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Optimal Sizing and Location of DG Units for Enhancing Voltage Profile and Minimizing Real Power Losses in the Radial Power Systems Based on PSO Technique

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Abstract. Distributed generation (DG) units have an important number of economic, environmental and technical features, which can contribute to the improvement of the reliability and security of the electric grid. However, all benefits that mentioned before cannot be maximised and enhanced unless the best sizing and position of distributed generation units are accurately determined. The arbitrary placement of DG units can lead to negative influences on the electrical networks. A noteworthy number of methods have been suggested to compute the optimal sizing and position of Distributed generation (DG) units in distribution networks. However, some of them focused on an analytical approach to estimate the optimum allocation of DG units in the radial distribution networks. Indeed, although this method was considered both constant and variable loads, as well as this method, overcome the problem of convergence, but the optimal sizing of DG units was not considered. The main intention of this study is to improve a technique that based on an intelligent algorithm for optimal planning and operation of DG technologies to minimise the real power losses, boost the voltage profile and enhance the overall reliability. IEEE Node-15 system has been taken to perform this study based on a MATLAB environment.in a single paragraph.

Keywords: DG units, Voltage profile, PSO, Power losses, IEEE-15 bus system.

1. Introduction

During the past several years, energy utilities are facing various challenges as the demand is growing dramatically and hence, the current transmission systems are not able to support such these increments in the power supply. The present need is either to increase the capacity of transmission systems or provide the consumer demand locally by Distributed Generation (DG). Indeed, the penetration of DG units into electrical networks has rapidly increased due to their economic, technical and environmental benefits [1]. As the penetration of the distributed generation devices proliferates inside the power distribution network, it is far within the satisfactory interest of all companies to assign them in a first approach such that it will rise reliability, lessen the power losses of network, and subsequently enhance the desired voltage profile while helping the chief purpose of the power injection [2]. Also, various methods could be used for the aim of optimum size and position of DG units such as power flow methods, GA, ABC, analytical methods and Particle Swarm Optimization (PSO) method. This research will employ PSO method to optimally determine the location as well as the size of DG units in the power distribution networks. In the previous researches, the proposed methods based on Newton

Raphson method, and Backward/Forward Sweep technique were employed to locate the best position of the desired size of a single DG. These methods are considered conventional as well as time-consuming, and the optimal size is not considered. Consequently, these bankruptcy goals to locate the most useful size and place of DG primarily based on the particle swarm optimisation approach for the goal of improving the voltage profile to minimise the overall real power losses in the power distribution systems. Besides, this paper considers one of a kind case research wherein the most advantageous length and region of a single DG as well as a couple of DGs intending to boost the voltage profile of system and decrease the full power losses. The proposed technique may be tested in IEEE-15 bus radial system to allocate the DG devices in addition to their sizes optimally.

2. Literature review

Distributed generation (DG) units are small units which generate depend on renewable power sources like wind, solar, and geothermal energy to generate electric power. Numerous benefits can be achieved, especially voltage profile and power losses if they are optimally injected in the power grid. However, the random selection of DG units can lead to many negative impacts on the power system. In this part, several previous researches is discussed to reach the optimal performance of the proposed system using DG units. A proposed method based on the Exact Loss Method was used in [3] for the aim of optimum sizing and setting of the distributed generation units and reducing the total losses of active power in the main distribution systems. However, the method in [3] has a limitation, as the multiple accommodations of DG units are not considered as well as this method is applicable whenever the distributed generation units supply active power to the network. A classical method based on the linear programming approach has been suggested in [4] for the aim of optimum position of DG units where several constraints such as voltage rise impacts and levels of the short circuit were considered. Conversely, this technique was only considered the location of DG units under fixed loads while the sizing planning has not been considered as well as variations in loads and generation uncertainties need to be also studied. A classical optimisation method based on continuous power flow has been projected in [5] in order to obtain the best placement of DG units through placing DG units at the critical load buses for the voltage breakdown. Nevertheless, this way has not considered the optimum sizing of DG units through the analysing process as well as time-varying demands has been not studied. Furthermore, a proposed technique based on the Dynamic Programming Approach has been proposed in [6] for the aim of optimum placement of DG units to lessen the power losses as well as enhance the reliability of the system. This method considers time changing loads where loads were modelled in various models, but this method was only limited to the location with no consideration to the size of DG units. Additionally, an intelligent method based on using genetic algorithm technique has been proposed in [7] for the aim of best position of DG units with considering many technical limitations, including voltage stability and the capacity of the feeders. This proposed method has successfully achieved the deferral of network upgrades and consequently minimize the total cost, but it was only considered the best sizing without the optimal size of DG units. Another optimization technique that used for optimally allocation and sizing of DG units is the Simulated Annealing (SA) approach [8]. For example, a multi-objective method based on the SA technique has been proposed in [9] for determining the best location of DG units so that real power losses, contingency and emissions could be minimised. Similarly, a proposed method in [10] for the aim of placing and sizing DG units optimally to decrease the overall costs due to power losses as well as the number of DG units. However, these two methods have limitations regarding high computational time, and less accurate results, as well as the power factor planning, has not been studied. A PSO based technique has been introduced in [11, 12] to calculate the best size and location of single DG unit in the radial distribution systems to minimise the real power losses. However, only one objective has been considered in these methods which are the real power losses as well as the ideal planning includes only single DG unit and with no consideration to the planning of power factor and time-varying demands. A multi-objective index approach based on PSO approach has been proposed in [16] to determine the best allocation and sizing of DG units in the distribution system to boost the voltage profile, enhancing the margins of maximum loading and decreasing the power losses. This method considered several technical constraints such as reactive and active power losses, loading of the line and the voltage profile as well as various models of load and non-unity power factor were also considered in this method, but the DG units were placed at peak demand conditions. Shortly, various methods have been utilized for solving the matter of best allocation and rating of distributed generation (DG) units where some of these approaches are based on traditional approaches while others based on using intelligent methods of optimisation.

3. Particle Swarm Optimization (PSO)

It is a kind of stochastic optimisation. It is fast, simple, robust, and high flexibility guarantees the results convergence differs from the Genetic Algorithm (GA) that does not contain crossover and mutation. It was usually applied for the continuous non-linear problem. Eberhart and Kennedy were first introduced PSO in 1995; it has been describing the behaviour of a group such as swarms of birds [13]. It is a type of stochastic optimisation technique. Every individual is a solution to the problem and has a fitness value where this fitness factor should be calculated and then be optimised. All agents have a memory and monitor the individual best position (p_best) as well as the relating fitness value. The agent has another best value which is called globathe l best position (g_best) which is the better value among all swarm (p_best). The velocity and position of individual is changed as exhibited in the Figure.1.

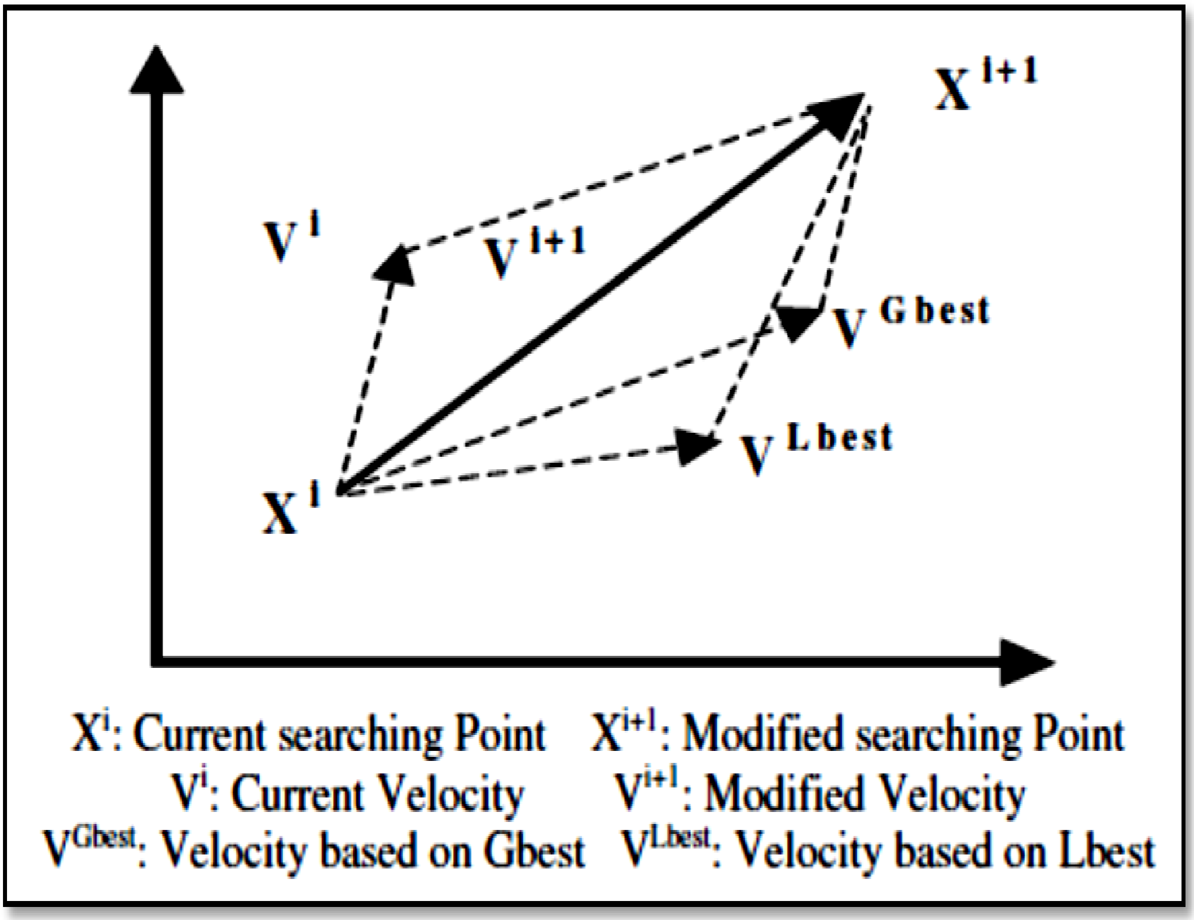

Figure 1. Concept of updating velocity in PSO

The basic flowchart of the PSO algorithm can be expressed in Figure 2 as follow:

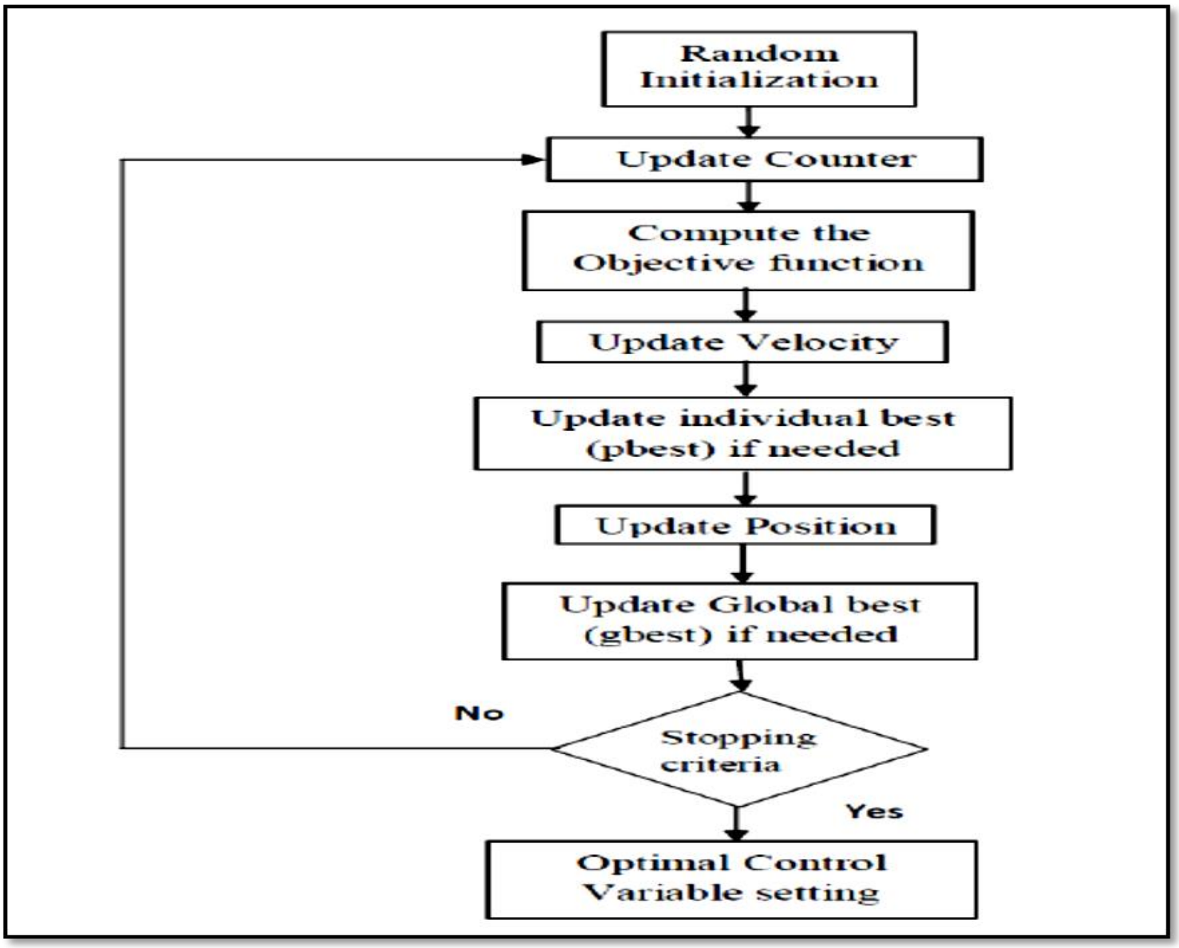

Figure 2. Basic flowchart of PSO algorithm

3.1 PSO parameters

There are several operational parameters in the PSO algorithm [14]:

3.1.1 Particle velocity

The current particles' velocity V^{k}_{id} is restricted to the range of $V_{id}^{min} \leq V_{id}^{k} \geq V_{id}^{max}$, where V^{max} determines the particles' fitness or resolution and guides the search areas between the current particles' position and the optimal position. A very high V^{max} value will make the particles to miss previously found good solutions because they will be moving in larger steps, preventing them from achieving the optimal solution. Similarly, a very low value of V^{max} will make the particles require a longer time to reach optimal solutions. In such situations, the particle may even fail to sufficiently explore the search space and will be susceptible to being trapped in local minima. Many experiments with PSO often set V^{max} value at 12 to 25 % of the particles' dynamic range on each dimension.

3.1.2 The random numbers

The stochastic behaviour of PSO is governed by a set of uniform random values in the range of [0, 1].

3.1.3 Weight coefficients

The parameters c1 and c2 represent the weightings of the stochastic acceleration terms. A high value of these parameters will cause a sudden particles' movement toward the optimal solution while a very low value of these parameters could cause the particles to roam away from the optimal solutions. Based on previous experiments with the PSO, the value of these parameters is usually set at 2.0.

3.1.4 Inertia weight

Balanced local and global exploration capabilities of the PSO can be achieved by ensuring a proper selection of the inertia weight w. This implies striking a balance between the exploration and exploitation capabilities of the PSO. To achieve faster convergence, a high value of w is often selected at the beginning of the optimisation and later decreased. The inertia weight w is generally adjusted to values of 0.4 for W_{max} and 0.9 for W_{min}. These values can be applied to the following equation:

$$w_k = w_{max} - \frac{(w_{max} - w_{min})}{k_{max}} * k$$

3.1.5 Termination criterion

After initialising the algorithm, several iterations (including the evaluation and updating steps) are executed until a termination criterion is met. This termination criterion is a pre-specified maximum number of iterations or a specific level of accuracy that must be achieved in the solution.

3.2 Poblem formulation

The issue studied in this paper is to locate most reliable DG power rating in addition to the bus allocation concurrently that make the radial distribution network actual power losses reduction in addition to decorating the voltage profile of all buses inside the examined systems.
The active power of the electrical power system can be written as follow [15]:

$$P_{Loss} = \sum_i^n \left|I_{branch\,(i)}\right|^2 R_i \tag{1}$$

Where
$\boldsymbol{I_{branch\,(i)}}$: The current in the branch i
N: The number of branches in the system
R_i: The resistance of each branch

The objective function is as below:
Minimise Real Power Losses $= Minimize \left\{\sum_i^n \left|I_{branch\,(i)}\right|^2 R_i\right\}$ (2)
Additionally, this object is subjected to the subsequent constraints:

$$V_j^{min} \leq V_j \leq V_j^{max} \; j = 1\;2\;3\;\ldots\ldots K \tag{3}$$

Where $\boldsymbol{j}$ is the number of the distribution bus

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \tag{4}$$

Concerning the proposed algorithm, the PSO equations can be expressed as follow:

$$v_i^{k+1} = W * v_i^{k} + C_1 * r_1 * (p_{best(i)}{}^{k} - x_i{}^{k}) + C_2 r_2 * (g_{best(i)}{}^{k} - x_i{}^{k}) \tag{5}$$

$$x_i{}^{k+1} = x_i{}^{k} + v_i{}^{k+1} \tag{6}$$

Where
$v_i{}^{k+1}$is the velocity of agent at $(k+1)$ iteration.
w is the inertia weight factor.
$v_i{}^{K}$ is the velocity of agent at current iteration.
$C_1,\ C_2$ are the two positive constants within $[0-4]$.
, $r_1\ r_2$ are the uniformly distributed positive random numbers within limit [0−1].
$p_{best(i)}{}^{k}$ is the local best value at (k) iteration.
$g_{best(i)}{}^{k}$ is the global best value at(k)iteration.
$x_i{}^{k+1}$ is the position at $(K+1)$ iteration.
$x_i{}^{k}$: is the position at current iteration k.

4. Simulation Results

The proposed technique is based entirely on the PSO algorithm can be examined at the IEEE-15 bus system with a purpose to locate the best size and position of DG units in the system. Also, different case studies that encompass the use of single and a couple of DG installations are analysed through the usage of these two take a look at systems. The following evaluation is implemented with the test systems and supplied, therefore:

- choose the best size of every DG
- choose the most efficient place of each DG
- The effect of the DG position of the voltage profile of the test network.
- The effect of the wide variety of DG installations
- The impact of DG units on the full power losses of the entire test network.

Additionally, the assumption made for the DG that each DG operates under the condition of optimal power factor where each DG is supposed to supply only real power where it is supposed to be solar photovoltaic-based DG.

IEEE 15 bus radial test system

The first test system that will be subjected to the suggested algorithm is IEEE-15 bus system in order to compute the best position and size of the DG units in this system based on PSO approach. The single line diagram of the IEEE-15 bus system is illustrated in the **Figure 3,** and the whole network data is taken from [16].

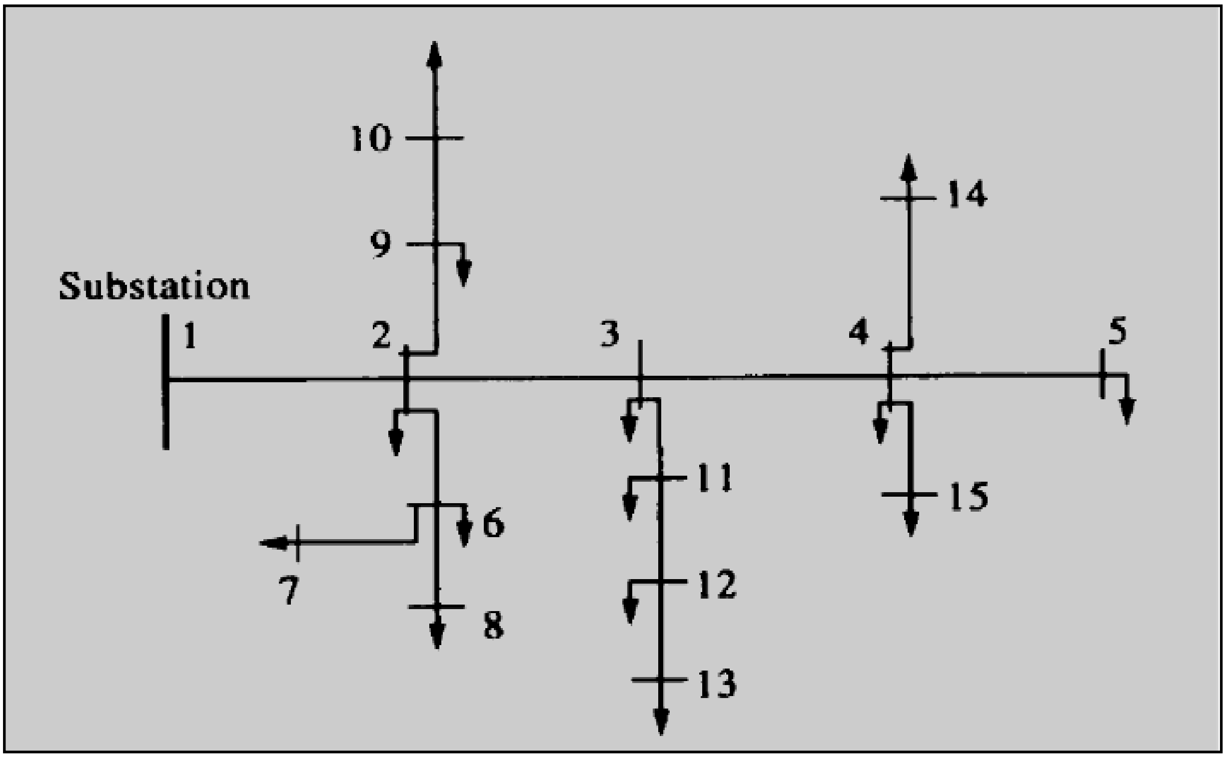

Figure 3. Single line diagram of the IEEE-15 bus system.

4.1 Scenario 1: Without DG

The proposed technique has been applied to the IEEE-15bus radial distribution system during the normal condition without adding any DG unit. Indeed, the voltage profile of all buses as well as the total power losses for the tested system for this case is recorded. Indeed, the voltage profile for all 15 buses as well as the active and reactive power losses in each point without installing any DG unit are presented in **Table 1**.

Additionally, **Figure 4** demonstrates the fluctuation of the voltage profile at all buses of the IEEE-15 bus system. From this figure, it could be noticed that the voltage profile of the projected system has some weak points that might be subjected to the failure at any contingency or normal variation in loads. The weakest points in the tested system are buses numbered 12, 13, 14 and 15 with a voltage profile of 0.9438, 0.9424, 0.9466 and 0.9465 respectively. Also, the overall real power losses are around 61.6281 KW, and the total reactive power losses are around 57.2886 KVAr.

Moreover, Figure 5 depicts the whole real power as well as reactive power losses in each bus in the system where it can be seen that some points have relatively high-power losses which consequently can affect the reliability and the voltage profile of the proposed system during abnormal conditions. Therefore, the desired voltage profile in addition to the active power losses of the system could be dramatically improved by installing DG units at suitable locations where these units play an imperative role in decreasing power losses and enhancing the voltage of the whole system.

Table 1. Voltage profile and power losses of all buses without DG in the IEEE-15 bus system

Bus Number	Voltage Profile in P.U	Active Power Losses in KW	Reactive Power Losses in KVAr
1	1	61.6281	57.2886
2	0.9702	39.1179	38.2621
3	0.9550	11.7592	11.5019
4	0.9490	2.5455	2.4899
5	0.9480	0.0577	0.0389
6	0.9625	2.4713	1.6669
7	0.9614	0.0621	0.0419
8	0.9571	0.9573	0.6457
9	0.9668	0.8991	0.6065
10	0.9655	0.1151	0.0776
11	0.9480	2.2672	1.5292
12	0.9438	0.6269	0.4229
13	0.9424	0.0771	0.0520
14	0.9466	0.2134	0.1440
15	0.9465	0.4582	0.3091

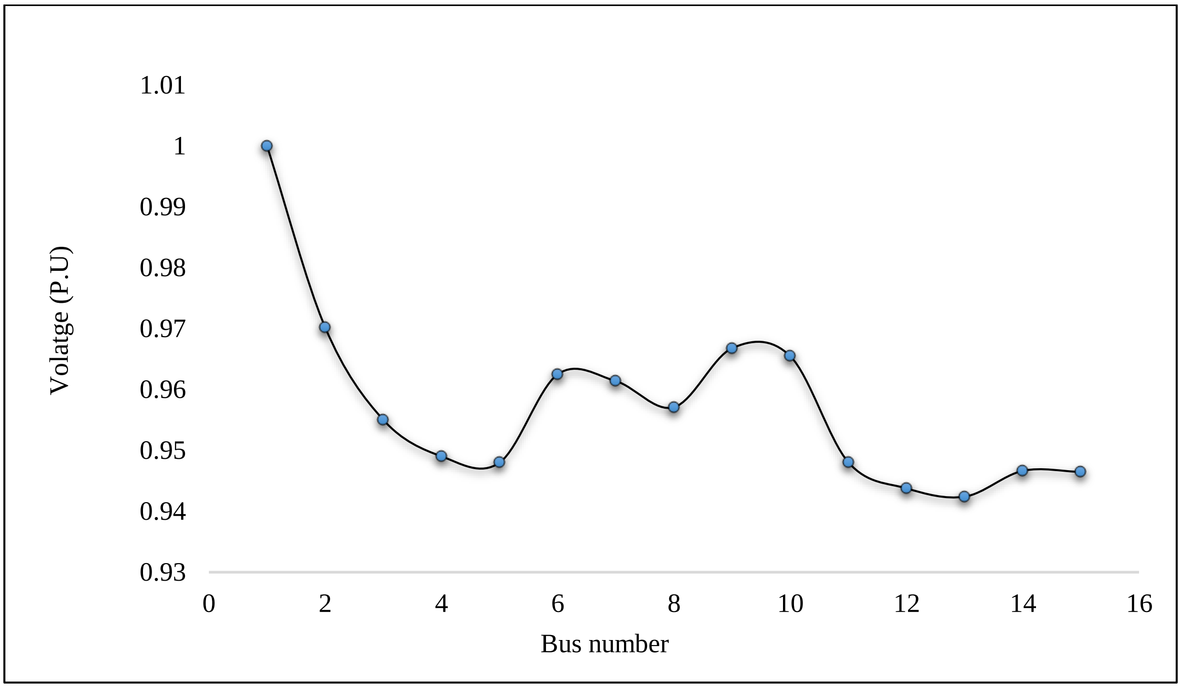

Figure 4. Voltage profile of all 15-bus system without DG

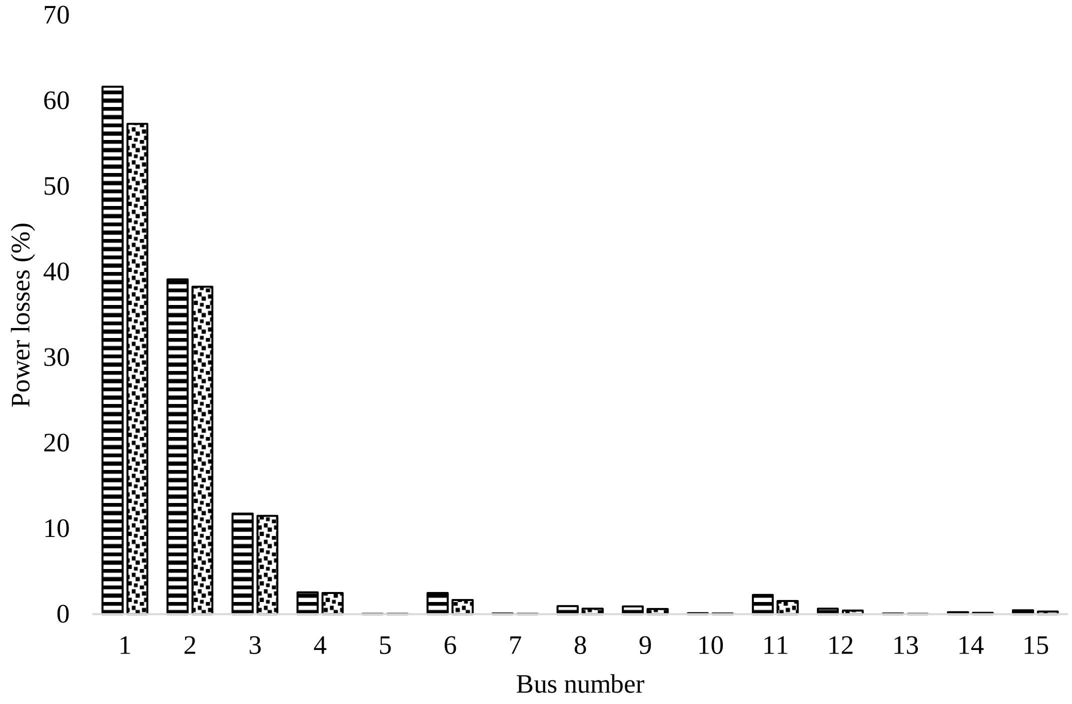

Figure 5. Whole real as well as reactive power losses in each point in 15 bus test system

4.2 Scenario 2: installing single DG unit

The second scenario includes the installation of a single DG in the 15-bus test system. Indeed, the proposed method has been applied to the IEE-15bus radial distribution network by installing single DG to locate the optimum placement and sizing of this DG unit. Also, all buses are considered as candidate buses in this test and all subsequent tests. Once applying the suggested method to the proposed system, the outcomes for best sizing and position of DG are as follow:

The optimum sizing of the DG units (KW)	Best placement of DG units
639	Bus 3

Also, after allocating a single DG unit that at the third bus the voltage profile has improved as well as the aggregate power losses are minimised in comparison with the first scenario. The voltage profile of the weakest buses, which are 12, 13, 14 and 15, in the test system has improved from 0.9438, 0.9424, 0.9466 and 0.9465 respectively in the first scenario to 0.9677, 0.9655, 0.9713 and 0.9712 respectively in the second scenario with single DG unit.

Correspondingly, the total active power losses for the test system has been minimised substantially from 61.6281 KW in the first scenario to 32.506 KW in the second one with one DG, and that represents approximately 47.254% improvement in comparison with the scenario of without DG as presented in the Figure 6.

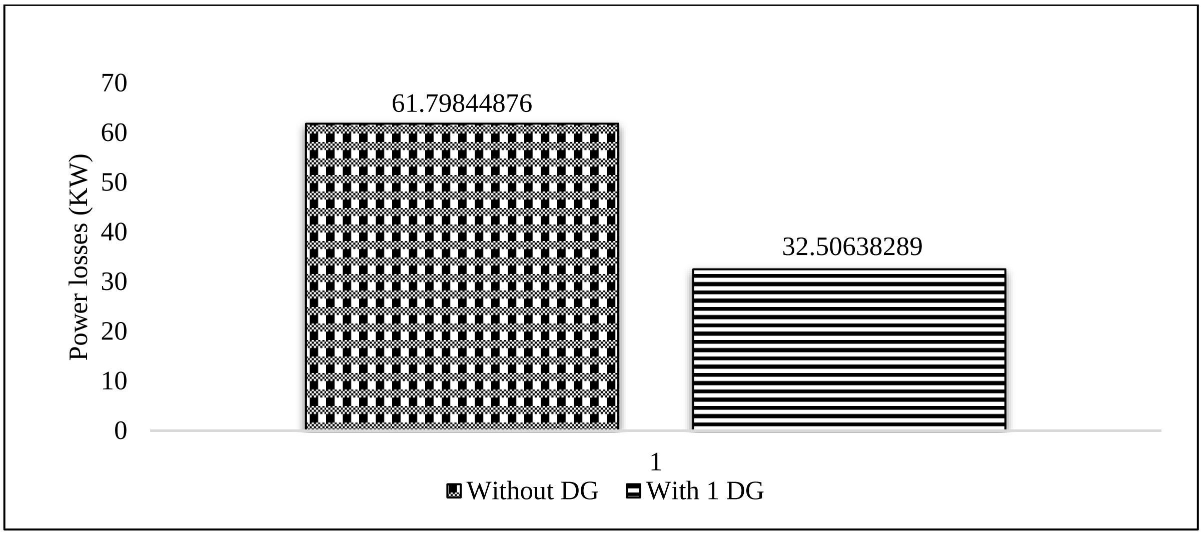

Figure 6. Power losses in a 15-bus system with and without one DG unit

Moreover, figure 7 indicates the voltage profile of all buses in the test system after the allocation of a single DG unit. From these figures, it could be noticed that the allocation of a DG unit can enhance the voltage profile in addition to lessen the overall power losses. Additionally, the voltage profile and active power losses could be similarly boosted with the aid of increasing the size of the DG units.

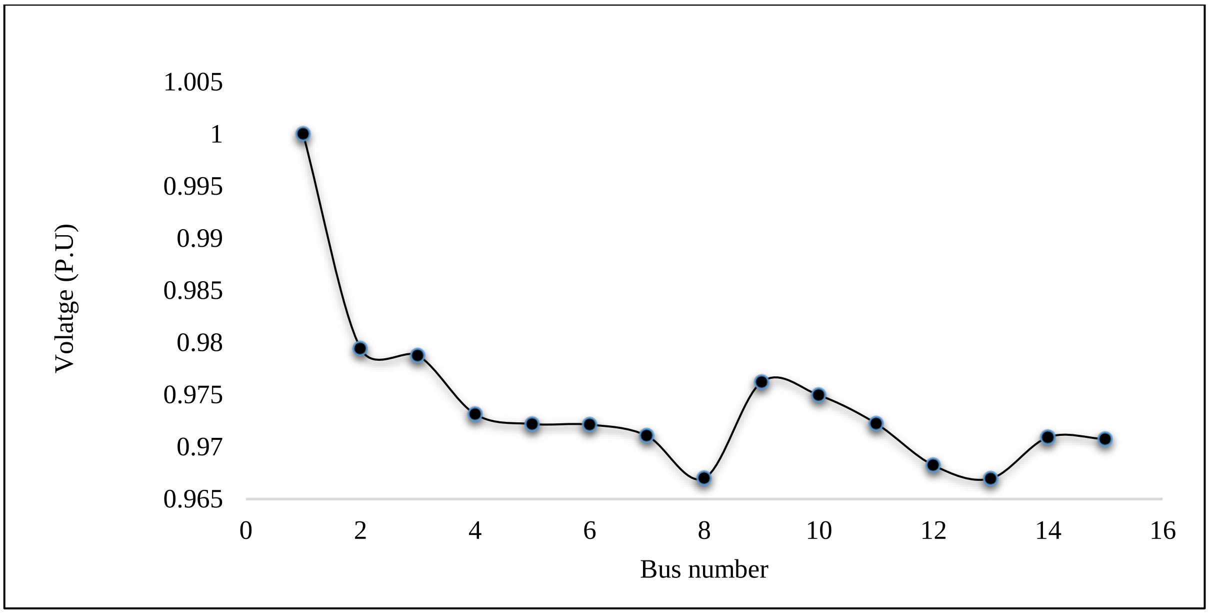

Figure 7. Voltage profile of all 15-bus system with single DG unit

4.3 Scenario 3: Installing multiple DG units

An additional decision variable was added to handle the second DG, and all combinations for allocating two DGs in a distribution system were investigated. The third scenario includes the application of DG units in the IEEE-15 bus system. Indeed, the suggested method turned into performed to a 15-bus radial distribution network utilizing installing two DG units to locate the ultimate size and allocation of each DG unit. Additionally, all buses are considered as candidate buses in this test in order to set the best location and rating of DG units. Once applying the suggested technique to the test network, the results for best sizing and position of DG units are as follow:

The optimal sizing of the first DG unit (KW)	The optimal position of the first DG unit	The optimal sizing of the second DG unit (KW)	The optimal position of the second DG unit
639	Bus 3	328	Bus 6

The voltage profile of the weakest buses in the test system are 12, 13, 14 and 15 have improved from 0.9438, 0.9424, 0.9466 and 0.9465 respectively in the first scenario without DG units to 0.9722, 0.9710, 0.9749 and 0.9747 respectively in the third scenario with the allocation of two DG units. This represents rapid enhancement even in comparison with the second scenario.

Furthermore, the aggregate power losses for the test system has minimized significantly from 61.6281 KW in the first scenario to 29.1737 KW in the third one with two DG units, and that represents approximately 52.66 % improvement in comparison with the scenario of without DG as demonstrated in figure 8. in addition, figure 9 demonstrates the voltage profile of all buses in the tested network after installing two DG units at bus 3and 6, respectively.

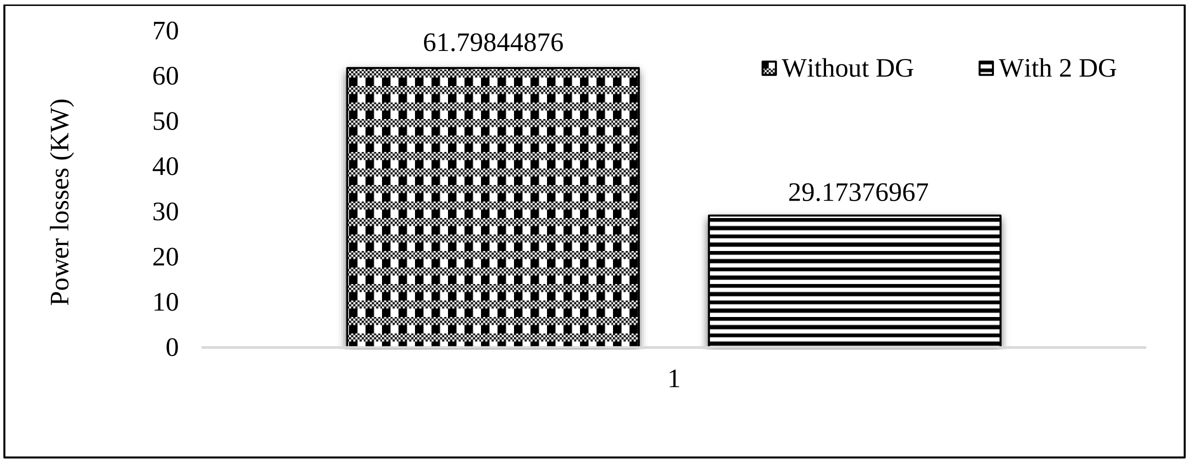

Figure 8. Comparison of power losses for 15 bus system for cases of without and with the installation of multiple DG units

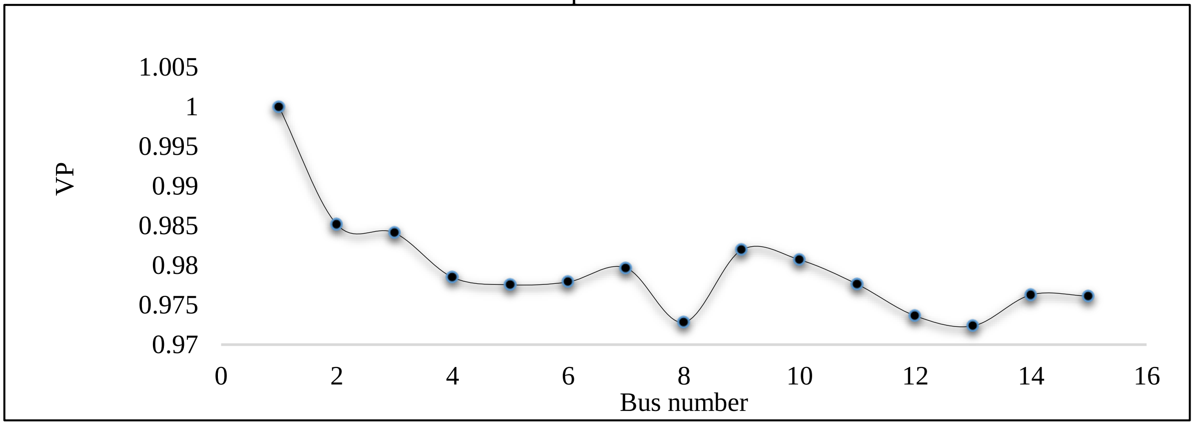

Figure 9. Voltage profile of all 15-bus system with two DG units

4.4 Comparison of case studies with 15 bus system

The best placement and size of DG units can play a noteworthy role in increasing the voltage profile of all buses in the tested systems in addition to lowering the whole power losses. Consequently, the reliability, stability and efficiency of the distribution systems can be dramatically improved and that contribute to the satisfaction of both consumers and suppliers. Moreover, the allocation of DG can increase the voltage of all buses with low values, and the use of multi DG can lead to further improvement as shown in Figure 10. Indeed, Table 2 illustrates the voltage profile for the weakest buses in the 15-bus system under different scenarios.

Additionally, Figure 11 and Figure 12 compare the total power losses between three various scenarios that studied previously in this chapter. It is worth mentioning that the total power losses have been lessened from 61.6281 KW for the standard case without any DG unit to 32.506 KW with the single allocation of DG unit to 29.1737 KW with multiple allocations of DG units.

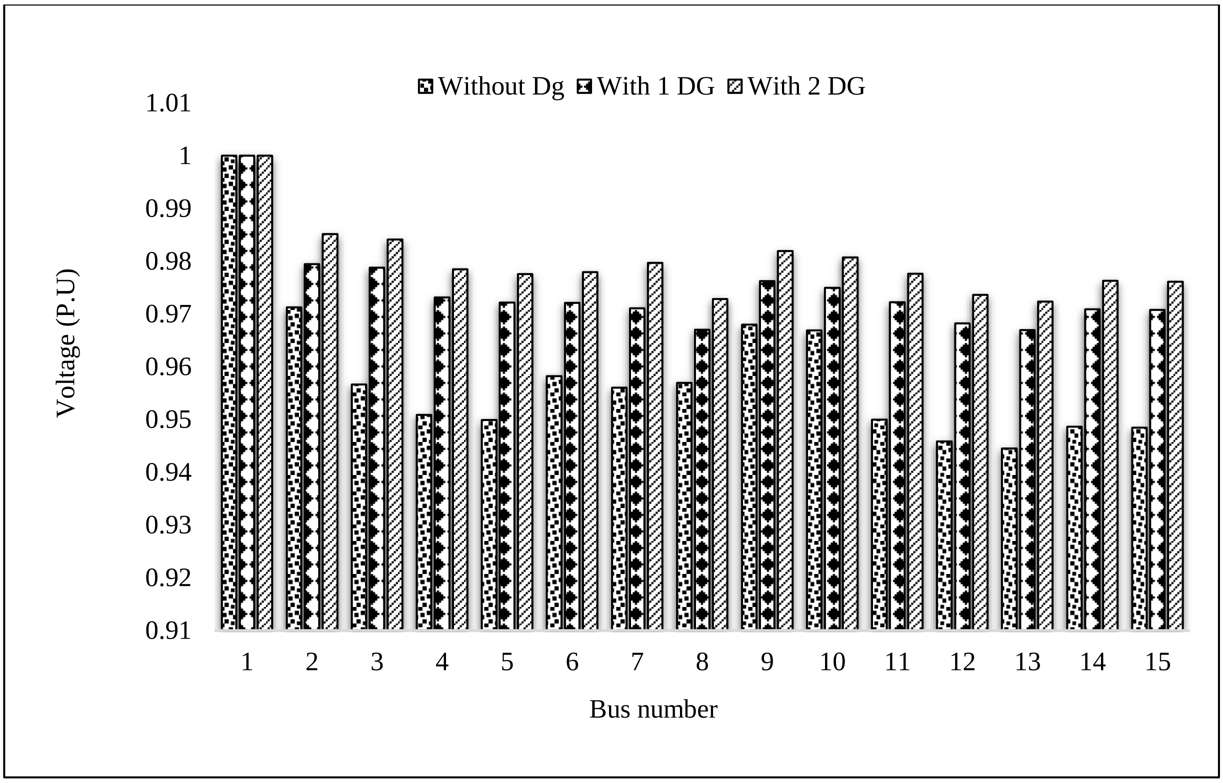

Figure 10. Comparison of voltage profile for Different Scenarios in 15 bus system

Table 2. Comparison of voltage profile for of weakest buses with different scenarios for 15-bus system

Bus Number	Without DG	With Single DG	With Multiple DG
12	0.945826	0.968238	0.973635
13	0.944515	0.966963	0.97237
14	0.948606	0.970918	0.976282
15	0.948437	0.970755	0.97612

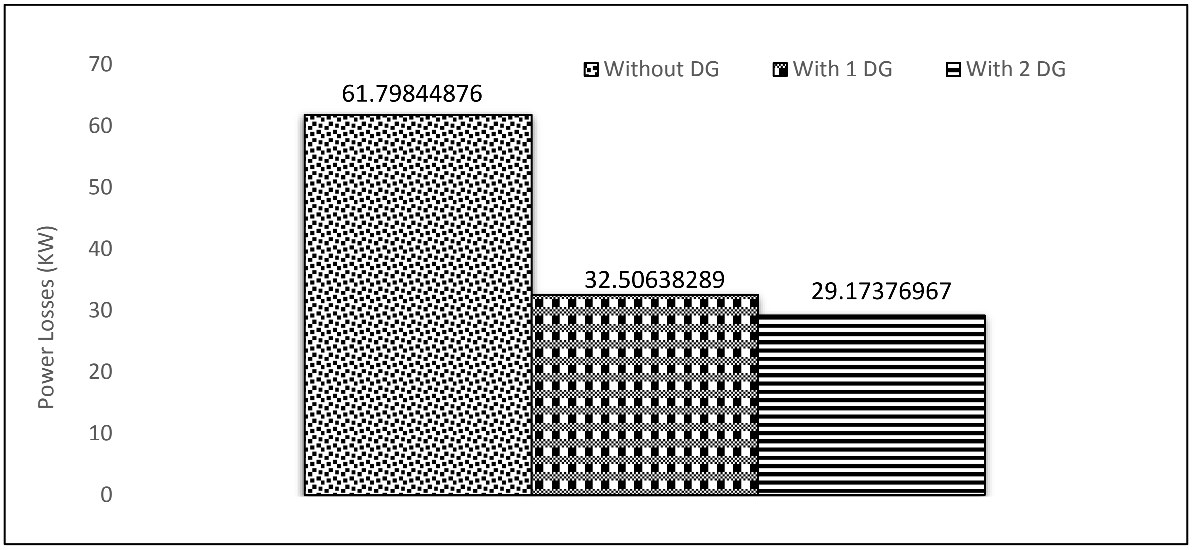

Figure 11. Comparison of power losses for a 15-bus system with different scenarios

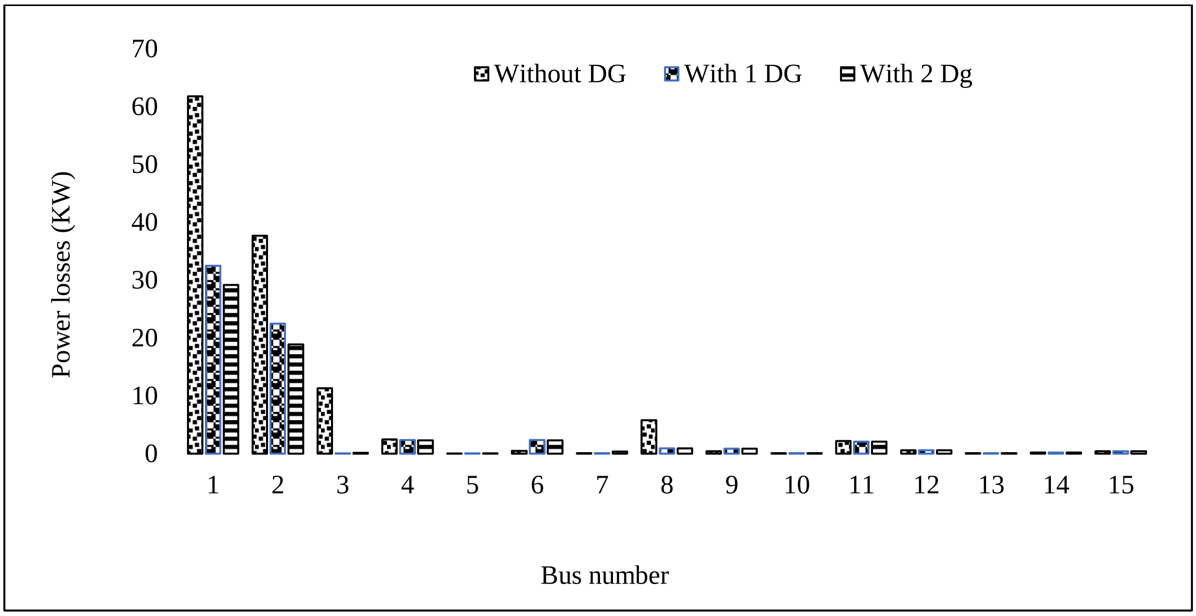

Figure 12. Comparison of power losses for each bus in a 15-bus system with different scenarios

5.Conclusion

In the presented paper, a PSO approach is applied to acquire the best size and place of single and multiple DG in which the outstanding objectives are to boost the voltage profile and lessen the active power losses. The suggested PSO approach is employed to locate the best allocation and size of DG units. Indeed, different case studies take into consideration numerous scenarios such as single DG in addition to multiple DG units. The proposed method was expressed as a constrained nonlinear programming problem and applied on the IEEE-15bus radial distribution network to illustrate its applicability. Additionally, single and multiple DG installation cases were performed for each test system then compared to the case without DG. The results demonstrated that DG size and placement have an essential influence in reducing power losses in addition to boosting the voltage profiles of the power system. It was also demonstrated that integrating multiple DGs reduces the system power losses more than integrating only one DG.

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