Optimal operation of distribution networks with high penetration of wind and solar power within a joint active and reactive distribution market environment

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HIGHLIGHTS

• A stochastic approach for active distribution networks operation.
• A joint active and reactive distribution electricity market at distribution level.
• Scenario Tree is used to model the uncertainties.
• Joint active and reactive optimal power flow to maximize the social welfare.

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Social welfare maximization
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ABSTRACT

In this paper, a stochastic approach for the operation of active distribution networks within a joint active and reactive distribution market environment is proposed. The method maximizes the social welfare using market based active and reactive optimal power flow (OPF) subject to network constraints with integration of demand response (DR). Scenario-Tree technique is employed to model the uncertainties associated with solar irradiance, wind speed and load demands.

It further investigates the impact of solar and wind power penetration on the active and reactive distribution locational prices (D-LMPs) within the distribution market environment. A mixed-integer linear programming (MILP) is used to recast the proposed model, which is solvable using efficient off-the-shelf branch-and-cut solvers. The 16-bus UK generic distribution system is demonstrated in this work to evaluate the effectiveness of the proposed method.

Results show that DR integration leads to increase in the social welfare and total dispatched active and reactive power and consequently decrease in active and reactive D-LMPs.

1. Introduction

1.1. Literature review and motivation

Utilization of renewable energy sources (RES) such as wind turbines (WTs) and photovoltaic (PV) cells are taking substantial attention around the world due to the economic and environmental concerns [1–5]. The intermittent behavior of wind speed and solar irradiance introduces technical challenges such as voltage stability, voltage deviation and power losses to distribution network operators (DNOs) [6,7]. DNOs have to introduce a reasonable operating strategy to model the uncertainties of electric loads, intermittent power generations of WTs, PVs, and the electricity price. Also, demand response (DR) has been introduced in [8] as an option to mitigate the impact of uncertainties and intermittencies of wind speed and solar irradiance and improving the system’s efficiency. DR is defined as the ability of consumers to alter their electricity demand in order to keep the reliability of system [9].

Under the deregulation of electric power systems, the integration of distributed generator (DG) and DR program is becoming the most beneficial way to provide ancillary services in power networks [10–12]. Ancillary services can be defined as a set of services required to support the transmission of electric power from supply to demand to maintain system security and reliability [13]. Ancillary services are classified as active power ancillary service (load frequency control) and reactive power ancillary service (voltage control) [14]. Most of the
researches are carried out about the impact of active power ancillary services as the main services in electricity markets at transmission level; for instance, Ref. [15] illustrates how frequency control constraints can be obtained and involved into a market dispatch algorithm. In [16] a new frequency control market is introduced in order to host frequency response reserve offers from both loads and generators. Ref. [17] introduces the flexible frequency operation strategy of power system with high renewable penetration in order to gain the flexibility of the power grids. Absence of reactive power ancillary services may cause voltage instability all over the power network and lead to voltage collapse which is the main reason of blackouts [18]. Supporting the reactive power ancillary services is considered as a part of distribution network operators’ (DNOs) activities.

In general, the reactive power markets can be cleared separately or simultaneously from active power markets. In reactive power markets, the market structure, payment mechanism and pricing model are main factors for determining the appropriate components of reactive power market [19]. Recently, most published papers have discussed the impact of reactive ancillary services in transmission systems; for example, in [20], a quadratic reactive power cost model for transmission system has been proposed to optimize reactive power procurement. Pay-as-bid pricing mechanism for reactive power market in the transmission system which take into account the local nature of reactive power during the clearing of reactive power has been introduced in [21]. In [22] active and reactive power markets at transmission level are implemented to present an interaction between energy market and reactive markets.

However, a few papers have discussed the reactive power market at distribution level. For instance, in [23], a settlement procedure for reactive/voltage ancillary services to minimize reactive power payment by DNOs. Ref. [24] discusses the application of a sustainable operational scheduling method which systematically focuses on a day-ahead active and reactive power markets at distribution level in order to dispatch active and reactive powers in distribution systems with WTs. The operation of distribution networks within reactive power

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