Optimal voltage regulation for distribution networks with multi-microgrids

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HIGHLIGHTS

• A fully decentralized approach to calculate voltage sensitivities is proposed.
• Participants approach final decision through a bi-level game bidding process.
• Microgrids are utilized to provide ancillary services of voltage control.
• The proposed method can be implemented in radial and weakly meshed distribution networks.

Abstract

With the increasing penetration of renewables, microgrid integration has been considered as one of the most promising approaches to enhance the utilizations of various types of energy resources in smart distribution systems. In the near future, with the higher levels of intermittent renewables are envisaged, the distribution network operators will face significant challenges to the control and operation of distribution networks dispersedly. Consequently, the development of effective and motivating ancillary service schemes in a decentralized way for executing real-time control and reducing calculation and communication burden is still in its infancy and needs to be researched. To address this issue, this paper explores an optimal voltage regulation method with the participants of multi-microgrids based on multiple agent systems. Without an arbitration agent, peer agents in the multiple agent system calculate voltage sensitivities by local and neighbourhood measurements only. In this paper, a bi-level game model is proposed for voltage control process. In the upper-level, the distribution network operator searches the reasonable incentive mechanism based on the Stackelberg game. In the lower-level, microgrids make voltage control strategies autonomously based on a static game among microgrids. In the proposed method, microgrids participate in voltage control in distribution networks as ancillary service providers while maximizing their own profits. Meanwhile, the distribution network operator reduces the infrastructure reinforcement and avoids unnecessary renewable energy curtailment. Finally, the feasibility and effectiveness of the proposed method has been demonstrated on a modified IEEE 33-bus system.

In this paper, all active, reactive and apparent power quantities have the units [MW], [MVAr], and [MVA] respectively.

1. Introduction

Due to the severe environmental pollution and decrease in primary energy, the dramatic increase of renewable energy resources (RESs) in distribution networks (DNs) has been significant, and expected to continue to increase. In the near future, with the higher levels of intermittent renewable energy resources are envisaged, the existing systems will not be able to get benefits from remaining excess capacity of dispatchable generation or other grids without network reinforcement. Consequently, the distribution network operators (DNOs) are expecting to face significant challenges to the control and operation of DN including protection, voltage and overloading, among which the voltage variation has been considered as one of the most significant issues [1–3].

In DN, controllable energy units, flexible loads and distributed storage systems, are normally installed dispersedly. Numerous voltage control methods combine coordinated control of controllable resources with traditional approaches, such as utilizing on load tap changers (OLTCS), shunt capacitor banks and network reconfiguration in a
recently, grid codes of many countries, such as Denmark, Germany, Italy and the UK, require distributed energy resources (DERs) to provide ancillary services of voltage control in DN. However, with the popularity of the electricity market, massive distributed resources installed in DN belong to different independent operators which cannot be controlled and dispatched directly by the DNOs. Therefore, DNOs need to define reasonable incentive mechanisms to motivate the independent systems to participate in voltage control. As independent systems, microgrids (MGs), entities that integrate DERs including DGs, loads, and distributed storages with inner management systems in a more decentralized way [19], can be considered as controllable cells of DN. DERs with power electronic devices in MGs have faster response than traditional OLTCs and capacitors, making MGs responsive in the event of dynamic variations [20]. However, the existing applications of MGs are mainly focused on economic operation and energy management to control the point of common coupling (PCC) power or optimize energy interaction among MGs [21-25]. The research of MGs providing ancillary services in DN is rare. In [25], MGs participate in DN energy management based on a bi-level optimization. In order to minimize the losses in DN, a day-ahead pricing mechanism is utilized to encourage MGs’ participation. However, the MGs have not been considered as independent operators [26].

In this paper, a fully decentralized voltage control method with the participants of multi-MGs is proposed based on a multiple agent system (MAS), applicable for radial and weakly meshed DN. MGs are motivated by incentives from the DNO to provide voltage supports while maximizing their own profits. The proposed method takes advantages of MGs to supply ancillary services of voltage control in DN, which can both reduce the investment of voltage regulating devices in DN and guarantee the profits of MGs during voltage control.

To summarize, the main contributions of this paper are as follows:

1. A fully decentralized method is proposed to calculate voltage sensitivities in radial and weakly meshed DN. Peer agents in MAS calculate voltage sensitivities by local and neighborhood measurements only.
2. A bi-level game scheme is proposed for the DNO and MGs. DNO and MGs calculate voltage sensitivities by local and neighborhood measurements only.
3. A bi-level game scheme is proposed for the DNO and MGs. DNO and MGs calculate voltage sensitivities by local and neighborhood measurements only.
4. MGs are utilized to provide ancillary services of voltage control in DN, which increases the effectiveness of energy and asset utilization.

The reminder of this paper is organized as follows: Section 2 presents a fully decentralized method to calculate voltage-power sensitivities in a MAS platform. Section 3 discusses the game bidding process of voltage control in electricity markets. Case studies are presented in Section 4, while Section 5 concludes this paper.

2. Decentralized voltage control based on sensitivities in radial and weakly meshed networks

Sensitivity analysis is one of the most common voltage control methods. Voltage sensitivity shows how much the nodal voltage changes with voltage as a result of a small change in a specific injection. The sensitivity of voltage to power injections is defined by the ratio of the change in voltage to the change in injection. Sensitivity analysis is used to determine the location and magnitude of voltage control actions. The sensitivity of voltage to power injections can be calculated using the following equation:

$$\frac{\Delta V}{\Delta P} = \frac{\partial V}{\partial P}$$

where $\frac{\Delta V}{\Delta P}$ is the sensitivity of voltage to active power injection, $\frac{\partial V}{\partial P}$ is the voltage sensitivity, $V$ is the nodal voltage, and $P$ is the active power injection.
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