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Determining the guaranteed energy purchase price for Distributed Generation in electricity distribution networks

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ABSTRACT

With widespread installation of Distributed Generation (DG) in distribution networks and considering their impact on the network, distribution companies (DisCos) have the option of supplying loads from these resources as well as the wholesale market. In the presence of DG, an incentive scheme is required to determine the reasonable purchasing price of energy from DG owners based on benefits to the DisCos. These prices should be determined in such a way that the risk to the DisCo can be controlled. Considering the guaranteed energy purchase price (GEPP) of DG as a risk-management option, this paper addresses the GEPP for a specified future period. The proposed methodology determines the GEPP based on expected loss reduction and reliability improvement achieved by DG. Due to uncertainties associated with load, market price, and future investment, Monte-Carlo simulation is used to determine the GEPP. The performance of the proposed methodology is evaluated for a 33-bus distribution test system and results are discussed for different cases. The obtained GEPP guides investors and planners toward an optimum place and size for installation of DG, which leads to maximum network benefits as well as profits.

1. Introduction

Today, environmental issues, the high price of fossil fuels, and deregulation of power systems have drawn attention to the widespread use of DG near loads in distribution networks. In addition, developments in micro-generation, power electronics, and storage, have enhanced Distributed Generation (DG) utilization in power distribution systems (El-Khattam et al., 2004; LIANG et al., 2003; Ackermann et al., 2001).

In recent years, assessing the technical and economic effects of DG on distribution networks has been a topic of great interest in power-system research (Senjyu et al., 2008; Guerrero et al., 2010; Coster et al., 2011; Boutsika and Papathanassiou, 2008; Manfren et al., 2011; Martinez and Martin-Arnedo, 2009; QIAN et al., 2008; Balaguer et al., 2011; Ochoa and Harrison, 2011; Keane et al., 2011; Dash et al., 2012; Wang et al., 2014; Abu-Mouti and El-Hawary, 2011; Wolsink, 2012). Implementation of DG close to end users in electricity distribution systems can bring integral benefits to both customers and utilities. The most important benefit is reduction in bulk generation and transmission investments, including expansion costs. Some other benefits are lower investment risks, faster installation time, less power loss, reduced carbon emissions, and improved reliability, power quality, and voltage profiles (Algarni and Bhattacharya, 2009; Brown and Rowlands, 2009; Siano et al., 2009).

Thus, DG can be an economical and cost-effective solution for power generation in distribution networks. Motivating investors to further develop DG in distribution networks is a priority for some electricity distribution companies (DisCos). In this regard, incentive-based regulatory rules and financial (pricing) mechanisms are the main policies aimed at DG development. In Iran and in other countries, the DisCo is the retailer, and manager of the electricity distribution system (Williams and Ghanadan, 2006). Under this structure, the DisCo can supply the electricity demand of its network by purchasing power (energy) from any DG unit owned by an investor and/or directly from the wholesale electricity market at prices λ_n^h and λ_{DG}^h, respectively; this financial and energy transaction is shown in Fig. 1.

The DisCo must decide the amount of energy to be bought in the wholesale electricity market and from the DG units. The amount of power and the DisCo's purchasing price are related to the DG's impact on active loss reduction and the wholesale market price (López-Lezama et al., 2011). The DisCo must weigh the DG power price against the potential benefits obtained from dispatching these

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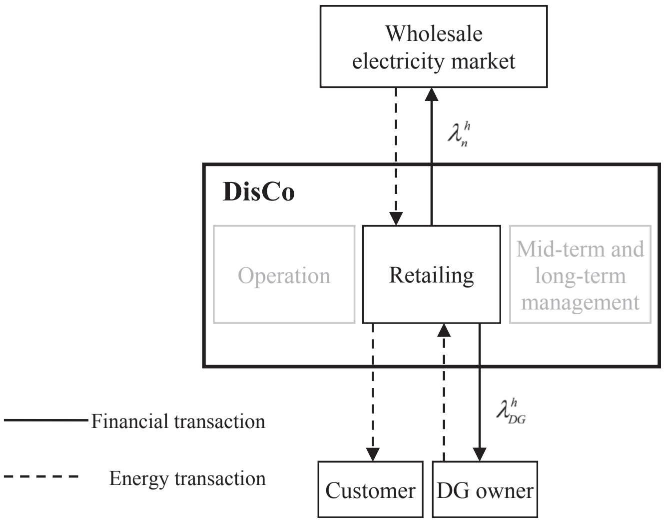

Fig. 1. Distribution Company retailing model in Iran.

units. For instance, if the power production of a DG unit has a positive impact, then the DG energy price should be slightly higher than the wholesale market price. Conversely, if the DG unit has a negative impact, its energy price should be lower than the wholesale market price (López-Lezama et al., 2011). These prices provide a mechanism to reward the DG investor who installs DG in optimal locations (López-Lezama et al., 2011; Sotkiewicz and Vignolo, 2006a, 2006b; Shaloudegi et al., 2012).

Appropriate nodal prices can encourage investors to connect their DG units at buses that lead to the most positive effects for the system. Sotkiewicz (Sotkiewicz and Vignolo, 2006a) proposed applying locational marginal pricing (LMP) in distribution systems. Other researchers (Shaloudegi et al., 2012; Sotkiewicz and Vignolo, 2007; MiriLarimi and Haghifam, 2012; Farsani et al., Hosseinian) have proposed alternative methods for applying this concept.

In all previous studies of which we are aware, real-time nodal prices were calculated considering existing DG at a certain place and size (operation capacity). However, it may be important for investors to know the energy price ($/kWh) that DisCo will pay to them for their energy production in the specified period and in the specified bus. One way that the DisCo can reduce investment risk is to effectively guarantee prices at each bus of the network. In other words, investors would be encouraged to install DG in pre-determined buses in the distribution network. We propose a methodology for determining the guaranteed price for purchasing energy from DG owners for a given future period. The proposed methodology considers the effect of each DG on reliability improvement and loss reduction.

In these regards, another important issue is investment dynamics. Due to the temporal and spatial intermittency of DG, different investment scenarios lead to different guaranteed prices for DG units. Monte-Carlo simulation modeling handles this intermittency challenge to GEPP determination.

The rest of the paper is organized as follows. In section 2 and 3 the structure of GEPP and , the proposed methodology for GEPP determination is discussed respectively. It is applied to GEPP determination for a standard 33-bus IEEE distribution test system and the results are discussed in section 4 and 5. Conclusions are provided in section 6.

2. The energy guaranteed purchasing price (GEPP) for Distribute Generation (DG)

Determination of a guaranteed price for purchasing electric energy from DG owners for a specified future period is a challenging issue for DisCo. From the viewpoint of the DisCo, the GEPP of each DG unit is determined based on its positive effects on the network. In addition, the effects of each DG unit on the distribution network depend on the DG place and its size. Therefore, depending on location and operating capacity, the GEPPs for DG units differ. Differential pricing will encourage DG investors to locate DG resources at appropriate places in the network.

To determine the GEPP, the DisCo must weigh the wholesale market price against the potential benefits obtained from dispatching these units. In other words, the DisCo must determine GEPP of each DG in order to send incentive signals to promote DG investment that have a positive impact on the network. For this purpose, the GEPP is determined based on DG effects on loss reduction and reliability improvement. Therefore, the GEPP is calculated according to the equation given by equation (1):

$$\lambda_i^g = \lambda^e + \lambda_i^{loss} + \lambda_i^{re} \tag{1}$$

where λ_i^g is the GEPP of the DG unit connected to ith bus, λ^e is the wholesale market price, λ_i^{loss} and λ_i^{re} are the price terms related to loss reduction and reliability improvement, respectively.

2.1. *Reflecting loss-reduction value in price*

Sotkiewicz et al. (Sotkiewicz and Vignolo, 2006a) used marginal active loss to determine active power nodal prices considering the DG impact on active loss. It has also been shown (Sotkiewicz and Vignolo, 2007) that this methodology leads to non-zero merchandising. Some researchers (Shaloudegi et al., 2012; Sotkiewicz and Vignolo, 2007) tried to solve this problem, but others (Larimi and Haghifam, 2013) have shown that these methods are inappropriate in distribution network, proposing instead a DG active price based on the value of loss reduction. According to this method, the negative impact of DG units on their nodal price is also considered. The actual value of DG in loss reduction can be determined based on average marginal cost according to the equation given by equation (2) (Majid Miri Larimi et al., 2015).

$$\lambda_i^{loss} = \frac{1}{2}\left(\lambda_{DG,i}^0 + \lambda_{DG,i}^p\right) \tag{2}$$

where, $\lambda_{DG,i}^0$ is the marginal loss cost with the assumption that the ith DG unit is the only one connected to the feeder, and $\lambda_{DG,i}^p$ is the marginal loss cost of the ith DG unit, with the assumption that all network DG units are connected to the feeder and are in operation mode.

2.2. *Reflecting reliability improvement value in price*

DG units also vary in terms of their contribution to reliability improvement. In the case of presence of several DG units in a distribution network, the contribution of each DG unit toward reliability improvement might be different based on its place and size. Determining each DG unit's share in reliability improvement is calculated by game theory from equations (3)–(6) (Larimi et al., 2013).

$$RII_i = \beta W_i + (1-\beta) w_i \tag{3}$$

where RII_i is the ith DG contribution in reliability index improvement, w_i and W_i are the minimum and maximum contribution of each DG in reliability index improvement which are determined by equation (4):

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