Original Article: Minimize Power Losses and Voltage Stability by Optimizing the Installation Location of Generators in Distributed Generation

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ABSTRACT

Considering the effects of DGs on the new power system, their importance has increased in the future smart grid. The number of DG units installed on the power system is growing significantly and the technical, economical and environmental effects of them on the power system are being analyzed. Currently, considerable technical effects include voltage profile, power loss, quality, reliability, protection, control and stability. The most important factors which affect the technical and the environmental issues include the type, the size and the location where the DG units are installed on the power system. The location and the size of the DG unit should be optimized in order to maximize the advantages and reduce the effects of them on the power system. In some conditions, inappropriate placement can reduce the advantage and even jeopardize the general performance of the system, so finding an optimal location and size of DG units encouraged most of the researchers to investigate this area. So far most of the researches use the DGs with unity power factor in distribution systems that have stable power loads. Moreover, most of the authors did not take the functional cost of DG into consideration and achieved minimization of the power loss and the voltage stability by installing several large scale DGs. In this paper, an attempt was made to investigate the installation location of the multiple distributed generators influenced by the changes of the load levels. In this part, we selected a suitable location to install the DG and investigated the results considering the load models in order to reduce the power loss of the transmission lines, reduce the voltage deviation index and reduce the cost of DG exploitation through optimize genetic algorithm.

Introduction

Most of the researches so far use the DGs with unity power factor in the distribution systems that only have stable power loads. And also, most of the authors did not take the functional cost of DG into account; and achieved minimization of the power loss and the voltage stability by installing several large-scale DGs. Having considered the stable node voltage called the power stability index (PSI), a new index was developed for the DG location to find the most

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sensitive bus, and a search algorithm was used to find an optimized DG size in an optimized location in order to minimize the power loss. A common search technique based on Newton-Raphson iteration method was implemented to investigate the load flow. The purpose of this action was to effectively reduce the cost and the loss; it focused on optimizing the cost and the loss unstoppably and helped to create some purposes with the maximum benefit by balancing the results [1-3]. The method based on the artificial neural network was developed owing to the complication of the multiple concepts of DG in order to find an optimal location and size of DGs; and genetic algorithm was used for finding an optimal location and size of DG's multiple units in order to minimize the power loss and the power supply by the main grid considering the voltage of each system bus [4-6]. A combination of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) was introduced in order to find the optimal location of a specific amount of DG units installed on the system to minimize the loss of the total power to improve the voltage profile and the voltage stability index. The PSO algorithm was used for a method based on the multi objective decision making to identify the optimal location and the size of the multiple DGs with various load models in the distribution system [7].

The above-mentioned methods brought about promising results according to the optimal location and size of the DGs, yet they have some deficiencies, including computational time in solving large-scale real systems, computational efficiency and convergence. The effect of the load changes on the programming of multiple distributions in the distribution system was investigated and revealed that load models can significantly affect the DG programming. In this paper, we tried to investigate the location of installing the multiple distributed generators influenced by load changes which is mentioned in the reference [8], While 3 points were randomly selected in the mentioned reference, here in order to achieve the purposes such as reducing the losses of the transmission line, the voltage deviation and the cost of DG exploitation through genetic algorithm, we consider the suitable location of installing DG as a variable and analyze the results. The proposed method is tested on the 33-bus system; the results are compared to the other classic methods.

Power Flow Equations

In the distribution systems, load flow is calculated by the following equations that use the linear diagram shown in the Figure 1. The Branch Current between the k and k+1 buses are calculated by Kirchhoff's current law [9-11].

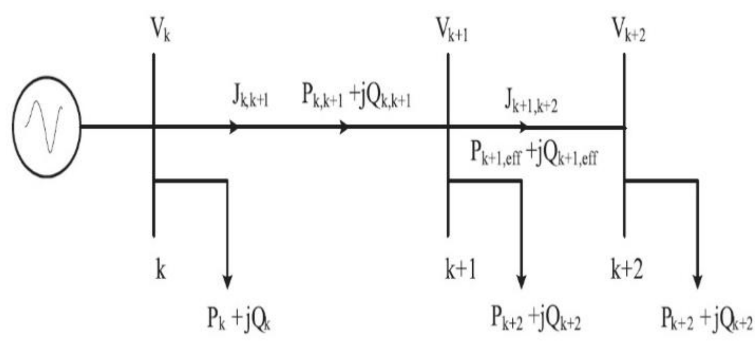

Figure 1. The linear diagram of sample distribution system

$$I_k = \left(\frac{P_k + Q_k}{V_k} \right)^* \quad (1)$$

$$J_{k,k+1} = I_{k+1} + I_{k+2} \quad (2)$$

The above-mentioned equation can be calculated by a matrix of the current of injecting the busses to the line current:

$$[J] = [BIBC][I] \quad (3)$$

In which the BIBC matrix included zero and one and it can be calculated considering the equation (2). The voltage in k+1 can be calculated by the Kirchhoff's current law. For example:

$$V_{k+1} = V_k - J_{k,k+1}(R_{k,k+1} + jX_{k,k+1}) \quad (4)$$

Power loss was calculated between k and k+1:

$$P_{Loss}(k,k+1) = R_{k,k+1}\left(\frac{P_{k,k+1}^2 + Q_{k,k+1}^2}{|V_k|^2}\right) \quad (5)$$

The general loss of the system is determined by the total loss in all parts:

$$P_{TLoss} = \sum_{k=1}^{b} P_{Loss}(k,k+1) \quad (6)$$

Power loss with DG

Installing the DG unit in an optimal location leads to reducing the power loss, and improving the stability of the voltage, the security and the protection. In this part, having installed the DG, the power loss between k and k+1 is calculated as follows:

$$P_{DG,Loss}(k,k+1) = R_{k,k+1}\left(\frac{P_{DG,k,k+1}^2 + Q_{DG,k,k+1}^2}{|V_k|^2}\right) \quad (7)$$

Where the power loss between the k and k+1 buses is after DG installation and is accessible in the calculation of the radial grid through the leading and the backward algorithm. The reduction of the total loss of the system with the total power loss in all parts of the system is calculated as follows:

$$P_{DG,TLoss} = \sum_{k=1}^{b} P_{DG,Loss}(k,k+1) \quad (8)$$

Power loss reduction with DG installation

Power loss index (ΔPLDG) from the ratio of the total loss with DG to the total loss without DG is as follows [8]:

$$\Delta PL_{DG} = \frac{P_{DG,TLoss}}{P_{TLoss}} \quad (9)$$

Voltage deviation index

One of the benefits of installing DG is to reduce the voltage deviation. This index examines the size of DG which increases the voltage deviation. The voltage deviation index can be defined as follows in which k is the number of the bus. During the installation of DG, the system has the limitation of the voltage violation. The proposed method tries to minimize the ΔVD which is closer to zero, so it improves the voltage stability and the grid performance [8].

$$\Delta V_D = \max\left(\frac{V_1 - V_K}{V_1}\right) \quad \forall \quad k=1,2,...,n \quad (10)$$

Operational cost minimization

Operational cost with the presence of multiple distributed generators includes two parts. The first cost is the cost of the active power production to compensate the system loss by substation, which is minimized by decreasing the total loss of the system. The second cost is the cost of the active power production of the installed generators. This cost can be minimized by reducing the real amount of power which is obtained from DG. Therefore, the total operating cost (TOC) is as follows:

$$TOC = \left(C_1 P_{DG,TLoss}\right) + \left(C_2 P_{DGT}\right) \quad (11)$$

In which is the aggregation of the active power production of the multiple production units; is the aggregation of the power loss after installing DG and also, $C_1$and $C_2$are the coefficients of the cost of the production of the real power to compensate the loss according to $/Kw. The pure operating cost (ΔOC) from DG reduction is calculated as follows:

$$\Delta OC = \frac{TOC}{C_2 P_{DGT}^{\max}} \quad (12)$$

Objective function of the problem

In order to minimize the power loss, voltage deviation and the total cost of the operation of the distribution system, the proposed objective function of the problem is formulated as follows:

$$\textit{Minimize } \mathrm{F} = \min(\alpha_1 \Delta PL_{DG} + \alpha_2 \Delta \mathrm{V}_D + \alpha_3 \Delta \mathrm{OC}) \quad (13)$$

According to the above-mentioned equation:

$$\sum_{q=1}^{3}\alpha_q = 1.0 \wedge \alpha_q \in [0,1] \quad (14)$$

These weights αq are created to make differences in the importance of the power loss, voltage deviation index and operating cost reduction of the objective function. We minimized the objective function based on the various operating limitations to eliminate the electrical needs of the distribution grid.

Constant impedance, constant current, constant power model

As it was mentioned, the simple load model PQ is usually used in the load flow programs. According to the type of the load, the current, the voltage and its impedance in different times, these amounts are not necessarily constant, so the final results are not adequately precise. The constant impedance, the constant current and the constant power model are another method of static modeling of the load. The loading model is mentionable through a mathematical equation between the voltage and the bus power and the effects of load changes in the node are defined as follows [12]:

$$P_K = \rho P_{K,actual} V_k^{\beta} \quad (15)$$

$$Q_K = \rho Q_{K,actual} V_k^{\beta} \quad (16)$$

In which the amount of β is zero for the constant power load (CP); for the constant current load (CC) is set to one and for the constant impedance load (CI) is two. The coefficient of the load ρ is a multiplier by which the demands for the power load increase or decrease in all of the nodes. Technically, decisions and results based on the hypotheses of the constant power load model in the system which is not in a constant power load situation are not simple. Therefore, three types of loads are simultaneously simulated in a different coefficient of the load in order to examine the proposed method.

Introducing the Investigated System

The investigated system is a 33-bus radial distribution system with 32 branches. The linear chart of the 33-bus system was shown in the Figure 2. The total real and imaginary loads of the system are 3.72 MW and 2.3 MVAr. The total power loss from the load flow, including the loads CC (1.0), CP (1.6), CP (1.0), CP (0.5) and CL (1.0) are respectively 180.29 kW, 603.36 kW, 210.98 kW, 48.78 kW and 154.62 kW (13).

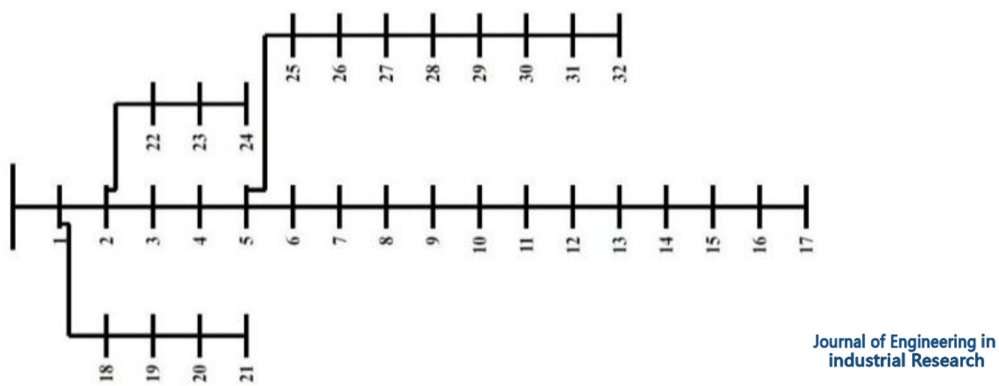

Figure 2. 33-bus test system

The flow chart of the used algorithm

In the following picture, the proposed method is represented. It is clear that in the beginning of this method, the information of the 33-bus test system is taken and the genetic algorithm determines its chromosome, which has 6 genes and considers the amount of the primary population 20 according to MATLAB default. The amount of the objective function is determined for each child (chromosome) considering the suggested objective function. The superior chromosomes (father) are selected to form the next population based on the amount of the objective function; this process is done until we reach a suitable convergence.

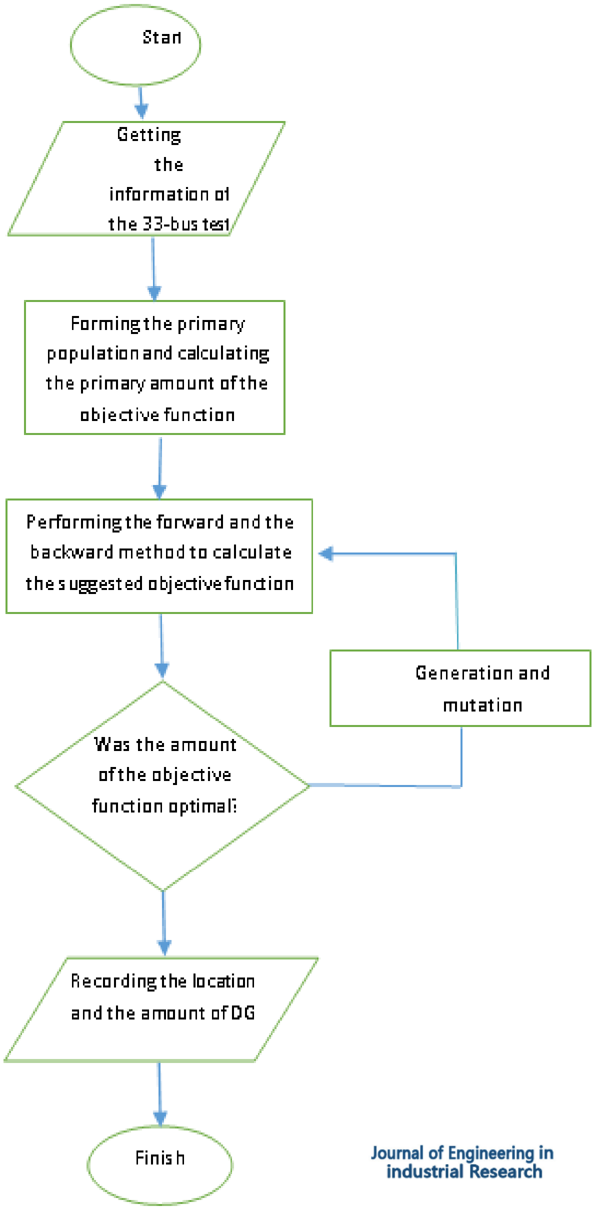

Figure 3. The flowchart of the proposed method

Analysis and Simulation

Investigating the objective function in the constant power load model (CP)

As it was mentioned, this kind of load is modeled from the Equations (15) and (16). In this case, β=0, so the power consumption of the load is not related to the bus voltage; when ρequals 0.5, 1, 1.5, we can model the load respectively in the light load, the full load and the heavy load. In the full load, the best chromosome in which the blue points are the average amount of the objective function calculated by the children in each step and the black points are the best amounts of the objective function by using the tool menu of the MATLAB genetic algorithm and considering the primary condition of all parameters and defining the chromosome 6 and performing the genetic algorithm at least 20 times. As can be seen, the amount of the objective function has reached convergence in the fourth repetition. In this situation, the first three numbers of the following chart indicate that the amount of DG is rounded and the next three numbers indicate the location of DG. Finally, voltage profile is represented as follows after installation. It shows the improvement of the voltage profile after installing the DG; the amount of the objective function is compared to the reference [8] in the Table 1. As it was mentioned, in the proposed method of this paper, in addition to the size of DG, its location is continuously considered by taking the proposed objective function in the reference [8] into account, so the amount of the suggested objective function is improved. In this case, total operating cost (TOC) and loss are reduced.

Table 1. The comparison of the calculated results in the constant power load

Parameters	**Full load**		
	Without DG	**Reference 8**	**Suggested method**
DG size(MW)		0.6521(14) 0.1984(18) 1.0672(32)	0.806(32) 0.585(15) 0.342(15)
KW(power loss)	210.98	89.90	87.72
Power loss reduction(pu)(bus)	0.9038(18)	0.9705(29)	0.9634(30)
TOC($)		9948	9015.9
Suggested of objective function		0.3141	0.3034

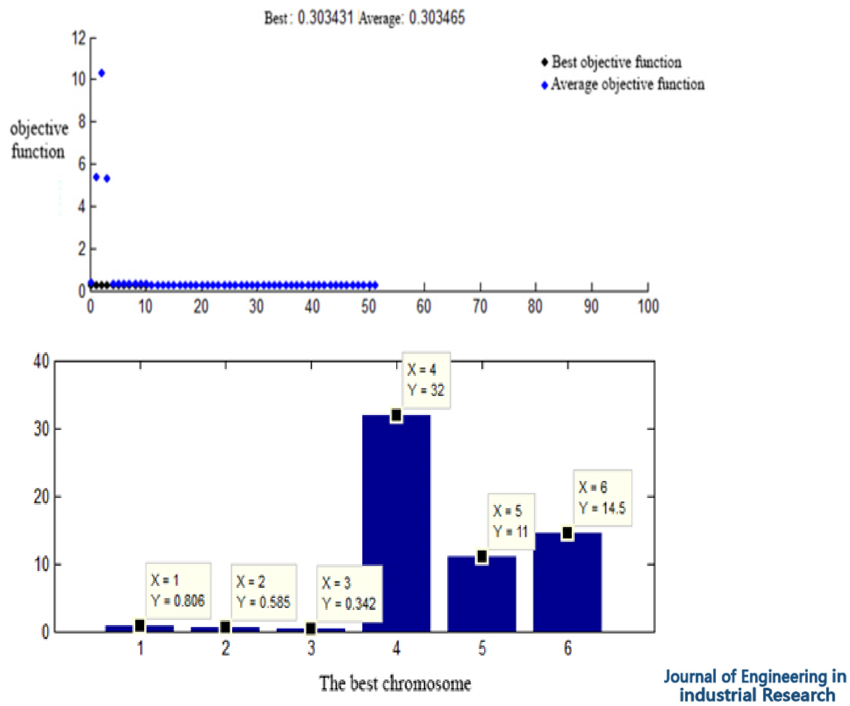

Figure 4. The best location for installation, calculated by the genetic algorithm in the constant power load

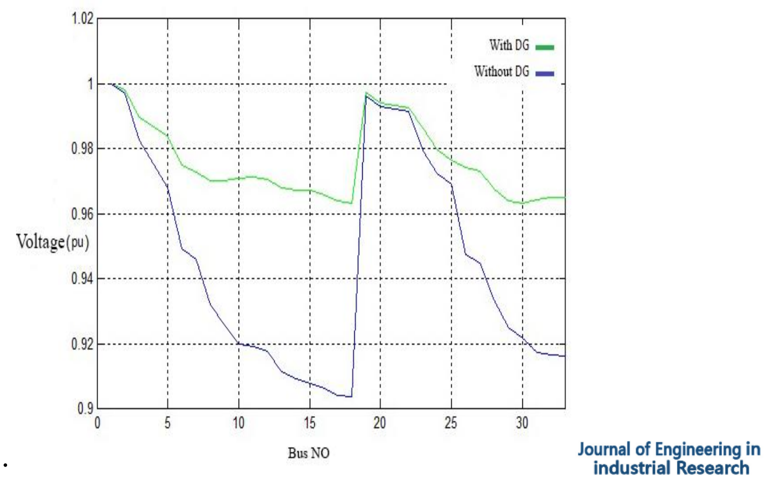

Figure 5. Voltage profile after installing the multiple distributed generators in the constant power load

Investigation of the objective function in the constant current load model (CC)

As it was mentioned, load of the constant current is modeled from the Equations (15) and (16). In this case, β=1 so that the power consumption of the load is related to the bus voltage with the power one; ρ=1in the full load, so the best voltage profile with the suggested method is drawn as you see in the following.

Which shows a good performance of the system after installing the DG. In this case, the best chromosome with performing the genetic algorithm for 20 times is calculated as follows. The amount of the objective function is compared to the reference [8] in Table 2.

According to the chromosome of the first row to the third row of the reference column [8] in the suggested method column, the points which are sited indicates different DGs, so the power loss is reduced and as you see, the amount of the total operating cost (TOC) is improved and the suggested objective function is reduced effectively.

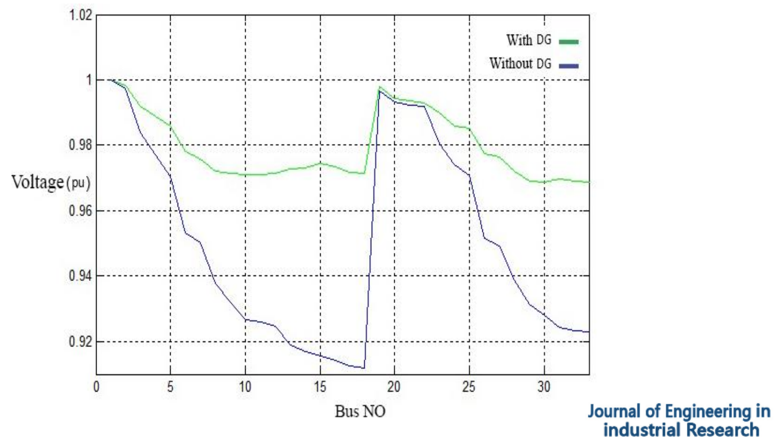

Figure 6. The voltage profile after installing the multiple distributed generators in the constant current load

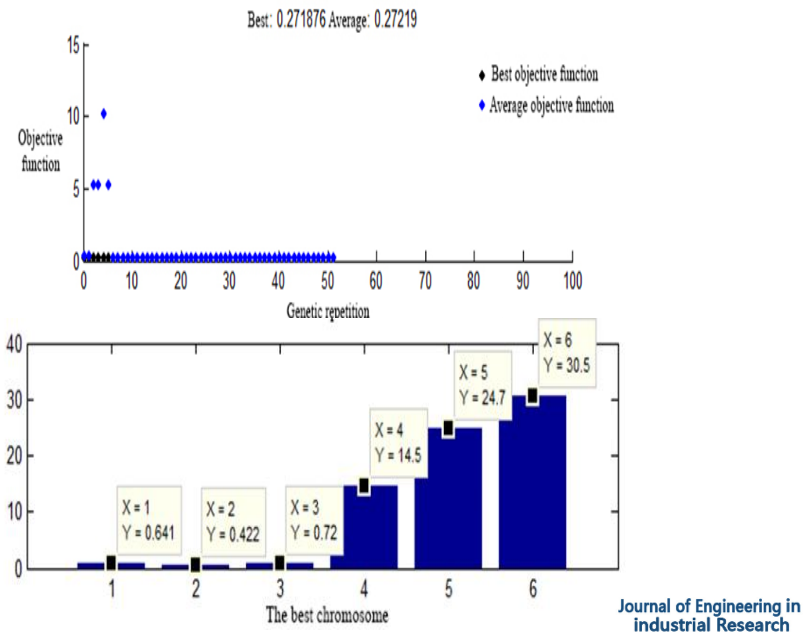

Figure 7. The best location for installing, calculated by the genetic algorithm in the constant current load

Table 2. The comparison of the calculated results in the constant current load

Parameters	Full load		
	Without DG	Reference 8	Suggested method
DG size(MW)		0.6023(14) 0.1836(18) 1.3029(32)	0.641(15) 0.422(25) 0.72(31)
KW(power loss)	180.29	78.49	61.26
Power loss reduction(pu)(bus)	0.9120(18)	0.9723(29)	0.9686(30)
TOC($)		10790	9160
Suggested of objective function		0.3322	0.272

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Investigation of the objective function in the constant impedance load model (CI)

The above mentioned load is modeled from the equations (15) and (16). In this case, β=2 so that the power consumption of the load is not related to the bus voltage; the best voltage profile with the suggested method was drawn as follows when ρ equaled 1 in the full load. In this case, the best chromosome is calculated as follows.

We can realize from the above picture that the amount of the objective function is convergence from the 24th repetition and it is converged when it reaches 0.2566 while this amount has been 0.2837 in reference [8], so it indicates that the suggested method is better than the last case in the constant impedance load model. The amount of the objective function is compared to reference [8] in the Table 3.

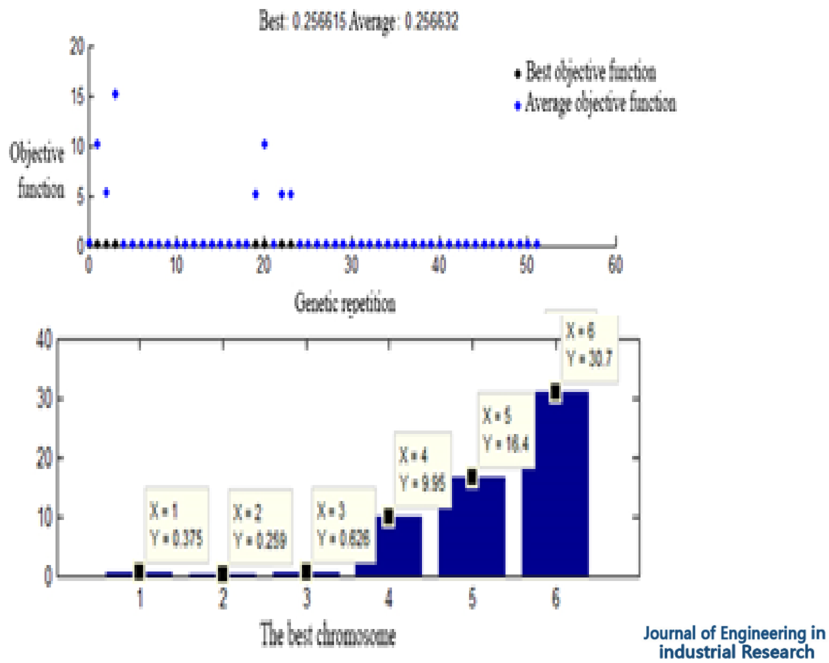

Figure 8. The best location for installing, calculated by genetic algorithm in the constant impedance load

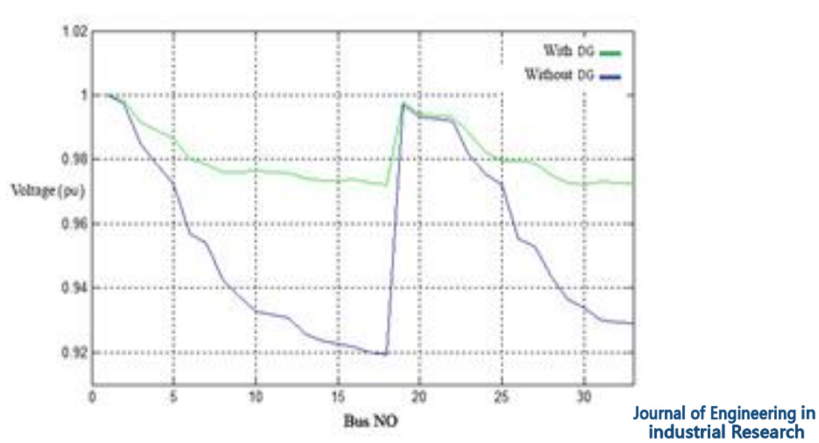

Figure 9. Finding the location of installing the multiple distributed generators and investigating the voltage profile in the constant impedance load

Table 3. The comparison of the calculated results in the constant impedance load

Parameters	Full load		
	Without DG	**Reference 8**	**Suggested method**
DG size(MW)		0.5229(14) 0.1996(18) 0.9102(32)	0.375(10) 0.259(16) 0.626(31)
KW(power loss)	154.62	68.78	54.01
Power loss reduction(pu)(bus)	0.9194(18)	0.9745(29)	0.9722(30)
TOC($)		8438	6510
Suggested of objective function		0.2837	0.2566

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In this case, as you see, the amount of the objective function (fifth row) has improved. Moreover, total operating cost (TOC) function (fourth row) and the transmission line loss (second row) is improved. In the following, a comparison of the location methods represented in this paper to the methods represented in other papers is indicated in the Table 4.

Table 4. The comparison of the results in the constant impedance load

Method	Power loss(kw)	TOC ($)	DG location	DG size (MW)	Amount of objective function
BFOA [6]	89.90	9948.1	14 18 32	0.6521 0.1984 1.0672	0.3141
GA [19]	106.3	15396.2	11 29 30	1.5 0.4228 1.0714	0.3972
SA [20]	82.03	12666.6	6 18 30	1.1976 0.4776 0.9205	0.3268
suggested method of GA	87.72	9105.9	32 11 15	0.806 0.585 0.342	0.3034

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As you see in the proposed method, given that the algorithm is variable in finding the location of installing the DG apart from being variable in the amount of producing power by DG, it dedicates better locations for the installation. This issue brought about the reduction of the power loss of the transmission lines and reduction of the operating cost of the mentioned power plant. In this case, the amount of the considered objective function from all other methods dedicated the lowest amount to itself.

Conclusion

In this paper, we selected a suitable location for installing the DG in order to achieve some purposes like reducing the loss of the transmission lines, reducing the voltage deviation and reducing the cost of DG production. In order to find an optimal location and size of the DG through a genetic algorithm, a method was suggested which was better and more effective to optimize the mentioned objective function in different references. This method was tested on the 33-bus system in which several models of the loads were also included. Considering the selection of the location of DG installation, aside from the amount of the production of the power plant, we got better results from other references through genetic algorithm; in all calculations, the primary condition of the MATLAB genetic algorithm tool was used such as the primary population of 20 individuals, the 50 times repetition process and so on. Total operating cost (TOC) reduced to 9105.9 dollars from the simulated results for the optimal location and size in each line while this amount was 15361.9 dollars in the previous references. And also, the amount of the suggested objective function dedicated the lowest amount to itself in the number 3034, the voltage profile eternally improved in all systems. The results represented by GA were compared to the results of BFOA (bacterial foraging optimization), SA (simulated annealing) and PSO (particle swarm optimization). They indicated that the performance of the suggested technique in reducing the loss of total operating cost (TOC) and increasing the constant voltage with DG was better than the compared methods. It can be concluded from these results that the suggested technique in finding an optimal solution was precise and this technique can be implemented for any kind of system with any number of buses and different types of loads.

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