Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2016) 24: 3049 – 3065
© TÜBİTAK
doi:10.3906/elk-1404-207

Optimal dispatchable DG allocation in a distribution network considering load growth with a mixed-PSO algorithm

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Received: 12.04.2014 • **Accepted/Published Online:** 11.02.2015 • **Final Version:** 15.04.2016

Abstract: In recent years, one of the major issues faced by distribution utilities is integrating distributed generation (DG) units in distribution networks. This paper proposes a population-based method called particle swarm optimization (PSO) for optimal planning of the location and sizing of different types of DG units in the distribution network, considering different loading conditions. The objective of this application is power loss minimization. In order to find the optimal location and size of DG units, continuous and discrete forms of PSO are deployed, respectively (mixed PSO). In addition, the optimal locations and sizes of the DG units are determined in the areas of significant feeder load growth. This meta-heuristic approach makes little or no assumption about the issue being optimized and can search large spaces of possible solutions. The presented method is tested on the standard IEEE 33-bus and IEEE 69-bus test systems. In order to show the effectiveness of the proposed methodology, the results are compared with another method of DG allocation and another loss minimization technique.

Key words: DG, load growth, loss minimizing, mixed PSO

1. Introduction

Electrical energy is continuously dissipated in power systems at the transmission and distribution levels. Power losses in the distribution network, due to lower voltage level and higher R/X ratio, in comparison with transmission level, are more significant. Power losses are important due to the economic and environmental effects (carbon emission) associated with them. Moreover, power losses have a noticeable impact on generation capacity and must be paid by consumers. With deregulation and liberalization, distribution network operators (DNOs) are responsible for operating, expanding, and maintaining distribution systems [1]. Electrical energy consumers anticipate DNOs to play a vital role in facing up to climate change and to accommodate their practices towards a low carbon future [1]. The values of electric power losses are different in various countries. Figure 1 illustrates power losses in various countries in 2009, 2010, and 2011. This information, which is related to the global bank, shows that power losses values are very deviant in different countries, and vary from about 3% to 43%. Nevertheless, these losses included both technical and nontechnical losses. A survey indicates that up to 70% of the total power losses in the power system relate to the distribution network [2,3]. DNOs have several incentives, combined with their allowed revenues, with efforts to reduce power losses. The active power losses associated with the distribution network are mainly attributed to electrical resistance and generally draw more attention from DNOs. Conventionally, network reconfiguration and capacitor placement were the two main techniques for loss reduction in distribution systems [4]. Within the last decade, due to the progress

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in DG technology, DG has been known as a reliable alternative leading to loss reduction in the distribution network.

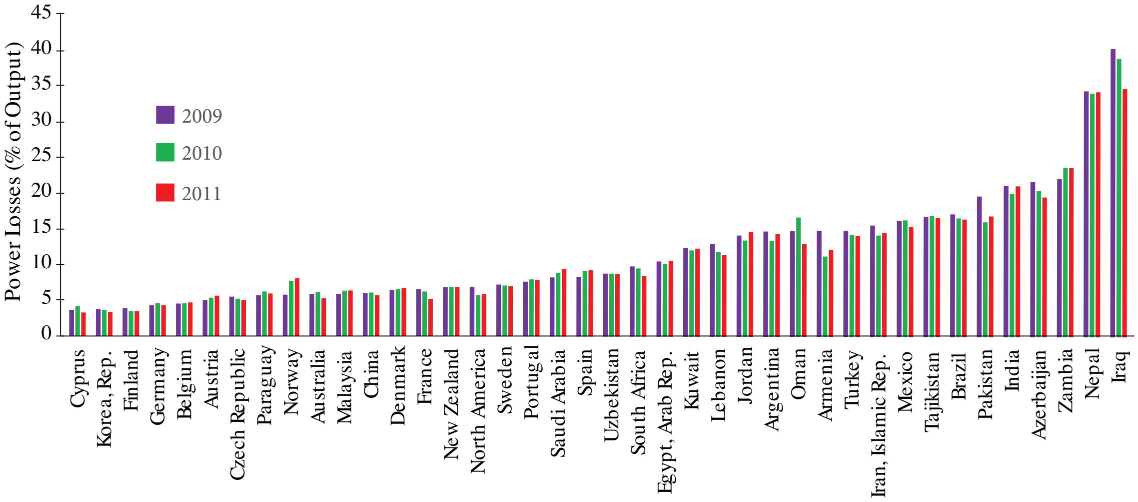

Figure 1. Power losses in different countries in 2009, 2010, and 2011.

The changes brought about by the governments in many countries to stop the monopoly of the vertically integrated power utilities and gradual depletion of fossil-fuel resources have fostered this new technology. DG has led to the generation of electrical energy, in a more cost-effective way, close to the area where power is consumed. The increasing reliability expectations as well as the inability to add new conventional power plants, transmission lines, and substations have become a driving force for development of DG. This condition provides an opportunity to effectively exploit the renewable energy, which is produced from refillable ample resources in nature. DG is perfectly suitable for the above-mentioned issues as it can be located close to the user and can be installed in small units according to the needs of the user and the customer. Based on the above mentioned points and the assumption that the owners of DG units are DNOs, DG can be claimed as an attractive option for DNOs to reduce power losses and improve other technical indices in their distribution networks. However, determination of optimal location and size of DG units is very important in order to maximize their environmental, economic, and technical benefits for DNOs. The main challenges in DG applications for loss reduction are appropriate location, sizing, and operating schemes. Studies [5,6] show that if DG units are improperly sited and sized, the reverse power flow from larger DG units can lead to excessive losses and can overload the feeders. It is worthwhile noting that the current policy of DG installation, which focuses on association rather than integration, is perfectly illogical. As a result, DG will not have the expected benefits for the system and even it could better be replaced by the energy produced by centralized units [7]. Thus, this strategy should be changed to active network management for accommodating a high level of DG penetration.

Conventionally, capacitor installation and reconfiguration are two main techniques for reducing power losses [8]. In the last decade, DG was introduced as an alternative option that is more appealing in every respect for DNOs. Optimal capacitor placement and reconfiguration as well as DG allocation are nonconvex problems and consequently, convergence to the global optimum may be impaired by the presence of local optima. Certain meta-heuristic approaches are good candidates for solving such problems.

In [9], an attractive analytical method has been introduced for optimal DG placement in radial and meshed systems to minimize power losses. In [5], an exact power losses formula has been utilized to calculate the size of a special type of DG unit (capable to inject only P). In [10], this method has been expanded and named the improved analytical (IA) method and applied to another type of DG units with any power factor. In addition, in [11], this approach has been developed for multiple DG allocation and achieved a higher power losses reduction. In [12], a new analytical approach has been introduced that is independent of formation of admittance, impedance, and the Jacobian matrix. For determining the optimal size, location, and operating point of the DG unit, the sensitivity of power losses to injected current of the DG unit has been studied in [13]. In [14], another analytical approach has been presented to find the optimal locations of multiple DG units. In [15], an ant bee colony algorithm has been proposed to determine optimal location, size, and power factor (PF) of DG units for power losses minimization. In [16], a genetic algorithm (GA) based method has been employed to find the optimal location of a single DG unit for power losses minimization. A probabilistic approach has been presented in [6] and [17] for renewable based DG units (PV-wind-biomass) accommodation, considering their uncertainties, in order to minimize annual energy losses. In [18], an evolutionary based approach has been presented for optimal allocation of the PV array and wind generator for energy losses minimization without constraints violation in the distribution network. In [19], an improved particle swarm optimization has been combined with Monte Carlo simulation for optimal allocation of DG units in order to minimize the costs of power losses and to improve the reliability and voltage profile. In [20], a cuckoo search algorithm (CSA) has been presented for DG allocation. In [21], a new method based on a modified teaching–learning optimization algorithm has been presented for finding the optimal location and size of DG units. In [22], a combined conventional iterative search and NR load-flow method has been presented for optimal allocation of DG units to reduce power losses and cost. In [23], a multiperiod AC OPF technique has been presented for the optimal accommodation of renewable based DG units in a future smart grid in order to minimize energy losses. In [24], a hybrid method that utilized discrete PSO and OPF has been presented for optimal allocation of DG units for loss minimization. Finally, comprehensive overviews on different methodologies in the optimal DG allocation area with appropriate classification have been presented in [25–27].

In this paper, in order to minimize real power losses, the location and size of various types of DG units, considering different loading conditions, are determined by discrete and continuous PSOs, respectively. For verification of the study, the obtained results are compared with another method. In addition, the results are compared with other loss minimization techniques to show the effectiveness of this method.

This paper is structured as follows: in Section 2 modeling and formulation of the problem are described. The proposed methodology for distributed generation allocation and sizing is addressed in Section 3. In Section 4 the numerical results of the application of the mixed PSO algorithm to two test systems are described. Finally, Section 5 summarizes our conclusions.

2. Problem modeling and formulation

2.1. Distributed generation modeling

In power flow studies, depending upon the type of DG and type of interconnection to the network, the connection bus of DG is modeled as either a PV bus or a PQ bus or static voltage characteristic model (SVCM), as classified in [28]. DGs may directly connect to the grid by a synchronous or asynchronous generator or indirectly via power electronic interfaces. The control methodology of the inverter and the electrical machine are determined by type of DG units and its operation principle. The DG units can also be modeled as a negative load, which, independent of the voltage, injects active and reactive powers into the system, and classified as a PQ bus. The

PV bus has a specific value of voltage and variable reactive power that may change at each iteration. The PQ bus may inject specific values of P and Q to the grid (power factor control mode) or independently control P and Q. The constant PQ model is generally found to be sufficient for distribution system load flow analysis [29–33]. It should be mentioned that, according to the IEEE standard 1547, it is not preferred that the DG units regulate the voltage at the installation bus. When DG-units operate in parallel with the system, negative load modeling, independent of the terminal voltage (i.e. injects active and reactive power), is the simplest representation of these units. In this paper, DG is modeled as a negative load.

2.2. Distributed generation types

DG can be categorized into four major types, based on their terminal characteristics, regarding active and reactive power delivering capability, as follows [10]:

Type 1: DG units that can generate only P, such as fuel cells, photovoltaic cells, and microturbines. It should be noted that a fuel-cell, microturbine, and PV array with a four-quadrant inverter can also produce/consume reactive power (Q) with a real power generation.

Type 2: DG units that can generate only Q, such as gas turbines. In this condition, there is no need to produce real power and gas turbine generators act as a synchronous condenser.

Type 3: DG units that can generate both P and Q. Voltage source convertor (VSC) based DG unit and synchronous machine based DGs are in this group.

Type 4: DG units that can generate P but absorb Q, such as induction generators used in wind farms.

In this paper, we assume that DNOs integrate dispatchable DG units in the distribution network. In this condition, DNOs can dispatch DG units under different loading conditions and maximize the technical and economic benefits of these units.

2.3. Load flow methodology in distribution networks

One of the most important factors in planning and operation studies of power systems is load flow. In transmission level, either Gauss–Seidel or Newton–Raphson or their derivatives are used for load flow analysis. The above-mentioned methods, in distribution level, owing to specific features of the distribution network, such as radial structure, high R/X ratio, and unbalanced loads, have been weak and have a very poor convergence characteristic. Load flow methods proposed for distribution networks can be classified into branch-based and node-based methodologies [32]. Bus voltage or current injection is used in node-based methods while in the branch-based approaches, power or current of the branch is used as state variable to solve the power flow problem [29–32]. Forward/backward sweep-based methods have been the most widely accepted methods for distribution system load flow analysis due to their low memory requirements, computational efficiency, and good convergence characteristics. The forward sweep consists of node voltage calculation from the sending end to the receiving end. The backward sweep calculates the branch current and/or total power from the receiving end to the sending end [29–33]. In this paper, we used Rajicic's sweep method [30] for power flow analysis.

2.4. Objective function and constraints

2.4.1. Objective function

As shown in [34], the value of real and reactive power losses in a distribution network can be determined by Eq. (1). It should be mentioned that this exact formula can be easily extracted from basic relation in power losses calculation.

$$\begin{aligned} P_L + jQ_L &= \sum_1^{NB}\sum_1^{NB}\left[a_{ij}(P_iP_j + Q_iQ_j) + b_{ij}(Q_iP_j - P_iQ_j)\right] \\ &\quad + \sum_1^{NB}\sum_1^{NB}\left[c_{ij}(P_iP_j + Q_iQ_j) + d_{ij}(Q_iP_j - P_iQ_j)\right], \end{aligned} \tag{1}$$

where

$$a_{ij} = \frac{R_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$$

$$b_{ij} = \frac{R_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

$$c_{ij} = \frac{X_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$$

$$d_{ij} = \frac{X_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

$Z_{ij} = R_{ij} + jX_{ij}$ are the elements of the impedance matrix and NB is the number of buses of the study distribution network [34]. In this paper, the objective function is defined so as to minimize real power losses ($Objective\ Function = min \sum_1^{NB}\sum_1^{NB}\left[a_{ij}(P_iP_j + Q_iQ_j) + b_{ij}(Q_iP_j - P_iQ_j)\right]$) and the equality and inequality constrains that must be met are shown in Eqs. (2)–(5).

- The active and reactive power generated by each DG unit must be less than the total active and reactive loads of the system, respectively. Mathematically, this constraint is defined as follows:

$$P_{DG} \le \sum P_{load} \tag{2}$$

$$Q_{DG} \le \sum Q_{load} \tag{3}$$

- The other inequality constraint is the buses voltage limitation. For safe operation of the system, the operating voltage must be in its acceptable range, i.e.

$$V_{\min} \le V_{i=1,2,\ldots} \le V_{\max} i \in [1,\ 2\ldots \mathrm{NB}] \tag{4}$$

- For each branch, the maximum thermal capacity of each line limits the power flowing in it, i.e.

$$S_{i=1,\ldots} \le S_{\max} \tag{5}$$

3. Proposed DG allocation methodology

Classical optimization techniques are mostly derivative based methods that can solve continuous or differentiable problems. However, these methods cannot guarantee that the obtained solution is a global optimum. The probability of being trapped in local optima, inability to cope with nondifferentiable or noncontinuous problems, and excessive computations are the main drawbacks of such methodologies. For overcoming such deficiencies, heuristic and meta-heuristic optimization approaches were introduced. Particle swarm optimization (PSO) is one of these methods [35–37] and is very popular. PSO is a stochastic population-based meta-heuristic optimization algorithm inspired by the social behavior of swarms. It is capable of handling continuous or discrete single-objective and multiobjective constrained optimization problems in many areas, especially power system optimization problems such as OPF, reconfiguration, capacitor placement, unit commitment, and economic dispatch. Figure 2 depicts the concept of velocity and position update in the search space. DG placement and sizing is a very large scale problem with an extensive searching space and continuous and discrete variables. This algorithm can handle such problems. In comparison with other intelligent algorithms (e.g., SA, ICA, G), it has

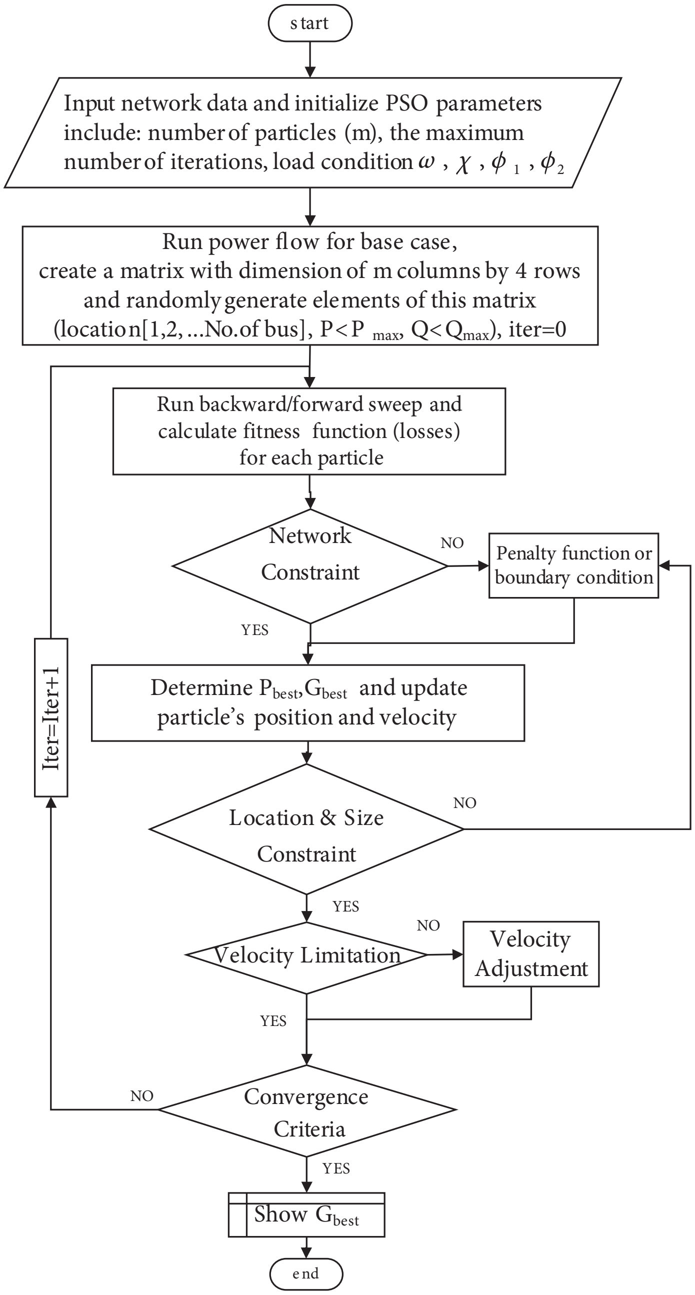

Figure 2. Concept of velocity and position update in the PSO algorithm.

less tunable parameters and understandable specification. Its simple structure, good convergence characteristics, and high global searching capability facilitate the application of this algorithm to the DG allocation problem. The proposed methodology is shown in the flowchart in Figure 3. The proposed algorithm in each loading condition is as follows:

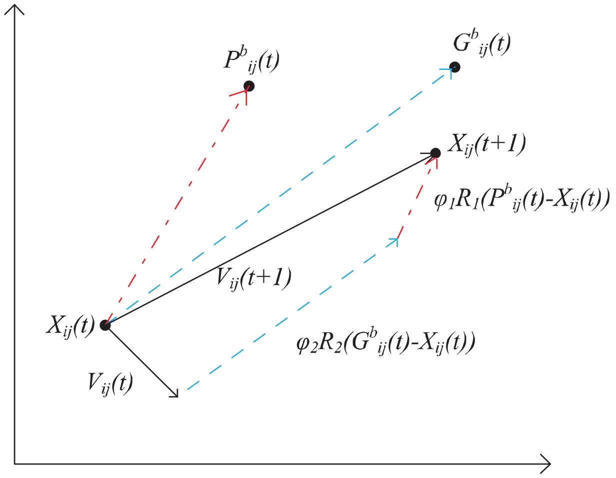

Figure 3. Flowchart of the proposed solution methodology.

Step 1: Enter the network data (considering loading condition), select DG type, and initialize mixed PSO parameters consisting of number of iterations, number of particles (m), constriction coefficient, cognitive coefficient, inertia weight. . . .

Step 2: Construct a matrix consisting of m (number of particles) rows and four columns (i.e. size, V_{size}, location, $V_{location}$), randomly initialized, and run power flow for the selected loading condition. It should be mentioned that in order to accelerate the proposed algorithm, deploying certain techniques such as sensitivity analysis can reduce the number of candidate locations for DG placement [5].

Step 3: Run power flow for each load condition (i.e. after DG installation) and calculate active power losses (fitness function) using (1), the bus voltages, and line power flows.

Step 4: Check the network constraint consisting of bus voltages and line power flows (thermal capacity). If all the constraints are satisfied, then go to step 6; otherwise go to the next step.

Step 5: Apply the penalty function method (PFM) to the DG units that violate the constraints. Omit the solutions that violate one or more constraints [38,39].

Step 6: Determine the best personal experience (P_{best}) of each particle and the best global experience (G_{best}) of swarms. (Find the optimal location and size).

Step 7: Update the position, size, and velocity of each particle. Note that the candidate location is a discrete variable and therefore discrete form of PSO is deployed for updating the location of each particle (candidate location of DG).

Step 9: Check the velocity of each particle. If it is in the predefined ranges then go to the next step. Otherwise it should be adjusted as follows:

$$V = \begin{cases} \pm V_{\max} & |V| > V_{\max} \\ V & otherwise \end{cases} \tag{6}$$

Step 10) Check the convergence criteria. The convergence criterion can be either reaching the maximum number of iterations or small improvements in the objective function value. If one of the above criteria is satisfied, the algorithm is finished and G_{best} is the optimal solution. Else, return to step 3.

4. Results and discussion

In this paper, two test systems were used to examine and verify the suggested mixed PSO method for optimal DG allocation in different loading levels. The first test system is the 33-bus radial distribution system with a total load 3.715 MW and 2.3 MVAr. The active and reactive losses of this system in the base configuration are 211 kW and 143.02 kVAr [40]. The second test system is the 69-bus radial distribution system with a total real and reactive load of 3.8021 MW and 2.6945 MVAr, respectively [41]. The active and reactive losses of this system in the base configuration are 225.04 kW and 102.12 kVAr, respectively. In this paper, we considered two different scenarios for the load. In the first scenario, which was implemented for both test cases, the main load level of the system was considered. In the second scenario, which was only applied to the first test case, different types of load growth were considered. In the first situation, only active load was increased by 50%. In the second situation, only reactive load and in the third situation both active and reactive loads were increased by 50%. In order to evaluate the performance of the proposed algorithm, it was run 100 times and the averaged value was presented as the final answer. The proposed mixed PSO algorithm was implemented in MATLAB, and was executed on an Intel core i7-2630^{TM} laptop with 2-GHz clock and 4 GB RAM.

4.1. First scenario

In this scenario, for two test cases the best location and size of the DG unit was found by the proposed mixed PSO algorithm. These allocations consisted of all the above-mentioned DG unit types.

4.1.1. 33-Bus test system

Figure 4 shows the rapid convergence of the proposed method over two independent runs on test case 1.

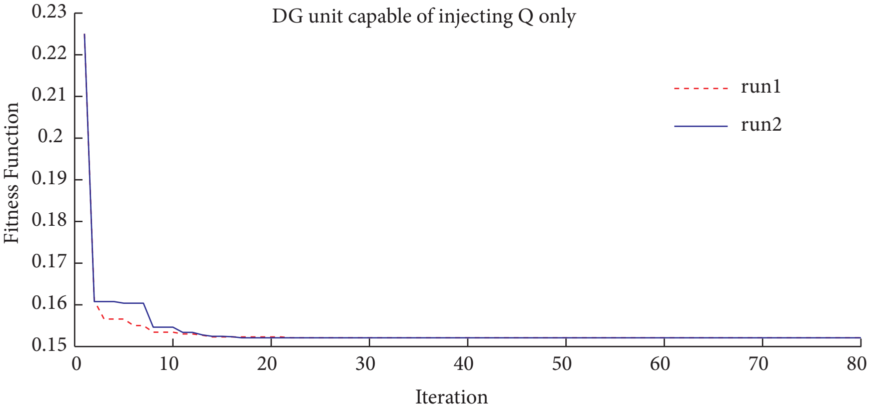

Figure 4. Convergence characteristics of proposed PSO algorithm.

Table 1 includes a summary of the results of optimal siting and sizing of all four types of the DG unit with the proposed mixed PSO allocation algorithm. Furthermore, a result of the IA method [10] is also presented for comparison purposes. As can be seen, for both methods, the optimal location is the same, but the sizes are slightly different. The obtained value for the DG size has a better fitness function in comparison to the value obtained from IA method. Furthermore, both type 1-DG and type 4-DG have the same values and locations. It is due to the consumption of reactive power in type 4-DG that the upstream network provides this value. The supplied extra reactive power by the upstream network increases branch currents and consequently results in an increase in losses. Hence, the optimal condition occurs when the DG unit does not consume any reactive power.

Table 1. Optimal location and size of DG unit for 33-bus system.

IEEE 33 bus	Location & size	DG type			
		Type 1	Type 2	Type 3	Type 4
PSO	Location	6	30	6	6
	Size(Mega)	2.5903	1.2583	2.55+j1.761	2.5916
IA	Location	6	30	6	6
	Size(Mega)	2.49	1.24	2.47+j1.728	2.49

Table 2 shows the losses in the system before and after installing DG in test case 1.

Table 2. Losses before and after DG installation for 33-bus system.

IEEE 33 bus	P_{loss}(kW)	Q_{loss}(kVAr)	P_{loss} reduction (%)	Q_{loss} reduction (%)
Without DG	211	143.02	-	-
Type 1	111	81.66	47.4	42.9
Type 2	151.38	103.81	28.25	27.41
Type 3	67.87	54.83	67.83	61.66
Type 4	111.04	81.69	47.4	42.88

As expected, the highest value of loss reduction is related to type 3-DG that produced both P and Q simultaneously. Table 3 summarizes the DG penetration percentage and the amount of power supplied by the upstream network. P_{UN} and Q_{UN} indicate the values of active and reactive power supplied by the upstream network, respectively. The value of power supplied by the upstream network varies depending on the type of DG unit. For example, in type 2-DG, because of DG being capable of injecting Q only, reduction in Q_{UN} is equal to 53.11%, while only 1.59% of P_{UN} was decreased. In [42], it was shown that after reconfiguration the active losses reduced to 139.55 kW, while by optimal placement of type 1, 3, and 4-DG, lower losses were obtained.

Table 3. Upstream power before and after DG installation for 33-bus system.

IEEE 33 bus	P_{UN}(kW)	Q_{UN}(kVAr)	P_{UN} reduction (%)	Q_{UN} reduction (%)
Without DG	3926.03	2443.01	-	-
Type 1	1235.74	2381.68	68.52	2.51
Type 2	3866.39	1145.50	1.59	53.11
Type 3	1232.88	593.83	68.59	75.69
Type 4	1236.02	2381.68	68.51	2.51

Voltage profiles for all kinds of DG units are shown in Figure 5. The voltage profile in type 3-DG is better than that in the other types. This is due to its ability of generating both P and Q simultaneously, which results in a reduction in the flowing current in the branch and consequently reductions of voltage drops.

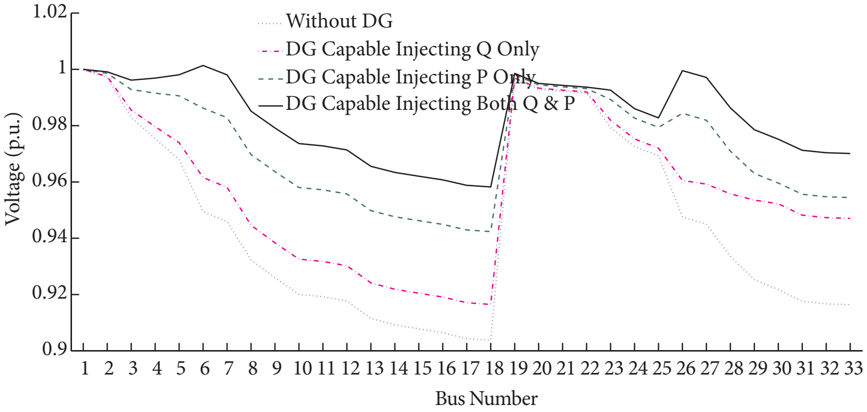

Figure 5. Voltage profiles before and after installation of DG in standard IEEE 33-bus test system.

Figures 6 and 7 show the real and imaginary parts of current in network branchs, respectively. From Figure 6, it can be observed that the major changes in the real part of the current occurred by allocating of units of type 1-DG or type 3-DG. In branches 5, 4, ??and 3, due to proximity to the optimal location, the direction of the real power is reversed. From Figure 7, it can be seen that in branches 29, 28, 27, 26, and 25, due to proximity to the DG installation bus, the direction of the reactive power is reversed.

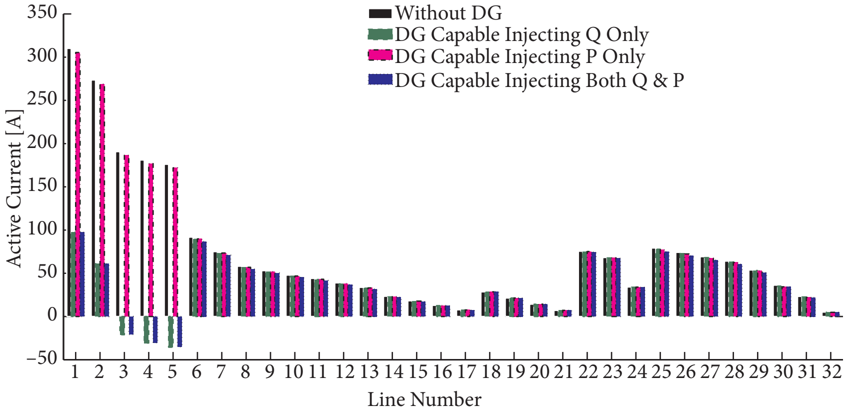

Figure 6. Real part of the current in network branchs in IEEE 33-bus test system.

The voltage angles at various buses in the 33-bus test system are shown in Figure 8. The enhancement in angles after DG placement is a sign of relieving of overload on branches of the system. The type 1-DG can inject active power and hence can increase the voltage angle. The type 2-DG can inject reactive power and therefore the voltage angle decreases. The type 3-DG can inject active and reactive powers and thus the voltage angle is not changed with respect to the case where DG is not installed.

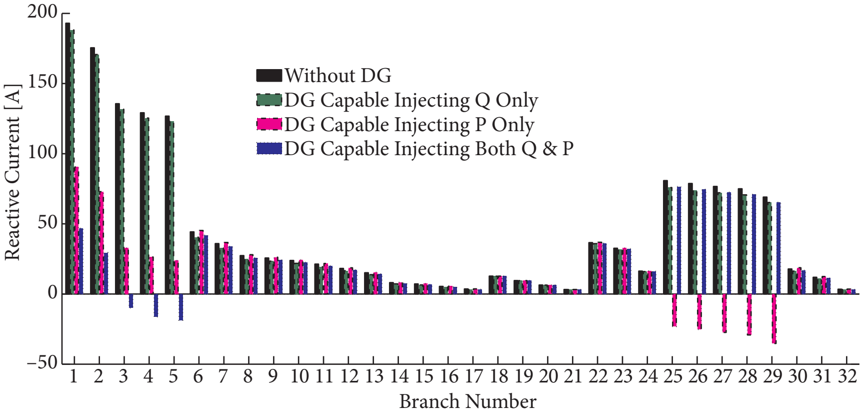

Figure 7. Imaginary part of the current in network branchs in IEEE 33-bus test system.

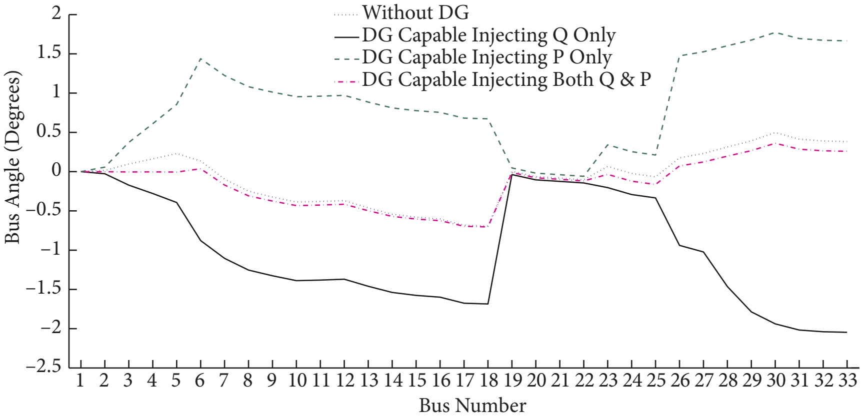

Figure 8. Angles of voltages of at various buses in 33-bus system.

4.1.2. 69-Bus test system

A second examination is directed to the 69-bus test system [41]. Table 4 summarizes the results of the optimal allocation of all four types of DG units for the 69-bus test system. Furthermore, the results for the IA method [10] are also presented for comparison purposes. In the 69-bus test system, bus 61 is the best location for installation of all 4 types of DG. By comparing the results of the mixed PSO method with the result of the ABC method in [14], it can be said that the mixed PSO method obtained a better solution than the ABC method did.

Table 5 shows the losses in the system before and after installing DG in the 69-bus system.

Table 4. Optimal location and size of DG unit for 69-bus system.

IEEE 69- bus	Location & size	DG type			
		Type 1	Type 2	Type 3	Type 4
PSO	Location	61	61	61	61
	Size(Mega)	1.8827	1.3299	1.851+j1.33	1.882
IA	Location	61	61	61	61
	Size(Mega)	1.81	1.33	1.832+j1.28	1.81

Table 5. Losses before and after DG installation for 69-bus system.

IEEE 69 bus	P_{loss}(kW)	Q_{loss}(kVAr)	P_{loss} reduction (%)	Q_{loss} reduction (%)
Without DG	225.04	102.12	-	-
Type 1	82.56	40.16	63.29	60.67
Type 2	151.45	70.18	32.67	31.27
Type 3	23.26	14.33	89.65	85.97
Type 4	82.56	40.16	63.29	60.67

Similar to the first case, type 3-DG has maximum loss reduction. The active and reactive losses are reduced by 89.65% and 85.97%, respectively.

The amount of power supplied by the upstream network is tabulated in Table 6. The amount of power supplied by the upstream network varies depending on the type of DG unit. For example, in type 1-DG, due to its capability of injecting P only, the reduction in P_{UN} is equal to 50.27% while only 2.2% of Q_{UN} was decreased. In [42], it was shown that after reconfiguration the active losses were reduced to 30.09 kW. However, by optimal placement of type 3-DG, lower losses were obtained.

Table 6. Upstream power before and after DG installation for 69-bus system.

IEEE 69 bus	P_{UN}(kW)	Q_{UN}(kVAr)	Reduction P_{UN} (%)	Reduction Q_{UN} (%)
Without DG	4027.15	2796.64	-	-
Type1	2002.64	2735.02	50.27	2.2
Type2	3954.18	1434.99	1.81	48.68
Type3	1975.36	1378.83	50.94	50.69
Type4	2002.64	2735.02	50.27	2.2

The voltage profile before and after DG placement on the 69-bus test system is shown in Figure 9. Similar to the first case, type 3 shows a better voltage improvement in comparison with the other types of DG.

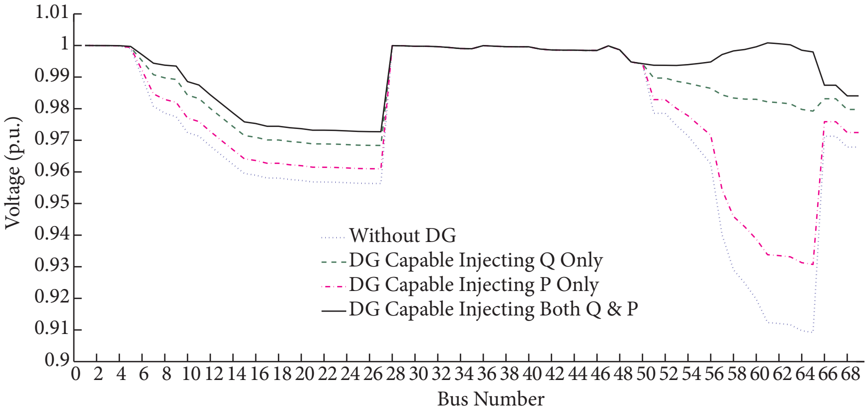

Figure 9. Voltage profiles before and after installation of DG in IEEE 69-bus test system.

4.2. Second scenario

This scenario represents the situation where the system's active or reactive load or both are increased. In the first situation an increase of 50%, only in the active load value, was assumed. In the second situation, an increase of 50%, only in the reactive load value, was assumed. In the third situation, both the active and reactive loads were increased by 50%. In Table 7 the results of load growth conditions are summarized. When the active load was increased by 50%, the active and reactive losses increased by 95.5% and 95.97%, respectively. Moreover, V_{min} was decreased by 0.0389 p.u. When the reactive load was increased by 50%, the active and reactive losses increased by 44.88% and 44.47%, respectively. Furthermore, V_{min} was decreased by 0.0159 p.u. When both active and reactive loads were increased by 50%, then the active and reactive losses increased by 146.37% and 146.79%, respectively. In addition, V_{min} was decreased by 0.05579 p.u.

Table 7. Summary of the load growth condition for 33-bus system.

IEEE 33 bus	Only P_{load} increased by 50%	Only Q_{load} increased by 50%	Both P_{load}& Q_{load} increased by 50%
P_{loss}(kW)	412.51	305.70	519.86
Q_{loss}(kVAr)	280.28	207.00	352.97
P_{UN}(MW)	5.98510	4.02075	6.09254
Q_{UN}(MVAr)	2.58020	3.65699	3.80290
V_{min}(pu)@BUS	0.86487@18	0.88784@18	0.84797@18

The results of the allocation and sizing of type 1 DG, type 2 DG, and type 3 DG under load growth conditions are summarized in Tables 8–10, respectively.

Table 8. Summary result for type 1-DG placement under the load growth condition.

33-bus test system		Only P_{load} increased by 50%	Only Q_{load} increased by 50%	Both P_{load}& Q_{load} increased by 50%
Type 1	Location	Bus 6	Bus 6	Bus 6
	Size(MW)	3.9140	2.6977	4.0225
	P_{loss} with DG	174.15	195.09	261.61
	Q_{loss} with DG	133.11	138.62	192.59
	P_{UN}	1.83267	1.21239	1.81163
	Q_{UN}	2.43310	3.58861	3.64257
	V_{min}(pu)@BUS	0.92579@18	0.92881@18	0.9121@18

Table 9. Summary result for type 2-DG placement under the load growth condition.

33-bus test system		Only P_{load} increased by 50%	Only Q_{load} increased by 50%	Both P_{load}& Q_{load} increased by 50%
Type 2	Location	Bus 30	Bus 30	Bus 30
	Size(MVAR)	1.3130	1.8684	1.9188
	P_{loss} with DG	341.82	170.30	363.94
	Q_{loss} with DG	233.58	117.93	250.03
	P_{UN}	5.91437	3.88531	5.93649
	Q_{UN}	1.22051	1.69951	1.78116
	V_{min}(pu)@BUS	0.87887@18	0.90759@18	0.86947@18

The results indicate that type 3-DG leads to better voltage profiles in comparison to the other two types.

When the active load was increased by 50%, maximum loss reduction was attributed to the type 3-DG. At this condition, active and reactive losses were reduced by 69.19% and 63.08%, respectively. Furthermore, the DG unit provided 68.08% and 76.59% of active and reactive demand, respectively.

Table 10. Summary result for type 3-DG placement under the load growth condition.

33-bus test system		Only P_{load} increased by 50%	Only Q_{load} increased by 50%	Both P_{load}& Q_{load} increased by 50%
Type 3	Location	Bus 6	Bus 30	Bus 6
	Size(MW+jMVAR)	3.8805+j1.841	1.5480+j1.888	3.965+j2.717
	P_{loss} with DG	127.06	88.44	156.98
	Q_{loss} with DG	103.45	66.89	126.99
	P_{UN}	1.81907	2.25545	1.7645
	Q_{UN}	0.56244	1.62888	0.85999
	V_{min}(pu)@BUS	0.94301@18	0.93118@18	0.93774@18
	V_{max}(pu)@BUS	1.00255@6	1.00298@30	1.00363@6

When the reactive load was increased by 50%, the maximum loss reduction was found again as belonging to the type 3-DG. At this condition, active and reactive losses were reduced by 71.07% and 67.68%, respectively. Furthermore, the DG unit provided 40.69% and 53.68% of active and reactive demand, respectively. When both active and reactive loads were increased by 50%, once again the maximum loss reduction was attributed to the type 3-DG. At this condition, active and reactive losses were reduced by 69.80% and 64.02%, respectively. Furthermore, the DG unit provided 69.20% and 75.95% of active and reactive demand, respectively.

5. Conclusion

In this paper, a new mixed PSO based algorithm was proposed for optimal planning the siting and sizing of different types of DG units considering different loading condition for minimizing losses in the distribution network. According to the type of this problem, for finding the location and size of DG units, the discrete and continuous form of PSO is utilized, respectively. The result shows that type 3-DG is a better choice for DNOs for integrating in the distribution network. Moreover, the results of the second scenario (load growth condition) are interesting, with an increase in the system load under different conditions. According to the results obtained, it can be said that different loading levels of the system have no effect on the optimal location and only optimal size of DG units is changed. Considering the variations of system loads during the day or month or year, a fixed size of DG unit cannot guarantee the optimal operation (from the power losses minimization point of view) in the system. This fixed optimal location is important for DNOs in their planning that can, by integrating dispatchable DG units with a wide range of power generation in this location, guarantee the optimal operation of the system. This method is very simple and can be applied to mixed integer nonlinear optimization problems in power systems. This method has a very good convergence characteristic and tuning its parameters is very simple. The validity of the proposed algorithm for finding optimal size and location was tested and verified on two test distribution networks and compared with an analytical approach. By integrating DGs at determined locations, the total active and reactive power loss of the system was reduced remarkably and the voltage profile of the system was improved.

Nomenclature

Indices:

i,j	Index for buses.

Variables:

P_{up}	Values of active power supplied by the upstream network.
Q_{up}	Values of reactive power supplied by the upstream network.
P_i	Injected active power at bus *i*.
Q_i	Injected reactive power at bus *i*.
P_L	Values of active power losses in kW.
Q_L	Values of reactive power losses in kVAR.
V_i	Voltage amplitude at bus *i*.
δ_i	Voltage angle at bus *i*.
R_{ij}	*ij* th element of real part of impedance matrix.
X_{ij}	*ij* th element of imaginary part of impedance matrix.
Z_{ij}	*ij* th element of impedance matrix.
P_{DG}	Active power produce by DG.
Q_{DG}	Reactive power produce by DG.
S_{max}	Maximum thermal capacity of each line.
$X_{ij}(\mathrm{t})$	Position of solution *ij* at iteration *t*.
$V_{ij}(\mathrm{t})$	Velocity of solution *ij* at iteration *t*.
$P_{ij}^{b}(t)$	Best position of solution *ij* at iteration *t*.
$G_{ij}^{b}(t)$	Global best position at iteration *t*.
φ_1, φ_2	Accelerate factor.
R_1, R_2	Random coefficient.
ω	Particle inertia coefficient.
χ	Constriction factor.
Iter	Current iteration.
M	Number of first population.

Parameters

NB	Number of buses.
a_{ij}, b_{ij}	Active power losses formula coefficient.
c_{ij}, d_{ij}	Reactive power losses formula coefficient.

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