	52	0.023	0.016	122.43	86.67
59	38	53	0.084	0.060	0	0
60	42	54	0.002	0.011	244.67	173.59
61	54	55	0.053	0.037	163.23	115.57
62	55	56	0.089	0.063	0	0
63	56	57	0.087	0.061	244.88	173.31
64	57	58	0.067	0.048	122.44	86.65
65	58	59	0.047	0.033	183.58	130.09
66	55	60	0.033	0.024	40.8	28.9
67	60	61	0.033	0.023	81.68	57.7
68	63	69	0.037	0.026	244.89	173.29
69	66	70	0.023	0.016	0	0
70	70	71	0.012	0.003	291.61	70.47
71	70	72	0.070	0.050	122.47	86.61
72	42	73	0.023	0.016	244.62	173.67
73	73	74	0.003	0.006	127.33	271.64
74	43	75	0.038	0.027	36.74	25.98

75	44	76	0.055	0.039	61.2	43.35
76	46	77	0.052	0.044	114.58	96.81
77	76	78	0.017	0.011	0	0
78	78	79	0.042	0.010	488.25	118.83
79	79	80	0.100	0.024	728.75	177.28
80	79	81	0.151	0.037	0	0
81	81	82	0.003	0.001	145.78	35.34
82	47	83	0.009	0.006	60.59	44.2
83	49	84	0.052	0.045	169.88	147.53
84	50	85	0.015	0.004	0	0
85	85	86	0.004	0.002	458.93	198.46
86	86	87	0.004	0.002	137.68	59.54
87	7	88	0.017	0.023	45.12	59.91
88	88	89	0.047	0.063	39.01	51.99
89	89	90	0.030	0.040	0	0
90	90	91	0.021	0.028	0	0
91	91	92	0.032	0.042	0	0
92	92	93	0.028	0.037	0	0
93	93	94	0.021	0.027	66.1	87.92
94	94	95	0.021	0.027	0	0
95	89	96	0.069	0.049	122.46	86.63
96	96	97	0.097	0.069	0	0
97	97	98	0.090	0.020	293.16	63.7
98	97	99	0.003	0.001	0	0
99	131	132	0.035	0.025	291.56	70.68
100	131	133	0.092	0.067	12.23	8.68
101	121	134	0.084	0.061	0	0
102	16	135	0.053	0.037	121.43	29.64
103	16	136	0.030	0.021	0	0
104	16	137	0.058	0.041	291.48	71
105	23	138	0.077	0.056	146.24	33.35
106	99	100	0.003	0.001	488.2	119.03
107	91	101	0.023	0.016	0	0
108	101	102	0.058	0.041	690.3	293.23
109	102	103	0.089	0.022	728.89	176.7
110	103	104	0.063	0.015	20.4	14.44
111	104	105	0.117	0.029	485.76	118.49
112	104	106	0.011	0.003	61.27	43.26
113	92	107	0.085	0.021	0	0
114	94	108	0.061	0.026	0	0

115	108	109	0.045	0.019	291.04	72.26
116	94	110	0.003	0.001	52.67	38.09
117	7	111	0.072	0.051	0	0
118	10	112	0.107	0.026	89.79	63.55
119	11	113	0.035	0.025	0	0
120	13	114	0.062	0.044	0	0
121	114	115	0.067	0.047	0	0
122	115	116	0.004	0.001	81.58	57.83
123	14	117	0.051	0.037	102.01	72.24
124	15	118	0.016	0.011	0	0
125	118	119	0.046	0.033	0	0
126	119	120	0.042	0.030	61.27	43.26
127	120	121	0.051	0.036	60.38	44.49
128	121	122	0.073	0.052	88.99	64.65
129	122	123	0.058	0.041	91.79	65.05
130	123	124	0.061	0.043	0	0
131	124	125	0.078	0.055	61.27	43.26
132	125	126	0.083	0.061	36.39	26.47
133	126	127	0.035	0.025	28.3	20.59
134	127	128	0.057	0.042	20.41	14.44
135	128	129	0.059	0.043	61.19	43.36
136	129	130	0.010	0.007	44.87	31.81
137	119	131	0.036	0.025	40.44	29.4
138	25	139	0.095	0.067	40.8	28.9
139	30	140	0.052	0.038	121.36	88.16
140	31	141	0.058	0.041	61.19	43.37

Appendix- J

Table J1: Co-ordinates and Data for 53 Load Points

Node Number	X-Coordinate	Y- Coordinate	Load(kVA)
1	Substation node, the coordinates for which are to be obtained from proposed algorithm		
2	1.00	2.00	25.0
3	2.00	15.00	25.0
4	3.00	4.00	25.0
5	4.00	12.00	50.00
6	5.00	11.50	63.00
7	6.00	10.00	63.00
8	7.00	7.00	50.00
9	1.50	5.50	25.00
10	11.50	13.50	16.00
11	7.50	17.50	16.00
12	8.50	15.50	25.00
13	12.50	10.50	50.00
14	11.00	17.50	63.00
15	8.00	7.50	63.00
16	11.00	6.00	25.00
17	5.50	5.50	16.00
18	3.50	8.50	16.00
19	13.00	8.00	16.00
20	14.00	13.00	63.00
21	16.50	14.00	25.00
22	5.50	17.00	25.00
23	20.50	12.00	50.00
24	8.00	9.00	100.00
25	5.00	7.00	100.00
26	8.00	5.50	100.00
27	10.50	8.00	50.00
28	10.50	15.00	50.00
29	9.00	19.00	25.00
30	7.50	19.50	63.00
31	5.50	19.50	63.00
32	3.00	17.50	25.00
33	13.00	15.50	50.00

34	14.00	16.50	50.00
35	12.50	19.00	25.00
36	11.00	20.00	25.00
37	5.00	15.50	50.00
38	2.00	10.50	50.00
39	3.00	3.50	63.00
40	6.00	4.00	25.00
41	9.00	4.50	25.00
42	14.00	11.50	50.00
43	15.00	10.00	50.00
44	15.00	14.50	25.00
45	15.50	12.50	25.00
46	12.00	12.00	63.00
47	14.50	7.50	63.00
48	13.50	6.00	25.00
49	13.00	4.50	16.00
50	13.50	18.00	16.00
51	4.00	5.00	25.00
52	9.50	6.50	16.00
53	9.50	17.00	25.00
54	12.00	2.50	50.00

Power Factor of the Load = 0.75

Demand Factor = 1.00

List of Publications

- Suman Bhullar and Smarajit Ghosh (2018), “Optimal integration of multi distributed generation sources in radial distribution networks using a hybrid algorithm”, *Energies*, Vol. 11, No. 3, pp. 628. <https://doi.org/10.3390/en11030628> (SCIE, **Impact Factor: 2.676**).
- Suman Bhullar and Smarajit Ghosh (2017), “A novel search technique to solve load-flow of distribution networks”, *Journal of Engineering Research*, Vol. 5, No. 4, pp. 59-75, 2017. (SCIE, **Impact Factor: 0.128**)

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Biography

Suman Bhullar born in Gurdaspur, Punjab, India on 13 March, 1976. She did B.E. (Electrical Engineering) and M. Tech. (Power Engineering) from Guru Nanak Dev Engineering College, Ludhiana, Punjab, India. She is working as assistant professor in the department of Electrical & Instrumentation Engineering (EIED) at Thapar Institute of Engineering & Technology (TIET), Patiala since 2003. She is pursuing Ph.D. as part-time research scholar in EIED at Thapar Institute of Engineering & Technology, Patiala, and Punjab, India under the guidance of Dr. Smarajit Ghosh (Professor, EIED, TIET, Patiala). Her areas of research include radial distribution systems, load-flow studies, distributed generation and substation planning.

Smarajit Ghosh born in Ghatal, West Bengal, India on 16 August, 1967. He did B.Sc. (Physics Hons.), B. Tech. (Electrical Engineering), M. Tech. (Electrical Machines and Power Systems) from Calcutta University. He completed Ph.D. from Indian Institute of Technology, Kharagpur, India in 2000. His research areas include load-flow studies, network reconfiguration, distributed generation, data security, applications of soft computing in electrical power distribution systems etc. He has authored number of books published by Prentice Hall of India Private Limited and Pearson education as single author. Dr. Ghosh has several research publications in the reputed engineering journals. He is presently serving as a professor at TIET in the department of Electrical and Instrumentation Engineering since 2007. He had also served BITS, PILANI and SMIT, SIKKIM as an Assistant Professor and Professor respectively.