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Multi-agent-system-based coupling control optimization model for micro-grid group intelligent scheduling considering autonomy-cooperative operation strategy

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ABSTRACT

The paper introduces multi-agent system (MAS) for intelligent scheduling model of multi-MG autonomy-cooperative operation. Firstly, wind power plants (WPPs), photovoltaic generators (PVs), conventional gas turbines, energy storage systems (ESSs) and controllable loads (CLs) are integrated into MGs with the price-based demand response (PBDR). Then, a 3-layer coordinate control system framework is designed for MGs, namely, a distribution management system (DMS), an MG central controller and MG controllable elements. Further, the influence of ESS modes on MG operation is discussed, namely, the longest life cycle (LLC) mode and the optimal economic efficient (OEE) mode. Finally, MORE MICROGRIDS project in Europe is taken as simulation platform. The results suggest: (1) the proposed strategy can be applied to the optimal scheduling of MG operation both in grid-connected and island modes. (2) Different ESS modes directly affect MGs scheduling, with the OEE mode optimizing MGs scheduling and with the LLC mode ensuring the ESS life cycle. (3) PBDR can smooth the load demand curve for promoting the output of WPPs and PVs. Note that the PBDR can stronger improve the MG operation in the ESS's LLC mode, because the output of the ESS in the LLC mode is lower compared with the OEE mode.

1. Introduction

Large-scale centralized power generation, long-distance power transmission, and large grid interconnection form an efficient industry chain to ensure power generation, transmission and distribution, allowing to transmit power at a limited power loss rate and thus improve the energy efficiency of these energy generation devices. However, large grid centralized power generation systems are not robust with respect to sudden disasters, fault accidents, and human errors [1]. A micro-grid (MG) refers to a small-scale power generation and distribution system, which consists of a distributed energy source, a load, an energy storage device, a converter, monitoring devices, and protection devices [2]. The MG is a kind of a self-controlled, self-protected and self-managed system that is connected to the public grid through a static switch, which allows to switch the MG operation mode between the grid-connected and island modes [3]. Using MGs can reduce the negative effects of distributed energy output intermittent on the distribution network by improving operation control and energy management technology, which makes MGs one of the most effective approaches to using distributed energy [4]. Therefore, research on the energy coordinate control of MGs has important theoretical significance and practical value for optimizing the use of distributed energy.

The concept of MGs attracts domestic and foreign attentions. In 2007, Holland established a smart grid program constituted by 10 co-generation of heat and power (CHP) units [5]. United States Virginia Tech University proposed the plan of sustainable building initiative for supplying power to Buildings [6]. Cassel University integrated wind turbine, solar photovoltaic system, biogas power station and hydro power plant into MG [7]. From 2009 to 2012, Denmark and Germany established electric vehicle in a distributed and integrated market using sustainable energy and open networks program [8]. In 2013, Japanese sakura internet formally launches server cabinet with dc power supply system in data centre [9]. In 2014, the wind-photovoltaic-hydro distributed demonstration project of China national electric power group corporation successfully connected into the grid and operate in Yunnan province [10]. From 2010 to 2015, Europe finished WEB2ENERRGY program,

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implemented intelligent energy management and power distribution automatic technology in smart power distribution [11]. In 2017, China has established 28 demonstration projects for new energy microgrids, which will bring 899 MW of new PV installations and more than 150 MW of new electric energy storage capacity [12]. Future, how to achieve the energy coordination control of multi-MGs is the key problems for MGs development.

Generally, the energy coordinate control is accomplished in either distributed energy cooperative operation or non-cooperative operation [13]. In the cooperative scenario, MG manager builds an optimal scheduling model of MG operations based on an intelligent algorithm [14]. In the non-cooperative mode, each distributed energy source has its own operation objective, which is different from the overall MG operation objective. Then, it is difficult to achieve algorithm-based centralized control and management of MG [15]. The existing related literature mainly considers a central agent as the control and decision centre of system, for coordination and optimization of different distributed energy sources. However, if this central agent fails, the safety of the MG operation cannot be guaranteed [16]. Multi-agent systems (MASs) are autonomous and light, and can be used to control scattered and complex MGs. Karavas et al. [17] designed a multi-function MAS to achieve failure self-healing for smart grid, including control functions, agent configuration, communication program architecture, agency operations and other rules. Mohammad et al. [18] proposed a new MAS control system for distribution network fault self-healing with distributed generator. Xi et al. [19] designed a MAS-based self-healing solution by using the blackboard model to coordinate the interaction between the various organizations. Vitor et al. [20] designed, developed and implemented a multi-agent systems for the intelligently management of distributed smart grids in real time. Therefore, developing MAS-based methods to achieve energy coordinate control for safe MG operation is very important.

When MGs operates in the non-cooperative operation mode, differences among the objectives of the component distributed energy sources and the overall MG objective preclude centralized control and management of MG. Rahman et al. [21] builts a multi-agent system that consisted of an MG control agent, a local control agent, a distributed energy agent, and a load agent. Logenthiran et al. [22] designes a public communication interface using the proposed multi-agent system, which achieved agents' communications and MG energy control. The above two literature adopt the centralized structure of MAS, which could achieve the high consistency of system information and promote system control coordination and integrated management, but hardly to solve the system decision control problem with more agents. Local failure has a greater impact on the overall situation. Karavas et al. [23] builts a 3-layer multi-agent system that contains a distributed energy layer, an MG layer, and a distribution network layer. Using this system, an MG was controlled by switching its' operation mode between the grid-connected and island modes, and other grid-connection operations could be performed. Djamel et al. [24] proposes a MAS for management of a wind-photovoltaic system with a fully distributed structure; the system considered both the MG overall objective and individual objectives of the component distributed energy sources. The above two literature adopt the distributed structure of MAS, which could improve the stability and flexibility of system control, but different agents makes the decision with the local information for achieving local planning objective. The willing, beheavior and objective of different agents are difficult to guarantee. Rahmani et al. [25] builts a 3-layer multi-agent system that consisted of an upper grid agent layer, an MG agent layer, and an element agent layer, realising flexible scheduling with the coordinated control of the constituting agents. Lagorse et al. [26] studies the implementation of the autonomy principle for MG energy management. In their study, the mixed structure of MAS is adopted, the distribution of energies and loads was locally controlled, system safety and stable operation were guaranteed, and agents in the system were relatively autonomous. However, the different operation modes of MGs and ESS are ignored, which should be further discussed and given more analysis.

The above studies have provided in-depth discussion of the problem of the energy coordination control of MGs. However, some issues still need to be addressed for optimal scheduling of MG operation. Firstly, most published research studies consider optimal scheduling problems for the cooperative case, and many methods have been proposed to address this problem. Yet, these methods can only solve energy coordination optimization problems assuming cooperation, but are not suitable for non-cooperation scenarios. MAS technology could solve the coordination problem for multi-agent non-cooperation case, which need further discussion. Secondly, some papers discussed the energy coordination problem for the non-cooperative case, and offered some MAS-based energy control strategies to solve the coordination problem among the upper grid, MG, and MG components. However, there has been no discussion about the problem of coordinated optimization of multiple MGs. Finally, most of the existing studies consider WPPs, PVs, conventional gas turbines (CGTs), energy storage systems (ESSs), and controllable loads (CLs, mainly interruptible load, corresponding to the incentive-based demand response) as MGs, but ignore the optimization effect of price-based demand response (PBDR) on the operation of MGs. Meanwhile, a typical ESS has two operation modes: the longest life cycle (LLC) mode and the optimal economic efficient (OEE) mode; this can directly affect the optimal operation of MGs. Taken together, the above considerations motivated us to design and propose an intelligent energy control strategy for cooperative operation of multiple autonomous MGs, considering the PBDR and different ESS operation modes. The main contribution of this work is threefold:

- WPPs, PVs, CGTs, ESSs, and CLs have been integrated into MGs and price-based demand response was implemented for optimizing the customers' power consumption behavior on the demand side. Correspondingly, dedicated agents were assigned to the different power sources to coordinate the operation of these sources. The effect of PBDR and different ESS operation modes on the cooperative operation of autonomous MGs is discussed.
- The study has proposed a 3-layer framework for coordinated control of MG(s). The layers are: the distribution management system (DMS) agent layer, the MG central controller (MGCC) agent layer, and the MG controllable elements (MGCE) agent layer. Then, a multi-agent energy coordination algorithm has been also constructed for ensuring coordinated control of MGs. This algorithm addresses the multi-agent interactive mode, regional autonomy, and global autonomy.
- Four simulation scenarios were considered for comparative analysis of the effect of PBDR, ESS's operation mode, and MGs operation status on the performance of the entire system. The contract network agreement under the FIPA97 specification has been taken as the interactive mode among the agents. Java agent development environment (JADE) was used for designing a MAS, and European Union's (EU's) MORE MICROGRIDS project was used for simulation-based analysis of the proposed intelligent scheduling mode.

The rest of this paper is organized as follows. Section 2 has described the structure of MGs that include WPPs, PVs, CGTs, ESSs, and CLs. In Section 3 we have introduced the multi-agent system,