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Editorial

Advances in Urban Power Distribution System

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1. Introduction

The urban power distribution system is one of the most complex artificial systems in the world. The expanding population and energy demand have brought expansive development space to the development of urban power distribution systems, but also brought many challenges. On one side, the high proportional renewable energy sources (RES) reduced the inertia of the power system, on the other side, the coordinated and reliable operation of the renewable energies is critical to the reduction in the greenhouse gas emissions. For example, in the European Union, the share of energy from RES rose from 14% in 2004 to 32% in 2008 for electricity consumption, where its goal is to achieve the net-zero greenhouse gas by 2050 [1].

In this context, the theoretical and practical studies in the control and operation of the urban power distribution system to help the application of advancing technologies is attracting more attention. Energy efficiency has been lauded as the primary strategy and motivation for stabilizing power systems for a long time. Currently, the carbon-friendly is fused into the operation of the urban power system and both the cost-effective and greenhouse gas reduction are promoted as the attractive energy alternative. To address the strategies to lower greenhouse gas emissions, the operation data, such as voltage and frequency, are first collected from the data acquisition system. Then, advanced technologies including the control strategies and coordinated operation of multi-energy sources are developed.

The articles solving the control and coordinated operation of the urban power distribution system follow the following general trend topics, such as:

- Operation of hybrid AC/DC urban power distribution systems;
- Measurement and data-driven approaches to improve the operation quality;
- Intelligent control for the reliable operation;
- Coordinated operation with high proportional renewable energies, flexible loads, and energy storage;
- Application of medium- and low-voltage level DC technology.

From a top view of the articles published, the issues of the optimal hybrid AC/DC typologies and improved control strategies, as well as the coordinated operation of urban power distribution systems under high proportional renewable energies, are predominant.

Based on the contributions presented in the articles, the technical challenges, opportunities, and solutions are concluded. In the following sections, Section 2 briefly summarizes the contributions of the published articles. Section 3 draws the conclusions and further research is indicated.

2. A Review of the Contributions for Addressing This Issue

Considering the large number of studies concentrated on the topics of advances in urban power distribution system, three primary applications are utilized to narrow this field and to better focus on the analytics, which includes:

- AC/DC topologies and data-driven applications;
- Intelligent control strategies within high proportional RES;
- Theory and method of a coordinated operation.

2.1. AC/DC Topologies and Data-Driven Applications

To improve the power flow of the distribution networks and reduce the power losses of the transmission lines, three major topologies, namely the AC, DC, and hybrid AC/DC structures, have been developed to integrate the critical modules, such as RES, distributed generation, flexible loads, and energy storage systems.

The paper named "Hybrid ac/dc microgrids—Part I: Review and classification of topologies" summarizes the characteristics of the AC and DC microgrids [2]. The hybrid AC/DC systems have become one of the most interesting approaches in the current urban power system. The coupled AC and decoupled AC architectures are epitomized where their advantages are suitable integration for photovoltaic (PV) generation, fuel cells, etc., no need for the synchronization of generation and storage, and simplified control strategy. Additionally, it also suffers from some drawbacks, such as lower reliability, higher control complexity, and protection differences between AC and DC architectures. It declares that the future tends of the hybrid AC/DC topologies are the power interface converters and their modularization, such as the dual active bridge based converters, which can be an interesting approach to connecting the AC and DC grids. In [3], some control strategies via VSC-based DC technology are proposed for urban power grid enhancement and modernization. The paper investigated the feasibility of converting the existing AC circuit to DC operation. In addition, proposing three operation modes to boost the power transfer capability of the critical transmission corridor and realize the flexibility of the urban power distribution system operation. In [4,5], the flexibility of the hybrid AC/DC structures is also discussed for different purposes, such as RES integration, the interconnection between the flexible loads and energy storage systems.

Based on these topologies, real-time measurement is required. To achieve the complete observability of the hybrid AC/DC system, the work in [6] investigates a method for the optimal placement of phasor measurement units. Specifically, utilizing the effective monitoring advantage, the data-driven methodology can be applied to address the detection of faults and prediction of the post-fault events. The work in [7] predicts the probabilistic voltage as the instability indicator thus, the preventive actions of the urban power distribution system can be carried out. The low-voltage hybrid AC/DC system is treated as the test-bed, the transient simulations are analyzed, and the results demonstrate the effectiveness of the data-driven application, as well as the voltage regulation.

2.2. Intelligent Control Strategies within High Proportional RES

The urban power distribution system within high proportional RES requires flexible control strategies since they need to control the microgrids and converters simultaneously and efficiently. A paper in [8] elaborates the levels of control strategies which can be classified as primary, secondary, and tertiary. The grid-forming and grid-following control are two effective strategies for islanding events and stabling the grid. The secondary control consists of centralized or non-centralized management, which focuses on compensating the voltage and frequency deviations in the grid. Moreover, the non-centralized control is more suitable for the distribution system since there is a variety of RES, such as roof-top PV modules and wind turbine loads. In addition, each component can be controlled separately without the requirements of the communications. The tertiary control manages the active and reactive power flow in the multiple microgrids and the utility grid, which is located at the microgrid central controller (MGCC).

Aiming at the diversity of the control strategies, the following two points of view can be concentrated:

- Tolerate plug-and-play capability of devices;
- Synchronization between the control strategies and the devices of the distribution system.

In research [9], a sectional droop charging control strategy is developed for electric vehicle aggregators. It can mitigate the charging power vibration while the electric vehicle is charging power. Therefore, the system inertia can be improved by applying this novel control strategy. The electric vehicle can be treated as the typical plug-and-play device that has individual attributes. The results also reveal that the frequency can be well regulated under different penetrations of electric vehicles compared with the conventional droop control.

2.3. Theory and Method of a Coordinated Operation

Apart from the aforementioned hybrid AC/DC topologies and control strategies, the coordinated operation can be a critical element for stable connection in the energy mix system. In the urban power distribution system, the energies and the loads tend to be a multi-period and multi-carrier energy system, which requires a coordinated control strategy to guarantee its regular operation. In the theory and method of a coordinated operation, the interdependency and heterogeneity of the energy mix system should be considered in complex scenarios.

To reach an overall optimum, some articles explore some state-of-the-art topics in this area. In the article [10], the authors solved the complex mixed-integer non-linear programming problem by decomposing the energy mix system into a PVbattery subsystem and a subsystem of conversion devices. The electrical–hydraulic–thermal–gas flow equations, the total costs, the self-consumption ratio, as well as carbon cost are constrained in the optimization. The tests on the whole-system optimal coordinated operation model demonstrate that the optimal operation strategies of storage and conversion devices can be determined by using the proposed tools.

The work in [11] explores the configurations of the microgrid clusters to increase the utilization of RES. A hybrid microgrid clustering architecture that is scalable and reconfigurable and a decentralized control method is proposed. Especially, the energy networking unit (ENU) is designed to interface the AC and DC system to form a hybrid microgrid clustering architecture. Considering the smooth mode switch and energy storage restrictions, the decentralized control strategy can achieve the autonomous power exchange for multiple microgrids. Both the islanded mode and grid-connected microgrid cluster cases emphasize that a higher energy cluster-compensation and cluster-consumption ratio can be realized.

As reviewed from the above articles, the coordinated operation of the urban power distribution system would most likely focus on the following highlights, including the novel hybrid AC/DC microgrid architecture and flexible control strategy, optimization modeling for the multi-variable power system. Recently, the advances using deep learning to solve coordinated operation problems have become another potential trend. The article in [12] uses multi-agent deep reinforcement learning to address these coordinated issues between automatic generation control controllers in multi-area power systems. By adjusting the coefficient of the controllers, the multi-agent deep reinforcement learning shows strong decision-making capabilities and control performance.

3. Conclusions

The discussions of the articles in this Special Issue provides an insight into the research progress and development of urban power distribution system from different perspectives. Three areas are collected to demonstrate the primary research directions including (1) AC/DC topologies and data-driven applications; (2) intelligent control strategies within high proportional RES; and (3) theory and method of a coordinated operation.

The urban power distribution system is an extremely complex and huge system that integrated different advanced technologies. Some research that can be further investigated in-depth are listed below:

- Novel scalable hybrid topologies and synchronized grid data measurement technology;
- Development of effective power interface converters;

- Optimization of control strategies to manage the multiple microgrids and stable the operation between the grid-tied and islanded modes under RESs;
- Robust real-time coordination operation strategy that simultaneously considers market demands and reduces carbon emissions.

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