Active distribution networks planning with high penetration of wind power

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1. Introduction

1.1. Motivation and approach

The connection of large amounts of renewable energy sources (RES) to distribution networks introduces many technical and economic challenges to distribution network operators (DNOs). Therefore, DNOs have to develop a rational operating strategy taking into account dispatching distributed generators (DGs), interrupting loads, and purchasing power from the wholesale market while keeping the system security. DNOs, in some cases, play the retailers role which buy power on the wholesale market at volatile prices and sell it again at fixed tariffs to small consumers. DNOs and retailers are separate market entities with different purposes, networks, and sizes [1]. However, assuming that the objective of DNOs is to maximize their benefits, two different regulatory cases can be taken into account: 1) DG-owning DNO – allowed to own DG and can exploit the financial benefits brought by considering new generation as an option for the investment in distribution network, 2) Unbundled DNO – forbidden from DG ownership but can maximize benefits based on a number of incentives. European Directive 2003/54/EC defines the technical and legal existing restrictions among different market actors of European electricity markets. In particular, it forms the unbundling regulations that DNOs have to be unbundled from generation interests, thus, forbidding DNOs from DG ownership. It splits the electricity distribution from retail supply where distribution utilities are not responsible to sell power to customers [2,3]. By introducing DGs in distribution systems, the planning for investment in distribution networks to meet the future load growth and its related infrastructures can be deferred [4]. On the other hand, emerging active network management (ANM) schemes have proved to be advantageous for DNOs, compared to passive network management [5]. ANM schemes can increase the operation of the assets of network that allow the distribution networks to accommodate more DGs within the existing infrastructure and therefore, defer or avoid expensive network upgrades. The main ANM schemes include coordinated voltage control (CVC) of on load tap changers (OLTCs) and voltage regulators, adaptive power factor control (PFC) of DGs and energy curtailment [5–7].

This paper provides a novel approach for DNOs to evaluate the
amount of wind power that can be injected into the distribution network over the planning horizon considering: 1) capability curve of doubly fed induction generator (DFIG)-based wind turbines (WTs), 2) uncertainties related to the stochastic variations of wind power generation and load demand, 3) multiple-WT configurations and 4) ANM schemes including CVC and PFC. The method also characterizes the impact of the abovementioned factors on the distribution-locational marginal prices (D-LMPs). Multi-configuration multi-scenario market-based optimal power flow (MMMOPF) is utilized to maximize the social welfare (SW) considering abovementioned uncertainties. A distribution market model, called the DNO acquisition market, is presented here under a distribution market structure based on pool and bilateral contracts within DNO’s control area. It is assumed that WTs and loads are owned or managed by the DG-owning DNO [8]. Here, the DNO is defined as the market operator of the DNO acquisition market, which determines the price estimation and the optimization process for the hourly acquisition of active power [9].

1.2. Literature review

Lots of studies have been reported on the benefits of ANM and its applications. Some of them revealed implementations, and experiences of ANM [10,11], online ANM application [12,13], and ANM challenges for network operators [14]. The cost-benefit analysis of investments and operation costs for various combinations of ANM schemes and techno-economic evaluation are studied in Refs. [15–17] and compared with passive network management scheme. Generally, it is found that as the DG penetration increases, the investment costs of ANM schemes become more viable and justifiable. Also, several works have been carried out about the planning and operation of distribution networks with integration of DGs [18,19]. In Ref. [18], the authors proposed a cost based model to allocate DGs in distribution networks to minimize DG investment and total operation costs. In Ref. [19], a method for optimal placement of WTs in distribution networks to minimize annual energy losses has been proposed. However, these studies also did not consider the distribution market environment as well as the effect of multi DG-configurations which considerably impact the allocations and amount of connected DG capacity.

1.3. Contributions

The gap that this paper tries to fill is how the combination of multi-WT configurations and ANM schemes can impact on the total dispatched energy of WTs and D-LMPs within a distribution market environment. To the best of the authors’ knowledge, no stochastic method for the planning of active distribution networks within a distribution market environment considering multiple-WT configurations and capability curve of DFIG-based WTs and ANM schemes has been reported in the literature. The dynamic nature of the power system operation has not been taken into account in the conventional planning studies with integration of DGs. For example, in Refs. [5–7] and [20–22], the authors have not addressed the impact on the overall DG penetration level when one or more existing DGs are absent. Moreover, the presence of a distribution market environment has not been addressed in the abovementioned studies. One of the innovative contributions of this paper is proposing a novel MMOOPF-based planning approach which considers the operational status of WTs at the planning stage, and assesses the dispatched energy of WTs considering various multi-configurations within the DNO market environment which has not been addressed so far. It also provides detailed analysis and results on how multiple-WT configurations and ANM...
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