Distributed EMPC of multiple microgrids for coordinated stochastic energy management

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HIGHLIGHTS

• Reducing the system wide operating cost compared to the no-cooperation energy management strategy.
• Maintaining the supply and demand balance within each microgrid.
• Handling the uncertainties in both supply and demand.
• Converting the stochastic optimization problems to standard quadratic and linear programming problems.
• Achieving a good balance between control performance and computationally feasibility.

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ABSTRACT

The concept of multi-microgrids has the potential to improve the reliability and economic performance of a distribution system. To realize this potential, a coordination among multiple microgrids is needed. In this context, this paper presents a new distributed economic model predictive control scheme for the coordinated stochastic energy management of multi-microgrids. By optimally coordinating the operation of individual microgrids, this scheme maintains the system-wide supply and demand balance in an economical manner. Based on the probabilistic forecasts of renewable power generation and microgrid load, this scheme effectively handles the uncertainties in both supply and demand. Using the Chebyshev inequality and the Delta method, the corresponding stochastic optimization problems have been converted to quadratic and linear programs. The proposed scheme is evaluated on a large-scale case that includes ten interconnected microgrids. The results indicated that the proposed scheme successfully reduces the system wide operating cost, achieves the supply-demand balance in each microgrid, and brings the energy exchange between DNO and main grid to a predefined trajectory.

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1. Introduction

Microgrid is emerging as a promising solution to overcome the challenges faced by conventional power systems. It provides a systematic approach to integrate distributed renewable energy sources, energy storage systems, as well as local loads into the existing power network [1,2]. The fundamental objective of a microgrid is to balance its electricity supply and demand, and maintain this balance in an economic way [3]. However, the inherent uncertainties in microgrid make this objective a challenging task [4,5]. These uncertainties occur in both supply and demand sides [6]. Due to the facts that the power output of renewable sources is naturally variable, and the small size of microgrid results in weaker smoothing effect of load aggregation. Because of these uncertainties, it is difficult to achieve a reliable supply-demand balance in an individual microgrid [7–12].

An attractive solution to the aforementioned challenge is the concept of multi-microgrids, that is, connecting multiple microgrids to a common distribution network. In this fashion, interconnected microgrids cannot only exchange energy between each other, but also share the capacity of their energy storage devices. In this way, for each individual microgrid, its local supply-demand balance can be improved and, hence, the customers can benefit from a more reliable power supply. In addition, by optimally controlling the energy flow among microgrids and distribution network, both microgrids and distribution network can benefit from lower operation costs.

This new picture has triggered the interest on multi-microgrids energy management, which has the ability to coordinate the
operation of multiple microgrids and distribution network, thus making them cooperate with each other for an overall optimal operation. To realize this synergy, some recent efforts have been made on the coordinated energy management of multi-microgrids [13–26]. In [13], the competitive situations of multiple microgrids were analyzed using bilevel programming, and the rules of the interaction between multiple microgrids and a large central production unit were determined in a bilateral contract. In [14], the optimal network topologies of multiple autonomous microgrids were identified, and the critical loads were allocated to appropriate distribution generators using the minimum spanning tree algorithm. In [15], both the distribution company and multiple microgrids were defined as independent systems, and a decentralized system-of-systems scheme was proposed to maximize the benefits of distributed network and multiple microgrids. In [16], a dynamic energy management strategy was proposed for the cooperative interaction of multiple microgrids and active distribution system. The strategy was formulated as a bi-level multi-objective optimization problem with the active distribution network in the upper level and microgrids in the lower level. In [17,18], multi-agent approaches were proposed to coordinate the operation of networked microgrids. In [19], a distributed convex optimization framework was developed for energy trading between islanded microgrids, the framework consisted of several islanded microgrids that exchange energy flows by means of an arbitrary topology. In [20], a scenario-based decentralized Markov decision process strategy was proposed to coordinate the operation of networked microgrids, which improved the efficiency of the distributed storages utilization. In [21,22], the distribution network operator and each microgrid were considered as distinct entities with individual objectives, and then scenario-based stochastic control schemes were proposed, which optimized the operation costs of both microgrids and distribution network. In [23], a stochastic cooperative dispatching scheme of interactions among networked microgrids was proposed, with the aim of minimizing the expected network operation cost. In [24], a sampling-based scheme was presented to determine the optimal economic operation of multiple microgrids, the corresponding optimization problem was solved using the particle swarm optimization algorithm. In [25], an interactive control framework for the interconnected microgrids has been developed, which achieved effective load sharing and guaranteed system-wide stability. In [26], the online dynamic security assessment of multiple coupled microgrids was studied.

After reviewing the above existing works, it is noted that there are three trends in the development of multi-microgrids energy management. The first one is the economic energy management, which minimizes the operation cost of the entire system. The second one is the decentralized control architecture, which provides autonomy to each individual microgrid. The third one is the stochastic modeling and optimization, which handles the uncertainties in microgrids. However, in terms of the control system architecture and the stochastic optimization, there are still some limitations in the existing works. First, in a fully decentralized control system, several microgrids may compete with each other, thus degrading the system-wide performance. In view of this, a distributed, rather than a decentralized control architecture, is more appropriate. Because in a distributed control framework, each local controller considers the system-wide impact of its local control actions. This way, multiple microgrids will cooperate, rather than compete, with each other. Second, in the majority of existing works, the uncertainties in microgrids are handled using scenario or sampling-based approaches, thereby suffering from computational difficulties. This calls for a computationally efficient stochastic optimization algorithm, which enhance the practicality of the energy management system.

Considering the requirements of economic and distributed, distributed model predictive control (DMPC) and economic model predictive control (EMPC) appear to be appropriate frameworks.
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