DETERMINATION OF LOCAL PURCHASING PRICE FROM DGS IN DISTRIBUTION NETWORK BY DSO WITH CONSIDERATION OF THEIR TECHNICAL IMPACTS

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ABSTRACT

With presence of distributed generation (DG) in distribution networks, distribution system operators (DSO) have the options to purchase energy from DG units and/or directly from the wholesale electricity market. The utility's desired purchasing price of DGs energy depends on their impact on network, and wholesale market price. This paper proposes a method to determine DG energy price in short-term operation with consideration their impact on loss and reliability. The performance of the proposed approach is assessed by using 8-bus distribution network.

INTRODUCTION

Distributed generation (DG) can provide benefits to the distribution utility such as power losses and environmental pollution reduction, investments deferral, and reliability indices improvement [1]. Distribution system operator (DSO) 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, DSO 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[2]. For determination of DG energy price, DSO must weigh the wholesale market price with the potential benefits obtained from the dispatch of these units. In other word, the utility must determine DG energy prices so that send incentive signal to DGs which has positive impact on network.
With consideration of DGs impact just on loss reduction, the nodal pricing is proposed in [3] 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. in [3] the mutual impact of DGs on each other price is not considered. It should be noted that presence or absence of each DG in distribution network influence on effectiveness of other DGs. In other word, the effect of each DG on network is composed of two parts. First part which is just due to given DG, and second part which is shared with other DGs.
So, in this paper with consideration of DGs impact on losses, reliability, and their mutual effect, the DGs energy prices is determined in distribution network.

PROPOSED METHOD

As mentioned, the DGs energy price is determined according to their effect on reliability and losses. The effect of DG on loss is composed of two parts. Part of that is directly related to DG unit which is called self impact, and part that is associated with multiple DGs which is called shared impact (Figure 1).

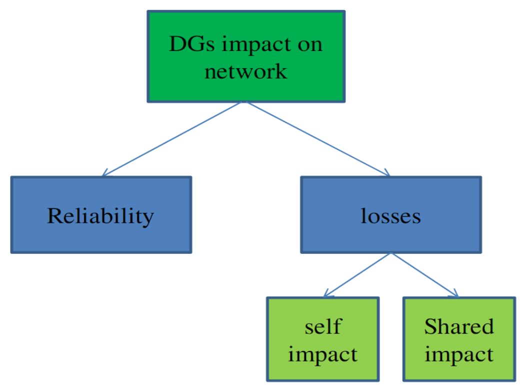

Figure 1: effect of DG on loss and reliability.

So, the energy price of DG which is located at bus i (λ_i) can express as:

$$\lambda_i = \lambda_{net} + \lambda_{loss,i} + \lambda_{re,i} \tag{1}$$

The first term (λ_{net}) is the wholesale market price. The second term (λ_{loss}) is associated with DG effect on loss, and the third term ($\lambda_{re,i}$) is related to effect of DG on reliability.
Loss term of price is composed of two parts; part which is related to self impact and part which is related to shared - impact.

Loss oriented pricing

With assumption constant power factor for DG, the current injection to bus i is expressed as follow.

$$I_{DG,i} = kP_{DG,i} \tag{2}$$

$$k = \frac{1}{V_i} \tag{3}$$

Which V_i is voltage at bus i, and $P_{DG,i}$ is DG power injection to bus i.
Without presence of DG in network, loss in section- J ($P_{loss,J}$) can be expressed as follow.

$$P_{loss,J}^{no-DG} = R_J I_J^2 = R_J (k_i P_J)^2 \tag{4}$$

Where, R_J is the ohmic resistance of section- J, I_J is current in section- J, and P_J is power flow in section - j.
With presence of DG at bus- i, and assumption unidirectional current, the current of upstream section of DG will be changed (will be reduced). So losses in section j change as follow.

$$P_{loss,J} = R_J (I_J^{no-DG} - \sum_{i=1}^{n} I_{DG,i})^2 \tag{5}$$

Where, I_J^{no-DG} is current in section- J without presence of DG, and $\sum_{i=1}^{n} I_{DG,i}$ is sum of DGs current which are located downstream of section- J. According to equation (4), the equation (5) can be expressed as follow.

$$P_{loss,J} = R_J (k_i P_J^{no-DG} - \sum_{\substack{i=1 \\ m \neq l}}^{n} k_i P_{DG,i})^2 \tag{6}$$

Equation (6) can be expressed as follow.

$$\begin{aligned} P_{loss,J} &= P_{loss,J}^{no-DG} + \sum_{\substack{m=1 \\ m \neq l}}^{n} P'_{loss,J} (P_{DG,m}) \\ &+ \sum_{\substack{m=1 \\ m \neq l}}^{n} P''_{loss,J} (P_J^{no-DG} \times P_{DG,m}) \\ &+ \sum_{\substack{i=1 \\ i \neq l}}^{n} \sum_{m=i+1}^{n} P'''_{loss,J} (P_{DG,i} \times P_{DG,m}) \end{aligned} \tag{7}$$

$$P_{loss} = \sum_{j=1}^{m} P_{loss,J} = P_{loss}^{no-DG} + P'_{loss} + P''_{loss} + P'''_{loss} \tag{8}$$

Where $P_{loss,J}$, $P'_{loss,J}$, $P''_{loss,J}$ are term of losses in section- j which are associated to each DG separately, each DG and network power flow, and multiple DG respectively, l is upstream bus of section j, and P_{loss} is total loss. It should be noted, due to unidirectional current assumption, each DG is impact just on upstream section.
According to [3], the loss term of DG energy price is determined as follow.

$$\lambda_{loss,m} = -\lambda_n \frac{\partial P_{loss}}{\partial P_{DG,m}} \tag{9}$$

According to equation (7) and (8) $\lambda_{loss,m}$ can be determined as follow.

$$\lambda_{loss,m} = -\lambda_n .(\frac{\partial P'}{\partial P_{DG,m}} + \frac{\partial P''}{\partial P_{DG,m}} + \frac{\partial P'''}{\partial P_{DG,m}}) \tag{10}$$

Where,

$$\frac{\partial P'}{\partial P_{DG,m}} + \frac{\partial P''}{\partial P_{DG,m}} = -2 \sum_{\substack{J=1 \\ J \neq s}}^{N} R_J k_m (k_j P_J - k_m P_{DG,m}) \tag{11}$$

$$\frac{\partial P'''}{\partial P_{DG,m}} = 2 \sum_{\substack{j=1 \\ j \neq s}}^{N} \sum_{\substack{i=1 \\ i \neq m,l}}^{n} R_j k_m (k_i P_{DG,i}) \tag{12}$$

$$\lambda_{loss,m}^{self} = -\lambda_n .(\frac{\partial P'}{\partial P_{DG,m}} + \frac{\partial P''}{\partial P_{DG,m}}) \tag{13}$$

$$\lambda_{loss,m}^{mult} = -\lambda_n \frac{\partial P'''}{\partial P_{DG,m}} \tag{14}$$

Where, s is downstream section of bus- m, N is the number of section, $\lambda_{loss,m}^{self}$ is the term of DG energy price whi*2ch related just to that DG effect. $\lambda_{loss,m}^{mult}$ is term of DG energy price which is related to multiple DG's effect. This term of price causes to reduction in DG revenue. So, we propose a method to allocate this term between DGs according to their location on feeder. For this purpose, the loss reduction index (LRI) is defined for each bus, and then $\lambda_{loss,m}^{mult}$ is determined as follow.

$$\lambda_{loss}^{mult,i,j} = -\lambda_n (\sum_{\substack{J=1 \\ J \neq S}}^{N} 2 R_J k_i . k_j (P_{DG,i} + P_{DG,j}) \tag{15}$$

$$\lambda_{loss,m}^{mult} = \sum_{j=1}^{n} \lambda_{loss}^{mult,m,j} \frac{1/f_m}{(1/f_m + 1/f_j)} \tag{16}$$

In above equations, s is downstream sections of bus i (i<J), $\lambda_{loss}^{mult,i,j}$ is the total shared impact which is allocated to DGs in term of price at bus i and j, f_m is loss reduction index (LRI) at bus m. LRI is between 0 and 1;

larger f_m indicate more important bus, f_j is DG downstream buses LRI which DGs are located at. In accordance with equation (16), most important bus will imposed less multiple negative impacts. So, the loss term price can be expressed as follow.

$$\lambda_{loss,m} = \lambda_{loss,m}^{self} + \lambda_{loss,m}^{mult} \tag{17}$$

Reliability oriented pricing

DGs will have impacts on Distribution networks reliability too. So, DSO will reward DGs with nodal pricing according their impact on reliability indices. For determination of reliability term of DG energy price, the hourly reliability worth is incorporate in the strategy proposed in this paper [4]. A time-varying failure rate $\gamma(t)$ can be obtained using the average failure rate in the normal weather condition weighted by the chronological variation of weather effect as follows:

$$\gamma\ (t) = f_{\gamma w}(t) \times \gamma_n \tag{18}$$

Where $f_{\gamma w}(t)$ is the failure rate weather factor at hour t, and γ_n is the average failure rate for the normal weather condition [4]. Similarly a time-varying restoration time $r(t)$ Can be calculated as follows:

$$r\ (t) = f_{rw}(t) \times f_{rd}(t) \times f_{rh}(t) \times r_n \tag{19}$$

Where r_n is the restoration time for the normal weather condition, $f_{rw}(t)$ is the restoration time weather factor, $f_{rd}(t)$ and $f_{rh}(t)$ are the restoration time daily and hourly factors, respectively, which represent the effect of available restoration resources determined by repair and switching experiences [4]. For determination of reliability oriented price, the hourly interruption cost $hc(t)$ of the loads is considered.

$$pc_{ij} = f(r_{ij}) \tag{20}$$

$$hc_{ij}(t) = f_{ch,i}(t) \times pc_{ij} \tag{21}$$

Where $f_{ch}(t)$ is the appropriate interruption cost hourly factor pc_{ij} is the per unit cost ($/MW) provide by sector customer damage function (SCDF)[4], r_{ij} is the outage duration, $f(r_{ij})$ is represented SCDF, and $hc_{ij}(t)$ is hourly per unit interruption cost of the load point i due to the failure event j [4]. With assumption equal $hc_{ij}(t)$ for all load point, the total customer damage cost ($TCDC$) at each hour can be expressed as follow.

$$TCDC = \sum_j \gamma_j(t) \times hc_j(t) \times (p_j + p_j^{'} - \sum_{\substack{i \\ i \neq s}} p_{DG,i}) \tag{22}$$

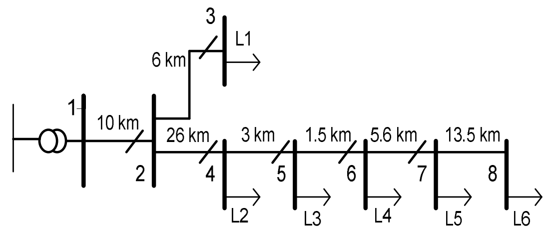

Figure 2: Rural distribution network

Where p_j and $p_j^{'}$ are the interrupted load downstream of section j and at section j respectively due to event at section j, and $\sum_i p_{DG,i}$ is the total of DGs power which are located downstream of section j. The reliability term of price can be calculated as follow:

$$\lambda_{re,m} = -\frac{\partial TCDC}{\partial P_{DG,m}} = \sum_j \gamma_j(t) hc_j(t) \tag{23}$$

Where j is upstream section of bus m.

CASE STUDY

The proposed method is tested using the 8-bus distribution system showing in Fig. 2 [5]. The line data are provided in the [5]. Load and wholesale market prices data are provided on table I. these data are provided for four hours. The DG units are denoted as DG1 and DG2 and are located in bus 6 and 8 respectively. Note that we are not addressing the problem of optimal location. Instead, it is supposed that these units have been located as a result of a previous optimization process carried out by the DG planner. Repair time, interruption cost, and loss reduction index are represented in table I and II.

Table I. load data

scenario	L1 (kWh)	L2 (kWh)	L3 (kWh)	L4 (kWh)	L5 (kWh)	L6 (kWh)	Wholesale price ($/MWh)
1	1020	488	542	76	547	379	24
2	1153	80	491	484	245	405	16.5
3	1457	488	542	76	547	379	14
4	2000	550	1060	376	646	247	22

Table II. failure rate and interruption cost

hour	Failure rate (failure/ hour.km)	$hc_j(t)$ ($/MW)
1	2.28×10^{-5}	2000
2	5.28×10^{-5}	1500
3	4.28×10^{-5}	500
4	2.28×10^{-5}	1000

Table III. LRI data

bus	f
1	-
2	-
3	0.2
4	0.05
5	0.05
6	0.3
7	0.3
8	0.1

Table IV shows DGs energy prices at each hour. It can be observed that $\lambda^{self}_{loss,DG1}$ is slightly higher than $\lambda^{self}_{loss,DG2}$ at all hours. It should be noted that power injection into bus-6 has more positive impact on loss reduction than power injection into bus-8. So DG at bus-6 make a greater contribution to power loss reduction than one at bus 8 and consequently its price (λ^{self}_{loss}) is higher than DG2 at each hour.

λ^{mult}_{loss} shows shared impact of loss reduction term of price which has a negative impact on each DG energy price. According to loss reduction index for each bus (table III) $\left|\lambda^{mult}_{loss,DG2}\right|$ is greater than $\left|\lambda^{mult}_{loss,DG1}\right|$. In other words, DG2 have been imposed to more negative impact of multiple impacts, because according to LRI, bus-6 is more important bus than bus-8.

Reliability term of price (λ_{re}) of DG2 is higher than DG1 at all hours, because DG2 is further away from the substation than DG1. So it makes a greater contribution to customer damage reduction than DG1 in events.

It can be seen that DG energy price (λ) at bus-6 is greater than bus-8 at each hours. It shows that DG1 is more valuable than DG2 at each hour from DSO point of view. Also DGs energy price is higher than wholesale market price at each hour which shows that DGs have positive impact on network at each hour. But this impact is varied in different hours due to loads and wholesale market prices changes. It can be seen that with increasing of wholesale market price, the DGs energy prices is increased, and higher wholesale market price lead to more increasing in DGs energy price.

CONCLUSION

DG units can provide benefits to the network through reduced line losses and reliability improvement. So, they should be appropriately rewarded through nodal pricing. A new method of DGs energy pricing is proposed in this paper. To determine these prices, the contribution of each DG in loss reduction and reliability improvement is used. It should be noted that loss term of price is composed of terms related to just self impact of given DG and multiple impacts of DG. These impacts are considered in proposed method. According to the results, DGs loss term of price in buses which have more positive impact on loss reduction is higher than other buses. Also DGs reliability term of prices in buses which are further away from substation is higher than other DGs. Because they lead to more number of customer damage cost reduction.

It should be noted that DGs energy price (λ) is higher than wholesale market price at each hour. The amount of variation from wholesale market is related to loads and wholesale market price.

Table IV: DGs energy price.

hour		λ^{self}_{loss}	λ^{mult}_{loss}	λ_{re}	λ
1	**DG1**	29.14	- 0.324	1.84	30.656
	DG2	27.87	- 0.972	2.102	29
2	**DG1**	17.64	-0.22275	3.207	20.624
	DG2	17.02	-0.66825	3.651	20.003
3	**DG1**	14.21	-0.189	0.8667	14.8877
	DG2	14.08	-0.567	0.98654	14.49
4	**DG1**	25.24	-0.297	0.9234	25.86
	DG2	23.82	-0.891	1.051	23.98

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