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Optimal Placement of Distributed Generation Sources Using Parato Multi-Objective Concepts in Power Distribution Networks

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Abstract

Connecting distributed generation units with their proper placement in the network will have various effects such as increasing network reliability, reducing losses, improving voltage profiles, reducing transmission and energy distribution costs, and improving power quality parameters, including voltage imbalances. Since voltage imbalance is one of the common problems of distribution networks, this paper deals with the optimal placement of these resources in the unbalanced distribution system at different and asymmetric loads in the structure of distribution lines. Reducing the voltage imbalance coefficient, in order to increase the quality of power delivered to customers, has been one of the goals of optimal placement of distributed products in this study. Due to the need to carry out load distribution studies in unbalanced distribution systems, this study was performed using CYME-Dist software and the optimization process, by establishing a relationship between the software and MATLAB software. By introducing the multi-objective function to locate the distributed generation sources, in order to minimize the unbalanced voltage coefficient and real power losses, improve the voltage profile and increase the economic gain, the concepts of multi-objective optimization (Parato) have been used. Furthermore, the NSGA-II algorithm has investigated the placement of scattered products in the IEEE standard 13-bus network, at three different load levels. What can be deduced from the results is that by properly placing the distributed generation sources in the unbalanced distribution system, the amount of losses and voltage imbalances can be reduced. Also shown in a placement it has been shown that placing distributed generation resources in the right place will bring significant benefits to its consumers.

Keywords: Parato optimization - Optimal placement of distributed generation sources - Unbalanced distribution systems - Voltage unbalance.
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1. Introduction

In today's restructured power distribution networks, especially with the growing trend of privatization and competitiveness of the electricity market, the primary goal of power distribution companies is to reduce costs related to operation, maintenance, network construction and at the same time increase reliability. Network and improve the quality of power delivered to subscribers. One of the most effective ways to respond to load growth as well as provide a certain level of reliability is to use distributed generation resources or generation (DG) is Distributed.

With the advancement of technology, increasing efficiency and reducing the cost of technologies related to distributed generation, as well as the harmonization of these products for the economic criteria of restructured power systems, such as low risk and competitive market, DG role is expected.

Increasingly play in the future of the electricity industry [1] .The use of distributed generation resources can be one of the effective ways to get rid of some problems such as high losses, low power quality and density in power systems. In addition, the small capacity of the DG makes it easier to design and install these units compared to using large, centralized units in a short time frame. Scattered products can be used as active power compensation in the network, just as a capacitor is used to compensate for reactive power [2]. Due to the nature of distributed generation, distribution networks are the most suitable part for connecting these resources to the power system. Also, due to the increasing influence of DG in distribution systems, one of the important goals is to reach their maximum value by optimally locating distributed generation sources, reducing losses and improving the network voltage profile. Studies show that improper selection of DG location and capacity can cause more network losses than before DG installation. Also, optimal placement and determination of the appropriate capacity of DG can free up the capacity of the lines. Hence the new investment costs, which are both heavier and have a longer period than DG installation; Delayed [3,4].

Distributed generation sources, in addition to the ability to supply the power required by consumers separately, can be used to provide energy for the entire system in a comprehensive and integrated manner. Provide peak power to reduce energy transmission and distribution network costs, reduce environmental waste through the use of clean and renewable energy technologies, combine heat and CHP power, high level of reliability and quality of power provided and delay capital costs Development of transmission and distribution networks is one of the main advantages of using DG.

Design and operation of electrical networks in the presence of distributed generation sources, requires a comprehensive study of the best, most efficient and most economical technology to be used, the number and capacity of units, the best location, type of system connection and so on. The impact of DG on system performance characteristics such as losses, voltage profiles, stability, reliability and parameters affecting power quality makes the need for comprehensive and complete studies more obvious.

Considering that the installation of DG units in inappropriate places can increase system losses, increase costs and negatively affect the basic parameters of the system, DG placement and determination problem Its size is one of the most important issues, which can be the best answer for the system in the presence of distributed generation resources by using appropriate optimization methods. Obviously, without accurate knowledge and feasibility studies, the potential capabilities of these resources in distribution networks and the resulting technical and economic benefits can not be achieved [4].

Research to date on the location of distributed generation sources assumes that the system is perfectly balanced. In other words, the system does not have any unbalanced load and the structure of the system transmission lines is completely symmetrical. Also, in most methods of locating distributed generation sources, only one distributed production source has been located. In this paper, the considered power systems have unbalanced loads in different parts of the studied networks. The studied systems are also structurally asymmetric, and the number of distributed generation sources for placement is also considered variable.

In addition, multi-objective optimization concepts (Parato) have been used to locate distributed generation sources in the studied networks.

2. Introducing the objective functions of the DG positioning problem

In this section, the objective functions of the problem under study are introduced by considering their constraints. Target functions include network losses, voltage profiles and cost function, which are described below.

A) Network losses

One of the goals in locating distributed generation resources is to minimize actual power losses in the network. Using Equation (1), real power losses in the distribution system can be obtained [3].

$$F_1 = Ploss = \sum_{P=A,B,C} P_{loss}^{(p)} = \sum_{P=A,B,C}\left[\sum_{j=1}^{n}\sum_{\substack{m=1\\ m>j}}^{n} V_j^{(P)} V_m^{(P)} Y_{jm}^{(P)} \cos(\theta_j^{(P)} - \theta_m^{(P)} - \delta_{jm}^{(P)})\right] \quad (1)$$

where in:

n:Total number of busbars
$\theta_j^{(p)}$: Phase voltage angle P in busbar j
$V_j^{(P)}$: Phase voltage magnitude P in bus j
$Y_{jm}^{(P)}$: Phase admitance size p line between busbars j, m
$\delta_{jm}^{(P)}$:Phase admission angle p line between busbars j, m

B) Voltage profile

Voltage profiles can be improved by optimally locating distributed generation sources. It can be stated that the purpose of improving the voltage profile is that the voltage of all buses is close to the value of one prionite. In the problem in question, the voltage profile is formulated as Equation (2).

$$VD = \left|V_{i,ref} - V_i\right| \quad (2)$$

where in:

Vi is the bus voltage range i and Vi, ref is the desired voltage value; Which is usually considered a prionite.

According to Equation (2), for each bus, a value of voltage deviation (Voltage Distortion) is obtained, which is the goal of minimizing the maximum value of VD, in other words, the other goal of the problem is to minimize the expression (3).

$$F_2 = MAX(VD_i) \quad (3)$$

C) Cost function related to the installation and operation of DG

Commercial information related to the investment costs and operation of distributed generation units, according to reference [5], is given in Table (1).

The cost of a DG investment includes the purchase of a DG unit, costs related to initial research, installation of a DG installation site, building and monitoring equipment. The sum of these costs is expressed as Equation (4).

$$C_1 = \sum_{i=1}^{N_{DG}} \sum_{k=1}^{K_{DG}} Cost_{Inv,ik} \quad (4)$$

where in:
$\mathrm{Cost}_{\mathrm{Inv}}$:DG Resource Investment Costs, ($/MW)
N_{DG}: Number of DG units installed in the network
K_{DG}:DG capacity from 100 kW to 1.5 MW

Table.1.
Business information of dispersed production units

Parameter	***unit***	***amount***
DG investment cost	$/MW	318000
Cost of operation and operation of DG	$/MWh	29
DG maintenance costs	$/MWh	7
Interest rate	%	12.5
The inflation rate	%	9
lifespan (Scheduled time)	Year	20

DG maintenance and repair costs include the cost of parts repair and annual mechanical and electrical inspection. This cost does not depend on the DG location and is the same for all DG locations. This cost can be formulated as Equation (5).

$$C_1 = \sum_{i=1}^{N_{DG}} \sum_{k=1}^{K_{DG}} Cost_{main,ik} \quad (5)$$

where in:
$Cost_{main,ik}$ = Maintenance cost ($ / MW-year).

The present value of this cost is calculated annually by Equation (6), taking into account inflation and interest rates in a planning period.

$$CPV(C_2) = C_2 \sum_{t=1}^{T} (\frac{1+InfR}{1+IntR})^t \quad (6)$$

Where in :
$IntR$ =Interest rate
$InfR$ =The inflation rate
T= life span DG
CPV= Amount of current value of cost

The cost of operating the DG is the same as the cost of fuel. This cost and its present value are expressed by Equations (7) and (8), respectively.

$$C_3 = \sum_{i=1}^{N_{DG}} \sum_{k=1}^{K_{DG}} T_J * DG_{j,ik} * CG_{ik} \quad (7)$$

$$CPV(C_3) = C_3 \sum_{t=1}^{T} (\frac{1+InfR}{1+IntR})^t \quad (8)$$

$DG_{j,ik}$ =Power generated by the DG source installed in the network at a specified load level
CG_{ik} = Operating cost of DG units
T_j =Time has passed

It should be noted that because the price of active power varies at different hours of the year (8760 hours), in this study, three different load levels have been used in three times during a year. In Table 2, commercial and technical information of different load levels at different time intervals, according to reference [5], is shown.

Table.2.
Technical and commercial information many times

Load level	***Percentage of load***	***Load type***	***period of time h/yeare***	***Market price $/MWh***
1	80	light	2190	35
2	100	medium	4745	49
3	120	peak	1825	70

D) Increase the capacity of transmission lines

In a power system, electricity distribution companies purchase the power they need from the transmission network. Part of this power is for distribution system consumers and the other part is spent on transmission line and equipment losses. Therefore, the total power received by the distribution network can be expressed as Equation (9).

$$PT_{N-DG,j} = PD_j + Loss_{N-DG,j} \quad (9)$$

Where in :
$PT_{N-DG,J}$ = Requested active power regardless of DG
PD_j =Active power required by the consumer
$Loss_{N-DG,J}$ =System losses regardless of DG

Distribution companies can supply part of the power required by the installation by installing DG in the network and receive less electrical energy from the transmission network. In this case, the received electrical energy is calculated as Equation (10).

$$PT_{DG,j} = \sum_{i=1}^{N_{DG}} \sum_{k=1}^{K_{DG}} \sum_{l=1}^{N_{loc}} (PD_j - DG_{j,ik} + Loss_{j,ikl}^{DG}) \quad (10)$$

Using Equations (9) and (10), the reduction of electrical energy received by the distribution network can be obtained as Equation (11).

$$\Delta_{PT} = PT_{N-DG,j} - PT_{DG,j=}Loss_{N-DG,j} + \sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}}\sum_{l=1}^{N_{loc}}(DG_{j,ik} - Loss_{j,ikl}^{DG} \quad (11)$$

Also, using Equations (9) and (10), the amount of reduced energy losses in the presence of DG can be calculated by Equation(12).

$$\Delta Loss_{j,ikl} = \sum_{i=1}^{N_{DG}}\sum_{k=1}^{K_{DG}}\sum_{l=1}^{N_{loc}}(Loss_{N-DG,j} - Loss_{j,ikl}^{DG} \quad (12)$$

According to Equation (12), Equation (11) can be rewritten as Equation (13).

$$\Delta_{PT} = PT_{N-DG,j} - PT_{DG,j=}DG_{j,ik} + \Delta Loss_{j,ikl} \quad (13)$$

Based on the above, the profit from active asset reduction for each year that distribution companies can earn is calculated as Equation (14).

$$B_1 = \sum_{j=1}^{3} C_{MWh,j} * \Delta PT * T_j \quad (14)$$

The present value of Equation(14) is calculated as Equation(15).

$$BPV(B_1) = B_1 \sum_{t=1}^{T}(\frac{1+InfR}{1+IntR})^t \quad (15)$$

Where BPV is the present value of the profit. According to the explanations provided, the capital saving goal function can be finally obtained by considering cost and profit as equation (16).

$$F_{saving} = BPV(B1) - [C1 + CPV(C2) + CPV(C3)] \quad (16)$$

In fact, the goal is to maximize the function obtained in Equation (16).

E) Consider the constraints and constraints of the problem on the objective function

In this section, the problem constraints, which are considered as penalty coefficients in the main objective function, are introduced. Restrictions and limitations of the study review problem include the penalty coefficient related to the bus voltage limit and the penalty coefficient related to the loss reduction constraint considering DG.

The voltage limit should be specified by specifying the upper and lower voltage limits. In other words, the voltage of each bus should not exceed its allowable range. So we will have:

$$V^{min} \le V_i \le V^{max} \quad (17)$$

According to IEEE-519 standard, Vmin = 0.9 (pu) and Vmax = 1.1 (pu) are considered. The penalty coefficient for limiting the bus voltage is defined as Equation 18. In this regard, max (V) and min (V), respectively, maximum and minimum bus voltages, in terms of prionite and index i, indicate the number of busbars.

$$F_V = \begin{cases} 1 & 0.9 \le vi \le 1.1 \\ \max(vi) & max(vi) > 1.1 and min(vi) \ge 0.9 \\ \frac{1}{min(vi)} & max(vi) \le 1.1 and min(vi) < 0.9 \\ max\left\{max(vi), \frac{1}{min(vi)}\right\} & \end{cases} \quad (18)$$

Power losses in the presence of distributed generation sources in the network should be less than the base network (without distributed generation sources). Therefore we will have:

$$p_{Loss}^{With-DG} \le P_{Loss}^{Without-DG} \quad (19)$$

To further reduce the active losses of the distribution system FΔPloss penalty coefficient defined as Equation(20); Used.

$$F_{\Delta PLoss} = \left(\frac{1}{|\Delta PLoss|}\right) = \left(\frac{1}{|P_{Loss}^{Without-DG} - P_{Loss}^{With-DG}|}\right) \quad (20)$$

Since the optimal concepts of Parato are used in this paper, so the general objective function is expressed in Equation (21) by considering the constraints of the problem.

$$F_{Tot} = \begin{cases} \min(1/F_{saving}) \\ \min(F_{\Delta PLoss}.F_1) \\ \min(F_v.F_2) \end{cases} \quad (21)$$

In the next section, the results of DG locating, using objective functions and by multi-objective genetic algorithm (NSGA-II) are presented. To learn more about this algorithm, refer to the reference [6].

3. Study of DG placement on sample feeder

In this section, a study has been carried out on the IEEE standard 13-bus network to locate distributed generation resources in unbalanced distribution system conditions. The single line diagram of this network is shown in Figure (1).

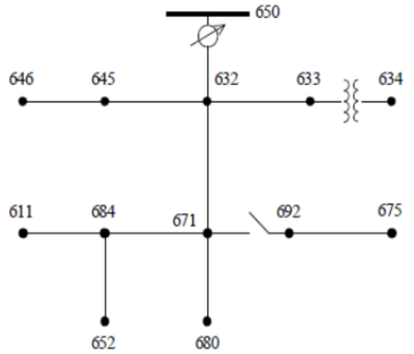

Fig. 1. IEEE standard 13-bus sample network single-line diagram

The results of applying the optimization algorithm on the studied feeder for three levels of load 100, 80 and 120% of the base load and based on their duration during the year according to the information in Table 2, are presented in Tables 3, 4 and 5, respectively. The reason for using several different load levels in the study is to show the efficiency of the proposed algorithms for locating distributed generation sources at different load levels in a real network. In this study, electrical calculations such as load distribution, voltage drop, etc. were performed using CYME-Dist software and optimization calculations related to NSGA-II algorithm were performed using MATLAB software. In this study, distributed generation sources are able to produce active and reactive power.

Table.3.
DG placement results for base load application

Number of DG	*Bass number*	*The amount of active power of the distributed*	*Source power% multiplier*	*Amount of losses (KW)*	VUF_{max}	*Saving(s)*
0	-	-	-	128.6	3.749	-
1	652	1.4843	87.83	58.70	1.335	1,101,000
2	611	1.1012	81.58	29.80	1.182	1,735,200
	675	1.3044	86.84			
3	692	0.9389	80.77	25.10	1.367	2,183,000
	675	1.0340	81.32			
	632	1.1747	80.02			

Table.4.
DG placement results for the application of 80% of the base load

Number of DG	*Bass number*	*The amount of active power of the distributed .*	*Source power% multiplier*	*Amount of losses (KW)*	VUF_{max}	*Saving(s)*
0	-	-	-	78.1	2.677	
1	652	1.4730	93.44	34.9	1.033	467.170
2	692	1.3934	85.55	15.9	1.054	811.440
	675	1.1241	90.31			
3	680	0.6104	89.09	15.1	1.098	860.800
	692	1.2926	85.77			
	645	0.75808	80.97			

Table.5.
DG placement results for 120% base load application

Number of DG	*Bass number*	*The amount of active power of the distributed*	*Source power% multiplier*	*Amount of losses (KW)*	VUF_{max}	*Saving(s)*
0	-	-	-	194	4.213	-
1	83.76	1.4783	611	90.7	1.667	1,061,100
2	85.55	1.0227	652	66.3	1.571	1,405,800
	85.10	0.965	692			
3	85.89	0.71791	652	59.5	1.546	1,589,900
	80.92	0.16376	646			
	93.18	1.3979	671			

The results of Tables 3 and 5 show that the use of distributed generation resources in terms of base load application and 120% of system base load, has economic benefits. In other words, in these conditions, the costs related to the construction and operation of distributed generation resources, the benefits of reducing losses and reducing capacity less revenue from the global network. Therefore, using DG in such conditions is economically viable. However, the results of Table 4 show that the use of distributed generation resources in the case of applying 80% of the base load of the system causes additional costs. In other words, the costs of constructing and operating distributed generation resources in these conditions are greater than the benefits of reducing losses and reducing the capacity received from the global network. Therefore, using DG in such conditions will not be economically viable.

Considering that the distributed generation resources used in the studied network are exploited for a year of 8760 hours and considering the load levels in three time periods according to Table 2; In this section, first, according to the optimal capacities obtained for DG in terms of using one, two, and three distributed generation sources, during the 20 years of the planned life of DG, the amount of costs and revenue is calculated for each year. Then, by calculating the difference between income and expenses, the amount of net profit for each year is obtained. It should be noted that in each case, given that the initial cost is required to operate the DG, it takes time for the project to become profitable. Table 6 shows the net profit for the operation of DGs over a period of 20 years and for each year separately. Figures 2, 3 and 4 also show the profitability of the project of exploiting one, two and three distributed generation sources in the 13-bus network, respectively. These diagrams show the head-to-head point at which the project enters the profitability phase.

According to Figures 2, 3 and 4 and extraction c of the breakpoints of the curve, the profitability trend of the operation of DGs can be expressed as the breakpoint of the curves (profit start time), 2 years, 10 months and 15 days for operation. From one DG, 3 years, 2 months and 18 days for the operation of two DGs and 3 years, 2 months and 29 days for the operation of three DGs.

4. Conclusion

Using distributed generation resources can be an effective way to get rid of some problems such as high losses, low power quality and congestion in power systems. Losses in power systems are important in terms of both cost and line capacity liberalization. In this paper, studies on unbalanced power systems in asymmetric loads in transmission line structure have been performed. Due to the fact that voltage imbalance is one of the common problems of distribution networks, reducing the unbalanced coefficient of distribution network voltage, in order to increase the quality of power delivered to customers, has been one of the important goals of optimal placement of distributed products in this study.

Table.6.
Net profit margin of DG over 20 years

Number of DG	***1***	***2***	***3***
Year		Net profit $	
0	-472010	-800565	-1000900
1	-297550	-542630	-681410
2	-128520	-292740	-371850
3	-35245	-50616	-71910
4	193910	183970	218690
5	347650	411260	500260
6	496620	631500	773090
7	640940	844870	1037400
8	780770	1051600	1293500
9	916250	1251900	1541600
10	1047500	1446000	1782100
11	1174700	1634000	2015000
12	1297900	1816200	2240700
13	1417300	1992700	2459400
14	1533000	2163700	2671200
15	1645100	2329500	2876500
16	1753700	2490000	3075400
17	1858900	2645600	3268100
18	1960800	2796300	3454800
19	2059600	2942300	3635700
20	2155300	3083800	3811000

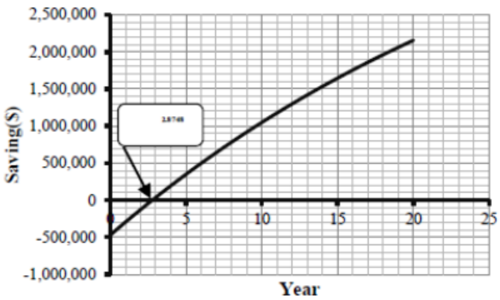

Fig. 2. Profitability of operating a DG 13-bus network

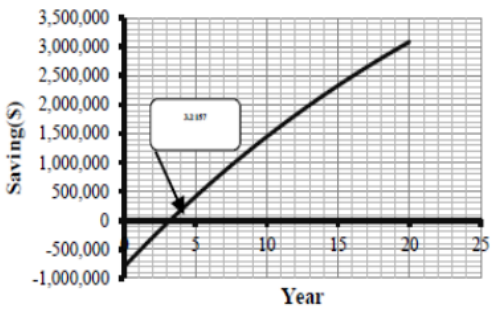

Fig. 3. Profitability trend of operating two DGs in 13-bus network

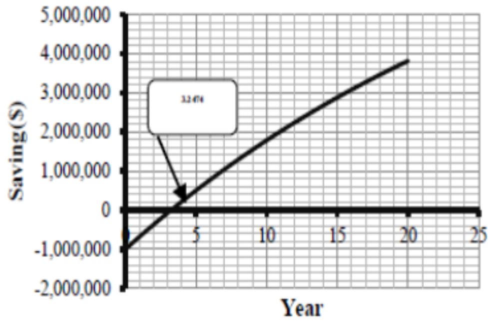

Fig. 4. Profitability trend of operating three DGs in 13-bus network

Due to the introduction of multi-objective function to locate distributed generation sources in this study, in order to minimize VUF and real power losses, improve voltage profiles and increase economic gain, the concepts of multi-objective (Parato) optimization have been used in the studied watersheds. In addition, in order to consider the constraints of the problem, a series of penalty coefficients have been used in the main objective function. The reason for using these coefficients in addition Controlling the constraints of the problem is also increasing the speed of convergence.

Reference

[1] Pepermans G., Driesen J., Haeseldonckx D., Belmans R.,D'haesseleer W., "Distributed generation: definition, benefits and issues", Energy Policy, 33(6), pp. 787-98, 2005.

[2] Acharya N., Mahat P., and Mithulananthan N., "An analytical approach for DG allocation in primary distribution network",Science Direct, Elec. Power and Energy Syst ., pp. 669-678, 2006.

[3] Mithulananthan N, Van Phu Le, "Distributed generator placement in power distribution system using genetic algorithm to reduce losses", TIJSAT, 9(3), pp. 55-62, 2004

[4] Griffin T, Tomosovic K, Secrest D, Low A., "Placement of dispersed generations systems for reduced losses.", Proceedings of the 33rd Hawaii International Conference on Sciences, 2000.

[5] Khalesi N., Rezaei N., Haghifam M.R., "DG allocation with application of dynamic programming for loss reduction and reliability improvement", International Journal of Electrical Power Energy Systems, vol. 33, no. 2, pp . 288-295 , 2011.

[6] Deb K., Agrawal S., Amrit P., Meyarivan T., "A fast elitism non-dominated sorting genetic algorithm for multi-objective optimization", IEEE Trans. on Evol. Computation, vol. 6, no. 2, April 2002 .