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A multi-agent-based energy-coordination control system for grid-connected large-scale wind–photovoltaic energy storage power-generation units

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Abstract

A multi-agent-based energy-coordination control system (MA-ECCS) is designed for grid-connected large-scale wind–photovoltaic energy storage power-generation units (WPS-PGUs) to address the challenges of low operation efficiency, poor stability, and complex decision making. The proposed system adopts the negotiation model of the contract net protocol with the non-fixed client–server cooperative mechanism among agents. When the power supply and demand are imbalanced, the system selects the state-changeable agent as the task initiator according to the load balance principle. In the energy-coordination process, the proposed system solves the global optimal-energy distribution plan of the system by considering the self-constraint and control objective of each agent and by using the improved particle swarm algorithm to achieve the maximum economic benefit on the basis of stable operations. The paper presents the overall design idea of the system, the agent models of different equipment, and the global energy-coordination optimization algorithm. An example is given to discuss the behavior characteristics of the agent and communication negotiation process and to verify that the system designed in this paper can realize the energy-coordination dispatching flexibly and efficiently. The method adopted by the system can improve the overall operation efficiency and economic benefits of WPS-PGUs.

Keywords: Wind–PV energy storage; Energy-coordination; Contract net protocol; Particle swarm algorithm

1. Introduction

The development of clean energies such as wind power and photovoltaic power has motivated many experts to study wind, photovoltaic, energy storage, power generation, and energy-coordination control systems. However, the operation process of large-scale wind, photovoltaic, energy storage, and power-generation units often suffer from low operation efficiency, poor stability, and lack of energy-coordination control strategies. Various countries around the world have successively conducted a number of demonstration projects showing improved intermittent power controllability by using energy storage technology (Campoccia et al., 2009; Mohammadi et al., 2012; Askarzadeh, 2013; Merei et al., 2013; Bayod-Rújula et al., 2013). Such tests are done in the peak and valley adjustments (Li et al., 2012) and in the adjustment and

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improvement of power quality (Golovanov et al., 2013). In terms of energy-coordination control, the United States, Spain, and Denmark can optimize wind power and photovoltaic power under existing economic leverage on the basis of perfect electric power market mechanisms. By contrast, developing countries with backward market mechanisms are inexperienced in energy-coordination control. Therefore, the design of the energy-coordination control system can be applied to large-scale renewable-energy power-generation units to optimize output according to the distribution characteristics of natural resources. Furthermore, the output characteristics of the power-generation equipment are conducive for improving the power supply reliability and economic benefits of the power-generation unit and for promoting the development of energy sustainability.

Traditional grid-connected energy-coordination control of wind–photovoltaic energy storage generation plant uses a centralized energy management strategy based on intelligent control algorithm. With the increasing construction of wind farms and photovoltaic arrays, as well as the increasing adoption of composite energy storage systems, the defects of the centralized energy control method in flexibility and extensibility hinders the operations of large-scale integrated power-generation systems for wind, photovoltaic, and energy storage units. The multi-agent system, which responds intelligently and flexibly to changes in working conditions and requirements, has been widely applied in various aspects of the power system (Kremers et al., 2013; da Rosa et al., 2012; Pipattanasomporn et al., 2012).

To date, the MAS-based energy-coordination control strategy mainly includes the optimal scheduling strategy based on the intelligent algorithm and the competition coordination strategy based on free market trading. The former provides the overall optimization objectives of the system and the constraints of the equipment, provides the equipment operation parameters and real-time load demand, and determines the energy-coordination scheme with the intelligent algorithm. For example, by reducing the operating costs and NO_x emissions as the objectives, Roche et al. (2012) considers economic and environmental constraints in the design of a MAS-based energy management system for a gas turbine power plant and validates the flexibility and efficiency of the system by providing an example. Jun et al. (2011) uses the minimum cost and operation reliability of the system as objectives to propose a solution for MAS-based distributed renewable-energy hybrid power-generation systems. The solution designs the behavior of the agent with the operation characteristics of the equipment and realizes a large MAS system based on the JADE environment, thus proving the rationality of the MAS in the energy-coordination control of the renewable-energy hybrid power-generation system. By using high fault tolerance, openness, and adaptability as the objectives, Lagorse et al. (2010) adopts the bottom-up approach to design a MAS-based distributed power-generation management system and verifies by simulations that this system is more efficient in handling problems than centralized energy management systems. Jiang (2008) uses high energy density, power density, and combustion efficiency as the objectives to design a MAS-based hybrid-power energy-coordination plan and proves the high efficiency and robustness of the system by simulations. Logenthiran et al. (2011) uses the minimized operation cost as the objective to design the energy-coordination strategy of distributed power-generation under an isolated environment based on MAS. The system uses three-stage energy dispatching strategies to maximize the use of renewable energies, to meet the demands of each independent micronetwork system and the overall requirements, and to minimize operation costs.

The free market trading-based competition coordination method simulates the tendering/bidding/bid winning mechanism. Each output equipment bids for the tendering control unit, and the tendering control unit achieves energy coordination based on the competitiveness of the bidding unit. For instance, Logenthiran et al. (2008) sets the market operator as the internal consultation control center under a microenvironment in the energy market. Dimeas and Hatziargyriou (2005) establishes three layers of control system under the micronetwork environment and designs MO, MGCC, and other agents to manage the internal consultation process in the energy market.

On the basis of existing research results, this paper presents the design of a multi-agent-based energy-coordination control system that enhances flexibility and extensibility of power-generation units with non-fixed client–server cooperative mechanism. The proposed system simulates the bidding mechanism in the market by using the contract network protocol. By considering the self-constraint and interests, the proposed system solves the global optimal-energy distribution plan of the system by the improved particle swarm algorithm to achieve the maximum economic benefit on the basis of stable operations. The paper focuses on the development of grid-connected MA-ECCS for optimizing the performance of large-scale wind–photovoltaic energy storage power-generation units based on the following steps:

(1) Design the architecture of multi-agent system based on the physical structure of wind–photovoltaic energy storage power-generation units, determine the overall system coordination mechanism and communication protocol.
(2) Develop corresponding control strategies according to the output characteristics of different power-generation equipment.
(3) Determine the system global optimization objective and energy coordinated control strategy.
(4) Achieve the overall optimal objective under the premise of meeting the demand of meteorological conditions, load, constraints of various aspects and personal interests, develop energy coordinated control process.