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Simultaneous Optimal Network Reconfiguration and Allocation of Four Different Distributed Generation Types in Radial Distribution Networks Using a Graph Theory-Based MPSO Algorithm

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Abstract: In this paper, for four different types of distributed generation (DG) units, a graph theory-based modified particle swarm optimization (MPSO) algorithm is proposed for the simultaneous optimal distribution network reconfiguration (DNR) and allocation (placement and sizing) of multiple DG units to minimize the total real power loss of the radial distribution network (RDN) while fulfilling all system operational constraints. Different cases are carried out for DNR and DG integration to evaluate the effectiveness of the proposed algorithm. To evaluate the objective function, an intelligent graph theory-based backward/forward (BW/FW) sweep load flow technique that can manage any topological alteration owing to DNR and DG integration is introduced. The proposed algorithm is assessed using IEEE 33-bus and IEEE 69-bus radial distribution systems and results are obtained using MATLAB software. The obtained simulation results show that the proposed algorithm can provide a wonderful solution in terms of real power loss minimization and voltage profile enhancement (compared with the base case, loss reduction of 74.29%, 92.15%, 54.3%, and 45.87% for DG type1, DG type2, DG type3 and DG type4, respectively for IEEE 33-bus, and loss reduction of 84.16%, 97.79%, 70.62%, and 63.01% for DG type1, DG type2, DG type3, and DG type4 respectively for IEEE 69-bus**).**

Keywords: Modified particle swarm optimization (MPSO), Distribution network reconfiguration (DNR), Graph theory, Distributed generation (DG) allocation, Real power loss minimization, Voltage profile enhancement.

1. Introduction

The complexity of the radial distribution network has increased due to the continuous increase in power demand, and this, of course, has caused significant challenges to the distribution utilities. Continuous increase in power demand leads to an increase in power loss and poor voltage profile which leads to inefficient performance of the distribution system. It is necessary for distribution system operators, under these challenging operational circumstances, to meet all power demand requirements with satisfactory quality for customers. Distribution network reconfiguration (DNR) and integration of distributed generations (DGs) into distribution systems are effective technical solutions for power loss minimization and voltage profile improvement and consequently enhancement of the distribution system performance and improvement of the power quality.

DNR is a process of changing the topology of the distribution system by changing the status of the sectionalizing switches, which are normally closed, and the tie switches, which are normally opened, to reach the optimal distribution network structure that has minimum power loss and good voltage regulation while maintaining all operational constraints. In the past, many researchers used the DNR only to improve the performance of the distribution system to avoid adding more additional cost burdens to the distribution system utilities if they consider capacitor placement and upgrading of the cable size. Solving the DNR problem by conventional methods takes a large computational time and cannot reach the optimal solution. So, enormous efforts have been done by many researchers for solving this complex nonlinear combinatorial constrained optimization problem by many different methods, heuristic methods and metaheuristic methods. But finding the optimal solution cannot be guaranteed using heuristic methods. So, many different metaheuristic methods were applied to the DNR problem for power loss minimization, e.g., ant colony search algorithm(ACSA) [1], improved Tabu search algorithm(ITS) [2] , artificial bee colony algorithm (ABC) [3], particle swarm optimization (PSO) [4], improved selective binary particle swarm optimization(IS-BPSO) [5], and improved harmony search algorithm (IHS) [6], fireworks algorithm (FWA) [7], selective particle swarm optimization (SPSO) [8],enhanced genetic algorithm (EGA) [9], and genetic algorithm with variable population size (GAVAPS) [10].

Due to the ever-increasing demand for power over generation capacities, the integration of the DG units into the distribution system is needed to aid the substation in meeting power demand needs with high quality and reliability. DGs are small-scale generating units connected directly to the distribution network or to the meter on the customer's side .DG units are categorized into four major types according to their terminal characteristics in terms of their ability to deliver active and reactive power as follows [11]:

Type1: DG units able to inject only active power as photovoltaic, full cells, and microturbines.

Type2: DG units able to inject both active and reactive power as cogeneration and gas turbine.

Type3: DG unit able to inject only reactive power as synchronous compensator.

Type4: DG units able to inject active power while absorb reactive power as induction generators in wind farms.

The optimal allocation of DG units in the RDN can effectively contributes to improve the performance of the distribution system in terms of reducing the system loss and enhancing the voltage profile. Many different techniques, analytical and metaheuristics, were used for optimal DG allocation to minimize the power loss in RDN. In [12], the exact loss formula was used to derive analytical expressions for determining the optimal sizing of DG units while loss sensitivity factor (LSF) was utilized to determine the optimal locations to minimize the power loss in RDNs. In [13], war optimization(WO) approach was proposed to find the optimal sizing and siting of DG units. In [14], hybrid technique was proposed for DG allocation problem; firstly, LSF was used to minimize the search space for DG locations then analytic approach was applied to determine the initial DG sizes and finally, sine cosine algorithm (SCA) was used to determine the optimal DG allocation. Binary particle swarm optimization and quasi oppositional chaotic symbiotic organisms search (QOCSOS) algorithm were proposed in [15] and [16] respectively for solving DG allocation problem, QOCSOS was used to determine the optimal number, location, size and power factor of DG units. Despite metaheuristics computationally slower than analytical methods but always produce global optimal solutions and can deal with large-scale systems.

In [17] a novel approach and a sound analysis was introduced for reliability assessment and determination of the optimal site and DGs unit capacity with multi-objective functions to reduce the power loss and enhance the voltage profile, in that paper a modified particle swarm optimization (MPSO) was used to determine the optimal location and the size of DGs units using MATLAB software and the reliability was assessed on IEEE 33-bus radial distribution test system using electrical transient analyzer program (ETAP) . In [18] hunter-prey optimization (HPO), a new and effective meta-heuristic technique, was introduced to find the optimal placement and sizing of the photovoltaic (PV) systems in RDNs, maximizing PV hosting capacity (HC) is the primary goal in addition to loss minimization and voltage profile enhancement where maximizing PV systems HC in RDNs guarantees performance improvement in terms of decreasing reliance on the grid, greenhouse gas emissions, and distribution losses in addition to an improved voltage profile. In [19] to solve the problem of DG allocation for power loss minimization and voltage profile enhancement , the optimal placement of DG was determined using a loss reduction sensitivity factor (LRSF) while a new enhanced symbiotic organisms search (NeSOS) was used to determine the optimal size of DG unit from type1. Using random weighted inverse vector (RWIV) and dual-phase parasitism (DPP) made NeSOS faster, more accurate and better performance than SOS. In addition, there are other technologies that are used to reduce losses and improve the voltage profile such as optimal integration of energy storage systems and capacitor bank as in [20], a coordinated optimal placement problem (COPP) of energy storage system (ESS) and capacitor bank was proposed and solved simultaneously using mixed-integer particle swarm optimization (MIPSO). Optimal ESS scheduling (OESSS) was considered as a sub problem and was solved by PSO, the goals of the COPP are to reduce distribution system annual losses.

Nowadays the use of the DNR without considering the optimal DG allocation has become no longer preferred. In the available literature, there are a few researchers that deal with DNR in parallel with DG allocation and they have found that the simultaneous optimal DNR and DG allocation (placement and size) can achieve more benefits for distribution utilities in terms of the system loss reduction and voltage profile improvements. But all previous studies addressing simultaneous optimal DNR and DG allocation have taken into consideration only one or two types of DG units at most. In [21], PSO algorithm was proposed to determine the optimal DNR and sizing (only) of DG units simultaneously for power loss minimization in RDNs. An improved sine cosine algorithm (ISCA) and Adaptive shuffled frogs leaping algorithm (ASFLA) were proposed in [22]and [23] respectively to solve this complex problem for loss minimization and voltage stability enhancement taking into account only the first type of DG units. In [24], optimal DNR and DG allocation simultaneously using both (JAYA) and improved Elitist - Jaya(IEJAYA) algorithms was introduced for power loss reduction and loadability enhancement taking into account the effect of different voltage-dependent load models considering only the first type of DG units .Three dimensional group search optimization (3D-GSO) and mixed particle swarm optimization (MPSO) algorithms were proposed in [25]and [26] respectively to solve the problem of simultaneous optimal DNR and DG allocation, for DG type1 only, for power loss reduction considering different load levels.

It is obvious that, all the above-mentioned research have focused only on the optimal allocation of the first type of DG units, which are capable of injecting active power only, simultaneously with the DNR and ignore the other different types of DG units in their studies. The main contribution of this paper is that, for four different types of DG units, an effective approach is proposed for solving the problem of simultaneous optimal DNR and allocation of DG units using graph theory based MPSO to minimize the total loss in real power of RDN while satisfying all system operational constraints considering the variation of load level and load pattern when modeling the load demand. The proposed algorithm is verified on two standard distribution test systems (IEEE 33-bus and IEEE 69-bus) considering four different cases.

The remaining parts of this paper is organized as follows: an intelligent graph theory-based backward /forward sweep load flow method capable of dealing with any topological changing owing to DNR and DG integration to evaluate the objective function is presented in section 2. In section 3, the problem formulation is described. In section 4, the proposed MPSO algorithm is explained. The test systems description and the case studies are illustrated in section 5. The simulation and comparison results and discussions are provided in section 6. Finally, the conclusion is outlined in section 7.

2. Graph theory-based BW/FW sweep load flow technique

The proposed MPSO-based algorithm makes use of an intelligent Graph theory-based BW/FW sweep load flow technique considering DG to solve the power flow problem in the RDN to obtain the node voltages and evaluate the total real power loss. This technique helps in checking the radiality and connectivity of the configuration then arranging the line data for any combination of tie switches positions before executing the load flow. This technique consists of four main steps as follows:

Step 1: Check the radiality

The topology of the system must be radial after the reconfiguration process. In MATLAB , the following function of graph theory is used to check the radiality [27].

$$TF = graphisspantree(S) \tag{1}$$

$$TF = \begin{cases} 1, & radial\ system \\ 0, & not\ radial\ system \end{cases} \tag{2}$$

Where, S is the sparse form of the system (undirected graph) which represents the line connection between two system nodes and eliminates all zero elements in the matrix.

Step 2: Check the connectivity

For checking the connectivity of all buses to the root bus, the following MATLAB function is utilized:

$$bus\_order = \mathrm{graphtraverse}(\mathrm{S}, \mathrm{source\ node\ number}, '\mathrm{METHOD}', '\mathrm{DFS}') \tag{3}$$

If length (bus_order) = number of buses, all buses are connected to the root bus otherwise there is no connection.

Step 3: Arrange the line data according to the topology of the network

This step is carried out as explained in detail in [28].

Step 4: Execute the load flow

The load flow problem is solved considering the following

- For RDN with N branches, $N+$ 1 buses, and a single voltage source at the root bus 0, branches are arranged in accordance with an appropriate numbering scheme.
- The DG is represented as a PQ bus. The total active and reactive power injected at the i^{th} bus are expressed as:

$$P_i \ = P_{DGi} - P_{Di} \tag{4}$$

$$Q_i \ = Q_{DGi} - Q_{Di} \tag{5}$$

Where, P_{DGi} and Q_{DGi} represent the output active and reactive power of DG unit placed at bus i respectively. P_{Di} and Q_{Di} are the active and reactive power of load demand at bus i, respectively, and those are modeled in the proposed algorithm taking into consideration the variation of load level and load pattern as follows:

$$P_{Di} \ = \mu \times P_{Di_n} \ \times \left[\frac{V_i}{V_{i_n}}\right]^{\alpha} \tag{6}$$

$$Q_{Di} \ = \mu \times Q_{Di_n} \ \times \left[\frac{V_i}{V_{i_n}}\right]^{\beta} \tag{7}$$

where P_{Di_n} & Q_{Di_n} are the reference constant real & reactive power demand of the ith bus at nominal voltage V_{i_n}, *respectively* . V_i is the actual supplying voltage of the ith bus. μ represents the value of the load variation ratio. α and β are the voltage characteristics exponents for the active and reactive power demand, respectively. When both α &β equal 0,1, and 2 in Eqs. (6, 7), the load model is constant power, constant current, and constant impedance, respectively.

An iterative method is carried out as follows:

- At first, set all bus voltages equal to the voltage of the root bus.

- Calculate the net injected current at each bus as follows:

$$\mathrm{I_i} \ = \left[\frac{\mathrm{S_i}}{\mathrm{V_i}}\right]^* = \left[\frac{\mathrm{P_i} + \mathrm{Q_i}}{\mathrm{V_i}}\right]^* \ , \mathrm{i}=1, 2,\ldots\ldots\ldots\ldots, \mathrm{N} \tag{8}$$

Where, N is the total number of buses excluding the root bus.

- Calculate the new bus voltages as follow:

$$V = \ V_0 \ + I \times Z_{bus} \tag{9}$$

Where $\mathrm{V_0}$ is a column vector of length N, all of its elements are equal to the voltage of the root bus. I is the bus injected currents column vector of length N, $\mathrm{Z_{bus}}$ is the network's bus impedance matrix referred to the root bus.

-If the difference between the new bus voltages obtained from Eq. (9) and the bus voltages used for current calculations in Eq. (8) is larger than a predetermined accuracy index, calculate the currents using the new bus voltages to start a new iteration and continue do that until the convergence occurs. At this time, the total real power loss of the network can be calculated using the obtained bus voltages.

3. Problem formulation

Since the objective function of the DNR and the DG allocation is to minimize the total loss in real power of the whole RDN and at the same time satisfying all operating constraints. So, the problem can be formulated mathematically as follows:

$$minimize\ Ploss = \sum_{j=1}^{N_{TBr}} (st)_j \left|I_j\right|^2 R_j \tag{10}$$

Where, I_j is the j^{th} branch current, R_j is the j^{th} branch resistance, N_{TBr} is the total number of branches in the network, and $(st)_j$ represents the status of the branch j (i.e., either branch j is unconnected $\mathrm{(st)_j} = 0$, or connected $\mathrm{(st)_j} = 1$)

Subject to:

i. Power balance constraints.

$$\sum P_{Gen} = Ploss + \sum_{i=1}^{N} P_{\mathrm{D_i}} \tag{11}$$

$$\sum Q_{Gen} = Qloss + \sum_{i=1}^{N} \mathrm{Q_{D_i}} \tag{12}$$

Where, P_{Gen} & Q_{Gen} are the total active and reactive power generation.

ii. Bus voltage constraints

The bus voltage must be within the acceptable limits.

$$|V_{min}| \leq |V_i| \leq |V_{max}| \tag{13}$$

Where, V_i is the voltage magnitude at bus i, V_{min} & V_{max} are the minimum and maximum acceptable voltage limits respectively ($V_{max} = 1.1pu$, $V_{min} = 0.9pu$).

iii. Feeder capacity limits

For all branches, the current magnitude of the branch shouldn't exceed its maximum current capacity.

$$\left|I_j\right| \leq \left|I_{j,max}\right| \tag{14}$$

Where, $I_{j,max}$ is the maximum current capacity limit of the branch j

iv. The radial network structures

Always maintain the network structure being radial.

v. The connectivity.

All buses in the network should be connected to the root bus.

vi. Generator operation limits

All DG units should be operated within their acceptable limits.

$$P_g{}^{min} \leq P_g \leq P_g{}^{max} \tag{15}$$

$$Q_g{}^{min} \leq Q_g \leq Q_g{}^{max} \tag{16}$$

Where, $P_g{}^{min}$ & $P_g{}^{max}$, $Q_g{}^{min}$& $Q_g{}^{max}$ are the minimum and maximum limits of active and reactive power output of DG unit respectively.

vii. DG penetration limits

The penetration level of DG should not exceed certain allowable limit. In the proposed algorithm, the penetration level of DG is modeled as follows.

$$\sum_{d=1}^{N_{DG}} S_{DG_d} \leq \gamma \times \sum_{i=1}^{\mathrm{N}} S_{D_{in}} \tag{17}$$

Where S_{DG_d} is the apparent power output of the d^{th} DG unit and $S_{D_{in}}$ is the reference constant apparent power demand of the ith bus at nominal voltage. N_{DG} is the total number of installed DG units. γ is the allowable penetration level of DG. in this paper, γ is taken to be equal to 0.6 as the penetration level of DG should not exceed 60% of the total system load.

4. The Proposed MPSO–based algorithm

PSO is a stochastic optimization technique inspired by nature, developed by Kennedy & Eberhart then modified by Shi &Eberhart [29]. PSO algorithm is initialized by a swarm of particles moving in multi-dimensional space to look for the optimal solution. Each particle in the swarm modifies its position depending on its personal experience over time (Pbest), experience of its neighbors (Gbest) and its current direction. The two factors c1&c2 and the two random variables r1 &r2 are used to accelerate the particle direction to its Pbest and Gbest while its current direction is multiplied by the inertia weight w. Eqs. (18) & (19) are utilized to update the velocity and position of each particle respectively.

$$v_{ij}^{k+1} = wv_{ij}^{k} + c_1 r_1 \left(Pbest_{ij} - x_{ij}^{k}\right) + c_2 r_2 \left(Gbest_j - x_{ij}^{k}\right) \tag{18}$$

$$i = 1,\ 2, \ldots\ldots\ldots\ldots l \quad ; j = 1,2, \ldots\ldots\ldots\ldots, m$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \tag{19}$$

Inertia weight (w) is updated as follows:

$$w = w_{max} - \frac{K \times (w_{max} - w_{min})}{K_{max}} \tag{20}$$

Where, k is the current iteration, v_{ij}^{k} is the current velocity of particle i in dimension j , v_{ij}^{k+1} is the modified velocity , x_{ij}^{k} is the current position, x_{ij}^{k+1} is the modified position, $Pbest$ is the best position, $Gbest_j$ is the global best position in the swarm in dimension j, w_{max}, w_{min} are the maximum and minimum inertia weight respectively (w_{max}= 0.9 & w_{min} = 0.4) , K_{max} is the maximum number of iterations , l is the number of particles, and m is the number of dimensions. The two acceleration factors c1&c2 are taken as random values between 0&1 rather than taking them as constant values and this makes the MPSO reach to the optimal solution faster.

The following steps describe in detail the proposed graph theory based MPSO algorithm for the simultaneous DNR and allocation of multiple DG units in the primary RDN to minimize the total real power loss while satisfying all system constraints.

Step1**:** Enter the line and bus data, the allowable bus voltage limits, the feeders' maximum current capacities, the number of DG units to be installed, the maximum and minimum limits of the power output of DG units, and MPSO parameters.

Step2: Apply the BW/FW sweep load flow approach explained in section 2 for the base case (the initial configuration of the network without installing any DG units) to calculate the node voltages, the branch currents, and the initial value of total loss in real and reactive powers.

Step3: Produce an initial population of particles with random velocities and positions, the particle position represents the tie switches positions, the location, and the size of each DG unit. The variable for tie switches is represented by r, for DG location is represented by loc ,and for DG size is represented by $size$. Each particle in the swarm can be written as:

$$x_{particle} = [r_1, r_2, \ldots\ldots, r_{Ntie}\ ,\ loc_1, loc_2\ , \ldots\ldots, loc_{N_{DG}}, size_1\ , size_2, \ldots\ldots\ldots, size_{N_{DG}}] \tag{21}$$

Where, $Ntie$ is the number of tie switches.

It is noteworthy that the part: $(size_1\ , size_2, \ldots\ldots\ldots, size_{N_{DG}})$ in the particle position represent the following:

- For DG type1, the active power output P_{DG} of each installed DG unit (Q_{DG} of each installed DG unit is equal to zero).

- For DG type2, the apparent power output S_{DG} of each installed DG unit, the active and reactive power output of each installed DG unit are calculated as follows:

$$P_{DG} = S_{DG} \times PF_{DG} \tag{22}$$

$$Q_{DG} = P_{DG} \times \tan\left(\cos^{-1}(PF_{DG})\right) \tag{23}$$

Where, PF_{DG} is the power factor of DG unit. In this work the power factor of DG type 2 unit is specified to be equal to that of the combined total load of the system.

- For DG type3, the reactive power output Q_{DG} of each installed DG unit (P_{DG} of each installed DG unit is equal to zero).

- For DG type 4, the apparent power output S_{DG} of each installed DG unit, the active power output P_{DG} of each installed DG unit is calculated using Eq. (22) while the absorbed reactive power Q_{DG} is calculated as follows:

$$Q_{DG} = -P_{DG} \times \tan\left(\cos^{-1}(PF_{DG})\right) \tag{24}$$

In this work, the power factor of DG type 4 unit is specified to be equal to 0.89 leading.

Step 4: For each particle in the initial population, apply the graph theory- based BW/FW sweep load flow technique explained in section 2. If all constraints are satisfied, calculate the total loss in real power using Eq. (10) otherwise the particle is considered as an infeasible particle.

Step 5: Consider each particle position in the initial population to be the initial Pbest of that particle then select Pbest that has the best fitness function (the minimumPloss) among all particles to be the initial G_{best} .

Step 6: Set the iteration counter k=1.

Step 7: Compute the inertial weight value using Eq (20) then update the velocity and the position for each particle by using Eqs. (18) & (19) respectively.

Step 8: Apply the graph theory- based BW/FW sweep load flow technique introduced in section 2 for the new position of each particle. If all operating constraints are fulfilled, calculate the total real power loss of the whole network otherwise considers that particle as an infeasible particle.

Step 9: Compare each particle's objective value to the objective value of its Pbest. if the objective value is less than that of Pbest, maintain this value and record the corresponding particle position as the current Pbest of that particle.

Step 10: Specify Pbest whose objective value is the minimum among all particles and record this Pbest to be the current Gbest.

Step 11: Set k=k+1, if $k<K_{max}$ then go to step (7) otherwise go to step (12).

Step 12: Print out the results including the best position Gbest which represents the optimal tie switch positions together with the locations and the sizes of the DG units, and its corresponding objective value which represent the minimum real power loss.

5. Description of the Test Systems and Case Studies

In order to verify the applicability of the proposed MPSO algorithm in solving the problems of simultaneous optimal DNR and allocation of four different DG types in RDNs, the proposed MPSO is applied to two standard test systems, IEEE 33-bus and IEEE 69-bus standard distribution test systems. The IEEE 33-bus radial distribution test system shown in Fig. 1 operates at a nominal voltage of 12.66 kV, has 33 buses, 37 elements, 32 normally closed sectionalizing switches from 1 to 32 represented in the figure by solid lines, and 5 normally opened tie switches from 33 to 37 represented in the figure by dotted lines. The line and bus data of the system are given in [30]. The total active and reactive load demand are 3715 kw and 2300 kvar respectively. The IEEE 69-bus radial distribution test system shown in Fig. 2 operates at a nominal voltage of 12.66 kV, has 69 buses,73 elements, 68 normally closed sectionalizing switches numbered from 1 to 68 represented in the figure by solid lines, and 5 normally opened tie switches numbered from 69 to 73 represented in the figure by dotted lines. The line and bus data of the system are given in [30] . The total active and reactive load demand are 3792 kw and 2694 kvar respectively. To validate the effectiveness and robustness of the proposed algorithm, the base case and other four different cases are studied and carried out to minimize the system loss and improve the voltage profile while fulfilling all the system constraints. These cases are as follows:

Base case**:** The distribution system with the initial configuration and without installing any DG units (the original IEEE 33-bus and IEEE 69-bus radial distribution systems).

Case1**:** only DNR is considered with the objective of minimizing the total active power loss of the system.

Case 2**:** For each type of the previously mentioned

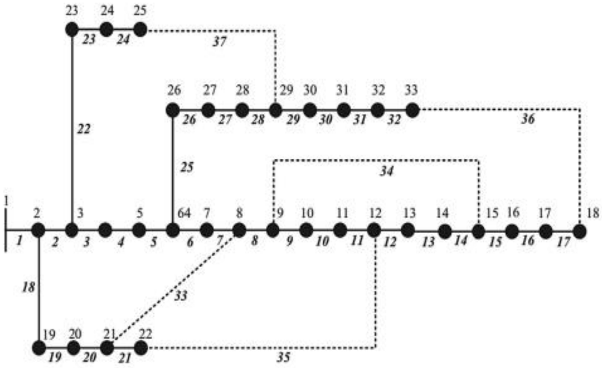

Figure. 1 IEEE 33-bus radial distribution test system

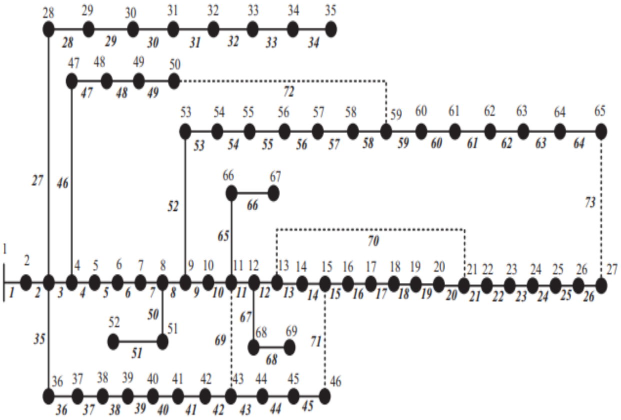

Figure. 2 IEEE 69-bus radial distribution test system

four different types of DG units, the impact of optimal allocation of 3 DG units with the penetration level of 60%, operated in PQ mode, on reducing the total active power loss of the system without reconfiguration action is analyzed.

Case 3**:** Optimal DNR simultaneously with DG sizing only for the four different types of DG unit. In this case, 3 DG units are considered and placed at predetermined locations obtained by applying the loss sensitivity analysis explained in details in [31] (for IEEE 33-bus system, buses 6, 28, and 9 for DG type1and DG type 4 and buses 6, 28, and 29 for for DG type2 and DG type3. For IEEE 69-bus system, buses 57, 58, and 61 for all DG types).

Case 4**:** Applying the proposed algorithm in which the simultaneous optimal DNR and allocation (placement and sizing) of 3 DG units, operated in PQ mode, for each type of the four different types of DG units.

6. Simulation results and discussions

The proposed MPSO algorithm is programmed in MATLAB R2017b and carried out on an Intel core i7 PC with a 2.3 GHZ CPU and 8 GB RAM. For the proposed MPSO parameters, l =300, no. of runs=8, c1&c2 are taken as random values between 0&1, K_{max}=1000 for case 1&2, K_{max}=2000 for case3&4, and m =5 for case1, 6 for case2, 8 for case 3, and 11 for case4. The no. of installed DG units is 3 for each type. For each DG unit, P_g^{min}=100 kw, P_g^{max}=1500 kw, Q_g^{min}=100 kvar, and Q_g^{max} =1500 kvar. The four cases described in section 5 are simulated and the results are presented in Table 1 for IEEE 33-bus system and Table 3 for IEEE 69- bus system. From the results shown in Table 1, for the IEEE 33-bus system, the base case is the worst case in terms of the total active power loss and the minimum voltage magnitude. The active and reactive power loss is 202.67 kW and 135.13 kvar respectively, and the minimum voltage is 0.9131 pu. For case1, the optimal reconfiguration obtained considers the tie switch positions to be switches number 37, 9, 7, 32, and14. The system active power loss is reduced by 31.14% with respect to the base case and the voltage profile has a modest improvement, the minimum bus voltage is 0.9378 pu . For case2, the results show that the optimal allocation of 3DG units with the penetration level of 60% successfully enhances the performance of the system compared with the base case. In case2, the total active power loss of the system is reduced by 64.29%, 90.17%, 34.78%, and 23.11% for DG type1, DG type2, DG type3 and DG type 4, respectively with respect to the base case, also the minimum voltage magnitude is improved to be 0.9672 pu, 0.9857 pu, 0.9378 pu, and 0.9303 p.u after installation of DG type1 units, DG type2 units, DG type3 units, and DG type4 units, respectively. For case3 in which the simultaneous optimal DNR and 3DG units sizing for the four different types of DG unit are carried out, the total power loss of the system is further reduced, and the voltage profile is significantly improved compared with the base case, case1, and case2. The percentage of active power loss reduction is 68.37%, 87.14%, 49.95%, and 42.76% with respect to the base case for DG type1, DG type2, DG type3, and DG type4, respectively. Also, the minimum voltage magnitude is improved to 0.9669 pu , 0.9780 pu, 0.9573 pu, and 0.9483 p.u after simultaneous optimal DNR and sizing of three DG units from type1, type2, type3, and type 4, respectively For case 4, the simulation results obtained indicate the superiority of the proposed algorithm, in which the simultaneous optimal DNR and 3DG units' allocation (placement and sizing) for the four different types of DG units are carried out, in terms of loss reduction and voltage profile improvement compared with other existing cases. The percentages of active power loss reduction reached 74.29%, 92.15%, 54.3%, and 45.87% with respect to the base case for DG type1, DG type2, DG

Table 1. Simulation results of the IEEE 33- bus system ($\mu = 1$; $\alpha = 0; \beta = 0; \gamma = 0.6$)

Case	**The optimal configuration Open switches numbers**	**Optimal DG locations and sizes**						**$Ploss$ (KW)**	**$Qloss$ (KVAR)**	**Minimum Voltage (p.u)**	**Active Loss reduction (%)**
		Bus No.	**DG size**	**Bus No.**	**DG size**	**Bus No.**	**DG size**				
Base case	33,34,35,36,37							202.67	135.13	0.9131	
Case 1 (optimal DNR only)	37,9,7,32, 14							139.55	102.30	0.9378	31.14
Case2 (Only Optimal allocation of 3 DG units)											
DG type 1	33,34,35,36,37	25	808 (kw)	14	750 (kw)	30	1063 (kw)	72.37	49.72	0.9672	64.29
DG type 2	33,34,35,36,37	14	749 (KVA)	25	579 (KVA)	30	1293 (KVA)	19.93	14.45	0.9857	90.17
DG type 3	33,34,35,36,37	13	379 (KVAR)	30	1037 (KVAR)	24	544 (KVAR)	132.17	88.33	0.9378	34.78
DG type 4	33,34,35,36,37	15	389 (KVA)	6	942 (KVA)	24	661 (KVA)	155.83	104.74	0.9303	23.11
Case3 (Simultaneous optimal DNR and DG sizing only)											
DG type 1	32,8,14,27,33	6	779 (kw)	28	1103 (kw)	9	739 (kw)	64.11	48.25	0.9669	68.37
DG type 2	14,33,11,17,5	6	974 (kVA)	28	147 (kVA)	29	1500 (kVA)	26.07	21.23	0.9780	87.14
DG type 3	32,33,9,14,28	6	510 (KVAR)	28	100 (KVAR)	29	1100 (KVAR)	101.44	71.34	0.9573	49.95
DG type 4	7,14,10,27,32	6	455 (kVA)	28	581 (kVA)	9	587 (kVA)	116.01	86.99	0.9483	42.76
Case4 (Simultaneous optimal DNR and DG allocation)											
DG type 1	34,11,28,33,31	33	664 (kw)	25	1158 (kw)	7	799 (kw)	52.11	39.22	0.9724	74.29
DG type 2	35,7,10,26,8	14	616 (KVA)	25	1097 (KVA)	31	908 (KVA)	15.92	12.27	0.9864	92.15
DG type 3	7,14,32,37,9	30	961 (KVAR)	21	623 (KVAR)	24	516 (KVAR)	92.63	69.91	0.9561	54.30
DG type 4	9,31,37,14,7	12	372 (KVA)	18	440 (KVA)	24	798 (KVA)	109.71	83.40	0.9407	45.87

type3 and DG type4, respectively. Furthermore, the minimum voltage magnitude is improved to be 0.9724 pu, 0.9864 pu, 0.9561 pu, and 0. 9407 pu after simultaneous optimal DNR and allocation of three DG units from type1, type2, type3, and type 4, respectively. On the other hand, from the obtained results it is clear that, the integration of the DG units from type 2 gives the best results in terms of power

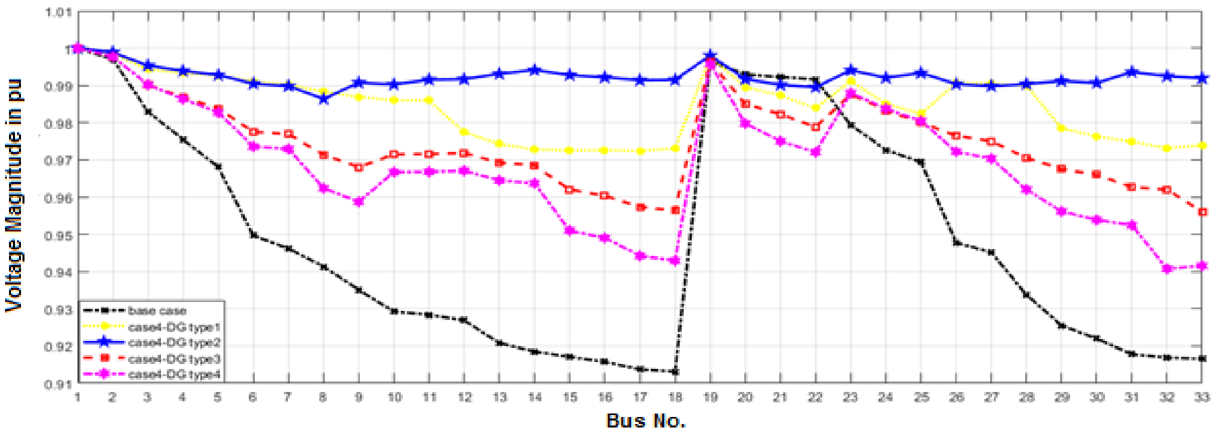

Figure. 3 The voltage profile of IEEE 33- bus system before and after the simultaneous Optimal DNR and allocation of 3 DG units of each type

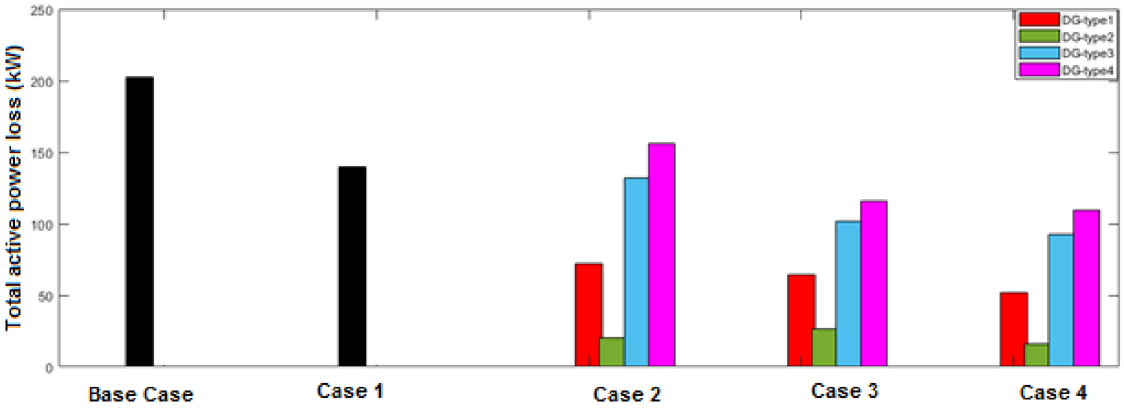

Figure. 4 The total active power loss of the IEEE 33-bus system at the different cases studied

loss reduction and voltage profile improvement compared to the other three types in case2, case3, and case4. The voltage profile of the IEEE 33-bus test system before and after the simultaneous optimal DNR and allocation (placement and sizing) of 3 DG units of each type is shown in Fig. 3. The total active power loss of the IEEE 33-bus system in the different cases studied is illustrated in Fig. 4. Table 2 provides a comparison between the proposed MPSO approach and other competitive existing approaches for the IEEE 33-bus system in the different studied cases (for DG type 1 only in cases 2, 3, & 4 as that is the available in the literature). for case 1, the proposed MPSO approach provides a similar result in terms of power loss reduction as the ISCA [22] and HSA[32] approaches, and is slightly better than the other existing approaches. For case 2, the proposed MPSO approach provides a better power loss reduction result compared to the other approaches. for case3 the proposed MPSO approach provides a better result in terms of power loss reduction compared to HAS[32]and FWA[33] approaches and is very close to ACSA[34] method. For case4 the proposed MPSO approach provides a better result in terms of power loss reduction compared with the other existing approaches. From Table 2, it is clear that the suggested MPSO approach consistently produced very high-quality results in terms of power loss reduction and voltage profile enhancement for the IEEE 33-bus system for all cases studied.

For the IEEE 69–bus system, from the results shown in Table 3, For case1, the optimal reconfiguration obtained considers the tie switch positions to be switches number 14, 58, 61, 69, and 70 which reduces the system active power loss by 55.72% with respect to the base case and improves the voltage profile; the minimum bus voltage becomes 0.9428pu. From the results obtained for case2, it is clear that the optimal allocation of 3DG units with the penetration level of 60% successfully enhances the performance of the system compared with the base case the total active power loss of the system is reduced by 68.39 %, 96.97%, 35.5%, and 24.93% for DG type1, DG type2, DG type3 and DG type 4, respectively. Also the minimum voltage magnitude is improved to be 0.9807 pu, 0.9941 pu, 0.9314 pu, and 0.9388 p.u after installation of DG type1 units, DG type2 units, DG type3 units, and DG

Table 2. A comparison between the proposed MPSO approach and other competitive approaches for the IEEE 33-bus system in different cases studied (for DG type 1 only in cases 2,3&4). ($\mu = 1$; $\alpha = 0; \beta = 0$)

case	**parameters**	**HSA**[32]	**FWA**[33]	**FA**[27]	**3D-GSO**[25]	**ISCA**[22]	**ACSA**[34]	**Proposed method (MPSO)**
Case 1 (Optimal DNR only)	**Open switches Numbers.**	7,9,14,32, 37	7, 14, 9, 32, 28	———	7,9,14 ,28,32	7,14,9,32, 37	7,14,9,32, 28	37,9,7,32, 14
	$Ploss$ (KW).	139.55	139.98	———	139.98	139.55	139.98	139.55
	V_{min}(p.u)	0.9378	0.9413	———	0.9413	0.9378	0.9413	0.9378
	Active Loss reduction (%)	31.14	30.93	———	30.93	31.14	30.93	31.14
Case2 (Only Optimal allocation of 3 DG units) DG type 1	**Open switches Numbers.**	33,34,35, 36, 37	33,34, 35, 36, 37	———	33,34,35, 36,37	33,34,35, 36,37	33,34,35, 36,37	33,34,35, 36, 37
	Size of DG in KW (location)	107(18) 572.4(17) 1046.2(33)	589.7 (14) 189.5 (18) 1014.6 (32)	———	766 (11) 285.2 (18) 903.3(32)	743 (14) 743 (24) 743 (31)	779.8 (14) 1125.1(24) 1349.6(30)	808 (25) 750 (14) 1063 (30)
	$Ploss$ (KW).	96.76	88.68	———	79.87	77.13	74.26	72.37
	V_{min}(p.u)	0.9670	0.9680	———	0.9928	0.9612	0.9778	0.9672
	Active Loss reduction (%)	52.26	56.24	———	60.59	61.94	63.26	64.29
Case3 (Simultaneous optimal DNR and DG sizing only) DG type 1	**Open switches Numbers.**	07,14,10, 32,28	07,14,11, 32,28	———	———	———	7,10,13, 32,27	32,8,14, 27,33
	Size of DG in KW (locations)	525.8 (32) 558.6 (31) 584 (33)	536.7 (32) 615.8 (29) 531.5 (18)	———	———	———	426.3 (32) 1202.4 (29) 712.7 (18)	181 (6) 241 (28) 1500 (9)
	$Ploss$ (KW).	73.05	67.11	———	———	———	63.69	64.11
	V_{min}(p.u)	0.9713	0.9713	———	———	———	0.9786	0.9669
	Active Loss reduction(%)	63.95	66.89	———	———	———	68.58	68.37
Case4 (Simultaneous optimal DNR and DG allocation) DG type 1	**Open switches Numbers.**	———	———	8, 9, 28, 32, 33	7,8,14, 25,36	7,9,14,28, 31	33,34,11, 31,28	34,11,28, 33,31
	Size of DG in KW (locations)	———	———	841.4(31) 340.8(32) 591.6(33)	630 (30) 600 (18) 1190 (12)	648.46 (30) 510.27 (13) 532.46 (16)	896.8 (18) 1438.1(25) 964.6 (7)	664 (33) 1158 (25) 799 (7)
	$Ploss$ (KW).	———	———	73.048	57.97	66.81	53.21	52.11
	V_{min}(p.u)	———	———	0.9735	0.9899	0.9611	0.9806	0.9724
	Active Loss reduction (%)	———	———	63.95	71.4	67.03	73.75	74.29

Table 3. Simulation results of the IEEE 69- bus system ($\mu = 1 ; \alpha = 0; \beta = 0; \gamma = 0.6$).

Case	The optimal configuration Open switches numbers	Optimal DG locations and sizes						$Ploss$ (KW)	$Qloss$ (KVAR)	Minimum Voltage (p.u)	Active Loss reduction (%)
		Bus No.	DG size	Bus No.	DG size	Bus No.	DG size				
Base case	69,70,71,72,73							224.92	102.13	0.9092	
Case 1 (Optimal DNR only)	14,61,69,70,58							99.59	114.66	0.9428	55.72
Case2 (Only Optimal allocation of 3 DG units) **DG type 1**	69,70,71,72,73	61	1490 (kw)	17	531 (kw)	64	290 (kw)	71.10	35.65	0.9807	68.39
DG type 2	69,70,71,72,73	61	1500 (KVA)	64	588 (KVA)	17	636 (KVA)	6.82	7.88	0.9941	96.97
DG type 3	69,70,71,72,73	21	230 (KVAR)	11	413 (KVAR)	61	1232 (KVAR)	145.08	67.64	0.9314	35.50
DG type 4	69,70,71,72,73	18	225 (KVA)	11	335 (KVA)	61	1024 (KVA)	168.85	77.94	0.9388	24.93
Case3 (Simultaneous optimal DNR and DG sizing only) **DG type 1**	13,57,69,12,64	57	181 (kw)	58	241 (kw)	61	1500 (kw)	45.98	52.79	0.9684	79.56
DG type 2	12,57,13,69,21	57	223 (KVA)	58	707 (KVA)	61	1500 (KVA)	13.46	11.86	0.9884	94.02
DG type 3	62,12,69,13,57	57	129 (KVAR)	58	151 (KVAR)	61	966 (KVAR)	73.01	82.46	0.9650	67.54
DG type 4	13,69,57,12,61	57	102 (KVA)	58	100 (KVA)	61	741 (KVA)	83.91	95.24	0.9504	62.69
Case4 (Simultaneous optimal DNR and DG allocation) **DG type 1**	61,13,12,55,69	64	496 (KW)	11	521 (KW)	61	1433 (KW)	35.63	41.91	0.9751	84.16
DG type 2	14,10,69,21,58	12	686 (KVA)	61	1500 (KVA)	64	604 (KVA)	4.97	7.77	0.9936	97.79
DG type 3	61,69,12,57,13	61	1050 (KVAR)	11	373 (KVAR)	27	401 (KVAR)	66.09	76.29	0.9674	70.62
DG type 4	58,10,12,13,61	64	251 (KVA)	61	813 (KVA)	43	425 (KVA)	83.21	99.20	0.9505	63.01

type4 units, respectively. For case3, simultaneous optimal DNR and 3DG units sizing for the four different types of DG unit leads to further reduction in the total active power loss of the system and significant improvement in the voltage profile compared with the base case, case1, and case2. The percentage of active power loss reduction is 79.56%, 94.02%, 67.54%, and 62.69% with respect to the base case for DG type1, DG type2, DG type3, and DG type4, respectively. Also, the minimum voltage magnitude is improved to be 0.9684 pu, 0.9884 pu, 0.9650 pu, and 0.9504 p.u after simultaneous optimal DNR and sizing of three DG units from type1, type2, type3, and type 4, respectively. Again, the results obtained for case4 strongly prove the superiority of the proposed algorithm in terms of active loss reduction and voltage profile improvement compared with other existing cases. The percentages of active power loss reduction reached 84.16%, 97.79%, 70.62%, and 63.01% with respect to the base case for DG type1, DG type2, DG type3 and DG type4, respectively. Furthermore, the minimum voltage magnitude is greatly improved to be 0.9751 pu, 0.9936 pu, 0.9674 pu, and 0.9505 pu after simultaneous optimal DNR and allocation of three DG units from type1, type2, type3, and type 4, respectively. Of course, it is clear that the simultaneous optimal DNR and allocation of DG units from type 2 gives the best results in terms of power loss reduction and voltage profile improvement. The voltage profile of the IEEE69-bus test system before and after the simultaneous optimal DNR and allocation (placement and sizing) of 3 DG units of each type is shown in Fig. 5. The total active power loss of the IEEE 69-bus system in the different cases studied is illustrated in Fig. 6. Table 4 provides A comparison between the proposed MPSO approach and other competitive existing approaches for the IEEE 69-bus system in the different studied cases (for DG type 1 only in cases 2, 3 & 4 as that is the available in the literature). For case 1, the proposed MPSO approach provides a similar result in terms of power loss reduction as other existing approaches. For case 2, the proposed MPSO approach provides a better power loss reduction result compared to the other existing approaches. For case 3 the proposed MPSO approach has obtained a power loss reduction result close to that obtained from the other existing approaches. For case4 the proposed MPSO approach has obtained a better power loss reduction result compared to the other existing approaches. From the comparison results shown in Table 4, it is clear that the suggested MPSO approach consistently produced very high-quality results in terms of power loss reduction and voltage profile enhancement for the IEEE 69 -bus system for all cases studied.

7. Conclusion

This paper presents a graph theory based MPSO algorithm for the simultaneous optimal DNR and allocation (placement and size) of multiple DG units in RDNs. the objective function of the proposed algorithm has focused on minimizing the total active power loss of the radial distribution system while fulfilling all system operational constraints. An intelligent graph theory-based BW/FW sweep load flow technique has been introduced for evaluating the

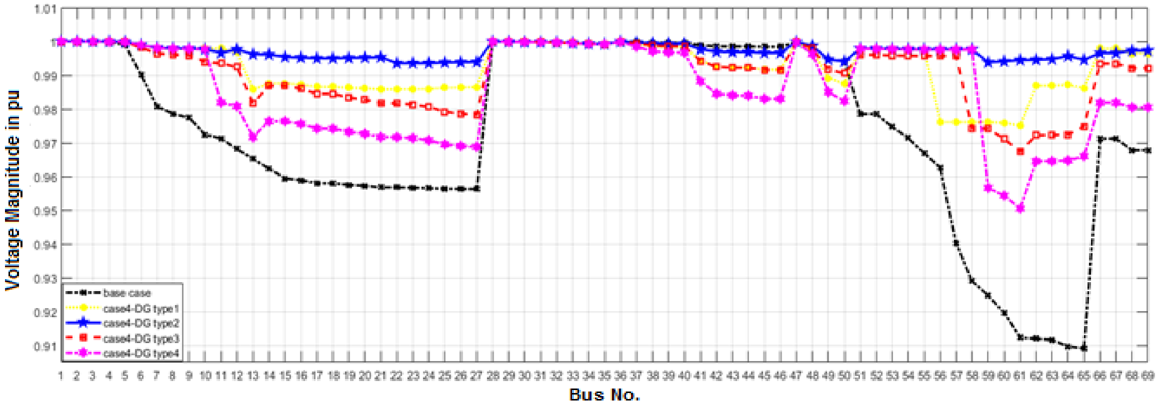

Figure. 5 The voltage profile of IEEE 69- bus system before and after the simultaneous optimal DNR and allocation of 3 DG units of each type

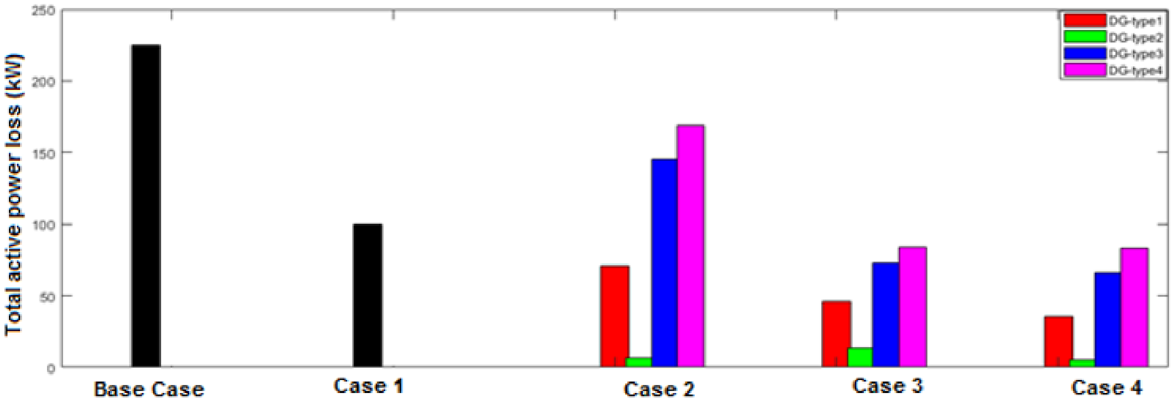

Figure. 6 The total active power loss of the IEEE 69-bus system at the different cases studied

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Table 4. A comparison between the proposed MPSO approach and other competitive approaches for the IEEE69-bus system in different studied cases for DG type 1 only. ($\mu = 1$; $\alpha = 0; \beta = 0$)

case	**parameters**	**HSA**[32]	**FWA**[33]	**FA**[27]	**3D-GSO**[25]	**ISCA**[22]	**ACSA**[34]	**Proposed method (MPSO)**
Case 1 (Optimal DNR only)	**Open switches Numbers.**	69,18,13,56,61	69,70,14, 56,61	———	14,56,61, 69,70	14,55,61, 69,70	69, 70, 14, 57, 61	14,61,69, 70,58
	$Ploss$ **(KW).**	99.35	99.59	———	99.59	99.59	99.59	[99.59
	V_{min}**(p.u)**	0.9428	0.9428	———	0.9428	0.9428	0.9428	0.9428
	Active Loss reduction (%)	55.85	55.72	———	55.72	55.72	55.72	55.72
Case2 (Only Optimal allocation of 3 DG units) DG type 1	**Open switches Numbers.**	69,70,71,72,73	69,70,71, 72,73	———	69,70,71, 72,73	69,70,71, 72,73	69, 70, 71, 72, 73	69,70,71, 72,73
	Size of DG in KW (locations)	101.8 (65) 369 (64) 1302.4 (63)	408.5 (65) 1198.6 (61) 225.8 (27)	———	388 (27) 1464(61) 289(64)	760.4 (12) 760.4 (62) 760.4 (61)	602.2 (11) 380.4 (18) 2000 (61)	1490 (61) 531 (17) 290 (64)
	$Ploss$ **(KW).**	86.77	77.85	———	73.477	74.4	72.44	71.10
	V_{min}**(p.u)**	0.9677	0.9740	———	0.9792	0.9717	0.9890	0.9807
	Active Loss reduction (%)	61.43	65.39	———	67.33	66.93	67.79	68.39
Case3 (Simultaneous optimal DNR and DG sizing only) DG type 1	**Open switches Numbers.**	69,17,13, 58,61	69,70,13,55,63	———	———	———	69, 70, 12, 58, 61	13,57,69,12,64
	Size of DG in KW (locations)	1066.6(61) 352.5(60) 452.7(62)	1127.2 (61) 275 (62) 415.9 (65)	———	———	———	1749.6 (61) 156.6 (62) 409 (65)	181 (57) 241 (58) 1500 (61)
	$Ploss$ **(KW).**	40.03	39.25	———	———	———	40.49	45.98
	V_{min}**(p.u)**	0.9736	0.9796	———	———	———	0.9873	0.9684
	Active Loss reduction (%)	82.08	82.55	———	———	———	82	79.56
Case4 (Simultaneous optimal DNR and DG allocation) DG type 1	**Open switches Numbers.**	———	———	2, 19, 57, 61, 69	14,56,61, 69,70	12,19,69,63,57	69, 70, 14, 58, 61	61,13,12,55,69
	Size of DG in KW (locations)	———	———	251.77(60) 1232.8(61) 452.54 (62)	1313 (61) 441 (62) 752 (50)	1000.9 (61) 410.6 (62) 461.6 (65)	541.3 (11) 553.6 (65) 1724 (61)	496 (64) 521 (11) 1433 (61)
	$Ploss$ **(KW).**	———	———	40.30	38.176	39.73	37.02	35.63
	V_{min}**(p.u)**	———	———	0.9816	0.9823	0.9798	0.9869	0.9751
	Active Loss reduction (%)	———	———	82.08	83.03	82.34	83.54	84.16

objective function. Different types of DG units differ from each other in terms of their capability to deliver active and reactive power are considered in this work. Different cases have been carried out to clearly show the effectiveness of the proposed algorithm. The proposed algorithm has been examined on two test systems, the IEEE 33-bus and the IEEE 69-bus radial distribution systems. The simulation results obtained strongly illustrate the superiority of the proposed algorithm in terms of active power loss reduction and voltage profile improvement compared with other cases. after simultaneous optimal DNR and allocation of three DG units from type1, type2, type3, and type 4, for the IEEE 33-bus system, the percentages of active power loss reduction with respect to the base case reaches 74.29%, 92.15%, 54.3%, and 45.87%, respectively, and the minimum voltage magnitude is improved to be 0.9724 pu, 0.9864 pu, 0.9561 pu, and 0. 9407 pu, respectively. For IEEE 69-bus system, after simultaneous optimal DNR and allocation of three DG units from type1, type2, type3, and type 4, the percentages of active power loss reduction with respect to the base case reaches 84.16%, 97.79%, 70.62%, and 63.01%, respectively, and the minimum voltage magnitude is improved to be 0.9751 pu, 0.9936 pu, 0.9674 pu, and 0. 9505 pu, respectively. In addition, the obtained results show that the integration of DG units from type 2, which are capable to inject both active and reactive power, gives the best results in terms of power loss reduction and voltage profile improvement compared to the other three types in case2, case3, and case4. Furthermore, to demonstrate the effectiveness of the proposed MPSO approach, a comparative analysis between the proposed MPSO approach and some existing approaches e.g HSA, FWA, FA,3D-GSO, ISCA, and ACSA has been made and the comparison results show that the proposed MPSO approach give the best result in terms of power loss reduction.

Conflicts of interest

The authors declare no conflict of interest.

Authors contributions

Conceptualization, A. R. A; Methodology, A. R. A; Software, A. R. A; Formal analysis, A. R. A; Resources, A. R. A; Data curation, A. R. A; writing - original draft preparation, A. R. A; Validation, A. H. and S. H; Investigation, A. H. and S. H; Writing - Review &Editing, A. H. A and S. H; Visualization, A. R. A, A. H. A, and S. H; Supervision, A. H. A, and S.H.

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