Determining the optimal capacity and place of DGs using GA algorithm: voltage profile improvement and loss reduction

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***Abstract*-Applications of distributed generation (DG) are taken into account more seriously due to urban growth, ever-increasing need for electrical energy, and existing economic and placement constraints in installing new substations and power plants. Determining the optimum location and capacity of DG resources is an important consideration in obtaining the maximum efficiency. DGs' optimal place and size can be determined according to different parameters and through different methods. In this paper, these parameters are decided with respect to voltage profile improvement and system total loss reduction, considering different constraints and using Genetic Algorithm (GA). The proposed formulation is capable of determining the required number of DGs as well as their optimal place. Increasing the number of DGs more than the decided number not only stops the network parameters from improving, but also may result in lower network performance. This method was tested on an actual network in Zanjan province in Iran and simulation results indicate how efficient the method is.**

***Index Terms*—DG optimal location and size, distributed generation (DG), genetic algorithm (GA), loss reduction, objective function (OF), voltage profile**

I. INTRODUCTION

Using DG may have positive and negative impacts on network performance [1]. Some advantages of DG installations are reduced distribution and transmission costs, deferring the need for substation capacity improvement, reduced power transmission loss, improved voltage profile, improved system stability, and applicability of new and restorable energies [2],[3]. Thus, it can be predicted that DG resources will play a profoundly significant role in networks the near future. For this reason, designers regard them as the best way of solving the problem of electricity generation in the case of an energy disaster.

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Almost all of the so-called advantages will be obtained only if these resources are placed in optimal locations and have optimal capacities [3]. Thus, determining the best capacity and placement of distributed generation resources are crucial and should be identified according to desired objectives [4],[5].

So far, many studies have been carried out for this purpose, each with respect to its desired goals. Authors in [2] have determined the optimal place and capacity of DGs according to repetitive search. [3] has used a multi-objective function to make a trade-off between different parameters in terms of costs. Since DGs have different types, their best location and capacity can be determined accordingly [6]. Determining optimality can be performed according to unidirectional and bidirectional load flow to minimize loss [7]. In [4] DGs were placed in optimal locations to reduce loss only. [5] quantified loss reduction benefits in a radial distribution feeder with concentrated load to decrease system loss. [8] determined location of DGs using Genetic algorithm (GA). The main idea of [9] is taking into consideration the technical constraints of the network. It can be observed from the preceding discussion that there are some shortcomings in determining the best size and placement of DG resources. Almost all the mentioned works determined the place and capacity of DG resources to reduce network loss and did not take into consideration the other parameters of the network. Controlling the loss reduction parameter has always been efficient is setting the size and location of DG resources but this can't guarantee the improvement of other parameters in a large network. This problem demonstrates the need for considering more parameters so that the optimization process becomes more efficient. To avoid the sophistication seen in other papers, this paper proposes a simple and multi-objective function which is aimed at improving voltage profile, reducing loss, and considering different constraints. The proposed function is also capable of deciding the number of DG resources, which was usually done manually by the designer.

The objective function is optimized using GA and the optimal location and size of DGs for an actual network is set. Some of the constraints taken into account include the maximum active power produced by a DG, DGs' maximum capacity, and the limits involved in exploiting a synchronous generator. This method was applied to an actual network where the best place and capacity of two DGs were determined with respect to the aforementioned parameters. Simulation results show that setting the optimum location and size of DGs by means of Genetic Algorithm can reduce network loss and improve voltage profile.

II. GENETIC ALGORITHM

Genetic algorithm is an evolutionary method which involves regarding all control variables as a single chromosome, producing an initial population, and then assessing it. Unlike other methods, this algorithm can optimally determine the place and capacity of more than one DG simultaneously. It is often used to optimize a function with different variables [7].

The objective function in this paper is voltage profile and total network loss and it is optimized in relation to different constraints.

III. DEFINING THE OBJECTIVE FUNCTION OF THE PROBLEM

To determine the best place and capacity of DGs, an objective function must be defined for Genetic Algorithm. The objective function in most papers is based on just one parameter. In this paper, however, the objective function is proposed on the basis of voltage profile improvement and loss reduction. Relative importance of each parameter is determined according to its weighting factor. Therefore, the capacity and place of DGs are optimally set via the following equation.

$$Min(f(W_P \times F_P + W_V \times F_V)) \quad (1)$$

Where F_P represents the loss reduction resulting from installing DG resources and is calculated for the entire network through equation below [9]:

$$F_P = \frac{P_{Loss}^{WithOutDG} - P_{Loss}^{WithDG}}{P_{Loss}^{WithOutDG}} \quad (2)$$

Where F_V is the sum of all voltage deviations up to 1Pu:

$$F_V = \sum_{i=1}^{n} \left|1 - V_{Level,i}^{WithDG}\right| \quad (3)$$

Where W_P and W_V are the weighting factors which are selected by the designer which show the relative importance of the associated parameter. The absolute values of the weights assigned to all impacts should add up to one as shown in the following equation [9]:

$$W_P + W_V = 1 \quad (4)$$

IV. CONSTRAINTS TAKEN INTO CONSIDERATION

Optimizing the objective function requires that many constraints be considered. This paper takes into account the following:

A. *The maximum active and reactive power produced by a DG*

Although DG exploitation can have many economical benefits, these benefits are significant only when the active and reactive power produced by a DG is less than network load [7].

$$\sum_{i=1}^{x} PG_i < PD \quad (5)$$

$$\sum_{i=1}^{x} PG_i < PD \quad (6)$$

B. *DG penetration level*

This constraint is applied so that the number of DG resources can be determined. Ignoring this and the previous constraint may result in reverse power flow and cause some problems for protective devices. DG penetration level is assumed to be 0.2.

C. *DG's maximum capacity*

This constraint puts the DG capacity at a lower level than the specified limit and is considered as below [7]:

$$CG_i < CG_{max} \quad (7)$$

where CG is the production capacity of each DG unit.

D. *Exploiting synchronous generator*

Limitations of synchronous generators are presented in this section [7].

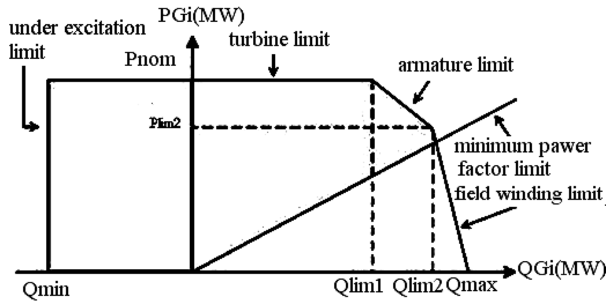

Figure 1- Constraint of exploiting a DG with a capacity of 1 MVA

As is clear Figure 1, the active and reactive power produced by a synchronous generator is determined by its operation curve. This curve shows the operation points of the synchronous generator, the mechanical constraint of the turbines, the winding constraint of armatures, thermal limits of windings, and under-excitation conditions of generators. The exploitation of a DG unit with a capacity of CG MWs can be expressed through the following equations:

$$PG_i < P_{Nom} \times CG \quad (8)$$

$$QG_i < Q_{min} \times CG \quad (9)$$

$$PG_i < \frac{P_{Nom} - P_{Lim2}}{Q_{Lim1} - Q_{lim2}}(QG_i - Q_{Lim1} \times CG) + P_{Nom} \times CG \quad (10)$$

$$PG_i < \frac{P_{lim2}}{Q_{lim2} - Q_{max}}(QG_i - Q_{max} \times CG) \quad (11)$$

$$PG_i \geq 0 \quad (12)$$

$$PG_i \geq QG_i \times \frac{PF_{Min}}{\sqrt{1 - PF_{Min}^2}} \quad (13)$$

E. *Voltage Level*

The voltage variation range in all buses must be between 0.95-1.05 (Pu) [9].

$$V_{min} \leq V_{Level}^{WithDG} \leq V_{max} \quad (14)$$

Since the electrical companies are interested in exploiting DG resources with a high power factor, the minimum power factor is assumed to be 0.8.

Penalty function is used to account for the impact of different constraints in the OF via adding an extra function to the main OF as $\lambda.P(x)$. This function punishes inappropriate answers [7], [10].

V. CASE STUDY

To study the proposed method, Zanjan Province network in Iran is simulated in DIGSILENT. Figure 2 illustrates the single-line diagram of this network. In this study, G_1 which is located at the 400kV bus and has a voltage of 0.9625 Pu is considered as the slack bus; G_2 with a voltage of 0.987 Pu as the PV bus.

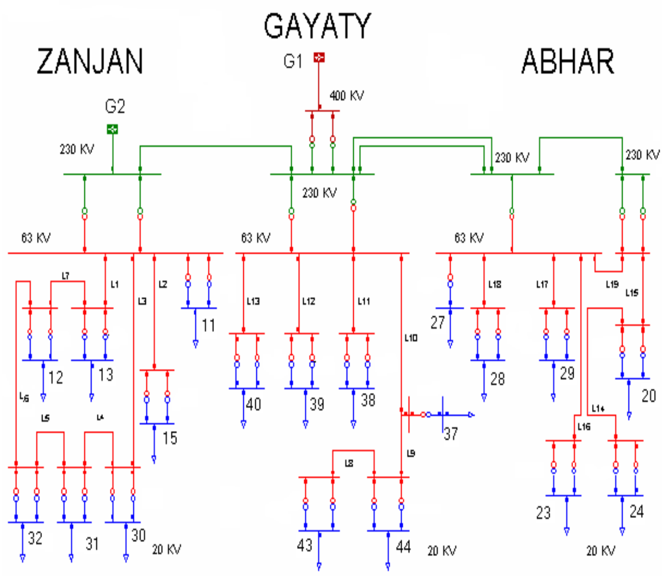

Figure 2- Single-line diagram of Zanjan Province network

Table I shows the data of distribution buses (bus voltage, active power, and reactive power) before installing DGs. It can be seen from this table that the total network loss is 10.72 MW before installing DGs. Since the DG capacities desired by electrical companies are 5, 10, or 15 MW, this paper concentrates on employing DG resources with these capacities.

Table I
Data of distribution buses before installing DGs

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	202.5	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

VI. SIMULATION RESULTS

The results show that after installing DG resources the penetration level of the DGs will be 0.19 percent, which is less than the considered penetration level. Another advantage is that the problem of reverse power flow will not be encountered. So the DGs taken into consideration will improve the parameters of the network while will not causing any problem for the network. Table II summarizes the results obtained by installing different DGs.

Table II
Results of installing different DG resources

	DG capacity (MW)	DG capacity (MVAR)	DG power factor
Placing the first DG	15	11.25	0.8
Placing the second DG	15	11.25	0.8
Placing the third DG	10	7.5	0.8
	DG place (Bus number)	Total network loss (MW)	Percentage of loss reduction
Placing the first DG	31	9.44	11.94
Placing the second DG	44	7.78	16.52
Placing the third DG	43	6.33	18.63

As it is shown in the table, after installing three DG resources, the network total loss is reduced to 6.33 MW, denoting a drop of 40.95 percent. Since this paper aims to find the number of required DG resources, it should be noted that after installing the third DG, the penetration level of DG resources will exceed the constraint of penetration level which was 0.2. In addition, the power factor for all DG resources is within the limitation of the third constraint.

Figure 3 depicts the influence of installed DG resources on voltage profile of the network. Before installing DG resources, only 5 of the 19 buses were within the allowable limit as far as voltage profile is concerned, but after installing DG resources the voltage profile improves in all buses.

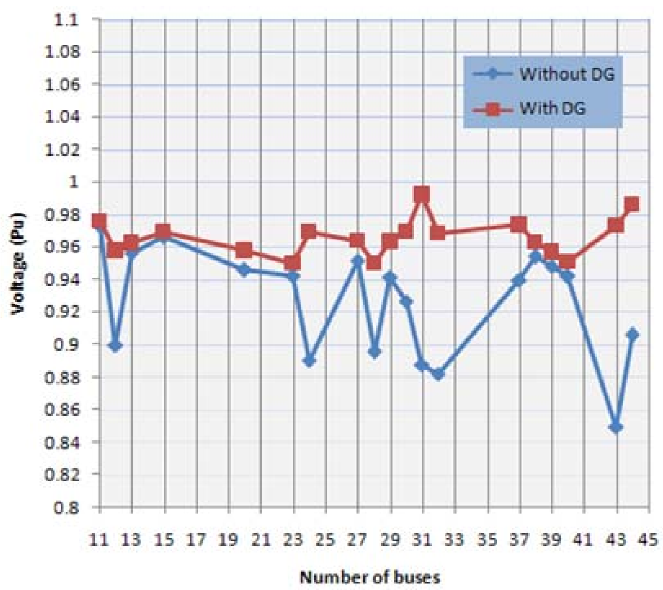

Figure 3- Voltage profile, before and after installing three DG resources

VII. CONCLUSIONS

The present paper, while considering different constraints, determined the place, capacity, and the required number of DG resources. The proposed formulation is capable of being applied to any network and of setting the place of DG resources without the need for sophisticated formulations.

The method was applied to an actual network in Zanjan Province, with the simulation results showing improved voltage profile and reduced total network loss. The method can also determine the required number of DG resources so that no problem is caused for the network.

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