Stable Optimal Planning of Electric Power Distribution System using Fuzzy Logic

A Thesis

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Submitted by

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CERTIFICATE

I hereby certify that the work, which is being presented in thesis entitled "***Stable Optimal Planning of Electric Power Distribution System using Fuzzy Logic***" to the Department of Electrical and Instrumentation Engineering, Thapar Institute of Engineering & Technology (Deemed to be university), Patiala in the 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 work, 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 in any other University or Institute.

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

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Dedicated to My Father

ABSTRACT

A methodology is proposed to solve the load flow solution of radial and meshed distribution networks using Fuzzy-PSO. To reduce the effective loss of the system, an approach for optimal DG size has been computed using a hybrid ABC-CS algorithm. The locations of DG units are the principal reasons for placement of DGs in the electric radial distribution networks. These investigations allow another deterministic technique that decides exact location for DG arrangement. The exact nodes for DG placement have been computed using the loss sensitive factors. The multi DG placement have given better results compared to the single DG placement. The proposed method has been implemented on 33-node, 69-node radial and 85-node meshed distribution networks and the results obtained by the proposed method have been compared with the other existing methods.

In this thesis an exact voltage stability index (VSI) has been proposed considering the voltage angle. The VSI indices have been calculated using the proposed load flow solution. The voltage stability indices obtained by the proposed method with other two existing VSI indices have been compared.

The VSI values have also been computed before and after DG placement. The above three distribution networks have been considered for the computation of VSI using the proposed VSI index and by the existing VSI indices.

The placement of only multi DGs cannot give the major loss reduction. Also, it is true that only the network reconfiguration cannot give the sufficient loss reduction. The network reconfiguration along with the multi DG placement in the reconfigured networks can give the better results. The hybrid algorithm ABC-CS is used here for network reconfiguration. The results obtained by the proposed method have also been compared with the other existing methods. The proposed method gives better results compared to the other existing methods.

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INTRODUCTION AND LITERATURE SURVEY

1.1 Introduction

The electrical utility network is generally separated into three subsystems, which are generation, transmission, and distribution. A fourth division is sub transmission that is created sometimes. Distribution has an essential influence as the purchasers are specifically influenced by its effectiveness. Distribution system planning is a “combinatorial optimization issue” for which the goal is to decide the optimal method for providing a given set of loads. This procedure includes the number selection, location and substations size and the configuration of main feeder likewise the installation cost. This also considers the energy loss cost, which is very low when compared to the maintenance of radial network. At the same time the voltage drops as well as the capacity constraints should not be violated anywhere in the whole arrangement [1]. The greatest load transferring capacity of power lines at peak load and the greatest permissible voltage drop are the constraints that are to be satisfied. To reduce the capital cost in typical rural networks where the customers are minor individuals and are extensively sparsely around the source station, radial networks are recommended [2]. Extending a current network by adding new feeders or by reconfiguring the distribution feeders of the existing network and also by constructing substations newly, these all are included in the normal Distribution System Planning (DSP). If the distributed generator (DG) is not at large level, the DG incorporation in distribution system planning reduces the cost of planning as it creates DSP models newly [3]. Electrical distribution networks are becoming complicated and huge, which paves the way greater system losses. Among the power system customers and the distribution substation, distribution network is presented [4]. It contains a number of analogous radial circuits. Considering the greatest load requirement, the distribution networks are premeditated. Almost all the traditional power distribution systems are provided with radial networks by means of one-way power flow [5]. Power flow analysis is one of the significant and primary apparatus. The upcoming expansion of the network is based upon the distribution system load flow analysis as the requirement of load is further enhanced. Steady state condition of a system can be attained by the load stream resolution [6]. Reducing losses in power distribution systems is an imperative requirement [7].

1.2 Literature Survey

Appropriate location and optimal sizes of DGs become the vital standard in picking up the most extreme advantages from them, yet then again, non-optimal arrangement or measuring of DGs may cause annoying impacts. Different optimization techniques are utilized to minimize the power loss, energy loss, cost, environmental emission and to augment the profit, or even to optimize the multi-objective index. Review of published literature on distribution system planning addressed several issues including system risk calculation, for example DGs' capacities, locations, distributions, and also component outage probabilities, size and placement of DGs and capacities, load flow solution, energy and power loss associated with the DG placement etc. The literature review of such kind of works related with the planning of the distribution networks including load flow solution and DG placement and sizing are represented as follows.

Marti ***et al.*** [8] had suggested a new model of load, which characterized the loads' voltage dependence. A curve-fitting method was utilized to obtain a load model dependent on voltage. With this illustration and a few numerical estimates on the non-real component of the voltages at nodes, it was viable to device the load flow technique as a linear power-flow (LPF) solutions requiring many iterations. The estimate was once proven in systems having 3000 nodes with quality results.

The LPF system used to be peculiarly main in the context of optimization algorithms for computerized smart distribution systems.

Jia ***et al.*** [9] had presented any hierarchical solution to evaluate the impact of alteration with the distribution system in power system threat evaluation. DGs may present critical loads within the distribution system through re-dispatching right after a few concurrent takes place. The discrete possibility style was currently employed to simulate the actual irregular output regarding DGs. Available supply capacity (ASC) was utilized like a standard constraint to make sure the actual safety level of the distribution system that required large reliability. The iterative computation involving transmission network and distribution network was also embraced to originate risk indices together with taking into consideration detail constructions with the energetic distribution network. Additionally, the influence regarding a few factors in system risk calculation, for example DGs' capacities, locations, distributions, and also component outage probabilities, were being talked about.

Kocar ***et al.*** [10] introduced three-phase load flow solution algorithms while utilizing modified-augmented-nodal-analysis method. The resolution of load stream procedures was being in comparison for the IEEE 8500-node distribution network feeder utilizing a presented regulator tap control approach.

Carpinelli ***et al.*** [11] suggested any probabilistic technique to review the actual steady-state operating circumstances associated with an active electric distribution structure program along with photovoltaic (PV) and wind (WD) production plants. The technique becomes the reason for the actual questions regarding power generation from reusable production and power load demands that also combine multi-linearized power stream conditions with Monte Carlo simulation methods. These equations for power flow involved modelling of a wind turbine in addition to photo voltaic production elements and multi-linearization completed via making use of any qualifying measure depending upon the total activation power of the system. That technique had sufficiently drawn out a probabilistic procedure proposed in the related artistic works for conventional electrical distribution systems towards a functioning electrical distribution network alongside PV and WD production elements. Mathematical utilizations were obtainable as well as reviewed by regards at 17-node radial distribution network seen as a WD and PV systems hooked up with diverse bus bars. The outcomes acquired with all the suggested criteria ended up in contrast to the outcomes acquired employing a Monte Carlo simulation criterion of which involved non-linear electrical power flow equations.

Nakhli ***et al.*** [12] confirmed that exactly how subjective variations in representing fuzzy inputs might have an effect on the final outputs. They regarded a constrained range of predicted samples in terms of fuzzy membership functions as good because the range of old forecasting mistakes in phrases of probability density features. Based on that, they proposed a joined fuzzy/probabilistic analysis of distribution network voltages, because of hybrid fuzzy/probabilistic uncertainties for consumption and iteration. The method allowed the sampled inputs to join in a Monte Carlo-based nonlinear fuzzy load flow together with Wind Turbine Generating units (WTGUs). The result of hybrid uncertainty illustration, the evaluation of fuzzy load flow outcome was assessed in probabilistic structure. Simulations were carried out on the unbalanced IEEE 34-node radial distribution system connected with WTGUs

Sayyad ***et al.*** [13] illustrated a brand new blended whole number non-linear programming method for capacitor placement in radial or mesh distribution networks, which evaluates the perfect sitting by measuring of capacitors through a motivation behind power loss decrease and capacitor charges subsidizing. The projected strategy was used in 10-node, 34-node, and 85-node radial distribution networks and CIVANLAR mesh distribution technique. A considerable amount of scale programming methods was utilized to assess the execution of the methodology with the Fuzzy thinking, particle swarm optimization (PSO), plant growth simulation algorithm (PGSA), and Heuristic method. Numerical results demonstrated that the proficiency of the MINLP approach was once superior to the other methods. Furthermore, the MINLP network used to be progressed to a couple of various methodologies as far as solution of power loss and costs.

Massignan ***et al.*** [14] presented a problem of calculating load flow in distribution feeders via the conventional three-phase backward/forward sweep method when voltage regulators in the bidirectional mode experienced reverse flow due to power injection from distributed generation downstream the regulators. The paper also presented a simple but effectively modification in the algorithm of that method to overcome the problem. A modified version of the IEEE 34 buses distribution test feeder had been used to demonstrate the problem and the proposed algorithm solution.

Wang ***et al.*** [15] established a fast sensitivity method for determining line loss and node voltages in active distribution network by making use of two sensitivity models namely Quadratic Sensitivity model of distributed generation (DG) output or load to Line Loss (QSLL model) and a Linear Sensitivity model of DG output or load to Node Voltages (LSNV model). The proposed work was based on sensitivity method in view of the accuracy and the conciseness of the QSLL and LSNV models, could play an important role on DG planning and dispatching in active distribution network.

Mohamed and Kowsalya [16] had exhibited a novel method to find the most optimal size and location of DG with system power losses minimization, operational expenses and making upgrades to voltage stability as a goal. Loss sensitivity factor (LSF) was used to decide the ideal locations of DG units' placement. Bacterial Foraging Optimization Algorithm (BFOA) was used to seek out the optimal DG size. BFOA was at one time a swarm insight strategy, which modeled the individual and workforce for maturing arrangements of the Escherichia coli micro-organism as a dispersed improvement method. The specialized imperatives of voltage and branch current conveying limit were consolidated in the valuation of the goal work. The proposed procedure was once affirmed on 33-node and 69-node radial distribution networks with various load models at explicit load levels and approved the efficiency and effectiveness of the strategy.

Murty and Kumar [17] had given an assessment of new power loss sensitivity, power stability index (PSI), and voltage sensitivity index (VSI) approaches for ideal size and location of DG in the distribution system. The main effect of their method was the optimal arrangement of DGs built up on Novel Power Loss Sensitivity and PSI approaches, proposed voltage steadiness record technique for optimal DG position, evaluation of affectability ways for DG location and size calculations, ideal situation of DG within the sight of burden development, impact of the DG situation of joining load control factor, and effect of voltage strength edge development on DG. Voltage profile, the real and reactive power utilization via the grid, active and reactive power flow, cost of power losses, investment in energy loss cost and power cost purchased from DGs are chosen. The outcomes demonstrated the centrality of fixing the appropriate component of DG on the perfect area. The outcomes are obtained with all affectability arranged ways on the original and modified 12-node, 85- node and 69- node radial distribution networks.

Hung and Mithulananthan [18] had investigated the difficulty of a multiple, distributed generator (DG units) placement to attain a high loss reduction in large-scale primary distribution networks. An improved analytical (IA) approach was presented in that paper. This system was established on IA expressions to compute the top-rated measurement of four exclusive DG varieties and a technique to classify the satisfactory location for DG allocation. A system to get the most optimal power factor was awarded for DG competent of supplying real and reactive power. In addition, loss sensitivity factor (LSF) and exhaustive load flow (ELF) methods were also presented. IA procedure was once tested and validated on three distribution experiment techniques with various sizes and difficulty. Results showed that IA procedure was once powerful as when put next with LSF and ELF solutions.

Doagou-Mojarrad ***et al.*** [19] had introduced an intelligent fuzzy satisfying method, which depended on Hybrid Modified Shuffled Frog Leaping Algorithm, and tackled the issue of the Multi-objective ideal position and estimating of DG units. Minimizing total electrical energy losses, total electrical energy cost and all out-contamination discharges delivered were the target capacities in that issue. Additionally, the improvement of the voltage profile was considered as a requirement in deciding the optimal arrangement. In the proposed technique, the target capacities were displayed with fuzzy sets. The multi-target issue was changed into a min-max issue, which was then taken care of by the proposed developmental calculation. At long last, the proposed calculation was tried on a 69-node RDN dependent on specialized, economic and environmental protection considerations. The simulated results showed the great execution and pertinence of the suggested technique.

Singh and Gyanish [20] analyzed distribution network operation, system voltage profile analysis, real and reactive power losses and cost of the system after placing DG units of different configurations and penetration levels in the system. The paper demonstrated that optimal power system performance and economical efficiency can be obtained by placing DG unit of optimal size at optimal location. The proposed method had been tested on 14-node distribution test system.

Reddy ***et al.*** [21] presented a new meta-heuristic algorithm called whale optimization algorithm (WOA) to find the optimal size of DG units whereas Optimal DG locations were obtained from power loss index method. The WOA algorithm was based on the unique hunting behavior of humpback whales. The WOA algorithm was tested on 15-bus, 33-bus, 69-bus, 85-bus and 118-bus test systems. The results obtained by the proposed WOA algorithm were compared with different types of DGs and other evolutionary algorithms. The proposed work in the paper resulted in reduction in system losses and improvement in voltage profile by the use of efficient and robust WOA algorithm which can handle mixed integer nonlinear optimization problems.

Kavousi-Fard and Akbari-Zadeh [22] had proposed another multi-objective improved shuffled frog leaping algorithm (ISFLA) to examine the distribution feeder reconfiguration (DFR) issue from the unwavering quality upgrade perspective. In any case, since the complete expense of MW loss was an essential and appealing subject to the electric influence utilities, the total active power loss was also considered as a target work in the analysis. Hence, the target elements of the issue to be improved were the total active power loss and average energy not supplied (AENS). Amid the enhancement procedure, the proposed ISFLA found a lot of non-overwhelmed ideal arrangements alluded to Pareto ideal arrangements that were kept in an outside memory called store. As the after effect of the clashing conduct of the target capacities researched, a fuzzy grouping strategy was utilized to control the extent of the archive in as far as possible. The attainability and the proficiency of the proposed method were analyzed by a standard distribution network.

Nguyen and Truong [23] had proposed a reconfiguration philosophy dependent on a cuckoo search algorithm (CSA) for limiting active power loss and the boosting voltage magnitude. The CSA strategy was another meta heuristic calculation enlivened from the commit brood parasitism of some cuckoo species, which laid their eggs in the nests of other host birds of other species for solving optimization issues. Contrasted with different strategies, CSA strategy had less control parameters and was increasingly powerful in optimization. The viability of the proposed CSA had been tried on three different distribution networks and the test outcomes had been contrasted with those from different methods in the literature. The simulated results had demonstrated that the proposed CSA could be a proficient and promising technique for the reconfiguration issues of distribution networks.

Ugranli and Karatepe [24] had examined an optimality model to limit losses by including load uncertainty, diverse DG entrance levels and responsive influence of numerous DG idea. The recreation results had demonstrated that it was impractical to frame an analytical equation for optimal arranging of DG regarding load distribution, infiltration level and reactive power. Because of the unpredictability of the various DG idea, artificial neural networks based optimal DG placement and size strategy was created. The proposed strategy was executed on 30-node radial distribution network and the outcomes were introduced and examined. The outcomes had established that the suggested technique could be connected to a power network for every conceivable situation.

Abdelaziz ***et al.*** [25] had displayed a novel calculation for optimal planning of a DG unit in the distribution systems. The proposed method used the firefly algorithm to most likely manage the basically compelled improvement issues by proposing recipes for tuning the algorithm parameters and updating equations. The proposed algorithm unbendingly decided the ideal location and size of the DG units so as to minimize the system power loss without violating the system parameter limitations. In addition, the optimum DG size with appropriate location for accomplishing a specific indicated power loss were resolved utilizing the proposed method and contrasted with the after effects of a proposed heuristic system. The DG units in the proposed calculations were demonstrated as voltage-controlled nodes with the adaptability to be changed over to steady power nodes on account of reactive power limit violation. The proposed calculations were executed in MATLAB and tried on the 33-node and the 37-node radial distribution networks.

Imran ***et al.*** [26] had exhibited a novel combination method for ideal system reconfiguration and distributed generation (DG) situation in distribution network with a goal of power loss minimization and voltage stability improvement. Fireworks Algorithm (FWA) was utilized to reconfigure and assign optimal DG units in a distribution network. FWA was another swarm intelligence-based optimization computation, which was conceptualized utilizing the fireworks blast procedure of searching for the best location of sparks. The radial nature of the network was secured by generating proper parent node-child node path of the network during power flow. Voltage stability Index (VSI) was used to pre-identify the optimal candidate locations for DG installation. Six different scenarios are considered during DG placement and reconfiguration of network to assess the performance of the proposed technique.

Tolabi ***et al.*** [27] had introduced a hybrid optimal multi-objective reconfiguration method to decide the size and location of DGs in a distribution network. The motivations behind that exploration were to reduce losses, improve voltage profile and equalize the feeder load adjusting in power distribution networks. To decrease the search space, the Improved Analytical (IA) method was utilized to choose the appropriate nodes for various DGs, while the Bees algorithm (BA) approach as a population-based algorithm was utilized to reconfigure and recognize at the same time the optimal limit with regards to establishment of DG units in the distribution network. So as to encourage capacity for multi-target look through the advancement issue was defined to minimize the fuzzy inference indices.

Dahalan ***et al.*** [28] had displayed the concurrent technique to distinguish the optimal network reconfiguration and DG measuring utilizing developmental programming. The fundamental objective of their work was to decrease the power loss and enhance the voltage profile, while in the meantime it satisfies the working imperatives. The created strategy was tried on 33-node and 69-node distribution networks with various working conditions. The test outcomes demonstrated an extraordinary improvement of power loss reduction and improvement of voltage profile of the network.

Georgilakis and Hatziargyrion [29] had just explained about the approaches used for ODGP issue with the classification as well as analysis of present and upcoming developments in the arena. The techniques used were decentralized generation, distributed energy resources, distribution systems optimization and optimal distributed generation placement (ODGP). Logical technique named “2/3 rule” was used by them for installing the DG of 2/3 capability for inward production at 2/3 of the distance of the route, and also gradient search was utilized to optimal sizing of DGs inside the interconnected systems. Heuristic methods were also implemented for solving the ODGP difficulty through dependability limitations. The algorithms used for heuristic method was Genetic Algorithm, Tabu Search, Ant Colony Optimization, Practical Heuristic Algorithms etc. The disadvantage of Heuristic method was that it required high computational effort. Coordinated planning, Dynamic ODGP, Active network management (ANM) was the future technique mentioned by them.

Rao ***et al.*** [30] had projected another strategy to take care of the system reconfiguration issue by utilizing distributed generation (DG) with a goal of minimizing active power loss and improving the voltage profile in distribution network. The calculation utilized by them was a meta heuristic Harmony Search Algorithm (HSA) that was utilized to reconfigure and distinguish the optimum locations for installation of DG units in a distribution network and furthermore a sensitivity analysis was carried out to recognize appropriate locations for integration of DG units. Harmony Search Algorithm, active power loss, reconfiguration, voltage profile was considered for the reconfiguration of system. The steps utilized in Harmony Search Algorithm (HSA) was to initialize the problem and algorithm parameters, initialize the harmony memory, improvise a new harmony, update the harmony memory, verify the termination criteria. The technique was connected with two test networks comprising of 69-node and 33-node distribution networks. DG placement gave close optimum power losses with close optimal size contrasted with other installations.

Zhou ***et al.*** [31] had built up a robust "Possibilistic Mixed Integer Programming (PMIP)" method to arrange metropolitan electric power systems (EPS). They gathered important information from government reports, yearbooks and significant literary works. At that point the capacity of electric power plant was expanded, likewise the consumption of power by the purchasers was determined and investigation was done on Electricity balance and self-sufficiency analysis. Then they solved the RPMP-EPS model with various conditions of robustness levels to estimate the penalty costs and system costs.

Ravadanegh and Roshanagh [32] had executed another Imperialist Competitive Algorithm (ICA) for the optimal extension arranging of distribution system to meet the load growth and overcome the pseudo unique conduct of system parameters and found that the capital investment and working expenses of expanded and new created establishment thinking about electrical, topographical and different requirements in Optimal Distribution System Placement had been limited by the ICA calculation. They found that the effectiveness and ability of the method had been improved with a huge decrease in the computational exertion.

Muttaqi [33] had proposed a method for minimizing the total operational cost and investment cost of the network by considering the location of the network and the size of DG. An approach depending upon the location and the optimal size of DG was presented by considering parameters such as quality, reliability and cost. The objective function was developed and an optimization algorithm known as Particle Swarm Optimization (PSO) algorithm was selected, which was used to obtain the optimal DG planning solutions. Around 100 to 500 populations and iterations were required to solve the optimization process utilizing PSO. That project was tested on a distribution feeder of an Australian power network, implied that when the payment toward reliability was high, a high investment on the DG should be expected as a backup supply in the case of a system failure.

Ramirez-Rosado and Dominguez-Navarro [34] had proposed the Optimal Planning of Electric Power distribution networks using Fuzzy Sets. New possibilistic (fuzzy) model for the multi-objective optimal planning of power distribution networks. That method was implemented through Fuzzy sets, multi-objective optimization, planning, power distribution systems, Tabu search for optimal location and size of the future feeders and substations in distribution networks with dimensions significantly larger. In the first phase, the set of non-dominated planning solutions was obtained using a parametric method based on an optimization by goals. In the second phase, a solution of the set of non-dominated solutions was selected using a suitable max-min approach. Tested in real distribution networks, which proves their practical application to large comparing the two distribution network topologies of with the possibilistic and deterministic models the mentioned best multi-objective planning solutions power distribution systems.

Kleinberg ***et al***. [35] had proposed an analytical partitioning method based on capacitor reactive power domains. Distributed control algorithm was used to support distribution operation applications with a focus on voltage spread reduction, also e-partitioning method was also applied to the commonly studied capacitor control objective of loss minimization. The results obtained on a real-world distribution feeder were presented and compared with an alternate geographically-based partitioning method. They concluded that it produced high quality solutions to the capacitor control problem.

Rupolo and Mantovani [36] had proposed to comprehend the reconfiguration issue of meshed distribution networks a based on a Meta heuristic-based calculation by means of node depth analysis. Strategy utilized was exponential load model, node-profundity representation. It was then led through the administrators and from the electrical power network point of view, results finding simply winding topologies. The analysis was directed utilizing 135-node distribution network.

Ortiz ***et al.*** [37] proposed a study for planning of radial distribution systems using a mixed-integer second-order cone programming. The paper made use of a model for solving the problems of the reconfiguration of feeders and allocation of capacitor banks simultaneously subjected to constraints of achieving a minimum overall investment, in both fixed and switchable capacitor banks, and operational costs and cost of energy losses. The approach included a voltage-dependent load representation. The use of a mixed-integer second-order cone programming model guaranteed convergence to the problem. The effectiveness of the technique was demonstrated using the 69-node distribution system and a real 2313-node distribution system. The results obtained in the paper indicated that better solutions can be obtained by performing the simultaneous optimization of the reconfiguration and capacitor placement in the radial distribution systems.

1.3 Research Gaps

- The placement of optimal sized multi-DG at the appropriate locations to reduce the losses and enhance the voltage profile for radial and meshed distribution networks using hybrid algorithm can be carried out.
- Voltage stability index with consideration of voltage angle can also be carried out.
- The network reconfiguration can reduce the loss. But network reconfiguration along with DG placement with hybrid algorithm can reduce the loss further and enhance the voltage profile and improve the voltage stability of the system.

1.4 Aim of the Research

The aim of this research is to determine the optimum location and sizing of the capacitors to maintain the voltage profile of the system as well as to minimize the associated feeder losses. Similarly, reconfiguration of distribution network is done for the purpose of power loss reduction of the system. Problem can be described for optimal DG placement as well as sizing by developing an objective function to minimize power losses, reliability cost losses and cost of DGs using constraints like voltage profile, power factor improvement, harmonic voltage limits. These objectives in this research work is divided as follows.

1. To propose a new load flow solution of radial and mesh distribution networks.

2. To propose a new method for integration of distributed generations in radial and mesh distribution networks.
3. To propose a new method for voltage stability analysis of distribution system without and with distributed generations.
4. To propose a new method for reconfiguration of distribution networks and simultaneous placement of distributed generations in the network for effective planning of the network.

1.5 Organization of the Thesis

This thesis is constructed as in the succeeding manner.

Chapter 1 presents about the basic introduction of the optimal planning of the distribution networks, literature review of the related works, the research gaps from the previous works, the aim of the research and the organization of the thesis.

Chapter 2 presents the load flow solution of the radial and mesh distribution networks and optimal integration of distributed generations using ABC-CS algorithm in radial and meshed distribution networks. The outcomes before and after integration of DGs are presented. This chapter is the combination of Objective 1 and Objective 2.

Chapter 3 presents the details about the voltage stability analysis and proposes a new voltage stability index. The proposed results are presented without and with DG placement. This chapter covers the Objective 3.

Chapter 4 presents a method of reconfiguration and optimal placement of distributed generations in the distribution networks using ABC-CS algorithm for effective planning of the network. This chapter covers the Objective 4.

Chapter 5 presents the conclusion of the overall research work and the enhancements to be done as the future works.

Bibliography

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CHAPTER-2

FUZZY LOAD FLOW AND OPTIMAL DG PLACEMENT

2.1 Introduction

A power network engineer constantly needs more up to date and better numerical model for taking care of network issue proficiently and adequately. Power flow analysis gives important solution to the power system engineers with the capacity to rapidly simulate the operation of the network. It is getting to be obvious that right now utilized load flow methods of transmission networks are not appropriate for distribution networks. The fundamental contrasts are the nearest of a number of various sorts of devices, multiphase conceivable outcomes and broadly fluctuating different types of loads in the distribution networks. The distribution systems are generally unbalanced because of the most extreme extent of single-phase loads and radial systems.

Notwithstanding these distinctions, load flow programs require topological information and system information. The topological information represents to the interconnections among the segments present in the system. The system data represents the line impedances and load data. Usually the topological and system data were not accessible directly to the load flow program. Rather this information was consolidated before it was put in the database. Power flow analysis is one such sub issue, which is so indispensable for practically all power network study. The algorithms proposed previously for the problem of power flow is basically divided into following three categories.

- Network reduction methods
- Backward forward sweep methods
- Fast decoupled methods

With the quick improvement in processing procedures since the 1970s, many power flow calculations dependent on present day figuring strategies have been accounted for. As indicated by these investigations, load flow analysis of RDNs might be partitioned into two classifications. The principal gathering of strategies incorporates: stepping stool arrangement techniques for radial structure distribution networks utilizing fundamental laws of circuit like Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL). Then again, the second classification incorporates Gauss-Seidel, Newton-Raphson and Decoupled Newton-Raphson techniques for transmission networks and are generally found by the nodal analysis method.

Load flow studies are utilized to guarantee that the electrical power exchange from generators to customers through the lattice network is steady, reliable and economic. The expanding nearness of distributed alternative energy sources, frequently in geologically remote areas, convolutes load flow analysis and has set off a resurgence of enthusiasm for the subject. In a three stage AC power network system, active and reactive power flows from the producing station to the load through various systems busses and branches. Load flow analysis must be as efficient numerical way to deal with assurance of different node voltages, three phase active and reactive power flow through various branches, generators and loads. So as to acquire a dependable power network activity under ordinary adjusted three stage conditions, it is required to have the followings:

- Bus voltage scales stay near to evaluated values
- Production delivers load requirement as well as deficits
- Transmission lines and transformers are not overloaded
- Generator operates within specific real and reactive power limits

2.1.1 Analysis and Design Challenges of Distribution Systems

- The analysis of distribution networks involves practical interest. A power network engineer must know the data about the number, size, location and type of the system elements in order to analyse the distribution network. Despite the fact that most of distribution network functions radially, different challenges must be overcome in their modelling and analysis.

- ***System:*** The distribution network, comprising of a wide assortment of segments that have distinctive stages, is complex and large.
- ***Load distribution:*** Load distributed over laterals and feeders is typically not the equivalent and henceforth the distribution network is unbalanced.
- ***Data:*** The entire distribution network is worked with minimum monitoring and control. In this way the actual network data accessible for its modelling and analysis is very limited.

The designers need detailed models and design alternatives for complex systems to overcome various problems associated with the planning, operation and control of the distribution systems. Solution of some typical problems such as conductor selection, voltage regulation, capacitor placement and network reconfiguration require the detailed models and techniques. The analysis and design studies are to be performed by utilities to ensure the supply of quality power. The evaluation of behaviour of any system or piece of system fulfils analysis studies whereas the evaluation of decisions made for the system behaviour to be better is referred to as design studies. Some of the reasons that complicate the design aspects of distribution system are presented below.

- ***Combinatorial parts of distribution networks:*** Due to the interconnection of various distribution equipment, one segment influences the specialized execution and economic matters of different segments in the network. This makes the assessment of a techno-affordable arrangement a surpassingly included procedure.
- ***Size:*** Many quantities of parts establish a distribution network. It implies that recognizable proof and investigation of such a large number of options are conceivable. It is extremely difficult procedure to assess all the alternatives set. Some of the time it might be impossible.

- ***Uncertainty:*** In long run designing predicting future enhancement is important. Any uncertainty affects the distribution system designing. Generally, the most effective designing priorities, load and money forecasts leave uncertainty concerning the system future resulting in inefficient distribution system. Thus, it is necessary to arrange the distribution system to fulfil, if not the foremost seemingly increased, future demand by avoiding uncertainty in prediction the load and alternative connected problems with distribution system.
- ***Other aspects of society:*** During designing the distribution system planners should take into consideration several aspects of the society like consulting the regulative authorities, community teams, intervene, business leaders and alternative utilities.

An extraordinary spotlight is put on the distribution network investigation and plan in the course of recent decades. The approximately collected methods embraced already will be supplanted by efficient methodology with the assistance of quantitative and subjective analysis and configuration investigations of network components. The advanced PCs allows the power designers to store mass volumes of information and face any snag applicable to the ideal arranging of distribution networks. A wide assortment of advancement calculations is created and effectively connected to take care of different complex issues, for example power flow analysis, conductor determination, proper reconfiguration, capacitor placement, distributed generator placement, voltage regulator placement and so forth. Some of the aspects presented in this work are power flow analysis, DG placement, Voltage stability analysis through VSI, network reconfiguration in radial distribution networks.

2.2 Analysis of Load Flow for Mesh and Radial distribution networks

The conventional power distribution networks have radial systems with unidirectional power flows. With the constant increment in load demand, the future augmentation of the network relies upon the distribution network load flow analysis. Load flow analysis can give the consistent state of a network. Minimizing the losses in the effective distribution networks is a basic necessity, in such a case that they surpass the losses concern the whole effective networks, from generation through transmission to distribution. The load flow analysis is conducted based upon assumption that maximum load currents can be reasonably well predicted for all load points, which is usually the case in network planning studies. The network configurations under investigation are weakly meshed and therefore close to ill conditioned networks. It prevents the use of the bus admittance matrix inversion as a straight way approach to determine the network node voltages from load currents. Therefore, a simple iteration procedure [38,39,40,41] was used based upon the network bus admittance matrix. The network source node is taken as slack bus and the calculated voltages at network nodes are voltage drops by reference to this node. A load flow knowledge is notably a large for the approaches with numerous load centers, equivalent to a refinery complex. The load flow to be trained is an analysis of the procedure’s capability to correctly deliver the load connected. The aggregate losses of the system, and furthermore line losses of the individual, are also tabularized. Tap positions of the transformer are selected to guarantee the precise voltage at principal locations equivalent to motor control centers. Carrying out a load flow study on a control setting provides perception and endorsements as to the operation of a system and optimization to receive maximum potential whilst operating cost minimization. The outcome of such an analysis is in phrases of reactive power, active power, and phase angle and magnitude. The distribution load flow becomes a significant tool for the analysis of the distribution system as well as it's utilized in the operation as well as in the planning phases. On a characterization of the distribution system by way of less power dealing with capacities, radial or weakly meshed structure, low X/R ratios, unbalanced loads, a tremendous number of branches.

Distribution networks are generally with the structure of radial and R/X ratio is very high compared to transmission network. Hence these networks are inherently ill-conditioned and traditional load flow approaches like Fast Decoupled, Gauss-Seidel and Newton-Raphson strategies are inefficient in solving such systems. Total value of transmission and distribution has a significant value.

2.2.1 Radial Distribution Network

In radial distribution networks the power is sent from the basic branch to the sub branch and so it splits out from the sub-branches once more as found in Figure 2.1 wherever the power is changed from root node and subsequently it is part at L1. It is the cheapest but the least reliable network configuration. In this configuration electrical service is interrupted when any piece of service equipment is de-energized to perform routine maintenance and service. A radial system leaves the station and goes through the system zone with no typical association with another supply. This can be typically in long rural lines with isolated load territories. As a rule, radial distribution network has more power failures than meshed distribution network.

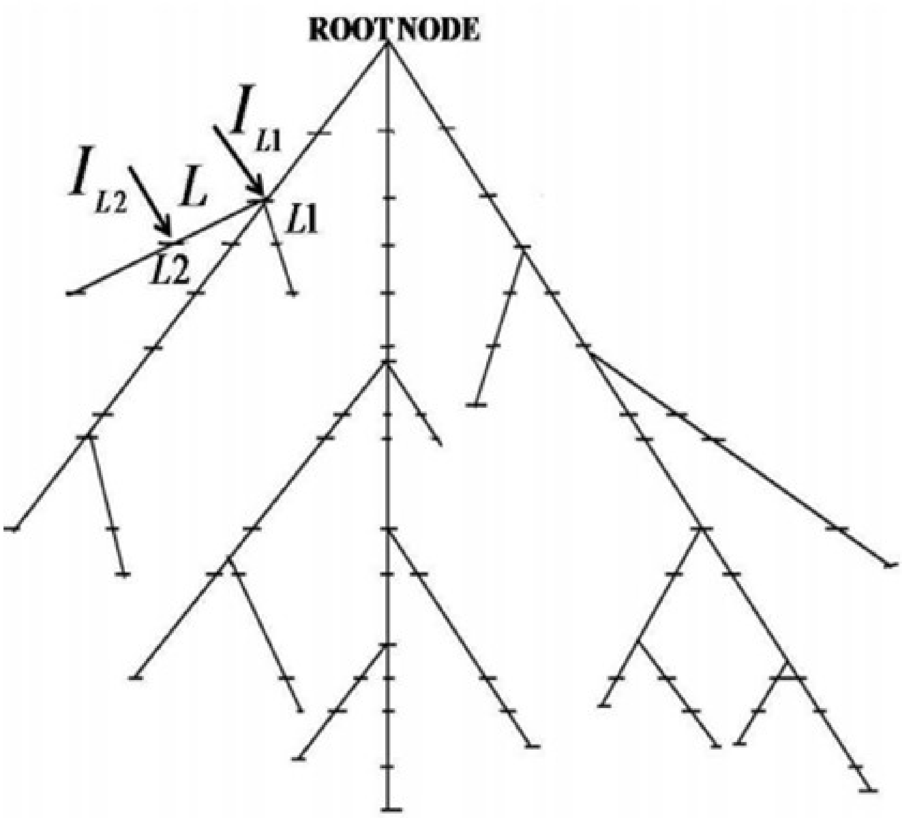


Figure 2.1: Classic Radial Distribution Network

2.2.2 Solution Methodologies for Radial Distribution Network

The power flow analysis in radial distribution network is used to obtain the power losses, voltage magnitude of the bus network. The main goal is to get the power flow using the Equation (2.1) and Equation (2.2).

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

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

Where, P_k is the real power flowing out of bus k,

Q_k is the reactive power flowing out of bus k,

$P_{L(k+1)}$ is the real load power at bus k+1 and

$Q_{L(k+1)}$ is the reactive load power at bus k+1.

The real and reactive power losses in the branch between the busses k and k+1 are given by Equation (2.3) and Equation (2.4).

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

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

$P_{loss}(k,k+1)$ is the real power loss in line segment between buses k and k+1 and $Q_{loss}(k,k+1)$ is the reactive power loss in line segment joining buses k and k+1.

The overall power losses of the feeder, $P_{T,loss}$ and $Q_{T,loss}$ may then be controlled by summing up the losses of all line segments of the feeder, which are given in Equation (2.5) and Equation (2.6) respectively.

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

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

Where, $P_{T,loss}$ is the total real power loss in the line section and $Q_{T,loss}$ is the total reactive power loss in the line segment.

The load flow methods solving the radial distribution networks plays important roles in the designing of radial distribution networks. The overall computation contains of three basic steps.

Nodal Current Calculation: The power of the load given in any of the bus the current injection at that node can be calculated as given by the following Equation (2.7).

$$I_n^t = \left(\frac{S_n}{V_n^{t-1}}\right)^* - Y_n V_n^{t-1} \tag{2.7}$$

In Equation (2.7),

n = 1, 2....N, I_n^t is the current at the n^{th} node at iteration *t*, S_n is the complex power at the n^{th} node, V_n^{t-1} is the voltage at the n^{th} node at iteration *t-1* and Y_n is the admittance at the n^{th} node.

Backward Sweep: The backward sweep is essentially a current or power flow analysis with conceivable voltage updates. At iteration n, beginning from the branches in the last layer and moving towards the branches associated with the root node organize the current in branch L appeared in Figure 2.1 is determined by Equation (2.8).

$$J_L^t = -I_{L2} + \sum (\text{Branch Currents Originating from L2}) \tag{2.8}$$

Where, I_{L2} is the current injecting at node L2 and J_L^t is the current in branch L at iteration t.

Forward Sweep: The forward sweep is essentially a voltage drop computation with possible current or power flow updates. Nodal voltages are updated in a forward sweep starting from branches in the principal layer toward those in the last. For each branch, L appeared in Figure 2.1, the voltage at node L2 is determined utilizing the updated voltage at node L1 and the branch current determined in the previous in reverse scope as given by Equation (2.9).

$$V_{L2}^t = V_{L1}^t - Z_L J_L^t \tag{2.9}$$

Where, Z_L is the series impedance at branch L.

Convergence criteria: The voltages at every node are first determined utilizing forward path. The most extreme mismatch at every node is discovered and contrasted to one another. The most extreme mismatch accordingly acquired is on the off chance that not exactly the estimated mismatching (€), at that point the program is ended. If the program is not terminated by the mismatch calculation, it is made to terminate by the maximum number of iterations.

$$€ \leq | V_n^{t+1} - V_n^{t} | \qquad for\ n = 1, 2, 3, ...N \tag{2.10}$$

2.2.3 Mesh Distribution Network

Unlike radial distribution networks, mesh distribution networks have closed paths which are created by closing normally open switches and power does not flow in one line. The closed paths/loops in the mesh distribution networks are called meshes. The *mesh distribution networks are more complex than radial distribution networks but are more reliable also and large power system networks are meshed in nature.* Distribution networks, due to their wide ranging resistance and reactance values are named as ill-conditioned power systems Therefore most widely used classical methods like Newton-Raphson, Gauss-Seidel and fast decoupled power flow algorithms face convergence problems when used for finding power flow solution of ill-conditioned systems or meshed distribution networks. Therefore, a new load flow method is proposed for the solution of meshed distribution network, by breaking the interconnected grid at a number of points (called breakpoints) in order to convert it into a radial network. Then the radial network is solved efficiently by the forward-backward sweep method.

2.2.4 Load Flow Analysis for Mesh Distribution Network

An interconnected or meshed system is commonly found in urban territories and will have different connections with different purposes of supply. The favorable circumstances of utilizing radial systems are (i) identification and isolation of fault is easy and (ii) highly reliable. The typical diagram of a mesh distribution network is shown in Figure 2.2.

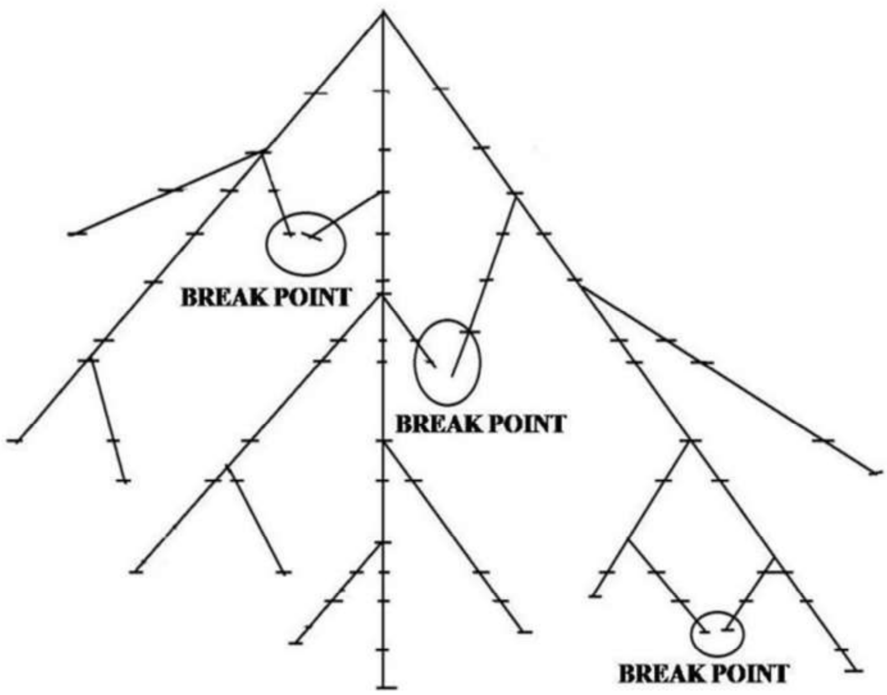


Figure 2.2: Typical Diagram of a Mesh Distribution Network

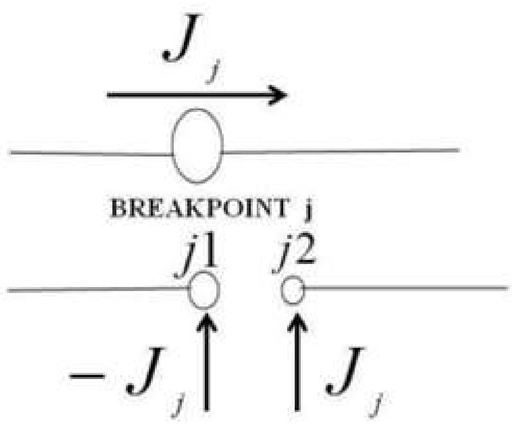


Figure 2.3: Break Point Representation using Node Current Injection

Some supply feeders serve high density load regions containing loops made by closing the sectionalizing switches. The load flow study for the radial distribution network can be extended to the mesh distribution network. Presence of loops in the network does not influence the bus current injections, but new branches might be added to the network.

2.2.5 Solution Methodologies for Mesh Distribution Network

The mesh system is first changed over to the radial system by taking proper break points at the appropriate places and then injecting current of opposite polarity at the two closures of the breakpoint without influencing the system working condition [42]. The resulting radial system can be solved utilizing radial system technique. Figure 2.2 demonstrates a weekly meshed distribution network with three breakpoints and Figure 2.3 demonstrates the injection of current $-J_j$ and J_j at the two nodes j1 and j2 of the breakpoint j. Thus, current at the j^{th} node at emphasis 't' is given by Equation (2.11).

$$I_{j1}^{t} = -J_{j}^{t} \text{ and } I_{j2}^{t} = J_{j}^{t} \tag{2.11}$$

In Equation (2.11) $j = 1, 2 \ldots P_b$ where P_b is the Number of Break Points

Computation of breakpoint current utilizing compensation method: Breakpoint current can be determined utilizing multiport compensation technique. Figure 2.4 demonstrates the idea utilized in this methodology. In Figure 2.4 radial system coming about because of the opening of breakpoints is appeared as a multi-port circuit with the breakpoint nodes forming the ports of the circuit. For a linear network, this multi-port equivalent can be the Thevenin equivalent circuit of the radial system seen from the open ports made by the breakpoints. Figure 2.5 shows Thevenin equivalent circuit of the network as seen from the breakpoint ports where V is the Thevenin Voltage, [Z] is to the Thevenin impedance and J the presents the current flowing through the load and the relation among them is given by Equation (2.12).

$$V = [Z]J \tag{2.12}$$

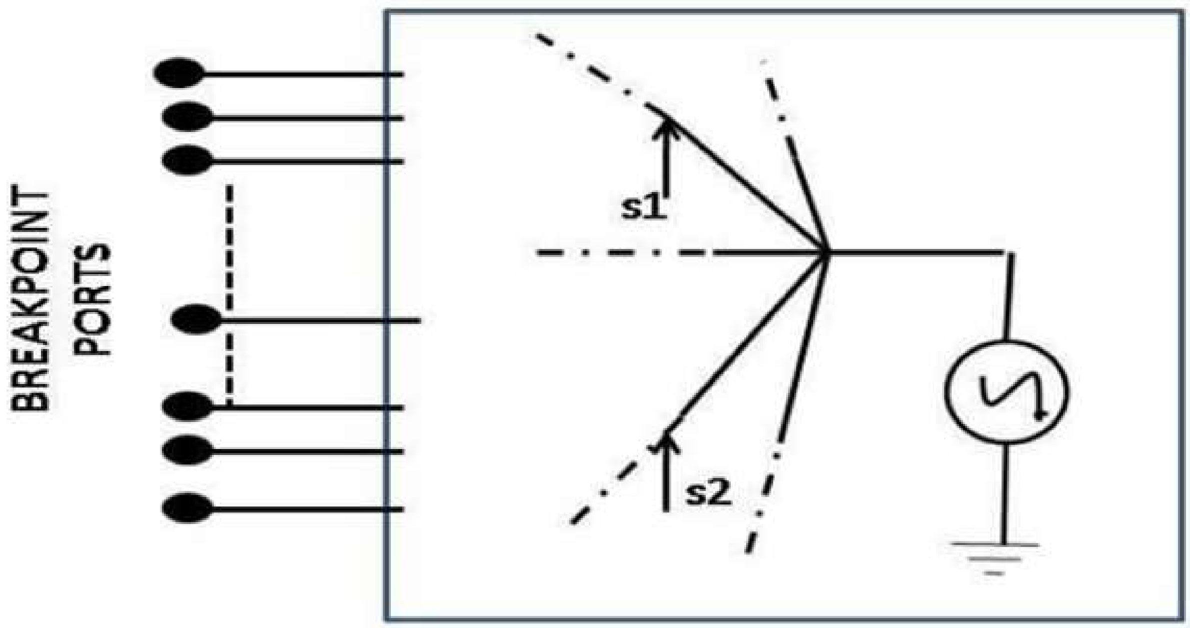


Figure 2.4: Multiport equivalent of the network as seen from the breakpoint ports [42]

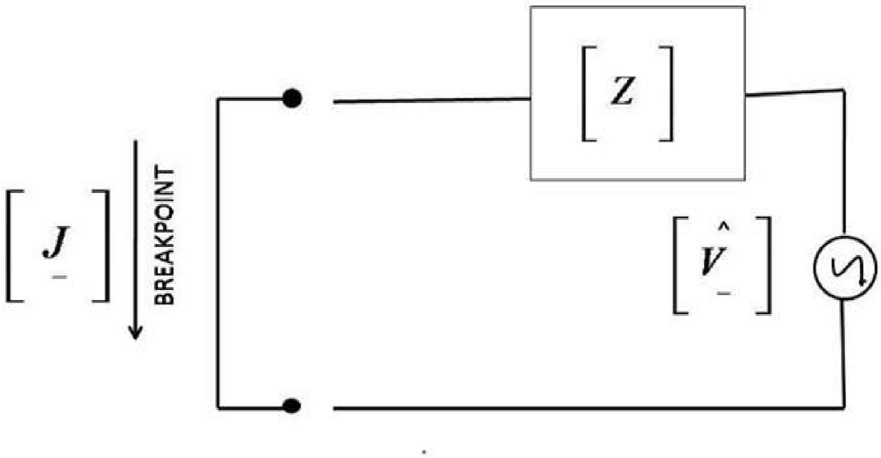


Figure 2.5: Thevenin equivalent circuit of the network as seen from the breakpoint ports

Figuring of breakpoint impedance grid: The breakpoint impedance network (Thevenin equal impedance) can be determined utilizing the accompanying strategy [42]. The Thevenin identical condition can be composed as in Equation (2.13).

$$\begin{bmatrix} V_1 \\ \vdots \\ V_J \\ \vdots \\ V_{Pb} \end{bmatrix} = \begin{bmatrix} Z_{11} & \cdots & Z_{1J} & \cdots & Z_{1Pb} \\ \vdots & & \vdots & & \vdots \\ Z_{J1} & \cdots & Z_{JJ} & \cdots & Z_{JPb} \\ \vdots & & \vdots & & \vdots \\ Z_{Pb1} & \cdots & Z_{PbJ} & \cdots & Z_{PbPb} \end{bmatrix} \begin{bmatrix} J_1 \\ \vdots \\ J_J \\ \vdots \\ J_{Pb} \end{bmatrix} \tag{2.13}$$

- Put J_j =1 p.u. and J_n= 0 , i=1, 2 ...p furthermore, i j, which is proportionate to infusing 1 p.u. current of inverse extremity at the two end nodes of the breakpoint j.
- The voltages of every breakpoints can be computed by deducting the voltages at the two end nodes of the breakpoint.

Iterative compensation process: The iterative compensation process for computing the breakpoint flows, utilizing the Thevenin's equivalent circuit of Figure 2.5 is portrayed underneath [42].

Step 1: Get the Thevenin identical impedance and keep it consistent all through the compensation procedure.

Step 2: Compute the Thevenin equivalent voltage of the radial system including the breakpoint flows determined from the past iteration of the compensation procedure assuming initial values of the breakpoint currents to be 0.

Step 3: Ascertain the gradual change in the breakpoint flows utilizing the Thevenin equivalent circuit. At emphasis 'm' of the pay procedure is given by Equation (2.14).

$$\Delta J^m = [Z]^{-1} V^m \tag{2.14}$$

Step 4: Update the breakpoint currents. At iteration *m*. J^m is expressed by Equation (2.15).

$$J^m = J^{m-1} + \Delta J^m \quad (2.15)$$

Step 5: Repeat conditions 2, 3 and 4 until the convergence is achieved (the most extreme breakpoint voltage determined at stage 3 is within recommended cutoff points).

The different steps involved in solving meshed distribution network are given below.

Stage 1: Initially the bus and line information are read.

Stage 2: The meshed network is then changed over to the radial system.

Stage 3: Branch numbering is done and the breakpoints are opened.

Stage 4: Breakpoint impedance matrix is then determined.

Stage 5: Set iteration count to m=1 and explain the radial system load flow utilizing Forward Backward Sweep.

Stage 6: If the most extreme voltage mismatch is not less than the predetermined voltage mismatch, exit the loop and print the outcome.

Stage 7: Else compute the breakpoint current and add them to nodal current.

Step 8: If the maximum iteration is reached and still specified voltage mismatch is not obtained, stop the process and print the result.

Step 9: Else increase the iteration number by 1 and go to step 6 and repeat the process till convergence point or the maximum iteration is reached.

Here both the radial and mesh systems are evaluated for the analysis of load flow.

The total I^2R loss (P_{TL}) in the network consuming 'n' number of branches is expressed by Equation (2.16).

$$P_{TL} = \sum_{i=1}^{n} I_i^2 R_i \quad (2.16)$$

Where, P_{TL} - Total Power Loss

Here R_i and I_i are the magnitude of resistance and current of the i^{th} branch. The current in the branch is computed using the load flow analysis. There are two components in branch current, active and reactive current. The total loss identified with the active and dynamic components of branch flows is composed as Equation (2.17).

$$P_{TL} = P_{Ia} + P_{Ir} \tag{2.17}$$

$$P_{TL} = \sum_{i=1}^{n} I_{ai}^2 R_i + \sum_{i=1}^{n} I_{ri}^2 R_i \tag{2.18}$$

From Equation (2.18) the power loss in real and reactive components of radial or mesh distribution systems is formulated. The Newton based ordinary power flow programs produced for transmission network are not satisfactory in light of the fact that the radial explicit power flow calculations can tackle distinctive arrangements in a brief time frame. Additionally, the traditional program results in poor convergence characteristics for radial systems. Hence an efficient load flow analysis for solving distribution networks with balanced and unbalanced load arrangement is required. The power flow solution forms the basis of all optimization problems. Some of the optimization problems such as network reconfiguration and capacitor placement related to distribution automation require the solution of power flow problems. The equipment parameters, system configuration and operating conditions are directly related to power flows. The distribution system power-flow analysis is similar to that of a transmission system connecting the generation plants to the loads. Prior to the power flow analysis, the voltage of each phase at the substation, the load model (constant complex power, constant impedance, constant current, or a combination) and the complex power of all the loads must be known. Sometimes, the input complex power supplied to the feeder from the substation is also known.

2.3 Fuzzy Logic in Load Flow Analysis

The power flow can be formulated by using the Equation (2.19) and Equation (2.20).

$$\frac{\Delta P}{V} = B^{'}\Delta\delta \tag{2.19}$$

$$\frac{\Delta Q}{V} = B^{''}\Delta V \tag{2.20}$$

In Equation (2.19), the state vector δ is updated but state vector V is fixed. Equation (2.20) is utilized to update the state vector V while state vector δ is fixed and where ΔP is the real power and ΔQ is the reactive power and B' and B'' are the constant sparse matrices. In fuzzy based load flow issue, Fuzzy Logic is utilized to update δ and V. The proposed fuzzy control stream technique depends on the past quick decoupled power stream condition. However, the repeated update of the state vector of the network will be performed by means of fuzzy logic control as opposed to utilizing the established power flow analysis. Equation (2.21) shows the relationship of ΔP with Δδ and ΔV and also ΔQ with Δδ and ΔV.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ M & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} \tag{2.21}$$

2.3.1 Fuzzy logic

The standard load flow methodology provides a misleadingly precise answer arising from a static snapshot solution of a dynamic system assuming perfect knowledge of the network parameters, loading and generation set points. Solutions are then used to make a variety of decisions in planning and operations. Uncertainty is one of the most important issues in power system planning when decisions are made regarding the future system expansion and operation. Two types of uncertainty are:

1. Errors in the calculated or measured parameters of the various lines and transformers in the system.

2. Errors in the magnitude of the demand assumed for the system load buses.

In trying to include uncertainty into the solution process, analysts have tried different approaches. Most frequently, planners repeat the analysis under varying system conditions. A better solution would be to provide solutions over the range of uncertainties included, i.e., solutions that are sets of values instead of single points. Fuzzy systems have been increasingly used to develop more efficient schemes for the power system operation, planning, control, and management. The main phases to solve any problem using the fuzzy logic approach are as follows:

1. Identify the issue and pick the kind of fuzzy network, which best suits the issue.

2. Defining the input and yield factors, their fuzzy qualities, and their participation capacities.

3. Articulating the arrangement of heuristic fuzzy guidelines.

4. Picking the fuzzy inference system, fuzzification and de-fuzzification methods. Equation (2.21) indicated above can be expressed with respect to the anticipated Fuzzy list by the Equation (2.22).

$$\Delta F = [J].\Delta X \tag{2.22}$$

Equation (2.22) implies that alteration of state vector ΔX at every node of the network is straightly proportional to vector ΔF. This designed fuzzy load flow is developed on the prior load flow equation. However, the repetitive state vector updating of the process might be carried out by Equation (2.23).

$$\Delta X = fuzzy(\Delta F) \tag{2.23}$$

In this procedure the power parameters such as real power and reactive power $(\Delta F_p \ and \ \Delta F_q)$ were computed. This procedure computes the state vector ΔX specifically alteration of voltage angle Δδ for the P-δ cycle and the voltage magnitude ΔV for the $q-V$ cycle. The procedure is presented in the Figure 2.6.

2.3.2 Fuzzy Logic Load Flow Controller

The center structure of the proposed FLFC contains three guideline segments

- Fuzzification interface
- Knowledge Base Decision logic
- De-Fuzzification

Fuzzification interface: The FLFC includes the subsequent functions through iteration.

- Compute the power parameters in every node of network.
- The parameters are chosen as crispy input signals. The maximum power parameter ($\Delta FP_{\max}$ (or) $\Delta Fq_{\max}$) regulates scope of scale mapping, which checks the input signals into an equivalent universe of dissertation for each iteration.

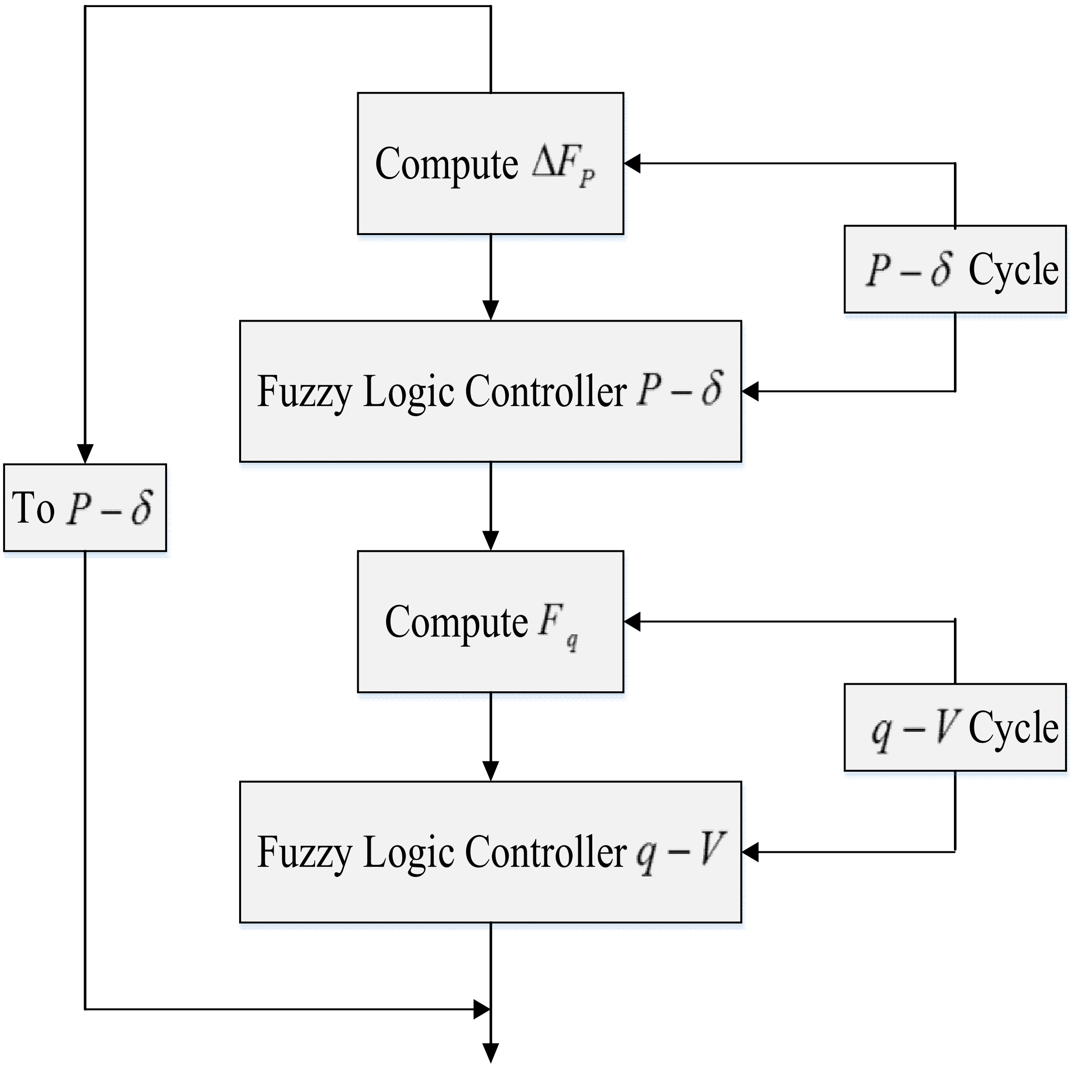


Figure 2.6: Fuzzy Load Flow Controller [43]

These input signals were fuzzified into equivalent fuzzy signals (Δ_{FPfuz} or Δ_{Fqfuz}) with seven linguistic variables namely Small negative (SN), Medium negative (MN), Large negative (LN), Zero (ZR), Large positive (LP), Medium positive (MP) and Small positive (SP).

Fuzzification: A triangular membership function is framed from the seven fuzzy signals outlines of this membership functions given in the Figure 2.7.

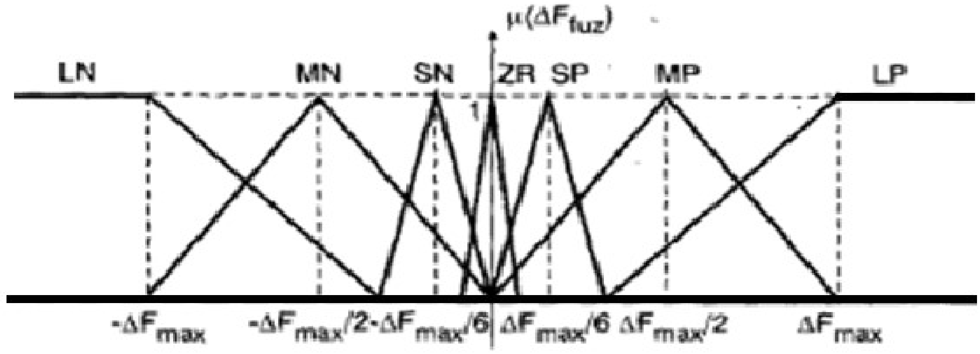


Figure 2.7: Triangular membership function [44]

Similarly, the output signals, which means in triangular membership function, depictions of those membership functions are displayed in the Figure 2.7. Therefore, all three points of the triangular membership function of ΔX_{fuz} are composed as given above.

Knowledge Based Decision Logic Using PSO: In this work a PSO system is created to locate the best arrangement of the multi target issue of putting of DG units. PSO is one of the enhancement systems and fits to developmental calculation methods. The strategy has been built up through a reproduction of streamlined social models. The highlights of the strategy are as per the following:

1) The method is created on the basis of researches on swarms such as fish schooling and bird flocking.

2) Here, the calculation time is minor and it involves couple of recollections. As indicated by the exploration results for bird flowing.

An advancement method dependent on the above idea is depicted as pursues: to be specific, winged animal running improves certain goal. Every specialist knows its best value up until this point (pbest) and its XY position. Also, every operator knows the best value so far in the gathering (gbest) among pbests. Every operator endeavors to modify its position utilizing the accompanying data:

- The current positions (x,y),

- The current speeds (vx,vy),
- The separate between the present spot, and pbest and gbest.

This adjustment can be described by the idea of speed. Speed of every operator is altered by the Equation (2.24).

$$V_i^{k+1} = wv_i^k + c_1\, rand \times \left(pbest_i - s_i^k\right) + c_2\, rand \times \left(gbest - s_i^k\right) \tag{2.24}$$

Where, V_i^k : velocity of agent i at iteration k, w: weight function, c_j: weighting factor, *rand*: random number between 0 and 1, s_i^k : current position of agent i at iteration k, $pbest_i$: pbest of agent i, $gbest_i$: gbest of group i. Utilizing the beyond condition, a specific speed, which step by step gets nearby *pbest* and *gbest* can be determined. As there is a huge impact of beginning speed in adjusting of investigation and misuse procedure of swarm, Inertia Weight (w) is utilized to control the speed. There are variations of inertia weights and these are utilized to change the speed refresh condition, for example, Constant Inertia Weight, Random Inertia Weight, Adaptive Inertia Weight, Sigmoid Increasing Inertia Weight, Sigmoid Decreasing Inertia Weight, Linear Decreasing Inertia Weight, Chaotic Inertia Weight, Chaotic Random Inertia Weight, Oscillating Inertia Weight, Global-Local Best Inertia Weight, Simulated Annealing Inertia Weight, Natural Exponent Inertia Weight Strategy (e1-PSO), Natural Exponent Inertia Weight Strategy (e2-PSO), Logarithm Decreasing Inertia Weight, Exponent Decreasing Inertia Weight [45,46]. Among these diverse kinds of latency loads Linear Decreasing Inertia Weight is broadly ideal. The particles change their condition as indicated by the accompanying three standards:

(1) To keep its dormancy,

(2) to change the condition as indicated by its most hopeful person position and

(3) to change the condition as per the swarm's most self-assured person position.

The position of each particle in the swarm is affected both by the most optimist position during its movement (individual experience) and the position of the most optimist particle in its surrounding (near experience). When the whole particle swarm is surrounding the particle, the most optimist position of the surrounding is equal to the one of the whole most optimist particle; this algorithm is called the whole PSO. If the narrow surrounding is used in the algorithm, this algorithm is called the partial PSO. The current position (searching point in the solution space) is modified by the Equation (2.25).

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{2.25}$$

In local PSO, instead of persuading the idealist particle of the swarm, each particle will hunt the idealist particle in its encompassing to adjust its speed and location. Formally, the expression for the speed and the position of the particle is completely alike to the one in the total PSO. The following are the procedures to derive the code of PSO.

- Initialize a population (cluster) of particles with irregular positions and speeds on 'd' measurements in the issue space.
- For each particle, assess the desired optimal fitness work in 'd' factors.
- Compare particle's fitness evaluation with particle's *pbest*. If current value is better than *pbest*, then set *pbest* value equal to the current value, and the *pbest* location equal to the current location in d-dimensional space.
- Compare fitness evaluation with the population's overall previous best. If current value is better than *gbest*, then reset *gbest* to the current particle's array index and value. Change the velocity and position of the particle according to Equation (2.24) and Equation (2.25), respectively.
- Loop to second step until a criterion is met, usually a sufficiently good fitness or a maximum number of iterations.

De-fuzzification: The extreme counter active accomplishment $\Delta X_{\max}$ of state factors plots the scope of scale mapping that handovers the yield motion into the relating universe of talk at each emphasis. The maximum corrections of these qualities is determined by Equation (2.26) and Equation (2.27).

$$\frac{\Delta F_{max1}}{\Delta X_{max}} = \frac{dF_1}{dX_1} \tag{2.26}$$

$$\Delta X_{max} = \left[\frac{dF_1}{dX_x} \right]^{-1} \Delta F_{max1} \tag{2.27}$$

where, F_1 is the real or reactive power balance equation at node with maximum real or reactive power mismatch of the system and X_1 is the voltage angle or magnitude at node 1.

Finally, the defuzzifier will transform fuzzy output signals ΔX_{fuz} into crisp values ΔX for every node of the network. The centroid-of-area (COA) defuzzification strategy is adapted and the state vector is updated by Equation (2.28)

$$X^{i+1} = X^i + \Delta X \tag{2.28}$$

Where, '*i*' specifies the iteration number.

2.3.3 DG Planning

DG planning is the way toward optimizing DG type, size and additionally location so as to accomplish a number of targets and subject to a set of constraints. This issue has nonlinear equality constraints, which are the power flow equations. It likewise incorporates some nonlinear optimization problem, for example, line loss minimization. This optimization problem can be managed utilizing two methodologies. The first is to apply a few suppositions so as to rearrange the detailing of the issue. In this way, the optimization problem can be tackled using traditional mathematical programming methods, for which powerful programming methods are available (e.g. Linear Programming). The second methodology depends on the utilization of heuristic optimization techniques, for example, Evolutionary Algorithms (EA). Such techniques enable more detailed modeling of the time-variability of DG. Recently, diverse techniques for optimizing the location, size as well as kind of DG have been proposed, with specific accentuation on DG position and sizing. Such optimization strategies can be outlined into two classes. The main gathering of DG planning techniques centers around the optimization of a single objective.

The second gathering of the proposed DG planning optimization procedures is a multi-target DG placement technique. Henceforth, planning objectives can be planned from alternate points of view, for example, the DG engineer, the LDC, or the regulator. The solution methods for multi-target issues to be partitioned into two main types. The principal type makes utilization of single-target objective and the arrangement set is recognized by changing the master objective iteratively. The weighted-sum is the most common for this purpose. The second kind of multi-objective optimization methods depend on Evolutionary Algorithms. There have been a few works on planning distribution network, bridging the gap between traditional distribution planning networks and methods for siting DG within the distribution system.

In both the radial and mesh distribution process, the optimal DGs are set up in appropriate nodes to improve voltage profile and to reduce the power losses of the distribution network.

2.4 DG Types

DG can be sorted as four major kinds on premise of their terminal highlights as far as genuine and receptive power conveying capacity as trails:

1) Type 1: DG which has the ability of injecting real power only.

2) Type 2: DG which has the ability of injecting reactive power only.

3) Type 3: DG which has the ability of injecting both real and reactive power.

4) Type 4: DG which has the ability of injecting real power but consuming reactive power.

2.5 Location of DG by Sensitivity Analysis

So as to identify location of DG in the distribution network, sensitivity analysis is utilized. The sensitivity analysis can predict the nodes, which have a larger reduction of losses once a DG is placed. Hence, these sensible nodes can be filled in as applicant nodes for situation of DG. The calculation of these competitor nodes helps in decrease of the search space for the upcoming optimization technique. Consider a branch segment interfacing buses *k* and k+1 with impedance $R_k + jX_k$ connected to a load $P_{Lk,eff} + jQ_{Lk,eff}$. Line real power losses can be calculated by using Equation (2.29).

$$P_{Loss,k} = I_k^2 R_k \tag{2.29}$$

This also can be expressed in another form [47] as given by Equation (2.30).

$$P_{Loss,k} = \frac{\left(P_{Lk,Eff}^2 + Q_{Lk,Eff}^2\right)R_k}{V_k^2} \tag{2.30}$$

where $P_{Lk,Eff}$ = Overall effective active power provided away from bus *k*. Currently the sensitivity factor can be evaluated by using Equation (2.31).

$$\frac{\partial P_{Loss,k}}{\partial P_{Lk,eff}} = \frac{2P_{Lk,Eff}R_k}{V_k^2} \tag{2.31}$$

By using the Equation (2.33), sensitivity factors are computed from load flow studies then the values obtained are arranged in descending order for all nodes of the specified distribution network. By using this sensitivity factors, the nodes to be considered for DG installation are noted. The objective functions and the locations of DGs are utilized in the optimization to determine the sizes of DGs, which is explained below.

2.6 Artificial Bee Colony (ABC) Algorithm

Artificial bee colony (ABC) procedure [48] is a standout amongst the most as of late presented swarm-based calculations. ABC mimics the wise searching conduct of a honeybee swarm. The execution of the ABC is superior to or like those of other population-based calculations with the benefit of utilizing less control parameters. The behavior of real bees is given as follows and from that the ABC optimization algorithm is constructed.

A model [49] of foraging behavior of a honeybee colony dependent on reaction–diffusion conditions had been built up. This model prompts the development of aggregate insight of honeybee swarms comprises of three fundamental parts: food sources, utilized foragers, and jobless foragers, and characterizes two driving methods of the honeybee colony conduct: enlistment to a food source and surrender of a source. He clarified the primary segments of this model as underneath:

1. *Food Sources:* In request to choose a food source, a forager bee assesses a few properties related with the food source, for example, its closeness to the hive, wealth of the vitality, taste of its nectar, and the simplicity or trouble of extricating this vitality. For the straightforwardness, the nature of a food source can be spoken to by just a single amount despite the fact that it relies upon different parameters referenced previously.

2. *Utilized foragers:* A utilized forager is utilized at a particular food source which she is as of now misusing. She conveys data about this particular source and offers it with different bees holding up in the hive. The data incorporates the separation, the course and the benefit of the food source.

3. *Jobless foragers:* A forager bee that searches for a food source to misuse is called jobless. It tends to be either a scout who searches the earth arbitrarily or a passerby who attempts to discover a food source by methods for the data given by the utilized bee. The mean number of scouts is around 5% – 10%.

The trading of data among bees is the most essential event in the development of aggregate information. While looking at the whole hive it is conceivable to recognize a few sections that regularly exist in all hives. The most essential piece of the hive as for trading data is the moving zone. Correspondence among bees identified with the nature of food sources happens in the moving region. The related move is called waggle move. Since data pretty much all the present rich sources are accessible to a passerby on the move floor, likely she could watch various moves and utilizes herself at the most productive source. There is a more prominent likelihood of onlookers picking progressively gainful sources since more data is required about the more productive sources. Utilized foragers share their data with a likelihood, which is relative to the benefit of the food source, and the sharing of this data through waggle moving is longer in term. Subsequently, the enlistment is corresponding to the benefit of a food source.

So as to all the more likely comprehend the fundamental conduct qualities of foragers, Figure 2.8 is to be analyzed. Expect that there are two found food sources: A and B. At the absolute starting point, a potential forager will begin as jobless forager. That forager bee will have no information about the food sources around the home. There are two conceivable choices for such a bee as shown in Figure 2.8.

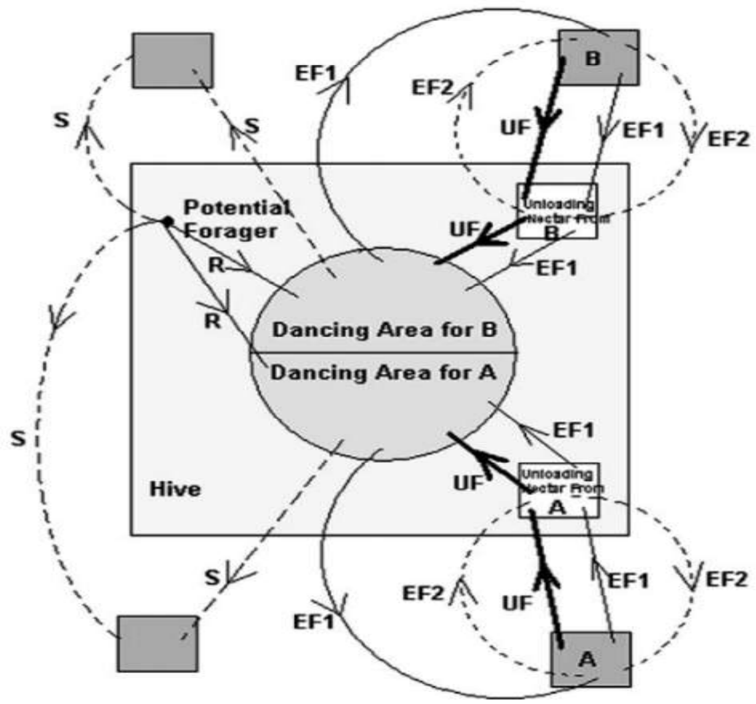


Figure 2.8: Behavior of honey bee foraging for nectar [50]

- It can be a scout and begins searching around the home suddenly for food because of some inside inspiration or conceivable outside piece of information (S on Figure 2.8).
- It can be an enrol subsequent to watch the waggle moves and begins search for a food source (R on Figure 2.8).

In the wake of finding the food source, the bee uses its own ability to remember the area and after that quickly begins abusing it. Consequently, the bee will turn into a utilized forager. The foraging bee takes a load of nectar from the source and comes back to the hive, unloading the nectar to a food store. Subsequent to unloading the food, the bee has the accompanying alternatives:

- It may turn into an uncertain devotee in the wake of forsaking the food source (UF).
- It may move and after those select home mates before coming back to a similar food source (EF1).
- It may keep on scavenging at the food source without selecting bees (EF2).

It is imperative to take note of that not all bees begin scrounging at the same time. The tests affirmed that new bees start scavenging at a rate corresponding to the distinction between the possible complete number of bees and the quantity of bees by and by for maturing.

In the ABC calculation, the artificial bees are arranged into three gatherings as expressed over: the utilized bees, the onlookers and the scout. Bee that misusing a food source is named utilized. The utilized bees share data with the onlooker bees, which are holding up in the hive and viewing the occasions of the utilized bees. The passer-by bees at that point pick a food source with likelihood relative to the nature of food source. The great food sources pull in a greater number of bees than the awful ones. Scout bees chase for new food sources arbitrarily in the region of the hive. At the point when a scout or onlooker bee gets a food source, it winds up utilized. At the point when a food source has been completely abused, all the utilized bees related with it will surrender the position, and may move toward becoming scouts once more. In this way, scout bees play out the activity of ''investigation'', though utilized and passer-by bees play out the activity of ''abuse''. The tasks in scout bee is performed by using Cuckoo Search (CS) algorithm, which encourages crafted by the scout bee stage increasingly robust. In the proposed calculation, a food source relates to a conceivable answer for the streamlining troubles, and the nectar measure of a food source compares to the wellness of the related arrangement. In ABC, the principal half of the colony comprise of utilized bees and the other half are onlookers. The quantity of utilized bees is equivalent to the quantity of food sources (SN) since it is accepted that there is just a single utilized bee for every food source. In this way, the quantity of onlooker bees is likewise comparable to the quantity of arrangements under thought. The ABC calculation starts with a gathering of arbitrarily produced food sources. The principle methodology of ABC can be portrayed as pursues.

Step 1: Initialize the food sources.

Step 2: Each employed bee starts to work on a food source.

Step 3: Each Onlooker bees selects a food source according to the nectar information shared by the employed.

Step 4: Determine the Scout bees, which will search for food sources in a random manner.

Step 5: Test whether the termination condition is met. If not, go back to **Step 2**.

The detailed description for each step is given below.

In ABC calculation, every iteration of the search contains of three stages: sending the utilized bees onto their food sources and critical their nectar sums; within the wake of sharing the nectar knowledge of food sources, the selection of food supply regions by the onlookers and assessing the nectar live of the food sources; deciding the scout bees and at the moment causation them arbitrarily onto conceivable new food sources. At the primary step of the cycle, tons of food sources are arbitrarily chosen by the bees and their nectar sums are resolved. At the initial step of the cycle, these bees inherit the hive and supply the nectar knowledge of the sources with the bees looking for the move territory. A bee trusting that creation selection can decide a food supply is named passerby and also the bee keeping off to the food source visited while not anyone else's input simply before is named as utilized bee.

In the wake of giving their knowledge to onlookers, every utilized bee goes to the food supply zone visited freelance from anyone else at the previous iteration since that food source exists in her memory, and subsequently picks another food supply by ways for visual knowledge within the space of the one in her memory and assesses its nectar total. At the second step, an onlooker prefers towards a food supply territory relying upon the nectar knowledge taken by the utilized bees on the move zone. Because the nectar measure of a food supply builds, the chance of food supply picked extra that increments. Within the wake of landing at the selected region, she picks another food supply within the space of the one in the memory, relying upon visual knowledge as on account of utilized bees. The reassurance of the new food supply is finished by the bees passionate about the analysis procedure of food source positions externally. At the third step of the cycle, once the nectar of a food supply is relinquished by the bees, another food supply is haphazardly set by a scout bee and supplanted with the deserted one. In this model, at every cycle at the most one scout goes outside for looking out another food supply, and also the amount of utilized and spectator bees is chosen to be love each other. These three stages are recurrent through a planned variety of cycles referred to as Most Cycle Number (MCN) or till a termination criterion is consummated.

It is obvious from the above clarification that there are three control parameters within the basic ABC: the amount of food sources, that is such as the amount of utilized or onlooker bees (SN), the estimation of farthest purpose and also the most cycle number (MCN). Within the case of honey bees, the enrollment rate represents to a proportion of how rapidly the bee colony finds and exploits a new-found food supply. Artificial enrolling might conjointly speak to the estimation of the speed with that the realizable arrangements or the nice quality arrangements of the hard improvement problems may be found. The survival and advancement of the bee colony are destitute upon the quick revelation and productive use of the best food assets. Similarly, the effective arrangement of hard building problems is related to the commonly fast revelation of excellent arrangements, significantly for the problems that ought to be explained more and more. In a very sturdy search procedure, investigation and misuse forms should be completed along within the ABCs calculation, whereas onlookers and utilized bees complete the abuse procedure within the search area, the scouts control the investigation procedure.

Settings for the ABC procedure: Except common parameters (population number and maximum evaluation number), the essential ABC utilizes just a single control parameter, which is called breaking point. A food source won't be misused any longer and is thought to be surrendered when limit is surpassed for the source. This implies the arrangement of which ''trial number" surpasses the limit value cannot be improved any longer. Equation (2.32) is characterized for the cut-off value utilizing the component of the issue and the colony estimate.

$$limit = (SN * d) \tag{2.32}$$

In Equation (2.32) ‘d’ is the dimension of the difficult and *SN* represents the quantity of employed bees or food source.

Initialization phase: It is the beginning period of the ABC calculation. The SN starting arrangements are arbitrarily created D-dimensional genuine vectors as shown in Equation (2.33).

$$FS_i = (FS_{i,1}, FS_{i,2}, ...FS_{i,D}\} \quad (2.33)$$

F_i signify the i[th] food sources, that has been attained from Equation (2.34).

$$FS_{i,d} = FS_d^{min} + rand \times (FS_d^{max} - FS_d^{min}) \quad (2.34)$$

Where *rand* is a even random number in the sort [0, 1] as well as FS_d^{min} and FS_d^{max} are the inferior and superior limits for dimension 'd' correspondingly *d=1… D.*

Employed bee phase: In this stage, each utilized bee is related with an answer. She applies an arbitrary adjustment on the arrangement (unique food source) for finding another arrangement (new food source). This executes the capacity of neighborhood search. The new arrangement v_i is produced from F_i utilizing a differential Equation (2.35).

$$s_{id} = FS_{id} + rand' \times (FS_{i,d} - FS_{k,d}) \quad (2.35)$$

Where *'d'* is randomly chosen from {1,….,D}, 'k' is arbitrarily chosen from {1,….,SN} with the end goal that, k≠1 and rand is a uniform random number in the range [-1, 1]. When Si is acquired, it will be assessed and contrasted with. On the off chance that the wellness of Si is superior to that of xi (i.e., the nectar measure of the new food source is higher than the bygone one), the bee will overlook the old arrangement and retain the enhanced one. Else, she will continue working on x_i.

Onlooker bee phase: In this stage, when every single employed bee have completed their nearby search, they share the nectar information of their food source with the onlookers, every one of whom will at that point select a food source in a probabilistic way. The probability Pb_i through that an onlooker bee selects food source x_i is calculated by Equation (2.36).

$$Pb_i = \frac{f_i}{\sum_{i=1}^{SN} f_i} \tag{2.36}$$

Where f_i is the fitness worth of x_i. Clearly, the onlooker bees can generally pick the food sources with higher nectar quantity. Once the onlooker has chosen a food source x_i, equally she will do a local search on x_i as per Equation (2.35). As within the past case, if the changed resolution includes a superior fitness, the new arrangement can supersede x_i.

Scout bee phase: In the scout bee period of ABC, if the nature of an answer can't be improved after a foreordained number (limit) of trials, the food source is thought to be abandoned, and the corresponding utilized bee turns into a scout. The scout will at that point produce a food source randomly by utilizing Equation (2.34). To improve the optimization performance of Scout bee phase, Cuckoo optimization is utilized here.

CS based Scout phase : The Cuckoo search algorithmic rule is associated in nursing optimization algorithm, that is propelled by a couple of varieties of a bird family referred to as cuckoo on account of their extraordinary manner of life and aggressive proliferation procedure. Cuckoo Search (CS) calculation [50] rotates round the conduct of needed brood parasitism of a couple of varieties of species of cuckoo even as the Levy Flights (after the name of French mathematician Paul Pierre Levy) of some birds and fruit flies, that pursue the random walk of considerable followed probability distribution step estimate. These perceptions are elaborated into calculations and actual as a completely unique and new plan. These species lay their eggs within the homes and evacuating the present eggs that growth the bring about probability of their eggs. Then again, some of the host fowls can battle these parasites conduct of cuckoos and dispose the found outsider eggs or manufacture their new in new locations. The first introductions concerning cuckoos are their pleasant tone. It might, apart from their sound, they need a terrific interruption fertile procedure. This can be referred to as brood interdependency. There are two styles of brood parasitism: non-mandatory and required. In non-mandatory brood interdependency, cuckoo lays eggs within the home of conspecifics (i.e., same species) and in their own homes additionally.

Models: It's been accounted for that 1% Chronicles of all feathered creature species pursues needed brood interdependency. Precedent: entire African Honey Guides, essentially five hundredth of the kinds of cuckoos, the Black Headed Duck in South America, Shiny Cowbirds, Screaming Cowbirds, Bronze Cowbirds and large Cowbirds. There are three sorts of brood interdependency: intraspecies brood parasitism, agreeable reproducing, and residential takeover. Currently, the host winged creatures participate in battle with interloper cuckoos. Either the host fowls might dispose the eggs within the event that they discover the eggs of trespassers or may leave the house and modify the home away. The season of egg-laying of some parasitic cuckoo is likewise astounding. These species lay their eggs in the nests and removing the existing eggs that increase the hatching probability of their eggs. On the other hand, some of the host birds are able to combat this parasites behavior of cuckoos and throw out the discovered alien eggs or build their new in new locations. Host flying creatures hatch parasitic chicks as their own. By regular nature, cuckoo chicks decide to expel the host eggs indiscriminately out of the house for its own existence and food. By analysis, it's been discovered that cuckoo chicken impersonates the sound of host chicken to induce a lot of food from the host mother.

The three perfect rules for cuckoo search are given as follows and also the basic of this idea is given within the Figure 2.9.

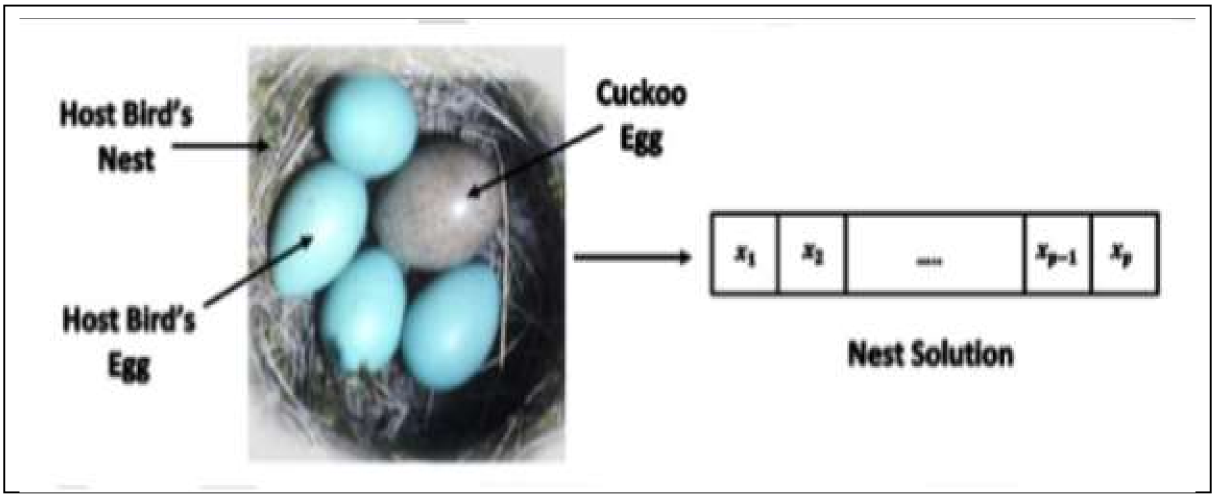


Figure 2.9: Nest solution representation in the Cuckoo search algorithm [50]

(i) Each cuckoo lays one egg at any given moment and dump the egg at arbitrarily picked home

(ii) A division of the homes containing the best eggs, or arrangements, will be completed for the people to come

(iii) The number of accessible host homes is fixed, and the egg laid by a cuckoo is uncovered by the host winged creature with a likelihood dad ∈ [0, 1].If this conditions happens, the host feathered creature can dispose of the eggs or surrender the home, and crisp home will be fabricated somewhere else. The division dad of n home is supplanted by new home.

(iv) In one type of activeness the quality or activeness of an answer is proposed to be corresponding to the estimation of the target work in the event of an amplification issue. Other type of activeness can be proposed in indistinguishable way from that of activeness capacity of GAs. In a straightforward way of portrayal, each egg in a home is spoken to by an answer and each cuckoo egg symbolizes another arrangement. The point is to misuse the new and most likely better/unrivaled arrangements (cuckoos) to substitute a not very great arrangement in the homes. Progressively mind-boggling cases like numerous eggs in a home, symbolizing a lot of arrangement, can be joined in this calculation. Here the least difficult methodology, i.e., one egg in one home, has been connected. Guided by the over three principles, the CS is shortened by the above pseudo code.

```
Cuckoo Search via Le'vy Flights

Begin

    Objective function f(x), x=(x1, x2 ...xd) r

    Generate initial population of a host nests xi (i=1, 2, 3......, n)

    While (1 < Max-generation) or (stop criterion)

        Get a cuckoo randomly by Levy Flights

        Evaluate its quality/fitness Fi

        Choose a nest among n (say, j) randomly

        If (Fi > F j),

            Replace j by the new solution;

        End

        A function (pa) of worse nests

        Are abandoned and new ones are built;

        Keep the best solutions

        (Or nests with quality solutions);

        Rank the solutions and find the current best

    End while
```

A new solution has been represented by $x^{(t+1)}$ and a cuckoo has been symbolized by *i*, then a Levy Flight is done by Equation (2.37).

$$x_i^{(t+1)} = x_i^t + \alpha \oplus Le'vy(\lambda) \qquad (2.37)$$

Where α > 0 is the progression estimate which is balanced by the size of the issue of interests. In the vast majority of the cases α is thought to be unity. Equation (2.37) represents to the stochastic condition of irregular walk. For the most part irregular walk is described by Markov chain where the following state is spoken to by the present area (the principal term of the above condition) and the progress likelihood (the second term). EX-OR symbolizes selective OR i.e., passage shrewd duplication.

This section astute augmentation is proportional as that of PSO; then again, actually the arbitrary walk by means of Levy Flight is increasingly effective in investigating/getting the search space since it's any longer advance size increments exponentially in the last stage. Levy Flight is a random walk with the random step size following a Levy distribution as given by Equation (2.38).

$$L\acute{e}vy \sim u = l^{-\lambda}, (1 < \lambda \leq 3) \tag{2.40}$$

Levy distribution has endless difference with unbounded mean with a power-law step size of a substantial tail as it is appeared in Figure 2.10.

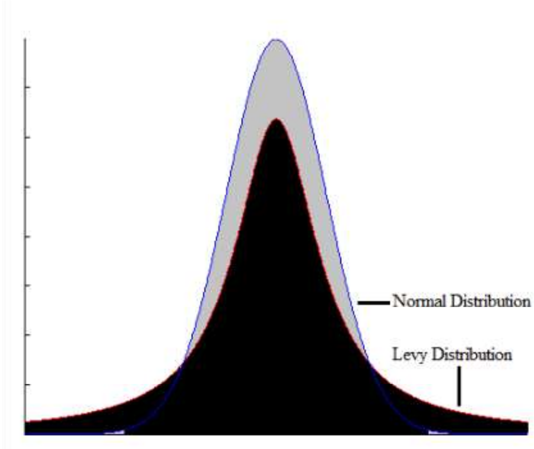


Figure 2.10: Normal and Levy Distribution

Utilizing Levy walk, couple of new products should dependably be investigated for its acceleration of neighborhood search by the most straightforward arrangements up until this point. This equitable on the off chance that end up remembered like a notice that this network must not be caught with the neighborhood ideal. For this reason, a portion just a sufficient quantity in regards to portion of another stock should potentially be sprung up originating from far box randomization inside areas sufficiently far in view of the current least difficult arrangement. From an extraordinary look, both CS alongside slope moving inside blend in couple of expansive scale randomizations showed up for you to wind up comparable. However, there is absolutely a couple of notable difference. Firstly, just like GAs as well as PSO, CS can be a population based algorithm, for the same time the item explores a number of kind connected with elitism and/or menu just as this of harmony search. Furthermore, the randomization is normally included productive, for example, the progression size can be substantial followed all through for all intents and purposes any conceivable extensive advance size. Thirdly, the sum related with tuning parameters is not as much as GAs in addition to PSO, which all through swing guarantees to help dependably be appropriate to most likely the more extensive class in regards to improvement issues. Also, a different home speaking to a decent outcome makes CS versatile on the class related with Meta population calculations.

In cuckoo search optimization, let the distributed generations be DG_i with r_i patterns. The value of host nest is defined as DG_i (i =1, 2... N) and r_i (i =1, 2...N). The host nest signifies number of DGs as well as number of configuration patterns. The population generation of DGs and the patterns are factored from L'evy Flight.

Lévy Flights: A Levy Flight can be thought of as an arbitrary walk where the progression measure has a Levy followed probability distribution. The term Levy Flight originated subsequently the French mathematician Paul Pierre Levy. The term Levy Flight was utilized explicit meaning of the circulation of the progression sizes. In the long run Levy Flight term has been utilizing to elude discrete network as opposed to nonstop space. It is a Markov Process. Exponential property of Levy Flight gives it a scale invariant property and they are utilized to display information for displaying/appearing. In nature numerous creatures and creepy crawlies pursue the properties of Levy Flight.

The L'evy Flight process executes the cuckoo until the DG population reaches maximum generation. After populating the maximum DGs, the cuckoo checks all the DGs to evaluate its Quality and Fitness F_i. The selected DGs are capable for network management and the remaining DGs are discarded. The fitness function is sharp as the voltage profile to power loss ratio. The fitness function is inversely proportional to the power loss. The fitness function F_i can be computed by Equation (2.39).

$$F_i = \max\left[\frac{V_P}{P_L}\right] \tag{2.39}$$

where V_P is the voltage profile, and P_L is the power loss. The L'evy Flight can be computed by using Equation (2.40).

$$DG_{t+1} = DG_t + \alpha X_t \tag{2.40}$$

where DG_t, represents the size of DG chosen for optimization, α represents how far-off the DG positions in the grid, X_t represents the L'evy distribution. The l'evy distribution valued at stages from $1 < l \leq$ three, where 'l' represents L'evy distribution. After the fitness computation, randomly decide a DG and relate to the fitness function. If the randomly chosen DG value is sophisticated, the chosen DG is kept as the answer else it is exchanged with the new DG value. For picking out the superlative place for DG, a fraction Pa is computed. By that fraction, the paramount DG is positioned in the grid. The most suitable DG placement established based on the voltage profiles and path loss. Utilizing (2.41) available in [18] the power loss will also be computed by Equation (2.41).

$$P_L = \sum_{k=1}^{N}\sum_{l=1}^{N}\left[\alpha_{kl}(P_kP_l + Q_kQ_l) + \beta_{kl}(Q_kP_l - P_kQ_l)\right] \tag{2.41}$$

where $\alpha_{kl} = \frac{r_{kl}}{V_k V_l}\cos(\delta_k - \delta_l)$; $\beta_{kl} = \frac{r_{kl}}{V_k V_l}\sin(\delta_k - \delta_l)$ are the complex voltage at bus i and j.

$r_{kl} + jx_{kl} = Z_{kl}$ is ij th element of [Z_{bus}] impedance matrix,

P_k *and* Q_k are the total real and reactive power injection in bus k respectively,

P_l *and* Q_l are the total real and reactive power injection in bus l respectively,

V_k *and* δ_k are Voltage magnitude and angle at bus k respectively,

V_l *and* δ_l are Voltage magnitude and angle at bus l respectively and

N is the number of buses.

The voltage profile V_p can be defined by Equation (2.42).

$$V_p = \sum_{i=1}^{n} V_i \, L_i \, W_{fi} \qquad (2.42)$$

where V_i represents the voltage magnitude of the bus i, load at bus i is represented by L_i, the weighting factor of load bus is W_{fi} . The weighting factor of load bus is given by Equation (2.43).

$$\sum_{i=1}^{n} W_{fi} = 1 \qquad (2.43)$$

On the basis of voltage profile and power loss, the DG is sized optimally so that the grid network is managed efficiently. The pseudocode of cuckoo search for optimal sizing of DG is shown below.

```
Begin
    Total number of Distributed Generation DGi,
    Generate initial population of n host nests DGi (i = 1, 2... N)
    while (t <Max Generation) or (stop criterion)
        Get a cuckoo randomly by Levy flights
        Evaluate its quality/fitness in Fx
        Choose a DG among N (say y) randomly
        if (Fx > Fy),
            Replace y by the new solution;
        end
        A fraction (pa) of worse nests are abandoned and new ones are
        built;
        Keep the best solutions
        Rank the solutions and find the current best
    end while
Post process results and visualization
end
```

The above proposed work by utilizing ABC-CS presents a new deterministic methodology, which determines the optimal size for DG placement. This technique is easy to be applied.

The flow chart of the proposed method for optimal DG placement is shown in Figure 2.11.

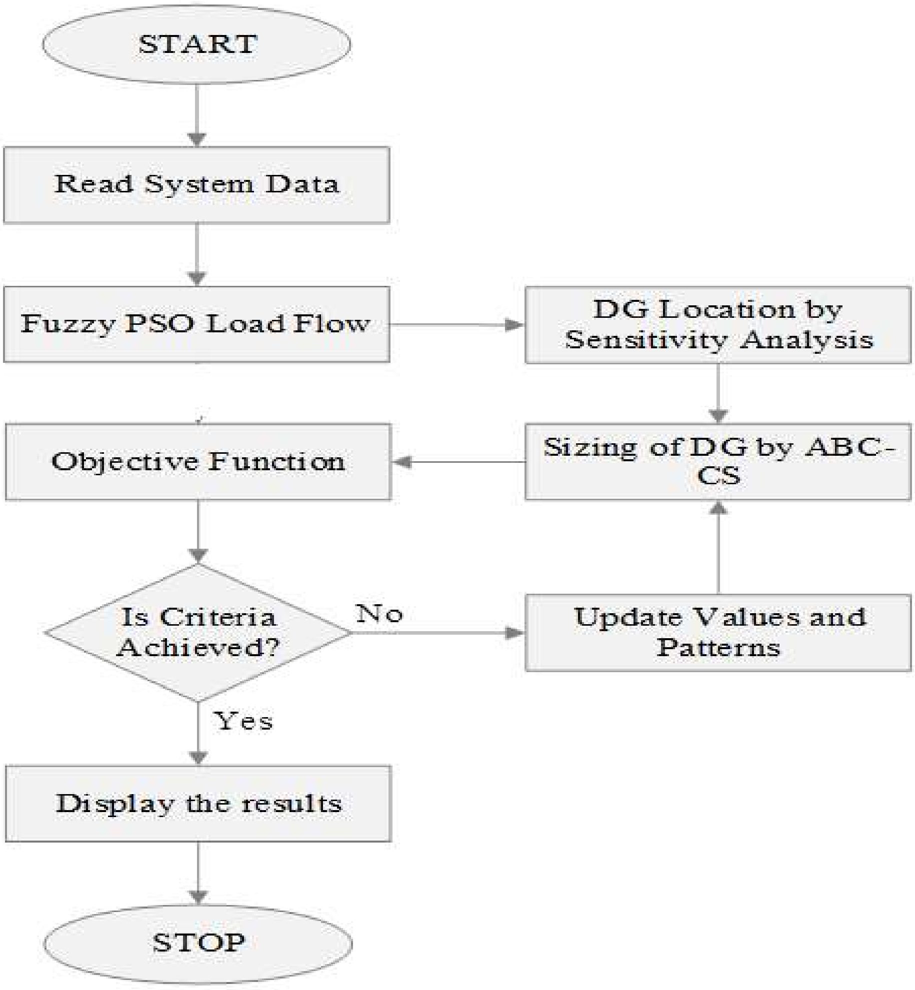


Figure 2.11: Flow chart of the proposed method

The analogies used in the hybrid grouping of ABC-CSO algorithm with respect to the DG sizing problem are presented in the Table 2.1. Table 2.2 presents the parameters and its values used in ABC-CSO algorithm.

Table 2.1: Analogies of the Proposed Algorithm Regarding DG Sizing Problem

Analogy	**DG sizing problem**
Nourishment source in ABC	Random value of DG sizes
Nourishment source positions in ABC	Fitness values for the corresponding DG sizes
Suitability value	Total power loss and energy loss after placing the DGs.
Objective Function	DG sizes with best fitness values
Position (P_a)	Replacing the worst one with the best
Rand	Arbitrarily generated numbers from 0 to 1
New cuckoo X_t	New DG size
Step size (α)	Step size parameter related to the scale of the problem
Best nourishment source	Best value of DG size

Table 2.2: Parameters and its values used in ABC-CSO

Parameters	Values
Random value of DG sizes	Randomly selected numbers
Rand	0.8
New cuckoo X_i	0.182 kW
Step size α	30
Best nourishment source	0.186 kW

2.7 Cost of DG and Cost of Energy Loss

The price of DG and price of energy deficit used are computed as given, using the formulas given in [17].

Cost of energy losses (CL): The annual charge of loss in energy is given by Equation (2.44).

$$\text{CL} = (\text{Total Real Power Loss}) \times (E_c \times T) \ \$ \tag{2.44}$$

Where E_c =Energy Rate ($/kW h) = 0.06 $/kW h

T=time duration (h) =8760 h.

The cost component of DG for real power: The cost of DG for supplying real power is given by Equation (2.45).

$$C(P_{DG}) = aP_{DG}^{\ 2} + bP_{DG} + c \quad \$/\text{h} \tag{2.45}$$

Where P_{DG} is real power provided by DG and the charge coefficients are occupied as: a = 0; b = 20; c = 0.25.

2.8 Outcomes before and after DG placement in radial and meshed distribution networks

2.8.1 33-node radial distribution network

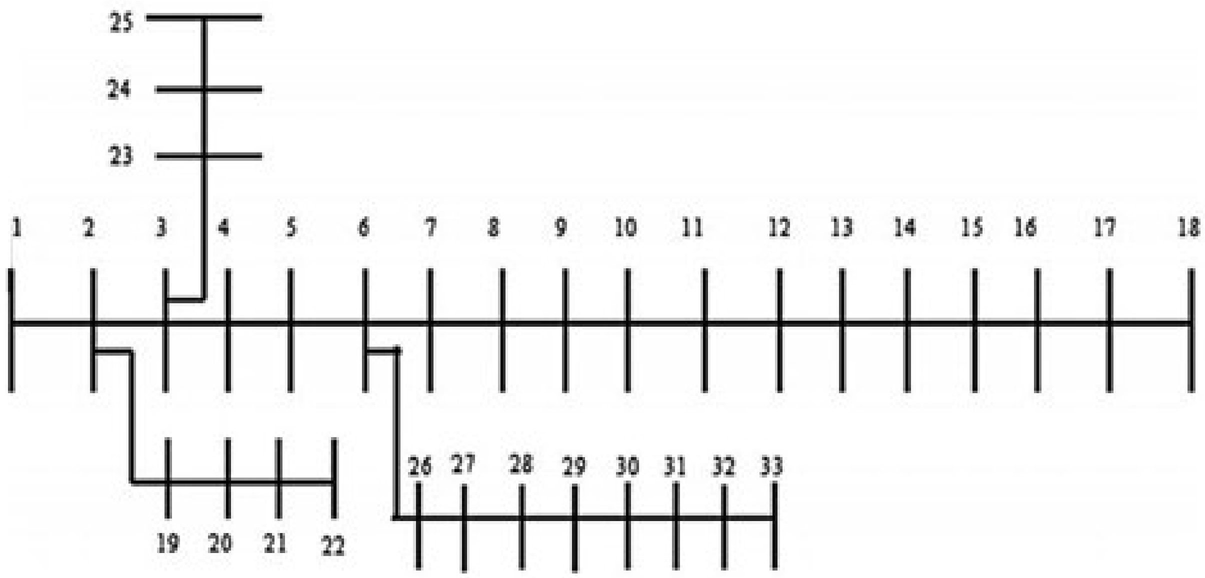


Figure 2.12: 33-node radial distribution network

Initially, it is applied to a small distribution system consisting of 33-node with 32 numbers of branches shown in Figure 2.12. The base kV is 12.66 and base MVA is 100. The system data [51] are given in **Appendix-A**. The respective total real and reactive power loads of the system are 3.7 MW and 2.3 MVAr.

Table 2.3 shows the results of excluding DG (base case) and including DG (single DG, double DG and triple DG) in terms of active power loss, minimum voltage (p.u.), location(s) of DG(s) and DG size(s), price of energy loss and price of DG for 33-node RDN for normal (100%) load.

The voltage profile of 33-node radial distribution network before and after DG placement is given in Figure 2.13 for normal load.

Table 2.3: Results of 33-node radial distribution network

Parameters	Excluding DG	Including DG (Type-1, pf = 1.0)		
		Normal (100%)		
		Single DG	Double DG	Triple DG
Real Power Loss (kW)	202.52	103.95	85.91	71.16
Reactive Power Loss (kVAr)	135.10	74.71	58.61	48.42
Minimum Voltage (p.u.)	0.9132 (18)	0.9514 (18)	0.9680 (33)	0.9756 (33)
DG Location (Node Number)	-	6	13, 30	13, 25, 30
DG Size (MW)	-	2.58	0.84, 1.14	0.78, 0.84, 1.12
Annual Cost of Energy loss ($/kWh)	106444.512	54636.12	45154.296	37990.368
Cost of DG ($/h)	-	51.85	39.85	55.05

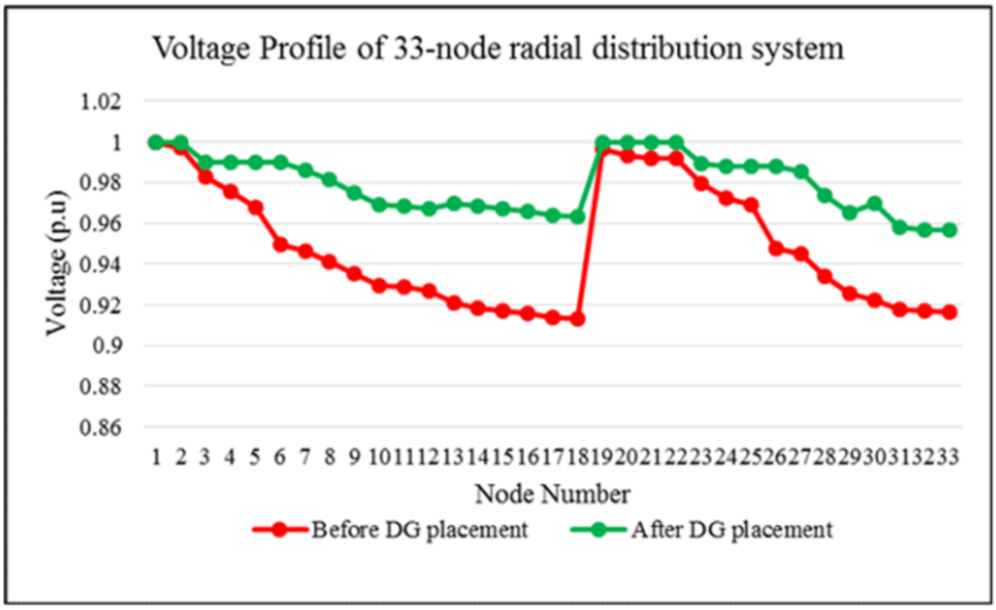


Figure 2.13: Voltage profile of 33-node distribution system

2.8.2 69-node radial distribution network

To validate the performance of the proposed method for a medium system, we applied the proposed method in 69-node radial distribution network [51], which consists of 68 numbers of branches as shown in Figure 2.14. The base kV is 12.66 and base MVA is 100. System data are given in **Appendix-B**. The respective total real power load of the system is 3.80 MW and reactive power loads on the system is 2.69 MVAr. The outcomes of 69-node radial distribution network are given in Table 2.4.

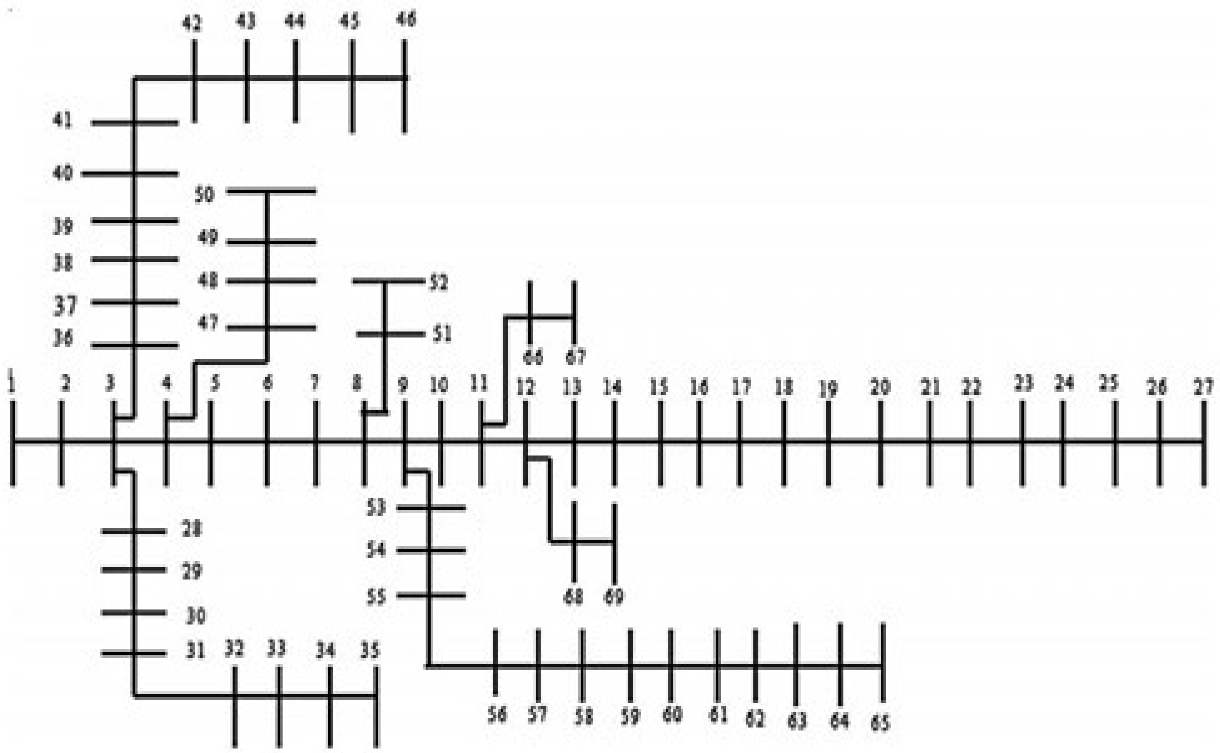


Figure 2.14: 69-node radial distribution network

Table 2.4 shows the results of excluding DG (base case) and including DG (single DG, double DG and triple DG) in terms of active power loss, minimum voltage (p.u.), location(s) of DG(s) and DG size(s), price of energy loss and price of DG for 69 node RDN for normal (100%) load.

The voltage profile of 69-node RDN before and after DG placement (single DG, double DG and triple DG) is shown in Figure 2.15 for normal load (100%).

Table 2.4: Results of 69-node radial distribution network

Parameters	**Excluding DG**	**Including DG (Type-1, pf = 1.0)**		
		Normal (100%)		
		Single DG	**Double DG**	**Triple DG**
Real Power Loss (kW)	224.94	83.21	71.70	68.10
Reactive Power Loss (kVAr)	102.19	40.62	35.81	34.02
Minimum Voltage (p.u.)	0.9091 (65)	0.9683 (27)	0.9795 (65)	0.9848 (65)
DG Location (Node Number)	-	61	18, 61	18, 61, 63
DG Size (MW)	-	1.87	0.51, 1.80	0.52, 1.45, 0.29
Annual Cost of Energy loss ($/kWh)	118228.464	43735.176	37685.52	36035.136
Cost of DG ($/h)	-	37.65	46.45	45.45

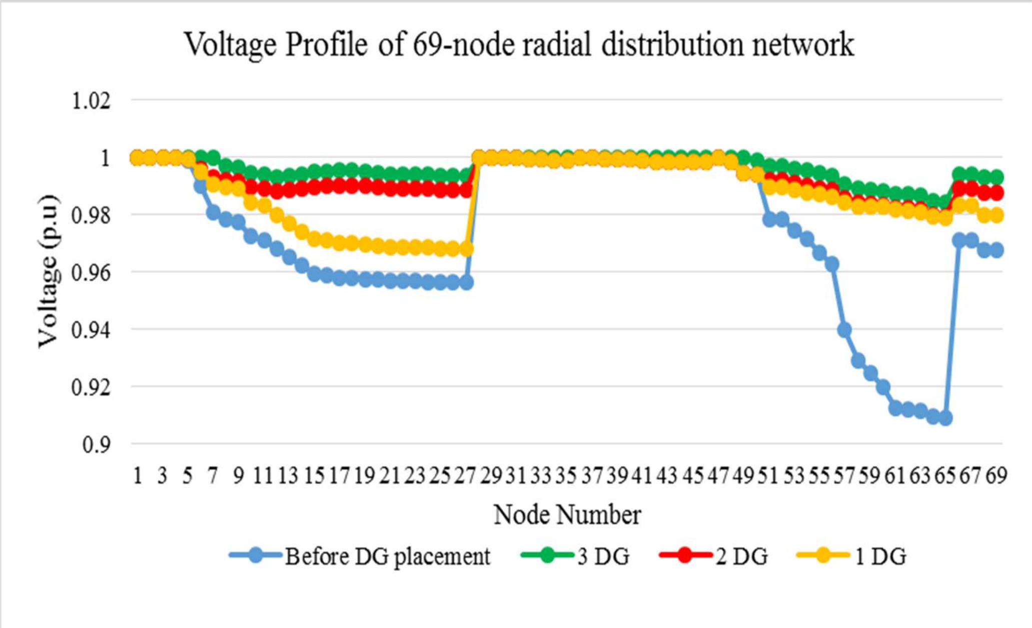


Figure 2.15: Voltage Profile of 69-node radial distribution network

2.8.3 85-node mesh distribution system

The schematic diagram of 85-node meshed distribution network [26] is shown in Figure 2.16, which consists of 85 nodes and 10 meshes. The system data is given in **Appendix-C**. The base kV is 11 and base MVA is 100. The total respective real power load is 2.57 MW and reactive power loads on the system is 2.62 MVAr.

Table 2.5 shows the results of excluding DG (base case) and including DG (single DG, double DG and triple DG) in terms of active power loss, minimum voltage (p.u.), location(s) of DG(s) and DG size(s), price of energy loss and price of DG for 85-node RDN for normal (100%) load.

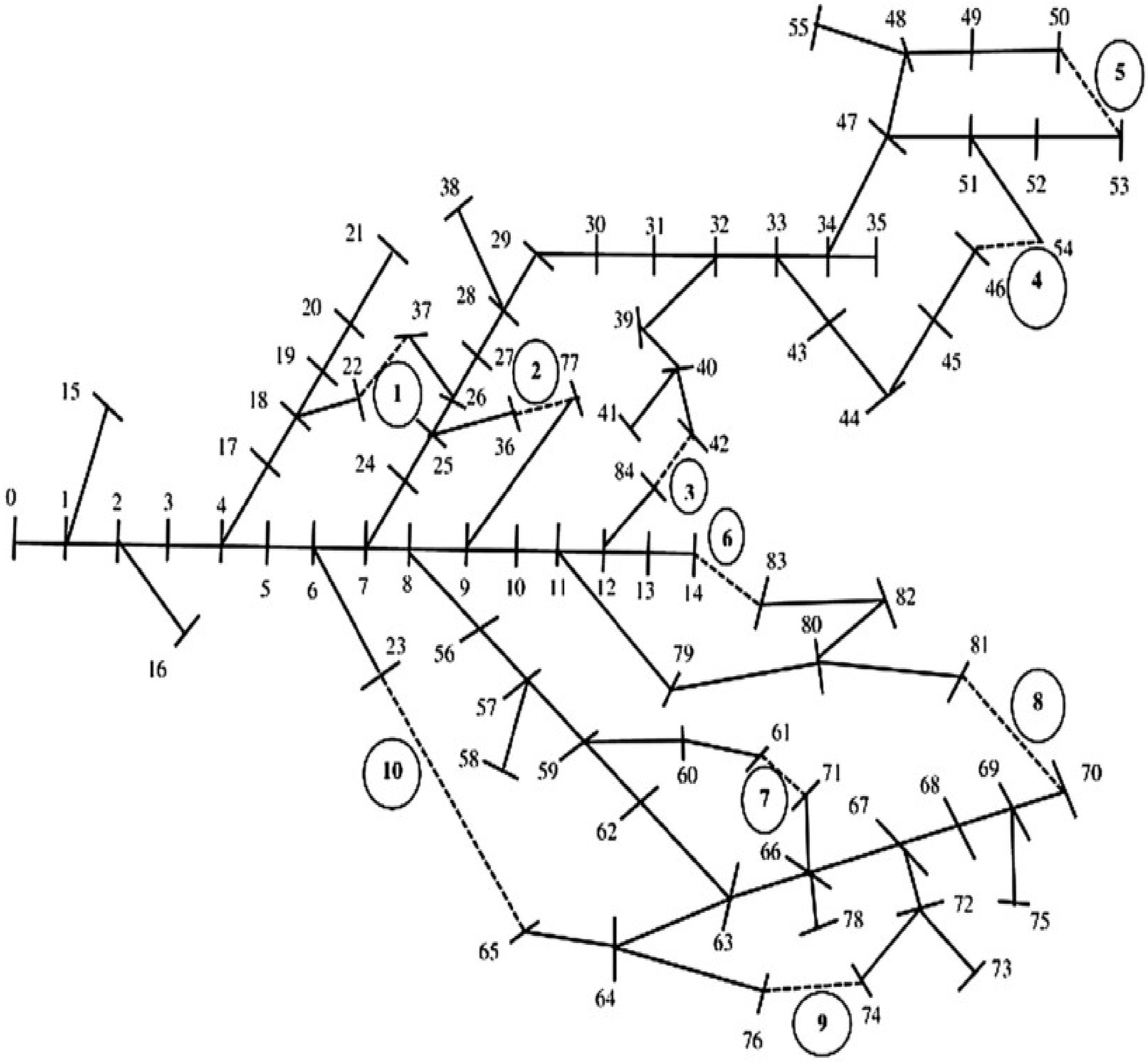


Figure 2.16: 85-node meshed distribution system

Table 2.5: Outcomes of 85-node mesh distribution system

Parameters	Without DG	With DG
Real Power Loss (kW)	286.52	91.25
Reactive Power Loss (kVAr)	180.52	75.45
Minimum Voltage (p.u.)	0.87749 (54)	0.9325 (54)
Number of DGs	-	3
DG Location (Node Number)	-	8, 58, 27
DG Size (MW)	-	2.2 (8), 1.53 (27), 0.16 (58)
DG Type	-	Type 1
AnnualCost of Energy loss ($/kWh)	150594.912	47961
Cost of DG ($/h)	-	78.05

The voltage profile of 85-node mesh distribution system before and after DG placement is shown in Figure 2.17 for normal load.

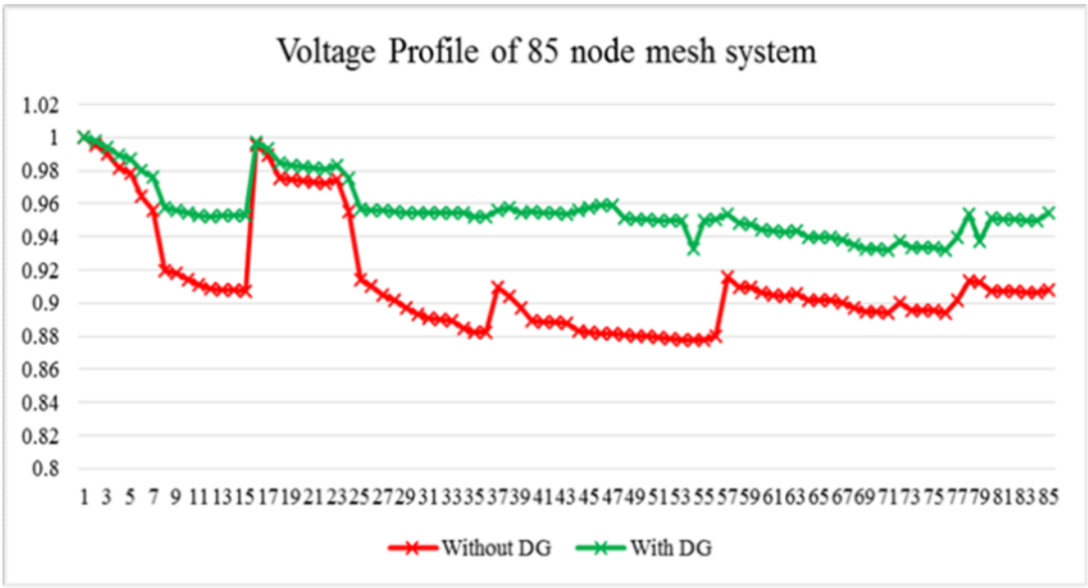


Figure 2.17: Voltage Profile of 85-node mesh distribution system

Table 2.6 shows the comparison of three DG placement in 33-node RDN utilizing the proposed method is compared with that obtained by ABC algorithm, Firefly algorithm , PSO algorithm and genetic algorithm (GA).

Table 2.6: Comparison of three DG placement in 33-node RDN by proposed method with that obtained by other algorithms

Three DGs by the algorithm	Total DG size (MW)	Real Power Loss (kW)	Minimum voltage (p.u.) and Node number	Cost of DG ($/h)
Proposed Method	2.74	71.16	0.9756(33)	55.05
ABC algorithm	2.77	72.16	0.9732(33)	55.65
Firefly algorithm	2.80	73.22	0.9712(33)	56.25
PSO algorithm	2.83	74.42	0.9692(33)	56.85
Genetic algorithm	2.87	75.58	0.9670(33)	57.65

Table 2.7 shows the comparison of three DG placement in 69-node RDN utilizing the proposed method is compared with that obtained by ABC algorithm, Firefly algorithm , PSO algorithm and genetic algorithm (GA).

Table 2.7: Comparison of three DG placement in 69-node RDN by proposed method with that obtained by other algorithms

Three DGs by the algorithm	Total DG size (MW)	Real Power Loss (kW)	Minimum voltage (p.u.) and Node number	Cost of DG ($/h)
Proposed Method	2.26	68.10	0.9848(65)	45.45
ABC algorithm	2.30	68.92	0.9815(65)	46.25
Firefly algorithm	2.36	69.24	0.9765(65)	47.45
PSO algorithm	2.41	69.62	0.9728(65)	48.45
Genetic algorithm	2.48	69.97	0.9693(65)	49.85

Table 2.8 shows the comparison of DG placement in 33-node and 69-node RDNs utilizing the proposed method is compared with other existing techniques **[16,38,39,40,41]**

Table 2.8: Comparison of three DG placement in 33-node and 69-node RDNs by the proposed method with other available methods

Methods	Bus System	Real Power Loss (kW)	V_{min} (p.u.) & (node no.)	DG size (MW) & (location)	Relative CPU Time
Proposed Method	**33 RDN**	**71.16**	**0.9756 (33)**	**0.780(13), 0.840(25), 1.120(30)**	**1.00**
	69 RDN	**68.10**	**0.9848 (65)**	**0.520(18), 1.450(61), 0.290(63)**	***1.00***
[16]	33 RDN	89.90	0.9705 (29)	0.6521(14), 0.1984(18), 1.0672(32)	1.45
	69 RDN	75.23	0.9808 (61)	0.2954(27), 0.4476(65), 1.3451(61)	*1.78*
IA [38]	33 RDN	81.05	0.9715 (18)	0.900(6), 0.900(12), 0.720(31)	1.65

	69 RDN	68.82	0.9779 (65)	1.700(61), 0.510(17), 0.340(11)	*1.97*
[38]	33 RDN	72.79	0.9685 (33)	0.800(13), 1.090(24), 1.050(30)	1.71
	69 RDN	70.08	0.9798 (65)	1.81(61), 0.510(17), 0.720(50)	*1.99*
[39]	33 RDN	72.89	0.9670 (33)	0.790(13), 1.070(24), 1.010(30)	1.39
	69 RDN	69.54	0.9771 (65)	0.510(11), 0.380(17), 1.670(61)	*1.80*
[40]	33 RDN	71.4	0.9686 (33)	0.754(14), 1.009(24), 1.072(30)	1.60
	69 RDN	71.5	0.9803 (61)	0.537(17), 1.200(61), 0.536(64)	*2.09*
[40] [SOS Studied]	33 RDN	77.0	0.9717 (33)	1.069(6), 0.643(14), 0.739(31)	1.64

	69 RDN	74.2	0.9776 (27)	1.200(61), 0.498(64), 0.833(66)	*2.12*
[41]	33 RDN	71.45	0.9686 (33)	1.07142(30), 1.09944(24), 0.75398(14)	1.64
	69 RDN	69.42	0.9789 (65)	1.71912(61), 0.38050(18), 0.52670(11)	*2.12*

From Table 2.8 the proposed method of DG placement in 33-node and 69-node RDNs utilizing the proposed load flow is compared with existing techniques **[16,38,39,40,41]** in terms of real power loss and reactive power loss of proposed method is less than the existing methods, minimum voltage is higher than the existing methods.

2.9 Conclusion

Load flow analysis is performed to solve the radial and mesh distribution network. The comparison of results corresponding to total real power loss and total reactive power loss, minimum voltage, DG location and DG size is obtained. The proposed load flow analysis is evaluated using fuzzy logic for 33-node and 69-node radial distribution networks and also for 85-node mesh distribution networks without and with integrating DG. The outcomes have also been juxtaposed with other existing methods.

CHAPTER-3

VOLTAGE STABILITY ANALYSIS USING FUZZY LOGIC

3.1 Introduction

With a developing concern for keeping up stable voltage operation of the system, numerous basic issues on voltage stability related analysis have been brought up in the zone of electric network. The issue of voltage instability is fundamentally considered as the failure of the system to satisfy the load demand imposed as far as deficient reactive power backing or real power transmission capacity or both. There exist two noteworthy systems viz, static methodology and dynamic methodology for this analysis. Although not very accurate, yet the static technique has gained wide acceptance for its inherent virtues, eg, simplistic approach, faster execution and less memory consumption. Voltage stability analysis refers to the voltage stability examination of the disappointment of a number of approaches. The maximum severe circumstances are incorporated to reduce the computation time. It is additionally characterized as the normal for a power network to stay in the condition of harmony after an unsettling influence and generally the stability issue has been the rotor point dependability, i.e., keeping up synchronous task. Instability may happen without the loss of synchronism, in which case the worry is the control and dependability voltage. Voltage stability is a property of power distribution network that empowers it to remain in a condition of equilibrium voltage under normal operating condition and the network additionally comes back to an equilibrium condition of balance voltage after a disturbance. On the off chance that the power utilization from the network goes past its capacity, a sequence of events going with voltage instability results in a low acceptable voltage profile of the distribution systems. Not at all like transmission systems, these distribution systems are radial in nature. The distribution systems have high R/X proportion contrasted with the transmission systems, and henceforth are ill-conditioned in nature. The stability index of distribution systems is generally unique in relation to that of transmission systems on the grounds that the last have X>>R. Amid inference of voltage stability index (VSI) of distribution systems, X and R are similarly critical and are commonly both considered. The distribution systems experience voltage collapse beyond certain critical loading conditions in light of the fact that the modern power distribution systems are always being looked with a consistently growing load demand. Voltage stability concerns stable load activity, and acceptable voltage levels all over the network busses. Its instability has been characterized into enduring state and transient voltage instability, as per the time range of the event of the phenomena. A power network is said to have entered a state of voltage instability when an unsettling influence causes an enlightened and wild decrease in voltage [52,53]. The network voltage stability is networks ability to keep acceptable voltages in all busses in normal conditions after disturbances. Voltage stability analysis frequently necessitates analysis of bunches of network states and numerous contingency situations. Hence the methodology dependent on steady state analysis is progressively attainable, and it can likewise give global insight of the voltage reactive power problems [54]. The voltage stability phenomenon has been very much perceived in distribution networks. Radial distribution networks having a high R/X ratio causes a high-power loss with the goal that the radial distribution network is one of the power networks, which may suffer the ill effects of voltage instability [55].

Anytime of time, a force framework working condition ought to be steady, meeting different operational criteria, and it ought to likewise be secure in the occasion of any tenable possibility. Present day power frameworks are being worked closer to their security limits because of monetary and ecological limitations. Keeping up a steady and secure operation of a force framework is along these lines a vital furthermore, difficult issue. Voltage unsteadiness has been given much consideration by force framework scientists furthermore, organizers as of late, and is being viewed as one of the significant wellsprings of force framework unreliability. Voltage unsteadiness wonders are the ones in which the less than desirable end voltage diminishes well beneath its typical esteem and does not return even in the wake of setting restoring instruments, for example, VAR compensators, or keeps on wavering for absence of damping against the unsettling influences. Addresses the need to perform voltage stability analysis in voltage-controlled buses and the capacity size of a new generator must be limited in order to assure correct voltage control. The stable and unstable nature of a hybrid system can be easily proved by stable operating regions, but it failed to explain about optimization of the stability analysis and filter design tool. Discrete abstractions of hybrid systems are possible when either the continuous or the discrete dynamics are restricted in a distributed generator [56]. A sensitivity analysis of the estimate of the load margin that is obtained via Look-Ahead method. The control actions were well ranked in terms of their efficiency to increase the load margin for all tested contingencies and it require an optimal power flow that minimizes the cost of the selected controls constrained to a minimal load margin.

3.1.1 Definition of Voltage stability

The voltage stability is the capacity of a power network to keep up enduring adequate voltage at all busses in the network at ordinary working condition and in the wake of being exposed to an unsettling influence. Power System is voltage stable if voltage after an aggravation is near voltage at typical working condition. A power network ends up shaky when voltages wildly decline because of blackout of gear (generator, line, transformer, bus bar and so on.), augmentation of burden, decrement of creation and additionally debilitating of voltage control.

3.1.2 Definition of Voltage Instability

Voltage instability comes from the load elements to reestablish control utilization past the capacity of the joined transmission and age network.

3.1.3 Definition for Voltage Collapse

Voltage collapse is that the procedure by that voltage instability prompts the loss of voltage during a critical piece of the network. This condition results from the reactive losses basically surpassing the reactive resources accessible to provide them. Circuits stacked on top of surge impedance loadings and reduced output of shunt capacitors as voltages decay will prompt quickening voltage drops. Voltage collapse will seem like each a steady state issue with time to reply and an issue wherever no viable administrator development is conceivable. It is very hard to predict the area that will be affected or electrically isolated from the grid.

3.2 Classification of Power System Stability

Power network stability is divided as rotor angle and voltage stability. A grouping of power network stability dependent on time scale and main thrust criteria is presented in the Table 3.1. The main thrusts for an instability mechanism are generator driven and load driven.

Table 3.1: Power System Stability classification

<table>
<tr><th>Time Scale</th><th colspan="2">Generator Driven</th><th colspan="2">Load Driven</th></tr>
<tr><td rowspan="2">Short term</td><td colspan="2">Rotor angle stability</td><td colspan="2" rowspan="2">Short term voltage stability</td></tr>
<tr><td>Small signal</td><td>Transient</td></tr>
<tr><td rowspan="2">Long term</td><td colspan="2" rowspan="2">Frequency Stability</td><td colspan="2">Long term voltage stability</td></tr>
<tr><td>Small disturbances</td><td>Large disturbances</td></tr>
</table>

The rotor angle stability is divided into small signal stability and transient stability. The small signal stability is available for little aggravations as undumped electromechanical motions. The transient stability is because of absence of synchronizing torque and is started by substantial aggravations. The time allotment is called momentary time scale in light of the fact that the elements regularly keep going for a couple of moments.

3.3 Reasons for voltage instability

The main reasons for the voltage instability are as per the following;

- The load on transmission line is too high.
- The voltage sources are too far from the load centres.
- The source voltages are too low.
- There is insufficient load reactive compensation.

3.4 Derivation of Voltage stability Index

Figure 3.1 depicts the voltage stability index, which is acquired from the 2 bus network and Equation (3.1) shows how current stream from bus 1 to bus 2 can be computed.

$$I_j = \frac{V_1\angle\delta_1 - V_2\angle\delta_2}{Z_j} \tag{3.1}$$

Where I_j is the flowing of current through bus 1 and 2, $V_1\angle\delta_1$ and $V_2\angle\delta_2$ are the magnitude of voltages and their angles at node 1 and 2 respectively.
$Z_j = R_j + jX_j$, where R_j and X_j is the resistance and reactance of the branch between bus 1 and 2.

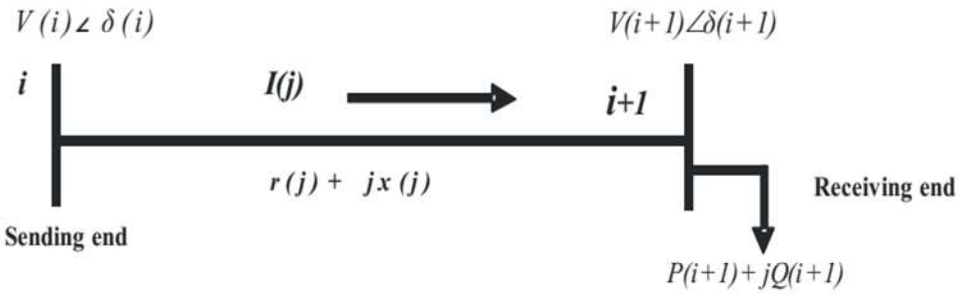


Figure 3.1: Electrical equivalent of two node system

The voltage stability study discusses the voltage stability analysis of the disappointment of a number of approaches. The time spent deliberating all likely occasions are simply too huge and a brief contingency list, the maximum severe circumstances are incorporated, is continually utilized to decrease the calculation time. The voltage stability index (VSI) is expressed from a two bus system and design equations are given as Equation (3.2) and Equation (3.3) respectively.

$$\overline{V_1} = \overline{V_2} + \bar{I}_j \overline{Z}_j \tag{3.2}$$

$$V_1 \angle \delta_1 = V_2 \angle \delta_2 + \left[I_{real_j} + jI_{imag_j} \right] \left[R_j + jX_j \right] \tag{3.3}$$

$$V_2 \cos\delta_2 + jV_2 \sin\delta_2 = V_1 \cos\delta_1 + V_1 \sin\delta_1 - \left[A + jB \right] \tag{3.4}$$

where $A = I_{real_j} R_j - I_{imag_j} X_j$, $B = I_{real_j} R_j + I_{imag_j} X_j$.

From Equation (3.4)

$$V_2 \cos\delta_2 = V_1 \cos\delta_1 - A \tag{3.5}$$

$$V_2 \sin\delta_2 = V_1 \sin\delta_1 - B \tag{3.6}$$

Then we have

$$\tan\delta_2 = \frac{V_1 \cos\delta_1 - A}{V_1 \sin\delta_1 - B} \tag{3.7}$$

From Equation (3.5) and Equation (3.6), we have

$$V_1^2 - 2\left[A\cos\delta_1 + B\sin\delta_1 \right] V_1 + \left(A^2 + B^2 \right) = V_2^2 \tag{3.8}$$

Since V_2 is always greater than 0, the following condition given by Equation (3.9) must satisfied

$$V_1^2 - 2\left[A\cos\delta_1 + B\sin\delta_1 \right] V_1 + \left(A^2 + B^2 \right) \geq 0 \tag{3.9}$$

Let

$$L_2 = V_1^2 - 2\left[A\cos\delta_1 + B\sin\delta_1 \right] V_1 + \left(A^2 + B^2 \right) \geq 0 \tag{3.10}$$

Accepting end node of branch-j is the sending-end node of branch j+1. The calculated $\delta(2)$ of branch j will be used as $\delta(1)$ for the next branch i.e., j+1. I_{real_j} is the real part of the current I_j through branch j and I_{imag_j} is the imaginary part of current I_j by means of branch j. The value of $\delta(1) = 0.0$ for substation.

The VSI values have to be less than one for the system to be steady. The VSI value around one proposes which the network is drawing near its load limit and is practically unstable. It is possible to define the level of stability of radial distribution networks using this index and thereby appropriate action may be taken. The node the highest VSI is considered for compensation. For stable operation of the radial distribution networks, the estimation of VSI got from Equation (3.10) ought to be more noteworthy than or equivalent to zero. The node at which the value of the VSI is least, is progressively delicate to the voltage collapse. At or near the collapse point, voltage stability index of one or more-line approach to unity. This technique is utilized to evaluate the voltage stability.

The voltage stability index proposed by Chakraborty and Das [57] is given by Equation (3.11).

$$\begin{aligned} VSI(i+1) = {} & \left[|V(i)|^4 - 4.0\{P(i+1)X_j - Q(i+1)R_j\} \right]^2 \\ & - 2.0\{P(i+1)R_j + Q(i+1)X_j\}|V(i)|^2 \end{aligned} \tag{3.11}$$

The voltage stability index proposed by Eminoglu and Hocaoglu [58] is given by Equation (3.12).

$$\begin{aligned} VSI(i+1) = {} & 2|V(i)|^2|V(i)|^2 - |V(i+1)|^4 - 2|V(i+1)|^2[P((i+1)R_j + Q((i+1)X_j] \\ & - [R_j^2 + X_j^2][P^2(i+1) + Q^2(i+1)] \end{aligned} \tag{3.12}$$

The proposed voltage stability index given by Equation (3.12), incorporates the voltage angle of the sending- end node. Hence this VSI one will give exact results.

3.5 Introduction to Fuzzy Logic Set and Membership functions

Fuzzy logic is basically a multi-valued logic that allows intermediate values to be defined between conventional evaluations like yes and no, true and false, black and white, etc. Thoughts like tall or excessively short or genuinely great can be detailed numerically and prepared by computers. Fuzzy rationale is a superset of customary (Boolean) rationale that has been reached out to deal with the idea of fractional truth. A partially true statement may be indexed any value between 'completely true' and 'completely false'. There is a strong relationship between fuzzy logic and fuzzy subset theory as compared to the relationship between Boolean logic and the concept of a subset. A fuzzy subset $\tilde{A}$ of a set 'U' could be characterized as a lot of requested sets, each with the principal component 'x' from 'U' and the second component from the interim {0, 1},with precisely one arranged pair present for every component of 'U'. This characterizes a mapping between components of the set 'U' and values in the interim {0, 1}. The esteem zero is utilized to signify whole non-enrollment, the esteem one is utilized to signify whole participation, and qualities in the middle of are utilized for signifying transitional degrees of participation. The set 'U' is mentioned to as the universe of talk for the fuzzy subset $\tilde{A}$. Actually, the mapping is portrayed as a function $\mu_{\tilde{A}}(x)$, the membership function of $\tilde{A}$. A numerical articulation for this mapping is presented in Equation (3.13).

$$\tilde{A} = \left\{ \left(x, \mu_{\tilde{A}}(x) \right) | \, x \in U \right\} \tag{3.13}$$

3.5.1 Fuzzy Modelling of Input Parameters

Truth be told, fuzzy sets and fuzzy rationale are seen as formal scientific hypotheses for the portrayal of uncertainty [59,60,61,62,63]. In this paper, the uncertainties in the input parameters are displayed with the assistance of L-R type trapezoidal enrollment capacities. A trapezoidal L-R fuzzy enrollment work as demonstrated in Figure 3.2 is typically communicated by the trademark focuses a1, a2, a3 and a4 to such an extent that the fuzzy number under analysis can accept an incentive somewhere in the range of a1 and a4. However, values inside the range a2 and a3 are well on the way to take place. All the qualities inside the range a2 and a3 have a participation esteem (μ_x = 1), which demonstrates total enrollment for the occasion. Be that as it may, the qualities inside extents (a1-a2) and (a3−a4) have enrollment values ($0 \leq \mu_x \leq 1$), that show incomplete enrollment values. Any incentive outside the choice of a1 and a4 has enrollment esteems (μ_x = 1) representing non-participation for the parameter. Consequently, the uncertainty of the parameter 'x' is helpfully described by a trapezoidal fuzzy distribution with appropriate left and right slants. A particular relationship for the component 'x' and its degree of participation 'μ_x' for the L-R trapezoidal enrollment work is exhibited in the Equation (3.14).

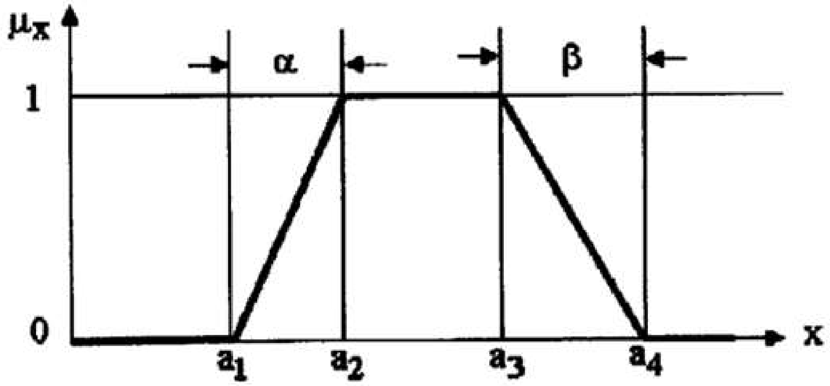


Figure 3.2: Schematic representation of a trapezoidal L-R type fuzzy membership function

$$\mu_{\tilde{A}}(x) = \begin{cases} L(x) & for\ a_1 \leq x \leq a_2 \\ R(x) & for\ a_3 \leq x \leq a_4 \\ 0 & otherwise \end{cases} \tag{3.14}$$

Where,

$$L(x) = \frac{x-(a_2-\alpha)}{\alpha}\Big|_{\alpha\geq 0} \tag{3.15}$$

$$\text{and, } R(x) = \frac{(a_3 + \beta) - x}{\beta}\Big|_{\beta \geq 0} \tag{3.16}$$

The schematic portrayal of trapezoidal L-R type fuzzy participation work enrollment work is given in the accompanying Figure 3.2.

Figure 3.3 shows the flow chart for the voltage stability index calculation based upon Fuzzy Logic.

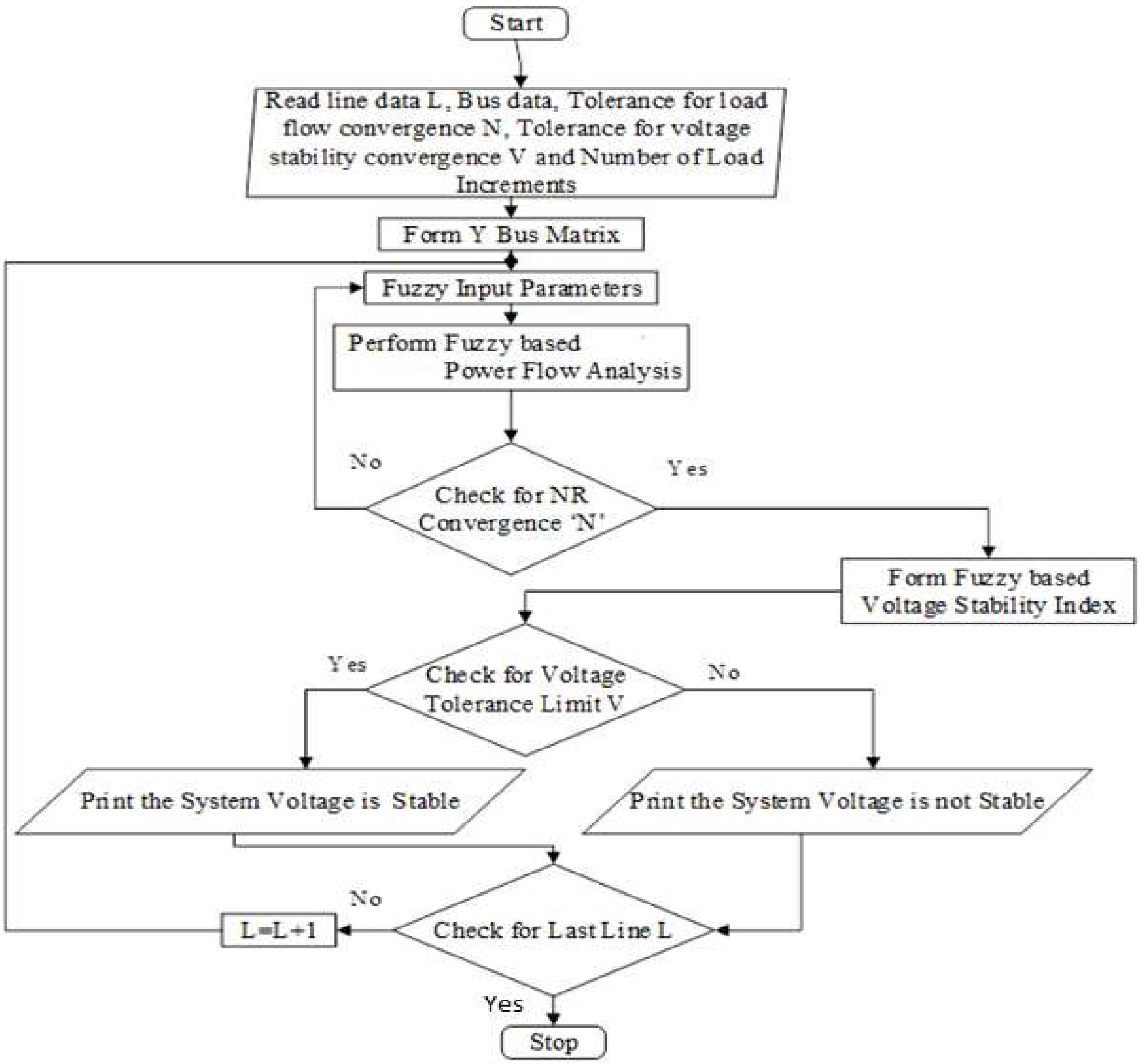


Figure 3.3: Voltage stability Index Calculation based on Fuzzy Logic

3.6 Voltage stability Index of Different Node Systems

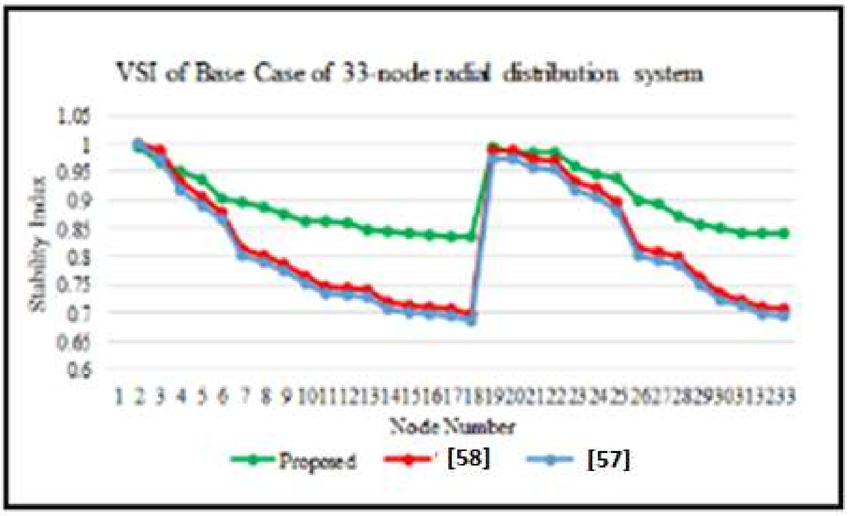
In this section the VSI measured using the proposed VSI on 33-node, 69-node RDNs and 85-node MDN are given below.

3.6.1 Voltage stability Index of 33-node System

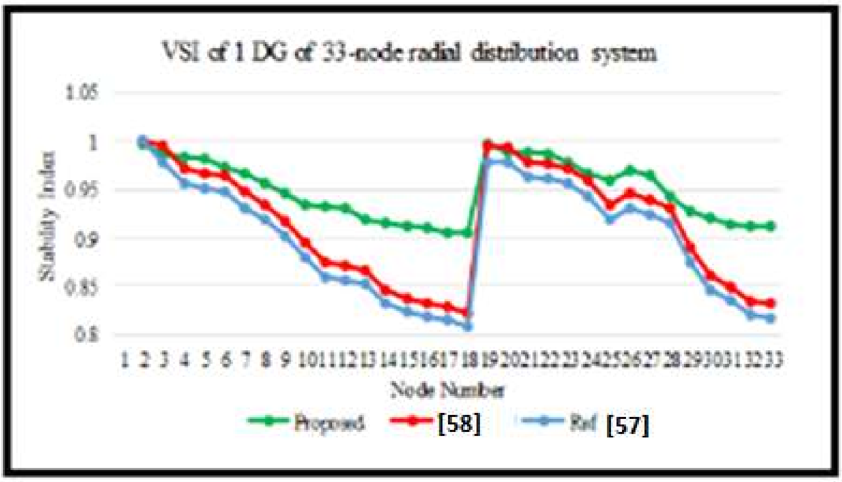
The voltage stability index (VSI) of 33-node radial distribution network is computed before and after DG placement in the case of single, double and triple DG and the outcomes have been shown in Table 3.2 for normal (100%) load. Figure 3.4 shows the comparison of VSI.

Table 3.2: Outcomes of 33-node radial distribution network without and with DG placement

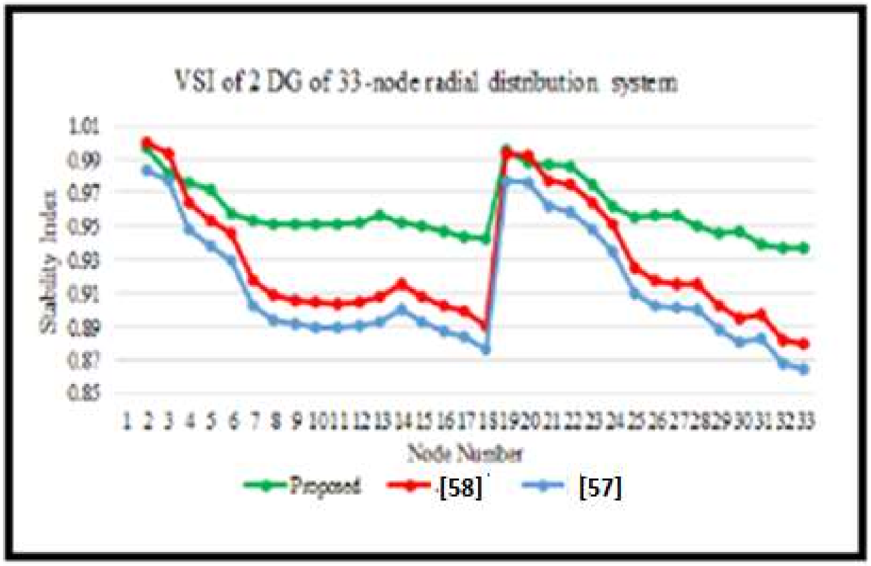
Parameters	**Normal (100%)**			
	Excluding DG	**Including DG Type-1, pf = 1.0)**		
	Base Case	Single DG	Double DG	Triple DG
DG Location (Node Number)	-	6	13, 30	13, 25, 30
DG Size (MW)	-	2.58	0.84, 1.14	0.78, 0.84, 1.12
VSI (Sensitive Node) by proposed method	0.83411 (18)	0.9053 (18)	0.9371 (33)	0.9409 (33)
VSI (Sensitive Node) by [58]	0.6981 (18)	0.8215 (18)	0.8789 (33)	0.8853 (33)
VSI (Sensitive Node) by [57]	0.6867 (18)	0.8080 (18)	0.8645 (33)	0.8707 (33)



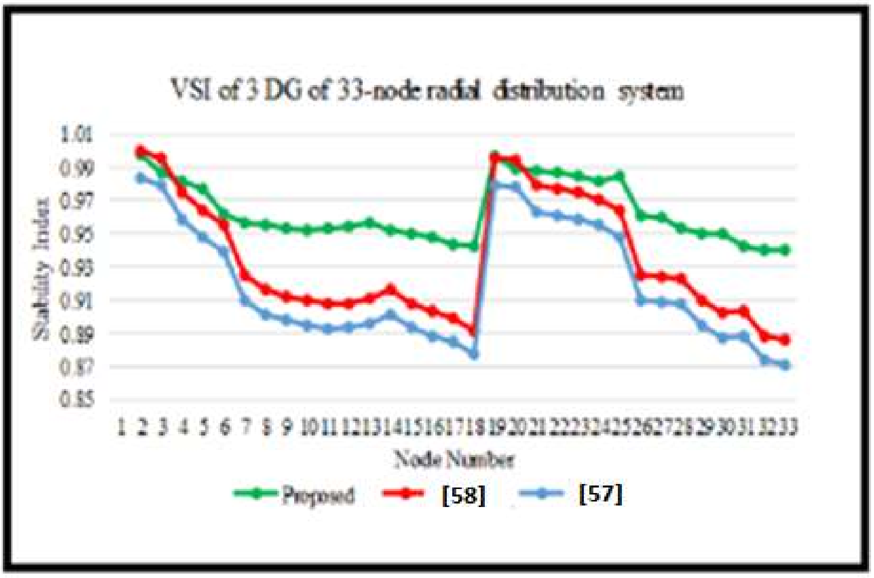
(a) Base Case



(b) Single DG Placement



(c) Double DG Placement



(d) Triple DG Placement

Figure 3.4: VSI of 33-node radial distribution network

3.6.2 Voltage stability Index of 69-node System

The voltage stability index (VSI) of 69-node radial distribution arrangement is computed before and after DG placement in the case of single, double and triple DG for normal load (100%) and the outcomes have been shown in Table 3.3. Figure 3.5 shows the comparison of VSI for triple DG placement.

Table 3.3: Outcomes of 69-node radial distribution network without and with DG placement

Parameters	**Normal Load (100%)**			
	Excluding DG	**Including DG Type-1, pf = 1.0)**		
	Base Case	Single DG	Double DG	Triple DG
DG Location (Node Number)	-	61	18, 61	18, 61, 63
DG Size (MW)	-	1.87	0.51, 1.80	0.52, 1.45, 0.29
VSI (Sensitive Node) by proposed method	0.8278 (65)	0.9381 (27)	0.9596 (65)	0.9605 (65)
VSI (Sensitive Node) by [57]	0.6842 (65)	0.8779 (27)	0.9244 (65)	0.9253 (65)
VSI (Sensitive Node) by [58]	0.6853 (65)	0.8793 (27)	0.9258 (65)	0.9268 (65)

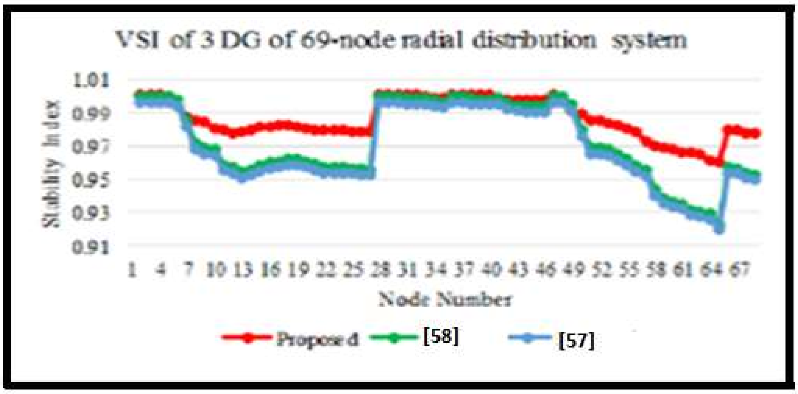


Figure 3.5: VSI of 69-node radial distribution network

3.6.3 Voltage stability Index of 85-node Mesh Distribution System

The voltage stability index of 85-node mesh distribution arrangement is calculated before and after triple DG placement and the outcomes have been shown in Table 3.4. Figure 3.6 shows the VSI values vs node for normal load condition.

Table 3.4: Outcomes of 85-node radial distribution network without and with DG placement

Parameters	Without DG	With DG
Real Power Loss (kW)	286.52	91.25
Reactive Power Loss (kVAr)	180.52	75.45
Minimum Voltage (p.u.)	0.87749 (54)	0.9325 (54)
Number of DGs	-	3
DG Location (Node Number)	-	8, 58, 27
DG Size (MW)	-	2.2 (8), 1.53 (27), 0.16 (58)
DG Type	-	Type 1
VSI (Sensitivity Node) (proposed method)	0.80111 (54)	0.92181 (54)
VSI (Sensitivity Node) [58]	0.69112 (54)	0.87481 (54)
VSI (Sensitivity Node) [57]	0.68423 (54)	0.86591 (54)
Cost of Energy loss ($/kWh)	150594.912	47961
Cost of DG ($/h)	-	78.05

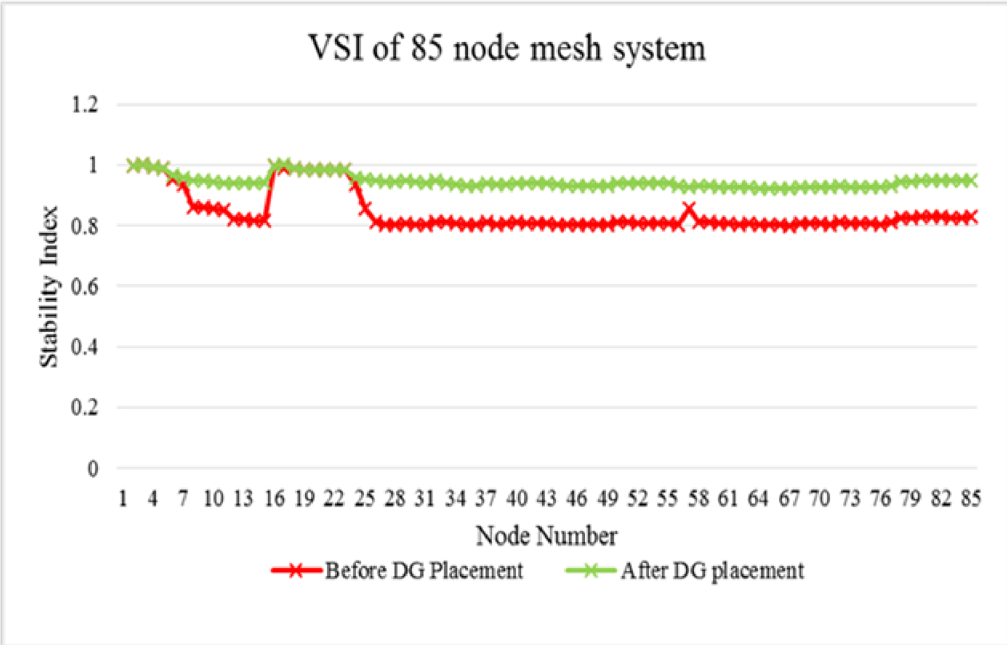


Figure 3.6: VSI of 85-node mesh distribution system

3.7 Conclusion

Voltage stability index of radial and mesh distribution system is obtained by implementing fuzzy logic in the proposed technique. This technique is highly useful to confirm voltage safety of power system by predicting the nearness of voltage collapse with respect to the present load condition. The proposed VSI is compared with existing VSIs [57,58].

CHAPTER-4

RECONFIGURATION AND DG PLACEMENT IN DISTRIBUTION NETWORKS WITH FUZZY LOGIC

4.1 Introduction

Optimal control of distribution systems is an exploration field that has gained expanded consideration recently, simulated by the requirement of industry for an increasingly proficient grid; the so-called smart grid. As utilities are seeking leaner operations through sustained utilization of automated equipment, optimal reconfiguration (OR) of distribution networks is emerging as a technically and economically sound choice. The sense of OR can be understood as follows: Switches are traditionally intended exclusively for protection purposes, for example, to clear faults for protecting the integrity of equipment, or to isolate line sections for protecting workers during scheduled maintenance. Moving forward however, OR suggests the utilization of switches during normal operation to route the transit of power at minimum loss.

The Optimal Feeder Reconfiguration (OFR) issue tries to change the on/off status of these switches, with the end goal of load adjusting or loss minimization subject to the above two requirements, e.g., [64-68]. A review has been given in [69] for some early papers and references to some ongoing work in [70]. The OFR problem is a combinatorial (on/off status of switches) optimization problem with nonlinear constraints (power flow equations) and can generally be NP-hard. Various algorithms have been developed to solve the OFR problems. Following the convention in [70], they roughly fall into two categories: formal methods and heuristic methods.

Reconfiguration of the distributed network is the remodeling of the distributed network to reduce or minimize the problem due to gradual loss, load balancing, etc. Power flow equations developed for radial distribution networks are used to calculate the new power flow in the system power. Flow estimation methods developed for power loss reduction can also be used for load balancing since the two problems are similar. With the impending deregulated environment faced by the electric utility industry and recent advances in technology, several distributed generation (DG) options are fast becoming economically viable in the last two decades, many researches have been carried out to solve DNR problems using different methods. The methods for power loss minimization and voltage strength up gradation are done by the network reconfiguration [70]. Distribution systems are generally configured radially for operative coordination of their protective devices [71]. Two kinds of switches are normally found in the system for both configuration and protection management. These are sectionalizing switches and tie switches [72], by altering the status of the sectionalizing and tie switches, the configuration of distribution structure is varied and loads are relocated among the feeders while the radial configuration layout of electrical supply is still conserved and all load points are not disturbed. Network reconfiguration for loss reduction in distribution systems is a very important way to save energy. The arrangement might be fluctuated by means of changing activities to exchange loads among the feeders [73]. Systems are reconfigured for loss decrease, and to mitigate overloads in the systems, for example for load adjusting [74]. This activity exchanges loads starting with one feeder then onto the next, which will essentially improve the working state of the general network. It is required to reconfigure the system every once in a while, since distribution lines show distinctive attributes as each of the distribution feeders comprises of residential, commercial, industrial, etc. type of load [75]. Nguyen and Pham [76] revealed a procedure dependent on a backtracking seek analysis (BSA) reconfiguration to limit feeder loss. The reconfiguration with distributed generators can only produce the maximum loss reduction. The distributed generators are considered as consistent power sinks and the loss minimization calculation has normal limitations alongside line limit imperative, which restricts the turnaround influence stream of dispersed generators [77]. The system reconfiguration was realized by means of various regularly closed switches (sectionalizing switches) and typically opened switches (tie switches) in a distribution network. First point abridges its effects while the second clarifies some heuristic enhancement methods for taking care of the system reconfiguration issue [78].

If the network reconfiguration and voltage control and reactive power adjustments become routine operations, the operators will not rely only on their criteria and experience to operate the system. It will be necessary to have dedicated software that assists the operator in selecting appropriate control actions. One of these actions is the network reconfiguration that can be oriented to different objectives. Under normal operating conditions, the network is reconfigured to reduce the system's losses and/or to balance load in the feeders. Under conditions of permanent failure, the network is reconfigured to restore the service, minimizing the zones without power [79].

Simulated annealing strategies are proposed for comprehending the system reconfiguration problem in [80] and [81]. Genetic algorithms considering multi objective [82], a fuzzy transformed genetic algorithm [83] and refined genetic algorithms [84] for ideal system setup are published in the writing. Artificial neural system-based strategies [85,86] are utilized for optimizing the distribution network. Advancement based calculations have been created for distribution system reconfiguration [87,88]. Das [89] presented a calculation dependent on the experiential rules and fuzzy multi-target approach for system reconfiguration. These current reconfiguration calculations work with a simplified model of the power network, and they handle voltage and current imperatives around, if by any stretch of the imagination. Then again, the heuristic calculations have the favorable circumstances as far as less calculation time, usability, and pertinence.

4.2 Reconfiguration in distribution networks without DG

Reconfiguration of distribution networks without DG has been performed in different studies taking into two aspects, using the maximum or average load values at all nodes of the system and using load profiles.

4.2.1 Reconfiguration with the use of maximum load

Different reconfiguration methods have been presented like by utilizing heuristic methodologies and network partitioning. Moreover, for solving reconfiguration optimization issue, various procedures have been implemented. GA is implemented where it has an interesting feature, which looks from a population of points and not from a specific particular search so that there is a plausibility of getting an ideal arrangement very quickly. GA has been used solely to find the optimum configuration for reducing the losses. Under normal operating conditions, the network is reconfigured to reduce the system's losses and/or to balance load in the feeders. Under conditions of permanent failure, the network is reconfigured to restore the service, minimizing the zones without power.

Tabu Search (TS) is also functioned for optimal reconfiguration of distribution networks in order to minimize the power loss. TS is a meta-heuristic approach which is superimposed on any other heuristic. The basic approach aims to avoid being trapped in cycles by preventing or penalizing moves which takes the solution in the next iteration to points in the solution space which were previously visited.

4.2.2 Network Reconfiguration using load profiles

Regarding the second facet wherever the load profiles are taking into consideration within the reconfiguration method of distribution network. A linear programming technique as well as an innovative heuristic search technique was given for the comparison. These different strategies are enforced on a large system supported a model of real network. Load summaries for industrial, residential and commercial are used through one year. The results showed that heuristic methodologies in spite of the fact that can give generous reserve funds if legitimately detailed and are reasonable for continuous usage.

The dynamic programming is used to minimize the loss in real distribution networks by reconfiguration. However, that reduction may not be relevant when compared with losses obtained with a fixed topology optimized for maximum or average demand. It has been concluded that it is not positive that a widespread response may be given. Consequently, a specific study should surely be carried out for any given network. Furthermore, three different studies using time varying loads were presented. At the point when the task states of the distribution networks change, the system is reconfigured for two primary purposes [90, 91].

- It can be utilized to adjust the load on each bus in the distribution system, and
- It can help to reduce the complete line power loss (LPL) in the distribution network.

System reconfiguration enables the network to serve a similar load to consumers with reduced power loss on the network lines. It can likewise relieve the overloads in the system, and avert lipid overload. System reconfiguration is a successful method to improve the power quality in the network and upgrade the unwavering quality of the voltage profile.

4.3 Reconfiguration in distribution networks with DG

The integration of DG in power distribution systems will expand the multifaceted nature of the reconfiguration issue. Reconfiguration of distribution systems can be led considering the production profile, load profile, combination of both, constant load or constant generation.

In the present work optimal reconfiguration of typical networks with the existence of DG units will be presented. Different DG technologies are implemented with their generation profiles. Switches at the two ends of each branch have been considered for reconfiguration process to match the reality.

In the proposed method, the distribution network is reconfigured to find the best configuration with the target work minimization of power loss as well as load balancing index to satisfy operating constraints like radial structure of the system, the current capacity of the feeder and voltage profile and simultaneously with DG placement.

4.3.1 Power Loss Minimization

The loss of power linking buses among k and k+1 afterwards network reconfiguration can be calculated by using Equation (4.1).

$$P'_{Loss}(k,k+1) = \frac{R_k}{\left|V'_k\right|^2}\left(P'^2_k + Q'^2_k\right) \tag{4.1}$$

Therefore, the total power loss for all feeders can be demonstrated through summing the loss of power in entire lines of the network taking n number of branches, which is specified by Equation (4.2).

$$P'_{Total\ Loss} = \sum_{k=1}^{n} P'_{Loss}(k,k+1) \tag{4.2}$$

The net power loss reduction of the system is the difference of power losses before and after reconfiguration of network, which is given by Equation (4.3).

$$\Delta P^R_{Loss} = \sum_{k=1}^{n} P_{Total\ Loss}(k,k+1) - \sum_{k=1}^{n} P'_{Total\ Loss}(k,k+1) \tag{4.3}$$

Where P'_k is the real power of bus k after reconfiguration of network,

V'_k is the voltage at bus k after reconfiguration of network,

Q'_k is the reactive power of bus k after reconfiguration of network,

R_k is the resistance between k and k+1,

$P_{Loss}(k,k+1)$ is the losses in line connecting k and k+1,

$P_{Total\,Loss}(k,k+1)$ is the total loss of feeder before reconfiguration of network, and

$P'_{Total\,Loss}(k,k+1)$ is the total loss of feeder after reconfiguration of network.

4.3.2 Load Balancing Index

Load Balancing Index (LBI) represents degree of loading among feeders. A compelling technique to build the loading edge of heavily loaded feeders is to exchange part of their loads to lightly loaded feeders. Equation (4.4) gives the feeder load balancing index.

$$LBI = \sum_{k \in B} \left(\frac{|I_{k,r}|}{I_k^{\max}} \right)^2 \tag{4.4}$$

Where B is the set of network branches establishing loops,

L_k is the length of branch *k,*

$I_{k,r}$ is the current capacity of branch *k* for feeder reconfiguration pattern *r and*

$I_k^{\max}$ is the extreme current capacity of branch *k*

4.3.3 Radial Structure of System

The final structure of the network after reconfiguration must be radial. In order to examine the network, the graph theory is applied. Consider *"A"* is the bus incidence matrix, which specifies that the network is not in radial structure when its determinant matrix is equal to zero. The network is in radial when it satisfies the condition represented by Equation (4.5).

$$\det(A) = 1 \ or \ -1 \tag{4.5}$$

4.3.4 Loss Reduction Using DG Installation

Allocation of optimal sized DG in appropriate node results in reduction of losses of the system, voltage profile improvement, reduced impacts on environment, overall energy efficiency increases, and deferred investments to upgrade existing generation, transmission, and distribution networks. The loss when DG installed in the network is given by Equation (4.6).

$$P_{Loss}^{DG} = \frac{R_k}{V_k^2}\left(P_k^2 + Q_k^2\right) + \frac{R_k}{V_k^2}\left(P_g^2 + Q_k^2 - 2P_kP_g - 2Q_kQ_g\right) \tag{4.6}$$

Therefore, the net power deficit decrease of the system is the distinction of intensity shortfall when DG allocation is given by Equation (4.7).

$$\Delta P_{Loss}^{DG} = \frac{R_k}{V_k^2}\left(P_g^2 + Q_g^2 - 2P_kP_g - 2Q_kQ_g\right) \tag{4.7}$$

Here, the positive value indicates that system losses reduces with DG allocation and the negative value indicates that DG introduces higher system losses.

4.3.5 Formation of Objective Function

The objective for the problem is formulated in order to get maximum reduction of power loss in distributed systems which is sum of reduction of power losses due to reconfiguration and integration of distributed generation units. The objective is formulated which is given by Equation (4.8).

$$\text{Objective Function, F} = \max\left(\Delta P_{Loss}^{R} + \frac{1}{LBI} + \Delta P_{Loss}^{DG}\right) \tag{4.8}$$

$$\text{Subjected to} \quad \begin{aligned} & V_{\min} \le |V_k| \le V_{\max} \\ & |I_{k,k+1}| \le |I_{k,k+1,\max}| \\ & \sum_{k=1}^{n} P_G \le \sum_{k=1}^{n}\left(P_k + P_{Loss,k}\right) \end{aligned} \tag{4.9}$$

Once the objective function is formulated the next step is to utilize the objective function in the optimization algorithm, but before that we need to find the location of DG, which is given in the next section.

4.4 Hybrid ABC-CS algorithm in reconfiguring the network and DGs Placement

A hybrid artificial bee colony and cuckoo search (ABC-CS) procedure is utilized for reconfiguring the distribution network based on power loss minimization and load balancing index to satisfy operating constraints like voltage profile, current capacity of feeder, and radial structure of system. The details of ABC-CS algorithm have been discussed in Chapter-1.

Figure 4.1 presents the flow chart of the proposed reconfiguration method.

4.5 Results of Network Reconfiguration with and without DGs

The results for the network reconfiguration with and without DGs by means of hybrid ABC-CS algorithm for the three test systems are represented below for four different cases. Case 1 is the base case, Case 2 is after reconfiguration of the base network, Case 3 is after integration of three DGs to base network and Case 4 is after integration of three DGs to the network obtained in case 2.

4.5.1 Simulation Results for Test System A (33-node)

The experimental results for the test system A (33-node) is given in this section. The details of this system data are given in Appendix-A. Table 4.1 shows the outcomes for four different cases.

From Table 4.1, it can be observed that the losses of the system are 202.32 kW, 100.15 kW, 63.30 kW and 49.15 kW respectively for the cases 1, 2, 3, and 4. This shows that, the loss of power decrease is very high in the case 4 i.e., simultaneous reconfiguration and DG placement, which shows the performance and advantage in the presented technique than the other cases. In Table 4.1, the development in the voltage profile and reduction of loss for case 4 are higher than the case 2 and 3. This shows that only reconfiguration or only DG installation does not produce the desired results of maximizing power loss reduction and voltage profile improvement. The improvement in least voltages (node number) of the system for case 1, case 2, case 3 and case 4 are 0.9136 (18), 0.9788 (16), 0.9788 (30) and 0.9894 (28) respectively. From this, it can be seen that development in least voltage of the network for case 4 is the highest.

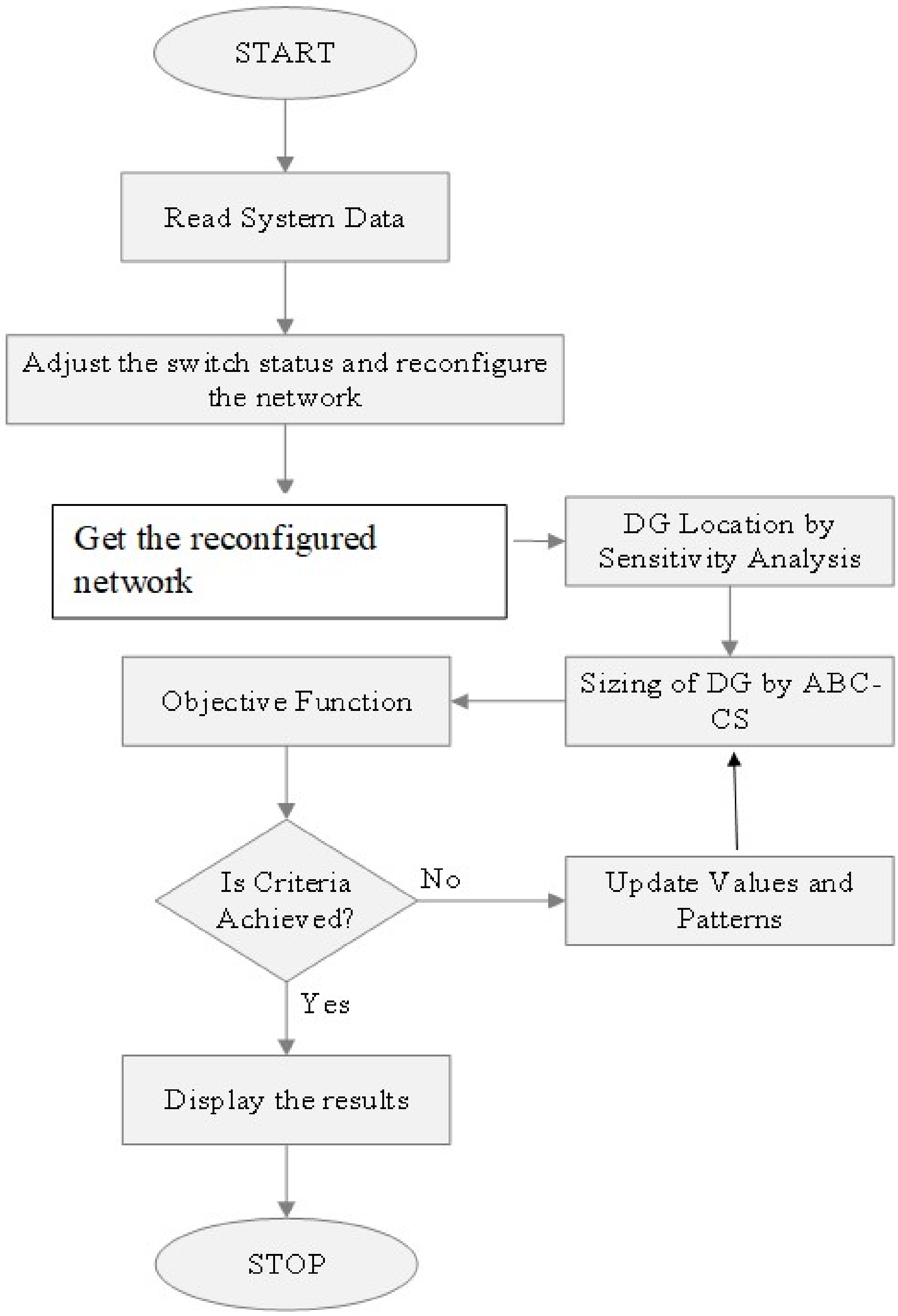


Figure 4.1: Flow chart of the proposed method

Table 4.1: Outcomes of the Network Reconfiguration for Test System A

Parameters	Different Cases			
	Case 1	Case 2	Case 3	Case 4
Switches Opened	33, 34, 35, 36, 37	13, 19, 21, 24, 30	33, 34, 35, 36, 37	13, 19, 21, 24, 30
Power Loss (kW)	202.32	100.15	63.3	49.15
Minimum Voltage (p.u.)	0.9136 (18)	0.9443 (16)	0.9788 (30)	0.9894 (28)
VSI	0.8341 (18)	0.9211 (16)	0.9409 (33)	0.9678 (28)
Number of DGs	-	-	3	3
DG Location	-	-	8, 13, 30	10, 19, 27
DG Size (MW)	-	-	1.15 (8),0.8 (13) 0.97 (30)	0.37 (10), 1.18 (19), 0.98 (27)
Annual Cost of Energy Loss ($/kWh)	106339.392	52638.84	33270.48	25833.24
Cost of DG ($/h)	-	-	58.65	50.85

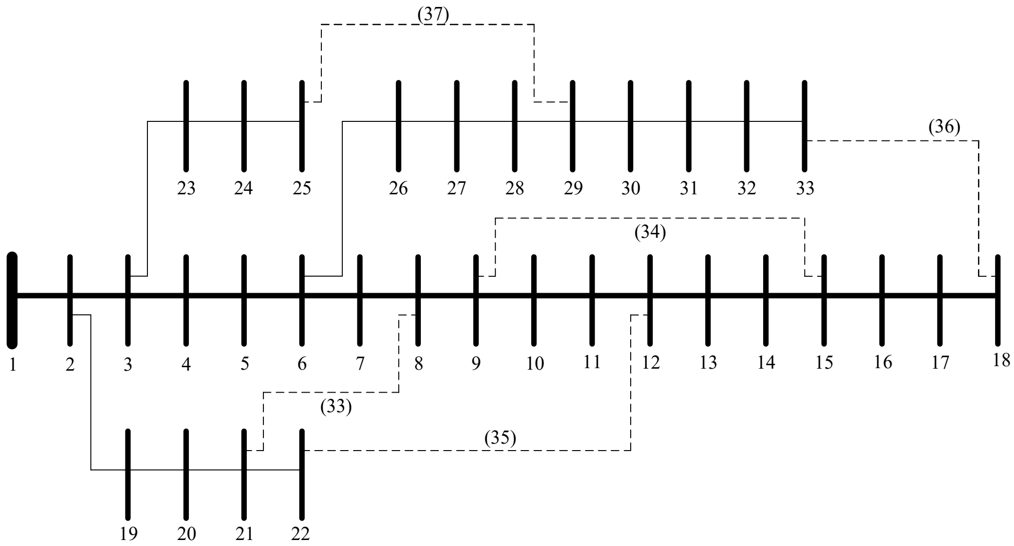


Figure 4.2 : Base Configuration of Test System A (Case 1)

The reconfigured network obtained for case 2 from base network shown in Figure 4.2 is depicted in Figure 4.3. Figure 4.4 shows the three DG placement in the base network. Figure 4.5 shows the three DG placement in the network obtained in case 2.

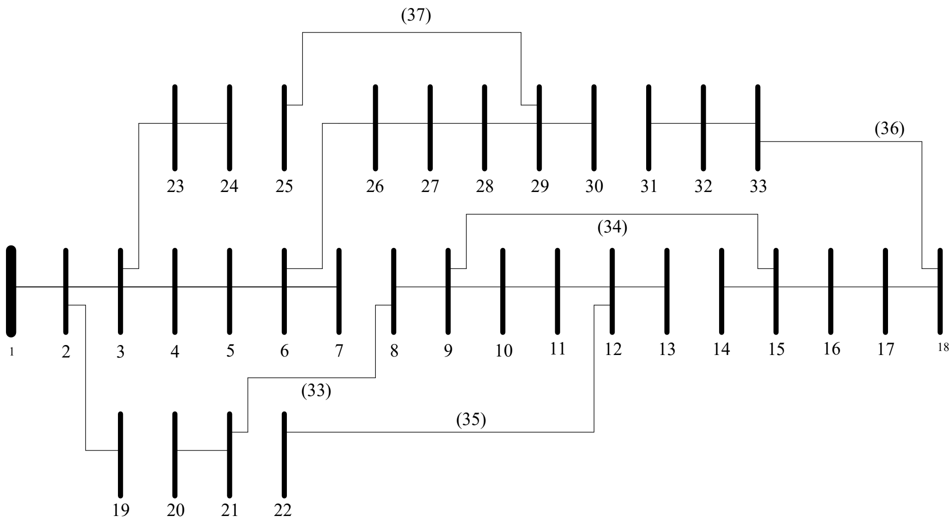


Figure 4.3 : Reconfigured Network for Test System A (Case 2)

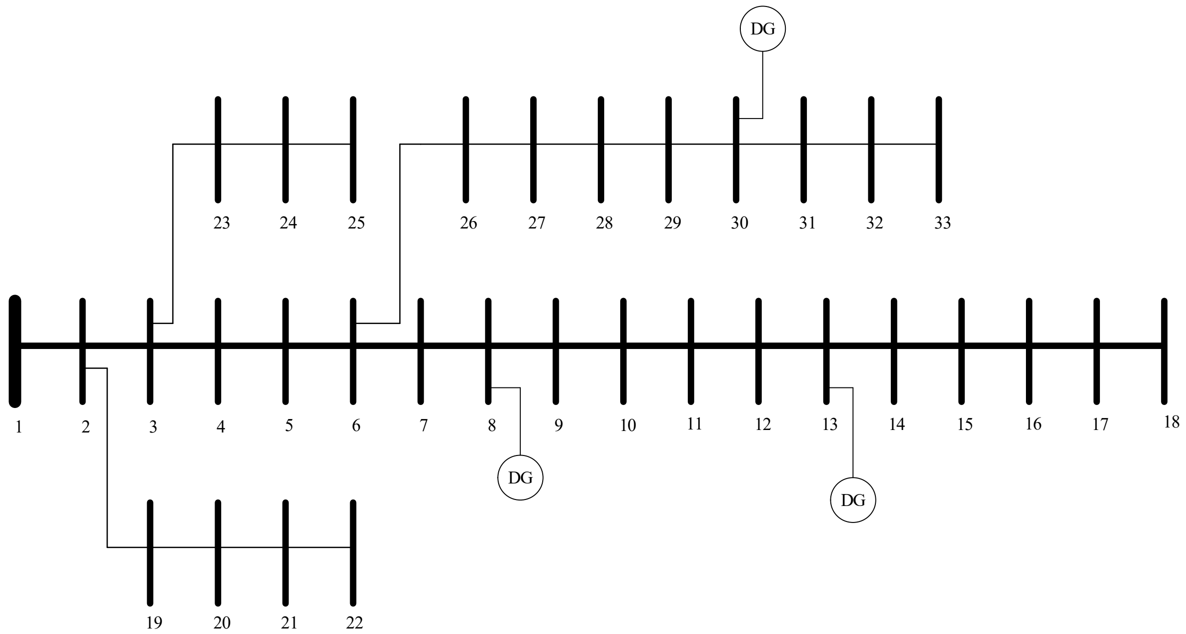


Figure 4.4 : DG Placement for Test System A (Case 3)

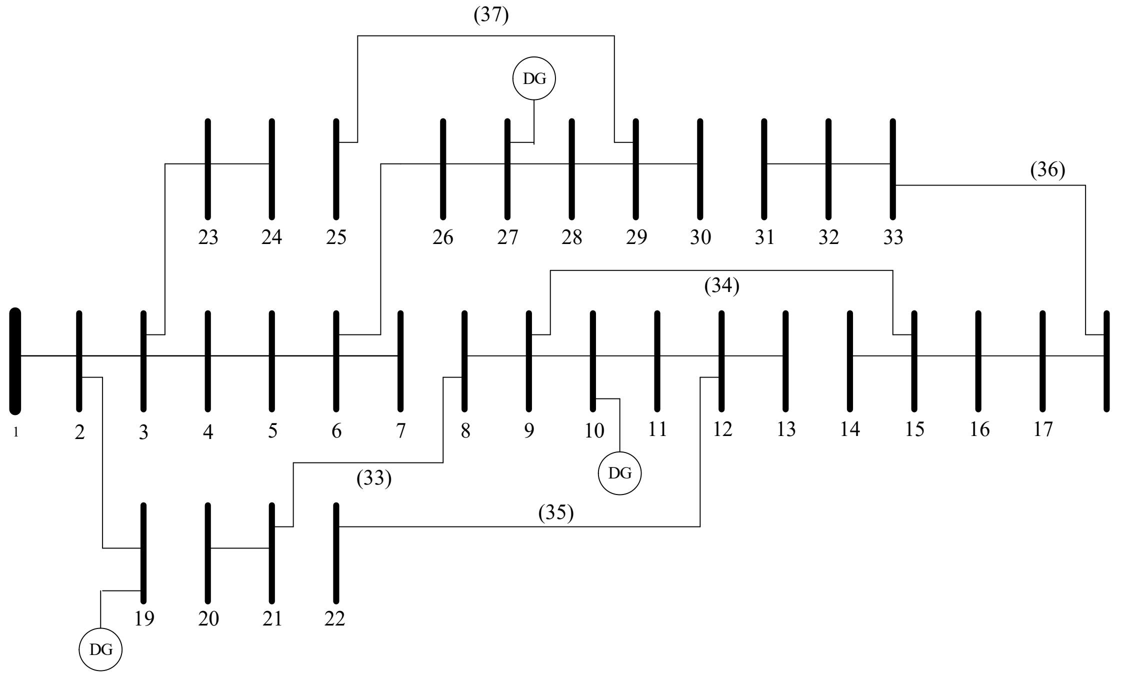


Figure 4.5 : Simultaneous DG placement and network reconfiguration for Test System A (Case 4)

The voltage profile curves for the four cases are shown in Figure 4.6.

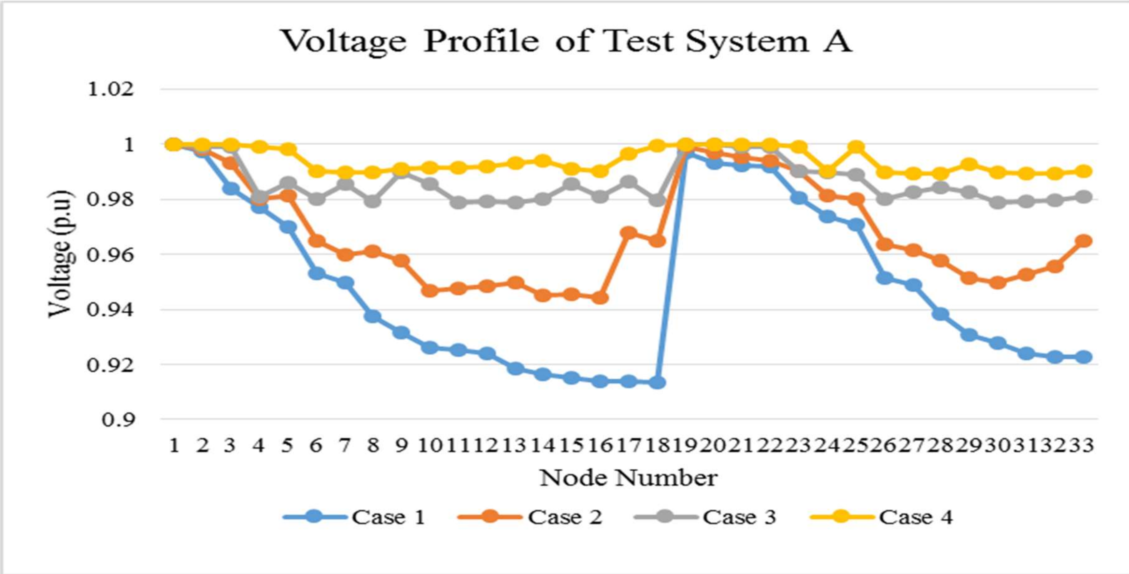


Figure 4.6 : Voltage Profile for Test System A

From Figure 4.6, the voltage profile of case 4 is better than other cases (Case 2 and Case 3).

4.5.2 Simulation Results for Test System B (69-Node)

Like test networks A, this test network is additionally considered for four cases and results are exhibited in the Table 4.2. The cutoff points of DG unit sizes picked for establishment at competitor bus areas are same as test network A. The trial results for the test network B is presented in this segment.

Table 4.2: Outcomes of the network configuration for Test System B

Parameters	**Different Cases**			
	Case 1	**Case 2**	**Case 3**	**Case 4**
Switches Opened	69, 70, 71, 72, 73	14, 58, 69, 70, 73	69, 70, 71, 72, 73	14, 58, 69, 70, 73
Power Loss (kW)	224.94	145.68	68.10	40.47
Minimum Voltage (p.u.)	0.9019 (65)	0.9543 (40)	0.9812 (61)	0.9852 (61)
VSI	0.8278 (65)	0.9371 (40)	0.9605 (65)	0.9712 (61)
Number of DGs	-	-	3	3
DG Location (Node Number)	-	-	18, 47, 63	58, 60, 27
DG Size (MW)	-	-	0.42 (18), 1.57 (47), 0.3 (63)	1.5 (58), 0.3 (60), 0.5 (27)
Annual Cost of Energy Loss ($/kWh)	118260	76569.41	35793.36	21271.032
Cost of DG ($/h)	-	-	46.05	46.25

From Table 4.2, it can be observed that is power loss is reduced from 225 kW to 40.47 kW using cases 2, 3, and 4. This shows that, the power loss reduction is very high in the case 4 i.e. simultaneous reconfiguration and DG placement, which shows the performance and superiority of the proposed method over other cases. From Table 4.2, the improvement in loss reduction and voltage profile for case 4 are higher than case 2 and 3 and this shows that only reconfiguration or only DG installation does not produce the desired results of maximizing power loss reduction and voltage profile improvement. The improvement in minimum voltage of the network for case 1, case 2, case 3 and case 4 is 0.9019 (36),0.9543, 0.9812 and 0.9852, respectively. From this, it can be seen that improvement in minimum voltage of the network for case 4 is highest.

The base network configuration is shown in Figure 4.7 in which dashed line indicates tie switches. The reconfigured network obtained for case 2 from base network shown in Figure 4.7 is depicted in Figure 4.8. Figure 4.9 shows the three DG placement in the base network. Figure 4.10 shows the three DG placement in the network obtained in case 2.

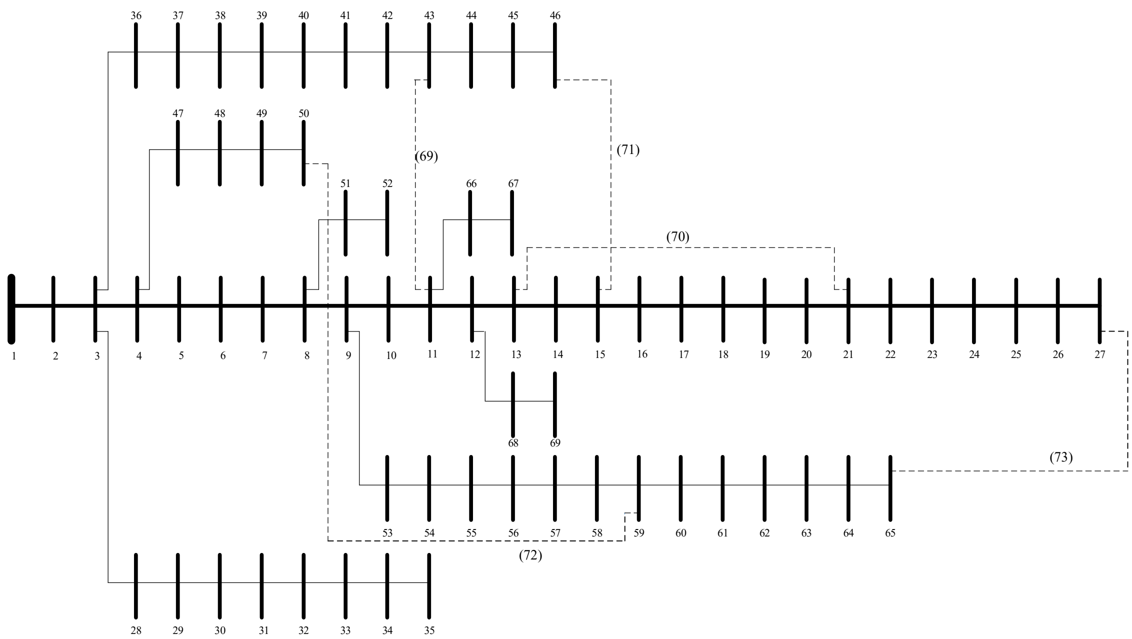


Figure 4.7 : Base Configuration for Test System B (Case 1)

The reconfigured network is depicted as in Figure 4.10 in which opened switches are 13, 56, 69, 70, and 73.

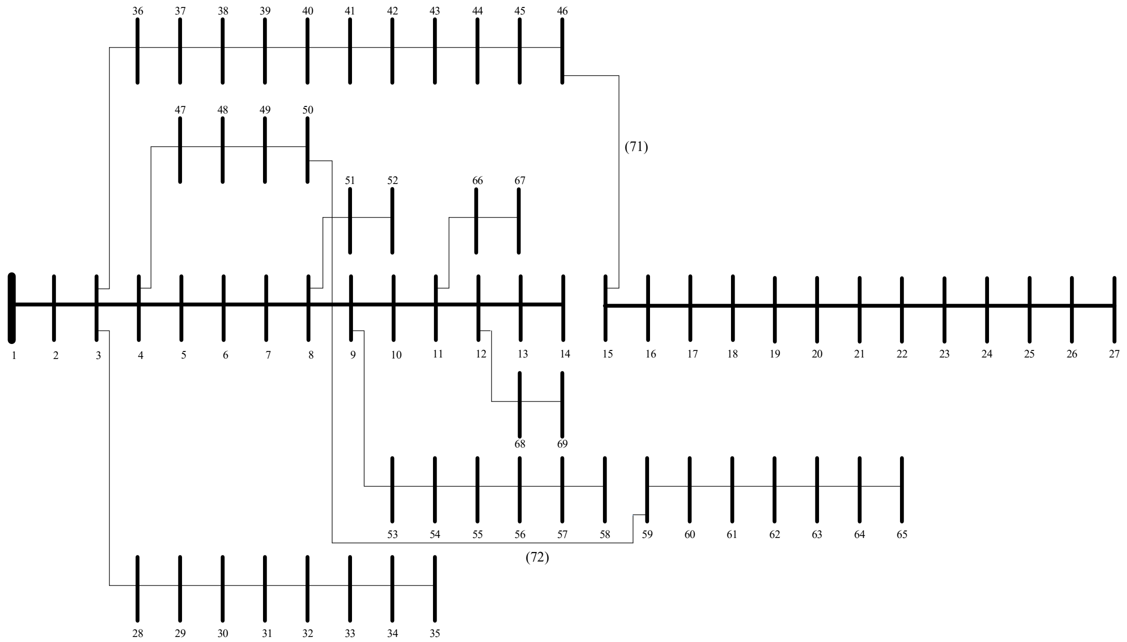


Figure 4.8 : Reconfigured Network of Test System B (Case 2)

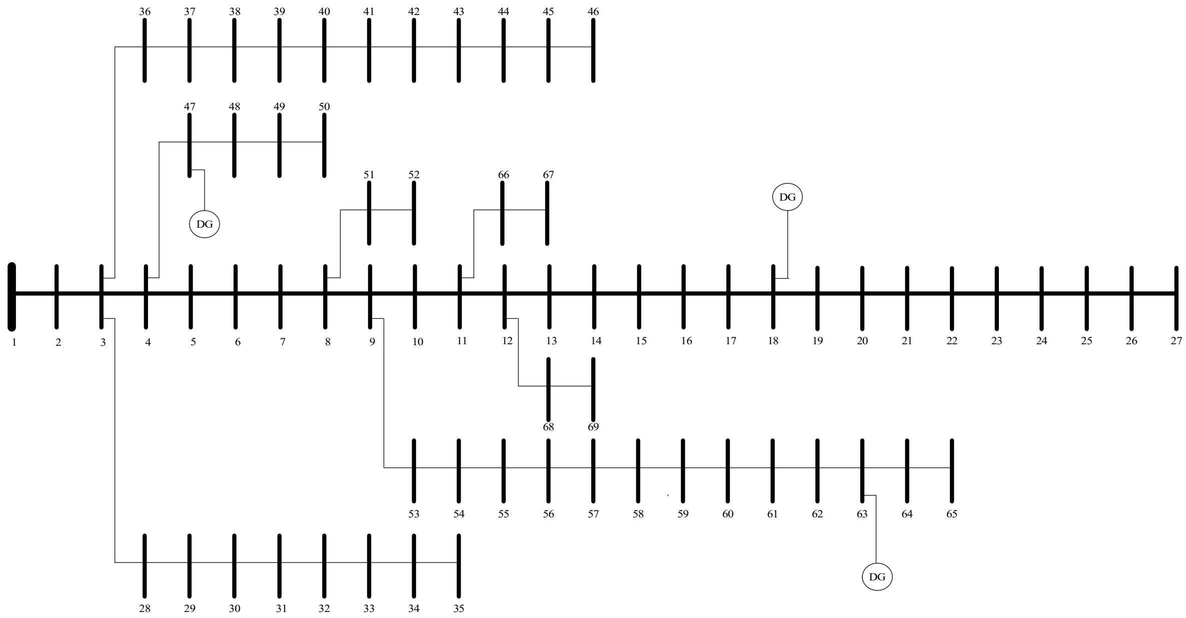


Figure 4.9 : DG placement for Test System B(case 3)

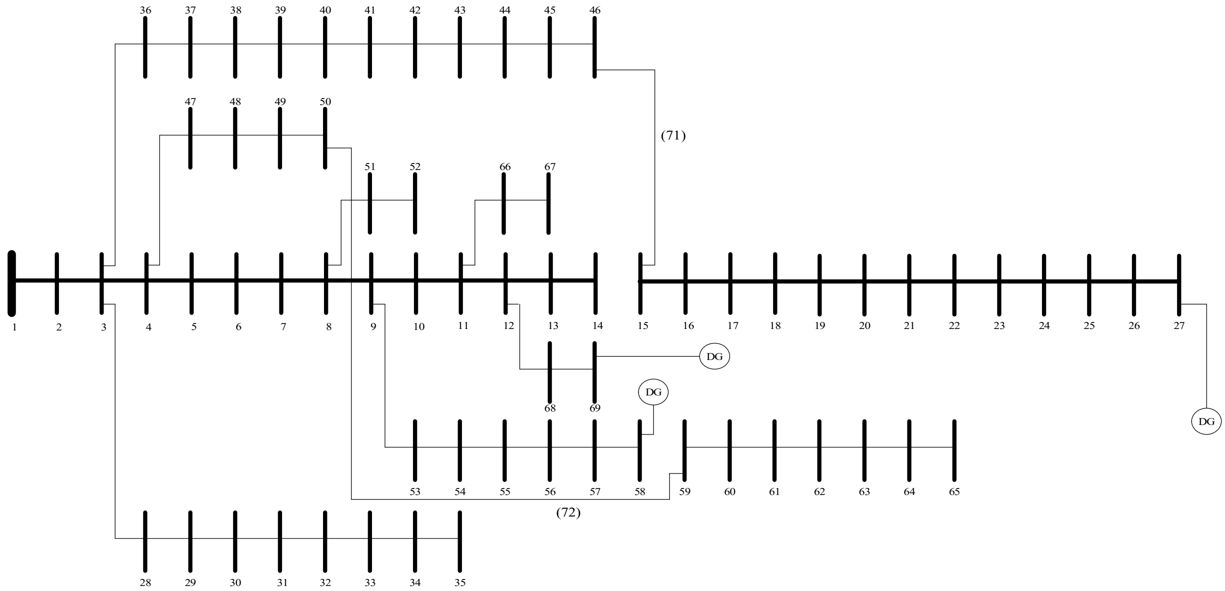


Figure 4.10 : Simultaneous DG placement and network configuration for Test System B (case 4)

Table 4.2 shows that the voltage profile of case 4 i.e., DG placement in reconfigured network is better than other cases.

4.5.3 Experimental Results for Test System C (83-Node)

Test system C is a 83-node practical distribution network [5] of Taiwan Power Company shown in Figure 4.11, which consists of 83 sectionalizing and 13 tie switches. The base kV is 11.4. The system data are given in **Appendix-D**. The total system load is 28.35 + j 20.7 MVA.

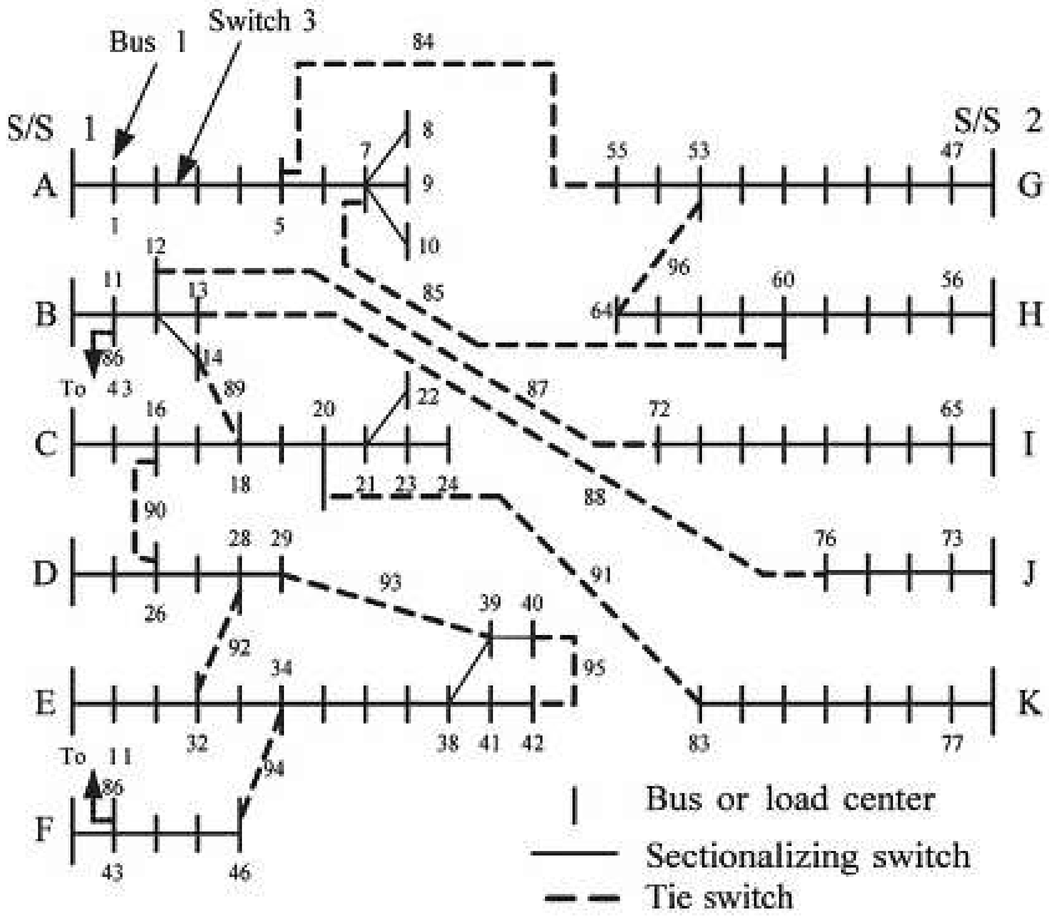


Figure 4.11 : 83-node practical distribution network (Test System C)

Similar to test systems A and B this test system is also simulated for four cases and results are presented in the Table 4.3.

Table 4.3 : Outcomes of network configuration of System C

Parameters	**Different Cases**			
	Case 1	**Case 2**	**Case 3**	**Case 4**
Switches Opened	84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96	6, 13, 34, 41, 55, 58, 63, 72, 83, 86, 89, 90, 92	84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96	6, 13, 34, 41, 55, 58, 63, 72, 83, 86, 89, 90, 92
Power Loss (kW)	531.995	461.14	321.73	202.58
Minimum Voltage (p.u.)	0.9285 (9)	0.9549 (71)	0.9833 (9)	0.9878 (71)
VSI	0.8643 (9)	0.9246 (71)	0.9381 (9)	0.9578 (71)
Number of DGs	-	-	6	6
DG Location (Node Number)	-	-	6, 9, 24, 45, 79, 83	8, 9, 28, 71, 79, 81
DG Size (MW)	-	-	2.2, 1.10, 1.8, 2.01, 0.7, 0.9	1.16, 2.1, 0.65, 2.15, 0.65, 1.3
Cost of Energy Loss ($/kWh)	279616.572	239221.584	169101.288	106476.048
Cost of DG ($/h)	-	-	174.45	160.45
Number of Iterations	-	28	36	41
CPU Time (Sec.)	-	19.89	29.15	36.38

From Table 4.3, it can be observed that the loss is reduced from 531.995 kW to 202.58 kW using case 4 alone. This shows that, the power loss reduction is very high in the case 4 i.e., simultaneous reconfiguration and DG placement, which shows the performance and superiority of the proposed method over other cases. From Table 4.3, the improvement in loss reduction and voltage profile for case 4 are higher than the case 2 and case 3. This shows that only reconfiguration or only DG installation does not produce desired results of maximizing power loss reduction and voltage profile improvement. The improvement in minimum voltage of the network for case 2 to 4 is 0.9549, 0.9833 and 0.9878, respectively. From this, it can be observed that improvement in minimum voltage of the network for case 4 is maximum.

From the results obtained for two test systems A, B and C, it can be concluded that reduction of loss and enhancement of voltage profile is significant for case 4 compared with other two cases. This shows the efficacy of the suggested method.

4.6 Comparison Results of base case and after DG placement of Proposed Work with Existing Works

The comparison of the proposed method with other existing method is shown in Table 4.4 and 4.5 separately for both Test systems A and B.

Table 4.4 and Table 4.5 show that the proposed method has achieved better results in each and every aspect like power loss reduction as well the voltage profile improvement from the detailed results given in the section shows that proposed simultaneous reconfiguration with DG placement using hybrid ABC-CS algorithm is the best method for radial distribution network.

Table 4.4: Performance Comparison with Existing Methods for Test System A

Different Cases	Parameters	Proposed Method	[27]	[28]	[29]
Case 2	Switches Opened	**13, 19, 21, 24, 30**	7, 14, 9, 32, 28	28, 20, 17, 10, 14	7,10, 13, 17, 37
	Power Loss (kW)	**100.15**	139.98	136.19	125.2
	Min. Voltage (p.u.)	**0.9443**	0.9413	0.9380	-
Case 3	DG Size (MW)	**2.92**	1.7937	2.825	2.965
	Power Loss (kW)	**63.3**	88.68	97.65	112.8
	Min. Voltage (p.u.)	**0.9788**	0.9680	0.9529	-
Case 4	Switches Opened	**13, 19, 21, 24, 30**	7, 14, 11, 32, 28	7, 9, 14, 32, 37	7, 9, 13, 16, 37
	DG Size (MW)	**2.53**	1.6841	2.942	2.9
	Power Loss (kW)	**49.15**	67.11	44.28	97.3
	Min. Voltage (p.u.)	**0.9894**	0.9713	0.9701	-

Table 4.5: Performance Comparison with Existing Methods for Test System B

Different Cases	Parameters	Proposed Method	[27]	[29]
Case 2	Switches Opened	**14, 58, 67, 70, 73**	69, 70, 14, 56, 61	9, 17, 24, 43, 55
	Power Loss (kW)	**145.68**	98.59	96.3
	Min. Voltage (p.u.)	**0.9543**	0.9495	-
Case 3	DG Size (MW)	**2.29**	1.8329	2.9254
	Power Loss (kW)	**68.10**	77.85	85.6
	Min. Voltage (p.u.)	**0.9812**	0.9740	-
Case 4	Switches Opened	**14, 58, 69, 70, 73**	69, 70, 14, 56, 61	12, 17, 55, 64, 69
	DG Size (MW)	**2.3**	1.3584	2.973
	Power Loss (kW)	**40.47**	43.88	69.5
	Min. Voltage (p.u.)	**0.9852**	0.9720	-

4.7 Conclusion

Reconfiguration of distribution network utilized a new methodology in the proposed method for simultaneous reconfiguration and installation of DG. The performance evaluation of the proposed method have been carried out using the three cases like only network reconfiguration, only DG installation, simultaneous reconfiguration and DG installation. Compared to the available methods, the proposed method gives **better loss reduction**, ease-of-use, and applicability.

CHAPTER-5

CONCLUSION AND FUTURE SCOPE OF WORKS

5.1 Conclusion

The proposed methodology in the first work grants the effective analysis of voltage stability, making use of Fuzzy-PSO and does acceptably on power distribution systems under all likely conditions such as load flow and line compensation. From load-flow solution most optimal sizes of DG are illustrated via ABC-CS. The DG unit location is the principal reasons for arranging as well as task to electric radial distribution networks. These investigations allow another deterministic technique that decides ideal location for DG arrangement. The technique proved that it can save massive quantity of power and reap significant growth in voltage stability. This planned procedure has been analyzed in the 33-node, 69-node and 85-node distribution networks. The proposed method gives better outcomes compared to the other existing methods.

In the second work, a new VSI index for voltage stability analysis of the distribution network has been proposed. The proposed VSI gives better results compared to the two existing indices. The VSI values before and after DG placement have been computed using the 33-node, 69-node and 85-node distribution networks.

In the third work, an innovative methodology has been presented to reconfigure as well as installation of DG instantaneously within distribution system. Moreover, the proposed method has been executed on three cases like only network reconfiguration of base network, integration of DG only in base network, integration of DG in reconfigured network. The analysis of sensitive nodes has been utilized for calculating applicant positions of DG placement. An efficient Hybrid ABC-CS procedure has utilized for optimization procedure in installation of DG and network reconfiguration. This planned procedure has been analyzed in the 33-node, 69-node and 83-node distribution networks. Outcomes showed that this simultaneous placement in DG and network reconfiguration methodology remains increasingly successful as it reducing power loss as well as enhancing the voltage profile analyzed with different methodologies.

5.2 Future Scope of Works

- The network reconfiguration as well as the optimum sizing of the DGs can be done with other artificial intelligence-based techniques.
- For saving the power loss of the systems other elements such as voltage regulators can also be incorporated and analysed.
- The proposed work can also be extended to unbalanced distribution systems as well.

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Appendix-A

Table A1: Line Data of 33-node Radial Distribution Network

Branch No.	Sending end	Receiving end	R(Ω)	X(Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.2511
3	3	4	0.3660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.707
6	6	7	0.1872	0.6188
7	7	8	0.7114	0.2351
8	8	9	1.0300	0.7400
9	9	10	1.0040	0.7400
10	10	11	0.1996	0.0650
11	11	12	0.3744	0.1238
12	12	13	1.4680	1.1550
13	13	14	0.5416	0.7129
14	14	15	0.5910	0.5260
15	15	16	0.7463	0.5450
16	16	17	1.2890	1.7210
17	17	18	0.7320	0.5740
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.8980	0.7091
24	24	25	0.8960	0.7011
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630
31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302

Table A2: Load Data of 33-Node Radial Distribution Network

Node Number	PL (kW)	QL(kVAr)
1(S/S)	0	0
2	100	60
3	90	40
4	120	80
5	60	30
6	60	20
7	200	100
8	200	100
9	60	20
10	60	20
11	45	30
12	60	35
13	60	35
14	120	80
15	60	10
16	60	20
17	60	20
18	90	40
19	90	40
20	90	40
21	90	40
22	90	40
23	90	50
24	420	200
25	420	200
26	60	25
27	60	25
28	60	20
29	120	70
30	200	600
31	150	70
32	210	100
33	60	40

Appendix-B

Table B1 : Line Data of 69-node bus system

Branch Number	Sending end node	Receiving end node	R (Ω)	X (Ω)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0251	0.0294
5	5	6	0.3660	0.1864
6	6	7	0.3811	0.1941
7	7	8	0.0922	0.0470
8	8	9	0.0493	0.0251
9	9	10	0.8190	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.0300	0.3400
13	13	14	1.0440	0.3450
14	14	15	1.0580	0.3496
15	15	16	0.1966	0.0650
16	16	17	0.3744	0.1238
17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.0690
20	20	21	0.3416	0.1129
21	21	22	0.0140	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021

26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.0640	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.3510	0.1160
32	32	33	0.8390	0.2816
33	33	34	1.7080	0.5646
34	34	35	1.4740	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.0640	0.1565
37	37	38	0.1053	0.1230
38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509
41	41	42	0.3100	0.3623
42	42	43	0.0410	0.0478
43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0.0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.1114
52	9	53	0.1740	0.0886
53	53	54	0.2030	0.1034
54	54	55	0.2842	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.5900	0.5337
57	57	58	0.7837	0.2630

58	58	59	0.3042	0.1006
59	59	60	0.3861	0.1172
60	60	61	0.5075	0.2585
61	61	62	0.0974	0.0496
62	62	63	0.1450	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.0410	0.5302
65	11	66	0.2012	0.0611
66	66	67	0.0047	0.0014
67	12	68	0.7394	0.2444
68	68	69	0.0047	0.0016
Tie line				
69	11	43	0.5000	0.50000
70	13	21	0.5000	0.50000
71	15	46	1.0000	0.50000
72	50	59	2.0000	1.0000
73	27	65	1.0000	0.50000

Table B2: Load Data of 69-node radial distribution network

Node Number	**P_L (kW)**	**Q_L (kVAr)**	**Node Number**	**P_L (kW)**	**Q_L (kVAr)**
6	2.60	2.20	37	26.00	18.55
7	040.40	30.00	39	24.00	17.00
8	075.00	54.00	40	24.00	17.00
9	030.00	22.00	41	1.20	1.00
10	028.00	19.00	43	6.00	4.30
11	145.00	104.00	45	39.22	26.30
12	145.00	104.00	46	39.22	26.30
13	8.00	5.00	48	79.00	56.40
14	8.00	5.00	49	384.70	274.50
16	45.50	30.00	50	384.70	274.50
17	60.00	35.00	51	40.50	28.30
18	60.00	35.00	52	3.60	2.70
20	1.00	0.60	53	4.35	3.50
21	114.00	81.00	54	26.40	19.00
22	5.00	3.50	55	24.00	17.20
24	28.00	20.00	59	100.00	72.00
26	14.00	10.00	61	1244.00	888.00
27	14.00	10.00	62	32.00	23.00
28	26.00	18.60	64	227.00	162.00
29	14.00	18.60	65	59.00	42.00
33	14.00	10.00	66	18.00	13.00
34	19.50	14.00	67	18.00	13.00
35	6.00	4.00	68	28.00	20.00
36	26.00	18.55	69	28.00	20.00

Appendix-C

Table C1: Line data of 85-node mesh distribution system

Branch No.	Sending end node	Receiving end node	R (Ω)	X (Ω)
1	1	2	0.108	0.075
2	2	3	0.163	0.112
3	3	4	0.217	0.149
4	4	5	0.108	0.74
5	5	6	0.435	0.298
6	6	7	0.272	0.186
7	7	8	1.197	0.820
8	8	9	0.108	0.074
9	9	10	0.59	0.410
10	10	11	0.544	0.373
11	11	12	0.544	0.373
12	12	13	0.598	0.410
13	13	14	0.272	0.186
14	14	15	0.326	0.223
15	2	16	0.728	0.302
16	3	17	0.455	0.189

Branch No.	**Sending end node**	**Receiving end node**	**R (Ω)**	**X (Ω)**
17	5	18	0.820	0.340
18	18	19	0.637	0.264
19	19	20	0.455	0.189
20	20	21	0.819	0.340
21	21	22	1.548	0.642
22	19	23	0.182	0.075
23	7	24	0.910	0.378
24	8	25	0.455	0.189
25	25	26	0.364	0.151
26	26	27	0.546	0.226
27	27	28	0.273	0.113
28	28	29	0.546	0.226
29	29	30	0.546	0.226
30	30	31	0.273	0.113
31	31	32	0.182	0.075
32	32	33	0.182	0.075
33	33	34	0.819	0.340
34	34	35	0.637	0.264
35	35	36	0.182	0.075

Branch No.	Sending end node	Receiving end node	R (Ω)	X (Ω)
36	26	37	0.364	0.151
37	27	38	1.002	0.416
38	29	39	0.546	0.226
39	32	40	0.455	0.189
40	40	41	1.002	0.416
41	41	42	0.273	0.113
42	41	43	0.455	o.189
43	34	44	1.002	0.416
44	44	45	0.911	0.378
45	45	46	0.911	0.378
46	46	47	0.546	0.226
47	35	48	0.637	0.264
48	48	49	0.182	0.075
49	49	50	0.364	0.151
50	50	51	0.455	0.189
51	48	52	1.366	0.567
52	52	53	0.455	0.189
53	52	54	0.546	0.226
54	52	55	0.546	0.226

Branch No.	**Sending end node**	**Receiving end node**	**R (Ω)**	**X (Ω)**
55	49	56	0,546	0.226
56	9	57	0.273	0.113
57	57	58	0.819	0.340
58	58	59	0.128	0.075
59	58	60	0.546	0.226
60	60	61	0.728	0.302
61	61	62	1.002	0.415
62	60	63	0.182	0.075
63	63	64	0.728	0.302
64	64	65	0.182	0.075
65	65	66	0.182	0.075
66	64	67	0.455	0.189
67	67	68	0.910	0.378
68	68	69	1.092	0.453
69	69	70	0.455	0.189
70	70	71	0.546	0.226
71	67	72	0.182	0.075
72	68	73	1.184	0.49?
73	73	74	0.273	0.113

Branch No.	Sending end node	Receiving end node	R (Ω)	X (Ω)
74	73	75	1.002	0.416
75	70	76	0.546	0.226
76	65	77	0.091	0.037
77	10	78	0.637	0.264
78	67	79	0.546	0.226
79	12	80	0.728	0.302
80	80	81	0.364	0.151
81	81	82	0.091	0.037
82	81	83	1.092	0.453
83	83	84	1.002	0.416
84	13	85	0.819	0.340

Table C2. Load data of 85-node Mesh distribution system

Node No.	PL(kW)	Node No.	PL(kW)
4	56.0	46	35.28
6	35.28	47	14.0
8	35.28	50	36.28
11	56.0	51	56.0
14	35.28	53	35.28
15	35.28	54	56.0
16	35.28	55	56.0
17	112.0	56	14.0
18	56.0	57	56.0
19	56.0	59	56.0
20	35.28	61	56.0
21	35.28	61	56.0
22	35.28	62	56.0
23	56.0	63	14.0
24	35.28	66	56.0
25	35.28	69	56.0
26	56,0	71	35.28
28	56.0	72	56.0
30	35.28	74	56.0
31	35.28	75	35.28

33	14.0	76	56.0
36	35.28	77	14.0
37	56.0	78	56.0
38	56.0	79	35.28
39	56.0	80	56.0
40	35.28	82	56.0
42	35.28	83	35.28
43	35.28	84	14.0
44	35.28	85	35.28
45	35.28	-	-
Power factor of all the load = 0.7 (lagging)			

Appendix-D

Table D1: System data of 83-node distribution system

Section (bus to bus)	Section Resistance (Ω)	Section Reactance (Ω)	End Bus Real Load (kW)	End Bus Reactive Load (kVAr)
B1- 1	0.1944	0.6624	0	0
1-2	0.2096	0.4304	100	50
2-3	0.2358	0.4842	300	200
3-4	0.0917	0.1883	350	250
4-5	0.2096	0.4304	220	100
5-6	0.0393	0.0807	1100	800
6-7	0.0405	0.1380	400	320
7-8	0.1048	0.2152	300	200
7-9	0.2358	0.4842	300	230
07-10	0.1048	0.2152	300	260
B2- 11	0.0786	0.1614	0	0
11-12	0.3406	0.6944	1200	800
12-13	0.0262	0.0538	800	600
12-14	0.0786	0.1614	700	500
B3- 15	0.1134	0.3864	0	0
15- 16	0.0524	0.1076	300	150
16- 17	0.0524	0.1076	500	350
17- 18	0.1572	0.3228	700	400
18- 19	0.0393	0.0807	1200	1000
19- 20	0.1703	0.3497	300	300
20- 21	0.2358	0.4842	400	350
21- 22	0.1572	0.3228	50	20
21- 23	0.1965	0.4035	50	20

Section (bus to bus)	Section Resistance (Ω)	Section Reactance (Ω)	End Bus Real Load (kW)	End Bus Reactive Load (kVAr)
23- 24	0.1310	0.2690	50	10
B4- 25	0.0567	0.1932	50	30
25- 26	0.1048	0.2152	100	60
26- 27	0.2489	0.5111	100	70
27- 28	0.0486	0.1656	1800	1300
28- 29	0.1310	0.2690	200	120
B5- 30	0.1965	0.3960	0	0
30- 31	0.1310	0.2690	1800	1600
31- 32	0.1310	0.2690	200	150
32- 33	0.0262	0.0538	200	100
33- 34	0.1703	0.3497	800	600
34- 35	0.0524	0.1076	100	60
35- 36	0.4978	1.0222	100	60
36- 37	0.0393	0.0807	20	10
37- 38	0.0393	0.0807	20	10
38- 39	0.0786	0.1614	20	10
39- 40	0.2096	0.4304	20	10
38- 41	0.1965	0.4035	200	160
41- 42	0.2096	0.4304	50	30
B6- 43	0.0486	0.1656	0	0
43- 44	0.0393	0.0807	30	20
44- 45	0.1310	0.2690	800	700
45- 46	0.2358	0.4842	200	150
B7- 47	0.243	0.8280	0	0
47- 48	0.0655	0.1345	0	0
48- 49	0.0655	0.1345	0	0

Section (bus to bus)	Section Resistance (Ω)	Section Reactance (Ω)	End Bus Real Load (kW)	End Bus Reactive Load (kVAr)
49- 50	0.0393	0.0807	200	160
50- 51	0.0786	0.1614	800	600
51- 52	0.0393	0.0807	500	300
52- 53	0.0786	0.1614	500	350
53- 54	0.0524	0.1076	500	300
54- 55	0.1310	0.2690	200	80
B8- 56	0.2268	0.7728	0	0
56- 57	0.5371	1.1029	30	20
57- 58	0.0524	0.1076	600	420
58- 59	0.0405	0.1380	0	0
59- 60	0.0393	0.0807	20	10
60- 61	0.0262	0.0538	20	10
61- 62	0.1048	0.2152	200	130
62- 63	0.2358	0.4842	300	240
63- 64	0.0243	0.0828	300	200
B9- 65	0.0486	0.1656	0	0
65- 66	0.1703	0.3497	50	30
66- 67	0.1215	0.4140	0	0
67- 68	0.2187	0.7452	400	360
68- 69	0.0486	0.1656	0	0
69- 70	0.0729	0.2484	0	0
70- 71	0.0567	0.1932	2000	1500
71- 72	0.0262	0.0528	200	150
B10- 73	0.3240	1.1040	0	0
73- 74	0.0324	0.1104	0	0
74- 75	0.0567	0.1932	1200	950

75- 76	0.0486	0.1656	300	180
B11- 77	0.2511	0.8556	0	0
77- 78	0.1296	0.4416	400	360
78- 79	0.0486	0.1656	2000	1300
79- 80	0.1310	0.2640	200	140
80- 81	0.1310	0.2640	500	360
81- 82	0.0917	0.1883	100	30
82- 83	0.3144	0.6456	400	360
5-55	0.1310	0.2690	-	-
6-60	0.1310	0.2690	-	-
11-43	0.1310	0.2690	-	-
12-72	0.3406	0.6994	-	-
13- 76	0.4585	0.9415	-	-
14- 18	0.5371	1.0824	-	-
16- 26	0.0917	0.1883	-	-
20- 83	0.0786	0.1614	-	-
28- 32	0.0524	0.1076	-	-
29- 39	0.0786	0.1614	-	-
34- 46	0.0262	0.0538	-	-
40- 42	0.1965	0.4035	-	-
53- 64	0.0393	0.0807	-	-

Publications in SCI/SCOPUS indexed Journal

1.Rajni Bala and Smarajit Ghosh, "Optimal Position and Rating of DG in Distribution Networks by ABC-CS from Load Flow Solutions Illustrated by Fuzzy-PSO," Neural Computing and Applications, Volume 31, Issue 2, pp 489–507. DOI: 10.1007/s00521-017-3084-7. (Impact Factor: 4.774)

2. Rajni Bala and Smarajit Ghosh, "Integration of Distributed Generations in Radial Distribution Networks using ABC Algorithm", International Journal of Engineering and Advanced Technology (IJEAT), Volume 8, Issue 6, pp. 1592-1594, August 2019

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