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Simple Strategy for Finding Optimal Location and Size of Distributed Generators and SVC Devices in Radial Distribution Systems

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Abstract: This study proposed a simple method for determining the best position and size of distributed generation (DG) and static VAR compensator (SVC) in the radial distribution system (RDS), as well as the impact of employing two different types of DG on total losses. The target functions are designed to reduce the system's overall power losses, improve the voltage stability margin (VSM), and reduce drop voltages. This method relies on the deployment of many sizes of DGs or SVCs in each bus and comparing their impacts of them on the system's overall losses and taking optimal sizing and placement of them if that given minimum losses. Moreover, the proposed strategy does not require extra work to set the parameter settings and weighting factors to obtain the objective functions. To assess the performance of the suggested approach, five instances were evaluated during DG and SVC installation in this study. The suggested approach is tested on the RDS's IEEE 33_bus and 69_bus to ensure its practicality. This method decreased losses by 92.72 % for IEEE 33_bus and 96.91 % for IEEE 69_bus. In the 33_bus, the minimum VSM is improved from 0.6674 to 0.9697 p.u, and the minimum bus voltage is improved from 0.9038 to 0.994 p.u. While in the 69_bus, the minimum VSM is enhanced from 0.6835 to 0.9761 p.u and the minimum bus voltage is enhanced from 0.9093 to 0.9958 p.u, with the results compared to other existing methodologies.

Keywords: Radial distribution system (RDS), Distributed generator (DG), Static VAR compensator (SVC), Voltage stability margin (VSM), Optimization technique.

1. Introduction

Because distribution systems have such a large influence on the design and efficiency of power grids, academics have paid increasing attention to them. The power system is vulnerable to several power quality issues like voltage collapse and high power losses. In addition, this network is considered a passive grid because it only consumes energy and does not contain any other supplied sources of power. As a result of the passive nature of traditional systems, the electrical designers of the power system have proposed several alternatives to increase system dependability and voltage control in distribution networks. Initially, planners were more inclined to create new lines. However, this is tough, and it comes at a large cost and takes a long time, not to mention the environmental challenges [1].

Distributed generators (DG) are power production mechanisms of small size and near to the customers that are an important factor in the generation of new electrical distribution systems, which will turn traditional passive networks into active networks [2]. The combination of DGs with flexible AC transmission system (FACTs) devices as real and reactive power compensating devices, respectively, plays a vital role in improving distribution system efficiency [3]. The use of DGs and FACTs can have disadvantages on distribution networks if they are not in the right location and size. Therefore, this equipment's best location and size significantly influence distribution system stability, such as reducing total losses and enhancing the voltage profile [4]. DG units are made up of renewable and non-renewable energy sources that feed into power systems that are handled at the distribution network. Integrating renewable sources into the traditional distribution network is now becoming increasingly profitable and appealing because of its economic and technical consequences.

Since the most of demands in distribution systems are inductive, the system's power factor lags. Networking losses, voltages, and system security may all suffer as a result of lagging. Special devices like distribution STATic COMpensator (DSTATCOM), dynamic voltage restorer (DVR), unified power quality conditioner (UPQC), and solid_state transfer switch (SSTC) could be utilized to eliminate these difficulties. Reactive power and imbalanced loads adjustment in the distribution system may be simply done with the aid of these components [5].

Many studies were previously proposed to determine the best location and size for DG and FACTs devices. Some of them will be discussed in this section. In [6], a crow search algorithm auto-drive particle swarm optimization (CSA-PSO) approach is utilized to describe the best renewable distribution generator placement, size, and numbers based on overall cost and loss reduction goals. In [7], the MOPSO (Multi_objective particle swarm optimization technique) was employed to tackle the issue of optimal DG and D_STATCOM, this strategy employs Pareto's optimization algorithms. Furthermore, a fuzzy-based technique is used to find the optimal solution for reducing overall losses, enhancing voltages, and lowering D_STATCOM costs. In [3], the optimal size of DG and D_STATCOM units is determined using a hybrid firefly and particle swarm optimization technique (HFPSO). The VSI method is used to determine the best position for DG and DSTATCOM. In addition, DG and DSTATCOM sizes are optimized using the HFPSO technique. In [8], the loss sensitivity factor (LSF) has been used to predict where the DG and DSTATCOM should be placed. To identify the ideal size of the DG and DSTATCOM, the bacterial foraging optimization algorithm (BFOA) was devised. In [9], the particle swarm optimization (PSO) technique is used to determine the optimal location and sizing of DGs and D_STATCOM in the distribution network for reduction of overall losses. In [10], the ideal position of DG and D_STATCOM is predetermined using the loss sensitivity factor (LSF) with voltage stability index (VSI) and the best sizing of DG and D_STATCOM is determined using a created inspired cuckoo search algorithm (CSA) to reduce the system's overall losses when equality, as well as inequality restrictions, were applied. Moreover, in [11], improved bald eagle search (IBES) is utilized for determining the appropriate placement and size of DSTATCOM resulting in considerable loss minimization and enhancement of voltage profile for various loads.

According to previous arguments, the distribution system will be active if distributed generators and compensators are used with an optimization technique that will be reducing network losses and keep the voltage in power distribution systems within acceptable ranges. In addition, to handle difficult optimization issues, the prior approaches required more statistical work, as well as more intricate ways to find the parameter settings and weighting factors. While the proposed simple optimization technique determined the ideal position and size for DG units and SVC devices without requiring such considerations.

The current article concentrated on the analysis and improvement of the IEEE 33_bus and 69_bus tests network. This paper proposed a new simple strategy to find the optimal location and size of DGs and SVCs. The proposed method will be using DG and SVC in each bus with changing the size of them to get minimum losses. At minimum losses will be indicated to optimal sizing and location for DGs and SVCs. Therefore, this strategy is utilized to lower the drop voltage and minimize power loss in the RDS.

This article's remaining parts are organized as follows. The mathematical model of the problems is described in the second part. The proposed strategy for reaching the research aim is explained in the third part. The simulation's results, as well as the discussions, are presented in context in part four. Part five contains the conclusions as well as future work.

2. Mathematical model

2.1 Modified newton raphson method

Although the Newton approach performs very well in transmission networks, it performs poorly for most distribution networks due to its higher R/X ratio, which reduces the Jacobian matrix's diagonally domination [12]. Therefore modified Newton Raphson is used in this article.

The Jacobian matrix for a radial distribution system (RDS) is created as UDU^T, where U is a fixed upper triangular matrix dependent purely on system topology and D is a diagonal matrix, with the following assumptions: low voltage differences between two neighboring buses, no shunted branch [13]. All backward/forward sweep techniques as well as the rapid decoupling approach have employed similar conversions. The active power (P_i) and reactive power (Q_i) at the bus i_th are as follows

$$P_i = \sum_{j=1}^{N} |V_i||Y_{ij}||V_j| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (1)$$

$$Q_i = -\sum_{j=1}^{N} |V_i||Y_{ij}||V_j| \sin(\theta_{ij} - \delta_i + \delta_j) \qquad (2)$$

Where $Y_{ij} = G_{ij} + jB_{ij}$ is the node admittance matrix and θ_{ij} is the angle of them. $V_i = |V_i|\angle\delta_i$ and $V_j = |V_j|\angle\delta_j$ are the sending and receiving bus voltages.

The power flow issue is solved by Eq. (3) for ΔP and ΔV using the traditional Newton approach.

$$\begin{bmatrix} C & D \\ E & F \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V/V \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad (3)$$

Where $C = \frac{\partial P}{\partial \delta}$, $D = \frac{\partial P}{\partial V}$, $E = \frac{\partial Q}{\partial \delta}$, and $F = \frac{\partial Q}{\partial V}$ are Jacobian matrices as explained below, and ΔP, ΔQ, Δδ, and ΔV/V are mismatch values for active power, reactive power, voltage angle, and amplitude voltage, respectively.

$$C_{ij} = -V_i V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \;\; j \neq i \qquad (4)$$

$$C_{ii} = V_i \sum_{j\in i \& j\neq i} V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \qquad (5)$$

$$D_{ij} = -V_i V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \;\; j \neq i \qquad (6)$$

$$D_{ii} = -V_i \sum_{j\in i \& j\neq i} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) - 2V_i^2 G_{ii} \qquad (7)$$

$$E_{ij} = V_i V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \;\; j \neq i \qquad (8)$$

$$E_{ii} = -V_i \sum_{j\in i \& j\neq i} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \qquad (9)$$

$$F_{ij} = -V_i V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \;\; j \neq i \qquad (10)$$

$$F_{ii} = -V_i \sum_{j\in i, j\neq i} V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) + 2V_i^2 B_{ii} \qquad (11)$$

Due to the small voltage change between two nearby nodes additionally $G_{ii} + jB_{ii} = -\sum_{j\in i \& j\neq i} (G_{ij} + jB_{ij})$, the Jacobian matrix for networks without shunted branch can be derived as:

$$C_{ij} \approx V_i V_j B_{ij} \cos\theta_{ij} \qquad j \neq i \qquad (12)$$

$$C_{ii} \approx -V_i \sum_{j\in i \& j\neq i} V_j B_{ij} \cos\theta_{ij} \qquad (13)$$

$$D_{ij} \approx -V_i V_j G_{ij} \cos\theta_{ij} \qquad j \neq i \qquad (14)$$

$$D_{ii} \approx V_i \sum_{j\in i \& j\neq i} V_j G_{ij} \cos\theta_{ij} \qquad (15)$$

$$E_{ij} \approx V_i V_j G_{ij} \cos\theta_{ij} \qquad j \neq i \qquad (16)$$

$$E_{ii} \approx -V_i \sum_{j\in i \& j\neq i} V_j G_{ij} \cos\theta_{ij} \qquad (17)$$

$$F_{ij} \approx V_i V_j B_{ij} \cos\theta_{ij} \qquad j \neq i \qquad (18)$$

$$F_{ii} \approx -V_i \sum_{j\in i \& j\neq i} V_j B_{ij} \cos\theta_{ij} \qquad (19)$$

According to Eqs. (12) – (19), matrices C, D, E, and F always have the same properties as the Nodal Admittance matrix (symmetric, sparsity patterns), therefore it may be constructed as follows:

$$C = F = H_{n-1} L_B H_{n-1}^T \qquad (20)$$

$$E = -D = H_{n-1} L_G H_{n-1}^T \qquad (21)$$

Where L_B and L_G are diagonal matrices with diagonally entries $V_i V_j B_{ij} \cos\theta_{ij}$ and $V_i V_j G_{ij} \cos\theta_{ij}$. As a result, Eq. 1 may be set as follows:

$$\begin{bmatrix} H_{n-1} & \\ & H_{n-1} \end{bmatrix} \begin{bmatrix} L_B & -L_G \\ L_G & L_B \end{bmatrix} \begin{bmatrix} H_{n-1}^T & \\ & H_{n-1}^T \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \frac{\Delta V}{V} \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \qquad (22)$$

H_{n-1} is an upper triangular matrix with all diagonal entries equal to 1 and all non_zero off_diagonal entries equal to -1 if nodes and branches are arranged correctly. Arranging branches by layering away from the root bus (source bus) is one technique to build such a H_{n-1}. This is the ordering strategy used here. Each branch is pointing towards the root bus. The branching and bus orders are executed simultaneously.

The modified Newton Raphson previously established that the Jacobian matrix Eq. (22), like the nodal admittance matrix, may be created as the product of three square matrices.

2.2 Static VAR compensator (SVC)

SVC is a FACTs device that utilizes a parallel-connected capacitor and reactor to produce reactive parallel compensation for improved bus voltages and lower reactive power usage in a power network.

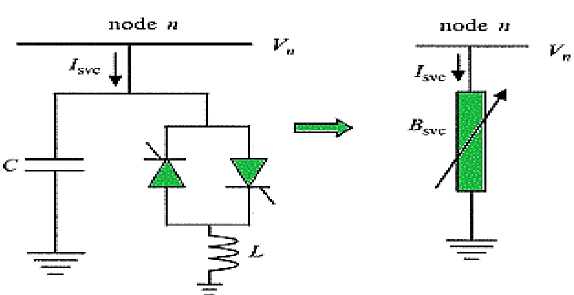

Figure. 1 Diagram of SVC

Capacitor banks and reactors are the major elements of SVC. Thyristor controlled reactor (TCR), thyristor switched capacitor (TSC), and TSC with TCR are three common forms of SVC [14]. Fig. 1 depicts a diagram of SVC.

SVC's corresponding impedance (X_{SVC}) may be written as :

$$X_{SVC} = \frac{X_C X_L}{\frac{X_C}{\pi}(2(\pi-\sigma)+sin(2\sigma))-X_L} \tag{23}$$

Where σ, X_C, and X_L are the thyristor's firing angle, SVC's capacitance, and reactance, respectively.

SVC susceptibility (B_{SVC}) can be determined by

$$B_{SVC} = \frac{1}{X_{SVC}} \tag{24}$$

The transferring current (I_{SVC}) formula for variable parallel compensator is as follows:

$$I_{SVC} = jB_{SVC}V_n \tag{25}$$

Where Vn is node voltage at SVC connection. In addition, SVC's reactive power (Q_{SVC}) may be computed using:

$$Q_{SVC} = -{V_n}^2 B_{SVC} \tag{26}$$

$$Q_{SVC}^{min} \leq Q_{SVC} \leq Q_{SVC}^{max} \tag{27}$$

Where Q_{SVC}^{min} and Q_{SVC}^{max} are the minima and maximum limitations of SVC's reactive power, respectively [15]. In this paper, the minimum value is set to zero and the maximum value must not exceed the total demand reactive power.

2.3 Distributed generator (DG)

The distributed generator is defined as small generation devices ranging from just a few kilowatts (kW) to 50 megawatts (MW) in other words it is defined as energy storage systems commonly positioned near load centers as distributed energy resources[16]. DG is separated into four groups, each of which has its explanation:

Type1: DGs with Real power injection
Type2: DGs with reactive power injection
Type3: DGs with real and reactive energy injection
Type4: DGs with real power injecting and absorbing reactive power [17].

This article suggested showing the impact of two types of DG (type1 and type3) on the improvement of total power losses. To prevent the flow of power toward the station, the ideal DG size must be within appropriate constraints and should not be exceeding the whole total of the demands and total power losses[18]. The following relationship represents the mathematics definitions of the inserted real power boundaries:

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \tag{28}$$

Where the P_{DG}^{min} and P_{DG}^{max} are the minimum and maximum real power of DG's injection. In this paper, the minimum value is set at zero.

2.4 Voltage stability margin (VSM)

Voltage stability is defined as the power network's ability to maintain the voltages on all network nodes within a suitable range after disturbances. The principal reasons for voltage instability are rising loads and the system's failure to supply necessary reactive power. As a result, the VSM is a meter that detects nodes on the edge of collapse[19]. A simple power flow approach was published in [20] to calculate a VSM in RDS. The following formula can be written using Fig. 2:

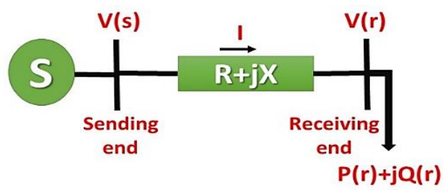

Figure. 2 Equivalent circuit of RDS

$$I = \frac{V(s)-V(r)}{R+jX} \tag{29}$$

Where I, R, X, V(s), and V(r) are the current, resistance, reactance, sending voltage, and received voltage respectively.

$$R = Real\{ (V(s) - V(r))/I \tag{30}$$

$$X = Imag\{ (V(s) - V(r))/I \tag{31}$$

$$P(r) - jQ(r) = V^*(r)I \tag{32}$$

Where P(r) and Q(r) are the real and reactive power of the received bus. By using Eqs. (29 – 32), we get

$$|V(r)|^4 - [|V(s)|^2 - 2P(r)R - 2Q(r)X] * |V(m)|^2 + [P^2(r) + Q^2(r)][R^2 + X^2] = 0 \tag{33}$$

Let

$$b = [|V(s)|^2 - 2P(r)R - 2Q(r)X] \quad (34)$$

$$c = [P^2(r) + Q^2(r)][R^2 + X^2] \quad (35)$$

Eq. (31) can be written as follows by using Eqs. (34) and (35):

$$|V(r)|^4 - b|V(m)|^2 + c = 0 \quad (36)$$

The criterion for load flow converging in RDS is clear in Eq. (36) as follows:

$$b^4 - 4c \geq 0 \quad (37)$$

After simplifying, we get Eq. (38) by putting (34) and (35) in (37).

$$|V(s)|^4 - 4\big(XP(r) - RQ(r)\big)^2 - 4(RP(r) - XQ(r))|V(s)|^2 \geq 0 \quad (38)$$

$$VSM(r) = |V(s)|^4 - 4\big(XP(r) - RQ(r)\big)^2 - 4(RP(r) - XQ(r))|V(s)|^2 \quad (39)$$

For reliable RDS operating conditions, we must have the following: $VSM(r) \geq 0$ for r=2,3,….no. of the bus. The preceding index has two important advantages: it only requires one load flow exercise to compute all of the VSMs, and it can be calculated at a reasonable speed.

2.5 Total real power losses

The overall real power losses (RPL) in a radial distribution system (RDS) with N buses are calculated as follows:

$$RPL = \sum_i^n \sum_j^n [(\frac{R_{ij}}{V_i V_j} cos\big(\delta_i - \delta_j\big) \big(P_i P_j + Q_i Q_j\big) + (\frac{R_{ij}}{V_i V_j} sin\big(\delta_i - \delta_j\big) \big(Q_i P_j - P_i Q_j\big) \quad (40)$$

Where n is the total number of buses and R_{ij} is the resistance of the branch between sending and receiving buses. V_i, V_j, δ_i, and δ_j are the voltages and angles of the sending and receiving bus, respectively. P_i and Q_i are the real and reactive power at the i_th bus. P_j and Q_j are the real and reactive power at the j_th bus [20].

2.6 Objective function

The objective function of this study is to decrease power losses while also enhancing the voltage stability margin and voltage profile by using the optimal location and size of DG and SVC in RDS.

$$minimize\ (function) = \min(RPL + \frac{1}{VSM} + drop\ voltage) \quad (41)$$

Subjected to

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (42)$$

VSM and RPL are defined by Eqs. (39) and (40), respectively. $P_{DG} < P_{\text{demand}}$ and $Q_{SVC} < Q_{\text{demand}}$. V_i^{min} and V_i^{max} are the minimum and maximum limit of bus voltage, respectively.

The goal function results in reduced real power loss, increasing voltage stability margin, as well as minimizes the drop voltages without the requirement for secondary concerns like weighting factors. This strategy may also be used to plan any RDS in the long term. If a new piece of the existing distribution network is installed, simulations must be redone, taking into account the new buses.

3. Proposed method for optimal sizing and location

Because of concerns associated with the non-optimal allocation of DG and SVC, such as increased power losses and drop voltages, the identification of acceptable locations for DG and SVC placement is critical. Against that backdrop, we offer three DGs and three SVCs with the best position and size based on the enhancement of VSM, bus voltages improvement, and loss reduction in this article. It has been observed by placing distributed generators and compensators in distribution networks that the change in real power loss with DG's and SVC's electricity production may be represented by an approximately quadratic equation as shown in Fig. 3. By increasing the energy supply from DG or SVC at this node, the overall network losses are lowered

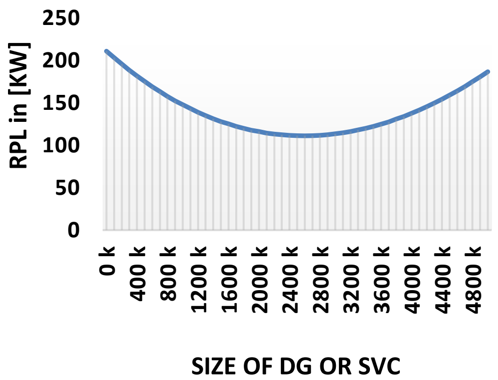

Figure. 3 The relation between real losses and size

until it reaches a minimal value. As a result, when the overall network losses are at their lowest, the best sizing for DG or SVC is determined.

This procedure is repeated in each node of the network, and the optimum size with total network losses is calculated at each bus of the network. When the overall network losses are the least, the optimum site and size are determined. Therefore, procedures to follow for this proposed optimization technique as explained in these steps:

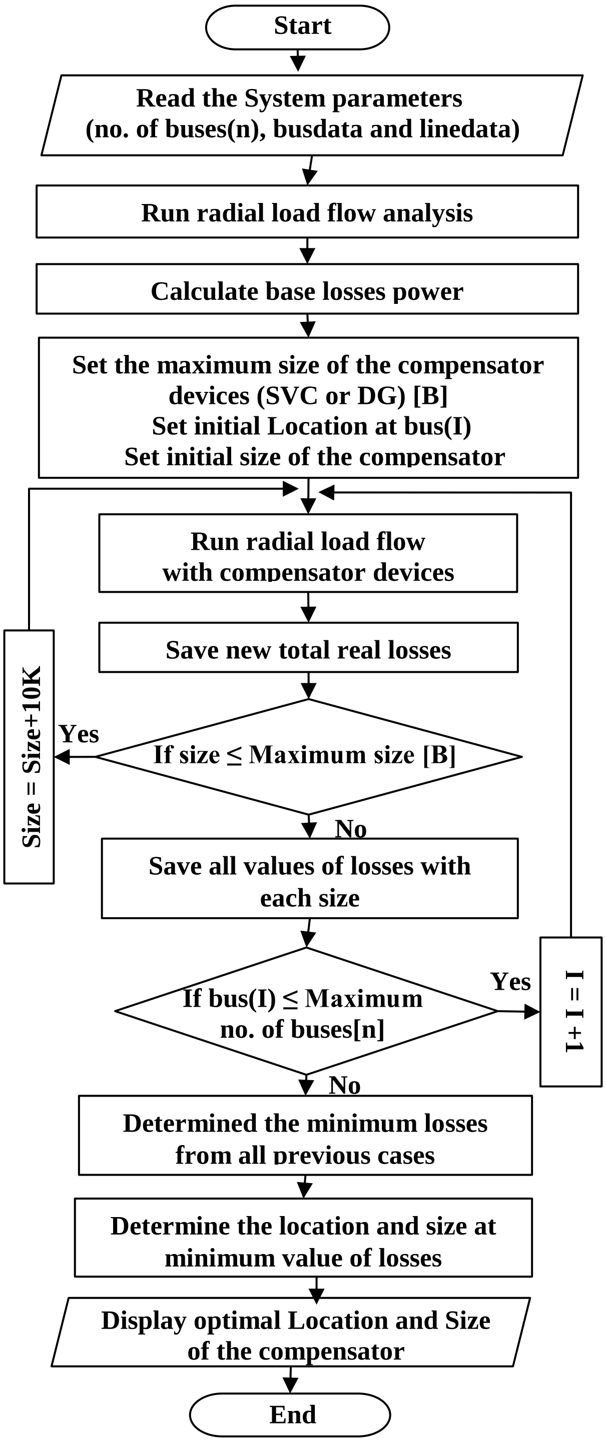

Figure. 4 The flowchart of the proposed method

Step 1: Read the system parameters such as line data, bus data, number of branches, and number of buses.
Step 2: Run the modified Newton Raphson method for a load flow analysis of RDS as described in 2.1.
Step 3: Determined the base total power losses without using any compensator devices (SVC or DG).
Step 4: Set all values that will be utilized in this proposed method such as the maximum number of iterations and maximum size (B) with defined the initial location at the bus (I) as well as the initial size.
Step 5: Run the Radial load flow again after using the compensator devices.
Step 6: Determined the new value of the total losses after using the compensator.
Step 7: Increasing the size of the compensator gradually with the setting step size as you like. And repeat steps 5 and 6.
Step 8: Check if the currently sizing of the compensator is less than or equal to the maximum size (B). If this condition is true, repeat steps (5, 6, and 7). And if this condition is false, apply the next step.
Step 9: Determine and save the minimal value of total real losses with the size of the compensator that is used in each of the preceding cases.
Step 10: Determine whether the present bus (I) is less than or equal to the network's total number of buses. If this is true, go back to step 5 and increase the placement of the compensator ($I = I + 1$). Apply the following step if this condition is false.
Step 11: Comparison of all the previous cases and determined the minimum real power losses with the sizing of the compensator and its location that is used.
Step 12: Display the optimal location and size of the compensator.

In addition, the proposed method will be the explanation the impact of using type 1 of DG with a unity power factor and type 3 of DG with a 0.85 lagging power factor on the total power losses. The flowchart of the proposed method is shown in Fig. 4.

4. Results and discussions

The suggested method’s efficacy is evaluated using conventional IEEE-33 and IEEE-69 node networks. To put it another way, one or many DG and SVC units have been placed in both testing networks for greater economic and technological advantages. The highest and lowest DG and SVC ratings are calculated as less than total demands and zero, respectively. Excluding the swing node, all of the other nodes are regarded as likely candidates for DG or SVC installation. The maximum and minimum bus voltage limitations are 1.05 p.u. and 0.95 p.u.,

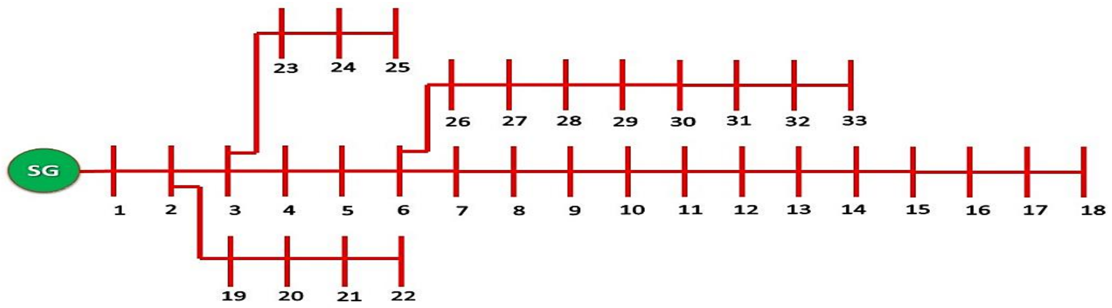

Figure. 5 IEEE 33_bus test system

Table 1. IEEE_33 bus with one SVC

	HFPSO [3]	**PSO** [9]	**MOPSO** [7]	**BFOA** [8]	**Proposed Method**
Size in KVAR @bus	1300@30	1233@7	1470.3@30	1102.7@30	**1260@30**
Total Losses[KW]	151.34	153	152.86	152.14	**151.282**
Min. Voltage[pu]	0.9169	0.922	0.9185	0.9151	**0.916538892**
Min. VSM	0.7068	0.726	0.7116	0.7012	**0.705671516**
Reduction in losses%	28.2%	27.41%	27.48%	27.82%	**28.23%**

respectively, ±5%[21]. MATLAB version 2017a was used to generate the simulation results.

Each system was established under five different scenarios to achieve the study's goals:

Case 1: A system with only one SVC.
Case 2: A system with only one DG.
Case 3: A system having a single SVC and a single DG.
Case 4: Using three SVC and three DG in the system.
Case 5: Impact of two types of DG on the real power losses.

4.1 IEEE 33 bus test system

The IEEE 33_bus basic configuration network is shown in Fig 5. There are 33 buses and 32 branches in the system. The load demands have a total active power of 3715KW and reactive power of 2300KVAR. It is powered by a synchronous generator with a base capacity of 100 MVA and a voltage of 12.66KV at 60Hz. Electrical data for the 33_bus test feeders can be found in [22]. For a 33-bus system without DG and SVC devices, active and reactive losses are 210.774KW and 142.855KVAR, respectively. On bus 18, it shows the lowest voltage of 0.9038 p.u, as well as the lowest value of VSM is 0.6674 on this bus. The proposed method findings are compared with the previous methods such as particle swarm optimization (PSO)[9], multi_objective (MOPSO)[7], bacterial foraging optimization algorithm (BFOA)[8], and hybrid firefly particle swarm optimization (HFPSO)[3].

Case 1: IEEE 33_bus with only one SVC.

Total losses reduction, VSM improvement, and enhanced bus voltages are being used as objective functions for sake of simplification and comparison. Table 1 shows the results achieved using this suggested approach. It shows that when a single SVC is utilized with size 1260 KVAR at bus 30, the losses produced by the suggested approach are 151.282 kW, while 153 kW is obtained using PSO, 152.86KW by using MOPSO, 152.14KW by using BFOA, and 151.34 KW by using HFPSO.

Case 2: IEEE 33_bus with only one DG.

The optimal size of the DG unit is equal to 2590KW with a unity power factor located at bus 6 by using the proposed method to reduce losses power to 110.997KW similar to that obtained by the MOPSO. Minimum VSM and bus voltage is improved to 0.7887 and 0.9424 p.u. respectively. As a compression with the previous methods, it shows the PSO reduced the losses to 114.89KW. While the BFOA reduced the losses to 113.14KW. In addition, the HFPSO has reduced the total losses to 111.23KW as explained in Table 2.

Table 2. IEEE_33 bus with one DG

	HFPSO [3]	**PSO** [9]	**MOPSO** [7]	**BFOA** [8]	**Proposed Method**
Size in KW @bus	2720@6	2895.1@7	2588@6	2200@6	**2590@6**
Total Losses[KW]	111.23KW	114.89	110.997	113.14	**110.997**
Min. Voltage[pu]	0.9442	0.9501	0.9424	0.9368	**0.942381062**
Min. VSM	0.7949	0.815	0.7886	0.764	**0.788688643**
Reduction in losses%	47.23%	45.49%	47.34%	46.32%	**47.34%**

Table 3. IEEE 33_bus with one SVC and DG

	HFPSO [3]	**MOPSO** [7]	**BFOA** [8]	**Proposed Method**
Size in KVAR @bus	1210@30	1168.5@30	1094.6@30	**1260@30**
Size in KW @bus	1900@8	2420.3@8	1239.8@10	**2590@6**
Total Losses[KVA]	64.8	59.32	70.87	**58.494**
Min. Voltage[pu]	0.9678	0.974	0.9615	**0.954502598**
Min. VSM	0.8744	0.8999	0.8465	**0.830057132**
Reduction in losses%	69.256%	71.86%	66.38%	**72.25%**

Table 4. IEEE 33_bus with three SVC and three DG

	HFPSO [3]	**PSO** [23]	**MOPSO** [7]	**BFOA** [8]	**Proposed Method**
Size in KVAR @bus	390 @12	214.2 @18	524.9 @2	400 @12	**370 @13**
Size in KVAR @bus	650 @24	375.6 @25	512.3 @11	350 @25	**430 @24**
Size in KVAR @bus	840 @30	1450.3@30	619.7 @30	850 @30	**1080 @29**
Size in KW @bus	880 @12	831 @3	720.5 @12	850 @12	**730 @14**
Size in KW @bus	870 @24	904.7 @14	465.67 @15	750 @25	**1010 @24**
Size in KW @bus	1030 @30	971.2 @30	1016.2 @28	860 @30	**1300 @29**
Total Losses[KW]	13.8	25.4193	35.4	15.07	**15.347**
Min. Voltage[pu]	0.985	0.9882	0.9795	0.9862	**0.994042094**
Min. VSM	0.9415		0.9204	0.9376	**0.969711536**
Reduction in losses%	93.45%	87.94%	83.20%	92.85%	**92.72%**

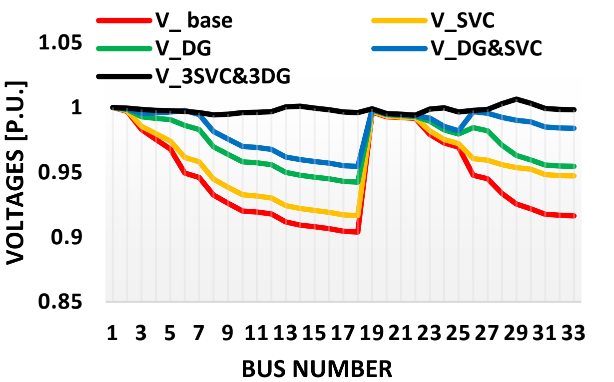

Figure. 6 Improvement of voltage profile of IEEE 33_bus system

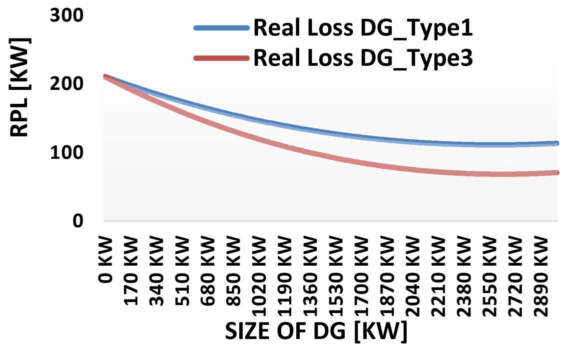

Figure. 7 The Impact of the DG types on the losses in IEEE 33_bus

Case 3: IEEE 33_bus has a single SVC and a single DG.

The total real losses are reduced to 58.494KW after utilizing a single SVC and DG. The proposed method determined the optimal location of SVC at bus 30 with size 1260KVAR and the optimal location of DG is obtained at bus 6 with size 2590KW. Also, the minimum VSM and bus voltage are enhanced to 0.830 and 0.9545 p.u. respectively. When comparing this method with the previous methods, this method gives the best results in the reduction of losses because the MOPSO reduced losses to 59.32KW and the BFOA reduced the total losses to 70.78KW while the HFPSO is reduced the real losses to 64.8KW, as explained in Table 3.

Case 4: IEEE 33_bus Using three SVC and three DG in the system.

In this case, the losses are reduced to 15.347KW after the insertion of three SVCs at buses 13,24, and 29 with the size of them 370KVAR, 430KVAR, and 1080KVAR, respectively. In addition, three DG units are utilized on buses 14, 24, and 29 with the size of them 730KW, 1010KW, and 1300KW, respectively. This reduction in losses is better than PSO and MOPSO methods. While getting that similar reduction by using the BFOA approximately. But this method has not given the best reduction in losses from HFPSO, spite the proposed method improved the VSM and bus voltages better than the previous methods (PSO, MOPSO, BFOA, and HFPSO), as explained in Table 4. The voltage profile of the previous four cases is explained in Fig. 6.

Case 5: Impact of two types of DG on the real power losses in IEEE 33_bus.

The proposed method explained the impact of two types of DG units on the total real power losses. DG type1 is the DG with a unity power factor such as a photovoltaic cell (PV) and another type of DG is type3 which represents DG with a 0.85 power factor such as a synchronous generator. The optimal location of the two types is obtained by the proposed method at bus 6. This method determined the size of the DG type1 equal to 2590KW while the size of the DG type3 is equal to 2640KW as real power and 1636.1KVAR as reactive power. That shows the first type of DG reduced the total real power losses to 110.997KW, but the third type of DG reduced the real power losses to 68.162KW. As a result, DG type3 is better than DG type1. The impact of DG types on the real power losses with changing the size of DG units is shown in Fig 7.

4.2 IEEE 69_bus test system

The IEEE 69_bus network is depicted in Fig 8. The system consists of 69 buses and 68 branches. The active power of the load demands is 3802KW, while the reactive power is 2694KVAR. A generation system with a base capacity of 100 MVA and a voltage of 12.66 kV at 60 Hz. The data for the 69_node test circuits from [22]. Active and reactive losses for this system without a compensator are 224.639 KW and 102.014KVAR, respectively. On bus 65, the lowest voltage is 0.9093 p.u., while the lowest VSM value is 0.6835. The proposed method is applied to this test system and compared to prior methods such as particle swarm optimization (PSO)[24], and Cuckoo Search Algorithm (CSA)[10].

Case 1: IEEE 69_ bus with only one SVC.

The results achieved using this suggested approach with one SVC are shown in Table 5. This method proposed the size of SVC is equal to 1330KVAR at bus 61. According to this insertion, the total power losses are reduced to 152KW. The minimum voltage is improved to 0.9307 p.u. at bus 65. As a comparison, PSO reduced the losses to 167.9KW while CSA reduced the losses to 152.95KW.

Case 2: IEEE 69_bus with only one DG.

Using the suggested approach to minimize losses of power to 83.181KW, equivalent to that obtained by the PSO, the ideal size of the DG unit is equal to 1870KW with a unity power factor placed at bus 61. The minimum bus voltage and VSM have been adjusted to 0.9683 p.u. and 0.8792, respectively. As a comparison to the prior approaches, Table 6 indicates that the CSA decreased the losses to 83.21KW.

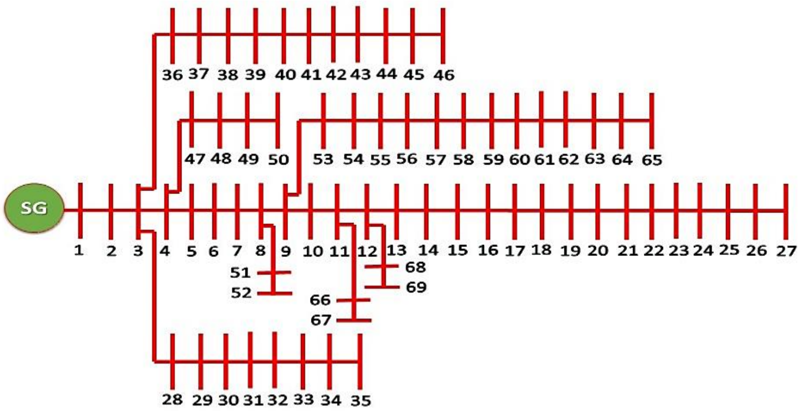

Figure. 8 IEEE 69_bus test system

Table 5. IEEE 69_bus with only SVC

	[PSO] [24]	**[CSA]** [10]	**Proposed Method**
Size in KVAR @bus	901.1 @61	1200 @61	**1330 @61**
Total Losses[KW]	167.9	152.95	**152.006**
Min. Voltage[pu]		0.9285	**0.930732219**
Min. VSM		0.7375	**0.750410097**
Reduction in losses %	25.26%	31.91%	**32.33%**

Table 6. IEEE 69_bus with only DG

	[PSO] [24]	**[CSA]** [10]	**Proposed Method**
Size in KW @bus	1876.1 @ 61	1872.7 @61	**1870 @61**
Total Losses[KW]	83.0	83.21	**83.181**
Min. Voltage[pu]		0.9682	**0.968319773**
Min. VSM		0.8788	**0.879174734**
Reduction in losses %	63.05%	62.96%	**62.97%**

Table 7. IEEE 69_bus with one SVC and DG

	[PSO] [24]	**[CSA]** [10]	**Proposed Method**
Size in KVAR @bus	904.5 @61	1150 @61	**1330 @61**
Size in KW @bus	122.3 @61	1750 @61	**1870 @61**
Total Losses[KW]	33.7	24.15	**23.232**
Min. Voltage[pu]		0.9715	**0.972851781**
Min. VSM		0.8908	**0.895749784**
Reduction in losses %	85%	89.25%	**89.66%**

Table 8. IEEE 69_bus with three SVC and three DG

	PSO [23]	**[CSA]** [10]	**Proposed Method**
Size in KVAR @bus	318.3 @25	270 @25	**270 @11**
Size in KVAR @bus	13.4 @27	980 @61	**360 @18**
Size in KVAR @bus	12112 @61	200 @63	**1260 @62**
Size in KW @bus	375.4 @27	490 @17	**530 @17**
Size in KW @bus	741.8 @60	1400 @61	**790 @49**
Size in KW @bus	597.3 @63	250 @63	**1710 @62**
Total Losses[KW]	19.411	8.07	**6.932**
Min. Voltage[pu]	0.9804	0.9925	**0.995792788**
Min. VSM		0.9587	**0.976145577**
Reduction in losses %	91.36%	96.41%	**96.91%**

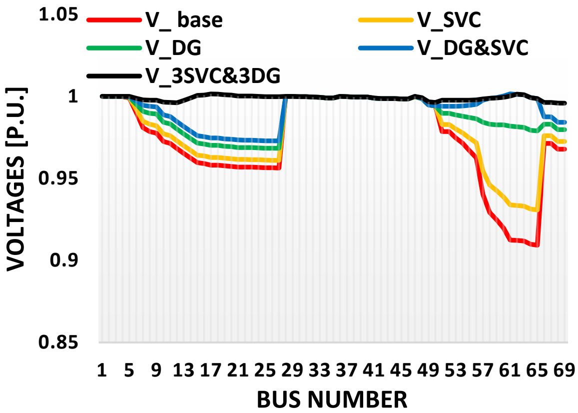

Figure. 9 Voltage profile of four cases for IEEE 69_bus test system

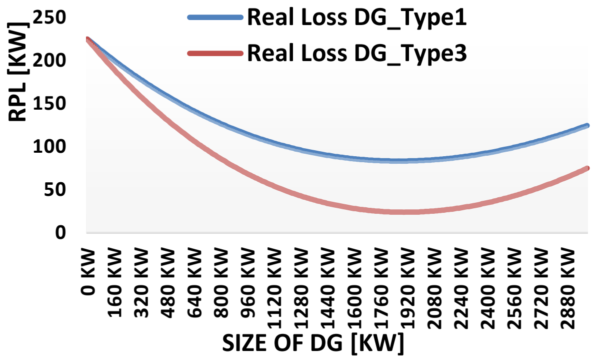

Figure. 10 Impact of DG types on real loss in IEEE 69_bus system

Case 3: IEEE 69_bus has a single SVC and a single DG.

After using a single SVC and DG, total actual losses are decreased to 23.232KW. The suggested technique found the ideal SVC placement at bus 61 with a size of 1330KVAR and the optimal DG position at bus 61 with a size of 1870KW. The minimum VSM and bus voltage have also been increased to 0.8957 p.u. and 0.9729 p.u., respectively. When compared to the previous approaches, this method provides the greatest results in terms of loss reduction, as the PSO reduced losses to 33.7KW and the CSA reduced total losses to 24.15KW, as shown in Table 7.

Case 4: IEEE 69_bus Using three SVC and three DG in the system.

The losses are decreased to 6.932KW in this case with the installation of three SVCs with sizes of 270KVAR, 360KVAR, and 1260KVAR at buses 11,18, and 62, respectively. In addition, three DG units with capacities of 530KW, 790KW, and 1710KW are used on buses 17, 49, and 62, respectively. As seen in Table 8, this strategy reduces losses better than PSO and CSA. Fig. 9 depicts the voltage profiles of the preceding four situations.

Case 5: Impact of two types of DG on the real power losses in IEEE 69_bus.

The influence of two types of DG units (DG type1 and DG type3) on total actual power losses as a function of DG size is depicted in Fig. 10. At bus 61, the suggested technique determines the ideal position of the two types. The size of the DG type1 was determined to be 1870KW, whereas the size of the DG type 3 was estimated to be 1900KW actual power and 1177.5KVAR reactive power with a 0.85 lagging power factor. The first form of DG lowered overall actual power losses to 83.181KW, whereas the third type reduced real power losses to 23.8KW. DG type3

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is thus superior to DG type1.

5. Conclusions and discussions

The placement of DG and SVC in the RDS compensates for actual and reactive power, resulting in lower network power losses, improved bus voltages, improved system performance, increased VSM, and higher overall power efficiency. To guarantee the program's optimum advantages, the DGs and SVCs must be placed in candidate sites with ideal KW and KVAR. The best places of DG and SVC in the RDS were determined using an integrated method in this study. By using this proposed method, the sizing of both compensating pieces of DG and SVC may be determined. The essential advantages of utilizing this proposed technique are that, unlike PSO, BFOA, HFPSO, MOPSO, and other optimization computations, it does not require extra work to set the parameter settings. The suggested technique is tested on IEEE 33 bus and 69 bus RDS in a variety of scenarios. Furthermore, this method demonstrates the influence of two different forms of DG (DG with unity power factor and DG with 0.85 lagging power factor). The simulations are compared with the performance of other existing strategies, and the findings reveal that the suggested method outperforms the others in terms of power loss reduction and system voltages improvement. The proposed strategy, based on the foregoing explanation, may be readily implemented in any RDS.

Conflicts of interest

The authors declare no conflict of interest.

Author contributions

The first author is working on implementing the paper's background, dataset collecting, editing draught, program execution, analytic findings, and comparison. The second author was in the care of supervision, work evaluation, conception, and methodology.

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