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OPTIMAL SIZING AND SITING OF DG RESOURCES AT 63KV/20KV SUBSTATIONS CONSIDERING THE EFFECT OF EARTHQUAKE ON TECHNICAL AND ECONOMIC PARAMETERS*

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Abstract– The Iranian Ministry of Energy commands the Regional Electrical Companies to install DG resources at 63kV/20kV substations and at the end of 20kV lines. The first and foremost challenge in installing these resources is deciding on the optimal place and capacity of these resources. This paper is aimed to propose an appropriate algorithm for siting and sizing such resources in Bakhtar Regional Electrical Company. The proposed algorithm takes into consideration all technical and economic factors important to the company. Due to the variety of important factors in sizing and siting, this paper proposes a new method to reduce limitations and constraints of this process. Accordingly, all technical and economic factors are assigned monetarily, so violating limitations reduces considered benefits. This method increases the probability of convergence of results and accordingly is appropriate for application in actual network where there are numerous factors. Another feature of this paper is considering the parameter of earthquake for the first time and is assigned monetarily according to its devastating effects on considered parameters. Applying this parameter while sizing and siting leads to increase in distributed generation impacts in reducing customer outage in locations with high probability of earthquake. The obtained results are reported and discussed.

Keywords– Distributed generation, siting, sizing, cost-to-benefit ratio, earthquake

1. INTRODUCTION

In the last decade, innovations in technology, environmental changes, and economic developments have drawn attention to Distributed Generation (DG) resources. The application of these resources can bring about many advantages such as voltage control, power quality and reliability improvement, loss reduction, energy saving, and deferring the necessity of development of substations [1-4]. Accordingly, DG has become an appropriate solution to the problem of generating and supplying electrical power from the point of view of designers [5].

The most critical issue in exploiting DG resources is sizing and siting them [1]. Without appropriate sizing and siting, the considered benefits cannot be derived [2]. In addition to the technical issues of installing DG, there are economic issues, which are becoming more important as a result of the creation of electrical markets. Improving the technical parameters of the network is not possible without economic justification. This means that sizing and siting necessitates a balance between technical and economic parameters.

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Many studies have addressed the issues of siting and sizing of DG resources which are reviewed in [6]. Analyzing different papers, it is obvious that power loss reduction has often been considered as an objective in most studies [6, 7]. Studies [8-12] are examples of papers which considered power loss reduction as a single objective of sizing and siting DG. Some other studies which are associated with power loss reduction have considered load uncertainties in sizing and siting process [13-15]. Studies [16, 17] have suggested another type of single objective sizing and siting which includes the purpose of increasing the penetration level of DGs in distribution networks. Although single purpose on sizing and siting process may result in improvement of the associated objective, it is likely to affect other parameters adversely. Thereby, the best answer is not acquired using these kinds of methods. Accordingly, studies [4, 18-20] aimed at power loss reduction and voltage profile improvement, [21-23] are aimed at power loss reduction, maintaining short-circuit level, and voltage profile improvement, and the algorithms proposed by [24, 25] for siting and sizing DGs considered loss reduction, and voltage profile and reliability improvements. Generally, these studies only considered technical aspects of sizing and siting process and had not considered economic aspects. In order to consider economic factors, authors in [26] selected the optimal types, sizes, and locations of DG resources, taking account of investment, maintenance, and operational costs. Also, study [27] has considered simultaneous sizing and siting DGs along with energy storages and having purposes of reducing costs of investment, operation, maintenance, and pollutant emission. Methods suggested in [26, 27] neglect technical factors of the network and are contemplated only in economic issues and cost reduction purposes. To solve this problem, [3, 28] used a multi-objective formulation in order to maximally balance the costs of improving the network, power loss, energy expected but not supplied, and the power purchased from the transmission network. As it is clear, these studies have neglected some important parameters such as voltage profile and short-circuit level of network. On the other hand, authors in [29, 30] presented some indices, such as the power loss index, and voltage profile index, in order to evaluate the efficiency of installed DG units.

This paper proposes a new approach for sizing and siting DG units which can solve defects and problems of previous studies. Since considered factors in sizing and siting are numerous, in order to increase convergence of answers and have the best answers, all technical and economic factors are assigned monetarily according to appropriate indices. Thereby, violating limitations reduces considered benefits and are not a barrier to achieving optimal answers. Since installing DG units enhances the reliability of the networks, it should also be considered in earthquake-prone areas. Accordingly, another feature of this paper is considering the parameter of earthquake for the first time and is assigned monetarily according to its devastating effect on DG units. Applying this parameter while sizing and siting leads to increase in DG impacts in reducing customer outage in locations with high probability of earthquake. In order to prove the efficiency of proposed method it is applied and tested on Bakhtar Regional Electrical Company (BREC) in Iran.

The rest of the paper is organized as follows. In section II, the new method and the proposed formulation are presented. Section III describes sample network, software, optimization technique, the algorithm used to identify the optimal number of DGs, and some assumptions are considered. Finally, section IV summarizes the simulation results and provides a brief discussion.

2. NEW METHOD

The Objective Function (OF) constitutes the benefit and cost of installing DG resources in 63/20 kV substations and is defined as Eq. (1) below:

$$Min\,(CBR) = \frac{Cost_{DG}}{Benefit_{DG}} \tag{1}$$

The purpose is to minimize the ratio of the cost of DG installation ($Cost_{DG}$) to the benefits derived from installation ($Benefit_{DG}$). Cost factors include cost of initial investment (C_1), maintenance cost (C_2), operational cost (C_3), and cost of replacing the circuit breaker (C_4). The benefit factors include purchasing less power from the transmission network (B_1), loss reduction (B_2), voltage profile improvement (B_3), deferring substation capacity development (B_4), and the benefit lost due to earthquake (B_5). Equation (1) is thus turned into Eq. (2) below:

$$Min(CBR) = \frac{C_1 + C_2 + C_3 + C_4}{B_1 + B_2 + B_3 + B_4 - B_5} \tag{2}$$

All the factors are assigned monetary values for a year.

a) Modeling of DG installation costs

1. Cost of Initial Investment (C_1): The annual cost of investing in DG units ($) is calculated using Eq. (3).

$$C_1 = \sum_{i=1}^{N_{DG}} F_C \times S_{DG,i} \times \cos\varphi_i \times A_{PB} \tag{3}$$

where F_c is the initial cost of purchasing and installing DG units ($\frac{\$}{MVA}$), $S_{DG,i}$ is the power produced by the i^{th} DG (MVA), $\cos\varphi_i$ is the power factor of i^{th} DG unit, N_{DG} is the total number of DG units, and A_{PB} is the factor of assigning money which is calculated using Eq. (4) [3].

$$A_{PB} = \frac{r(1+r)^n}{(1+r)^n - 1} \tag{4}$$

where r is the interest rate, and n is the length of time the investment is expected to yield profit.

2. Maintenance costs (C_2): DG units require maintenance and cannot operate continuously for an entire year. Maintenance costs are divided into two parts: the cost of maintaining DG units and the benefit which is not acquired while maintaining. The cost of maintaining DG units is calculated using Eq. (5).

$$C_2 = \sum_{i=1}^{N_{DG}} C_M \times S_{DG,i} \times \cos\varphi_i \tag{5}$$

where C_M is the cost of maintaining a DG unit for a year ($\frac{\$}{MVA}$).

An important issue which has not been considered in most previous research is the benefit which is not acquired while the DG unit is out of service. Since the benefit obtained mostly depends on the existence and operation of the DG unit, almost no benefit is acquired while the DG units are out of service.

3. Operational costs (C_3): Operational costs in non-renewable technologies come from the fuel used for generating electrical power [31]. Since the DG units used in this research are gas-fired reciprocating engines, the operational cost ($\frac{\$}{kWh}$) is equal to the cost associated with the gas consumed by these units and is calculated through Eq. (6).

$$C_o = \frac{B \times F_o}{HV \times R} \tag{6}$$

where B is the coefficient of changing the Kcal to kWh (equaling 860), F_O is the cost of the natural gas ($\frac{\$}{m^3}$), HV is the thermal value of the natural gas ($\frac{kCal}{m^3}$), and R is the efficiency of the DG unit (%). Placing C_o in Eq. (7), we can calculate the annual operational cost of the DG units.

$$C_3 = \sum_{i=1}^{N_{DG}} C_o \times S_{DG,i} \times \cos\varphi_i \times 10^3 \times (8760 - h_{main,i}) \quad (7)$$

where $h_{main,i}$ is the length of time when the DG unit is out of service, 8760 is the total number of hours in a year, and 10^3 coefficient is used to change kWh into MWh.

4. Cost of replacing the circuit breakers (C_4): Since installing DG units increases short-circuit level of network, it is effective in proposed method for sizing and siting DGs in this paper [22]. This increase may cause problems if the short-circuit level of the buses exceeds that of the circuit breakers (CBs). If this happens, the CBs must be replaced. The annual cost of replacing CBs is calculated using Eq. (8).

$$C_4 = A_{PB} \sum_{i=1}^{N} C_{Switch,i} \quad (8)$$

where N is the number of 20kV buses, and $C_{Switch,i}$ is the cost of replacing the i^{th} CB.

b) Modeling the benefits obtained from DG installation

1. The Benefit of Purchasing Less Power from the Transmission Network (B_1): Electrical companies have to purchase power from the transmission network. However, installing DG units will allow them to obtain some of the power they need from these resources. The benefit obtained from purchasing less power from the transmission network (B_1) considering maintenance time of DGs is calculated through Eq. (9).

$$B_1 = \sum_{i=1}^{N_{DG}} S_{DG,i} \times \cos\varphi_i \times E_P \times (8760 - h_{main,i}) \quad (9)$$

where $S_{DG,i}$ is the power produced by the i^{th} DG (MVA), and E_P is the price for electricity ($\frac{\$}{MWh}$).

2. The benefit resulting from loss reduction (B_2): The annual benefit obtained from reducing power loss for one year is calculated using Eq. (10) [31].

$$B_2 = (P_{Loss}^{WithoutDG} - P_{Loss}^{WithDG}) \times E_P \times 8760 - \sum_{i=1}^{N_T} DP_{Loss,i} \times E_P \times h_{main,i} \quad (10)$$

where, $P_{Loss}^{WithoutDG}$ and P_{Loss}^{WithDG} are the power loss in the absence and presence of DG units respectively, and $DP_{Loss,i}$ is the amount of change in the loss when the i^{th} DG is out of service.

3. The benefit obtained from improving voltage profile (B_3): Given the fact that the voltage is regulated by tap changes, installing DG units can reduce the number of tap changes in transformers, thus increasing transformer lifetime. The decrease in the number of transformer taps in order to make the voltage profile close to 1(pu) is calculated from Eq. (11).

$$DT = N_{Tap}^{WithoutDG} - N_{Tap}^{WithDG} \quad (11)$$

where $N_{Tap}^{Without\,DG}$ and $N_{Tap}^{With\,DG}$ are the number of taps required to regulate the voltage profile before and after installing DG resources, respectively.

The monetary benefit obtained from improving voltage profile as a result of DG installation (B_3) can be calculated using Eq. (12). In this equation, $C_{invt,ij}$ is the cost of each substation transformer, DT_{ij} is the change in the number of taps of i^{th} substation and j^{th} transformer, Tap_{Max} is the maximum number of taps allowed for each transformer, N_s is the number of 63/20 kV substations, N_{Tr} is the number of i^{th} substation transformers, 8760 is the total number of hours in a year, and $h_{main,ij}$ is the length of time when a DG unit connected in i^{th} substation is out of service.

$$B_3 = A_{PB}.0.55\sum_{i=1}^{N_S}\sum_{j=1}^{N_{Tr}}\frac{DT_{ij}}{Tap_{Max,ij}}C_{T,ij}\times(\frac{8760-h_{main,ij}}{8760}) \quad (12)$$

4. The benefit obtained from deferring substation capacity improvement (B_4): The necessity of improving substation capacity can be deferred by installing DG resources. Accordingly, maximum loading of the substation before a DG unit is added can be calculated through Eq. (13).

$$P_{SMax}=P_{DMax}(1+\alpha)^K \quad (13)$$

where P_{DMax} is the peak load of the substation, α is the growth rate of the load, and K is the number of years under consideration. Once a DG unit is installed, maximum loading of the substation can be calculated from Eq. (14).

$$P_{SMax}=P_{DMax}(1+\alpha)^K(1-\gamma) \quad (14)$$

where γ is the ratio of the capacity of the DG unit to the peak load of the substation. Eq. (15) is used to calculate how long substation capacity improvement can be deferred.

$$\Delta T=\frac{Log(\frac{1}{1-\gamma})}{Log(1+\alpha)} \quad (15)$$

where ΔT is the length of time substation capacity improvement can be deferred. The annual benefit obtained from deferring improving the capacity of a 63/20kV substation is calculated via Eq. (16).

$$B_4 = A_{PB}\sum_{i=1}^{N_S}C_{invt,i}.N_{Tr,i}\left[1-\left[\frac{1+IF}{1+r}\right]^{\Delta T}\right] \quad (16)$$

where A_{PB} is the factor of assigning money (calculated from Eq. (4)), and IF is the annual inflation rate.

5. The benefit lost due to earthquake (B_5): As is clear in Fig. 1, if an earthquake occurs at point 2, the DG resources installed at points 1 and 3 will be damaged and go out of service. This means that part of the expected benefit will not be obtained.

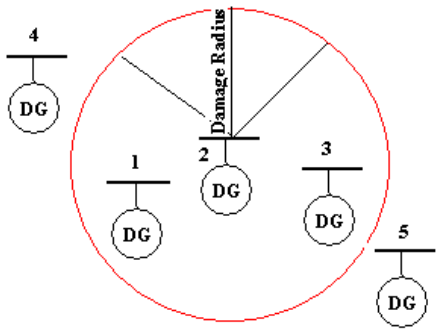


Fig. 1. Earthquake damage radius

The cost of the damage to a bus (i) as a result of an earthquake is calculated using Eq. (17).

$$C_{Ei}=D_i\times P_{Ei} \quad (17)$$

where D_i is the cost ($) of the damage caused by an earthquake to bus i, and P_{Ei} is the probability of an earthquake occurring at bus i. D_i can be further classified as increased power loss (DP_{Lossi}), degraded voltage profile (DV_i), increased power purchase from upper hand network (DA_i), and DG repair or replacement cost (Dd_i). Eq. (18) gives the calculation.

$$D_i = DP_{Loss,i} + DV_i + DA_i + Dd_i \quad (18)$$

The factors associated with D_i are considered for a year and can be obtained from equations in previous parts.

The maximum yearly cost of the damage associated with earthquakes (B_5) is obtained by multiplying maximum cost ($Max(C_{Ei})$) of the damage caused to each bus by the probability of an earthquake occurring in the region where the considered network is located (P_N). Eq. (19) shows this.

$$B_5 = P_N \times Max\ (C_{Ei}) \tag{19}$$

P_N is the probability of earthquakes occurring in region.

c) Constraints of the problem

Two constraints are considered in this paper and are presented below.

1. The constraint of coordination between demand and generation at each bus: Since the electrical companies in Iran are not allowed to send power from downstream networks to upstream networks to avoid changing the protection settings of the networks, the capacity of installed DG resources should be less than the demand from an associated bus.

2. Earth constraint: This constraint is considered because this paper is the result of an investigation performed on an actual network (BREC). There is not enough space for installing DG resources in some substations. This problem is exacerbated in substations located in urban areas. The substations which do not have enough space for installing DG resources are omitted from the sizing process.

3. PROPOSED METHOD

a) Case study and simulation setup

The method proposed in this paper was applied to the BREC in Iran. This network includes the electrical networks of three provinces of Markazi, Hamedan, and Lorestan. It has 97 substations which are 63/20 kV (See Appendix for a graphical representation, Fig. 5). Table presents some information about this network. More information can be found in Table 10 in Appendix. In addition, the proposed method and the BREC network were simulated in DIgSILENT Power Factory 14.0.523 program. Further information about this software is presented in [32].

Table 1. Specifications of the BREC network

Province	Number of 20-kV buses	Active load (MW)	Losses(MW)
Markazi	35	692.6	16.85
Hamedan	33	631	22.84
Lorestan	29	475.3	12.04
Total	97	1798.9	51.75

b) Optimization technique

Referring to study [6] most sizing and siting studies are carried out using Genetic Algorithm (GA). Studies [22, 27, 33] are such studies that have used this algorithm for sizing and siting DGs in recent years. Since efficiency of this approach for sizing and siting is proven, in this work GA was used to optimize the objective function. Further information about GA and its operators are presented in [22].

c) Determining the optimal number of DG units

Determining how many DG units should be installed in a network is vitally important, and any miscalculation could have an adverse effect on network parameters. The present paper proposes an algorithm for this purpose. The following steps are involved:

1. DG units are installed at all 20kV buses of the network.

2. The GA algorithm determines the optimum capacities of the DG units.
3. If the determined capacity is smaller than the minimum capacity (10MW), the determined capacity is replaced with zero.
4. If the determined capacity is larger than the maximum capacity (25MW), the determined capacity is replaced with the latter.
5. If the determined capacity is larger than the nominal load of the bus, the determined capacity is replaced with the latter.
6. If the determined capacity is for a substation where there is not enough space, the capacity is replaced with zero.
7. The OF is calculated using Eq. (2).
8. Step two is repeated until the designer is satisfied.

d) Assumptions

1. The capacity of DG units: *As the BREC aims to install gas reciprocating DG units with the capacities of 10 MW up to 25 MW and steps of 5 MW, the capacity of the DG units are assumed to be these values.*

2. The cost of replacing the CBs: It is assumed that the CBs in need of replacement are replaced with 25 kA switches, at a cost of $ 430,022.

3. Maximum allowed tap (Tap Max): According to the research carried out in the Azerbaijan Regional Electrical Company (AREC) in Iran, 63kV/20kV transformers start to malfunction at about 200,000 taps. This number was taken in the present study as the allowable number of transformer taps.

4. The amount of voltage change in each tap: Each tap is assumed to be capable of changing the voltage profile by 2.5% [34].

5. The power factor of the resources: Since the BREC is interested in generating active power due to the problem of lack of active power, it is assumed that the DG units work at unitary power factor and generate active power only.

6. Cost of transformers: Table 11 in Appendix presents the cost of transformers at 63/20 kV substations of the BREC.

7. Substations lacking enough space: According to the information provided by the BREC, some substations (including substations 2, 10, 14, 22, 39, 45, 58, 66, 76, and 81) do not have enough space for installing DG resources.

8. The probability of earthquake occurrence: This probability is 43.785% for the BREC. This factor for each of the substations in BREC is presented in Table 12 in Appendix.

9. Earthquake damage radius: According to the information obtained from the Geology Institute in Iran, the damage radius of an earthquake is assumed to be 40 Km.

10. The growth rate of the loads: The growth rates of the loads in BREC are presented in Table 13 in Appendix.

Other sizes for OF parameters are presented in Table 14 in Appendix. All the preceding information was obtained from the BREC.

4. SIMULATION RESULTS

Table 2 summarizes the results of applying the proposed method to the BREC network. As can be seen, the optimal number of DG units to be installed in the BREC network is 56. Of these, 15 units are installed in Lorestan Province (generating 230 MW), 19 units in Hamedan Province (generating 330 MW), and 22

units in Markazi Province (390 MW). Altogether, the DG resources generate 950 MW of electricity. All capacities are within the allowed ranges.

Table 3 presents the annual values of benefit and cost factors. As it is shown the value of the presented OF would be 0.361, so the total amount of the benefit to be obtained is 2.7 times as large as that of cost. This proves the efficiency of the proposed method. The benefit of voltage profile improvement is given a minus sign, indicating that the numbers of taps which are used for changing the impact of voltage profile into dollar are more than the state before installing the resources.

Table 2. Obtained capacity and location of DG resources

Location	Capacity (MW)	Location	Capacity (MW)	Location	Capacity (MW)	Location	Capacity (MW)	Location	Capacity (MW)
1	15	21	0	41	20	61	25	81	0
2	0	22	0	42	10	62	0	82	10
3	25	23	25	43	10	63	20	83	10
4	25	24	0	44	0	64	0	84	15
5	15	25	20	45	0	65	25	85	0
6	25	26	10	46	10	66	0	86	20
7	0	27	25	47	0	67	20	87	10
8	10	28	15	48	10	68	20	88	0
9	20	29	10	49	25	69	15	89	20
10	0	30	0	50	10	70	15	90	0
11	10	31	0	51	0	71	0	91	0
12	0	32	0	52	25	72	10	92	0
13	0	33	15	53	20	73	15	93	0
14	0	34	15	54	15	74	0	94	0
15	25	35	15	55	0	75	0	95	25
16	0	36	0	56	0	76	0	96	15
17	25	37	25	57	20	77	15	97	0
18	10	38	0	58	0	78	25		
19	25	39	0	59	10	79	0		
20	10	40	0	60	10	80	10		

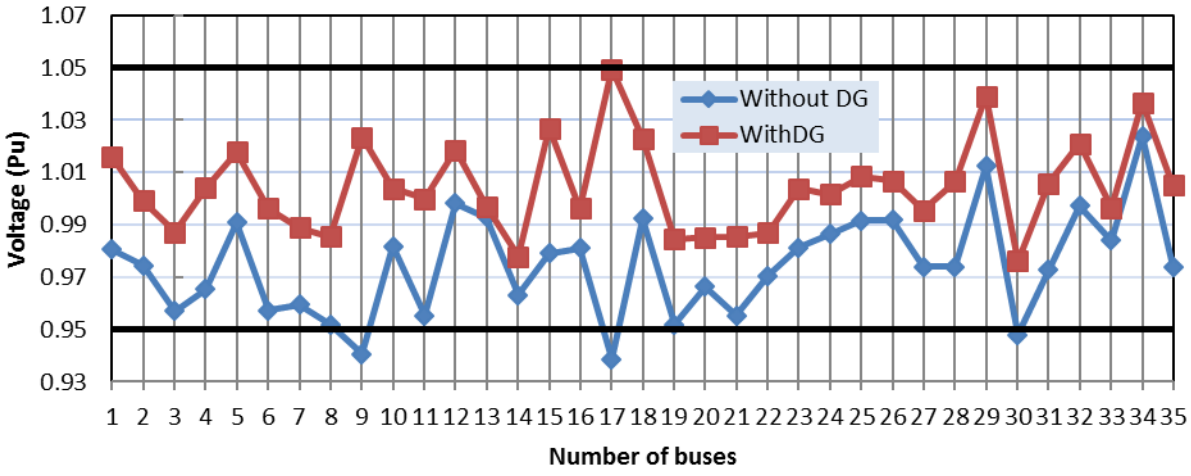
Table 3. Annual values of benefit and cost factors

Annual cost factors ($)		Annual benefit factors ($)	
Initial investment	82435117.49	Purchasing less power	226575000
Repair cost	8835	Power loss reduction	7112240
Operational cost	1699312.5	Voltage profile improvement	-1.3123
Changing CBs	3440176	Deferring improving the capacity of the substations	1598776
Total	87583441	Lost benefit at the time of an earthquake	7148084.92
		Total	242434099.6

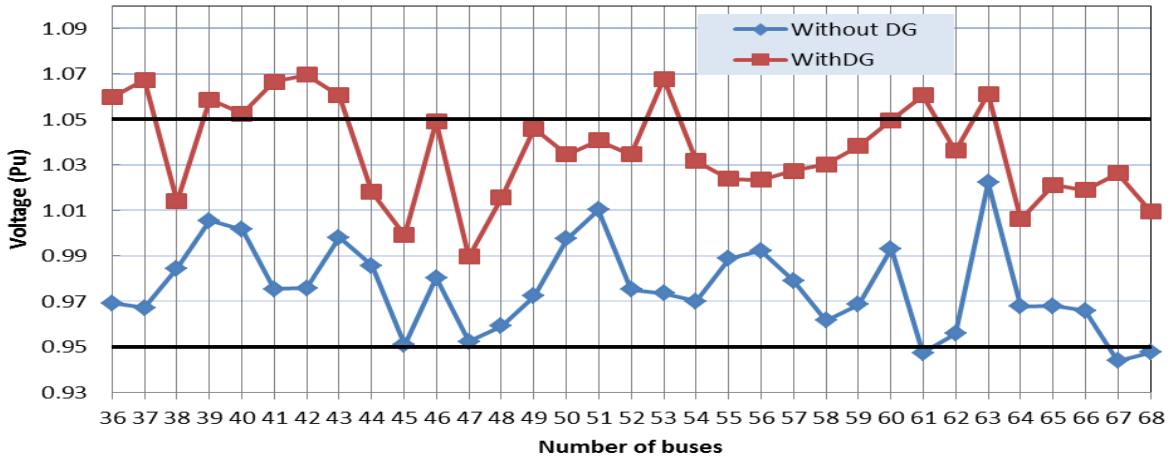
Since Iran is rich in natural gas resources, gas prices are cheap in this country. This issue may affect the OF and reduce its value. So, considering the results in Table 3, operation cost is 1.94% of the overall cost. According to Eq. (7) where F_o and C_3 have a direct relationship, it can be concluded that the natural gas price has an impact of 1.94% on the total cost. This indicates the low impact of gas prices on the OF and the chosen algorithm, because 98.06% of the impact is resulted from other parameters. Hence, it is concluded that with low cost of gas in Iran, the value of OF and the proposed algorithm are not diminished.

Figure 2 depicts the voltage profile of the 20kV buses for the three provinces. This table is before applying transformer taps. As is apparent, DG resources had a positive impact on voltage profile in

Markazi Province. Also, all the buses in this province have their voltage profiles within the allowable range. This did not hold true for the other provinces, where, according to Table 4, installing DG resources resulted in using more taps in transformers.



(a)



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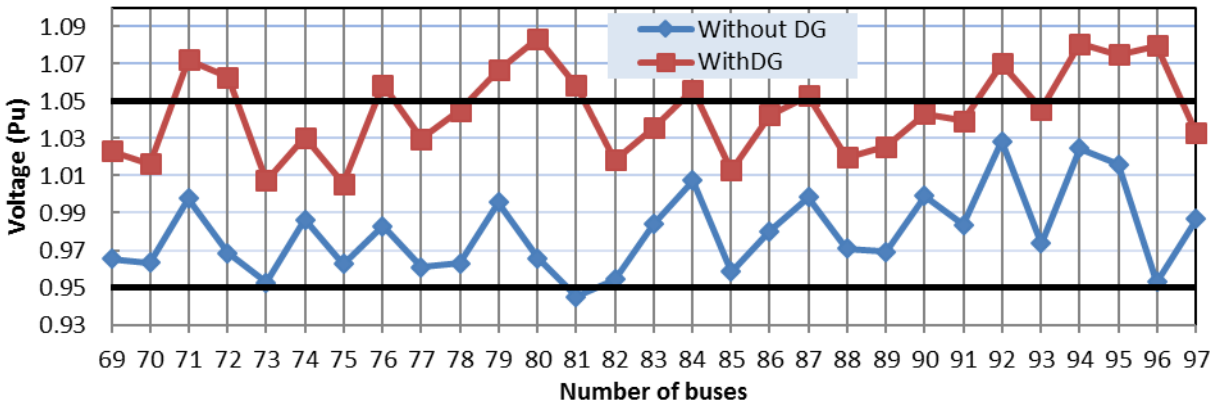


(c)

Fig. 2. Voltage profile of 20 (kV) buses for Markazi Province (a), Hamedan Province (b), Lorestan Province (c)

Table 4. Changes in the number of taps used in transformers for 20kV buses
(a) Markazi Province

Bus number	The number of taps used in transformers before DG installation	The number of taps used in transformers after DG installation	Benefit obtained ($)
1	1	0	0.14062
2	1	0	0.14062
3	2	0	0.5625
4	1	0	0.375
6	2	0	0.5625
7	2	0	0.28125
8	2	0	0.5625
9	2	1	0.28125
10	1	0	0.28125
11	2	0	0.28125
14	2	1	0.14062
15	1	1	0
16	1	0	0.28125
17	2	2	0
18	0	1	-0.375
19	2	1	0.28125
20	2	1	0.28125
21	2	1	0.1875
22	1`	1	0
23	1	0	0.28125
24	1	0	0.28125
27	1	0	0.28125
28	1	0	0.14062
29	0	1	-0.28125
30	2	1	0.14062
31	1	0	0.14062
32	0	1	-0.1875
33	1	0	0.28125
34	1	1	0
35	1	0	0.14062
		Sum	5.48434

(b) Hamedan Province

Bus number	The number of taps used in transformers before DG installation	The number of taps used in transformers after DG installation	Benefit obtained ($)
36	1	2	-0.28125
37	1	2	-0.28125
38	1	0	0.14062
39	0	2	-0.28125
40	0	2	-0.5625
41	1	2	-0.1875
42	1	2	-0.1875
43	0	2	-0.5625
45	2	0	0.5625
46	1	2	-0.28125
47	2	0	0.28125
48	2	0	0.5625
49	1	2	-0.28125
50	0	1	-0.28125
51	0	2	-0.5625
52	1	1	0
53	1	2	-0.14062
54	1	1	0
55	0	1	-0.0937
56	0	1	-0.28125
57	1	1	0
58	2	1	0.14062
59	1	1	0
60	0	2	-0.5625
61	2	2	0
62	2	1	0.14062
63	1	2	-0.28125
64	1	0	0.28125
65	1	1	0
66	1	1	0
67	2	1	0.28125
68	2	0	0.5625
		Sum	-2.15621

Table 4 continued.

(c) Lorestan Province

Bus number	The number of taps used in transformers before DG installation	The number of taps used in transformers after DG installation	Benefit obtained ($)
69	1	1	0
70	1	0	0.28125
71	0	3	-0.28125
72	1	2	-0.5625
73	2	0	0.5625
74	0	1	-0.28125
75	1	0	0.14062
76	0	2	-0.375
77	1	1	0
78	1	2	-0.28125
79	0	2	-0.5625
80	1	3	-0.28125
81	2	2	0
82	2	1	0.14062
83	0	1	-0.28125
84	0	2	-0.375
85	2	0	0.5625
86	1	2	-0.28125
87	0	2	-0.5625
88	1	0	0.1875
89	2	1	0.28125
90	0	2	-0.0937
91	1	2	-0.0937
92	1	3	-0.5625
93	1	2	-0.0937
94	1	3	-0.5625
95	0	3	-0.8437
96	2	3	-0.14062
97	0	1	-0.28125
		Sum	-4.64043

Table 5. Power loss and the power purchased before and after DG installation

Power loss before DG installation (MW)	Power loss after DG installation (MW)	Benefit obtained from power loss reduction ($)	Power purchased before DG installation (MW)	Power purchased after DG installation (MW)	Benefit obtained from purchasing less power from the transmission network ($)
51.753406	24.816908	7112240	1850.65	873.72	226575000

Table 6. Total network loss before and after DG installation in Markazi Province (a), Hamedan Province (b), and Lorestan Province (c)

(a)

Power loss before DG installation (MW)	Power loss after DG installation (MW)	Amount of loss reduction (%)
16.858400	9.561772	43.28

(b)

Power loss before DG installation(MW)	Power loss after DG installation(MW)	Amount of loss reduction (%)
22.845792	9.703585	57.53

(c)

Power loss before DG installation(MW)	Power loss after DG installation (MW)	Amount of loss reduction (%)
12.049214	5.551551	53.93

As observed in Table 1, Markazi Province is considered an industrial province with a high demand for electricity. The voltage profile in this province had a worse condition than the other two provinces before installing DG resources. After installing DG units capable of generating 390MW of electricity, the

voltage profile of this province was placed within the allowable range, and use less transformer tapping for regulating voltage profile ($V \cong 1(pu)$). On the other hand, in the other provinces, the voltage profile exceeded the allowable range although a smaller number of DG resources were installed. So the electrical companies of Hamedan and Lorestan Provinces have to use more transformers tapping for regulating voltage profile, compensating overvoltage, and placing the voltage profile within the allowable range.

The number of transformer taps of 20kV buses in the provinces is presented in Table 4. The benefit not obtained is given a minus sign. The loss due to using more transformer taps is subtracted from other benefits. As it was discussed, installing DG resources in Markazi Province in Iran was more beneficial than other two provinces. The purpose of regulating voltage is making it as close as possible to 1(pu). According to Table 4, installing DG reduced transformer taps in Markazi Province, but in the two other provinces it increased usage of transformer taps.

Table 5 shows power loss and the power purchased from the transmission network before and after installing DG resources. Also, Table 6 presents the power loss in three provinces before and after installing DG resources. It is apparent that power loss and purchased power were reduced after DG resources were installed. These benefits are calculated considering maintenance time for DGs. Considering this time interval increases accuracy compared with other similar studies. It should be pointed out that since DG resources are installed near loads, power loss decreases significantly. According to Table V, after installing DG resources, the value of power loss decreased more than 50 %.

The loadings of 63/20 kV substations of the BREC in the provinces under study are depicted in Fig. 3. The loadings diminished significantly when DG units were installed. This was especially so for substation 61 of Hamedan Province where loading was 92.94%, violating the BREC's allowable range of 90 %. Hence, at this substation, capacity needed to be improved before DG installation. However, installing these resources made this improvement unnecessary. Once DG resources were installed, the loading of this substation dropped to 33.15% and the need for capacity improvement was deferred for two years.

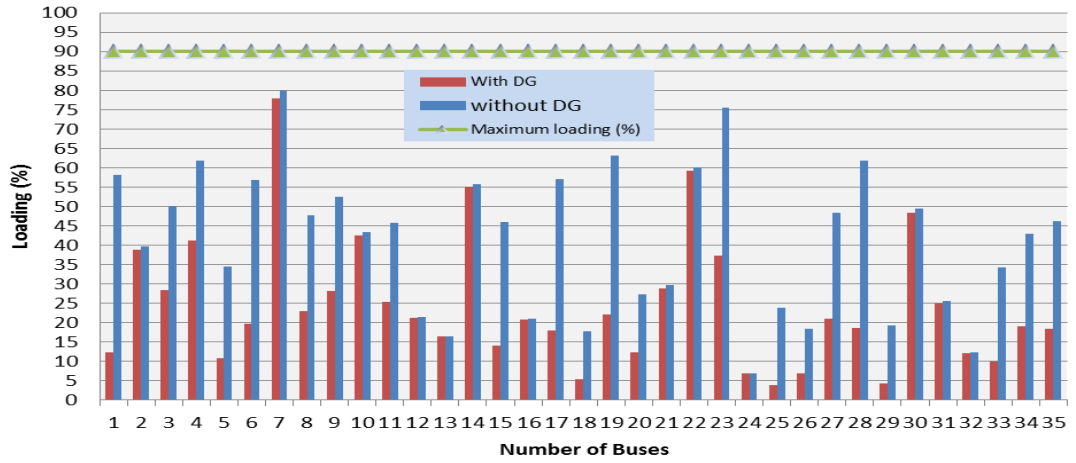
The length of deferment for Bakhtar substations are given in Table 7. Installation of DG resources resulted in $ 1,598,776 worth of benefit applying average deferment of 1.5 years for all 97 substations of BREC network. Indeed, installing DG resources in substations reduces the amount of loading and therefore defers the need for necessity of developing their capacity. This issue also increases reliability of system because it increases the ability to maneuver on system.

Table 3 shows that changing the CBs requires $ 3440176. This means that the increase in short-circuit level was not within allowable range for some of the buses and that the CBs of those buses must be changed. The short-circuit level of 20kV buses of the three provinces is depicted in Fig. . From the values of the short-circuit level of the 20kV buses and the rating values of the CBs it is clear that five buses in Markazi Province, one bus in Hamedan Province, and two buses in Lorestan Province violated the constraint. The annual cost of replacing these breakers equals $ 3440176.

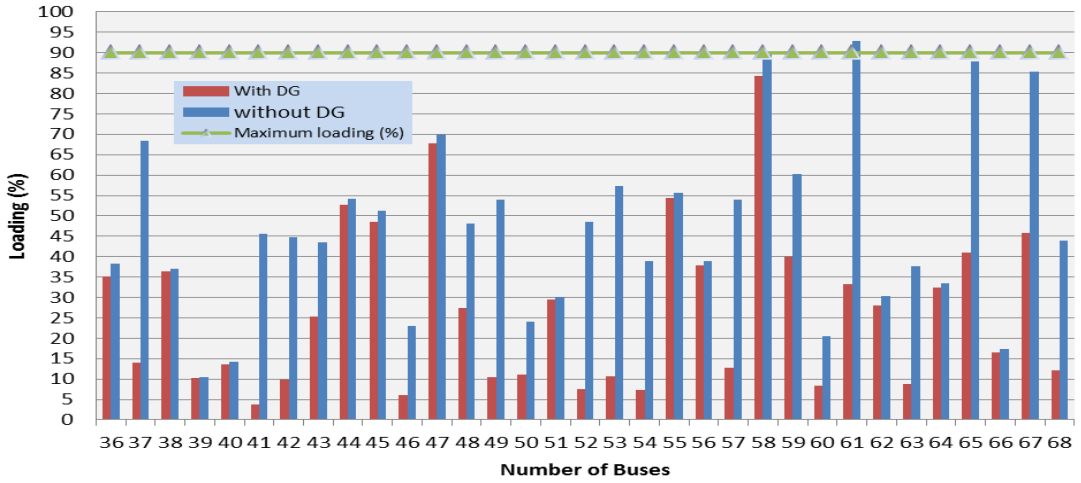
Figure 3 also shows that the short-circuit levels of some CBs changed drastically once DG units were installed. This is because the cooperation of DGs in supplying faults. Thus, the BREC had to change the CBs of different buses so that they were appropriate for the post-installation short-circuit level. A total of 8 buses in the BREC network were changed, Table 8.

The preceding method makes it unnecessary to purchase new CBs. This means that the factor of cost of buying new CBs would be zero and that the cost of installing and using DG resources is reduced. Therefore, the value of the presented OF would be 0.347, and it follows that the obtained benefits outstrip the costs 2.88 times.

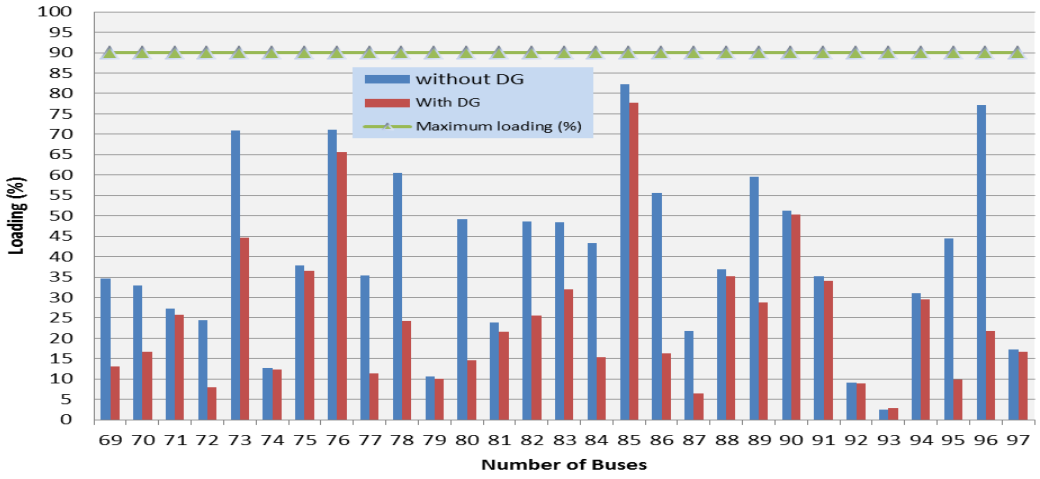
Figure 3. Loadings of BREC substations in Markazi Province (a), Hamedan Province (b), Lorestan Province (c)". I sent you Figure 3 in attached file. Please put this figure according to original file of the paper which I sent you in attached file.



(a)

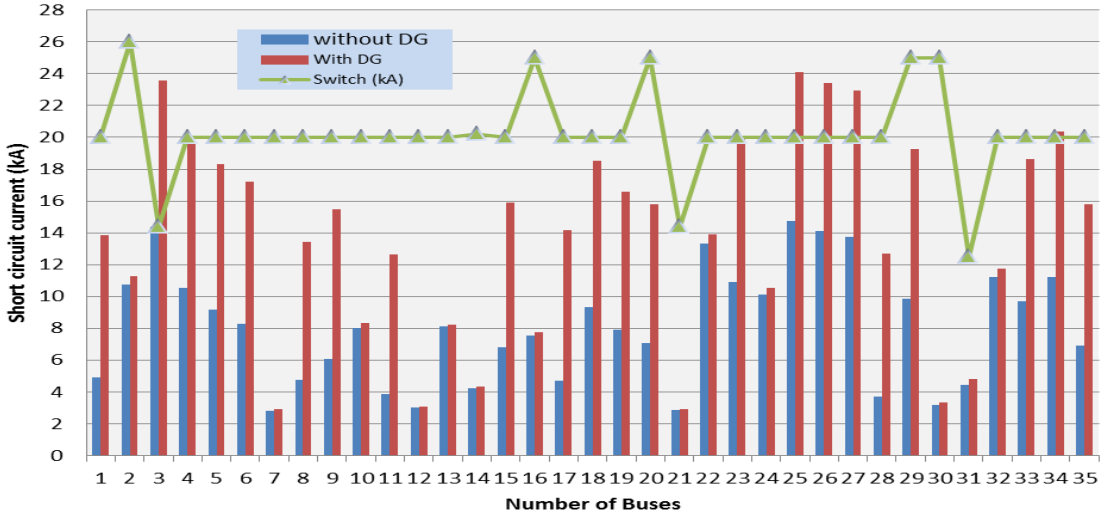


(b)

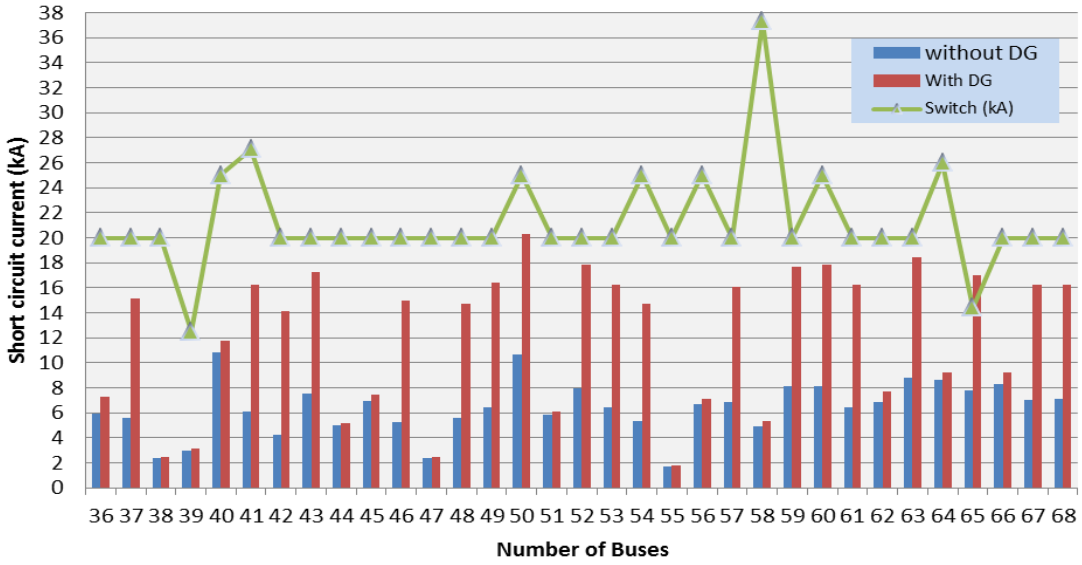


(c)

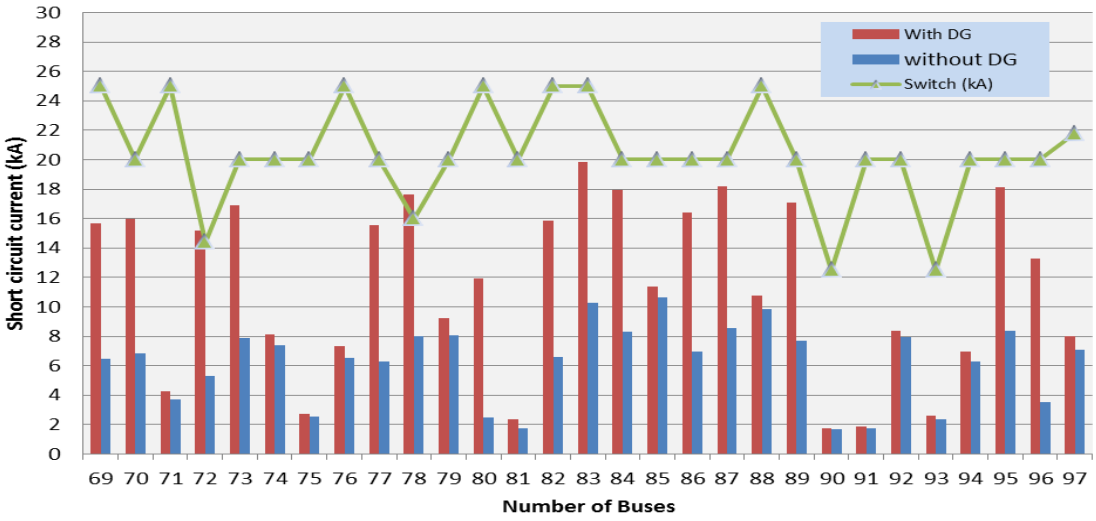
Fig. 3. Loadings of BREC substations in Markazi Province (a), Hamedan Province (b), Lorestan Province (c)



(a)



(b)



(c)

Fig. 4. The short-circuit level of 20kV buses in

Markazi Province (a), Hamedan Province (b), and Lorestan Province (c)

Table 7. Length of deferment and the benefit obtained

Substation number	Length of deferment (Year)	Annual benefit obtained from deferment($)	Substation number	Length of deferments (Year)	Annual benefit obtained from deferment ($)	Substation number	Length of deferments (Year)	Annual benefit obtained from deferment ($)
1	3.154632	27648.15	36	0	0	71	0	0
2	0	0	37	3.572608	28386.9	72	1.91561	25516.65
3	1.603914	37491.96	38	0	0	73	0.9423518	23906.23
4	1.854457	42356.3	39	0	0	74	0	0
5	1.963413	42662.05	40	0	0	75	0	0
6	2.319414	43669.2	41	5.285466	31511.63	76	0	0
7	0	0	42	1.998255	25656.04	77	2.002187	25662.68
8	2.513164	13266.76	43	0.6847586	23489.73	78	2.662568	26791.03
9	2.884844	27176.51	44	0	0	79	0	0
10	0	0	45	0	0	80	1.731111	25206.96
11	4.299957	29695.12	46	1.655611	25080.82	81	0	0
12	0	0	47	0	0	82	1	24000
13	0	0	48	3.299418	13951.48	83	0.7080646	23527.24
14	0	0	49	1.950674	25575.74	84	3.596484	28429.39
15	5.436773	31794.82	50	2.031685	25712.53	85	0	0
16	0	0	51	0	0	86	2.487679	26489.73
17	2.523591	26551.46	52	2.785024	27003.05	87	2.089886	25811.05
18	1.780164	42148.5	53	2.32193	26205.82	88	0	0
19	2.580315	26649.11	54	3.323141	27944.81	89	3.57204	28385.89
20	1.584962	24963.09	55	0	0	90	0	0
21	0	0	56	0	0	91	0	0
22	0	0	57	2.717436	26885.92	92	0	0
23	1.386247	24633.58	58	0	0	93	0	0
24	0	0	59	0.5292014	23240.22	94	0	0
25	4.181855	44221.17	60	3.267738	27847.1	95	4.569885	30187.73
26	1.712815	41960.6	61	1.804754	25330.33	96	1.940451	25558.51
27	1.261041	61067.99	62	0	0	97	0	0
28	3.16568	27667.55	63	2.766358	26970.67			
29	2.856978	27128.03	64	0	0			
30	0	0	65	2.001405	25661.36			
31	0	0	66	0	0			
32	0	0	67	0.8596753	23772.1			
33	1.82214	25359.5	68	2.511439	26530.56			
34	1.072568	24118.34	69	2.082837	25799.11			
35	2.293079	26156.57	70	3.557681	28360.35			

Table 8. Changing CBs

The number of the bus whose short-circuit level was violated after DG units were installed	The number of the bus whose CB was changed
3	2
25	16
26	20
27	29
34	30
65	64
72	71
78	76

Another factor innovatively added to the OF is the earthquake factor. According to this factor, the DG units are so placed that the least possible damage is caused during an earthquake. For this purpose, the impact of an earthquake on voltage profile, the power purchased from the transmission network, power losses, and the cost of the damage to the resources were calculated. The maximum harm from an earthquake is for buses 82, 83, 86, 87, and 88. The amount of damage to each of these buses is shown in Table 9.

Table 9. Maximum damage from an earthquake

Location of earthquake	Other damaged buses	Lost power (MW)	Amount of increase in power loss (MW)	Cost of increase in power loss($)	Cost of voltage profile degrading ($)	Cost of increase power purchasing($)	Cost of damage to resources($)	Total damages($)
82	82-83-86-87-88	50	0.2296865	61728.3	0.79688	11925000	4338690.39	16325419.49

Multiplying the damages from this table by the probability of an earthquake occurring in a region (43.785%), the lost benefit is obtained and placed in the OF (B_5). This value equals $ 7148084.92 and is deducted from other values.

5. CONCLUSION

This paper proposed a method for optimizing the process of siting and sizing DG resources. The method takes into consideration the technical and economic parameters and assigns monetary values to all the factors using appropriate indices. This method increases the probability of convergence of results and accordingly is appropriate for application in actual network where there are numerous factors. In addition, since Iran is located in an earthquake-prone area and given the salient role of DG in the future of Iran's electrical industry, the earthquake factor was innovatively included in the OF. Results show that this factor effects about $0.8M of the process of siting and sizing DG resources in this paper. In addition, since the optimal number of installed DGs has been a problem in previous studies, this paper proposed a method to indicate it. The proposed method of sizing and siting, and deciding optimal number of DGs, was applied to 97 buses of the BREC, and all the costs and values were based on the information obtained from this company. The simulation results showed the proposed method to be efficient. Applying this method on case study, 56 optimal locations for installing DG with total capacity of 560 MW are identified. Applying these locations and capacities, the network power loss and purchase of power from upstream network have reduced more than 50 %. In addition, the voltage profile of most buses are in permitted range and loading of all substations is deferred for average duration of 1.5 years and the benefit of 1,598,776 $ is acquired. The application of this method to the network caused the benefit of the BREC to be 2.88 times more than the expenses the company incurs. It should be mentioned that acquired benefit is calculated after considering all actual assumptions such as considering maintenance time for DGs. Thereby, according to results, the proposed approach is a practical one which can be used for sizing and siting DGs on any network and considering any factors.

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APPENDIX

Table 10. Peak load of each 63/20kV BREC substation

Location	Max Load (MW)	Location	Max Load (MW)	Location	Max Load (MW)	Location	Max Load (MW)	Location	Max Load (MW)
1	16.8	21	8.4	41	20.5	61	35	81	6
2	22.4	22	35.5	42	13	62	13	82	20
3	36.9	23	40	43	26	63	22.7	83	25.5
4	34.2	24	3.5	44	9.6	64	17	84	16.2
5	20	25	21	45	27	65	33	85	49
6	40	26	14	46	13.5	66	10	86	23.5
7	9.5	27	41.5	47	9.5	67	44	87	12.5
8	12	28	16.7	48	11.1	68	24	88	19.2
9	23	29	11.5	49	31.4	69	18.6	89	21.7
10	25	30	13.9	50	13	70	16	90	2.5
11	10.5	31	6.6	51	9.1	71	5.4	91	3.3
12	3	32	6.5	52	28	72	13	92	4.6
13	9.6	33	20	53	25	73	36.6	93	0.2
14	15.5	34	26	54	16.4	74	7.3	94	19
15	25.5	35	18.7	55	5.5	75	4.8	95	26
16	11	36	21.5	56	23	76	26.1	96	20
17	30	37	27	57	23.2	77	19.5	97	9.6
18	13.9	38	5.2	58	21	78	30		
19	35	39	1.4	59	32	79	5.2		
20	15	40	8.4	60	11	80	14		

Table 11. The cost of transformers of 63/20 kV

The capacity of the transformer (MVA)	Cost($)
5	100000
10	200000
15	300000
20	400000
25	500000
30	600000
35	700000
40	800000

Table 12. The probability of an earthquake occurring at each 63/20kV BREC substation

Location	P_{Ei}	Location	P_{Ei}	Location	P_{Ei}	Location	P_{Ei}	Location	P_{Ei}
1	0.00375	21	0.00375	41	0.005	61	0.00666	81	0.00375
2	0.00375	22	0.005	42	0.005	62	0.00666	82	0.00375
3	0.00375	23	0.005	43	0.00375	63	0.00375	83	0.005
4	0.00375	24	0.005	44	0.00375	64	0.005	84	0.005
5	0.00375	25	0.005	45	0.005	65	0.005	85	0.005
6	0.00375	26	0.005	46	0.00375	66	0.005	86	0.005
7	0.00375	27	0.005	47	0.00375	67	0.005	87	0.005
8	0.00375	28	0.00375	48	0.005	68	0.005	88	0.00666
9	0.00375	29	0.00375	49	0.005	69	0.00666	89	0.00666
10	0.00375	30	0.00375	50	0.00375	70	0.00666	90	0.00375
11	0.005	31	0.005	51	0.005	71	0.00375	91	0.00375
12	0.005	32	0.00375	52	0.00375	72	0.00375	92	0.00375
13	0.00375	33	0.00375	53	0.00375	73	0.005	93	0.00375
14	0.00375	34	0.00375	54	0.00375	74	0.005	94	0.005
15	0.00375	35	0.00375	55	0.00375	75	0.005	95	0.005
16	0.00375	36	0.00375	56	0.00375	76	0.00666	96	0.00375
17	0.00375	37	0.005	57	0.00375	77	0.00666	97	0.005
18	0.00375	38	0.00375	58	0.005	78	0.00666		
19	0.005	39	0.00375	59	0.005	79	0.0666		
20	0.00375	40	0.00375	60	0.005	80	0.00375		

Table 13. The growth rate of each 63/20kV BREC substation

Location	α	Location	α	Location	α	Location	α	Location	α
1	1.03	21	1.037	41	1.019	61	1.002	81	1.3
2	1.03	22	1.042	42	1.083	62	1.137	82	1
3	1.025	23	1.029	43	1.032	63	1.159	83	1.02
4	1.03	24	1.17	44	1.05	64	1.2	84	1.062
5	1.026	25	1.071	45	1.44	65	1.03	85	1
6	1.03	26	1.078	46	1.26	66	1.2	86	1.15
7	1.037	27	1.078	47	1.16	67	1.024	87	1.16
8	1.04	28	1.058	48	1.015	68	1.041	88	1
9	1.026	29	1.04	49	1.26	69	1.2	89	1.04
10	1.02	30	1.029	50	1.058	70	1.18	90	1
11	1.03	31	1.16	51	1.22	71	1.083	91	1
12	1.04	32	1.33	52	1.23	72	1.15	92	1.33
13	1.1	33	1.14	53	1	73	0.75	93	1.25
14	1.093	34	1.23	54	1.097	74	1.15	94	1.05
15	1.061	35	1.027	55	1.25	75	1.055	95	1.04
16	1.035	36	1.027	56	1.072	76	1.061	96	1.043
17	1.034	37	1.072	57	1.073	77	1.08	97	1.06
18	1.042	38	1.15	58	1.071	78	0.96		
19	0.625	39	1.23	59	1.03	79	1.42		
20	1	40	1.01	60	1.083	80	1.062		

Table 14. Other considered values and costs

$C_M(\frac{\$}{MW})$	n(Year)	$F_C(\frac{\$}{MW})$	IF(%)	r (%)
9.3	15	462000	15	17
R(%)	h_{main}(hour)	$E_P(\frac{\$}{MWh})$	$F_0(\frac{\$}{m^3})$	HV $(\frac{kCal}{m^3})$
45	810	30	0.005	8600

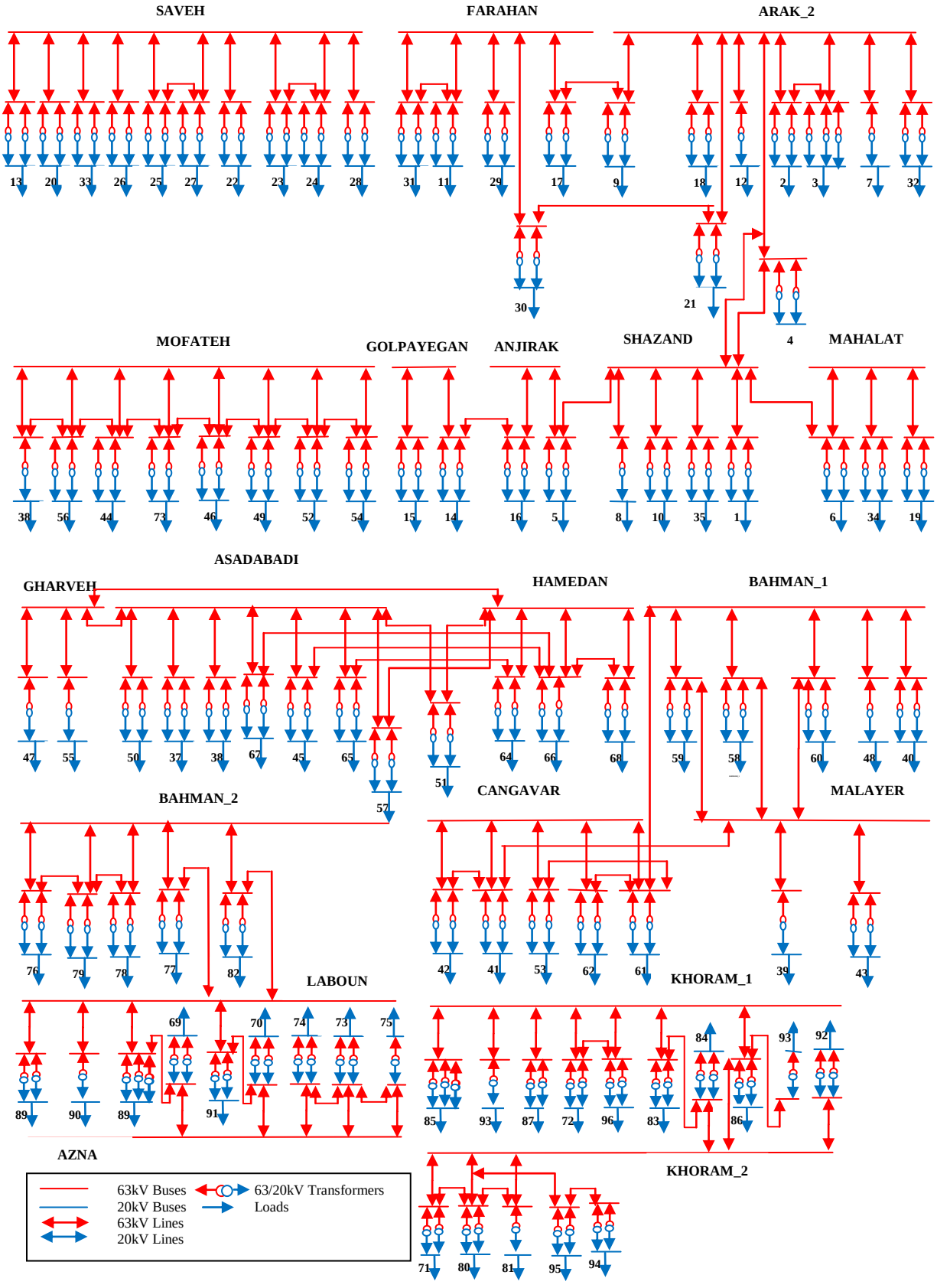

Fig. 3. Single line diagram of BREC network