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# Active distribution networks planning with integration of demand response

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**Abstract**

This paper proposes a probabilistic method for active distribution networks planning with integration of demand response. Uncertainties related to solar irradiance, load demand and future load growth are modeled by probability density functions. The method simultaneously minimizes the total operational cost and total energy losses of the lines from the point of view of distribution network operators with integration of demand response over the planning horizon considering active management schemes including coordinated voltage control and adaptive power factor control. Monte Carlo simulation method is employed to use the generated probability density functions and the weighting factor method is used to solve the multi-objective optimization problem. The effectiveness of the proposed method is demonstrated with 16-bus UK generic distribution system.


*Keywords:* Photovoltaic cells; Uncertainties; Loss minimization; Demand response; Distribution network operators; Monte Carlo simulation

## 1. Introduction

### *1.1. Aim and approach*

Distributed generators (DGs) and renewable energy sources (RES) are supposed to develop the design and operation of distribution networks, which are evolving toward smart grids (SGs). The SG is defined as a grid which is able to deliver electricity to consumers in a smart and controlled way (The Modern Grid Initiative, 2007). In fact, the advantages of SGs are because of its ability to improve reliability performance and responsiveness of customers and to encourage customers and the utility provider to make better decisions. Therefore, demand response (DR), represents an integral part of SG (Saffre and Gedgein, 2010). The integration of DR needs communication systems and sensors, automated metering, intelligent devices and specialized processors. DR refers to programs implemented by utility companies to manage the energy consumption at the customer side of the meter (Ramanathan and Vittal, 2008). Both utilities and customers can receive the advantages of DR programs that can assist electricity markets to operate in an effective way, thus reducing peak demand and spot price volatility (Marwan et al., 2011). This paper provides a probabilistic multi-objective methodology for assessing the amount of PV power that can be injected into the grid and the energy losses of the lines with integration of DR considering active network management (ANM) schemes such as coordinated voltage control (CVC) and adaptive power factor control (PFC). The method simultaneously minimizes the total operational cost and the total energy losses of the lines from the point of view of DNOs over the planning horizon

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**Nomenclature**

*Indices*

- $b$ slack bus
- $i,j$ buses
- $g$ generator buses
- $l$ loads
- $t$ number of years

*Variables*

- $V_{i,t}$ voltage at bus $i$ and year $t$
- $\delta_{i,t}$ voltage angle at bus $i$ and year $t$
- $P_{g,t}/Q_{g,t}$ active/reactive power of PVs at each bus and year $t$
- $P_{b,t}/Q_{b,t}$ active/reactive power at slack bus at each bus and year $t$
- $T_{ij}$ tap magnitude of OLTC
- $\phi_{g,t}$ power factor angle of PVs at each bus and year $t$
- $P^{i}_{DR(l,t)}/Q^{i}_{DR(l,t)}$ active/reactive power decrement in demand response program for load demand $l$ at bus $i$ and year $t$

*Parameters*

- $w_1,w_2$ weighting factors
- $G_{ij}/B_{ij}$ real/imaginary part of the element in the admittance matrix corresponding to $i$th row and $j$th column
- $P^{i}_{l,t}/Q^{i}_{l,t}$ active/reactive power of load demand $l$ at bus $i$ and year $t$
- $C^{i}_{g,t}$ price offered by PVs to increase/decrease active power at bus $i$ and year $t$
- $C^{i}_{DR(l,t)}$ price offered by load demand $l$ at bus $i$ and year $t$ to decrease its active power schedule in the context of demand response
- $S^{\max}$ maximum solar inverter rating
- $V_i^{\min}/V_i^{\max}$ minimum/maximum values of voltage at bus $i$
- $\delta_i^{\min}/\delta_i^{\max}$ minimum/maximum values of voltage angle at bus $i$
- $P_{g,t}^{\min}/P_{g,t}^{\max}$ minimum/maximum values of active power of PVs at each bus and year $t$
- $Q_{g,t}^{\min}/Q_{g,t}^{\max}$ minimum/maximum values of reactive power of PVs at each bus and year $t$
- $P_b^{\min}/P_b^{\max}$ minimum/maximum values of active power of slack bus
- $Q_b^{\min}/Q_b^{\max}$ minimum/maximum values of reactive power of PVs at slack bus
- $\phi_g^{\min}/\phi_g^{\max}$ minimum/maximum values of power factor angles
- $T_{ij}^{\min}/T_{ij}^{\max}$ lower/upper values of the tap magnitude of OLTC

considering network constraints and uncertainties. The uncertainties related to solar irradiance, load demand and future load growth are modeled by probability density functions (PDFs). The stochastic nature of solar irradiance is modeled by Beta PDF and other abovementioned uncertainties are modeled by Normal PDF. Monte Carlo simulation (MCS) method is utilized to use the generated PDFs and the weighting factor method is used to solve the multi-objective optimization problem.

### 1.2. Literature review

Probabilistic approaches are utilized to handle various uncertainties in planning and operations of distribution network. In (Mokryani and Siano, 2013), the authors proposed a combined MCS and optimal power flow (OPF) to maximize the social welfare by integrating DR scheme considering different combinations of wind generation and load demand over a year. A stochastic formulation of load margin taking into account the uncertainties related to RES integration into the network is proposed in Haesen et al. (2009). In Choi et al., 2005, a probabilistic reliability criterion considering uncertainties related to component outage in the expansion planning is proposed. Moreover, the method minimizes the investment budget for constructing new transmission lines considering the uncertainties of the transmission system. In (Wangdee and Billinton, 2006), the MCS is used to combine the correlated load demands and wind power generations by using the multivariate distribution to choose random variables. The authors in Khorramdel and Raoofat (2012) proposed a stochastic programming approach for reactive power scheduling of a microgrid considering the uncertainty of wind power. In (Kirby, 2003), the authors presented that fast/emergency reserve can be provided by responsive loads such as residential and small commercial air conditioners. The control of residential heaters and pumps has been applied for managing daily peak demands in Heffner et al. (2006).

### 1.3. Contributions

To the best of our knowledge, no probabilistic method for evaluating the impact of ANM schemes and DR on operational cost and energy losses has been reported in the literature. The method allows the assessment of the amount of energy generated by PVs and the energy losses that can be reduced considering uncertainties and network constraints. The proposed probabilistic method can assist DNOs in evaluating the impact of PV integration in active distribution networks in terms of technical and economic effects. The method can be used by DNOs to better allocate PVs at more advantageous locations in terms of consumers' benefits and cost reduction, network constraints and reliability. Conventional planning of distribution