DG ALLOCATION BASED ON MODIFIED NODAL PRICE WITH CONSIDERATION OF LOSS AND RELIABILITY USING PSO

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ABSTRACT

This paper proposes a multi objective optimization to determine the optimal size and location of distributed generation in the distribution network to minimize load supply cost and enhance reliability improvement. In this paper the cost of DG investment, maintenance and operation is considered as well as the benefits of load supply cost reduction and reliability improvement. Also a new method is proposed in this paper to determine the nodal price. This nodal price is used to determine the actual value of load supply cost reduction. Finally particle swarm optimization is used to solve the optimization problem.

INTRODUCTION

In the last decade, the electric power industry has shown a renewed interest for distributed generation (DG). DG can provide benefits to the distribution utility such as loss reduction, emission reduction, reducing the cost of curtailed energy, increasing the reliability of power supply, voltage profile improvement, reducing the risk of overloading the distribution feeders, maximizing the DG penetration level, enhancing the social sustainability, reducing the construction period and reducing the cost of energy purchased from power market and investments deferral[1]. As the potential benefits of DG largely depend on its location and size, many of the studies regarding DG address the problem of its optimal placement and size [2-4].

So, this paper presents a multi-objective function to determine the optimal locations and size of DGs in distribution system to minimize the power loss of the system and enhance reliability improvement. Time varying load is applied in this optimization to reach pragmatic results meanwhile all of the study and their requirement are based on cost/benefit forms. The DG is considered to be working at a specified power factor (lagging).

To follow this proper purpose, first time-varying loads and wholesale market price are divided into 52 levels corresponding to 52 weeks a year. then multi-objective function is considered based on a cost/benefit form that enhance benefits of DG allocation in the system to compensate system loss, system reliability and cost of purchased power from transmission line along the planning period. Finally the allocation problem is solved by binary swarm optimization (PSO).

PROPOSED METHOD

As be noted in the previous section, in this paper, a multi objective function is used to determine the optimal locations and size of DGs in distribution system to minimize power loss of the system and enhance reliability improvement. Time varying load is applied in this optimization to reach pragmatic results meanwhile all of the study and their requirement are based on cost/benefit forms.

Economical benefits and DG application costs are submitted and modeled. In this model, distribution system companies are responsible for providing customer demand, DG operation and distribution system management. All of these responsibilities are based on cost reduction and improving quality and reliability of customer service. Therefore costs and benefits of DG allocation in network can be expressed as follows:

DG costs: investment cost, maintenance cost, operating cost of DG, electricity cost.

DG Benefits: Active power demand reduction from transmission line, loss reduction, interruption cost reduction. The electricity cost is evaluated on the basis of proposed nodal prices at the buses. It should be noted that increasing use of DGs in distribution network has changed its characteristics from passive to active. Consequently, pricing mechanisms that have been employed in transmission, such as nodal pricing are good candidates for use in distribution networks. Nodal price indicates the marginal price of electricity at the network buses. Integration of DG in the distribution network affects the nodal prices at buses. If the presence of DG reduces the losses in the distribution network, nodal prices of power will come down and vice versa.

With consideration of DGs impact on loss reduction, the nodal pricing is proposed in [5] to send the right price signals to located DGs and to properly reward DGs for reducing losses through increased revenues derived from prices that reflect marginal costs. According to [5], the nodal price is determined as follows.

$$\lambda_{DG,i}^{h} = \lambda_{n}^{h} + \lambda_{loss}^{h} \quad (1)$$

$$\lambda_{loss}^{h} = \lambda_{n}^{h} \left. \frac{\partial P_{loss}}{\partial P_{D,i}} \right|_{P_{D,i}=P} \quad (2)$$

Where λ_{loss}^{h} is the marginal loss cost at hour h, λ_{n}^{h} is the wholesale market price at hour h, P_{loss} is network total loss, and $P_{D,i}$ is the the load at the bus-i.

In the above equation, the marginal loss cost is used as the value of load impact on loss reduction to determine the nodal price. But the marginal loss cost does not represent the actual value of load impact on loss reduction. For description of this issue, consider the following sample network (figure 1). As can be seen, a DG is installed at the end of the feeder. This DG has a positive impact on network loss reduction. Figure 2 shows the changes in network loss versus DG capacity changes.

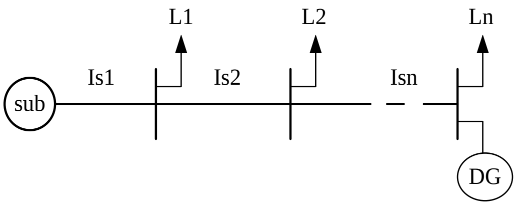

Figure 1: sample network.

As can be seen from figure 2, an increased in DG capacity up to P_1 lead to a decreased in network loss. In other words, the maximum loss reduction occurs in capacity P_1 .

Also, figure (3) shows the changes in marginal loss cost versus DG capacity changes. As can be seen from figure (2) and 3, according to equation (1) and (2), an increase in DG capacity leads to a decrease in DG nodal price, so that the marginal cost is zero in the capacity of P_1, while the loss is minimum in capacity P_1 . Therefore the nodal price does not represent the actual value of DG from loss reduction point of view. In other words, the reward allocated to DG based on marginal loss cost criteria is lower than the contribution of DG in loss reduction.

The actual value of DG in loss reduction should be determined based on average marginal cost. The average marginal cost can show the actual value of DG in loss reduction. It can be calculated as follows:

$$\lambda_{loss,i}^{h} = \frac{1}{2}(\lambda_{DG,i}^{0,h} + \lambda_{DG,i}^{p,h}) \quad (3)$$

Where, $\lambda_{DG,i}^{0,h}$ is the marginal loss cost in the case that no DG is connected to feeder, and $\lambda_{DG,i}^{p,h}$ is the marginal loss cost in the case that all DG are connected to feeder. According to equation (3), DG energy price can be determined as follows:

$$\lambda_{DG,i}^{h} = \lambda_{n}^{h} + \frac{1}{2}(\lambda_{DG,i}^{0,h} + \lambda_{DG,i}^{p,h}) \quad (4)$$

Where λ_{n}^{h} is the wholesale market price. It should be noted that DG is considered a negative load in this paper. So, the load nodal price is determined as well as DG nodal price is determined. The cost of DG allocation in network can be formulated as follows:

$$\text{cost} = C_i + C_m + C_o \quad (5)$$

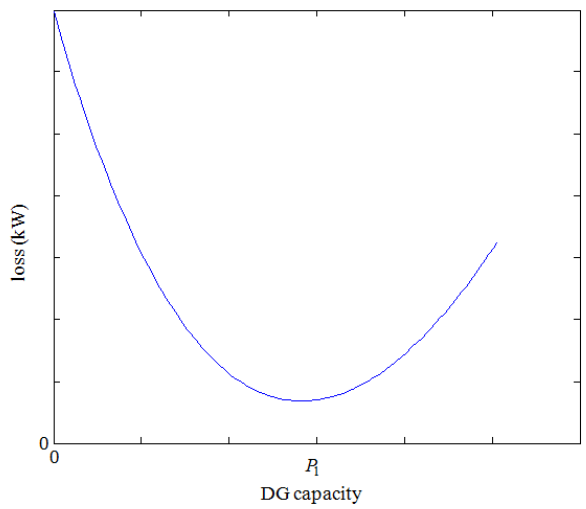

Figure 2:feeder loss changes versus DG capacity changes.

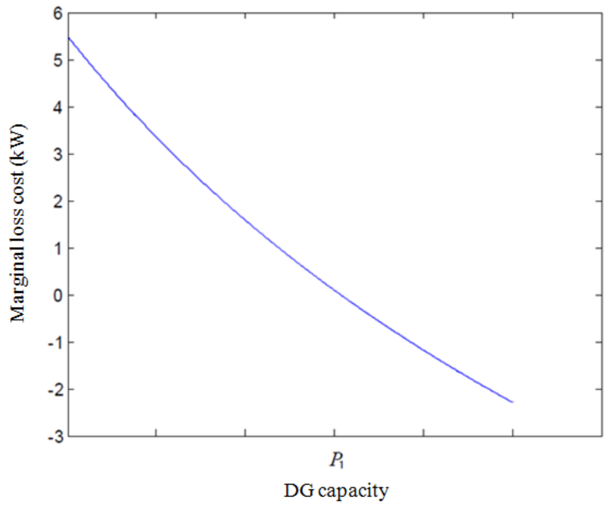

Figure 3:marginal loss cost changes.

Where, C_i is investment cost, C_m is maintenance cost, and C_o is operation cost. These costs can be formulated as follows:

$$C_i = \sum_{j=1}^{N_{DG}} \text{cost}_{inv,j} P_{DG,j} \quad (7)$$

$$C_m = \sum_{j=1}^{N_{DG}} \text{cost}_{main,j} P_{DG,j} \quad (8)$$

$$C_o = 8760 \sum_{j=1}^{N_{DG}} \text{cost}_{op,j} P_{DG,j} \quad (9)$$

DG benefits can be formulated as follows:

$$B = B_{SR} + B_{RI} \quad (10)$$

Where B_{SR} is the benefit of electricity bill reduction, and B_{RI} is the benefit of DG on reliability improvement. These benefit can be formulated as follows:

$$B_{SR} = C_S^{no-DG} - C_S^{DG} \quad (11)$$

$$B_{RI} = C_{ENS}^{no-DG} - C_{ENS}^{DG} \quad (12)$$

Where C_S^{no-DG} and C_S^{DG} are the supply cost without incorporating and with incorporating DG respectively. C_{ENS}^{no-DG} and C_{ENS}^{DG} are the energy not supplied cost without and with incorporating DG respectively. C_S^{no-DG}, C_S^{DG} and C_{ENS} can be determined as follows:

$$C_S^{no-DG} = \sum_{i=1}^{N_{DG}} \sum_{h=1}^{52} \lambda_{new}^h P_{D,i}^h T_h + \lambda_n^h P_L^{no-DG,h} T_h \tag{13}$$

$$C_S^{no-DG} = \sum_{i=1}^{N_{DG}} \sum_{h=1}^{52} \lambda_{new}^h (P_{D,i}^h - P_{DG,i}^h) T_h + \lambda_n^h P_L^{DG,h} T_h \tag{14}$$

$$ENS = \lambda' \left[\sum_{b=1}^{N_b} \gamma_b \times L_b \times (\sum_{res=1}^{Nres} p_{res} t_{res} + \sum_{rep=1}^{Nrep} p_{rep} t_{rep}) \right] \tag{15}$$

Where $P_{D,i}^h$ is active demand at bus-i and at week-h, T_h is duration of week-h, $P_L^{no-DG,h}$ and $P_L^{DG,h}$ are active power loss at week-h without and with incorporating of DG, λ' is price of energy not supplied ($/MWh), N_b is the number of branches in network, γ_b is branches failure rate(f/km.year), L_b is branch length (km), N_{rep} is number of nodes isolated during fault location, P_{res} is load s which are restored during fault, P_{rep} is loads are not restored during fault, t_{res} is duration of the fault location and switching time, and t_{rep} is duration of the fault repair [3].

In this paper monte carlo simulation is used to determine the reliability improvement.

In conclusion, cost and benefit are considered in one unique objective function that formulated below:

$$\begin{aligned} \max Z &= profit = benefit - cost \\ &= BPV(B_{SR}) + BPV(B_{RI}) \\ &- BPV(C_{main}) - BPV(C_{op}) - C_{INV} \end{aligned} \tag{16}$$

Where $BPV(h)$ calculate the present worth of h in planning period[3].

So, DG allocation problem can be solved by using particle swarm optimization (PSO) which is appropriate optimization technique for the proposed function. Given function has been optimized considering constrains include voltage limits, capacity of feeder limit, and penetration rate limit in accordance with [3].

CASE STUDY

The proposed method is tested using the 33-bus distribution system showing in figure (4) [6]. The line data are provided in the [6]. Weekly load and wholesale market price data are provided in figure (5),(6) and table I. The power factor is considered to be 0.85 lagging at main bus. it should be noted that each bus load is determined as follows:

$$\begin{aligned} P_i^w &= P_{sub}^w \times CF_i^P \\ Q_i^w &= Q_{sub}^w \times CF_i^Q \end{aligned} \tag{17}$$

Where P_i^w, Q_i^w are active and reactive power at week w in bus i respectively, P_{sub}^w, Q_{sub}^w are active and reactive power at week w in main bus respectively, and CF_i^P, CF_i^Q are active and reactive contribution factor of bus-i. the maximum penetration rate is considered 20%.

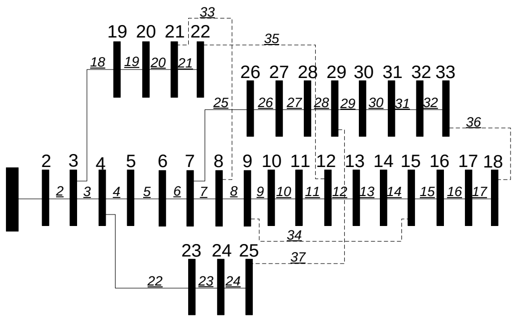

Figure 4:sample 33-bus system.

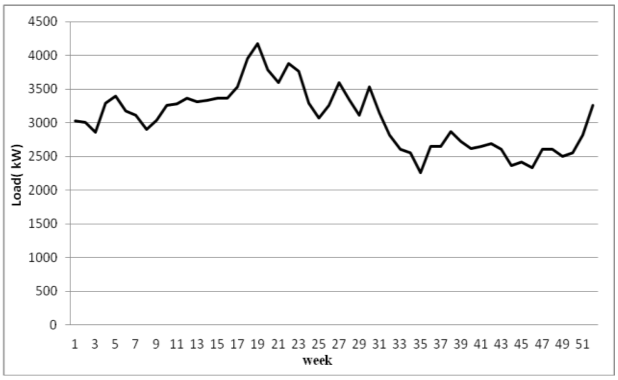

Figure 5: weekly load curve in main substation.

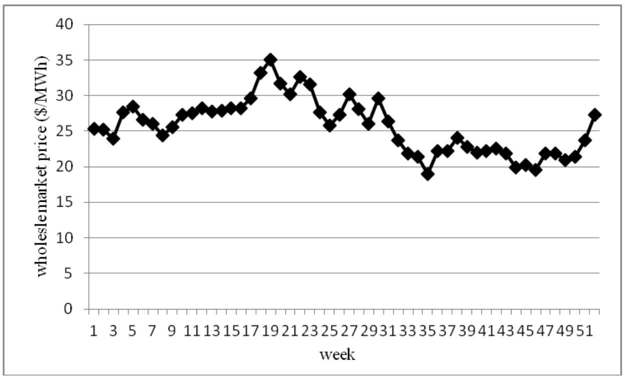

Figure 6: weekly wholesale market price.

Table I. bus load contribution factor

bus.No	Active power	Reactive power	bus.No	Active power	Reactive power

1	0	0	18	0.02	0.02
2	0.03	0.03	19	0.02	0.02
3	0.02	0.02	20	0.02	0.02
4	0.03	0.04	21	0.02	0.02
5	0.02	0.015	22	0.02	0.02
6	0.02	0.01	23	0.02	0.025
7	0.05	0.05	24	0.11	0.1
8	0.05	0.05	25	0.11	0.1
9	0.02	0.01	26	0.02	0.013
10	0.02	0.01	27	0.02	0.013
11	0.01	0.015	28	0.02	0.01
12	0.02	0.018	29	0.03	0.035
13	0.02	0.018	30	0.05	0.3
14	0.03	0.04	31	0.04	0.035
15	0.02	0.005	32	0.06	0.05
16	0.02	0.01	33	0.02	0.02
17	0.02	0.01			

Interest rate and and inflation rate are considered 9% and 20% respectively. It is supposed that the maximum allowable number of DGs in the distribution network is considered 5. The cost data are considered as [3]. The output of the optimization problem is the size and location of these DGs. Table (2) illustrates the optimal size and location of DGs in the distribution network. As can be seen, the maximized capacity is allocated at bus 33. Because DG which is allocated at this bus have a greater effect on loss reduction. The contrition of each DG in loss reduction will be increased with increasing of distance from main bus. So, as can be seen, the optimal buses for DG placement are further away from main bus.

Table (3) shows the economical costs and benefit for allocation of DGs in the distribution network. As can be seen the benefit of installation in the network is 1,258,358 ($) while the cost is 1,044,599 ($). This means that the installation of DGs in the network make 213759 ($) profit for the utility.

Table II:DG's size and location

DG. No	Bus. No	Capacity (kW)
1	33	210
2	29	170
3	18	175
4	13	145
5	7	110

Table III: Economical costs and benefit for allocation of DGs in the network.

Economical cost	Cost ($)	Benefit	($)
Investment	254,400	Reliability improvement	57,407
Operation	771,575	Load supply cost reduction	1,200,951
Maintenance	18,624		
Total costs($)	1,044,599	Total benefits	1,258,358

CONCLUTION

In this paper a multi objective optimization has been proposed to determine the optimal size and location of distributed generation in the distribution network. In this paper the cost of DG investment, maintenance and operation is considered in objective function as well as the benefits of load supply cost reduction and reliability improvement. From the studied results it has been derived that due to the greater impact of DGs on load supply cost reduction at buses which are further away from the main bus. these buses are determined as optimal buses. Also the utility can earn a profit of 213759 ($) by the installation of DGs at optimal buses.

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