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Decentralized self-discipline scheduling strategy for multi-microgrids based on virtual leader agents

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ABSTRACT

A decentralized self-discipline scheduling strategy based on virtual leader agents is proposed for the coordination of microgrids and distributed generations, which has incorporated the optimization for tie-line power, distributed consensus λ-iteration algorithm and reference tracking under the framework of multi-agent system. Using synchronous ADMM algorithm, the sub-optimization problems coupled with boundary constraints are transformed into decoupled sub-optimization problems. With the help of virtual leaders, both the scheduling of distributed generations and that of interconnected microgrids, are integrated. That is, it can infinitely approach to global optimization obtained by traditional centralized algorithm. On the other hand, it can avoid the sharing of participants' private information and the need for a control center with a dedicated wide-area communication network. Finally, an actual study case with 5 microgrids verifies the effectiveness and robustness under various uncertainties of the proposed scheduling strategy.

1. Introduction

With the advance of renewable energy utilization technologies, a number of distributed generations (DGs) have been connected to the power system, where remarkable economic and social benefits can be obtained. While microgrid (MG), a localized cluster of loads, DGs and battery energy storage systems (BESS), paves a way to effectively integrate various sources of DGs, especially renewable energy sources (RES). Nowadays, MG has been promoted widely in many countries. As a result, multi-MGs system is becoming one of the forms of large-scale utilization of RES inevitably.

However, the increase of distributed devices creates difficulties to information interaction and global control, which brings unprecedented challenges to traditional centralized control strategy. The disadvantages of traditional scheduling strategies can be summed up as follows:

1) The required functions, such as global optimization, point-to-multipoint communication and vertical control for all distributed components, are ambitious to be deployed in large-scale and wide-area DGs access.
2) Due to the strong stochastic and time varying characteristics, rolling correction and dynamic optimization are essential in multi-MGs dispatch. However, under centralized scheduling strategy, these are difficult to achieve satisfactory tracking performance limited by communication delay and server capacity.
3) Centralized decision is unable to effectively protect the privacy of controlled objects.
4) The interests of all participants cannot be properly considered and the total revenue is difficult to be allocated fairly.

In recent years, distributed synergetic scheduling strategies featuring with plug-and-play are drawing much more attention. The European Integrated Research Programme puts forward the concept of 'Web of Cell' on International Conference of Power Engineering [1]. In this framework, a 'cell' is defined as interconnected flexible combinations of DGs within a certain power or geographical boundary [2,3]. Through practicable information sharing between cells, peer-to-peer decentralized decisions are made and global optimization is realized. In addition, it can make effective adjustments in time to respond to internal fluctuations of RES and load, where dynamic collaboration within 'cell' is realized.

On the other hand, scalable architecture not only gives a plug and play individual interface for new devices, but also significantly improves system reliability. The communication between two points in a temporary interruption does not affect the stability of the system, which avoids the collapse of control system caused by the centralized controller failure for human attack [4]. As a result, the distributed scheduling with self-discipline intelligence is the preferred method applied

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in the multi-MGs system.

So far, some research has been carried out on the above problems. Traditional centralized strategies, such as bi-level dynamic energy management strategies, are designed in Refs. [5,6] to cooperate the interaction of multi-MGs and distributed network. In the aspect of distributed scheduling, consensus algorithms are widely used in distributed on-line energy management of interconnected MGs [7,8] and the algorithms are extended in grid-connected mode [9]. In addition, electric vehicles and market transaction behaviors are considered in Refs. [10,11] respectively. ADMM has found a large number of applications in diverse areas such as compressed sensing [12], machine learning [13], image processing [14], regularized estimation [15], and detecting the identity of false data-injection attackers [16]. This broad range of applications has triggered a strong recent interest in developing distributed optimization in microgrids [17,18]. However, existing literature lacks the consideration of tie-line losses in the ADMM objective function of wide-area interconnected MGs. Besides, only scheduling orders are optimized in most literature, how to coordinate each participant to track the reference is still a problem to be solved. Refs. [17,18] propose multiagent-based microgrid control schemes using a fully distributed strategy, whose lower level implements a distributed pinning droop control and upper level implements distributed neighboring communication for energy management. However, there is lack of a general way and more deeper investigations in the decentralized energy management of interconnected MG.

To solve the above problems, this paper proposes a novel decentralized scheduling strategy for multi-MG based on virtual leader agents, which consists the distributed optimization for tie-line power among multi-MGs, distributed lambda iteration and decentralized reference tracking control. Compared with related works, our strategy has some improvements in different aspects. The contribution comparison between our paper and related works is shown in Table 1.

Ref. [19] provides a method for BESS to adjust tie-line power, while it fails to coordinate other adjustable DGs via rolling correction. Adjustable DGs are controlled by day-ahead scheduling curve. Ref. [20] proposes a centralized optimization for active distribution network. It does not give a reference tracking scheme either. Ref. [21] considers transmission losses in distributed economic dispatch. However, it defaults that the target system is an isolated system and there is no tie-line power to be optimized or tracked. This paper analyzes the decentralized scheduling for interconnected MGs in depth. Transmission losses is considered in tie-line optimization and we design distributed consensus Lambda algorithm with virtual leader to reconcile the objectives of tracking tie-line power and rolling optimization. What's more, we design a second-order consensus algorithm to accelerate reference tracking.

The key contributions of this paper are fourfold:

(1) Based on the hierarchical multi-agent design of multi-MGs, sub-gradient method and synchronous alternating direction method of multipliers (SADMM) are developed in the distributed optimization for tie-line power to deal with energy management of interconnected MGs. (2) Discrete consensus algorithm with virtual leaders is designed for lambda iteration. Brought into full play the rapidity of virtual leaders, the adjustment is not only economic but also fast. (3) High order continuous consensus algorithm is designed for rapid reference tracking. It has higher sensitivity and easy to cooperate with lambda iteration. (4) The stability and convergence proof of distributed algorithms is given in this paper and the results of the distributed optimization converges to the global optimal solution under the condition that only a small amount of information interaction is required.

This paper is organized as follows: in Section 2, as the foundation of decentralized scheduling, a hierarchical multi-agent architecture for multi-MG is designed. In Section 3, based on sub-gradient descent algorithm and SADMM, we propose a distributed optimization for tie-line power in multi-MGs. In Section 4, with the help of virtual leadership, all DGs in a MG can be scheduled automatically under the principle of marginal cost consistency. In Section 5, decentralized reference tracking control is realized via second-order consensus iteration. Section 6 generalizes the links of the above methods. Finally, in Section 7, an example of multi-MGs system demonstrates the effectiveness of this strategy.

2. Multi agent architecture for multi microgrid decentralized scheduling

Multi-MGs system, composed of multiple interconnected MGs, offers an effective means to seamlessly integrate wide-area loads, DGs and BESS, where notable gains can be obtained by energy interaction. Our target systems are the medium-sized energy systems. With the high penetration of DGs, many small power distribution systems are equipped with adjustable DGs on user side and uneven load distribution leads to the widespread distribution of multiple MGs. This generates the demand for self-discipline energy interaction optimization and distributed scheduling in MGs.

MAS is a computerized system composed of multiple interacting intelligent agents and its intelligence may include methodic, functional, procedural approaches or algorithmic search. Each agent has adaptability and can be used to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve [22,23]. In this paper, a decentralized self-discipline scheduling strategy based on multi-agent consensus is proposed, which can effectively coordinate all the adjustable resources automatically. The specific functions of 4 kinds of multi agents are:

Management agent (MA): Synergistic agent between bulk power system and multi-MGs system. As a connection agent with bulk power system, it has 3 functions. Firstly, it can receive the control signal from administrators directly and realize mode switch via interconnection switch control. Secondly, as a virtual microgrid control center to simulate the bulk power system, MA collects the time-of-use price from power system and regard it as the fixed marginal cost to interact with other MGs. Thirdly, MA is equipped with a fault-knowledge base and has the ability to manage emergency initiatively.

Microgrid control center agent (MGCCA): Coordinator for local MG and neighboring MGs. Tie-line power optimization is carried out with the local MGCCA and adjacent MGCCA. In addition, in the process of solving sub-optimization problems, the boundary state information

Table 1
Contribution comparison between our paper and related works.

Y/N	Method in Refs. [5,6,19]	Method in Refs. [7,8,20]	Method in Ref. [21]	Proposed method
Fully decentralized	Y	N	Y	Y
Consider transmission losses	N	N	Y	Y
Tie-line power tracking	Y	Y	N	Y
Dynamic economic adjustment (Rolling optimization)	Y	Y	Y	Y
Fast reference tracking	N	N	N	Y