THE EFFECT OF THE DISTRIBUTED GENERATION (DG) ON THE CONTRIBUTORY FACTORS IN THE IRANIAN 33-BUSES DISTRIBUTION NETWORK

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ABSTRACT

The main purpose of this study is to present an optimized capacity for the distribution generation (DG) units using a location memetic algorithm in order to minimize the losses and improve the voltage profile considering the technical limitations of the network and DG units. Due to the increasing DGs applications, it is essential to determine the location and optimal capacity, as well as examining the practical effects of these units on the power system, particularly in the distribution network. Since Micro Turbine has been selected as one of several types of DG, the economical aspects regarding the costs of these units have been studied in this article. A sample of Iran's 33-Bus Radial Network System (IEEE) has been utilized for the simulations and the representation of the results. The related findings show that the proposed algorithm has good effects on determining the capacity and location of the DG units.

Key words: *mimetic algorithm, distributed production, optimized location, decreasing loses, micro turbine.*

1. INTRODUCTION

The structural renewal in power industry has caused electrical engineers to pay increasing attention to the distributed production resources. Hence, in recent years, there has been an increasing role of DGs in planning the power systems and power markets performance. Generally, every type of energy production in relatively small capacities, which takes place inside or close to the consuming place regardless of the used technology in the production process, is called DG. These resources tend to utilize new energies. Some advantages of the DG are as follows: a decrease in production costs, power losses, load congestion and voltage imbalance, an improvement in the voltage profile and power quality, an increase in the network reliability, a delay in investment, the creation of an opportunity for new energies, as well as having positive environmental effects. In order to achieve these purposes, it is required that the optimal location and capacity of DG in the distribution network be determined precisely. Some problems due to the improper locating of DG in the network are: the increase of losses and harmonics, the destruction of the voltage state and voltage flicker, the decrease of the protection level, network reliability and stability and so forth. It is obvious that the proper locating of DG is highly crucial. The increasing trends in the uses of the DG units and advantages in regard to their correct locations contribute to developing and using several advanced methods for the DG optimized location. As a result, the location and capacity of the DG units are determined, depending on the purposes and the improving of the different indicators in the power system.

In recent years, numerous efforts have been made to explore and locate different DG units. The researchers in [1] have studied the optimal location and size for DGs in the distribution system using the particle swarm optimization (PSO) algorithm in order to improve the voltage profile and decrease the losses and total harmonic distortion (THD). The optimized DG location was also investigated in [2] with the aim of decreasing the losses in the radial feeder. The optimal location and size of the DG units were investigated in [3] with the aim of improving the voltage profile and decreasing the voltage losses. The optimal capacity and location of multiple DGs have been studied in [4] using a colonial competition algorithm in order to decrease the losses and to improve the voltage profile. The authors in [5] have investigated the DG and capacitor locations in the distribution network using binary particle swarm optimization (BPSO) so as to decrease losses and improve the reliability and voltage. The optimal location of DGs in the distribution networks has also been explored in [6] by modeling and the related results have been presented. In [7] the authors investigated the voltage profile improvement and the minimization of losses in the distribution systems by finding the optimal DG location and size. In [8] the authors attempted to reach the voltage stability and to decrease the losses by the optimized planning of the DG units. In [9] the genetic algorithm (GA) was also used for the appropriate location of the DG units to decrease the losses and to improve the voltage profile.

The researches show that the non-optimal locations and non-optimal sizes of the DG units may lead to an increase in losses and a destructive effect on the voltage profile and harmonics. Accordingly, many researchers have concentrated on determining the optimal location and size of the DG units in their studies. The economic costs of the system can be minimized by using intelligent algorithms such as PSO and GA, replacing DGs and determining their sizes meticulously. All these optimization methods are utilized to minimize the initial costs of DGs and power losses. At first a power flow (PF) algorithm is used in the radial network to find an optimized comprehensive solution. Then intelligent algorithms are used to calculate the objective function and measure the bus voltage limits considering the voltage profile, THD, decrease of losses, and sensitivity analysis. At last the initial cost returns are calculated in order to account for the advantages of using DG. These results show the efficiency in the voltage profile improvement and the decrease of power losses, the increase of the power transmission capacity and the maximization of loading.

2. PROBLEM FORMULATION

2.1. OBJECTIVE FUNCTION

The main purpose is to minimize the total cost of the real power losses and to install the DG and total active power injection by DGs to buses so as to improve the voltage. These purposes have been expressed as a cost function below:

$$Maximize V_{index} = \frac{(\sum_{n=1}^{N} V_n)}{96}, n = 1, 2, ..., N \tag{1}$$

Where

$$V_n = \frac{V_{P,withDG}}{V_{P,withoutDG}} \tag{2}$$

$$V_P = \sum_{i=1}^{m} V_i L_i K_i \tag{3}$$

Thus, the maximum value V_{index} represents the best situation for the installing of the DG units in order to improve the voltage. Thus, we have:

$$V_{index} \begin{cases} < 1 \\ = 1 \\ > 1 \end{cases} \tag{4}$$

$V_{index} < 1$: DG units worsen the voltage limit.

$V_{index} = 1$: DG units have no effect on the voltage limit.

$V_{index} > 1$: DG units improve voltage limit.

2.2. LIMITATIONS OR CONSTRAINTS

The flux power equations are as follows:

$$P_{G_{n,1}} + C(n,1) * P_{DG^{D_i}} + C(n,2) * P_{DG^{W_i}} + C(n,3) * P_{DG^{S_i}} + C(n,4) * \mathrm{P}_{D_i} = \sum_{j=1}^{m} V_{n,i} * V_{n,i} * Y_{ij} * \cos(\theta_{ij} + \delta_{n,j} - \delta_{n,i}) \tag{5}$$

(6)
$$Q_{G_{n,1}} - C(n,4) * Q_{D_{n,i}} = -\sum_{j=1}^{m} V_{n,i} * V_{n,i} * Y_{ij} * \sin(\theta_{ij} + \delta_{n,j} - \delta_{n,i})$$

The current category equations are as follows:

(7)
$$I_{n,ij} = |Y_{ij}| * \left[(V_{n,i})^2 + (V_{n,i})^2 - 2 * V_{n,i} * V_{n,j} * \cos(\delta_{n,j} - \delta_{n,i}) \right]^{1/2}$$

Where $I_{n,ij}$ denotes the feeder current, which connects the i and j buses. The values for the bus voltage and the angle for the first bus are as follows:

(8)
$$V_{n,1} = 1.025$$
$$\delta_{n,1} = 0.0$$

The value of the buses voltage during the optimization process must be between the acceptable operation constraints. Hence, the voltage constraint for the other buses should be:

(9)
$$0.95 \le V_{n,i} \le 1.05$$

The limit for the feeder capacity is:

(10)
$$0 \le I_{n,ij} \le I_{ij_{\max}}$$

The maximum penetration in each bus must not exceed 10 MW. Therefore, we have:

(11)
$$P_{DG^{D_i}} + P_{DG^{W_i}} + P_{DG^{S_i}} \le 10MW$$

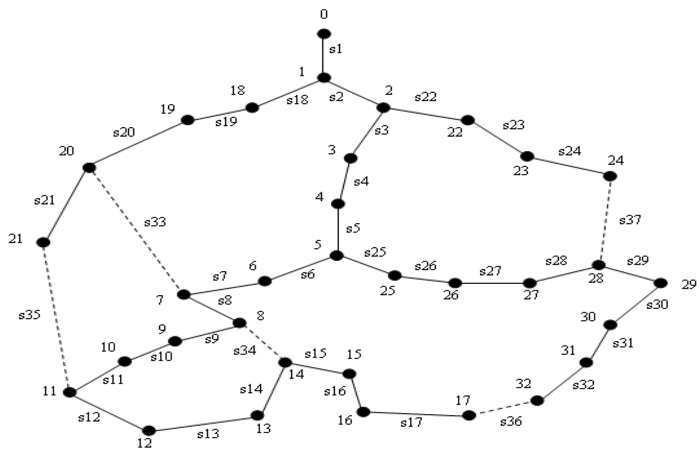
The maximum penetration of the DG units on system:

(12)
$$\sum_{i=1}^{m} P_{DG^{D_i}} + \sum_{i=1}^{m} CF_{\omega} P_{DG^{W_i}} + \sum_{i=1}^{m} CF_s P_{DG^{S_i}} \le y * \sum_{i=1}^{m} P_{D_i}$$

Where y is the maximum penetration amount and the load percentage. The amount of penetration will be below 30% if y= 0.3. In the above relations, P_{G_i} is the applied active power, Q_{G_i} is the applied reactive power, $\Delta\theta$ is the changes in the buses voltages angles, P_{DGD_i} is the active power of the dispatchable DG connected to the bus i, P_{DGW_i} is the active power of the wind DG connected to the bus i, P_{DGS_i} is the active power of the solar DG connected to the bus i, Q_{DGD_i} is the reactive power of the dispatchable DG connected to the bus i, P_{D_i} is the active peak load in the bus i, Q_{D_i} is the reactive peak load in the bus i, $V_{n,i}$ is the amount of voltage in the bus i, C is a matrix with 4 columns consisting of the probable mix of the wind, solar output power, and load, N is the number of mixes, $V_{P,\text{withDG}}$ is the profile of the voltage in the system with DG units, $V_{P,\text{withoutDG}}$ is the profile of the voltage in the system without DG units, V_i is the voltage range in the bus i, L_i is the load demand in the bus i, K_i is the weight ratio for the bus i, and m is the number of loads in the distribution system. It would be worth mentioning that the cost for the real power losses per unit is constant. Also, the loss-per-unit cost for the active power injection is constant. Here, K_p is equal to 773 Rials/KW year. K_{ci} is equal to 1800000 Rials/KW year. The initial cost of installing the micro-turbine DG is 5000000 Rials.

3. INTRODUCING THE INVESTIGATED NETWORK

The investigated network is a real 33-bus distribution network, and its general scheme has been shown in Figure (1). All the information about the load distribution, production and consumption powers is extracted from the network and then is used in the simulation. The sum of the real power of the network loads is about 2.5 MW and the total power is injected from the bus 1 to the network.



Figure(1): The linear scheme of the 33-buses IEEE network

This network is the standard 33-bus IEEE distribution network in Iran, whose scheme has been presented in Figure (2).

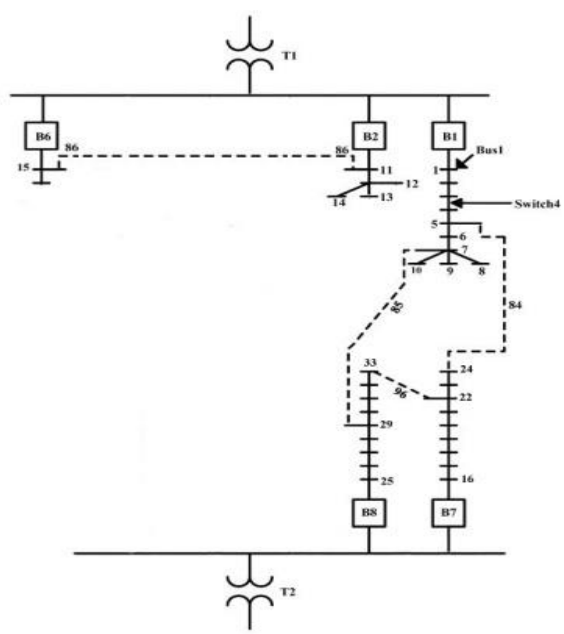


Figure (2): The real network investigated

4. SIMULATION RESULTS

4.1Proposed algorithm

In recent years, a new algorithm, known as the memetic algorithm, has been developed to solve the complex optimization problems. This algorithm is much better and more exact than the other evolutionary algorithms. Complex problems are those whose optimized solutions cannot be found by global search algorithms. Memetic algorithms are a group of the revolutionary algorithms mixed with a local search part in order to enhance the responses. Memetic algorithms are helpful in solving numerous optimization problems, such as combinatorial optimization, variable functions optimization and multi-purpose optimization. The methods for combining the revolutionary and local search algorithms have been identified by various names, including the hybrid genetic algorithm, Baldwinian revolutionary algorithm, and Lamarckian revolutionary algorithm. Moscato uses the name of the memetic algorithm to cover all algorithms based on the revolutionary search, combined with a local search algorithm. Here, a new memetic optimization algorithm has been presented, which operates with a nested local algorithm based on the PSO algorithm. At first one-fifth of the participles with the best solutions are selected and then updated. At each stage of the local search algorithm, the velocity and position of the particles are updated using the equations of (13) and (14) stage, thereby enhancing the convergence and improving the algorithm solution.

(13) $$x_i(t+1) = x_i(t) + v_i(t+1)$$

(14) $$v_{i,j}(t+1) = v_{i,j}(t) + c_1 r_{1,j}\left[y_{i,j}(t) - x_{i,j}(t)\right] + c_2 r_{2,j}\left[\hat{y}_j(t) - x_{i,j}(t)\right]$$

Fifty particles have been used in this study. At first 10 particles were selected as the first favorite particles to apply the local search (having better cost function); then 5 particles among the 10 particles were selected as the second favorite particles (having better cost function) and updated. The semi-code for the proposed memetic algorithm is as follows:

1) Determining and evaluating the initial position and velocity of the particles.
2) Calculating the cost function for each particle and determining the best particles (having the minimum cost function).
3) Selecting the first favorite particles and applying the local search on them (updating the velocity and then the position of the particles using the equations (13) and (14)).
4) Selecting the second favorite particles and applying the local search on them (updating the velocity and then the position of the particles using the equations (13) and (14)).
5) Until the stop conditions are not satisfied:
6) Evaluating the cost function of the particles and selecting the best particle (having the best cost function).
7) Updating the velocities and positions of all particles and calculating their cost functions.
8) Selecting the favorite particles and applying the local search on them (updating the velocity and then the position of the particles using the equations (13) and (14)).
9) Selecting the second favorite particles and applying the local search on them (updating the velocity and then the position of the particles using the equations (13) and (14)).
10) Evaluating the cost function and selecting the best particle (having the best cost function).
11) Ending the algorithm.

4.2 The proposed algorithm performance

All algorithms must be applied on the multiple complex mathematical criterion function in order to determine their performance. These criterion functions are in the following order: Rosenbrock, Rastrigin, Himmelblau, Michalewicz, and Ackley. Table1 presents the mathematical functions, their dimensions and their search area. For better and more exact comparison, the maximum and minimum dimensions have been considered. Each algorithm has been applied 100 times and each time 200 replicates have been made. Table 1 consists of the following parts:

● The values for the best, worst and mean for the cost functions have been found by the algorithms.

● The value of the standard deviation (SD) has been determined by equation (15), and n is the number of parameters.

(15) $$S.D. = \left(\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right)^{\frac{1}{2}} \quad , \quad \bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

Table 1: The criterion mathematical functions

Name	Mathematical Representation	Dim.	Range of Search
Rosenbrock	$F_1(x)=\sum_{i=1}^{D-1}[100\left(x_i^2-x_{i+1}\right)^2+\left(x_i-1\right)^2]$	100	$(-30,30)^D$
Rastrigin	$F_2(x)=\sum_{i=1}^{D}\left[x_i^2-10\cos(2\pi x_i)+10\right]$	30	$(-5.12,5.12)^D$
Himmelblau	$F_3(x)=\frac{1}{n}\sum_{i=1}^{D}[x_i^4-16x_i^2+5x_i]$	100	$(-5,5)^D$
Michalewicz	$F_4(x)=-\sum_{i=1}^{D}[\sin(x_i)sin^{20}\left(\frac{i\times x_i}{\pi}\right)]$	100	$(0,\pi)^D$
Ackley	$F_5(x)=-20\exp\left(-0.2\sqrt{\frac{1}{D}\sum_{i=1}^{D}x_i^2}\right)-\exp\left(\frac{1}{D}\sum_{i=1}^{D}cos\,2\pi x_i\right)+20+\exp(1)$	30	$(-32,32)^D$

The results of the simulation and optimization of the functions shown in Table 2:

Table 2: The results of the simulation and optimization of functions

Test functions		GA	PSO	GA-MA	PSO-MA	Proposed MA
F_1	Best	6.7930E+05	5.2280E+05	2.0795E+03	6.3143E+03	38.3031
	Mean	3.4666E+06	1.0116E+07	2.3005E+04	5.1350E+04	84.6321
	Worst	1.8741E+07	1.9264E+07	2.6985E+05	9.7094E+05	239.0562
	S.D.	5.8661E+07	2.7142E+07	4.7195E+06	3.1779E+06	2.2940E+06
	N.F.E.	12562	15360	11267	14885	9434
F_2	Best	18.3152	17.2925	14.88561	16.9143	8.8945
	Mean	41.7875	43.5097	47.35161	57.4131	32.3356
	Worst	75.4657	120.1117	72.0025	119.3948	98.8540
	S.D.	60.5615	6.3572	13.3357	15.9807	21.2892
	N.F.E.	3527	4105	3251	3749	2744
F_3	Best	-2.6705E+03	-2.8341E+03	-3.5288E+03	-3.4985E+03	-3.7373E+03
	Mean	-2.4097E+03	-2.5134E+03	-3.1128E+03	-3.2416E+03	-3.2576E+03
	Worst	-2.1894E+03	-2.2361E+03	-2.9586E+03	-3.0415E+03	-3.0526E+03
	S.D.	172.6362	51.0950	201.2546	221.8417	203.5937
	N.F.E.	10038	13769	9842	10360	8522
F_4	Best	-43.1911	-59.0538	-71.3810	-69.9763	-93.7466
	Mean	-49.6345	-27.2571	-62.1148	-60.9471	-62.2331
	Worst	-41.6520	-23.3157	-43.8891	-48.6166	-48.4863
	S.D.	5.5727	2.8493E-14	6.0036	5.9520	7.1308
	N.F.E.	9781	12884	9650	11520	8907
F_5	Best	7.1428	3.6777	1.1566	1.8997	0.0079
	Mean	4.8483	9.4604	3.5597	4.8468	1.8666
	Worst	7.1103	10.6038	8.9631	9.6250	4.7000
	S.D.	2.9688	1.0646	0.6945	0.5144	1.5817
	N.F.E.	4250	10050	7244	8511	6975

As can be seen, in all 5 functions, the proposed memetic algorithm has found the most optimized solution. Also, by comparing the values for the SD, one can conclude that the amount of SD for the proposed algorithm is less than that for the other algorithms. Thus, the proposed algorithm has better performance, as compared to the others. For the comparison and complete evaluation of the algorithms performances in optimizing the criterion functions, the procedure of optimization has been presented in Figures (3) to (7).

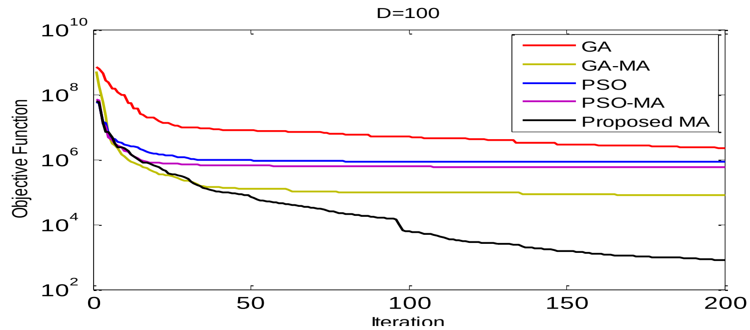


Figure (3): The comparison of the algorithms performances in the optimization of the Rosenbrock function

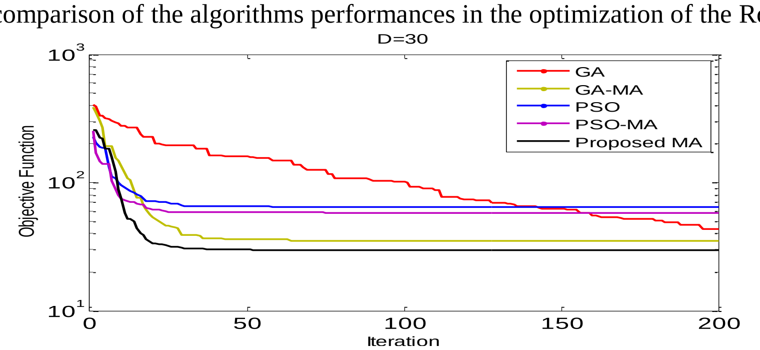


Figure (4): The comparison of the algorithms performances in the optimization of the Rastrigin function

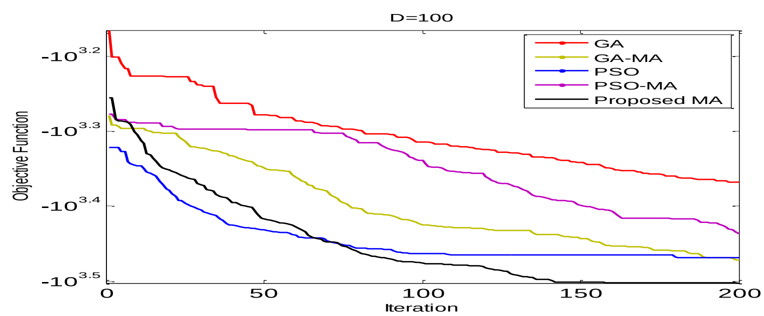


Figure (5): The comparison of the algorithms performances in the optimization of the Himmelblau function

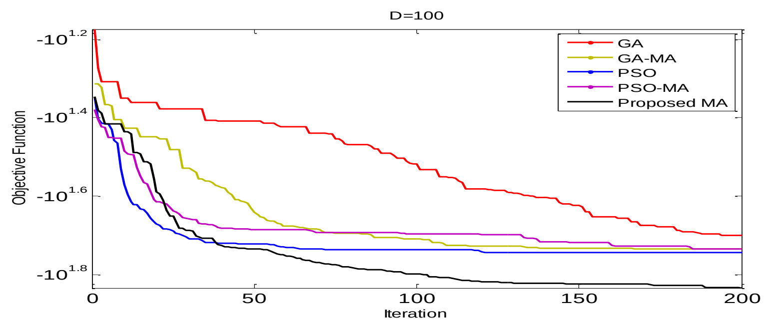


Figure (6): The comparison of the algorithms performances in the optimization of the Michalewicz function

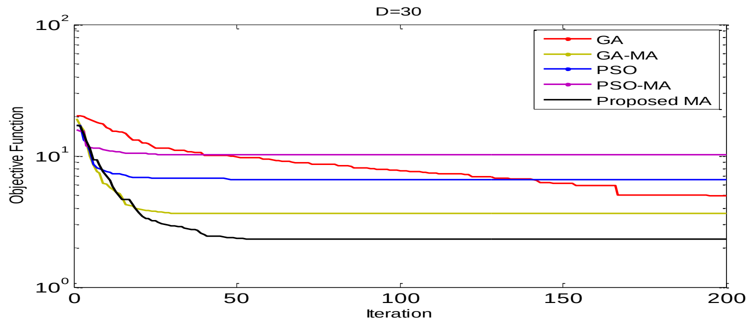


Figure (7): The comparison of the algorithms performances in the optimization of the Ackley function

According to Figures (3) to (7), the proposed memetic algorithm shows better and more appropriate performance in optimizing the numerical problems than the others.

4.3 The voltage profile and branches current before and after installing the DGs in the 33-buses standard test network

According to the diagram and the load distribution in Figure (8), one can observe a clear improvement in the voltage profile and reach an acceptable level. The red diagram is related to the voltage profile before installing the DGs and it can be seen that after installing the DG in the selected buses, there is a significant improvement in the voltage profile (the blue diagram).

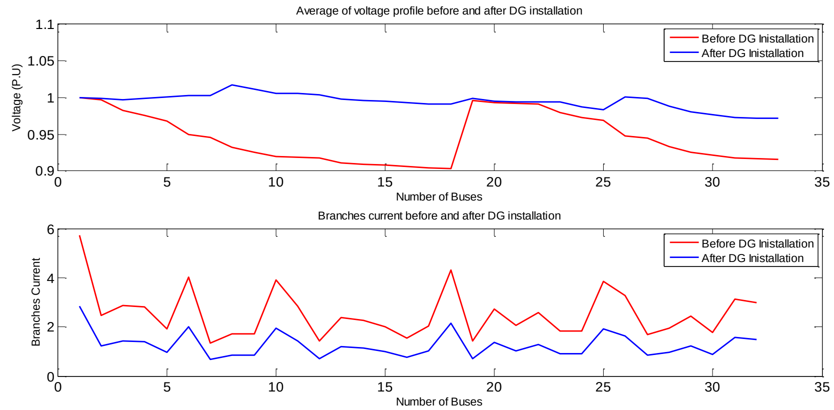


Figure (8): The voltage profile and current of branches in 33-buses IEEE network

According to Figure (8), after installing DGs on the buses 6, 14 and 15, the voltage losses are remedied completely and reach the level of 0.95 p.u.. Also, by this remedy, the voltages of the other buses reach the level of 0.95 p.u. and above. Considering the bad states in some parts of the network, such a gain in the voltage profile is highly crucial.

Table 3 presents the branches currents before and after installing 3 DG units of the micro-turbine type. The costs of losses are 1355905.359975 Rials and 378413.974051 Rials before and after installing DGs, respectively.

Table 3: Branches currents before and after installing DGs

Branch No.	Branches Current		Branch No.	Branches Current	
	Before	**After**		**Before**	**After**
1	6.033880	3.187613	18	4.549991	2.403696
2	2.618396	1.383261	19	1.499608	0.792222
3	3.043289	1.607726	20	2.877667	1.520231
4	2.978668	1.573588	21	2.185745	1.154698
5	2.032826	1.073913	22	2.736441	1.445623
6	4.248325	2.244329	23	1.941854	1.025854
7	1.406129	0.742838	24	1.943590	1.026771
8	1.812196	0.957357	25	4.077639	2.154159
9	1.801027	0.951457	26	3.454013	1.824706
10	4.143412	2.188905	27	1.787351	0.944232
11	3.004019	1.586981	28	2.050968	1.083497
12	1.518319	0.802106	29	2.580958	1.363484
13	2.499495	1.320448	30	1.863626	0.984527
14	2.392200	1.263765	31	3.299209	1.742925
15	2.128716	1.124570	32	3.148624	1.663373
16	1.620625	0.856153	33	4.549991	2.403696
17	2.149575	1.135590			

4.4 Return of investment

The annual cost of losses is 1355905.359975 Rials, regardless of installing 3 micro-turbine DG units. Besides the installation , this cost consists of the annual loss cost and the DGs installation cost and the income due to the DG-produced power. The related values are, respectively, as follows:

378413.974051, 5002046.608195, and 13267501.000854 Rials.

Table 4: Costs and capital return before and after installing DG

	Cost of Annual Losses	**Cost of DGs**	**Annual Income of Release of Power**	**Cost P Loss**	**Total cost**
Before Installation	1355905.359975	0	0	1355905.3599	1355905.359975
After Installation	378413.974051	5002046.608	13267501.000854	-7887040.4186	378413.974051

According to table 4, by installing DGs, not only will there be a return in investment, but it is also possible to make an annual profit of 7887040.418608 Rials.

5. CONCLUSION

The location and capacity of the DG are two main factors in decreasing the power losses and enhancing the voltage profile in the distribution networks. A simple and rapid method has been introduced in this article, which can bring about the best advantages from installing DGs by determining the location and capacity of the DG units. The memetic algorithm in 3 micro-turbine units is located in the most sensitive part of this network and can improve the voltage profile, thereby improving the power quality. In addition, the economical benefits are also obvious by installing the DG units. In addition to the decreases of the network loss costs due to an improvement in the voltage profile¸ one can gain a considerable profit through selling the power produced by the micro-turbine DG units, thereby compensating for the initial costs of installing the DG units. At first one may hold that installing the DG units lacks any technical and economical justification, yet in this paper it has been proved that it is likely to optimally determine the location of DGs via an appropriate and intelligent algorithm. Then by selecting the suitable size for these units and considering the network situation, it is possible to reach a desirable technical and economical justification. It is noteworthy that should the above-mentioned process not be carried out properly and accurately, not only will the desired advantages not be achieved, but also it will lead to the network instability and an increase in losses.

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