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Finding the Optimal Capacity and Location of Distributed Generation Resources and Analyzing the Impact of Different Coefficient Factors

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ABSTRACT

Applications of Distributed Generation (DG) are taken into account more seriously due to the growth of cities, ever-increasing demand for electrical energy, and economic constraints affecting the installation of new substations and power plants. Using these resources can have positive and negative impact on the distribution networks. Installation place, resource capacity, and exploitation method are some important issues that should be taken into consideration to obtain maximum efficiency.

This paper presents a new method for determining the optimum location and size of Distributed Generation (DG) resources in order to improve technical parameters and to satisfy network constraints using Genetic Algorithm (GA). Technical parameters include voltage profile, energy losses, and short-circuit level. Network constraints consist of technical constraints of the network and of the DG. Using the proposed method, some problems of previous studies are solved: not considering constraints, not studying important parameters, and not allocating multiple DGs. In order to determine the effectiveness of sizing and siting, some indexes are defined, which represent the improvement level of network parameters and constraints. The proposed method is tested on an actual power network of Zanjan Province in Iran and simulation results indicate how efficient the method is.

KEY WORDS: DG Optimal Location and Size, Loss Reduction, Objective Function, Short-Circuit Level, Voltage Profile, Weighting Coefficient.

INTRODUCTION

DG is usually defined as electrical power resources, which are directly connected to the system [1]. Nowadays, DG plays an increasingly significant role in the electrical power systems [2]. Employing DG resources may have positive and negative impacts on the performance of distribution networks. Some advantages of DG installations are less expensive distribution and transmission, deferring the need for improving substation capacity, reduced power transmission losses, improved voltage profile, improved system stability, and applicability of new and renewable energies. On the other hand, one of the most important problems of installing DG in a distribution network is the increase in short-circuit level due to the changes in thevenin impedance calculated from the point of view of network buses [3].

The optimum siting and sizing of DG resources is the most important consideration in using these resources [4]. Studies [5] and [6] show that incorrectly determining the size and site of DG resources causes technical problems. There are several methods for this purpose, which can be divided up into two groups from three perspectives:

1) The number of considered parameters
2) The number of constraints
3) The type of connectivity to the main network.

The parameters can be one or more. Considering one parameter for allocating DG resources improves the chosen parameter but does not affect other parameters and even, in some cases, causes problems to them. Considering different constraints can affect the results of DG allocation. In addition the connectivity can be unidirectional (considering the distribution network rather than the main network) or bidirectional (which considers both networks).

Over the past few decades, several studies have been done for the purpose of siting and sizing DG resources. In order to satisfy the constraints, the authors of [1] introduced a new method which checked the possibility of placing DG resources in the power system one by one. If the constraints associated with a DG did not meet the expected standards, the DG was dismissed and the system checked the next DG. It is easy to realize that this method does not consider all suitable places which are potential candidates for installing DGs. In [3], a new algorithm is presented using unidirectional and bidirectional power flow in order to reduce the power losses. In addition to the problem of considering only one parameter, there is the protective problem which occurs as a result of bidirectional power flow. Therefore, this method is not applicable in distribution companies. Another study [4] was carried out to decrease power losses and installation expenses. This study, however, does not take account of such constraints as technical issues, voltage profile, and short-circuit level.

Siting and sizing DG resources was done in [7] analytically so as to reduce energy losses and to determine a suitable

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power factor. As a result of not using any optimal method, this model increased the speed convergence to find a suitable answer. This paper, also, disregards the issues mentioned for study [4]. References [8] and [9] determined the optimum location and size of DG resources with economic indices in mind. These indices were initial investment, expenses of DG operation and maintenance, and expenses of DG relocation. These studies failed to notice the technical advantages of installing DG resources during the optimization process. Authors in [10] determined the maximum capacity of DG resources to prevent the resulting miss coordination between and within fuses and reclosers. The main problem with this algorithm is that it ignored the possibility of obtaining profits from installing DGs. In [11], siting was done in order to determine the maximum capacity of DG resources of distribution system. This study was overly strict about such constraints as the power of terminals, the capacity of transformers, voltage profile, and short circuit level. Needless to say, fulfilling the constraints does not necessarily mean that the best answer can be achieved. Additionally, the study overlooked the losses impact. Reference [12] determined the optimum location and size of DG resources analytically, considering a single parameter, in order to reduce energy losses. Voltage profile was the only constraint taken into consideration in this study. Study [13] sited and sized DG resources with the aim of maximizing the profits of reducing losses and improving the voltage profile, given that increasing power generation leads to reduced power losses and nodal prices and vice versa. Short-circuit level was overlooked in this study and this resulted in the failure to provide for the disadvantages of changing the breakers. In [14], determining DG location was done irrespective of DG capacity and in such a way that maximum loss reduction would be obtained. Authors failed to consider such issues as sitting only one DG, improving only one parameter, and not sizing DG capacity. Because of constraints playing important roles in sitting and sizing DGs, Authors in [3] and [15] presented a different method for constraint analyzing included inappropriate answers strategy, repetition strategy, and penalty strategy. So as to determine the impacts of installed DG resources on grid, reference [16] represented such indices as power losses of grid, voltage profile and short-circuit level of buses, and current capacity of transmission lines. In this study, some indices introduced represent the maximum of improvement rather than the average of. Additionally, what the method does not represent is the ignoring of some constraints.

This paper deals with the sizing and sitting of several DG resources simultaneously, in order to improve such technical parameters as voltage profile and short-circuit level of busses and power losses of grid with considering the constraints using Genetic Algorithm (GA). As all constraints are inserted into objective functions, there is no need to use such traditional solutions as penalty coefficient, which is necessary to be determined personally. In order to determine the exact profit of installed DG resources, subsequently, some indices are introduced to show the improvement level of network parameters and the satisfaction level of network constraints. The method is applied to an actual network of Zanjan Province. As there is an actual network, the problem was solved with some requests from the company. The results show that the method is flexible and suitable for industry demand.

PROBLEM STATEMENT

Most previous studies concentrated on improving only one parameter and the impact of installed DG resources on other parameters of the network are not studied. To clarify the caused problem, an example is presented. In Fig. 1, all needed energy of load is obtained from substation.

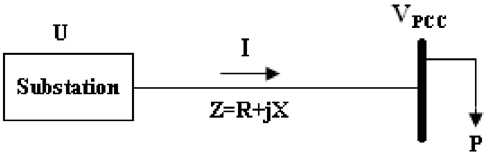

Fig. 1. One-bus sample network without DG

Therefore, the load current is equal to the transmission line current, as in Eq. 1.

$$I = I_{Load} \tag{1}$$

Due to the existence of resistance and inductance of line, there is a voltage drop at PCC which is obtained from Eq. 2.

$$V_{PCC,BeforeDG} = U - Z.I \tag{2}$$

Power loss of transmission line is associated with current and resistance of line, and is obtained from Eq. 3.

$$Loss_{BeforeDG} = 3RI^2 = 3R\left(\frac{P}{V_{PCC}}\right)^2 \tag{3}$$

After installing DG, the equivalent circuit can be represented by Fig. 2.

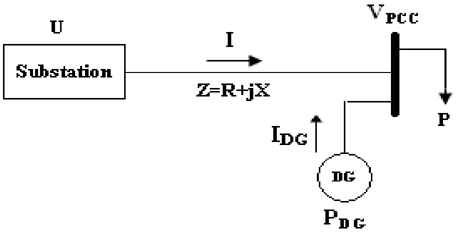

Fig. 2. One-bus sample network with DG

In this network, DG can provide a part of electrical power of load demand. As shown in Eq. 4, it results in reduction of the line current.

$$I = I_{Load} - I_{DG} \tag{4}$$

Combining Eq. 2 and Eq. 4, results in Eq. 5 which presents the PCC voltage.

$$V_{PCC,AfterDG} = U - Z.I = U - Z.I_{Load} + Z.I_{DG} \tag{5}$$

By rewriting Eq. 5 based on DG injected power (P_{DG}), Eq. 6 is obtained.

$$V_{PCC,AfterDG} = V_{PCC,BeforeDG} + Z.\left(\frac{S_{DG}}{V_{PCC}}\right)^* \tag{6}$$

On the other hand, after installing DG, power losses change to Eq. 7.

$$Loss_{AfterDG} = 3.R.\left(\frac{P - P_{DG}}{V_{PCC}}\right)^2 \tag{7}$$

Therefore, the improvement of power losses is equal to Eq. 8.

$$\Delta Loss = Loss_{BeforeDG} - Loss_{AfterDG} = 3.R.\left(\frac{2P.P_{DG} - P_{DG}^2}{V_{PCC}^2}\right) \tag{8}$$

According to Eq. 6 and Eq. 8, the injected power of DG affects the voltage profile and power losses. It is clear from Eq. 8 that the improvement of power losses is obtained provided that $P_{DG}<2P$ and from Eq. 6 that more power injection than source power cause overvoltage at PCC as in Eq. 9.

$$V_{PCC,After\ DG} > V_{\max} \tag{9}$$

where V_{max} is equal to maximum allowable voltage which is equal to 1.05 pu with respect to the standard [3]. Short-circuit is another issue which can be affected by installing DG.

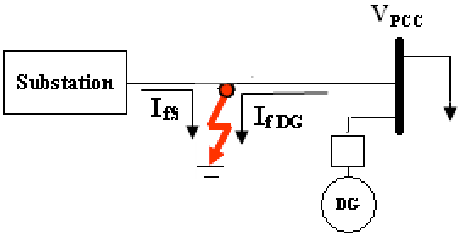

Fig. 3. One-bus sample network with DG

DG unit is almost always placed in parallel with the network. Therefore, the calculated impedance from fault point of view diminishes and the fault current level increases. Increasing the DG unit capacity, the equivalent impedance of DG unit diminishes and the short-circuit level of the network changes [17]. As it is shown in

Fig. 3 installing DG unit in PCC point, the current in fault location would be I_{fs}+ I_{fDG}. Before installing DG unit this amount was I_{fs}. If the increase in short-circuit level exceeds the circuit breakers rating, the circuit breakers must be changed and changing circuit breakers imposes excessive cost. Considering short circuit level while siting and sizing DG units, this problem can be avoided.

The preceding discussions highlight the fact that finding the optimal place and capacity, according to the improvement of one parameter may have an adverse effect on other. In addition, the network parameters must be changed within the allowable ranges. Therefore, the related constraints must be considered in sizing and siting procedure.

Another defect of the previous works is siting and sizing just one DG unit. In these methods, the single DG units are sited and sized until the network parameters reach the appropriate value and then the procedure is stopped. The probability of having a better answer by installing further DG units is ignored. One of these methods is proposed in [1]. Therefore, it can be concluded that the best answers are usually not obtained, using these kinds of methods. Since electrical companies require the exploitation of more than one DG unit together and simultaneously, these kinds of methods are not applicable.

NEW METHOD

The process of finding the optimal size and location of DG resources is aimed to improve the network parameters and keep the parameters in an allowable range. The method proposed in this paper, is capable of identifying the best places and locations of DG resources and satisfying different constraints of the network. In this section the proposed method and the considered constraints are presented and discussed.

Constrains

This paper is aimed to find the best place and location of DG resources according to the technical parameters of DG resources. Therefore, technical constraints of the network and operational constraints of DG are considered as constraints. Technical constraints of the network includes: constraint of the voltage level of the buses, short-circuit level and the power losses. Technical constraints of the DG includes: the penetration level of DG resources and constraint of the minimum power factor of the DG units. In addition, constraints can be soft or hard [3,15]. The constraint is considered hard, if could not have been violated. On the centrally, the constraint is considered soft if the algorithm violated some constraints to find the best answers [3]. Since electrical companies are interested in installing DG resources while undertaking the least costs and changes all the constraints are assumed to be hard constraints an must not be violated.

Technical constraints of the network

I. Voltage level constraint

Feeders of distribution network are usually radial and therefore, voltage profile at the end of these feeders encompasses a significant decrease. These voltage drops may be harmful for the consumers [18]. In addition, the existence of the DG resources may cause the voltage profile to increase more than the allowable limit. Therefore, a range must be specified for voltage profile, as in Eq. 10 [8].

$$V_{\min} \leq V_{Level}^{WithDG} \leq V_{\max} \tag{10}$$

where V_{min} and V_{max} are the minimum and maximum of voltage limit, respectively. In this paper V_{min} is assumed to be 0.95 and V_{max} is assumed to be 1.05.

II. Constraint of protective devices coordination

Since installing DG resources at buses, increases the short-circuit level of the bus and the nearby buses and causes the obligation of changing the protective devices, it is pivotal to consider a constraint to prevent the increase of this parameter too much, as in Eq. 11 [1].

$$I_{SC,i}^{With\ DG} < \text{the short-circuit level of the currently installed protective devices} \quad (i = 1,2,...,n) \tag{11}$$

where n is the number of buses and $I_{SC,i}^{With\ DG}$ is the short-circuit level of the buses after installing DG resources.

III. Loss reduction constraint

Selecting an inappropriate place and capacity of DG resources, brings about the increase of losses [5,6]. Therefore, by considering the constraint of loss reduction, the losses would certainly be decreased after installing DG resources, as shown in Eq. 12.

$$P_{Loss}^{WithDG} < P_{Loss}^{WithOutDG} \tag{12}$$

where $P_{Loss}^{With\ DG}$ and $P_{Loss}^{Without\ DG}$ are network losses after and before installing DG resources, respectively.

Technical constraints of DG resources

I. Constraint of DG penetration

Since DG resources are usually founded and installed by the privet companies and electrical companies are interested in controlling the power flow of the network, the injected power of the DG resources should be limited. This problem causes the necessity of considering the constraint of DG penetration level. DG penetration level is defined as the ratio of injected power of DG resources and the capacity of the feeder, as in Eq. 13 [3].

$$\sum_{i=1}^{NDG} P_{DG,i} \leq DG_{Penetratio\ n} \times P_{Load} \tag{13}$$

Where $P_{DG,i}$ is the produced active power of the i_{th} DG, $DG_{Penetration}$ level is the allowed penetration level. $DG_{Penetration}$ level is usually identified by the electrical networks and is assumed to be 0.2. P_{Load} is the active load of the network, and N_{DG} is the total number of installed DG resources.

II. Constraint of the minimum power factor of the DG units

Exploiting DG resources in high power factors is more beneficial. Thus, another constraint should be considered about the produced reactive power. This constraint prevent power factor from diminishing from an identified value, as in Eq. 14.

$$P_{DG,i} \geq Q_{DG,i} \times \frac{PF_{\min}}{\sqrt{1 - PF_{\min}^2}} \tag{14}$$

In this equation PF_{min} is the minimum amount of power factor for exploiting DG resources. In this paper, this amount is assumed to be 0.8 due to the request of Zanjan's electrical company, and $Q_{DG,i}$ is produced reactive power of the i_{th} DG.

Objective function

The proposed objective function of this paper consists of parameters of voltage profile, short circuit level and losses. On other feature of the proposed OF is the capability of inserting different constraints. The first section of objective function represents losses, as in Eq. 15.

$$F_1 = Max\left[0, (P_{Loss}^{WithOutDG} - P_{Loss}^{WithDG})\right] \tag{15}$$

If the constraint of losses were violated, the output of F_1 would be zero. Therefore, the probable answers of F_1 are shown in Eq. 16.

$$F_1 = \begin{cases} 0 & P_{Loss}^{WithOutDG} < P_{Loss}^{WithDG} \\ \\ P_{Loss}^{WithOutDG} - P_{Loss}^{WithDG} & P_{Loss}^{WithOutDG} > P_{Loss}^{WithDG} \end{cases} \tag{16}$$

The second section of objective function represents the voltage of the buses, as in Eq. 17.

$$F_{2,i} = Max(0, V_i^{WithDG} - V_{\min}) + Max(0, (V_{\max} - V_i^{WithDG})) + Min((V_{\min} - V_i^{WithDG}), (V_i^{WithDG} - V_{\max}), 0) \quad , \quad i = 1, ..., n \tag{17}$$

where $V_i^{With\ DG}$ is the i_{th} bus voltage after installing DG resources. $F_{2,i}$ is calculated for each bus independently. If the voltage of even one bus were not in defined range, $F_{2,i}$ would be zero. Otherwise, it will have a positive value. Therefore, the possible values of $F_{2,i}$ are shown in Eq. 18.

$$\begin{cases} F_{2,i} = 0 & (V_i^{WithDG} < 0.95 \ \ Or \ \ V_i^{WithDG} > 1.05) \\ & \qquad\qquad i = 1, 2, ..., n \\ F_{2,i} > 0 & 0.95 < V_i^{WithDG} < 1.05 \end{cases} \tag{18}$$

The last section of objective function represents the short-circuit level of the distribution network, as in Eq. 19.

$$F_{3,i} = Max\left[0, (I_{Sc,i}^{Switch} - I_{Sc,i}^{WithDG})\right] \ | \ i = 1, ..., n \tag{19}$$

where $I_{Sc\,i}^{Switch}$ is the maximum sustainable short-circuit current of i_{th} circuit breaker. If the short-circuit level of each bus was violated the constraint of short-circuit level, $F_{3,i}$ would be zero and otherwise, it would have a positive value. Therefore, the Eq. 20 are probable answer for $F_{3,i}$.

$$F_{3,i} = \begin{cases} 0 & I_{Sc,i}^{Switch} < I_{Sc,i}^{WithDG} \\ \\ I_{Sc,i}^{Switch} - I_{Sc,i}^{WithDG} & I_{Sc,i}^{Switch} > I_{Sc,i}^{WithDG} \end{cases} \tag{20}$$

Since all the constraints of this paper are considered to be hard, obtained answer must be rejected if any of the foregoing constraints were violated. F_4 function is defined as the Eq. 21 for this purpose.

$$F_{4,i} = Min\left(F_1, F_{2,i}, F_{3,i}\right) \qquad | \ i = 1, ..., n \tag{21}$$

$F_{4,i}$ is either zero or a positive value. If $F_{4,i}$ was zero, at least one of the constraints is violated. Thus, the obtained answer must be rejected. Otherwise all the constraints are satisfied. The objective function is therefore calculated as Eq. 22.

$$\begin{cases} if \ \ F_{4,i} = 0 \Rightarrow OF = 0 \\ \\ if \ \ F_{4,i} \neq 0 \Rightarrow OF = K_1\left(\dfrac{P_{Loss}^{WithOutDG} - P_{Loss}^{WithDG}}{P_{Loss}^{WithOutDG}}\right) + K_2\left(\dfrac{1}{n}\sum_{i=1}^{n} - (\left|1 - V_i^{WithDG}\right|\right) + K_3\left(\dfrac{1}{n}\sum_{i=1}^{n} \dfrac{I_{Sc}^{Switch} - I_{Sc}^{WithDG}}{I_{Sc}^{Switch}}\right) \end{cases} \tag{22}$$

The best case occurs when the $F_{4,i}$ maximizes. In this case, losses become minimum, voltage profile has the most improvement and the short-circuit level has the most difference from the short-circuit level of the breakers. Optimization algorithms, like GA, can minimize a function. Therefore, to optimize the objective function by these kinds of algorithm, $F_{4,i}$ must be multiplied by a negative value, as shown in Eq. 23.

$$OF = -(K_1\left(\frac{P_{Loss}^{WithOutDG} - P_{Loss}^{WithDG}}{P_{Loss}^{WithOutDG}}\right) + K_2\left(\frac{1}{n}\sum_{i=1}^{n} - (\left|1 - V_i^{WithDG}\right|\right) + K_3\left(\frac{1}{n}\sum_{i=1}^{n} \frac{I_{Sc}^{Switch} - I_{Sc}^{WithDG}}{I_{Sc}^{Switch}}\right)) \tag{23}$$

where K_1, K_2 and K_3 are weighting factors of losses, voltage profile and short-circuit level, respectively. The Eq. 24 must be satisfied about the weighting coefficients [1].

$$K_1 + K_2 + K_3 = 1 \tag{24}$$

Efficiency indices of installed DG resources

To evaluate the efficiency of the proposed method some indices should be applied. These indices include: voltage profile index, losses index, short-circuit level index and loading index. The presented indices are capable of identifying the violation of constraints.

I. Voltage profile improvement index (VPII)

VPII represents the overall status of the voltage profile and satisfying the considered constraints of the voltage. Comparing the voltage profile of the network, before and after installing DG resources, this index is obtained as in Eq. 25.

$$VPII = \left|\frac{VP_{WithDG}}{VP_{WithOutDG}}\right| \tag{25}$$

Using this index brings about one of two situations:

1. VPII>1: installing DG resources has a positive impact on voltage profile.
2. VPII<1: installing DG resources has a negative impact on voltage profile.

where $VP_{\text{With DG}}$ and $VP_{\text{Without DG}}$ are calculated as in Eq. 26.

$$VP = \sum_{i=1}^{n} \left|1 - V_i\right|^2 \times OC_V \tag{26}$$

Two situations can be considered for OC_V, as in Eq. 27.

$$OC_V = \begin{cases} 1 & \mathit{if}\ \max(0,(\left|V_i - V_{\min}\right| - (V_i - V_{\min})) + (\left|V_{\max} - V_i\right| - (V_{\max} - V_i))) = 0 \qquad i = 1,2,...n \\ -1 & \mathit{if}\ \max(0,(\left|V_i - V_{\min}\right| - (V_i - V_{\min})) + (\left|V_{\max} - V_i\right| - (V_{\max} - V_i))) > 0 \qquad i = 1,2,...n \end{cases} \tag{27}$$

Equation (26) has two parts. First part presents the square of deference of voltage of buses from 1 pu. Second part presents the relationship of violating the constraint. If VP becomes negative the constraints are violated.

II. Line loss reduction index (LLRI)

Diminishing losses is one of the main advantages of installing DG resources. To evaluate the efficiency of DG resources in reducing losses, LLRI is defined as in Eq. 28 [16].

$$LLRI_P = 1 - \frac{P_{Loss}^{WithDG}}{P_{Loss}^{WithOutDG}} \tag{28}$$

Similar equation stands for reactive power, as in Eq. 29 [16].

$$LLRI_Q = 1 - \frac{Q_{Loss}^{WithDG}}{Q_{Loss}^{WithOutDG}} \tag{29}$$

where $Q_{Loss}^{Without\ DG}$ and $Q_{Loss}^{With\ DG}$ are total reactive losses before and after installing DG resources. There are three possibilities:

1. LLRI<1: installing DG resources has a positive impact on loss reduction.
2. LLRI=1: installing DG resources has no impact on loss reduction.
3. LLRII>1: installing DG resources has a negative impact on loss reduction.

III. Level of Short-Circuit Index (LSCI)

Installing DG resources increases the short-circuit level of the network. The following index is presented to evaluate this amount of increase, as in Eq. 30.

$$LSCI = \left|\frac{I_{Sc}^{WithDG}}{I_{Sc}^{WithOutDG}}\right| \tag{30}$$

where $I_{SC}^{Without\ DG}$ and $I_{SC}^{With\ DG}$ represent the short-circuit current before and after installing DG resources.

This index should show the amount of variation in short-circuit level of the distribution network and the cases where the related constraint is violated, as in Eq. 31 and Eq. 32.

$$I_{Sc} = \sum_{i=1}^{n} I_{Sc,i} \times OC_i \tag{31}$$

$$OC_i = \begin{cases} 1 & \mathit{if}\ \max(0,(\left|I_{Switch,i} - I_{Sc,i}\right| - (I_{Switch,i} - I_{Sc,i}))) = 0 \qquad i = 1,2,...n \\ -1 & \mathit{if}\ \max(0,(\left|I_{Switch,i} - I_{Sc,i}\right| - (I_{Switch,i} - I_{Sc,i}))) > 0 \qquad i = 1,2,...n \end{cases} \tag{32}$$

Two situations may occur for I_{Sc}

1. $I_{Sc} > 0$: short-circuit level of all the buses is in allowable range
2. $I_{Sc} < 0$: short-circuit level of some buses isn't in allowable range

IV. Loading index

Since one of the main objectives of installing DG resources is deferring the developments of the substations, loading of the transformers should be calculated in the indices of siting and sizing. The amount of this reduction is related to the decided locations and capacities of DG resources. The index of the loading is therefore presented to evaluate the amount of loading of different elements of the power network. This index is defined as in Eq. 33.

$$IL_{Loading} = 1 - \frac{Loading_{After\ DG}}{Loading_{Before\ DG}} \tag{33}$$

In Eq. 33 $\text{loading}_{\text{Before DG}}$ and $\text{loading}_{\text{After DG}}$ present the amount of loading before and after installing DG resources. According to this equation three possibilities may occur.

1. IL > 0: installing DG resources has reduced the amount of the loading
2. IL = 0: installing DG resources has no impact on the amount of loading
3. IL < 0: installing DG resources has increased the amount of loading

PROPOSED METHOD

Case study

Actual power network of Zanjan Province is selected for simulation. Fig. 4 depicts the single line diagram of this network. In this network, G_1 bus is considered as Slack bus. The voltage value of this bus is 0.9625pu. G_2 is considered PV bus and the voltage value is 0.987pu. The produced power of this bus is 110MW. The active and reactive loads of this network are 288.55MW and 93.53MVar, respectively. Further information of this network is indexed in appendix.

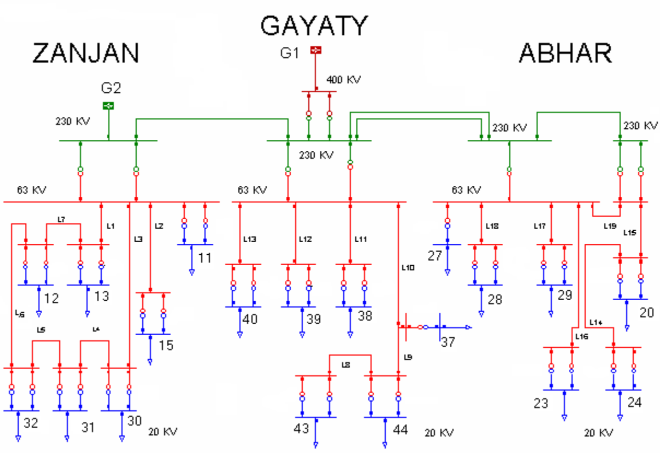

Fig. 4. Single line diagram of Zanjan Province network

Software

The proposed method and the sample network are simulated in DIgSILENT Power Factory 14.0.523 program. DIgSILENT program is an advanced software package for simultaneous analyzes of power network and control systems. This program is capable of calculating load flow; short-circuit level, active and reactive losses of the network and the parameters of the network. The main feature of this program is the ability of programming, which is called DPL (DIgSILENT Programming Language). Using this feature, applying the proposed method of this paper becomes very simple.

Optimization technique

In this paper, Genetic Algorithm is used to optimize the objective function. To optimize a problem, using the GA, a population is required to be defined at the first step. This population is formed by binary accidental quantization of chromosomes. In the next step, produced population is applied to the objective function and the fitness of chromosomes is obtained, using Eq. 34. Some of the best answers are chosen and new generation is produced by the genetic operators of crossover and mutation. In the first type, two gens, that should be combined, are placed beside each other and are divided from a specified point. Then, the sides that are placed in front of each other are combined together. In the second type, a percent of chromosomes are substituted by another value of their allowable confine, in order to make the optimization, global and not local. To have a global and the fastest answers, both of these genetic operators are used in this paper.

$$Fitness = \frac{1}{OF} \tag{34}$$

Proposed algorithm

Since most of the electrical power companies of Iran are interested in using the DG resources with capacities of 5, 10 and 15 MW, this paper consider these amounts as the possible capacities of DG resources. Using GA the best places and capacities are decided. The optimal number of DG resources are identified, using considered constraints. The details of the proposed method are presented in following steps.

1. DIgSILENT writes the zero in text file to flag the start the initial calculation. Detecting this flag, GA won't start the associated program.

DIgSILENT writes the matrix $\begin{bmatrix} 1 \\ n_{Vars} \\ Population\_size \end{bmatrix}$ in the text file. The first row is the flag that identifies the program that must start its operation. When the flag is set to 1, GA must run. n_{Vars} identifies the number of the chromosomes that are used by GA.

GA writes the matrix $\begin{bmatrix} 2 & L_1 & L_2 \ldots L_n & X_1 & X_2 \ldots X_n \end{bmatrix}$ in the text file. In this matrix L_1, L_2, … and L_n are the locations of DG resources and X_1, X_2, … and X_n are the capacities of DG resources. The flag 2 identifies that the DIgSILENT must starts its operation again.

2. After applying the obtained locations and places to DG resources, their technical and operational constraints are checked. If the constraints are satisfied, the program will go to the stage 6 and otherwise it will go to the stage 5.

If the obtained answers violate the constraints, the OF becomes zero and the program writes it in the $\begin{bmatrix} 3 & \\ & OF \end{bmatrix}$ of the text file and the program returns to the stage 3, otherwise it goes to the next stage.

In this stage F_1, $F_{2,i}$, $F_{3,i}$, $F_{4,i}$ are calculated. The program will go to the next stage if $F_{4,i}$ was not zero and otherwise it returns to stage 5. The value of the OF is calculated and written in the $\begin{bmatrix} 3 & \\ & OF \end{bmatrix}$ matrix of the text file.

3. If the number of iterations was fewer than the Population-Size, the program will retune to the stage 3. Otherwise, the last matrix of the sizes and locations is selected as the optimal sizes and locations.
4. GA writes the flag 4 in the text file to identify the end of process of DIgSILENT and GA.
5. The indices are calculated.

SIMULATION RESULTS AND DISCUSSION

In this paper, the optimal size and location of DG resources are decided in two cases. In the first case, the weighting coefficients are assumed to be equal and in the second case, the weighting coefficients are assumed to have different value. In the second case, the weighting coefficients of losses have a bigger value due to the importance of this parameter.

Case one: equality of weighting factors

Equality of the weighting coefficients shows that the relative importance of them is equal. Assuming $K_1 = K_2 = K_3 = 0.333$, Table I presented capacities and locations are obtained for DG resources.

According to the obtained values of Table I, it is clear that the constraints associated with the penetration level of DG resources are satisfied.

Fig. 5 depicts the voltage profile before and after installing DG resources for the first case.

TABLE I

Obtained capacities and locations for the first case

DG Locations	Produced active power of DG (MW)	Produced reactive power of DG (MVar)	Power factor
11	10	7.5	0.8
12	10	7.5	0.8
20	10	7.5	0.8
39	10	7.5	0.8
43	10	7.5	0.8
44	5	3.75	0.8
$\sum_{i=1}^{6} P_{DG,i} = 55MW$	$\sum_{i=1}^{6} Q_{DG,i} = 41.25MVar$	$DG_{Penetration} = 0.19$	

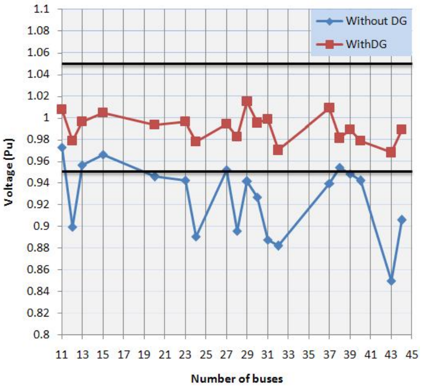

Fig. 5. The voltage profile before and after installing DG resources for the first case

It is clear from Fig. 5 that the voltage values of 16 buses are out of the allowable rang and only the voltage values of the buses 11, 13, 15, 27 and 38 are in the allowable range. After installing DG resources, voltages of all the distribution buses are in the allowable range. In this case, the voltage values of 9 buses are near the 1pu.

Fig. 6 shows the total active losses of the network, before and after installing DG resources for the first case.

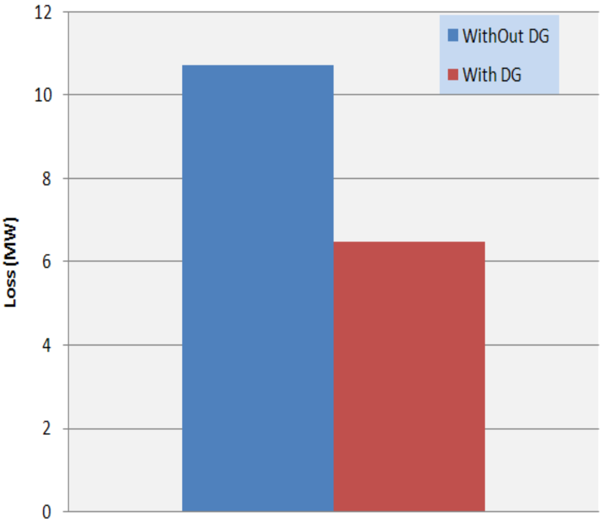

Fig. 6. Total active losses of the network after and before installing DG resources

TABLE II

Losses of 63 kV lines

Line number	Losses after installing resources (MW)	Reduction amount (MW)
L1	0.22	0.304
L2	0.1	0.023
L3	0.2	0.207
L4	0.182	0.141
L5	0.001	0.001
L6	0.13	0.201
L7	0.24	0.48
L8	0.48	0.78
L9	0.5	0.528
L10	0.46	0.34
L11	0.1	0.017
L12	0.21	0.029
L13	0.22	0.013
L14	0.35	0.029
L15	0.5	0.037
L16	0.51	0.01
L17	0.26	0.027
L18	0.37	0.143
L19	0.197	0.12

As it is shown in

Fig. 6, total loss of the network is 10.72MW, before installing DG resources. This value diminished to 6.47MW, after installing DG resources. Therefore, the total loss of the network is reduced 39.64%.

As depicted in Table II, 5.23MW of losses, after installing DG resources, is associated to the 63 kV lines and 1.23MW is associated to the other components of the network. The share of each 63 kV line, from losses, is identified in Table II. According to Table II, power losses of all 63 kV lines are diminished after installing DG resources.

As discussed in the previous sections, limiting the short-circuit level of the buses has a critical impact on avoiding the unnecessary changing of the circuit breakers. Therefore, the short-circuit level of the buses are allowed to be increased up to the endurable short-circuit level of the buses.

Fig. 7 illustrates the short-circuit level of the distribution buses, before and after installing DG resources.

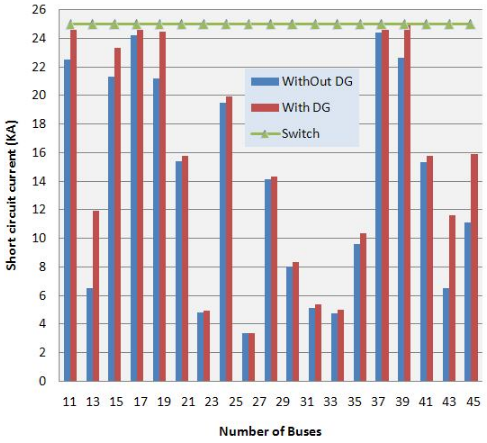

Fig. 7. Short-circuit current of the distribution network for the first case

TABLE III

Obtained capacities and locations for the second case

DG Locations	Produced active power of DG (MW)	Produced reactive power of DG (MVar)	Power factor
12	15	10.5	0.82
43	15	11.2	0.8
28	10	7.5	0.8
31	10	5	0.89
44	5	3.75	0.8

$$\sum_{i=1}^{5} Q_{DG,i} = 37.95MVar \qquad \sum_{i=1}^{5} P_{DG,i} = 55MW$$

$$DG_{Penetration} = 0.19$$

It is clear from

Fig. 7 that the short circuit of all the buses increases after installing DG resources. The buses, where DG units are installed, have the biggest amount of increase. The biggest amount of increase is for the bus 12, the short-circuit level of this bus increases from 6.52 kA to 11.92 kA, after installing DG resources. On the other hand, the least amount of increase is for the bus number 28. The short-circuit level of this bus increases from 3.36 kA to 3.38 kA, after installing DG resources. As it is clear from

Fig. 7, all the increases are in a sustainable range of the circuit breakers.

According to the simulation results, all the objectives of installing DG resources are satisfied, using the proposed algorithm.

Case two: difference in weighting factors

Since one of the major problems of electrical systems is power losses and it imposes a high expenditure to the electrical companies, reducing this parameter is of a great importance. Therefore, to reduce the power losses more, the related coefficient of this parameter is assumed to be bigger. It will have expected that by increasing the weighting coefficient, the power losses would have decreased more. In this case, the weighting coefficient of losses is assumed to be 0.5 and two other weighting coefficients are assumed to be 0.25. The optimal place and capacity of DG resources are obtained, using the proposed algorithm and assuming these weighting coefficients, as in the Table III.

In this case, the number of DG units is decreased to 5. The same as the previous case, all the constraints are also satisfied in this case.

Fig. 8. The voltage profile before and after installing DG resources for the second case

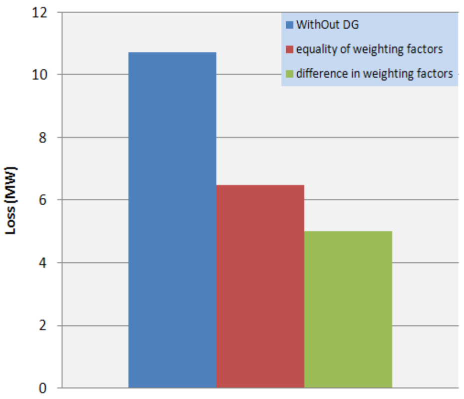

Fig. 9. Total active losses of the network after and before installing DG resources

Fig. 8 illustrates the voltage profile of the distribution network, before and after installing DG resources. As it is obvious, the voltage profile is improved in this case. Similar to the previous case, the voltages of all the buses are in the allowable range, after installing DG resources. The improvement of the voltage profile of this case is less than the previous case, due to reducing the related weighting coefficient.

The impact of installing DG resources on losses is presented in the Fig. 9. As illustrated in Fig. 9, power losses of the network are reduced to 5MW, after installing DG resources. This amount is 22.7% less than the first case and is 53.36% less than the state, before installing DG resources. As shown in Table IV, 4.555MW of this amount is in association with 63kV lines, which has 13.02% reduction, comparing with the first case.

The impact of installing DG resources on short-circuit level of buses is presented in

Fig. 10. Decreasing short-circuit weighting coefficients, in the second case, short-circuit current is expected to increase more.

TABLE IV
Losses of 63 kV lines

Line number	Losses after installing resources (MW)	Amount of reduction (MW)
L1	0.16	0.364
L2	0.09	0.033
L3	0.38	0.027
L4	0.28	0.043
L5	0.002	0
L6	0.25	0.081
L7	0.18	0.54
L8	0.29	0.97
L9	0.3	0.728
L10	0.24	0.56
L11	0.023	0.094
L12	0.18	0.059
L13	0.2	0.033
L14	0.36	0.019
L15	0.24	0.297
L16	0.51	0.01
L17	0.28	0.007
L18	0.5	0.013
L19	0.09	0.227

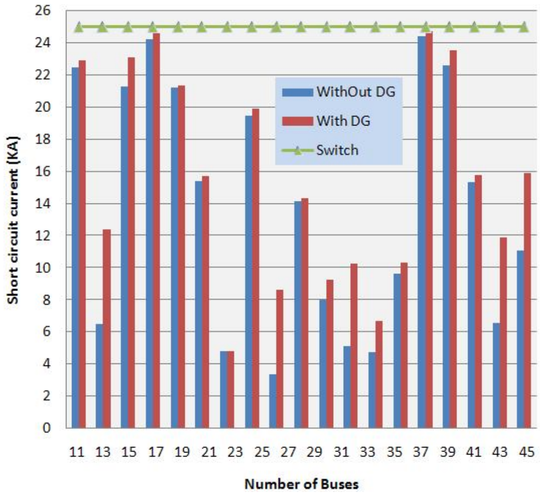

Fig. 10. Short-circuit current of the distribution network for the second case

Similar to the previous case, the maximum increase is for the buses where, DG units are installed. Buses 12, 28, 31, 43 and 46 with the increase values of 5.88, 5.27, 5.16, 5.36 and 4.81 kA have the most amount of increase, respectively. This figure also illustrates that the short-circuit level of the buses is within the sustainable range and no requirements for changing the circuit breakers are felt.

Calculating the indices of sizing and siting

The indices, introduced before, are calculated in this part. Table V, shows the values of voltage profile, losses and short-circuit level for both of the cases.

TABLE V: The indices for sited and sized DG resources

Equality in weighting factors (case 1)							
VPII			**LLRI**		**LSCI**		
$VP_{withOut\ DG}$	VP_{withDG}	VPII	$LLRI_P$	$LLRI_Q$	$I_{WithOut\ DG}$	I_{WithDG}	LSCI
- 0.2083	4.75×10^{-3}	0.22	0.39	0.38	260.44	289.11	1.11
Difference in weighting factors (case 2)							
VPII			**LLRI**		**LSCI**		
$VP_{withOut\ DG}$	VP_{withDG}	VPII	$LLRI_P$	$LLRI_Q$	$I_{WithOut\ DG}$	I_{WithDG}	LSCI
- 0.2083	0.133	0.64	0.53	0.41	260.44	296.044	1.13

The value of $VP_{WithoutDG}$ shows that the voltage profile was not in allowed range, before installing DG resources. The difference of the voltage profile from ideal value of 1pu, before installing DG resources, was too much. In both of the cases, VP_{WithDG} become a positive value after installing DG resources. Therefore, the voltage profile is improved significantly in both of the cases. This improvement is more significant for the first case, where the relative weighting coefficient had a higher value.

It can be also observed form the Table V that LLRI is 0.39, for the first case. For the second case, this index is increased to 0.53. Therefore, increasing the weighting coefficients has reduced losses more. The reactive losses also undergo the same procedures. This parameter has decreased 38% and 41% for the first and second case, respectively. An important point to mention is that, the parameter of reactive power has not inserted in the formulation, directly and the relationship between installing DG resources and reduction of lines current has brought about the reduction of reactive losses.

Table V also presents the short-circuit index. As the short-circuit index shows, the short-circuit lever of all buses is increased. Since the value of short-circuit index is positive, it can be concluded that the increase in the short-circuit level is within the sustainable range of circuit breakers. The values of this index are 1.11 and 1.13 for the first and the second case, respectively. Therefore, it has a less increase in the first case.

TABLE VI: Loading and loading index of 63 kV lines and transformers

Equality in weighting factors (case 1)							
	lines 63kV				**transformers 63 kV/20 kV**		
Number	**Loading** $_{\text{Before}}$	**Loading** $_{\text{After}}$	**IL**	**Number**	**Loading** $_{\text{Before}}$	**Loading** $_{\text{After}}$	**IL**
L1	35.05	24.39	0.304	**11**	35.24	18.7	0.469
L2	23.13	23.02	0.004	**12**	123.06	38.73	0.685
L3	17.94	16.09	0.103	**13**	28.93	28.62	0.01
L4	11.42	9.64	0.155	**15**	42.07	18.28	0.565
L5	4.73	3.13	0.338	**20**	37.9	18.28	0.517
L6	2.97	2.83	0.047	**23**	59.38	59.27	0.001
L7	19.16	9.55	0.501	**24**	89.15	87.9	0.014
L8	23.29	11.14	0.521	**27**	54.7	54.59	0.002
L9	36.56	19.05	0.478	**28**	62.65	62.52	0.002
L10	36.92	19.36	0.475	**29**	26.17	26.12	0.001
L11	19.37	19.23	0.007	**30**	23.91	23.66	0.01
L12	23.28	11.91	0.488	**31**	24.96	24.53	0.017
L13	19.95	19.79	0.008	**32**	25.13	24.64	0.019
L14	12.25	12.08	0.013	**37**	2.65	2.59	0.022
L15	33.08	21.81	0.34	**38**	35.24	34.97	0.007
L16	32.65	32.59	0.001	**39**	42.34	21.66	0.488
L17	14.39	14.36	0.002	**40**	72.57	72	0.007
L18	8.61	8.59	0.002	**43**	42.35	20.27	0.521
L19	6.78	6.74	0.005	44	48.41	28.76	0.405

Difference in weighting factors (case 2)					
	lines 63kV			**transformers 63 kV/20 kV**	
Number	**Loading** $_{\text{After}}$	**IL**	**Number**	**Loading** $_{\text{After}}$	**IL**
L1	16.46	0.53	**11**	34.8	0.012
L2	23.01	0.005	**12**	29.21	0.762
L3	7.61	0.575	**13**	28.4	0.18
L4	2.03	0.822	**15**	41.85	0.005
L5	4.68	0.01	**20**	37.84	0.001
L6	1.58	0.468	**23**	59.14	0.004
L7	4.91	0.743	**24**	89	0.001
L8	8.3	0.643	**27**	54.48	0.004
L9	15.48	0.576	**28**	39	0.377
L10	15.72	0.574	**29**	26.06	0.004
L11	19.26	0.005	**30**	23.01	0.037
L12	23.13	0.006	**31**	17.28	0.307
L13	19.82	0.006	**32**	23.18	0.077
L14	12.23	0.001	**37**	2.58	0.026
L15	33.03	0.001	**38**	35.02	0.006
L16	32.52	0.003	**39**	42.08	0.006
L17	14.33	0.004	**40**	72.11	0.006
L18	5.36	0.377	**43**	15.09	0.643
L19	4.55	0.328	**44**	28.52	0.41

Another important index, which is usually noticed in designing, is the index of the equipments loading. Table VI shows the loading index of the 63kV/20kV transformers and the 63 kV transmission lines, before and after installing DG resources and for both cases. As shown in Table VI, except transformer 12, the loading of all of the buses are in suitable conditions. The loading of this transformer was 102.06% before installing DG resources and the calculated indices show that the loading of the transformers and lines are reduced in both cases. In the first case, the loading of this transformer is reduced to 0.658 and in the second case, it is decreased to 0.762.

CONCLUSION

This paper presented an algorithm to identify the optimal place and locations of DG resources. In this algorithm the place, capacity and the optimal number of DG resources was decided, considering the parameters of voltage profile, loss reduction and short-circuit level. In addition, some indices were presented to evaluate the efficiency of installed DG resources. The proposed algorithm was tested on actual power network of Zanjan Province, considering two different cases for the weighting factors. It is also proven that increasing the weighting coefficient of a parameter has a significant impact on improving it. Simulation results have proven the efficiency of proposed method.

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APPENDIX

TABLE VII
Data for the 63 kV lines

Line number	Line length (km)	Active loss (MW)
L1	10.6	0.524
L2	4.5	0.123
L3	66.3	0.407
L4	84.15	0.323
L5	19.9	0.002
L6	51.5	0.331
L7	46.5	0.72
L8	40	1.26
L9	14	1.028
L10	11	0.8
L11	6	0.117
L12	8.3	0.239
L13	10.3	0.233
L14	45.3	0.379
L15	9	0.537
L16	11.3	0.52
L17	23.8	0.287
L18	116.6	0.513
L19	28.5	0.317

TABLE VIII
Data for the voltage, active power, and reactive power of distribution buses before installing DG

Bus number	Bus Voltage (pu)	Active Power (MW)	Reactive Power (MVar)
11	0.9726	21	7
12	0.8993	15.4	6.2
13	0.9561	15.4	6.2
15	0.9659	22.5	9.4
20	0.9456	20.5	6.5
23	0.9423	33	6.2
24	0.8905	11.6	2.7
27	0.9519	12	10
28	0.8955	8.2	1.9
29	0.9411	14.2	4.1
30	0.9268	6.5	1.4
31	0.8876	6.5	1.4
32	0.8818	6.5	1.4
37	0.9393	0.35	0.13
38	0.9541	19.2	6.2
39	0.9481	22.5	8.6
40	0.9418	19.2	7.2
43	0.8495	21	5
44	0.9055	13	2

TABLE IX
Short-circuit level, before installing DG resources and short-circuit level of CBs

Bus number	Short-circuit level, before installing DG resources (kA)	Short circuit level of the CB (kA)
11	22.5	25
12	6.52	25
13	21.31	25
15	24.2	25
20	21.22	25
23	15.4	25
24	4.8	25
27	19.49	25
28	3.36	25
29	14.12	25
30	8.01	25
31	5.11	25
32	4.76	25
37	9.62	25
38	24.43	25
39	22.62	25
40	15.34	25
43	6.54	25
44	11.09	25