Optimal Planning of Distributed Generation in Distribution Networks using the Differential Evolutionary Algorithm

Ali Norouzizad and Salah Bahramara
Department of Electrical Engineering
Sanandaj Branch, Islamic Azad University
Sanandaj, Iran
{alinorouzizad; s_bahramara}@yahoo.com

Abbas Divian
Department of Electrical Engineering
Iran University of Science and Technology
Tehran, Iran
abbas.divian@gmail.com

Gerardo J. Osório
C-MAST, University of Beira Interior
Covilha, Portugal
gjosilva@gmail.com

Miadreza Shafie-khah
School of Technology and Innovations
University of Vaasa
Vaasa 65200, Finland
miadreza@gmail.com

Fei Wang
Department of Electrical Engineering
North China Electric Power University
Baoding 071003, China
feiwang@ncepu.edu.cn

João P. S. Catalão
Faculty of Engineering of the
University of Porto and INESC TEC
Porto, Portugal
catalao@fe.up.pt

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***Abstract*—The use of distributed generators (DGs) in the distribution networks has many economic and technical advantages. In order to achieve these advantages, DGs should have the proper size and be installed in suitable locations. In this work, a differential evolution algorithm is proposed to find the best location and capacity of DGs in the distribution network with the aim of getting to the minimum losses and optimal voltage profile. The important loads need continuity of power supply when the network is in islanding mode due to various events such as short circuit faults. The existence of at least one DG in these networks is necessary. In this paper, the proposed method is applied to the IEEE 33-bus distribution network in two connection modes. First, it is connected with the power grid and then it works in the islanding operation mode. The results show the effectiveness of the proposed algorithm.**

Keywords—Differential evolution algorithm; Distributed generation; Islanding; Power loss; Voltage profile.

I. Introduction

In recent years, the use of distributed generators (DGs) in order to reduce the use of fossil fuels and increase the efficiency of power grids has grown significantly. Several factors such as environmental pollution, problems of the establishment of new transmission lines and technological advancement in the economic field of small-scale generation units manufacturing compared to large plants have led to an increase in the use of DGs [1-3].

Since DGs are close to load centers, electrical energy transfer is not needed for long distances and hence it reduces the cost of the electric power supply. DGs have several advantages to the power systems including decreasing the investment of new power plants, transmission and distribution networks, environmental pollution reduction, the voltage profile improvement, and frequency stability, improving the reliability and enhancing the security margin of the system [2-4].

The existence of generators in the distribution network affects the power flow and the voltage profile. It can have a positive or negative effect on the performance of the distribution networks [5-7]. Determining the optimal location and optimal size of DGs has an important role in reducing losses, managing voltage profile and improving other parameters [8] and achieving expressed goals. Many research activities have been performed in this field [1-20].

The locating problem of multiple DG units to achieve the maximum power losses reduction in large distribution networks was presented in [7]. For this purpose, the improved analytical method (IA) is proposed.

In reference [9] have determined the optimal location and capacity of the DG unit using the particle swarm optimization algorithm. Minimizing the power losses of radial distribution network lines was the objective function. Reference [10] presented an index-based multi-objective method for determining the optimal location and capacity of several DG units in distribution networks with different load models. The proposed multi-objective function, which should be optimized, includes a short circuit level parameter to realize the requirements of the protective devices.

Reference [11] has introduced a new method based on fuzzy logic and bee colony algorithm for the DG locating problem in a radial distribution network to reduce active power losses and improve the voltage profile. The proposed method was implemented in the two stages. In the first step, the fuzzy theory was used to determine the optimal locations, and in the second step, the ABC algorithm was used to find the DG capacity.

In [12], the ZIP model was considered for loads, which includes three sections of constant impedance (Z), constant current (I) and constant power (P) – the ZIP model, and the least squares method was used to determine it. Locating the DG and determining its capacity to reduce losses was carried out in each bus by considering the load model. The DG unit is considered as the PQ constant power generator too. In [13] taboo search algorithm has been used to reduce power losses.

In [14], a fuzzy genetic algorithm has been used to allocate DG units, which objective function is reducing the overall system losses and costs. It has taken into account the different load levels and time periods in the distribution system in the optimization process and compared the results.

Reference [15] has proposed a novel multi-objective particle swarm optimization (NMO-PSO) method for locating distributed generation sources based on wind and solar power [16-18] in the distribution system considering the power and voltage constraints.

From the previous works overview, in this work, the optimal allocation of DG units, as well as the determination of their optimal size is done with a continuous supply of power for important loads in distribution networks.

If the fault occurs in the upstream network or within the distribution network in some branches and lines that cause the distribution network to be disconnected from the power grid, or the distribution network is divided into several discrete zones, important loads should be continuously supplied. Therefore, the division of the distribution network to different island zones according to the continuous power supply constraint has been made.

Thus, the number of DG units is determined according to the number of discrete zones. The main contribution of this paper is optimal sizing and placement of DG units in the both modes of the continuous network and separate networks with the number of different zones using the differential evolution (DE) algorithm.

The proposed algorithm is applied in each case to reduce power losses and improve the voltage profile. Most of the DG units are able to inject active and reactive power into the network simultaneously. The only effect of active power generation on voltage profile and loss reduction is considered and investigated because most DG units are purchased based on active power capacities.

Therefore, the purchased DG units have to be able to supply the active power of the island network loads to maintain the voltage and frequency stability of the network. Furthermore, with respect to the reactive power generation of DGs, voltage profile also will be better considerably compared to the optimizing based on the only active power generation.

Before using the proposed method, the active and reactive power losses of the network are calculated using the forward-backward sweep method. The remaining manuscript is structured as follows. Section 2 describes the problem formulation, the objective functions and the constraints of the problem. Section 3 the algorithm DE is introduced. The simulation results and conclusion are presented in Section 4 and 5, respectively.

II. Objective Functions and Optimization Constraints

Loss reduction and improve voltage profile are followed by different methods for determining the optimal position and capacity of DGs. Network constraints such as voltage domain constraints and DGs are proposed as problem constraints.

A. Objective functions

An index is presented as equation (1) to define the objective function to improve the voltage domain.

$$\begin{aligned} &Minimum \quad \Delta V = \sum_{i=1}^{n} \Delta V_i \\ &Subject\ to \quad \Delta V_i = \left| V_{ref} - V_i \right| \quad V_{ref} = 1^{pu} \end{aligned} \tag{1}$$

where n is the number of buses. To define the objective function to reduce losses, the total loss of the distribution system, which is equal to the sum of all branches losses, is presented as (2) [4].

$$\begin{aligned} P_{Loss} &= \sum_{i=1}^{m} R_i I_i^2 \\ &= \sum_{i=1}^{m} [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] Y_{ij} \cos\varphi_{ij} \end{aligned} \tag{2}$$

In (2), m is the number of system lines, V_i and δ_i are the amplitude and angle of ith bus voltage respectively, Y_{ij} and φ_{ij} are the amplitude and angle of the existing line admittance between bus i and j, respectively. The objective function is usually considered as a combination of other goals to improve efficiency and better results of the algorithm. Usually, the total objective function is defined as the weighted sum of the other objective functions.

$$F_T = w_p \times P_{loss} + w_v \times \Delta V \tag{3}$$

In (3), w_p and w_v are the weight coefficients of the total system losses, and the total sum of the difference of the bus voltages from the reference voltage, respectively.

Both the losses and voltage difference from the reference voltage should be minimized to minimize the above function, i.e. reducing system losses and improving the voltage profile must be simultaneous. Also, the sum of absolute values of weights, which are applied for all the effects, is given by (4).

$$\left| w_p \right| + \left| w_v \right| = 1 \tag{4}$$

Assigning any value to each of the two above parameters determines the importance of the effect of the objective function of the loss and the voltage profile in the overall objective function.

B. Grid Constraints

In a distribution system, the algebraic sum of the input and output loads is equal, which is presented as the limitation of equality of power production and power consumption. Thus:

$$P_{Grid} + \sum_{i=1}^{N_{DG}} P_{DG(i)} = P_{Loss} + \sum_{i=1}^{N_{Load}} P_{Load}(i) \tag{5}$$

$$Q_{Grid} + \sum_{i=1}^{N_{DG}} Q_{DG(i)} = Q_{Loss} + \sum_{i=1}^{N_{Load}} Q_{Load}(i) \tag{6}$$

where P_{Grid}, Q_{Grid} are respectively the active and reactive powers received from the grid, P_{DG}, Q_{DG} are the active and reactive powers generated by DG units, P_{Load}, Q_{Load} are also the active and reactive powers consumption of loads. N_{DG}, N_{Load} are the numbers of DGs and loads, and P_{Loss}, Q_{Loss} are the active and reactive power losses of the whole grid lines, respectively.

The values of P_{Grid} and Q_{Grid} are zero in the apart from the grid and island mode. The following constraints are, respectively, the limitation of the grid buses voltage magnitude and the capacities of DGs, which are expressed in terms of (7) to (9), respectively.

$$V_{min} \le \left| V_i \right| \le V_{max} \tag{7}$$

$$P_{DG}^{min} < P_{DG}(i) < P_{DG}^{max} \tag{8}$$

$$Q_{DG}^{min} < Q_{DG}(i) < Q_{DG}^{max} \tag{9}$$

According to the standard for voltage constraints, V_{min} and V_{max} values are selected to 0.95 p.u and 1.05 p.u, respectively.

III. Differential Evolution Optimization Algorithm

The heuristic algorithms are divided into two general categories dependent on single-solution-based and population-based algorithms, where single-solution-based algorithms change a solution during the process of searching, whereas in population-based algorithms, a population of solutions is considered.

DE algorithm is a population-based algorithm. This algorithm starts by creating a primitive population, and then by applying the operators such as mutation and crossover, the newborn generation is formed. In the next stage, which is called the selection stage, in order to evaluate the degree of competence measured by the objective function, the newborn generation is compared with the parent generation.

The best group is selected and then enters the next step as the next generation. This will continue to achieve the desired results. The steps of DE algorithm and the details of each step are as follows [19, 20].

A. Creating a Primitive Population

The problem variables at this algorithm are denoted by X. Each of these variables has one upper and one lower limit. The initial population with NP number is generated randomly according to (10).

$$X_{i0} = X_i^{min} + rand[\delta_i * (X_i^{\max} - X_i^{min})] \quad i = 1 : NP \qquad (10)$$

where δ_i is a random number in the range 0 and 1, and NP is the number of populations, which index i is counted to this number.

B. Mutation and Crossover

A suitable strategy described by (11) can be used:

$$Z_{i,G} = X_{best,G} + F.(X_{r1,G} - X_{r2,G}) \qquad (11)$$

where F is the criterion factor. X_rs are randomly selected entities. X_{best} is the best member of the current population. By tuning the F parameter, the amount of diversity or search around the previous generation will be determined.

C. The Estimation and Selection Step

At this stage, newborns and parents are valued according to the objective function, and the parents are replaced by newborns if the newborns have a greater value than the parents. Otherwise, the parents go to the next step with the next generation.

$$Z_{i,g+1} = \arg\max(f(Z_{i,g}), f(Z_{i,g+1})) \qquad (12)$$

where $Z_{i,g+1}$ is the population of the new generation (newborns), and $Z_{i,g}$ is the population of the previous generation (parent).

D. Repeat Steps B and C until Complete Stop

Steps B and C continue until algorithm stopping criteria is met. A stopping criterion can be based on the convergence of the total population (reaching the maximum repetition) or zeroing changes in the best answer fitness function [19, 20].

IV. Simulation Results

The IEEE standard 33-bus distribution system [6], shown in Figure 1 and 2, with 32 branches, has been selected for the study and testing considering the proposed method. Table I shows the values of the loads considered. Table II shows the total active and reactive loads, and losses of the system considered for this study, which are the results of the initial load flow calculations without the presence of DG.

In this study, several scenarios are considered as well. First, the distribution network is considered as one-zone network connected to the power grid and optimization is performed in this network, with the presence of one, two and three DGs.

Then, the network with assuming fault occurrence is divided into two separate zones. Next the network is divided into three separate zones. In this work, the partitioning of this network should be carried out on the basis of continuous supplying power for important loads. With this assumption, at least one DG is located in each region.

In an interconnected network, the power supplying condition of the load is meaningless, because in this case the energy of all loads is provided by the upstream network. At the result, the optimization is performed only based on finding the optimal location and size of the DGs. Also, three cases are investigated based on the changes at values of w_p and w_v weights in the objective function of (3). The location and capacity of the units are found optimally based on:

- The sum of power loss weight (w_p) and voltage profile weight (w_v) with the same value of 0.5;
- The sum of power loss and voltage profile by applying w_p and w_v coefficients of 0.3 and 0.7, respectively, for the power loss and voltage profile;
- The sum of power loss and voltage profile by applying w_p and w_v coefficients of 0.7 and 0.3, respectively, for power loss and voltage profile.

The DE optimization algorithm has been applied to all simulations. In this algorithm, the population is 100, the maximum number of iterations is 150, and the response accuracy for stopping the algorithm is equal to 10^{-6}, the step size weight is equal to 0.3 and the crossover probability is equal to 0.8.

In choosing the type of method, the rand method is chosen, which makes the algorithm more robustness and increases convergence precision. The minimum and maximum limits for power generation are zero and 3 MW, respectively, which are the DG generation constraints. In the case of reactive power constraints, there is no clause according to the explanation given about the effect of its production.

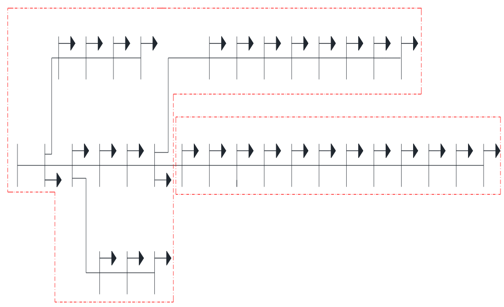

Fig. 1. The division of the network into two zones

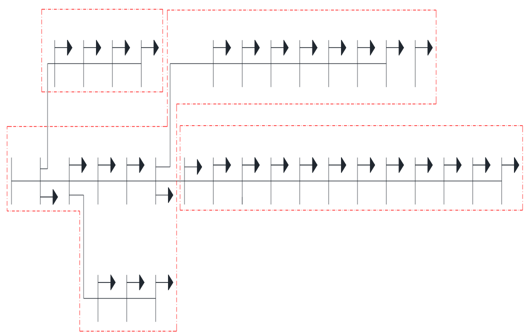

Fig. 2. The division of the network into three zones

TABLE I. IEEE 33-Bus Distribution System Loads Value (Active and Reactive Power per KW and KVAR)

Bus Number	Active Power	Reactive Power	Bus Number	Active Power	Reactive Power	Bus Number	Active Power	Reactive Power
1	-	-	12	60	35	23	90	50
2	100	60	13	60	35	24	420	200
3	90	40	14	120	80	25	420	200
4	120	80	15	60	10	26	60	25
5	60	30	16	60	20	27	60	25
6	60	20	17	60	20	28	60	20
7	200	100	18	90	40	29	120	70
8	200	100	19	90	40	30	200	600
9	60	20	20	90	40	31	150	70
10	60	20	21	90	40	32	210	100
11	45	30	22	90	40	33	60	40

TABLE II. TOTAL ACTIVE AND REACTIVE POWER LOADS AND LOSSES

33-Bus Grid	Total Loads	Total Loss
Active Power (KW)	3715	202.677
Reactive Power (KVAR)	2300	135.141

The simulation results for active and reactive power losses for locating one, two, and three DGs are shown in Table III for all specified objective functions. Although the DG generates only active power, Table III shows that its presence effectively reduces both the active and reactive power losses in all cases.

For the maximum capacity of DG, the use of only one DG with the aforementioned capacity cannot satisfy all requirements of objective functions, but it reduces active and reactive losses by more than 32% in any case. At all three cases, the maximum active and reactive power losses reduction is related to the weight of 0.7 and then to the weight of 0.5 for the active power loss.

The weight of 0.3 for active power loss also causes the lowest reduction in active and reactive power losses. The presence of two or three DGs causes to significantly moving the location of DGs and appropriately reduction in their capacity than the presence of only one DG.

This subject is truthful for all three objective functions. The algorithm has selected the buses of 12 to 14 and buses 29 and 30 as the best DGs installation locations for the case of two DGs. For the case of the three DGs, in addition to the foregoing locations, the locations of buses from 24 to 25 are selected.

It is observed that the DGs locations are changed in terms of the importance of the losses and voltage profile between the mentioned buses for different scenarios, where the range of variation is small. The changes in the capacity of DGs are high and have a larger range. Comparison between optimal values for the capacities and locations of DGs indicates that the centralization of DGs in the vicinity of buses with larger loads is higher than other buses.

For instance, loads on buses 30 and 14 are larger than loads on other buses (Table I). This fact is true also for capacity so that it is observed the optimal capacitance at the buses of 29 and 30 is higher than the buses of 13 and 14 due to larger loads values on these buses. Also, for the case of the three DGs, larger loads are located on the buses of 24 and 25 compared to the surrounding buses. Thus, the DE-algorithm tends to choose the third DG in the vicinity of these buses.

Figure 3 to 5 show the voltage profile curves at the network buses for objective functions of 1 to 3, for one to three DGs. It can be seen that the voltage profile after the DG installation has been improved at all network buses. This improvement, irrespective of the type of objective function, is due to the reduction of current in the lines and the resulting voltage drop. The change in the coefficient of the voltage profile only affects the degree of improvement.

Whatever the weight coefficient of the voltage profile in the objective function equation is greater, the voltage profile improves more too. In these figures, there is a significant difference between the state of adding a DG and the absence of DG, but there is not much difference between the mode with single DG and the modes with two or three DGs. The difference between states of the two DGs and the three DGs is negligible too.

As stated before, two scenarios are considered for the multi-area network operation mode of the distribution network. In the first scenario, with the assumption of the existence of two important loads in the 13th and 27th buses of the network, the distribution network is divided into two separate areas apart from the power grid.

TABLE III. OPTIMAL LOCATION AND CAPACITY OF DGS IN THE 33-BUS DISTRIBUTION NETWORK CONJUNCT WITH THE POWER GRID

DG with Active Power Generation (Max:3 MW)	Objective Function Type	Optimal Location Bus Number	DG Optimal Size (kW) at Relevant Bus Number	Total Active & Reactive Power Losses	
				kW+ jkVAR	Reduction (%)
Two DGs	1	13 29	1224.18 1693.68	104.142+ j73.165	%48.62+ j%45.86
	2	13 29	1170.62 2078.14	118.96+ j84.97	%41.31+ j%37.12
	3	13 30	1062.09 1343.83	90.21+ j62.128	%55.49+ j%54.03
Three DGs	1	13 24 30	1162.03 1297.03 1395.17	86.3+ j59.69	%57.42+ j%55.83
	2	12 25 30	1304.22 1057.16 1801.82	106.73+ j73.82	%47.34+ j%45.37
	3	14 24 30	973.52 1111.41 1258.66	76.118+ j53.078	%62.44+ j%60.72

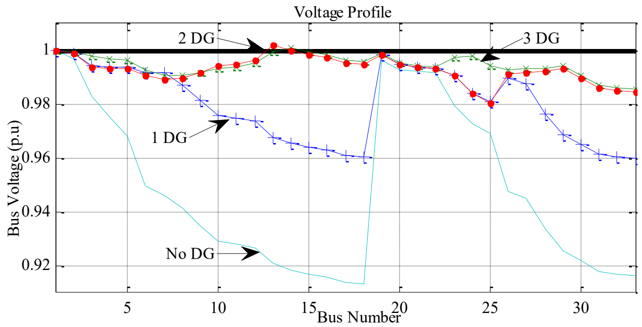

Fig. 3. The voltage profile diagram of the network buses before and after installation of one, two and three DGs with purpose 1

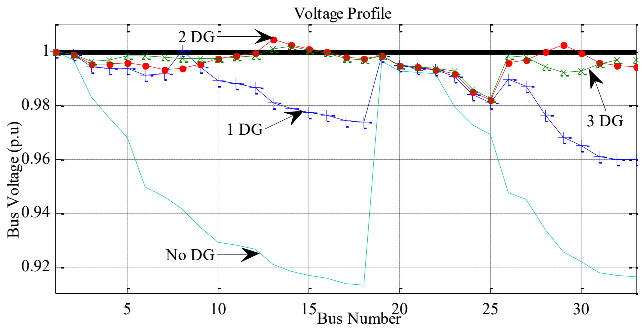

Fig. 4. The voltage profile diagram of the network buses before and after installation of one, two and three DGs with purpose 2.

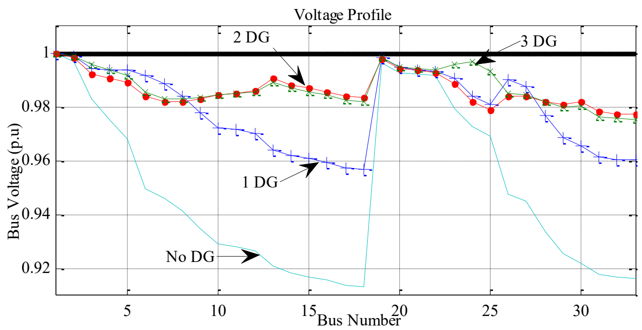

Fig. 5. The voltage profile diagram of the network buses before and after installation of one, two and three DGs with purpose 3.

Hence, it is assumed that the circuit breaker is located between buses 6 and 7 and is equipped with a synchronizer too, which divides the distribution network into two zones 1 and 2 shown in Fig. 6.

It is also assumed that there is one circuit breaker at the beginning of the network before the bus 1 that disconnects the entire distribution network. In the second scenario, it is assumed that three important loads are located at the buses of 13, 20 and 30. Another circuit breaker is located between the buses of 2 and 19 in addition to the circuit breaker at between buses of 6 and 7. Therefore, the segmentation of zones according to the position of the important loads of the three zones is as Fig. 7.

The optimization results for the two scenarios are shown in Tables IV and V. One DG is located in each region. The location and capacity of each DG, and the total load and losses of each area, as well as their reduction in each area after the DG installation compared to the state of the interconnected network and absence of DG in the distribution network, is calculated. The losses in lines between buses 6-7 and 2-19 are shown separately, that in island conditions, these lines are eliminated and the current does not flow through them.

As a result, their losses are eliminated in islanded networks (for two-zone and three-zone islanding mode). The calculations for the objective functions 1 to 3 are also presented in these tables. The total losses in each area after the installation of DGs in each region in the island state are calculated and it is assumed that, if, again, (after installing DGs), the distribution network is fed in its usual condition (in the integrated mode with power grid), how much are the amount of active and reactive power losses and their reduction relative to the state of the absence of DG in the connected mode, that the amount of them is shown in Tables IV, V.

It is observed that the optimal power value in the island mode operation is smaller than the integrated mode operation because the number of loads that need to be supplied is reduced. Thus, the required capacity for optimization is decreased, too. Moreover, when the network operates in island mode, the system's total losses are less than the normal operating mode. Because in the island state, losses associated with lines that are disconnected after islanding, are eliminated from total losses.

TABLE IV. LOCATION AND SIZE OF DGS IN THE ISLANDED DISTRIBUTION NETWORK WITH 2 ZONES AND GRID-CONNECTED MODE

Total Load in Each Zone	Zone 1 Zone 2	2640kW+j1790kVAR 1075kW+j510kVAR	
Total Losses in Each Zone and Separating Lines Without Presence of Any DG Before Islanding	Zone 1 Zone 2 Line 6-7	182.41kW+j117.25kVAR 18.353kW+j11.56kVAR 1.88kW+j1.48kVAR	
DG With Active Power Generation	Optimization in Two Zones With Two DGs		
Objective Function Type	1	2	3
Optimal Location Zone 1 Zone 2	Bus Number 30 15	Bus Number 30 15	Bus Number 30 14
DG Optimal Size (kW) at Relevant Bus Number	1445.37 758.19	1760.05 770.06	1218.98 758.51
Active & Reactive Power Losses in Each Zone (1,2)			
kW+ j kVAR	59.63+ j41.56 5.82+ j4.397	70.33+ j49.78 6+ j4.55	55.6+ j38.22 5.22+ j3.86
Reduction (%)	%67.31+j%64.55 %68.29+j%61.96	%61.44+j%57.54 %67.31+j%60.64	%69.52+j%67.4 %71.56+j%66.61
Total Active & Reactive Power Losses (kW+ j kVAR)			
in Islanded Mode	65.45+j45.957	76.33+j54.34	60.82+j42.08
in connected Mode after Islanding	88.84+j61.44	97.07+j68.11	86.17+j58.82
Total Active & Reactive Power Losses Reduction (%) than Integrated Mode			
Islanded Mode	%67.71+j%65.99	%62.34+j%59.79	%69.99+j%68.86
Connected Mode after Islanding	%56.17+j%54.54	%52.11+j%49.6	%57.48+j%56.48

TABLE V. LOCATION AND SIZE OF DGS IN THE ISLANDED DISTRIBUTION NETWORK WITH 3 ZONES AND GRID-CONNECTED MODE

Total Load in Each Zone	Zone 1 Zone 2 Zone 3	2280kW+j1630kVAR 1075kW+j510kVAR 360kW+j160kVAR	
Total Losses in Each Zone and Separating Lines Without Presence of Any DG Before Islanding	Zone 1 Zone 2 Zone 3 Line 6-7 Line 2-19	181.27kW+j116.17kVAR 18.353kW+j11.56kVAR 0.98kW+j0.93kVAR 1.88kW+1.48kVAR 0.16kW+j0.15kVAR	
DG With Active Power Generation	Optimization in Three Zones with Three DGs		
Objective Function Type	1	2	3
Optimal Location Zone 1 Zone 2 Zone 3	Bus Number 30 15 21	Bus Number 30 15 21	Bus Number 30 14 21
DG Optimal Size (kW) at Relevant Bus Number	1435.38 758.19 356.15	1751.5 770.06 356.15	1211.01 758.51 310.57
Active & Reactive Power Losses in Each Zone (1,2,3)			
kW+ j kVAR	57.45+ j39.87 5.82+ j4.397 0.343+ j0.353	68.15+ j48.08 6+j4.55 0.34+j0.35	53.49+ j36.6 5.22+ j3.86 0.25+ j0.26
Reduction (%)	%68.31+j%65.68 %68.29+j%61.96 %65+j%62.04	%62.4+j%58.61 %67.31+j%60.64 %65.31+j%62.37	%70.49+ j%68.5 %71.56+j%66.61 %74.49+j%72.04
Total Active & Reactive Power Losses (kW+ j kVAR)			
in Islanded Mode	63.61+j44.62	76.49+j52.98	58.96+j40.73
in connected Mode after Islanding	87.29+j60.27	95.51+j66.92	84.67+j57.67
Total Active & Reactive Power Losses Reduction (%) than Integrated Mode			
in Islanded Mode	%68.62+j%66.98	%62.26+j%60.8	%70.91+j%69.86
in connected Mode after Islanding	%56.93+j%55.4	%52.88+j%50.48	%58.22+j%57.33

DG location in the regions one and two due to structural similarity and the status of these areas in both scenarios two regions and three regions for the various objective functions are almost the same.

Larger loads are located around the buses 14-15 and 30 in comparison with other buses, and therefore the DGs are located about these buses. The total network losses when the optimal location and capacity of DGs are determined in island conditions, and then the separate zones connect to each other and to the global network, relative to where the optimal location and capacity of DGs are determined in network-connected mode will be greater, because the network zoning as a constraint restricts the placement problem. This is clearly illustrated by comparing the same values in Tables III, IV, and V.

Figure 6 and 7 show the voltage profile of the network buses for normal network mode without and with the two and three DGs and in the island modes with two-zones and three-zones, showing as well as the voltage profile for the network connection mode after islanding.

By comparing the voltage profile curves, it is concluded that when the placement of the DGs are performed in island mode and the network is remained in island condition, the voltage profile will be in the best situation and the network buses voltages are closer to 1 p.u.

After that, when the network is employed in connected mode, the voltage profile drop isn't negligible, and the buses voltage profile is worse than the first state that optimization has performed without islanding mode and constraining conditions. However, the voltage profile at this status is very much better than the absence of DG. Table VI shows the speed of the DE algorithm for all cases. It also shows the amount of objective function 1.

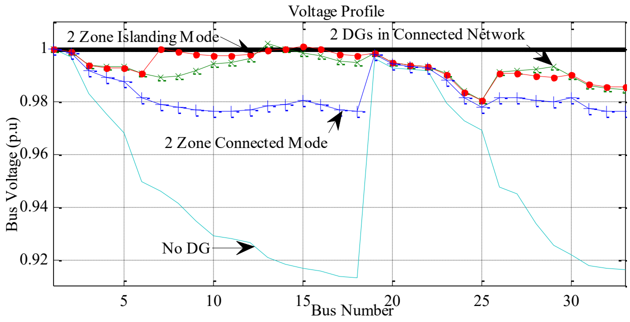

Fig. 6. The voltage profile diagram before/after the installation of two DGs (after optimizing the capacity and location of the DGs in island mode).

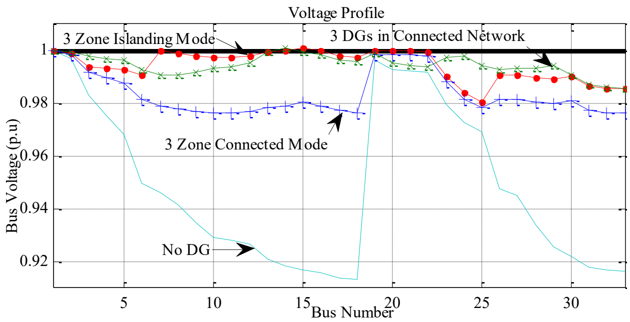

Fig. 7. The voltage profile diagram before/after the installation of three DGs (after optimizing the capacity and location of the DGs in island mode).

TABLE VI. THE NUMBER OF ITERATIONS FOR CONVERGENCE AND THE VALUE OF THE OBJECTIVE FUNCTION 1 IN DIFFERENT STATES

Network Configuration	Number of Zones (or DGs)	Convergence Iterations Number	Objective Function Value
Integrated mode	One DG	19	0.8747
	Two DGs	54	0.6403
	Three DGs	137	0.541
Two Zones	Zone 1	14	0.3924
	Zone 2	18	0.0375
Three Zones	Zone 1	11	0.3707
	Zone 2	18	0.0375
	Zone 3	16	0.00214

V. CONCLUSIONS

In this work, the use of differential evolution algorithm to determine the optimal location and capacity of DGs in normal and island conditions of the network has caused a significant reduction in the power losses and improving the voltage profiles. Increasing the number of DGs in the integrated distribution network develops the size of the problem and increases the iteration and the solution time of the algorithm.

The speed of the algorithm increases for islanded networks, since the number of buses and the selectable range of DGs capacity reduces in every zone. The improvement amount for each target has a direct relationship with its weight in the total fitness function.

By increasing the importance of the voltage profile, a larger capacity for DGs is required and the voltage profile improves more, but power losses increase too, and vice versa. The use of more DGs in both normal and islanding conditions lead to a further reduction in reactive and reactive power losses and further improvement of the voltage profile.

There are no significant changes in terms of voltage profile improvement and loss reduction rate between the uses of two or three DGs sources in the 33-bus network. Therefore, according to DGs costs, the increase in the number of resources from a specified limit does not provide significant technical and economic advantages.

In general, the determination of DGs at islanding operation conditions lead to a better voltage profile and lower total active and reactive power losses than normal operating conditions (with the same number of DGs). Because some lines are out of service and zones are smaller too. Hence, if the optimization of location and size of DGs is performed in the islanding mode, and then the separated regions of the distribution network are connected to each other, and to the global network, the losses are more than when determining the optimal location and capacity of the DGs is performed in the integrated network (without disconnection in the network) and the voltage profile is worse too. In addition, the impacts caused by DGs on distributed network protection [21-24], demand response and energy trading [25-27] will be paid more attentions in the future works as more and more various DGs have been introduced into power grid.

VI. ACKNOWLEDGMENT

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