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RESEARCH ARTICLE

A self-regulating optimization algorithm for locating and sizing a local power generation source for a radial structured distribution system in deregulated environment

Shaik Chanbasha[1*], N. Jayakumar[2], N. Bupesh Kumar[3]

Abstract

The Indian power sector is a large and complex network. Maintaining that complex network with the present regulatory format is very difficult for the government as well as transco and discom companies in terms of cost, efficiency, and reliability. That is why the government encourages deregulation in the power sector. One of the deregulation concepts is the integration of local sources into the distribution network. While integrating local sources into the system, several challenges come up, like voltage fluctuations and losses, safety and stability, protection coordination, and mitigation strategies. From those problems, one of the problems is deciding 'the right place with the right size' for the local source in radial structure distribution system. This work proposes a modified pathfinder optimization algorithm that has a fast convergence rate and the best balance between exploration and mining ability compared to other methods and previous pathfinder optimization. Applying modified path finder optimization to the IEEE-12 test feeder bus and IEEE-33 test feeder bus systems to find the optimal place and size of the local source with the help of VSI and LSF. Compare other traditional methods.

Keywords: Deregulations, LS-Local source, MPFO-Modified pathfinder optimization, RSDS-Radial structure distribution system, RFO-Red fox optimization, GA–Genetic.

Introduction

Generation, transmission, and distribution companies maintaining an interconnected, large, and complicated network with the least amount of loss while providing quality power to consumers is a big issue. We are all aware that generated power does not directly reach the consumer; it must overcome transmission and distribution losses before it does.

[1]Annamalai University, Annamalai nagar, Chitambaram.

[2]Department of Electrical and Electronics Engineering Government Polytechnic College, Ariyalur, Tamil Nadu, India.

[3]Department of Electrical and Electronics Engineering.

***Corresponding Author:** Shaik Chanbasha, Annamalai University, Annamalai nagar, Chitambaram., E-Mail: bashaeee7862007@gmail.com

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In this scenario, generation does not satisfy demand; as a result, the government supports renewable energy (local power sources such as solar power). Users' "local generation meets local demand" will alleviate the burden on the central system. By establishing the local source in a suitable location and size within the radial structure distribution system, the voltage profile of the system increases, the proportion of active and reactive power losses falls, and the system's availability rate improves. A deregulated environment is when there is competition among electricity vendors and suppliers, allowing consumers to choose between them. By using this approach, we may eliminate the monopoly in the electric power market and simultaneously decrease reliance on fossil fuels. Additionally, it will aid in establishing control over price regulation. Governments encourage the use of local power-generating methods by providing subsidies for solar plants and similar initiatives. The primary benefit of deregulation is an increase in system efficiency and accountability. The primary aim of this work is to locate a local source in a radial system at its optimum position along its size. In order to conclude the previous work, I proposed and applied a new, modified algorithm to 33 BUS and 69 BUS, resulting in reasonably excellent outcomes. It is difficult to introduce local sources into the radial system. Before adding a local source to the radial structure distribution system, we

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need to analyze three main points: technical, environmental, and financial (G. V. Naga Lakshmi & A. Jayalaxmi,2021). One of the first steps we must when installing local sources to any radial structure distribution system, it is to determine whether the local source system parameters are suitable for the current RSDS (Arya Christy C.B &Savier J.S. 2018).

In Figure 1a, the literature review mentions three distinct parameters of a distribution line in Figure 1b mention topics such as enhancing the voltage profile, managing load variability, minimizing active and reactive power loss, maintaining system availability rates, and coordinating protection equipment (Hosein Ghasemi *et al.* 2023; Yixiang Ma *et al.* 2023; Fan Chen, Ruichi Wang, Zheng Xu, Haitao Liu, 2023; Zhengnan Gao 2023, Dosung Kim & Deukyoung Lee 2023; Takele Ferede Agajie 2023; Lin Zeng, Hsiao-Dong Chiang 2022; Naqash Ahmad 2022). These concepts are crucial for maintaining the stability and reliability of a radial distribution system in a deregulated environment. From a system stability analysis perspective, the voltage profile is the most important parameter to consider. The integration of local sources into the system can influence the voltage profile, so it's crucial to ascertain if the voltage falls within an acceptable range (Imran Ahmad Quadri *et al.*,2018). If the current RSDS allows local source penetration, then need to consider another important aspect is the reliability of the system. Suppose we want to maintain the system's reliability. In that case, we have to protect the system, including the local source, against network contingencies like short-circuit fault current, line disturbance and frequency deviation (A.K. Singh, S.K. Parida 2023, Meng Yen Shih *et al.* 2019; Sadegh Jamali *et al.* 2019,). If we disregard this factor, the installation of a local source in RSDS results in a reduction in the system's reliability and stability rather than an improvement in performance. After going through several problems like protection coordinates changes, transient stability, and operational failure issues, which address the system reliability and stability (Bindu Vadlamudi & T. Anuradha 2023; Abdellatif Hamouda, Khaled Zehar 2011).

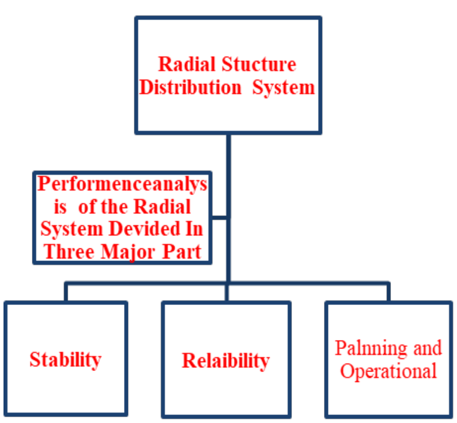

Figure 1: a. RSDS division based on performance

The initial objective is to determine the optimum location and size of local power sources (N. A. Khan *et al.* 2022) second objective is to reconfigure the RSDS with and without local resources and the final objective is to allocate the total loss to local sources and loads. Here in, this paper concentrates on the optimal placement and sizing of local sources in the RSDS network.

The entirety of the total literature is divided into three main sections, which are clearly seen in Figure 2. The PSO algorithm requires minimal computational effort. The algorithm updates particle positions based on historical and current global best positions (Subhasis Sanyal, 2023). Occasionally, the local optimal conditions of highly dimensional solution spaces trap the PSO. Since the true global optimum is so dependent on local information, it is challenging to find and depart from these suboptimal positions (personal best and global best). You may find yourself trapped in the local optima of high-dimensional solution spaces. Since, it relies so heavily on local Knowledge (personal best and global best), it can be challenging to go past these suboptimal regions and find the true global optimum and lack of diversity (Ahmed G. Gad 2022). We have improved the real-code genetic algorithm. The algorithm's main goal is to improve the voltage profile while minimizing total real power losses in radial structural distribution systems (RSDS). This is one way to install local source units. We couple this local search scheme-based algorithm with the actual coded genetic algorithm to capitalize on its advantages. This integration reduces the time required to determine the optimal location and size of local source units (Emad Ali Almabsout, 2022). We can use the hybrid genetic dragonfly approach as an optimization method to

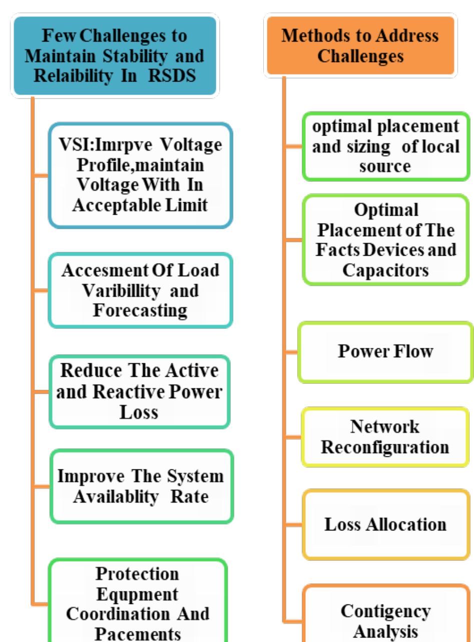

Figure 1: b. Challenges and methods to address

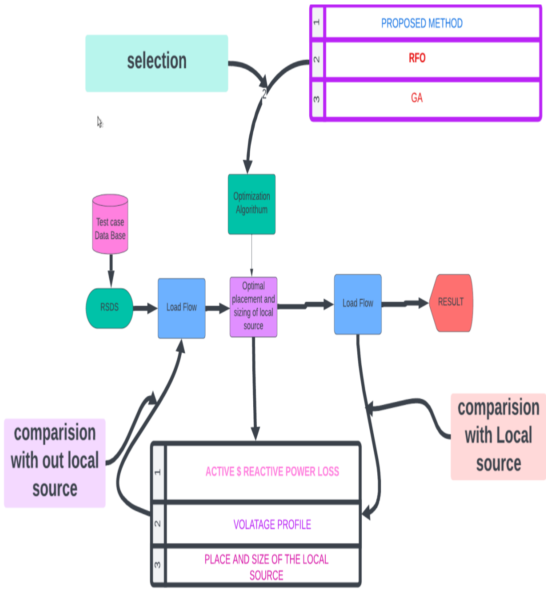

Figure 2: Total workflow diagram

determine the optimal placement and size of local source units. (Lakshmi, G.N., Jayalaxmi, 2021). The Honey Ba local source algorithm (HBA) can reduce a system's net power loss by determining the optimal size and placement of capacitors and different types of local sources. When used with the HBA, the combined power loss sensitivity (CPLS) factor can help identify possible candidate buses for the best placement of local sources and capacitors. This speeds up the estimation process (Elseify, M.A., Kamel *et al.* 2022). I propose an improved path-finding method that includes mining and exploration capabilities for all team members. We generate new candidate solutions utilizing the prior best one using search dimensional ratio (SDR). ASDR-PFA dynamically updates the SDR parameter to balance exploration and mining, accelerating convergence to the optimal value (Ajit Kumar Mahapatra, Nibedan Panda 2023, Chengmei Tang, Yongquan ZhouAn 2022).

Problem Statement

The primary objective of the study is to minimize the P_{loss} of the RSDS without affecting the system's stability and reliability. This is achieved by carefully measuring and placing the local source units in the right spot. Although they have certain limitations, genetic algorithms and PSO search can handle constrained optimization problems pertaining to the ideal placement and size of local sources. They are prone, for instance, to local extreme solutions and partial optimization. They must also operate in extremely large-dimensional workspaces, as errors occur when this algorithm operates in such situations. The PSO algorithm often produces inaccurate results because it becomes trapped in local optima. This work aims to handle the above-mentioned constraints effectively while reducing P_{loss}.

Proposed Methodology

A new method for selecting local sources in the finest places of radial structure distribution networks (Figure 3) is proposed with the goal of minimizing $P_{loss.}$ Using powerful metaheuristic optimization strategies and proportionate sharing to allocate loss, the method solves the nonlinear optimization issue. Under both equality and inequality Limitations, the optimal location for the local sources is determined to minimize the total P_{loss} using the LSF and VSI. The best place for local source is determined using the modified pathfinder algorithm (MPFO). The power contribution and power-sharing matrices are used to estimate the loss allocation among the local sources after the location and size of each local source have been chosen. The proposed method will be tested on 12_bus and 33_bus radial structure distribution systems (RSDS in order to confirm its viability). The results will be compared with other approaches that are currently in use. Reduced $P_{loss,}$ increased efficiency, increased reliability, and an improved voltage profile are among the benefits associated with the placement of local sources.

Objective Function

Allocating local sources requires careful attention to the definition of the objective function and restrictions. The objective function of the optimization problem should focus on reducing the P_{loss} in the system and improving the voltage profile of the buses with appropriate weighting. To achieve this goal, minimizing the cumulative voltage deviation (CVD) at each bus is critical. The CVD is calculated using equation 1 and serves as an indicator of the improvement in the voltage profile. Therefore, it is important to carefully model the objective function and constraints when addressing the problem of local source allocation.

$$\mathrm{CVD} = \begin{cases} 0 & \text{if } 0.95 \leq |V_m| \leq 1.05 \\ \sum_{m=1}^{N_b} |1 - V_m|, & \text{else} \end{cases} \quad (1)$$

The objective function has two goals that are weighted accordingly, and it is subject to specific constraints as given below

$$\text{Minimise} \left\{ \omega . \frac{\sum_{m=1}^{nl} P_{loss}(m)|_{wLS}}{\sum_{m=1}^{nl} P_{loss}(m)|_{woLS}} + (1-\omega) . \frac{\mathrm{CVD}|_{wLS}}{\mathrm{CVD}|_{woLS}} \right\} \quad (2)$$

To achieve the minimum value of a given objective function, certain constraints must be adhered to, including both equality and inequality constraints. These constraints must be satisfied simultaneously in order to find the optimal solution.

Power Balance

The P and Q power balance is given in eqns (3) and (4) (Figure 3).

$$P_{slack} + \sum_{m=1}^{N_{LS}} P_{LS,m} = \sum_{m=1}^{N_l} P_{D,m} + \sum_{m=1}^{nl} P_{loss}(m) \quad (3)$$

$$Q_{slack} + \sum_{m=1}^{N_{LS}} Q_{LS,m} = \sum_{m=1}^{N_l} Q_{D,m} + \sum_{m=1}^{nl} Q_{loss}(m) \quad (4)$$

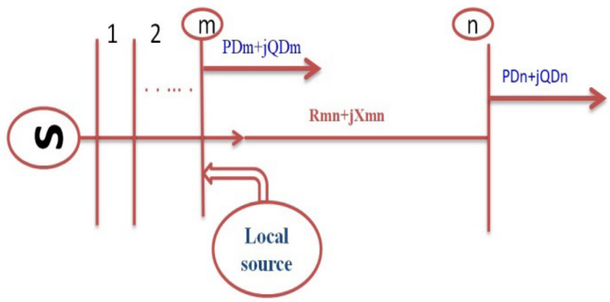

Figure 3: Radial distribution portion between nodes m and n

Bus Voltage Limits

To guarantee a steady and reliable supply, the network must maintain an acceptable voltage profile. The voltage threshold is provided by

$$|V_{min}| \leq |V_m| \leq |V_{max}|, \quad m\forall N_b \quad (5)$$

Local Source Sizing Limits

$$P_{LS,min} \leq P_{LS,m} \leq P_{LS,max}, \quad m\forall N_{LS} \quad (6)$$

$$PF_{LS,min} \leq PF_{LS,m} \leq PF_{LS,max}, \quad m\forall N_{LS} \quad (7)$$

$$Q_{LS,m} = P_{LS,m}.\tan\left(\cos^{-1}(PF_{LS,m})\right) \quad (8)$$

Maximum Level of Local Source Penetration

The total power generated by local source must be limited to a certain degree of implementation in order to preserve network stability and avoid problems brought on by over generation.

$$\sum_{m=1}^{N_{LS}} P_{LS,m} \leq \mu \,.\sum_{n=1}^{N_l} P_{D,n} \quad (9)$$

The term "penetration" refers to the ratio between the power generated by local sources and the total load demand of the power system. It is given by Eqn. (10)

$$\mu = \frac{\sum_{m=1}^{N_{LS}} P_{LS,m}}{\sum_{m=n}^{N_l} P_{d,n}} \quad (10)$$

Network Active Power Loss

Local sources should reduce overall system losses compared to a scenario without local source

$$\sum_{m=1}^{nl} P_{loss}(m)|_{wLS} < \sum_{m=1}^{nl} P_{loss}(m)|_{woLS} \quad (11)$$

Minimization Function

Loss sensitivity factor (LSF)

The loss sensitivity factor (LSF) is given by

$$LSF(n) = \frac{\partial P_{mn-loss}}{\partial P_n} \quad (12)$$

$$= \frac{2P_n}{|V_n|^2}.R_{mn}, \quad n\forall\{2 \ldots.. N_b\}, m\forall\{1,..(N_b-1)\} \quad (13)$$

Voltage stability index

The distribution system usually has a radial structure, where buses that are further away from the substation experience more voltage drop and are more prone to voltage collapse. Therefore, VSI is utilized to determine the most vulnerable buses to voltage collapse.

$$VSI = |V_m|^4 - 4(P_nX_m - Q_nR_m)^2 - 4(P_nR_m + Q_nX_m)\,|V_m|^2 \quad (14)$$

Local sources should be installed in the busses that show the greatest suitability values based on both voltage indications and the LSF. Due to their reliance on network circumstances, load, and configuration, LSF assessments might not always be accurate.

Modified Pathfinder Algorithm

Step 1: Initialization In this step, we initialize the parameters like Nb, Vm, m.

Step 2: Random generation Input vectors are randomly created after the initialization stage.

Step 3: Fitness evaluation each individual member & find the pathfinder.

Fitness=

$$Minimise\left\{\omega.\frac{\sum_{m=1}^{nl} P_{loss}(m)|_{wLS}}{\sum_{m=1}^{nl} P_{loss}(m)|_{woLS}} + (1-\omega).\frac{CVD|_{wLS}}{CVD|_{woLS}}\right\} \quad (15)$$

Step 4: Calculate the pathfinder's new location.

$$X_p^{t+1} = X_p^t + 2 \times r_3 \times \left(X_p^t - X_i^t\right) + A \quad (16)$$

t = iteration count,

$$r_3 = rand\,(1, problem\ size),$$

$$A = u_2 \times exp^{\frac{(-2\times t)}{tmax}}; \quad (17)$$

$$u_2 = rand\,(1, problem\ size)$$

Step 5: If the pathfinder's new location is superior to its previous one, it should be updated.

Step 6: Start initialize the follower population size, compute the new position and fitness of each follower by using:

$$X_i^{t+1} = X_i^t + 2 \times R_1 \times \left(X_j^t - X_i^t\right) + R_2 \times \left(X_p^t - X_i^t\right) + \varepsilon;$$

$$i \geq 2. \quad (18)$$

$$\varepsilon = \left(1 - \frac{t}{tmax}\right) \times u_1 \times D_{i,j} \quad (19)$$

$$u_1 = rand\,(1, problem\ size)$$

$D_{i,j}=\left\|X_i^t - X_j^t\right\|$; ["j" is the adjacent position to "i"]

Step 7: New fitness is better than the current fitness, then update the follower.

Step 8: Choose the best one from the total group of search agents (followers).

Step 9: The best agent chosen is better than the pathfinder (leaders) then update the pathfinder.

Step 10: Iterations until the most optimal global one is found (Figure 4).

Results and Discussions

The proposed MPFO to local sources insertion method was tested on IEEE 12_bus, IEEE 33_bus, and RSDS, and the

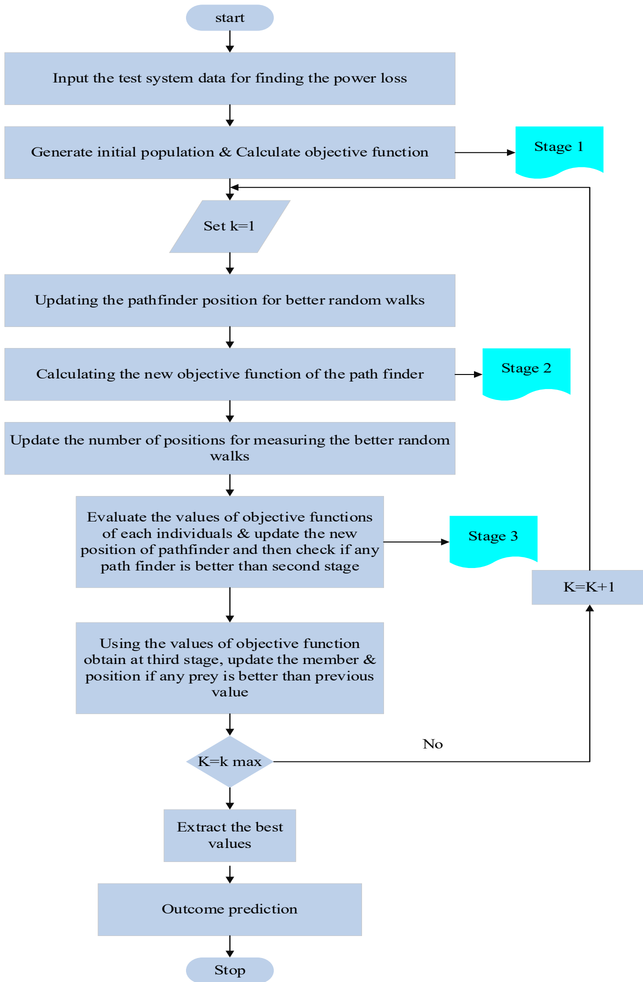

Figure 4: Proposed MPFO method flow chart for optimal place and size of local source

Table 1: Evaluation of performance of proposed method compared with other existing techniques in IEEE 12_bus system

	Proposed MPFO	*RFO*	*GA*
P_{loss}	3.2519	4.7052	10.9858
Q_{loss}	1.3412	5.3852	6.3998
Number of local sources	2	2	2
Optimal local source location	11 7	7 11	4 8
Optimal local source size P kW	121 193	265 155	60 323
Optimal local source size Q kVAR	58.603 93.4742	128.3454 75.06993	29.05933
Minimum voltage	0.9561	0.92789	0.85292
Minimum voltage bus number	9	3	5
Maximum voltage	0.99875	0.91225	0.89169
Maximum voltage bus number	2	11	8

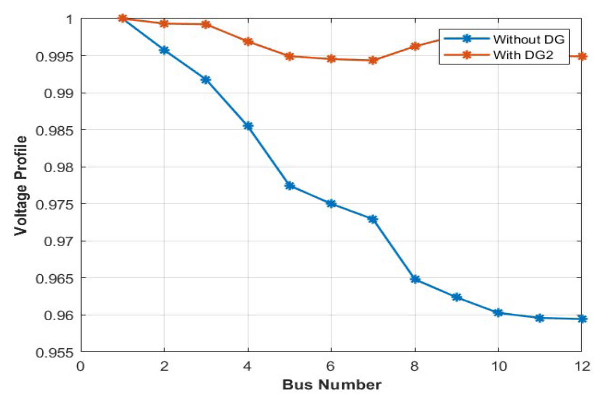

Figure 5: voltage profile of the 12 bus system of placing two Local sources

results were compared with existing accepted approaches (Figure 4). According to the study, the suggested approach produced superior voltage profiles, increased efficiency and reliability, and notable drops in P_{loss} and power consumption. These advantages emphasize how crucial it is to include Local sources in electrical power distribution networks.

CASE I: Evaluating Performance on the IEEE-12 Bus System

If Local source is not placed in a 12-bus RSDS system, the active power loss is 14.99107 KW. I then arbitrarily arranged the local source1 and local source 2 in the 12 bus, and the active power loss was 5.4844 KW. When I used the MPFO, RFO and GA algorithms, I saw active power losses of 3.25, 4.70 and 1098 KW respectively. The significance of the algorithm for positioning and sizing a local source in a network is evident here. And the results of the suggested technique definitely outperform the results of the reaming method which can be observe by seeing Table 1. We were able to reduce the active power loss by roughly 77.6% using the proposed method, 68% using RFO, and 26% using the genetic algorithm (Table 1).

We can see in Figure 5 how the voltage profile of the system increases after inserting local source 2 into a 12-bus RSDS system. Maximum and minimum voltages also show a lot of difference.

CASE II: Evaluating the Performance on the IEEE-33 Bus System

After applying the proposed method to the 33 bus system got a notable difference in active power loss of 129.2875 and reactive power loss of 81.9301 compared to some of the algorithms, which is shown in Table 2 and also, seen maximum voltage percentage reaches 99.2 and minimum voltage percentages 93 at bus number 18, at the same time optimal place and location for local sources are find, which are shown in Table 2.

In Figure 6 we can see the active and reactive power loss difference between the proposed method and reaming method RFO, GA.

Table 2: Performance analysis of the proposed method compared with other existing techniques in IEEE 33_bus System

	Proposed MPFO	RFO	GA
P_{loss}	129.2875	134.2563	146.8021
Q_{Loss}	81.9301	86.1035	87.4528
Number of local source	2	2	2
Optimal local source location	30 32	14 17	16 33
Optimal local source size P kW	377 332	430 286	388 325
Optimal local source size Q kVAR	182.5894 160.79	208.2585 138.5161	187.917 157.4047
Minimum voltage	0.9402	0.88748	0.87885
Minimum voltage bus number	18	33	31
Maximum voltage	0.99176	0.91584	0.90148
Maximum voltage bus number	2	2	2

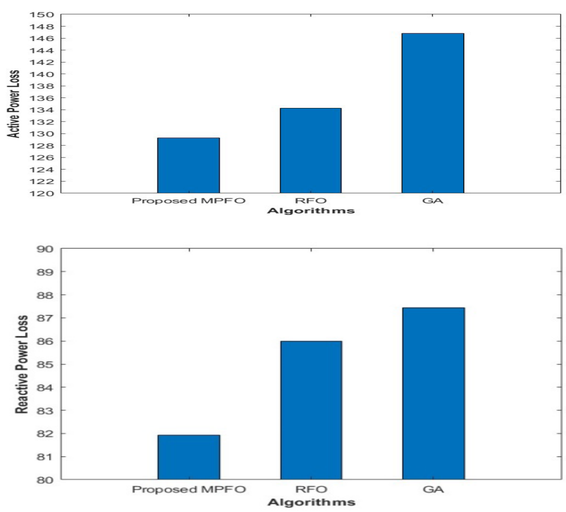

Figure 6: Active and reactive power loss comparison between proposed MPFO, RFO and GA algorithms

The Table 2 and Figure 6 show that there is some discrepancy between the suggested technique and RFO In terms of active power loss and reactive power loss reduction. In comparison to GA, there is a noticeable difference. Applying the algorithm to the 33-bus system yields the best positions for the local source change for each technique: 30 and 32 buses for the suggested method, 14 and 17 buses for the RFO method, and 16 and 33 buses for the GA method. When comparing the size of the Local source to RFO and GA, the suggested procedure produced a good result. The voltage profile of the system increases when local sources are placed by using the proposed method. When compared to alternative approaches, minimum bus voltage, and maximum bus voltage in the suggested method are good, which can be observed in Figure 7.

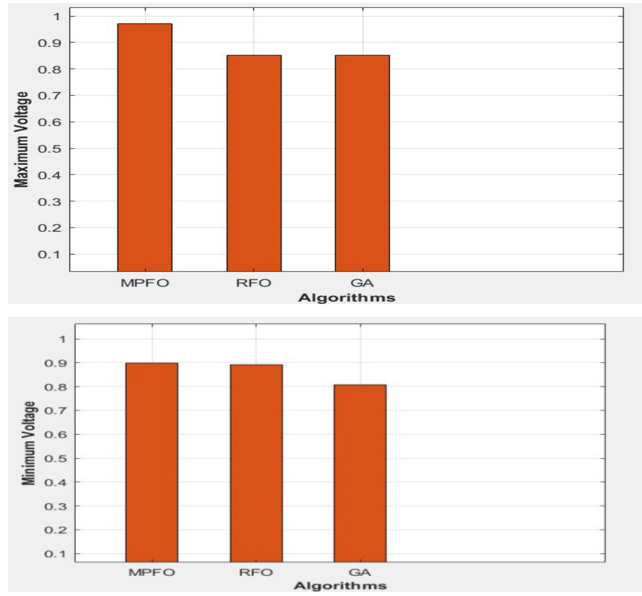

Figure 7: Maximum and minimum voltages comparison between algorithms

Conclusion

In order to reduce P_{loss}, a novel method for choosing the best locations for local sources in distribution networks is presented in this work. The method divides up the loss using strong metaheuristic optimization techniques and fair sharing. The LSF and VSI are used to find the best place for local sources while lowering the overall P_{loss}. MPFO is a new version. The proposed method's viability is evaluated using IEEE 12_bus, IEEE 33_bus, and RSDS, and the outcomes are contrasted with those of other methods now in use. According to the study, there are several advantages to using the proposed approach for placing local sources, such as lower P_(loss),q-loss, increased reliability and efficiency, and better voltage profiles. When the penetration of local sources is increased, the total power loss decreases. Power contribution and power-sharing parameters are used to determine the optimum local source size and loss distribution among local sources. The suggested method provides a practical and cost-effective way to position local sources, which can reduce power loss and enhance the performance of power distribution networks. Power system planners and operators can find a useful tool in the implementation of the modified pathfinder optimization model, which can help identify the best places for local sources.

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