Journal of Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.7688377

OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION USING A MULTI-OBJECTIVE SWARM INTELLIGENCE ALGORITHM FOR POWER LOSS AND VOLTAGE STABILITY

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Abstract
The loss of power and variation of voltage are major bottleneck problems in the distribution system. The factors of loss decline with the efficiency of network configuration, including the addition of a distributed generation (DG) segment in the distributed network. However, the optimal placement and sizing of DGs play an important role in the efficient distribution of power. This paper employed optimization algorithms for the optimal placement of DGs in a network system. All employed algorithms are multi-objective and control the positioning of DGs in distributed networks. The employed algorithms are particle swarm optimization, genetic algorithms, and firefly algorithms. An active distribution network's optimal network configuration with DG coordination reduces power losses, elevates voltage profiles, and boosts system efficiency. A penalty factor that is taken into account when considering real-world power system scenarios is essential for minimising overall power loss and enhancing voltage profiles. With the addition of DG units to the test system, the simulation results demonstrated a significant improvement in the percentage power loss reduction (31% and 66.05% before and after reconfiguration, respectively). Similar improvements are made to the system's minimum bus voltage, which is 3.9% and 5.53% before and after reconfiguration, respectively. The results of the comparative study demonstrated that the suggested approach is effective at lowering the voltage deviation and power loss of the distribution system. the optimization algorithms tested on the IEEE-33 bus and the IEEE-69 bus systems.
Keywords: - Distributed Generation, Voltage Deviation, Power Loss Minimization, Particle Swarm Optimization; Genetic Algorithm, Firefly Algorithm, Network Reconfiguration, Voltage Stability Enhancement

Introduction

In the current decade, the integration of DG resources in distribution and transmission grids is increasing worldwide, and the connection of distributed generation to the grid and its impact on voltage support, voltage stability, voltage flicker, loss of energy reduction, and deployment of system capacity are examined. The increasing demands for electricity face several issues. The reported survey suggests that 70% of the losses are occurring at the distribution level, while 30% of the losses are occurring at the transmission level [1,2]. The distribution system is now the most important concern in the power system. The target levels of distribution are about 7.5%. However, using power sources like distributed generation (DG), capacitor banks, etc., reduces loss. Now several authors have proposed swarm intelligence optimization methods for the optimal sizing and placement of DGs. The potential of distribution generation investigates the use of optimal resource placement and sizing for the location of local generations. To get the most out of the power system and cut down on losses, it's important that DGs are set up in the right way. Despite several studies of power losses and variations of voltage in power systems, there are several authors' proposed algorithms for optimal allocation and placement of DG. Bio-inspired algorithms such as particle swarm intelligence, the firefly algorithm, the Bactria forging algorithm (BFO), and many others derive from swarm intelligence and machine learning[3,4]. This paper analysed a particle swarm optimization (PSO), genetic algorithm (GA), and firefly algorithm (FF) to optimally locate and size DG positions with the suggestion of a multi-objective function for reconfiguration and DG installation, loss of power system, and stability of voltage. The methodology developed is tested on IEEE 33- and 69-bus radial distribution systems. The obtained results show the effectiveness and robustness of the PSO, GA, and FF methodologies in solving the optimal location and sizing of the DG in the distributed network, which reduces total power loss and boosts the voltage profile within a defined network system. Some complexities in engineering optimization problems are too complex for effective deterministic techniques to handle. The problem of sitting and sizing the capacitor and the DG is one of combinatorial optimization. As a result, metaheuristics are employed to optimise the DG and capacitor's capacity and location. In order to reduce power losses, a new strategy for DG allocation under uncertain load conditions was presented in [5]. The best location and DG capacity are determined using a fuzzy-based approach. For multiple DG installations, an effective methodology was developed in [6] to increase the technical and financial advantages. It is possible to obtain a novel multi-objective function for various performance evaluation indices. Therefore, one of the objectives of DG optimal allocation should take voltage stability into consideration. To test this effect, different optimal locations are used. The system voltage stability is primarily influenced by the location of the DG. In order to achieve the best performance, the effects of optimal DG locating and sizing on improving voltage stability, lowering power losses, reducing voltage deviations, and DG installation cost are simultaneously investigated. The optimal placement of DGs and resources optimization of the power system's main objective is the formulation of methodology, the applied DGs system, and fundamental background, as well as the employment of algorithms such as particle swarm optimization, the genetic algorithm, and the firefly algorithm. The employed algorithms resolve the issue of optimal DG reconfiguration with objective function, reduce power loss, and improve the voltage profile. The employed algorithms were simulated in MATLAB software, and the results were analysed and compared to validate the objective of this paper. The rest of the paper, organised as follows in Section II, describes the recent work on optimal placement of DGs and applied algorithms. Section III describes the methodology of power loss and objective function formulation; Section IV simulates the bus-33 and bus-69 systems; and Section V concludes.

II. Related work

The continuous efforts of research scholars working on the integration of DGs into networks to minimise power loss, improve power efficiency, improve voltage profile, improve system stability, and boost load performance The recently applied swarm intelligence and machine learning algorithms are applied to the optimal sizing and placement of DGs, as described here.

The author [1] PSO is used to find the best location for the WTs as well as their size and power factor. Implementations of the suggested approach use 84- and 32-bus standard grids. The suggested technique was applied to regular grids with 84 and 32 buses. In this study, a two-stage PSO algorithm was suggested to make it easier for WTs to choose a site while taking their maximal capacity into account. The author [2] says, the 85-bus system is used to test the suggested algorithm's efficacy. The experimental findings demonstrate that AQiEA outperforms certain other known algorithms. Four instances are used to test the usefulness of the suggested algorithm. When compared to the other cases, Case IV exhibits a significant reduction in power losses. The experimental findings demonstrate that the suggested algorithm outperforms competing algorithms. The author [3] the convergence issue was solved using this strategy, but the ideal DG unit size was not taken into account. This study's primary goal is to refine a method for DG technology planning and operation that is based on an intelligent algorithm in order to minimise real power losses, improve the voltage profile, and increase overall reliability. Using a MATLAB environment, this study has been carried out using an IEEE Node-15 system. To demonstrate the applicability of the suggested strategy, it was applied to the IEEE-15bus radial distribution network as a constrained nonlinear programming problem. The author [4] says, the analytical findings using the suggested algorithm are more efficient for lowering overall active power losses and improving the voltage profile for different distribution networks and multi-DG units. When compared to WOA and SSA done separately, the suggested approach is more successful in determining the appropriate position and size of DG units. The actual results demonstrate how well this algorithm performs in terms of determining the ideal size and position for the installation of different numbers of DG units, as well as faster execution times when compared to competing methods. Economically, the simulation on the IEEE 13- and 123-node test systems reduced the overall real power losses by 34.4% and 26.5%, respectively. The author [5] from a variety of artificial intelligence techniques described the proposed Genetic Algorithm (GA) as a solution to the issue. According to the research, the presence of DG sources in the microgrid can significantly lower the network's power losses. The author [6] on test systems for the IEEE 15-, 33-, and 69-buses, the proposed algorithm is evaluated. When compared to other approaches in the literature, the suggested algorithm, which uses a type III DG unit operating at 0.9 pf, produces better results. With DG at 0.9 pf lag, we may infer that there is a significant decrease in real, reactive power losses and an improvement in voltage performance because of its reactive power supply to the system. The author [7] the study's findings show that the suggested methodology is effective in ensuring the best possible voltage profile and loss reduction in the tested system for the location and sizing of DTCs and DGs. The author [8] The proposed methodology, however, can be employed as a trustworthy way in DG settings and scaling in distribution network systems that generate superior results than hybrid big bang big crunch and grey wolf optimization (GWO). Therefore, rather than using Hybrid GWO and Hybrid big bang big crunch, the proposed approach may be used as a trustworthy way for DG setting and sizing in distribution network systems, conferring good implementation and the foremost results. The author [9] of the suggested MATLAB software makes an attempt to assess voltage stability by basing it on a nonlinear optimization problem. On the IEEE 30 bus test system, the proposed method has been used, and the results demonstrate proper performance and acceptable operation. On a test system, the suggested methodology has been evaluated. It is shown that the voltages of the load buses are improved, the losses are significantly decreased, and static voltage stability is effectively raised as a result of the installation of the optimal DG size at its ideal location. The author [10] to reduce power losses and enhance the voltage profile through the ideal sizing and placement of DGs in the distribution network, a Matlab-Software wurde created. The overall voltage deviation, active and reactive power losses were reduced by 85.20%, 84.94%, and 85.73%, respectively, after the DG was sized and installed in the network. Gr MHSA outperforms MOPSO in terms of lowering voltage variation and power losses in the system, according to a performance comparison between the two technologies. The author [11] an effective weighted factor multi-objective function is modelled to produce the required results. To minimise the system's goals, Particle Swarm Optimization (PSO) and Butterfly Optimization (BO) algorithms are chosen and put into use. For the purpose of minimising the suggested objective function, two algorithms, BO and PSO, have been chosen and put into practice. The author [12] the results show that integrating three DGs with a unity power factor reduced losses in the two systems by 67.40% and 80.32%, respectively. The usefulness of the suggested MLPSO algorithm in DG placement and sizing was proved by comparing the results with those from other optimization strategies. The author [13] says: „For the best sizing and positioning of distributed energy supplies, a backward-forward sweep method is used. The success of the suggested strategy is demonstrated using the IEEE 33-bus test system. In this paper, a two-stage methodology has been put forth with the goal of identifying the best combination of various alternative energy source types and allocating them in the distribution network in a way that minimises power losses and ensures that the voltage profile of each bus complies with the set constraints. The author [14] the novel SAPSO methodology presented in this study prevents the flaws of SA and PSO. The IEEE 33 bus system has been used to test the proposed algorithms. The algorithms were shown to be capable of offering the best answer for the problem optimization. This shows that the suggested methods are highly effective and accurate at predicting the best location and size for DGs. The author [15] the major goal of this study is to use the suggested SPSO technology to reduce real power losses and increase the VP of a distribution system. The SPSO approach was evaluated using the IEEE 33-bus radial distribution system after being written in the MATLAB R2016b software (RDS). According to the test results, the real power was increased for the light, normal, and heavy load circumstances, respectively, by 99.341%, 97.289%, and 95.389%. The author [16] in this paper, a modified search algorithm that can find the best answers is proposed. The effectiveness of the proposed updated algorithm to solve the optimal location and sizing problem with the effect of PV and wind power variation together with the variable load is established by the quality of the results. The issues have been resolved using recently created soft computing techniques and a proposed algorithm (MOBOSA). The author [17] Therefore, it can be concluded that the optimal DG allocation problem in the distribution network has been solved by the suggested strategy. It is hoped that the suggested FA-based DG placement will be expanded to include other factors that were not included in this study, such as RES, investment costs, societal impacts, and environmental impacts. The author [18] The GWO, WOA, and PSO optimization algorithms are used to identify the best sizes for decentralised generation units in a power distribution network. Results from DGs with a trailing power factor are superior to those from DGs with a unity power factor. The VSI index with a DG at a power factor of 0.9 produces the greatest results in terms of loss reduction and minimum bus voltage.

The author [19] it is evident that the suggested methods offer the best possible deployment of several distributed generators, which lowers power losses and enhances the voltage profile. As DG penetration increases, losses are decreased and the voltage profile is improved. However, after a given number of locations and DG size, this trend turns around. The author [20] the artificial bee colony (ABC) algorithm is suggested to resolve the multi-objective issue at hand. Standard algorithms are used to test the suggested ABC algorithm's performance. It has been observed that the suggested ABC algorithm outperforms GA in both IEEE 33- and 69-bus radial networks in terms of total active power loss, average voltage drops, and total energy cost. In addition, the suggested ABC algorithm converges faster in both scenarios than GA. The author [21] the effectiveness of the suggested technique is evaluated using an IEEE 33-bus RDS and a 52-node realistic Indian RDS. The obtained results demonstrate that, while DGs are positioned in the system optimally, a decrease in distribution system losses and an improvement in bus voltages are achieved within the required limitations. The suggested method uses HS for DG location and size to address optimal node selection. The author [22] This study employs an objective function that seeks to minimise grid power losses. The particle swarm optimization (PSO) and genetic algorithms are employed to solve this objective function (GA). The resulting simulation results demonstrate that, in terms of speed convergence, power loss reduction, and grid quality enhancement, the PSO algorithm outperforms the GA. The author [23] The proposed algorithm was put to the test on the IEEE 14-BUS network for seven different DG types, and the results showed that out of these seven DGs, three DGs were able to lower the total capacity of the network lines to less than the full capacity of the lines and raise the price of LMP to the price of UMP, and the other four DGs were able to lower the price of LMP compared to their cost function. The author [24] the suggested method improves the voltage profile at the system's nodes and reduces power loss. The simulation is performed in MATLAB, and the Electrical Transient Analysis Program also verifies the results (ETAP). An SPSO-based approach is put forth in this study for the ideal positioning and sizing of several DGs in DN. With DGs, active power loss is seen to be decreased by 92%. The author [25] Particle swarm optimization (PSO) and hybrid swarm optimization (HSO), a recently proposed method that combines the features of modified IL-SHADE and PSO, are used to size the DG optimally after congested lines have been identified. HSO greatly improves performance by reducing the population size by removing the least fit individuals at every generation, giving results that are far superior to those obtained with PSO. The author [26] the application of the optimization algorithm to the IEEE 69-bus standard RDS with various situations, including DG and capacitor banks, shows the performance of the algorithm (CBs). Future researchers will be encouraged to apply the suggested approach to complex optimization problems by the great accuracy it achieves. The author [27] On IEEE 33 and 69 bus RDNs, the effectiveness of the implemented HHO is validated, and the results are analysed by comparing them to the traditional optimization techniques. As demonstrated by Case 3 of a 33-bus RDN and 69-bus RDN, the best results were obtained when the specified number of DGs could be integrated into the RDNs. As a result, the increasing rate of DG deployment in RDNs has greatly decreased the overall P and Q losses as well as bus voltage dips, leading to better outcomes and a strong HHO trend. The author [28] the suggested method is utilised to enhance VP and decrease power and energy losses in the distribution system. On a test system with a typical 33-bus-system, the effectiveness of the suggested strategy was evaluated. Loss reduction for the 69-bus system is 98%, and energy loss reduction is 66%. The VP performance is also enhanced compared to the base system. The author [29] On an IEEE-30 bus network system with DGs allocations, the effectiveness of the proposed HGAIPSO was evaluated, and the test results were contrasted with those from alternative approaches. According to the simulation results, the suggested HGAIPSO can be a successful and promising optimization approach for issues involving distribution network reconfiguration. Incorporating DGs at different locations in the IEEE-30 bus test system resulted in reductions in overall real power loss of 40.7040%, 36.2403%, and 42.9406%, respectively. The author [30] through numerical simulations on a genuine Italian DC railway system, the efficiency of the suggested strategy is demonstrated. A 125V-63F SC basic module is chosen for the suggested application, and 4 modules are connected in series to create a 500V-15.65F SC final module. Because of this, it is impossible to provide general guidelines for the ESS design and placing along the track; instead, it is necessary to analyse each individual case study using appropriate simulation tools.

III. Methodology

This section describes the methodology of minimising power losses and ensuring voltage stability and formulates objective functions for the optimal sizing and placement of distribution generation. The methodology of distribution generation employed three algorithms: particle swarm optimization, a genetic algorithm, and the firefly algorithm. The process of methodology is explored in three sections: the first section describes the objective functions of losses, the second section describes the algorithms, and the third section describes the employed algorithms for the IEEE bus system for the estimation of results.

Minimization of power loss

The loss of power system in generation to distribution depends on the distance of generation and transmission lines to user. All the distribution system of transmission is not ensuring 100 % delivery of power. The loss of transmission system depends on the optimal position and size of DG systems. The real loss of power in a distributed system with given operational computing using equation (1) [16]

$$Ploss(OF1) = \sum_{I=1}^{nbr} Ii^2 Ri \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here Ii and Ri are the current magnitude and resistance corresponding to the circuit branch I, the number of branches represent by br. The current of branch circuit break into two segment active component (Iac) and reactive component (Irc)

$$PLa(OF2) = \sum_{i=1}^{n} I^2 aciRi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$PLr(OF3) = \sum_{i=1}^{n} I^2 rciRi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Now optimal placement of DGs can manage the active loss components in the branch

PG=PD+Losses……………………………………..(4)

The generator power and the demand power are given by PG and PD respectively.

The equation(5) is objective of improving the voltage profile

$$FO4 = \sum_{Ni=1}^{NN} (V_{Ni} - V_{rated}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Optimization Algorithm

Genetic Algorithm

The genetic algorithm plays a vital role in the search and mapping of resource allocation in power system. The main objective of genetic algorithms is the optimization of placement of DGs. The processing of genetic algorithms is inspired by the process of evaluation and bio-inspired genetics. The resources of the network are represented as genes, and optimal parameters are set as chromosomes. The main function of a genetic algorithm is the fitness function, which can take many forms, including the wheel method, tournament method, and probability-based method. A set of population, crossover, mutation, and fitness constraints [16] are used to explain how genetic algorithms work.

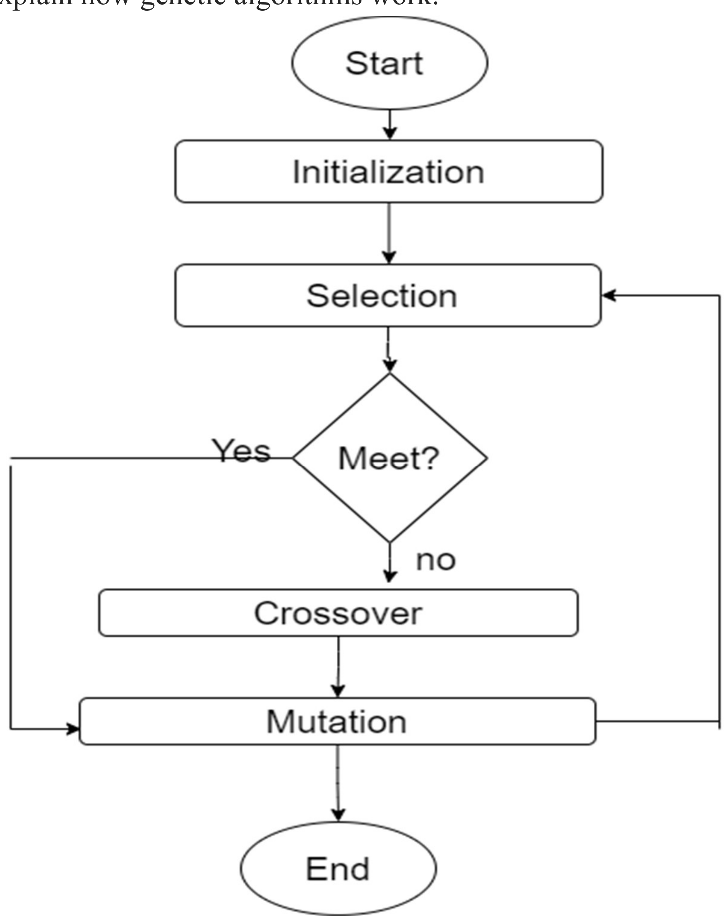

Figure 1 Processing of Genetic Algorithm [14]

Figure 1 shows the processing steps of a genetic algorithm, which consist of all phases from population to optimal results.

Particle Swarm Optimization (PSO)

Particle swarm optimization is a dynamic population-based heuristic approach. The particle swarm optimization algorithm's working behaviours are inspired by the forks of birds. The velocity and position of particles to satisfy the selection condition of population data are the main processing components of the particle swarm optimization algorithm. An algorithm's processing uses the previous value of the iteration to store the next value and move the particle. The process of iteration maintains the updated position of the particle. The constant acceleration function accelerates the particles for the last iteration of population [12]. The processing of particle swarm optimization is shown in figure (2).

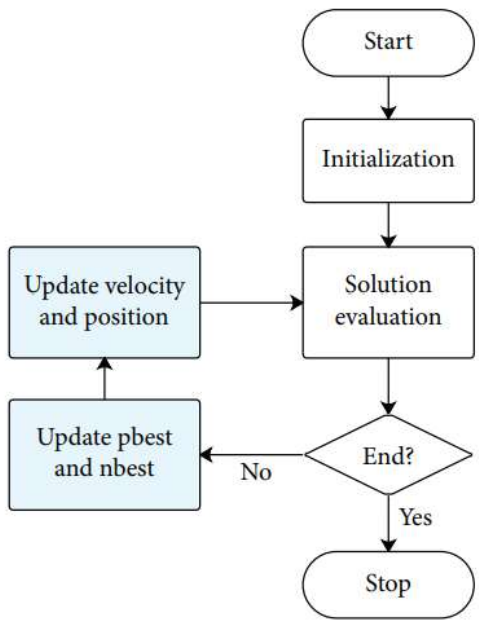

Figure 2 processing block diagram of particle swarm optimization [12]

Figure 2 explores the working process of the particle swarm optimization algorithm in all stages, from population to optimal results.

Firefly algorithm is meta-heuristic optimization algorithm based on the flashing behaviors of fireflies in environment. Firefly algorithm resolve the problem of NP-hard problem and manage the dynamic behaviors of data. It's a random algorithm, to put it another way, a random search is utilized to locate a collection of solutions. The FA, at its most basic, focuses on producing solutions inside a search area and selecting the greatest surviving option. A random search avoids being stuck in local optimums. Exploration in metaheuristic algorithms refers to discovering multiple solutions inside the search space, whereas exploitation refers to the search process focusing on the best neighboring solutions[18]

Processing of firefly algorithm

1: Initialize fireflies [x] randomly ⊲ firefly $[x] = [loc(DC2), Size(DC1), Size\ (DC2)]$

2: Find RPL for each Firefly

3: Find brightness for each firefly using equation (1)

4: Set iteration t=1

5: Set firefly i=1

6: Set firefly j=1

while t ≤ epochs do
while i ≤pop do
while j ≤pop do
Compute r= $\sqrt{\sum_{f=1}^{4}(X[i,f]-[j,f])\dot{2}}$
if Brightness$(X[i]) <$ Brightness $(x[i])$ then
$X * [i] = X[i] + \beta o * e - \gamma r * r * (X[j] - X[i]) + \alpha * (rand - 0.5)$
Impose boundary limits
Find brightness for firefly ”i” using equation (1)
if Brightness $(X[i]) \leq$ Brightness $(x[i])$ then
Set $X[i] = X * [i]$
end if
end if
$j = j + 1$
end while
i=i+1
end while
$X\,best = X\,best + \alpha * rand$ ⊲ Exploitation
$t = t + 1$
end while

IV. Simulation and Result analysis

To validate the performance of optimization algorithms such as the genetic algorithm, particle swarm optimization, and firefly algorithm implemented in MATLAB tools. The employed optimization algorithm approach detects the location and size of DG units in order to reduce actual losses of power and maintain voltage stability. The algorithms used to solve the problem of optimal distribution reconfiguration and optimal DG arrangement with the goal of reducing power losses and improving voltage stability. The process of simulation considers four scenarios for the placement and allocation of DGs. The employed algorithms test on the IEEE-33 bus system and the IEEE-69 bus system. the performance analysis of the simulation of both bus systems mentioned in tables 1 and 2.

Radial distribution systems of IEEE 33
The IEEE-33 bus system is a radial distribution system (RDS) with a total load of 3.72 MW, 2.3 MVar, 33 buses and 32 branches as shown in Fig. 3. The line loading system and line data are obtained from Baran and Wu (1989). Table 1, describes the performance of the employed algorithm.

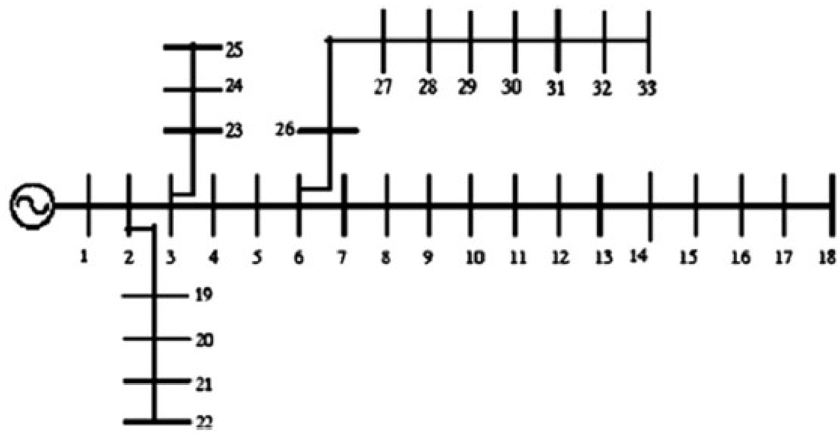

Figure 3 IEEE standard 33 bus radial distribution system single line diagram[28]

IEEE 69 radial distribution systems results

the IEEE-69 bus system is a radial distribution system (RDS) with a total real and reactive power load of 3.80 MW, 2.69 MVar, 69 buses and 68 branches. The system load line and line data are taken from Sahoo and Prasad (2006).

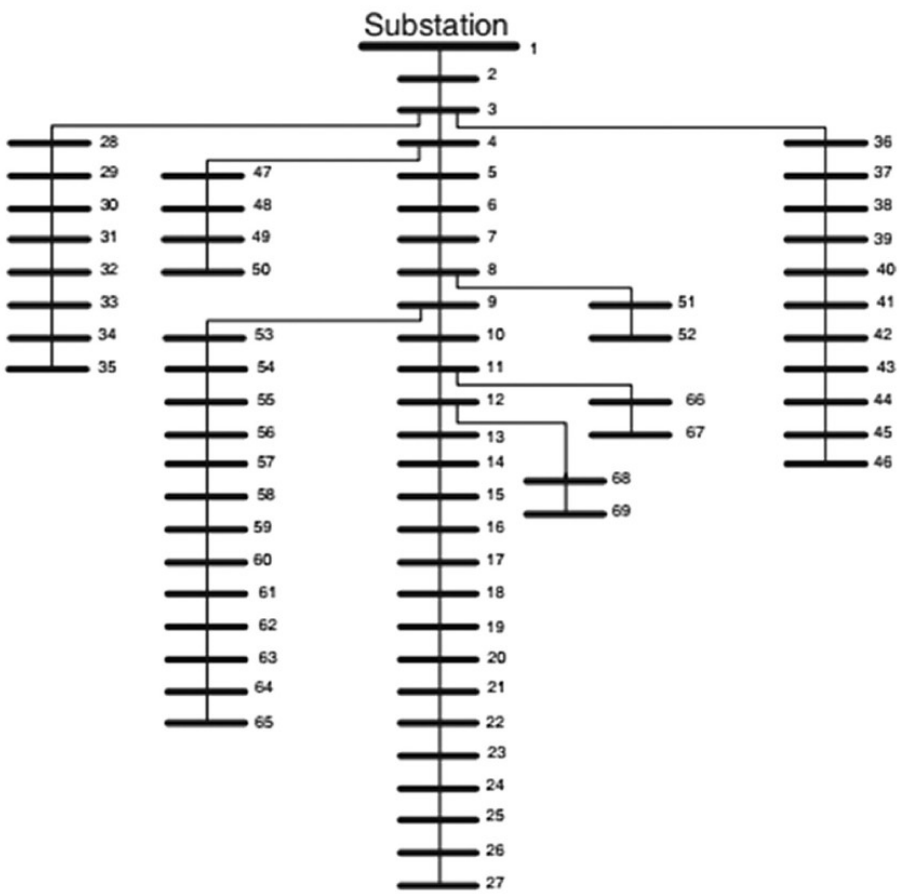

Figure 4 The IEEE 69 bus-radial network single line diagram[15]

Table .1 Simulation results of 33-bus system

Methods	DG location	DG optimal size (MW)	Ploss (kW) (TLR %)	Q loss (kVAr) (TLR %)	Vmin (pu)
Base case	-	-	281.579	187.561	0.881
PSO 30	upf	1.6219	151.6719 (47.13)	107.914 (43.13)	0.919
	upf	1.6994	105.3944 (62.22)	77.0344 (58.014)	0.929
GA 30	upf	1.6221	152.6809 (45.13)	105.9615 (44.09)	0.9187
	upf	1.7895	106.4663 (61.225)	77.1703 (59.95)	0.927
FF 30	upf	1.3221	152.681 (46.14)	106.8808 (43.15)	0.9182
	lag	1.7995	106.3663 (61.22)	77.1705 (58.95)	0.927

Table .2 Simulation results of 69-bus system

Methods	DG location	DG optimal size (MW)	Ploss (kW) (TLR %)	Q loss (kVAr) (TLR %)	Vmin (pu)
Base case	-	-	281.579	187.561	0.883
PSO 61	upf	1.9044	112.0784 (66.48)	55.3295 (63.92)	0.9594
	lag	2.0447	52.7468 (84.64)	29.0548 (82.38)	0.9628
GA 61	upf	1.9044	113.0867 (66.46)	54.2343 (63.00)	0.9597

	lag	2.0447	52.7503 (84.67)	28.0637 (81.38)	0.9529
FF 61	upf	1.9143	113.063 (66.479)	54.2725 (62.975)	0.9595
	lag	2.0447	51.7486 (84.658)	28.0790 (81.35)	0.9629

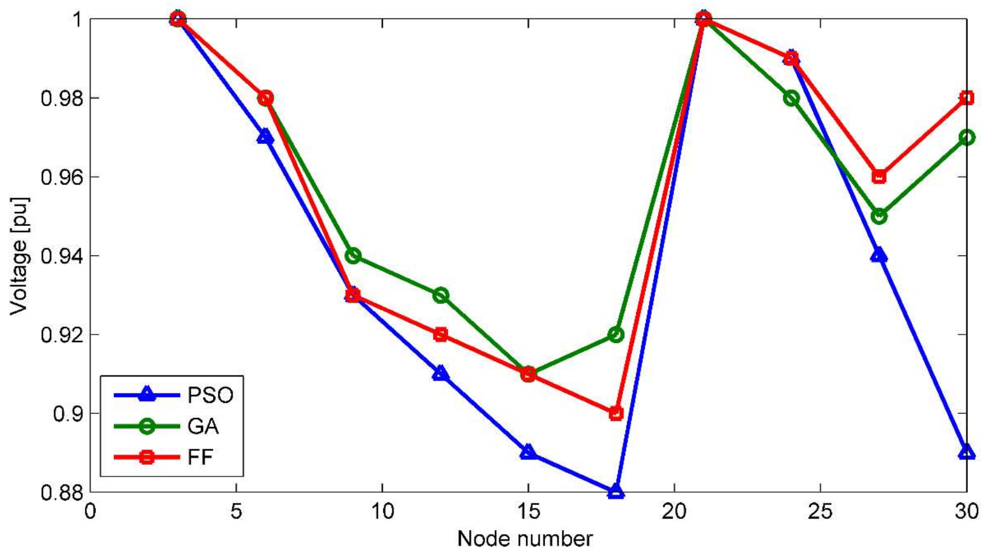

Figure: 5 Comparative performance of result analysis of PSO, GA and FF, using method of voltage (Pu) and node number.

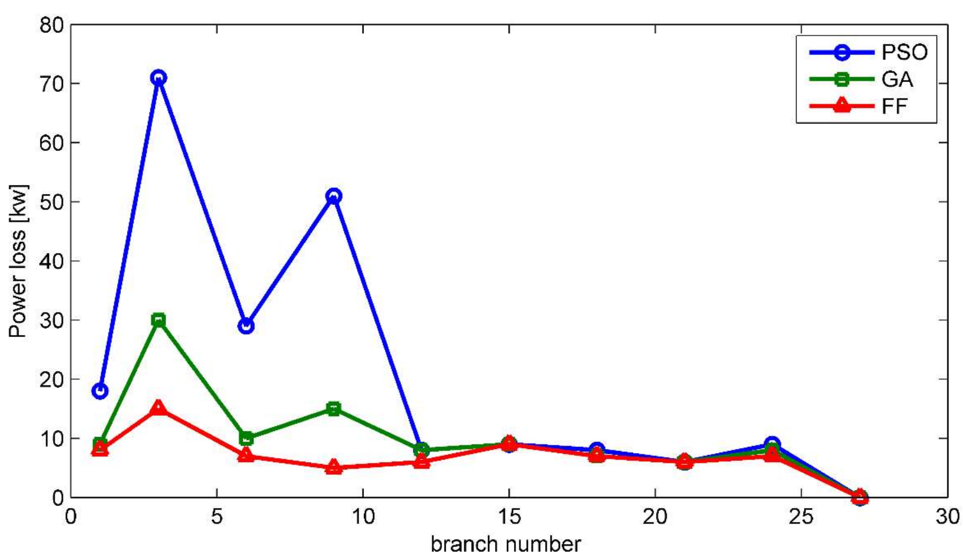

Figure: 6 Comparative performance of result analysis of PSO, GA and FF, using method of power loss (KW) and branch number.

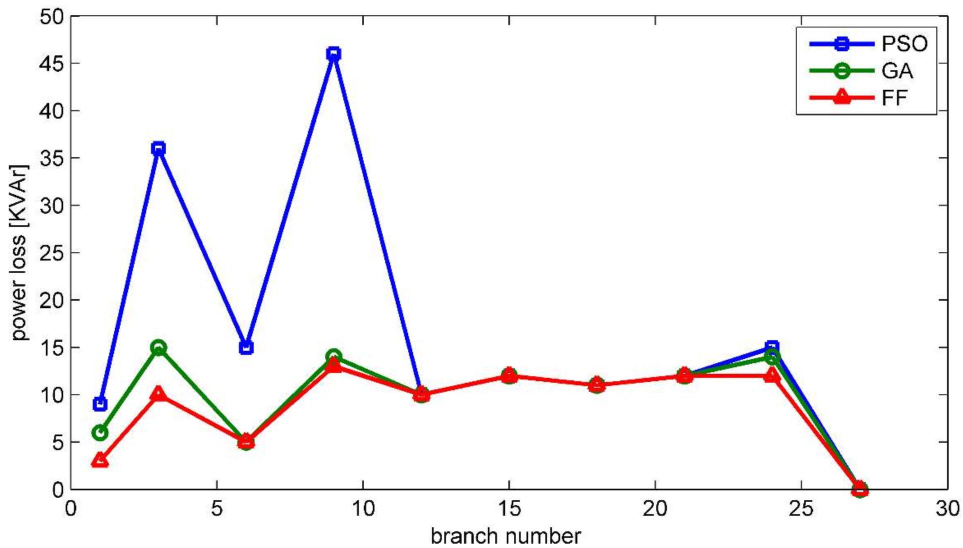

Figure: 7 Comparative performance of result analysis of PSO, GA and FF, using method of power loss (KVAr) and branch number.

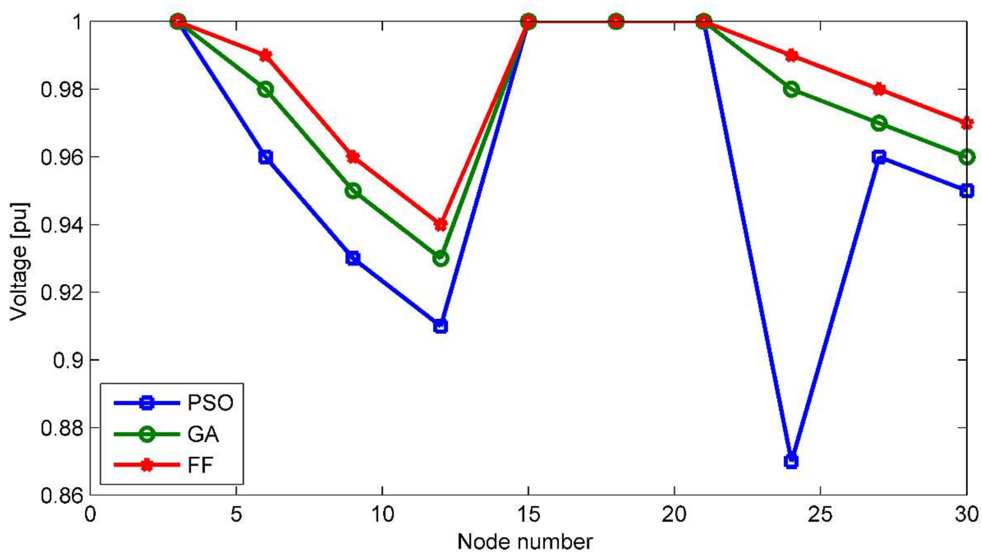

Figure: 8 Comparative performance of result analysis of PSO, GA and FF, using method of voltage (Pu) and node number.

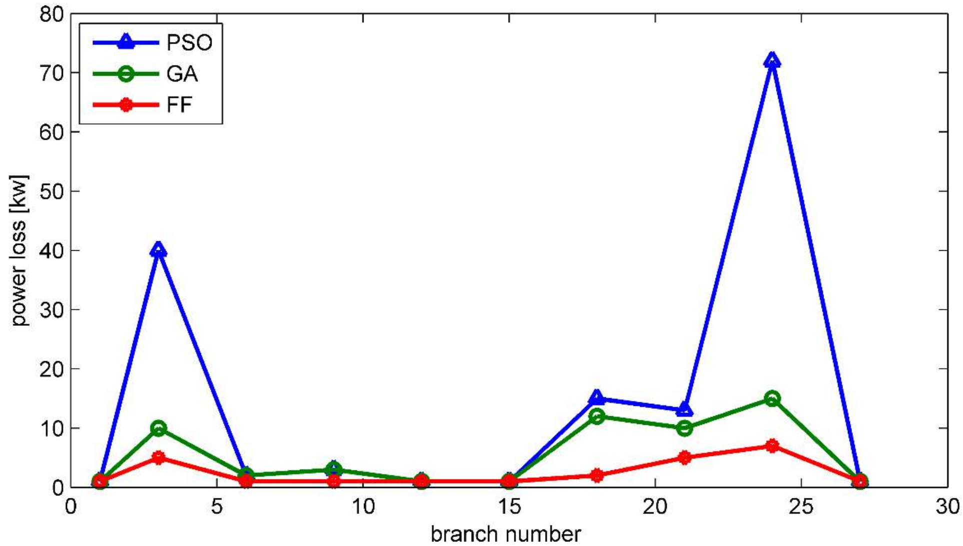

Figure: 9 Comparative performance of result analysis of PSO, GA and FF, using method of power loss (KW) and branch number.

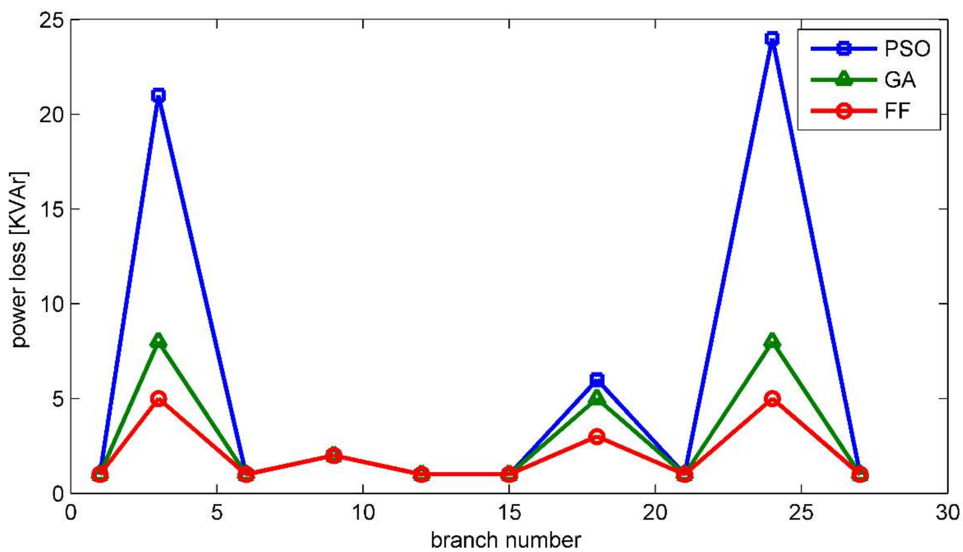

Figure: 10 Comparative performance of result analysis of PSO, GA and FF, using method of power loss (KVAr) and branch number.

V. Conclusion & Future Work

This paper study of bottleneck problem of location and sizing of DGs to reduces the total power loss and improved and boost voltage profile of a radial distribution system. The employed optimization algorithms supported the multi-objective function of power factors. By installing DG at the 13th, 10th, and 30th bus, the optimization algorithms study was conducted on the IEEE 33 and 69-bus power network system, and it was successful in lowering network power losses and enhancing voltage profile. The obtained result demonstrates that FF algorithm outperforms PSO and GA big bang big crunch for both test results in terms of reducing power loss, improving voltage profile, and enhancing reliability. Therefore, rather than using GA and PSO's big bang, big crunch approach, the methodology can be used as a trustworthy method for DG setting and sizing in distribution network systems, resulting in good implementation and the best outcomes. Using multi-DGs re-configuration placement, the system's power losses have been significantly reduced, down to 31.8244 kW, which is expected as part of the research work's goal. Controlled power factor has helped to significantly improve voltage profile and voltage stability, which have been boosted by reconfiguring the system and installing numerous DG units.

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