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Optimal DG Placement with the Aim of Profits Maximization

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Abstract

Using distributed generation power plants is common due to advantages such as system capacity release, voltage support and reduced energy losses in power networks. Prior to the creation of distributed generation plants (DG), economic calculation is needed in order to find the optimum location. In this study, IEEE 57 bus test system is evaluated using two index of LMP and CP. Then, the optimal location of distributed generation plants is studied in experimental network. Finally, the effects of DG correct location on buses LMP after DG installation is studied.

Keywords*: distributed generation, consumer payment (CP), optimal power flow, locational marginal price (LMP)*

1. Introduction

Distributed generation plants can be considered as plants that complete large central power plants [1, 2]. In the last decade, since the power market has progressed to restructuring from monopoly state, power has been transformed from service state to product. In this regard, profit maximization has been investigated for the owners of central power plants and DG as the underlying issue. It has a great effect on success or failure of power plants in power market.

Optimal DG placement is one of the key factors for distributed generation plants. If this is not done correctly, it will not offer a good profit for DG owners and will generate serious problems for power networks. The correct location of DG will increase the stability of power grid [3]. It can support voltage against the significant backdrop of voltage in overload time [1]. On the other hand, the Optimal DG Placement reduces the lines congestion and obstruction significantly [4]. That is more studies have been done on different aspects of DG correct location.

Capacity investment planning of distributed generation under competitive electricity market from the perspective of a distribution company is proposed in Reference [5]. In Reference [6], a method has been presented for optimum design of network connected DG systems due to the size and DG type in order to solve the reliability and environmental problems. In Reference [7], a method has been provided for DG location using GA in order to minimize active power losses in distribution network. in Reference [8] Optimal placement of DG with Langrangian based approach using traditional pool based OPF and voltage stability constrained OPF formulations is proposed.

In this paper, LMP and CP indices are studied totally. Then, IEEE 57 bus test system buses are ranked based on these two indicators. Optimal DG Placement is evaluated using a continuous loop. Finally, the effects of DG correct location on buses LMP after DG installation are studied.

2. Local Marginal Price (LMP)

Local Marginal Price (LMP) is the lagrangian multipliers associated with the active power flow equations for each bus in the system. Usually, LMP consists of three parts as follows [9]:

1) The marginal cost of generators production
2) The cost of losses

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3) The cost of lines density and obstruction
Considering the case of real power spot price at bus i, LMP is given by:

$$LMP_i = \lambda + \lambda \frac{\partial P_L}{\partial P_i} + \sum_{ij=1}^{N_L} \mu_{L_{ij}} + \frac{\partial P_{ij}}{\partial p} \quad (1)$$

$$LMP_i = \lambda + \lambda_{L,i} + \lambda_{C,i} \quad (2)$$

In Equation (1) and (2), λ is marginal cost of energy production in a reference bus, $\lambda_{L,i} = \lambda \frac{\partial P_l}{\partial P_i}$ is the cost of losses and $\lambda_{C,i} = \mu_{i,j} + \frac{\partial P_{ij}}{\partial p}$ is the incremental cost-per- congestion of lines [1]. LMP index is used as useful tool in order to rank the used network buses. Accordingly, the load buses are ranked in descending order of LMPs with the first node in the order as the best candidate for DG placement as shown below.

$$LMP_i = \begin{bmatrix} LMP_1 \\ LMP_2 \\ LMP_3 \\ . \\ . \\ . \\ LMP_n \end{bmatrix} \quad (3)$$

Table 1 shows ranking of network buses from 1 to 5 based on LMP index:

Table 1. Ranking network buses based on LMP index

Rank	Bus number	LMP
1	31	48.38
2	33	47.77
3	32	47.60
4	34	47.40
5	35	47.02

3. Consumer Payment Index (CP)

Consumer Payment (CP) is one of the important factors in the placement of distributed generation systems. According to equation 4, it can be said that CP is as a product of LMP [1].

$$CP_i = P_d \times Load_i = \begin{bmatrix} CP_1 \\ CP_2 \\ CP_3 \\ . \\ . \\ . \\ CP_n \end{bmatrix} \quad (4)$$

The flow rate is included in CP index; its logic is that the bus flow is very important for DG location with the aim of maximizing producer profits. It is important that in that if LMP is alone as above and there is no or low consumer in bus, the profit of DG owner will be small; therefore the bus cannot be offered for DG install. Table 2 shows ranking of network buses from 1 to 5 based on CP index. Table 2 analysis shows that the most CP is for bus 12 and therefore, bus 12 is selected for study from CP index perspective.

Table 2. Ranking network buses based on CP index

Rank	Bus number	P_d	LMP	CP
1	12	377	43.32	16333.33
2	8	150	40.43	6065.48
3	9	121	41.95	5074.42
4	6	75	41.45	3109.33
5	16	43	43.47	1869.24

4. Studied Network Implementation and Simulation

The studied network of this research is IEEE 57 bus test system. The studied network has 7 generator bus and 50 load bus. The most amounts of active losses occur in line 8-9 as 3.36 MW [9]. Figure 1 shows IEEE 57- bus network standard.

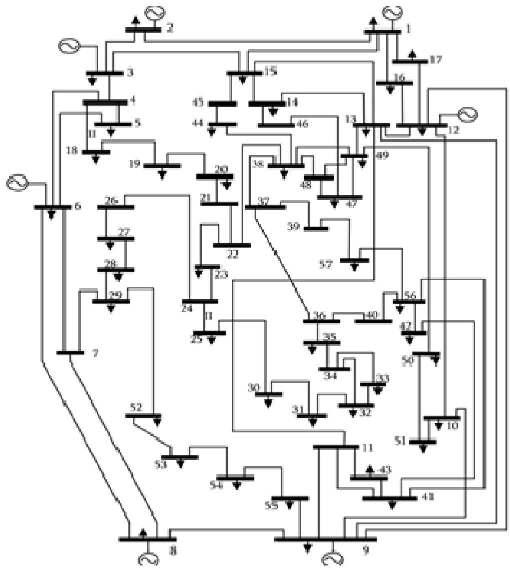

Figure 1. IEEE 57 bus test system

5. Cost Function and Incremental Cost of Studied DGs

Distributed generation power plants are various types that each has its own cost function. It is clear that increased cost function of DG power plant leads to reduced DG owner profit. Table 3 shows cost function coefficients of studied DG. Figure 2 shows drawings of studied DG in Table 3. Differentiation of Figure 2 functions leads to incremental cost graph. Figure 3 shows the incremental cost.

Table 3. Cost function coefficients of studied DGs

DG No.	a_{DG}	b_{DG}	c_{DG}
DG 1	0.002	15	0
DG 2	0.004	19	0
DG 3	0.04303	20	0
DG4	0.25	20	0
DG 5	0.1	30	0
DG 6	0.01	40	0
DG 7	0.003	43	0

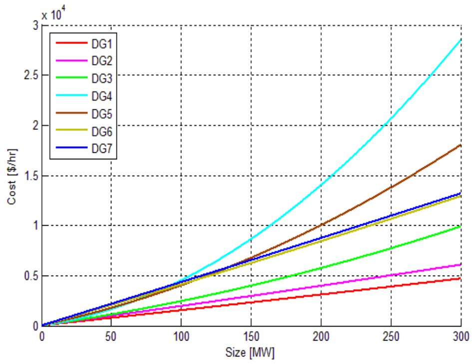

Figure 2. Cost functions of studied DGs

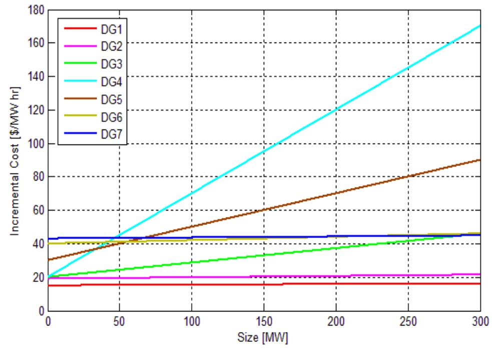

Figure 3. Incremental cost characteristics of studied DGs

6. Maximize DG Owner Benefit

One of the important issues of distributed generation placement is DG owner profit maximization. In this paper, profit maximization of DG owner is studied using continuous loop method.

OPF (Optimal Power Flow) is solved in grid in order to get the maximum benefit. Where, λ is achieved after DG installation. The profit of DG owner is obtained from Equation (5) using λ and P_{dgi} that is obtained from OPF.

$$Profit_i = \lambda_i \times P_{dgi} - C(P_{dgi}) \quad (5)$$

In above equation, λ_i is LMP after DG placement, P_{dgi} is DG productivity power and C(P_{dgi}) is DG cost function. In Equation (5), λ_i and P_{dgi} are variables; therefore, their change leads to profit change. For example, if we locate DG6, profit changes graph of Equation (5) is shown by Figure 4. The P_{dgi} amount equals to zero, OPF problem is solved, output λ_i and P_{dgi} are set in Equation (5) and the profit is calculated in order to find the optimal P_{dgi} and λ_i in a bus. Then, 0.5 MW is added to P_{dgi} and OPF is solved with new P_{dgi} and λ_i . P_{dgi} amounts are set again in equation 5 and the profit is calculated; the loop will continue as long as the profit of next step becomes less than previous step (Profit2>Profit1) that is called maximum power point.

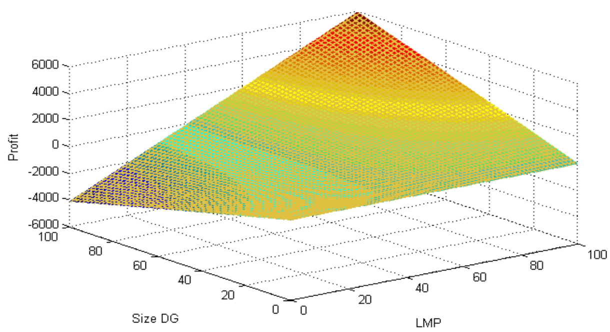

Figure 4. DG6 location in Equation (5)

6.1. Maximizing the Benefit from LMP Index Perspective

As it was described, LMP is one of the selection indices of bus in order to create DG index. According to Table 1, the most LMP of IEEE 57 bus test system is related to bus 31. According to Figure 5, it can be said that correct location of DG in network buses leads to reduced amount of LMP. Figure 5 shows LMP status of network buses before and after the location of DG6 and DG7. It can be seen that location of DG6 in bus 31 has greater effects on network bus LMPs; the reason for this can be less cost of DG6 compared to DG7.

If DG7 is located in bus 31 that the most costs among studied DGs and its location is more acute, Figure 6 graph will be obtained. Figure 6 graph shows that increased production of DG in a bus leads to increased profit. If the increase is continued, LMP will be gradually reduced and LMP amount will be more than operating costs that leads to negative DG. Figure 7 graph shows the optimal size per each location of DG in bus 31.

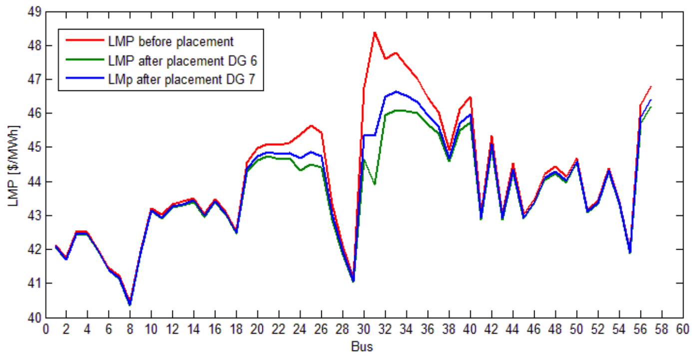

Figure 5. LMP changes graph through placement DG6 and DG7 in bus 31

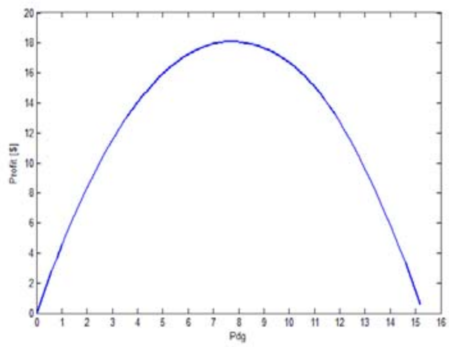

Figure 6. Placement of DG7 in bus 31

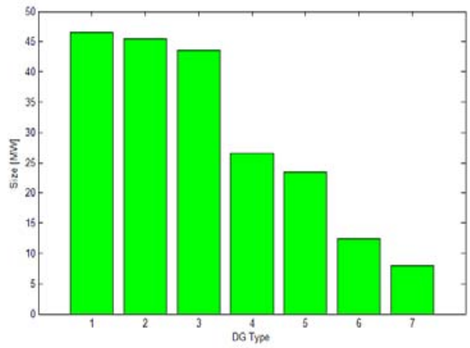

Figure 7. Placement of DGs 1-7 in bus 31

6.2. Maximizing the Benefit from CP Index Perspective

The best bus in IEEE 57-bus network is bus 12 from CP index perspective. Locating DG in bus 12, bus LMP is changed as Figure 8 graph. Figure 8 shows that correct location of DG leads to reduced LMP of buses.

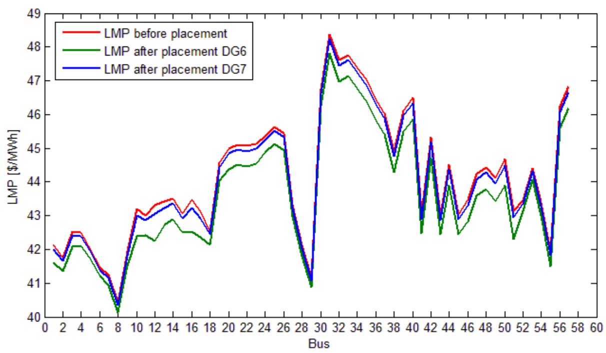

Figure 8. LMP changes graph through placement DG6 and DG7 in bus 12

Figure 9 graph shows interest changes per DG resizing. It can be found that size and optimum benefit of bus 12 (CP Index) is more compared to bus 31 (LMP Index). Figure 10 graph shows the optimum size per each location of DGs in bus 12.

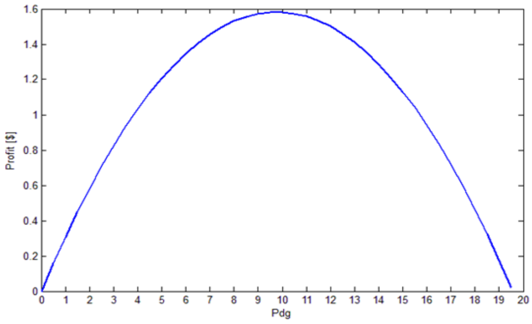

Figure 9. Placement of DG7 in bus 12

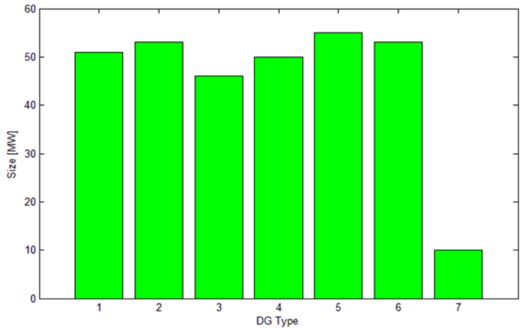

Figure 10. Placement of DGs 1-7 in bus 12

7. Conclusion

One of the important issues of distributed generation placement is profit maximization for DG owner. In this paper, LMP and CP indicators were explained and buses 31 (LMP Index) and 12 (CP index) were selected for study using both indices among IEEE 57 bus test system buses. Then, optimum size of distributed generation plants was obtained considering DGs with different cost functions and using continuous loop and OPF method. It is suggested that future study is conducted in order to find the optimal size considering different objective functions including maximization of social welfare function, maximizing network flow rate and using of DG in objective bus.

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