DETERMINATION OF MINIMUM GUARANTEED PRICE FOR ENERGY PRODUCED BY DGS IN DISTRIBUTION NETWORK

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ABSTRACT

With the presence of distributed generation (DG) in electric distribution networks, distribution companies (DisCo) have the options to purchase energy from DGs units and/or directly from the wholesale electricity market. The DisCo's desired purchasing price of DG's energy depends on their impacts on network, and as well as wholesale market price. This paper proposes a new method to determine the minimum guaranteed price of DG's energy with consideration their impacts on loss. These prices are as efficient economical signal so that lead the investors to installation of DGs at buses with more positive technically impact on the distribution network.

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INTRODUCTION

Distributed generation (DG) can provide benefits to the distribution company (DisCo) such as power losses and environmental pollution reduction, investments deferral, and reliability indices improvement [1-2]. DisCo might be willing to buy energy from DGs that are optimally located in the distribution network. To supply the demand of its network, a utility purchases energy from wholesale market. Most of this energy is bought through long-term bilateral contracts at a price based on the wholesale electricity market price. With presence of DG, DisCo has the option to purchase energy from any DG units owned by investor, and directly from the wholesale electricity market. The amount of energy and the price at which purchased by utility are related to the DG's impact on network and the wholesale market price. If DG unit power production has positive technically impact, then the DG energy price is slightly higher than the wholesale market price. Conversely, if the DG unit has a negative impact, its energy price is lower than the wholesale market price[3]. On the other hand, it is important for investor to know the minimum energy price ($/kWh), that DisCo will pay to them for their energy production during the specified period of time and specified bus. To reduce the investment risks, the DisCo should guarantee these prices at the buses in the network. Therefore, investors are encouraged to install DGs in pre-determined buses in the distribution network [4-5].

This paper proposes a method to determine the minimum guaranteed prices at network buses that DisCo will pay to investor at each hour, if investor installs DG in those buses. DGs minimum energy price, which is named based-price, is determined considering their effect on losses. As shown in this paper, the impact of a DG on losses is related to the size and location of all DGs which are installed in the distribution network. So, the energy price of DG is related to all DGs which are installed in the distribution network. Thus, energy price of DG is decomposed into two terms: Term which is independent to DGs and term which is associated with multiple DGs. Dependent term of price is variable and is related to the presence or absence of other DGs. While the independent term of price is related just to the considered DG. In this paper the independent term of price is determined as minimum DG's energy price.

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PROPOSED METHOD

For determination of DG energy price, DisCo must weigh the wholesale market price with the potential benefits obtained from the dispatch of these units. In other word, the DisCo must determine DG energy prices so that send incentive signal to DGs which has positive impact on network.With consideration of DGs impact on loss reduction, the nodal pricing is proposed in [6] to send the right prices signals to located DGs and to properly reward DGs for reducing losses through increased revenues derived from prices that reflect marginal costs. According to [6], the nodal price of a DG with capacity of P is determined as follow.

$$\lambda_{DG,i}^{h} = \lambda_{n}^{h} + \lambda_{loss}^{h} \tag{1}$$

$$\lambda_{loss}^{h} = -\lambda_{n}^{h} \left. \frac{\partial P_{loss}}{\partial P_{DG,i}} \right|_{P_{DG,i}=P} \tag{2}$$

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 $P_{DG,i}$ is the capacity of DG which is installed in the bus-i.

In the above equation, the marginal loss cost is used as the value of DG impact on loss reduction to determine the DG's nodal price. But the marginal loss cost does not represent the actual value of DG 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.

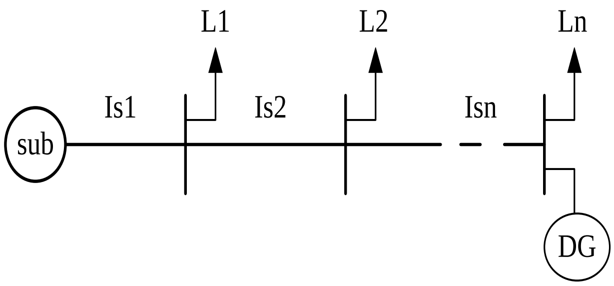

Figure 1: sample network.

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, and 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 can not represent the actual value of DG from loss reduction point of view. In other words, the reward allocated to a 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.

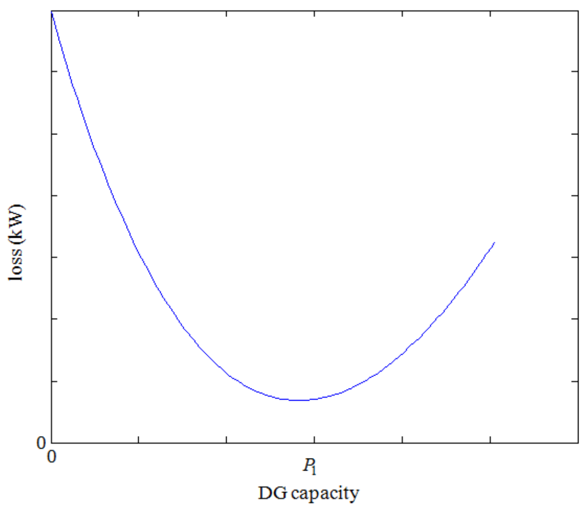

Figure 2:feeder loss changes versus DG capacity changes.

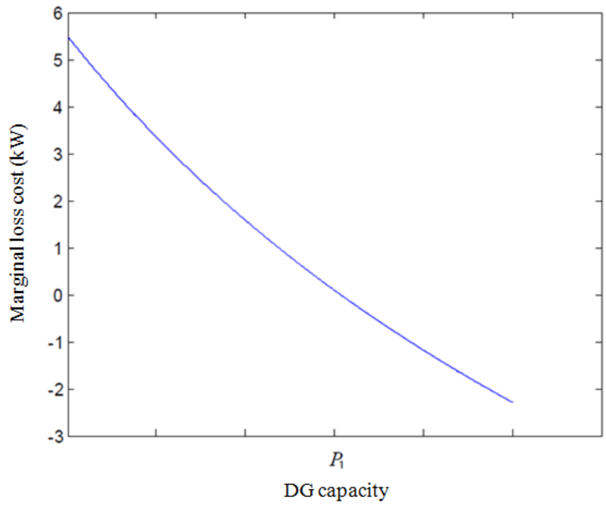

Figure 3:marginal loss cost changes

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.
The impact of a DG on losses is related to the size and location of all DGs which are installed in the distribution network. So, the energy price of DG is related to all DGs which are installed in the distribution network. Thus, energy price of DG is decomposed into two terms: Term which is independent to DGs and term which is associated with multiple DGs. Dependent term is variable and is related to the presence or absence of other DGs. While the independent term of price is related just to the considered DG. So the equation (4) can be expressed as follows:

$$\lambda_{DG,i}^{h} = \lambda_{n}^{h} + \lambda_{DG,i}^{inde,h} + \lambda_{DG,i}^{dep,h} \quad (5)$$

Where $\lambda_{DG,i}^{inde,h}$, $\lambda_{DG,i}^{dep,h}$ are independent and dependent terms of loss-related price respectively.
According to equation (4) and (5), the dependent and independent term of loss-related price can be calculated as follows:

$$\lambda_{DG,i}^{inde,h} = \frac{1}{2}\lambda_{DG,i}^{0,h} = -\frac{1}{2}\lambda_{n}^{h}\frac{\partial Ploss}{\partial P_{DGi}}\bigg|_{\{P_{DG,J}=0 \mid J=\{1,2,\ldots,n\}\}} \quad (6)$$

$$\lambda_{DG,i}^{dep,h} = \frac{1}{2}\lambda_{DG,i}^{1,h} = -\frac{1}{2}\lambda_{n}^{h}\frac{\partial Ploss}{\partial P_{DGi}}\bigg|_{\{P_{DG,J}=P_J \mid J=\{1,2,\ldots,n\}\}} \quad (7)$$

So, as regards $\lambda_{DG,i}^{inde,h}$ is not related to DGs, the minimum energy price of DG can be expressed as follows:

$$\lambda_{DG,i}^{\min,h} = \lambda_n^h + \lambda_{DG,i}^{inde,h} \qquad (8)$$

According to the equation (5) and (6), the minimum energy price of DG can be expressed as follows:

$$\begin{aligned} \lambda_{DG,i}^{base,h} &= \lambda_n^h + \lambda_{DG,i}^{ind,h} \\ &= \lambda_n^h - \frac{1}{2}\lambda_n^h \left.\frac{\partial Ploss}{\partial P_{DGi}}\right|_{P_{DG,J}=0 \;\; J=\{1,2,\ldots,n\}} \\ &= \lambda_n^h \Big(1 - \frac{1}{2} \left.\frac{\partial Ploss}{\partial P_{DGi}}\right|_{P_{DG,J}=0 \;\; J=\{1,2,\ldots,n\}}\Big) \\ &= \alpha_i^h \lambda_n^h \end{aligned} \qquad (9)$$

Where

$$\alpha_i^h = 1 - \frac{1}{2} \left.\frac{\partial Ploss}{\partial P_{DGi}}\right|_{P_{DG,J}=0 \;\; J=\{1,2,\ldots,n\}}$$

$\lambda_{DG,i}^{base,h}$ is the minimum price that DisCo will buy DG's energy with that price. To reduce the investment risks, DisCo can guarantee these prices at the buses in the network. Indeed DisCo is committed to buy DG's energy at least, with a coefficient (α_i^h) of the wholesale market price at each hour.

CASE STUDY

The proposed method is tested using the 33-bus distribution system showing in Fig. 4[7]. The line data are provided in the [7]. Weekly load data at each bus are provided in figure 5 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:

$$\begin{aligned} P_i^w &= P_{sub}^w \times CF_i^P \\ Q_i^w &= Q_{sub}^w \times CF_i^Q \end{aligned} \qquad (9)$$

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.

As mentioned in the previous section, the minimum guaranteed price depends on the network structure, load, and wholesale market price. If the annually wholesale market price is not definite, DisCo will determine and guarantee the coefficient of minimum guaranteed price (α_i^h).

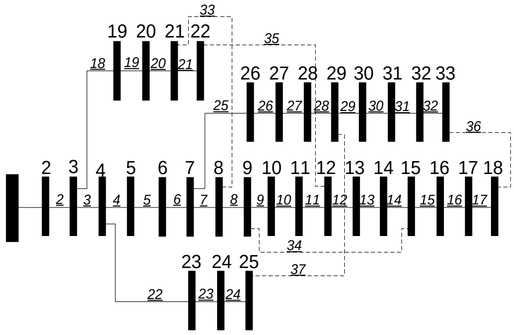

Figure 4:sample 33-bus system.

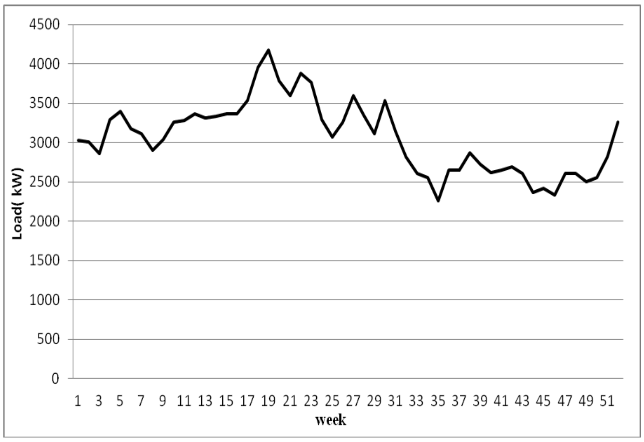

Figure 5: weekly load curve in main substation.

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			

Based on the provided data, the coefficient of minimum guaranteed price is determined for bus 3,7, 18, and 33. These coefficients are represented in figure (6).These coefficients are not related to the presence or absence of DGs, but are related to the load condition; so that the greater load levels lead to greater coefficients.figure (6) confirms this issue.as can be seen in figure (6), as the maximum load occurs during the week-19, this week's coefficient has the largest value compared to the other weeks coefficient.

The coefficient of the week-35 is the lowest coefficient in the year. Because the load has the lowest level in this week compared to the other weeks in this year.

It is also observed that, in all weeks the guaranteed coefficients at the buses which are further away from substation are higher than ones at other buses. Because DG placement at these buses have a greater impact on loss reduction.

CONCLUSION

This paper proposes a new method to determine the minimum guaranteed price of DG's energy with consideration their impacts on loss reduction .These prices are related to the wholesale market price and the impact of DGs on loss reduction. When the wholesale market price is not specified, the DisCo can determine the minimum coefficient of wholesale market price at each bus. These coefficients are just related to the configuration of the network and the loads in each bus.DisCo guarantees these coefficients at each bus. According to the results, the guaranteed coefficients at the buses which are further away from substation are higher than ones at other buses.

Also, the greater load level at each bus leads to a greater guaranteed coefficient.These pre-determined prices send investment signal to investor to install DG with optimal capacity at optimal buses.

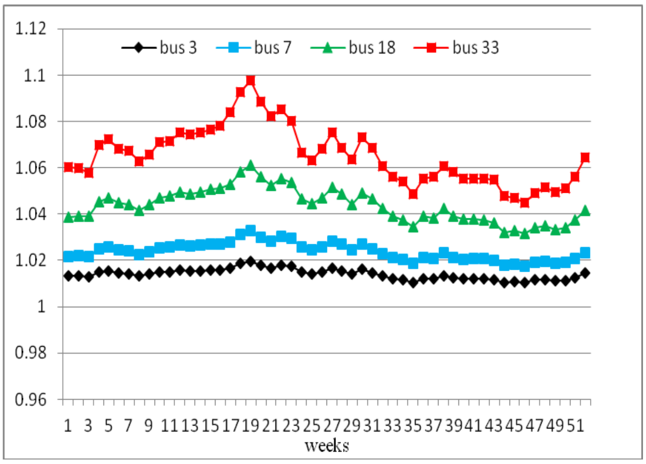

Figure 6: minimum guaranteed price coefficient.

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