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Optimal Allocation of Distributed Generation in Microgrid by Considering Load Modeling

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Abstract

Recent increment in carbon emission due to the dependency on fossil fuels in power generation sector is a critical issue in the last decade. The motivation to Distributed Generation (DG) in order to catch low carbon networks is rising. This research seeks to experience DG existence in local energy servicing in microgrid structure. This paper for simultaneous power loss reduction and voltage profile improvement follows optimal sizing and placement of DG units. Optimization is solved by applying Limited Constraint Method (LCM) for converting of multi-objective problem to single-objective one. A typical Genetic Algorithm (GA) is presented from the array of artificial intelligence methods for solving the optimization problem. The algorithm is implemented on the IEEE 33 buses standard network. This study is presented in two scenarios, primarily to elaborate the effect of location and determination of DGs has been done to reduce losses and improve the voltage profile. Secondly, the research shows the necessity to load modeling in case of DG presence in networks.

Keywords: Distributed Generation (DG), Genetic Algorithm (GA), Limited Constraint Method (LCM), load modelling.
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1. Introduction

The excessive increase in emissions from fossil fuel plants has led to the signing of the Kyoto agreement by EU countries. Accordingly, these countries required a substantial reduction in greenhouse gas emissions. According to the US Environmental Protection Agency, Greenhouse gases have been the main cause of climate change, and their presence in the atmosphere has increased by about 7% between 1990 and 2014. Most of the environmental pollution caused by greenhouse gases is due to the electric power generation, and according to the annual report released in 2014, the electric power generation system occasions to 29% of the pollution [1].

So far, many studies have been done to optimize DGs presence in the distributed network. Turning to dispersed production sources with the goal of generating clean energies and using unlimited lifetime resources was the first reason why the idea of using these resources was more important, then the voltage profile as an index of power quality assessment in the distribution system will increase the importance of the issue. Distributed generation (DG) can have positive or negative effects on the voltage profile of distribution networks. Therefore, determining the appropriate location of these resources can reduce or increase the losses, so studying methods that determine the location and capacity of the optimal production of DGs are important. This is well illustrated in Figure.1.

In [2] the weighting factor method is applied for converting the multi-objective function to a unique function, and optimization with two objectives is done to reduce losses and improve the voltage profile. Using this method, with easy understanding and simple implementation has its own barriers:

A) The need for a method for generating weight factors that can improve the accuracy of the optimization results.

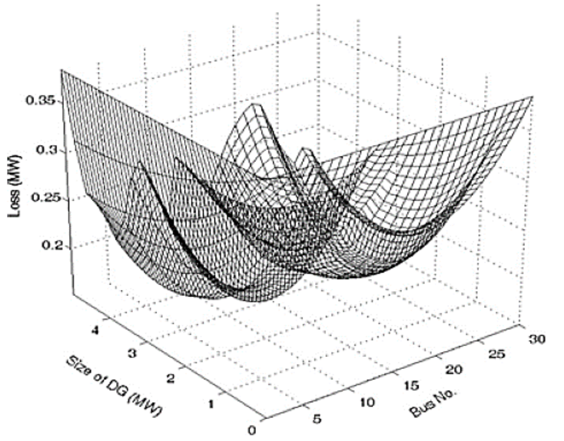

Fig.1. The Impact of DG Capacity and Position on System Losses [2]

B) In this method, the objective space of the problem should be a convex space, so the use of this method is limited to some special circumstances.

Meanwhile, in this method, the use of the power flow algorithm has increased the enormous amount of problem-solving time, while the existence of an initial random population in artificial intelligence algorithms decreases over time.

In [3], an improved analytical method has been used, but only the reduction of power losses has been achieved and the voltage profile has not been considered, while the presence of DG sources in different buses can affect the bus voltage profile. Increasing the voltage profile at low load hours due to the reactive power injected by these resources and the unreasonable reduction of the voltage profile in network pick hours can greatly affect the power quality of the network, in addition, the program is just considered for one level of load.

In [4] and [5], an analytical method has been used to determine the optimal capacity of DGs. In general, numerical and analytical methods are less accurate than artificial intelligence algorithms. Using the derivation to achieve minimal loss rates requires the definition of a differentiable function, so this method is not responsive in the absence of a differentiable objective function. In [4], this method is only used to determine the optimal resource capacity. The DG installation is limited to two specified buses by the user, thus the exact optimal point cannot be accessed. Accordingly, power loss is not minimized, but both parameters of power losses and DG power factor are targeted. In [5], the optimal location and capacities of the DGs are determined and both the power loss and DG power factor parameters are targeted, however, DGs with different power coefficients increase the costs of the proposed algorithm. In addition, the use of distributed generation sources in the voltage regulation mode is not allowed according to the IEEE-1547 standard, and it is usually planned for the worst conditions with a power factor of 0.9. Also, schedules are only done for the nominal load, and results cannot be generalized to all conditions.

In [6], an intelligent genetic algorithm is used for optimization, and load levels including low load, average load and pick load are considered in scheduling, which allows the use of the results obtained for all conditions in the network. Also, regarding the IEEE- 1547, the lack of use of DGs in the voltage control mode is considered to be the worst condition for the power factor, but the use of the weight coefficient method for converting a multi-objective problem to a single object has the same problems as the reference [2] which reduces the accuracy of the solutions and limits the optimizer discovering space.

In reference [7], the method of plant growth simulator algorithm (PGSA) is used to determine the location and optimal capacity of DGs to reduce losses and improve the voltage profile of the grid. The proposed method of this reference is compared with the proposed algorithm of this dissertation.

The rest of this paper is organized as follows. In section II, the mathematical formulation of the problem is described. Section III presents the genetic algorithm strategy. Section IV will give experimental results and analysis by defining a test case. Finally, the research will be concluded in the last section.

2. Mathematical modelling

Optimization is done with the goal of reducing losses and improving the voltage profile. Solving the multi-objective problem in the format of single objective function are fulfilled by certain methods. Here, with the aid of the bounded constraints method, the problem will be converted into a single objective function. The objective function is defined as follows:

$$Function = loss \tag{1}$$

We consider that the objective function includes power losses, only. This function is used as an indicator of optimal DG location. The second goal of the problem that concerns the improvement of the voltage profile is considered as a constraint of the optimization problem, which is One of the principles of converting multi-objective optimization to single-objective optimization in bounded constraint method.

Adding DG to the network should not cause network hazardous operation, so the requirements for the correct operation of the network are considered as follows:

Bus Voltage Limit: The maximum allowable voltage drop in this research is considered to be 5%.

$$0.95 \le |v_{bus}(i)| \le 1.05 \quad (2)$$

In which $v_{bus}(i)$ is the voltage in bus i^{th}.

Limit of active power generated by DGs

$$P_{DGi}^{min} \le P_{DGi} \le P_{DGi}^{max} \quad (3)$$

Reduction of reactive power generated by DGs:

$$Q_{DGi}^{min} \le Q_{DGi} \le Q_{DGi}^{max} \quad (4)$$

DG-power factor: According to the description in section I, we are not authorized to use DGs in voltage control mode, and these results are obtained after the IEEE-1547 standard review, while the reference [8] emphasizes that the power factor of distributed generation sources ranges from 0.9 to 1, and this number is usually very close to 1, but it is planned to be 0.9% as the worst possible conditions.

Limit on the number of DGs: If there is a limitation on the number of DGs, this restriction will be entered into the target function.

Restrictions on DG Installation Points: If the potential for installing a DG doesn't exist in a number of network buses, this restriction will be considered in the target function. here P_{DGi} and Q_{DGi} are the active and reactive power produced by DG, respectively.

For simplicity, DG units are modelled as PQ bus with a negative value for active and reactive power.

3. Genetic algorithm

The genetic algorithm considers the creation of a random population of a location for each DG source. After executing the load flow program, it calculates the losses in the predicted states for the position of the DG per bus, then separates the optimal states from non-optimal modes. And these optimal states are used by the parent to generate population in the next generation, and this process is repeated repeatedly until the conditions for stopping the algorithm will be satisfied. The summary of the proposed genetic algorithm is as follows:

A. Create a random population with n2 numbers for each gene composed of n locations and n capacity (n is the selected number of DGs).

B. Calculation of the power loss function for each gene and the selection of some of the best members of the population as parents and the practice of combining (intersection) on them to create children.

C. Selection of some members of the population randomly, a mutation on them and the creation of a population of the mutated members.

D. Integration of the main population, the population of children and the population of the mutated members in order to create a new population.

E. Evaluation and sorting of the answers and the removal of additional answers.

F. Review the condition for stopping the genetic algorithm if the results are satisfied, the process will stop; otherwise, the algorithm returns to step (B).

The flowchart of the algorithm is given in Fig. 2.

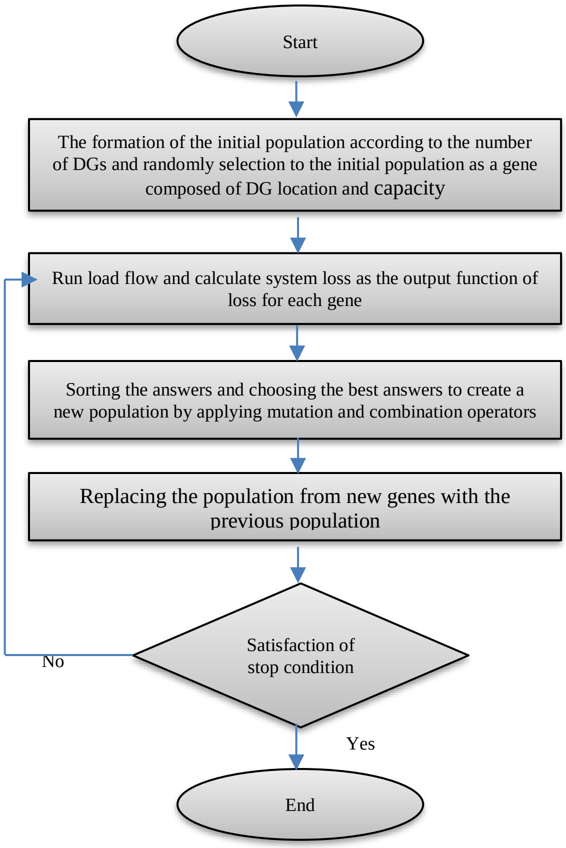

Fig.2. Flowchart of Genetic Algorithm

4. Case study

The microgrid in this dissertation as is shown in Fig. 3, has a radial system of 12.66 kV with 33 buses and 32 lines, the base power is considered 1 MW. The total network load is 72.3 MW. The network total load is 3.2 MW active power and 2.3 MVAr reactive power. Power losses in this network before installing DG units is 211 kW which equal to 5.6 percent of the total load. Fig. 4 demonstrates the detailed information on the test case study.

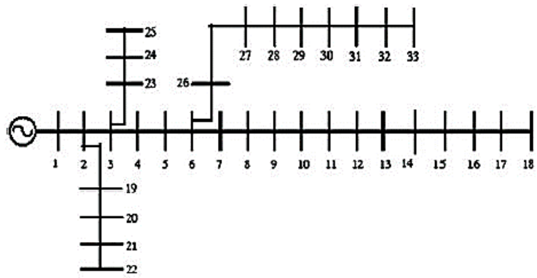

Fig.3. IEEE-33 buses test case

Sending bus	Receiving bus	R (Ohm)	X (Ohm)	Load at receiving bus P_L (KW)	Q_L (KVAR)
1	2	0.0922	0.0470	100	60
2	3	0.4930	0.2511	90	40
3	4	0.3660	0.1864	120	80
4	5	0.3811	0.1941	60	30
5	6	0.8190	0.7070	60	20
6	7	0.1872	0.6188	200	100
7	8	0.7114	0.2351	200	100
8	9	1.0300	0.7400	60	20
9	10	1.0440	0.7400	60	20
10	11	0.1966	0.0650	45	30
11	12	0.3744	0.1238	60	35
12	13	1.4680	1.1550	60	35
13	14	0.5416	0.7129	120	80
14	15	0.5910	0.5260	60	10
15	16	0.7463	0.5450	60	20
16	17	1.2890	1.7210	60	20
17	18	0.7320	0.5740	90	40
2	19	0.1640	0.1565	90	40
19	20	1.5042	1.3554	90	40
20	21	0.4095	0.4784	90	40
21	22	0.7089	0.9373	90	40
3	23	0.4512	0.3083	90	50
23	24	0.8980	0.7091	420	200
24	25	0.8960	0.7011	420	200
6	26	0.2030	0.1034	60	25
26	27	0.2842	0.1447	60	25
27	28	1.0590	0.9337	60	20
28	29	0.8042	0.7006	120	70
29	30	0.5075	0.2585	200	600
30	31	0.9744	0.9630	150	70
31	32	0.3105	0.3619	210	100
32	33	0.3410	0.5302	60	40

Fig.4. IEEE 33 buses network detailed information

The importance of installing DG sources in the microgrid is examined in two scenarios, which primarily show the impact of the DGs in reducing losses and improving the voltage profile. Secondly, the ineffectiveness of the results is expressed in terms of the different levels of the network load.

First Scenario: Optimal determination of the location and capacity of DGs in nominal load condition:

At this stage, the load is considered in constant power and scheduling is performed for a single load level (nominal load). The results of this scenario are compared with the results in [7] which, the plant growth simulator algorithm (PGSA) has been used to optimize the problem.

Our method gradually reduces the amount of active power losses by comparing the pre-DG setting with the increase in the number of DG sources. The results for DG locations and capacities and the reduction of losses are summarized in TABLE. I and TABLE. II. Then, provided charts in Fig. 5 make it easy to compare power losses in different assumptions. It is observed that the presence and increment of DG sources significantly reduced the active power losses in the network. As it is clear, the installation of one DG source reduce the power losses of the network by approximately 45%, and the installation of two sources and three sources leads to 59 % and 67% reduction in losses, respectively.

Table.1.
Selective DGs Capacity and Location Using GA for the 33-buses network

Total DG capacity (MW)	*DG capacity (MW)*	*Point of DG installation*	*Number of DGs*
-	-	-	0
2.886	2.886	7	1
2.023	0.844 1.179	13 30	2
3.013	0.761 1.17 1.082	14 24 30	3

Table.2.
Active power loss for 33-buses network for increasing DGs

Percentage of loss reduction	*Power loss (kW)*	*Number of DGs*
-	211	0
45%	114.1464	1
59%	84.7206	2
67%	68.6484	3

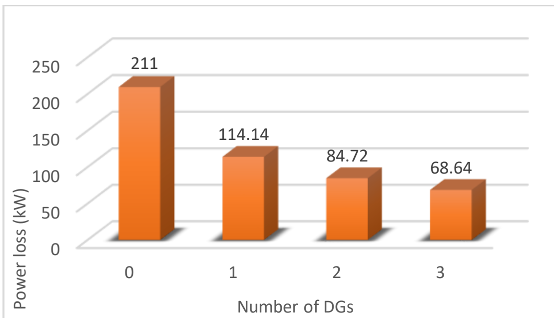

Fig.5. Active power loss for the test network for increasing the number of DGs

Fig. 6 shows the effect of increasing the number of DGs in improving the voltage profile exclusively by using the proposed algorithm in this project. According to the network diagram, having a minimum voltage of 0.9131 and a maximum voltage of 1 per-unit, there is a voltage drop of 8.69% in the network before the DG application. After the installation of DG units and increase their number, it is possible to obtain flattened voltage graphs with percentages of lower voltage variations.

Table. III gives an overview of the results of loss reduction and improvement of the voltage profile of the plant growth simulator algorithm (PGSA) and the proposed algorithm in this research. By analyzing the results recorded in Table III for the optimal placement and allocation of three DGs for both methods, we will conclude that the proposed GA in this research has better results in reducing losses and improving the voltage profile.

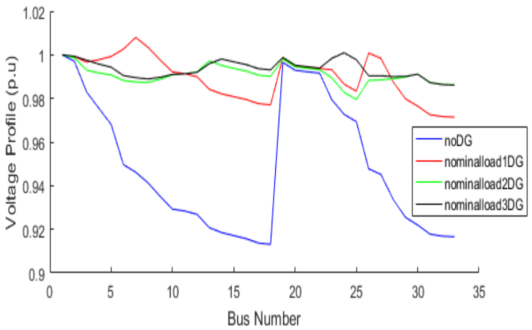

Figure 6. Comparison of the changes made in the voltage profile for increasing the DG number in the proposed method

Table.3.
Comparing two methods

Method	***Point of DG installation***	***DG capacity (MW)***	***Power loss (kW)***	***Percentage of loss reduction***	***Minimum Voltage***
GA	14 24 30	0.761 1.17 1.082	68.6	67%	0.9861
PGSA [7]	17 18 33	0.573 0.182 0.984	97	52%	0.9664

Second Scenario: Determination of the location and capacity of DGs in multi-levels load condition

In this scenario, the load is modelled by considering the dependence of the load on the voltage. In fact, the load power is not constant and it is dependent on the bus voltage. This will increase the accuracy of calculations in losses. Load models are mathematically summed in the below formulas [9]:

$$P_i = P_{oi} (\frac{v_i}{v_{oi}})^{\alpha} \quad (5)$$

$$Q_i = Q_{oi} (\frac{v_i}{v_{oi}})^{\alpha} \quad (6)$$

In which v_i is the voltage in bus i^{th} and P_i and Q_i are the active and reactive power in the bus *i*, respectively. Consequently, v_{oi} is the rated voltage in bus i^{th} and P_{oi} and Q_{oi} are the active and reactive power in the bus *i*, at the nominal condition.

α and β coefficients illustrate the commercial, industrial and residential loads by applying different quantities. Also, different load levels consumption do not occur simultaneously for all types of load, and accordingly the values of these coefficients are calculated for taking load variations at the 24 hours in the day and the changes in the summer and winter seasons. The values of these coefficients are given in Table. IV. Note that, in the first scenario, these coefficients are assumed to be zero.

In order to take account of various commercial, industrial, and residential loads in the network, Table. V shows the paper assumptions for load types in all buses. Bus-1 is the slack bus (reference) and is not included in this categorization.

The results presented in the second scenario are based on the three load levels in a typical region with the following conditions:

a. Minimum load on the winter days
b. Average load on the summer nights
c. Maximum load on the summer days

In these results which are summarized in Table. VI, by considering the three levels of load, the results of the location and optimal capacity of the DG sources are different from the first scenario. In other words, the results of the decisions in unrealistic situations without considering the daily change in the load and the load dependence on the voltage profile cannot be generalized to the real situation of the network, and moreover, it can have devastating effects on the network operation.

The obtained amount of power loss before load modelling is different from the second scenario outputs. So, we do not have the correct information on the amount of network losses before load characteristics modelling and the delivered answers that were given for the amount and location of the DG sources in the first scenario are completely different from the second scenario and should not be applied to the actual network conditions. This illustrates the importance of load modelling in dependence on voltage variations, as well as changes in daily and annual climate.

Table.4.
The values of α and β coefficients for different load states [9]

Bus Number	***Subscriber Type***	***Bus Number***	***Subscriber Type***
2	Commercial	18	Residential
3	Commercial	19	Commercial
4	Commercial	20	Commercial
5	Residential	21	Commercial
6	Residential	22	Commercial
7	Industrial	23	Commercial
8	Industrial	24	Industrial
9	Residential	25	Industrial
10	Residential	26	Residential
11	Residential	27	Residential
12	Residential	28	Residential
13	Commercial	29	Commercial
14	Commercial	30	Industrial
15	Residential	31	Commercial
16	Residential	32	Industrial
17	Residential	33	Commercial

Table.5.
Determining the Load Type for each Bus [9]

Bus Number	***Subscriber Type***	***Bus Number***	***Subscriber Type***
2	Commercial	18	Residential
3	Commercial	19	Commercial
4	Commercial	20	Commercial
5	Residential	21	Commercial
6	Residential	22	Commercial
7	Industrial	23	Commercial
8	Industrial	24	Industrial
9	Residential	25	Industrial
10	Residential	26	Residential
11	Residential	27	Residential
12	Residential	28	Residential
13	Commercial	29	Commercial
14	Commercial	30	Industrial
15	Residential	31	Commercial
16	Residential	32	Industrial
17	Residential	33	Commercial

The proposed approach has reduced the power loss significantly for all three load levels, and approximately maintains network losses for all three levels by equal quantities after DG installation, and thus will not create more costs for the network operator.

Also, the comparison of the results at three levels of load indicates that, in the low load and pick load conditions after DGs placement, the losses are slightly higher than the average load status of the network, which is due to the voltage imbalance at these two levels of load that leads to more reactive power flow.

The results are thus to be considered in order to present a proposal for installing a distributed source in the surveyed network:

1. If we can only accommodate two DGs in the network, 24 and 30 buses are appropriate candidates.

2. If we can only accommodate three DGs in the network, the buses 13, 24, and 30 are appropriate.

3. For accommodation of four DGs, we recommend the buses 13, 14, 24 and 30.

Fig. 6, 7 and 8 show the results of the improvement of the voltage profile after modelling the load for three levels of low load, average load and peak load.

Bus-18 is more clearly marked for a comparison of the cases at three levels of load prior to the installation of a DG source, which indicates an increase in the voltage profile due to the network load reduction. This is elaborated in the blue lines of Fig. 6, 7 and 8. In Fig. 9, the voltage stability of bus-18 which is fixed at 0.995, is noticeable at all three levels. It is emphasized that bus number 18 has the highest voltage drop before DG installing due to the distance from the slack bus.

Table.6.
Results of loss reduction, location and capacity of DG for different load levels

Network Condition	***Point of DG installation***	***DG capacity (MW)***	***Power loss before DG installation (kW)***	***Power loss after DG installation (kW)***	***Percentage of loss reduction***
Before load modelling	14 24 30	0.761 1.17 1.082	211	68.6	67.48%
Low Load	30 24 13	1.001 1.133 0.733	161.96	40.27	75.13%
Medium Load	30 13 24	1.012 0.745 1.134	164.01	39.58	75.86%
Pick Load	13 24 30	0.748 1.135 1.009	165.58	40.91	75.29%

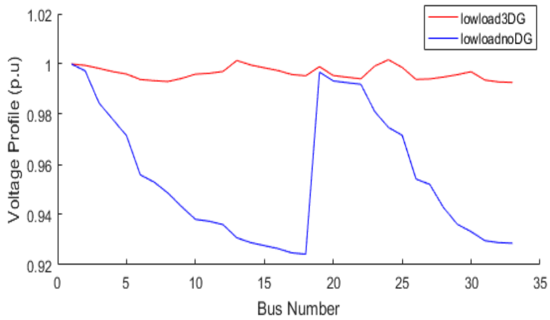

Fig.6. Improves low voltage profile

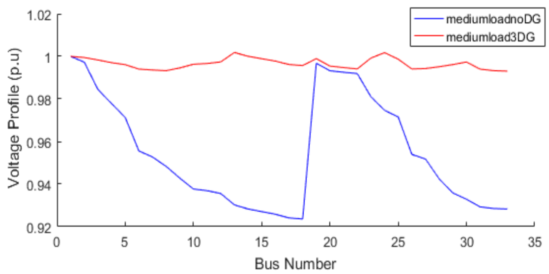

Fig.7. Improves medium voltage profile

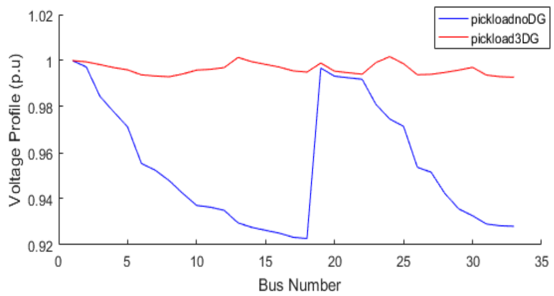

Fig.8. Improves pick voltage profile

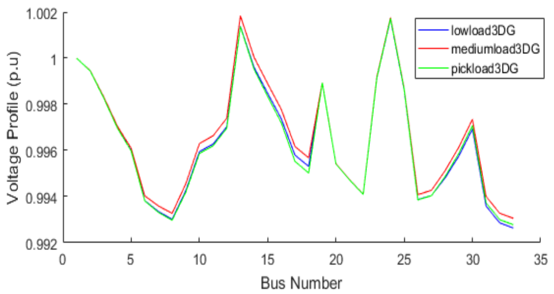

Fig.9. Results of voltage profile at three load levels after DG installation

5. Conclusion

In this project, a genetic algorithm has been used to find the optimal solution of the problem of positioning and the capacity determination of dispersed generation units to reach two goals of reducing power losses and improving the voltage profile. Considering the first goal as the main objective and the second goal as the limitation of the optimization problem made it easier for handling a multi-objective problem in a single objective format with LCM. The research shows that the presence of DG sources in the microgrid can dramatically reduce the power losses of the network. Decisions are not secure before modelling the load for real network conditions, and in order to obtain more accurate answers, annual and daily changes in load pattern should be considered for all types of industrial, residential and commercial subscribers. In other words, the results obtained for the single-level load in nominal condition cannot be generalized to all levels of load in active distribution networks.

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