Management of MicroGrid in Power System in the Perspective of Communication Process of Multi-agent System

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Abstract. Nowadays, The microgrid(MG) provides a way for the stable access of many kinds of distributed energy to power grid, and multi-agent system(MAS) is an important control form and general utility tool of it. MAS can separate large, complex systems into small ones that can communicate and coordinate with each other and can be easy to manage. This paper starts from the concept and characteristics of MAS and microgrid, analyzes the wide range of MAS applications in micro-grid and its necessity. Then this paper focuses on the communication process of MAS in different scenarios (power restoration and power dispatch), and clearly demonstrates the convenience and practicality of MAS in MG applications. Finally, the paper looks forward to the application of MAS in MG, and believes that the emergence of 5G technology will greatly expand the application field of MAS.

Keywords: Microgrid; Multi-agent system; MAS applications; Communication process.

1. Introduction

The microgrid (MG) converts a large number of distributed source connection problems into controllable MG connection problems, which will reduce the negative impact of random and unstable intermittent energy on the safe and stable operation of the grid and power quality, and provide an optimal way for distributed energy access to the grid. However, there are still some challenges in the development of MG, such as how to optimize the control strategy (like power generation dispatching, energy management and so on) of MG which can realize the resource complementarity and optimal utilization between different MGs, reduce the loss in using renewable energy in micro-grid, and improve the security and reliability of the whole power supply system.

The multi-agent system (MAS) has attracted the attention of researchers in various research fields due to its advantages of its accessible distributed control [1] [2]. For forty years, with the rapid development of computer network technology and the need of distributed artificial intelligence, multi-agent(MA) concept gradually became a tool in the area of engineering applications. By the 1990s, the theory of multi-agent technology was gradually enriched which had caused its application gradually broadened. International organizations and conferences such as the International Conference on Multi-Agent Systems (ICMAS) have made multi-agent technology a new area of scientific research that intersects computer technology, network technology and distributed artificial intelligence technology.

In MG, methods of electrical energy use compared with the traditional way is very different. With the diversification of electricity use, when large amounts of renewable energy sources, such as photovoltaic and wind power which have characteristics of distribution and uncertainty, integrated into power system, the power system is facing serious challenges, the traditional load and generator control strategies have been unable to meet the existing requirements. By the statements above, MAS should
be able to provide a solution to deal with these challenges above in MG, and it is suitable to study in areas of computer technology, network technology distributed artificial intelligence technology and so on. Therefore, it is necessary to study the role of MAS in many applications of MG from the perspective of communication process.

The following content is divided into four sections to discuss the application and communication process of MAS in MG. Section 2 describes the basic principles and characteristics of MAS; Sections 3 and 4 start with examples of the application of MAS in the power system, and show the communication process of MAS under different needs and scenarios. Finally, the last section summarizes the content of the paper, and looks forward to the application and challenges of MAS in power systems.

2. Conception of Multi-agent System(MAS)

Contemporary power system is a huge and extremely complex nonlinear system, and have various time scale and space scale in its running process, and the centralized control is bound to be unable to meet the current situation of large number of integrated renewable energy in power system. The concept of MA provides the possibility for more efficient management and control. Power system uses the MAS concept to assign management and control tasks to independent software and hardware programs (i.e. multiple agents), which makes MGs gain new attributes such as autonomy, reactivity, sociality and initiative which will be discussed in Subsection 2.1 [3]. In that way, each agent is an independent individual, which are aggregated to achieve specific functions together, and hope to make themselves optimized in management and control process (i.e. “selfish”). At the same time, their social properties allow them to contact and consult with each other, and then make them participate various decisions of the power market. Finally, the overall optimal solution is acquired as much as possible in this MAS structure [4].

The region under the management of each agent can be regarded as a small-scale energy-load station, which include traditional generators, storage systems, controllable load and so on. For this reason, MAS is widely applicable to control and management in regions with large amount and wide distribution of distributed energy resources, and the advantage of low single-point failure rate compared with centralized control, also makes the MAS system have a more promising development prospect.

2.1. Agent Characteristics

MASs are the frontier disciplines in artificial intelligence today, and an important branch of distributed artificial intelligence research. The goal is to build large complex systems (software and hardware systems) into small ones that communicate and coordinate with each other and are easy Managed system.

From the perspective of distributed artificial intelligence, a MAS is a loose network composed of problem-solving entities. The MAS is used for a system composed of multiple autonomous components. The system generally has the following characteristics: each agent has not complete knowledge of problem solving, no global system control, data is decentralized, and calculations are asynchronous. The unified MAS has the following characteristics:

- Autonomy. Agents can run independently without direct intervention and guidance from humans or other agents, and can independently determine and control internal states and their own behaviour based on their internal states and perceived environmental information.
- Reactivity. Agent can sense the changes of external environment through various interfaces and communication mechanisms and produce complex and appropriate responses in time.
- Sociality. Agent possesses the information and knowledge of other entities (Agent, people, objects and their environment), and can interact and collaborate with these entities through a certain communication language.
- Initiative. Agent can take the initiative to act according to the promise, showing the characteristics of goal-driven. Agent is purposeful rather than simply reacting to the external environment.
And the following content in this paper will also be expounded around these characteristics.

2.2. Advantage and Implementation Tool of MAS

Compared with centralized artificial intelligence, MAS additionally considers agent’s social capabilities, including the ability to communicate, cooperate, and reach agreement with other participants. MAS can give full play to the autonomy of the agent, through the interaction, coordination and energy optimization management between the Agent and the Agent and the system, to achieve the participation of the agent team in formulating solutions.

This paper uses JADE (Java Agent DEvelopment) to develop the information processing function and communication function of agents. And the Agent Communication Language (ACL) defined by FIPA (The Foundation for Intelligent Physical Agents) established in 1996, which is an accurate and mature language, can be used as the language of communication simulation in this article. In order to clearly describe the above process, this paper uses JADE’s SNIFFER to demonstrate the communication process. JADE is a software development framework that complies with FIPA (The Foundation for Intelligent Physical Agents) standards and aims to develop multi-agent systems and smart agent applications that follow FIPA standards. [5]

3. MAS Application in Single MG’s Failure Recovery

Feeder automation system (FAS) is an important part of advanced distribution system or MG [6]. The system can automatically monitor, isolate and clear faults. [7][8] Due to the low inertia and instability of the new power supply, the power flow direction becomes unpredictable, and the protection device will refuse to operate or malfunction more frequently. It is necessary to conduct in-depth research on FAS. This chapter is based on a consideration that a mature and strong MG should perceive their own status and external environment, and also know how to maintain their health status or return to health from unhealthy state. According to the agents’ different position, we can classify agents into LBAs (Load Bus Agents, which are located in distributed load, energy devices and so on), FAs (Feeder Agents, which are located in feeders) and RAs (Regulator Agents, which are located in substations). Then based on MAS, the control structure and control logic are described as figure 1.

![Figure 1. A general model of a distributed multi-agent system architecture](image)

3.1. Agent in FAS

Distributed generator (DG) and load are generally connected to the bus managed by LBA. The role of LBA is to monitor and control the components on the load bus (load and DG, etc.), collect information on the load bus and respond to various situations (monitor current and voltage amplitude and phase, record bus power flow information, send and receive communication signals, etc.); LBA can also control the local normally closed switches on both sides of the local bus. LBAs’ operation can be carried out after self-judgment, or after exchanging information with the superior agent.

FA is generally responsible for the voltage monitoring and congestion monitoring of the feeder under its management. The communication principle is similar to that of LBA, and it can transmit information between the same level agents and the upper and lower agents, which in turn requires the FA to have certain self-decision capabilities.
As the highest-level agent of the FAS, RA is generally installed in substations and is responsible for receiving and sending signals, controlling transformer taps and receiving communication requests from lower agents and deliver necessary information.

The following analyses the agents’ performance in FAS from the characteristics of the agent. Taking LBA as an example:

- **Autonomy**: When the voltage is too low, LBA can automatically calculate and judge.
- **Reactivity**: LBA can sense the electrical signal of the bus.
- **Sociality**: LBA can send signals to specific agents and request to jointly solve the problems of the system as a whole, that is, to ensure the quality of power supply.
- **Initiative**: When LBA determines that the voltage is too low, it will actively send a signal.

### 3.2. MAS Application in Agent in FAS

For content refinement, this chapter only discusses MAS-based recovery control in distributed network. The purpose of recovery control is to quickly restore the power supply of the load in the faulty area after various events (such as system reconfiguration) without affecting the power supply of other normal area. The following describes the communication process of recovery control.

a) Suppose there was a fault at the load bus, and the system has correctly isolated the fault by opening the circuit breaker.

b) After the FA corresponding to the power-loss area receives the “REQUEST” to restore the voltage of the LBA in power-loss area, if the FA realizes that the voltage cannot be restored by ordinary reactive power adjustment, it returns the “REFUSE” information to the lower LBA in power-loss area and requests the superior RA to start the system reconstruction.

c) The RA transfers the control instructions (“INFORM”) layer by layer down to guide the LBA to act to restore power in the power-loss area.

d) If LBA thinks that the instruction from RA can be completed, it returns "ARGEE" to FA and performs power restoration.

This paper uses the IEEE-33bus model to show the recovery control communication process based on MAS, and the system model is shown in the figure 2 below. \( T_n \) \((n=1,2,3,4,5)\) is normally open tie lines. Each bus \( n \) has an LBA\( n \). Assuming that the feeder between bus 20 and bus 21 is short-circuited to ground, the bus 21 and bus 22 will lose power.

**Figure 2.** A MG model with IEEE-33bus form

At this time, LBA21 and LBA22 are ready to receive the system reconfiguration signal of RA after judging that the support of capacitor, FA and RA have no effect. The communication process is shown in figure 3; For clarity of expression, set FAU to be the FA on the feeder where the fault is located (i.e. FA3) and LBAU to be LBAs (i.e. LBA21, LBA22) at the fault location. In addition, set otherFA as a feeder agents on feeders connected with FAU by tie lines (i.e. FA1 or FA2).
Figure 3. The transmission process of recovery control

First, the LBAU sends a request to restore the voltage. After receiving the request and determining that the FAU alone cannot restore the LBAU’s voltage level, the FAU returns a “REFUSE” signal to the LBAU and sends a “REQUEST” signal to the superior RAU to request the restoration of the voltage. After the RAU receives the signal, if RAU judging that only tap movement or other compensation measures cannot restore the voltage of the LBAU, it will determine that the LBAU is out of power due to a fault, so that it sends a “REQUEST” signal requesting support to the non-faulty otherFA, while the RAU stands by and waits to receive the signal from otherFA. Assuming that otherFA can provide support, so “AGREE” information is returned. Then RAU sends an “INFORM” signal for system reconfiguration to FAU. Finally the FAU “INFORM” the LBAU with the tie-line switch. After the LBAU receives the signal, it will return the “AGREE” or “REFUSE” information after judging that the conditions of the bus meet the requirements of the system reconfiguration, and close the tie-line switch or do not close. Otherwise, the judgment and decision-making behavior of LBAU enters the circular queue, and the voltage is restored until conditions is satisfied.

4. MAS Application in Multi-microgrid (MMG) Optimal Power Support

The problems studied in this chapter are aimed at multi-microgrid (MMG) systems. In MMG, due to the existence of multiple interest body, each subject tends to maximize its own benefits, but this self-benefits often contradicts the overall benefits. That is, when the overall benefits are optimized, it can not meet the optimal benefit of each subject (MG). In order to maximize the overall benefits, it is obviously not feasible to adopt the method of isolating each MG to optimize the entire MMG system. Therefore, it is necessary to make dispatching contracts between different MGs so that different MGs can coordinate and support each other. [9][10][11]

The system structure studied in this chapter can be assumed as the following figure 4. There are 5 relatively independent and connected MGs in the figure. Each MG is managed and controlled by an agent. In addition, the thick black line is the electrical connection between the MGs. The self-goal of the 5 Agents is to make their own MG electricity cost (including electricity purchase cost and energy storage maintenance cost) be the lowest, and the overall goal is to ensure the lowest energy cost of the whole MMG system. For the sake of brevity, the change of power flow exchange between the five MGs only comes from the power storage (i.e. MGs’ capacity in the below) in MGs.

Figure 4. MMG topology studied in this chapter

4.1. Agent in MG

The following analyses the performance of the agent in MMG optimal power support in the perspective of characteristics of the agent:
• Autonomy: The agent automatically makes generation/power-using strategies by considering energy storage costs and power purchase costs.
• Initiative: The agent can actively seek solutions when the MG encounters problems and try to communicate with other MGs.
• Reactivity: The agent can perceive the MG power supply situation in time.
• Sociality: The agent is able to consider the global optimum and sacrifice their own best benefit under some specific control.

4.2. MAS Performance in MMG Optimal Power Support
Suppose that in a same hour, the load of MG1 and MG3 suddenly increases, causing the actual power consumption of these two MGs to be greater than the originally planned power consumption. At this time, according to the agent's program settings, after both MG1 and MG3 have calculated the spare capacity that they need to purchase from other MGs, they begin the communication process as shown in the figure 5.

Figure 5. Process of MMG's power support communication
• MG1 and MG3 send out the "REQUEST" signal and asking if nearby MGs can provide power support;
• After self-calculation, MG2, MG4 and MG5 respectively reply "AGREE" or "REFUSE" signal to MG1 or MG3 to indicate agreement or denial of power support;
• After a series of grid dispatches, both MG1 and MG3 are able to obtain sufficient power. So MG1 and MG3 reply "INFORM" signal to the MGs that support them to indicate the message of "Electrical connection is normal and support is successful".

5. Conclusion
This paper starts with the characteristics of MAS and MG and then describes the cooperation between them. It can be concluded that the use of MAS in MG can better solve the challenges encountered in the development of MG. In today’s world, the research on MG is mainly carried out from the aspects of model framework, optimal dispatch, operation control and market bidding. And with the development of clean energy and emerging technologies, MG has a broad development space in the distributed network and the global Energy Internet (EI). This has also given MAS a vast space for development. In the following content, this paper focuses on the important role of MAS in the application of MG, and uses JADE as a tool to show the communication process of MAS in two instances of fault recovery and power scheduling. The purpose of this is to let readers clearly realize the practicability and reliability of the latest application of MAS in MG. It can be seen from these cases that MAS and its internal communications can make full advantage of distributed agents, and MAS can meet the needs of different time scales and spatial scales in the control and management in MGs. It can be expected that with the advancement of 5G technology, many problems in the application of MAS, such as communication delay, excessive reliance on communication quality and communication protocols that are difficult to coordinate, will also be solved.
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References
[1] Hu J, Cong H and Jiang C 2018 Coordinated scheduling model of power system with active distribution networks based on multi-agent system Journal of Modern Power Systems & Clean Energy 6 125-135
[2] Mishra S 2019 A multi-agent system approach for optimal microgrid expansion planning under uncertainty International Journal of Electrical Power & Energy Systems 109 696-709
[3] Hutchinson G 2010 A Multi-Agent System for decentralised control of low voltage distribution networks 45th International Universities Power Engineering Conference UPEC2010
[4] Ai Q, Liu S and Wu R 2016 Current status and prospect analysis of multiagent systems in energy internet High Voltage Technology 42 2697-2706
[5] Bellifemine F and Caire G 2007 Developing Multi-Agent System with JADE (7 John Wiley & Sons, Ltd.) pp 89-103
[6] Li C, Luo L and Wang D 2019 Design and implementation of network monitoring and fault location system for process layer network in smart substation Electric Power Engineering Technology 38 117-122.
[7] Elmitwally A, Elsaid M and Elgamal M 2015 A Fuzzy-Multiagent Service Restoration Scheme for Distribution System With Distributed Generation IEEE Transactions on Sustainable Energy 6 810-821.
[8] Kang Q, Cong W and Sheng Y 2019 Protection methods of single-phase broken-line fault for distribution line Power System Protection and Control 47 127-136
[9] Xu Z 2017 Risk-Averse Optimal Bidding Strategy for Demand-Side Resource Aggregators in Day-Ahead Electricity Markets Under Uncertainty IEEE Trans. Smart Grid 1 96-105
[10] Gao Y, Ai Q and Wang J 2018 Consensus Cooperative Control of AC/DC Hybrid Microgrids Based on Multi-agent System High Voltage Engineering 44 2372-2377.
[11] Wang Z, Yang P and Liu S 2017 Coordination and optimization strategy of VPP considering demand response and multi-energy coordination Electric Power Construction 38 60-66.