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Optimization Operation Status and Prospect of Multi-microgrid System

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Abstract: The uncertainty and intermittency of renewable resources, the time-varying power generation and radiation of generator sets, and the energy coupling between generator sets in the process of energy trading all bring severe challenges to the stable operation and optimal dispatch of the power system. To this end, the energy management system in the current multi-microgrid system is analyzed. The topology, time scale and dispatch optimization structure in microgrid are discussed. The results show that the microgrid structure is conducive to the construction of new power system and plays an important role in promoting the transformation and reform of power system in the future.

Keywords: Multi-microgrid System; Scheduling Optimization Structure; Topologic Structures; Energy Management.

1. Introduction

In recent years, the multi-microgrid system has become a widely used network structure in the power grid, which consists of multiple independent microgrids, which are often geographically close and connected on the same busbar. Highly efficient energy transfer, conversion, and coordination between microgrids helps improve the reliability and stability of the entire system. Therefore, the research on the application of multi-microgrid systems in smart grids is increasing day by day. In particular, the efficient consumption and sharing of distributed renewable energy and how to promote the efficient utilization and consumption of distributed energy resources are key issues in the research[1].

The multi-microgrid system has many obvious advantages. Among them, whether it is grid-connected mode or island mode, the energy sharing between microgrids allows them to meet electricity demand through relatively economical renewable energy, so it has good economic characteristics, so that the cost of fossil fuel power generation is reduced. At the same time, since the energy exchange between microgrids is mainly between adjacent microgrids, the construction cost of long-distance transmission lines and the potential energy loss during power transportation are reduced[2]. Second, compared with the traditional independent microgrid, the multi-microgrid system is more in line with the development trend of smart grid and highly flexible power grid in the future. On the one hand, with the large-scale development and utilization of renewable energy, multiple microgrid interconnections will effectively improve the utilization rate of renewable energy; On the other hand, the energy exchange between multi-microgrid systems also reduces the burden on the main network, alleviates the congestion of distribution lines, and improves the reliability of itself and the distribution network. Third, considering the resilience of the future multi-convergence highly resilient power grid, when a fault occurs or a natural disaster causes a power outage, usually a microgrid can be isolated from the damaged part of the power grid, and by sharing energy and backup resources with adjacent microgrids, it can not only restore stable operation, but also divide the distribution network into multiple microgrids to improve the operational reliability of the distribution network[3]. In addition, the multi-microgrid systems support each other to achieve overall reliability and minimize the total load shedding of the system load[4].

Despite the above advantages, there are still many challenges to achieving reliable operation. First, renewable energy has a higher penetration rate in a multi-microgrid system than an independent microgrid, so the volatility and intermittency and the temporality of load will be enhanced on the temporal and spatial scales. It is very necessary to reduce the impact of this fluctuation on the system[5]. Second, the strong coupling caused by interconnection makes any change in any of the microgrids affect the connected microgrids. As the number of microgrids in multi-microgrid systems increases, the impact will become more complex. This paper reviews the existing research on multi-microgrid systems at home and abroad, focusing on the interconnection structure and optimal scheduling structure of multi-microgrid[6].

2. Topologic Structures in a Multi-Microgrid System

Multi-microgrid systems can work in either grid-connected mode or island mode. The microgrids in the system are interconnected, and energy can be exchanged and shared between each other or distribution networks through power exchange lines [7], so as to form a variety of different power transmission structures of AC and DC microgrid distribution network collaborative operation system. In addition, distributed network operators oversee power flow control and market operations, such as buying and selling active and reactive power to the grid, alleviating possible network congestion through energy transfer in transactions. Each microgrid is composed of distributed power sources, energy storage devices, loads, and microgrid controllers. These three topologies are discussed below [8].

2.1. Model A -- Radial Topology

In this structure, each microgrid is directly connected to the main network, forming a typical star or radial topology, and each microgrid is first attached to the bus, through which energy exchange with the main network. As shown in Figure 1, there is no direct energy exchange between the microgrids.

It demonstrates a local energy system consisting of N microgrids and the exchange of information between microgrids and distributed network operators (DNOs). Each microgrid responds to the DNO's decision and its own microgrid controller (MC). Energy sharing and trading mainly rely on dedicated power exchange lines. For example, if a microgrid cannot meet its own load demand, it can purchase power from the main network through the busbar. In addition, microgrids with excess power can sell additional power to the main network through the bus. Therefore, in this radial connection structure, it is necessary to focus on the total power of the busbar, alleviate the congestion of the transmission line, and improve the reliability of the main network[9].

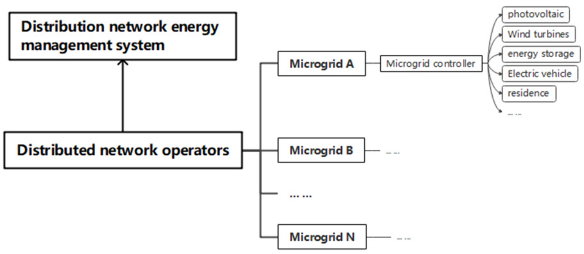

Figure 1. Model A -radial topology

2.2. Model B -- Chain Topology

In this structure, multiple microgrid systems are connected to form a chain topology, and energy flow and information flow can flow in both directions between two adjacent microgrids and between the microgrid and the main network, as shown in Figure 2. It can be seen that each microgrid is not only connected to the main network, but also to two adjacent microgrids on both sides. Multi-microgrid systems can form a line or a ring, and each microgrid can directly exchange energy and information with adjacent microgrids or main networks.

In this topology, the MC not only needs to coordinate with the main network, but also needs to exchange energy with adjacent microgrids, so its design is different from the radial topology. This structure allows the energy and information exchange between adjacent microgrids directly, as well as between microgrids and DNOs, thus realizing energy cooperation between adjacent microgrids. Therefore, the coupling effect between microgrids is stronger, so more network constraints need to be added when considering optimal scheduling. In addition, considering the privacy protection of users, each microgrid needs to determine its own operation plan as an independent individual through point-to-point communication with non-critical information of neighboring microgrids.

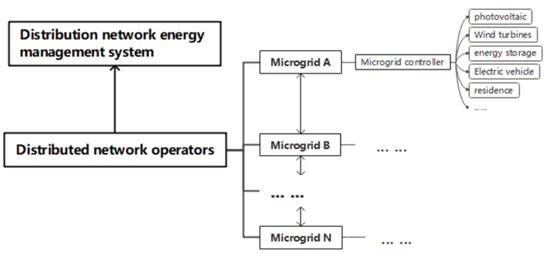

Figure 2. Model B -- chain topology

2.3. Model C -- Mesh Topology

Multi-microgrid systems can also form a mesh topology, so they are interconnected through transmission infrastructure and communication networks. In this structure, microgrids typically contain multiple renewable resources, as shown in Figure 3. Through the cooperation between microgrids, power and information exchange between microgrids can be realized, effectively improving operational efficiency and reducing operating costs. In addition, it can be seen that this structure is more complex than the above two topologies, and therefore energy cooperation and coordination are also more complex. The scheduling of each microgrid is not only affected by its local power supply and demand, but also by other microgrids in the multi-microgrid system network.

From radial to chain structure to network topology, the level of interconnection and cooperation of multi-microgrid systems has been improved, which has brought more research space, so that it is more likely to find its optimal energy management solution under different conditions, improve energy absorption rate and the economic benefits of the entire system. However, optimization algorithms for energy management will become more complex and challenging.

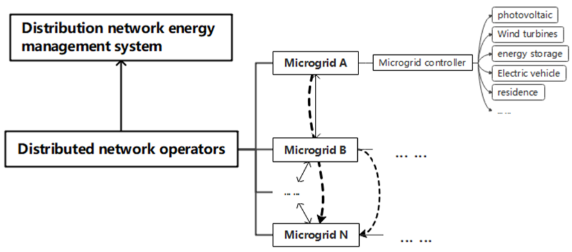

Figure 3. Model C -- mesh topology

3. Optimization Goals in Multi-Microgrid Systems

Common optimization goals in multi-microgrid systems include: utilization of renewable resources, transmission loss, environmental benefits, and user satisfaction.

3.1. Absorption of Renewable Resources

Maximizing the use of renewable resources is an important goal of multi-microgrid systems, which are usually achieved through two methods. The first method is to exchange the remaining energy of the system with the high-demand microgrid, and the second method is to track the output power of the distributed power supply by shaping the load curve[10].

3.2. Transmission Loss

For energy transactions between microgrids and maingrids, there are two types of energy transmission losses. The first is transmission loss between microgrids, and several recent studies have focused on reducing this loss. The other is the transmission loss between the microgrid and the main network. Since the connected microgrid is usually low-voltage, while the main grid is actually high-voltage, the power exchange between the microgrid and the distribution network will cause greater losses[11].

3.3. Environmental Benefits

For the "dual carbon" indicators proposed by the state, namely: "carbon neutrality" and "carbon peak", the multi-microgrid system, as the basic mechanism, plays the function of increasing the absorption of new energy and reducing carbon emissions. Meet the new requirements of ecological environmental protection, reduce carbon emissions, and build a new power system based on the ecological civilization framework and energy security strategy. The power system gradually led by fossil energy is transformed into fossil energy and new energy, occupying half of the functional body, and finally converted into a new power system dominated by new energy.

3.4. User Satisfaction

This is a subjective objective measure because users are usually different, and user satisfaction may be different even in the face of the same energy demand and supply. In order to have a quantitative parameter measure that can be incorporated into the optimization or control framework, various models have been developed on the relationship between the user's actual allocated power and their expected demand.

A common approach is to divide loads into different types, for example: dispatchable and non-dispatchable loads; Elastic and inelastic loads. The former is a hard requirement that must be met for a certain period of time (such as lighting), and the latter is a soft requirement that can be partially met or delayed to a certain extent. User satisfaction for the latter type of load is a decrease function of the gap between demand and allocated power, or a decrease function of delay. Dispatch algorithms are then leveraged to delay or sacrifice elastic loads for a given power demand and supply to maximize social welfare. Another commonly used method is to introduce a cogeneration system in a multi-microgrid system to regulate electrical and thermal energy. In this way, the electric energy meets the load demand as much as possible, and the thermal energy meets the user's requirements for indoor temperature indicators.

4. Optimization Method and Scheduling Optimization Structure

For optimal control problems, how frequently a new decision is made and executed is a critical system parameter that needs to be carefully selected. At this stage, there are two commonly used time scales for the optimization of multi-microgrid systems[10].

4.1. Offline Optimization

This method is typically used for day-ahead dispatch or multi-microgrid system planning based on all forecast information (such as renewable resource generation, load controllability, market price, etc.) when known. On this basis, based on the probability characteristics of uncertainty, the maximum possibility is achieved by Monte Carlo simulation and scenario reduction technology, which is a widely used uncertainty optimization method, and finally the deterministic or random method is used to obtain the optimal power distribution [12].

4.2. Real-time Optimization

Although the current optimization method can obtain the global optimal power dispatching, because the actual value of the day may be different from the predicted value, the expected result of the day-ahead method calculation of the optimal result is often not obtained. In practical applications, the changes of distributed renewable energy and the strong correlation uncertainty make the design of microgrid energy management more complicated. A growing body of research tends to optimize real-time scheduling to reduce the impact of uncertainty.

Although offline optimization has some disadvantages, it is still helpful for real-time optimization in multi-microgrid distributed networks. On the one hand, the convergence of the algorithm can be tested using the results of offline optimization, and the algorithm is optimized online; On the other hand, when the energy interaction between interconnected microgrids is coupled and the target can be decomposed, the offline optimization model can be decomposed into independent microgrid energy optimization subproblems, and the distributed optimization algorithm can solve the energy optimization problem of the microgrid in parallel and reduce the computational complexity[13].

5. Prospects and Future Development Trends in Multi-Microgrid Systems

In the future, the power grid will build a highly flexible power grid with diversified integration in the form of energy Internet, and build a highly flexible power grid with all-round interaction of massive resources and double improvement of safety efficiency by comprehensively mining and mobilizing the four physical systems of source-grid-load-storage, as well as social system resources such as markets, mechanisms and formats, so as to realize a new power system. Considering the increasing load demand worldwide, the high demand for renewable resources, the high loading, high interaction, high self-healing and high efficiency characteristics of the highly elastic power grid, the high consumption requirements for new energy in the construction of the new power system and the realization of the "dual carbon" goal, the multi-microgrid system that meets the demand in an economical, stable and reliable way is studied. The following briefly summarizes the future development trend of multi-microgrid system operation optimization research:

(1) Since the power-related variables and market-related variables in the multi-microgrid system are random, the real-time optimization algorithm is considered to be an algorithm with a wide panorama in energy dispatching. The focus is on reducing computational complexity and achieving good convergence performance for real-time offline global results.

(2) The needs of the customer are not the same as the needs of the power supply company. The multi-microgrid system should take into account these differences, while protecting user privacy, meet the requirements of the user power supply company, specify the optimal strategy for the system, and achieve fair energy distribution.

(3) Most of the recent research has focused on active trading and sharing of multi-microgrid systems. However, labor power is also an indispensable part of multi-microgrid systems, and reactive power should be considered in energy management to improve the reliability of the entire system. When active and reactive power are regulated at the same time, the optimal strategy should have low complexity in order to effectively manage and operate the system.

(4) The multi-microgrid system can solve the problem of local consumption of new energy, reduce the overall carbon emissions of multi-microgrid groups, and help build a new power system. Promote the power system to accelerate the transformation to new energy as the main form, to the carbon

neutrality stage, and gradually evolve to a highly intelligent new energy Internet system.

6. Concluding Remarks

This paper summarizes the current research progress of the optimization structure of multi-microgrid systems at home and abroad, reviews the commonly used topologies of multi-microgrid systems, and discusses the most commonly used optimization objectives, operation time scale and scheduling optimization structures in microgrids. It is found that the interconnected multi-microgrid system can effectively promote the absorption of new energy, reduce the overall carbon emission in the microgrid group, and improve the economic benefits of the overall system. In the future, the multi-microgrid system will be used as the basic architecture to promote the gradual transformation of the power system from fossil energy to a new power system dominated by new energy, and after the "carbon neutral" stage, it will promote the evolution of the power system to a highly intelligent energy Internet system, so it has great promotion prospects.

References

[1] Li Y, Vilathgamua D M, Loh P C. Design, analysis, and real-time testing of a controller for multibus microgrid system[J]. IEEE Transactions on Power Electronics, 2004, 19(5): 1195-1204.

[2] Rahbar K, Chai C, Zhang R. Energy Cooperation Optimization in Microgrids with Renewable Energy Integration[J]. IEEE Transactions on Smart Grid, 2016: 1482-1493.

[3] Utkarsh K, Srinivasan D, Trivedi A et al. Distributed Model-predictive Real-time Optimal Operation of a Network of Smart Microgrids[J]. IEEE Transactions on Smart Grid, 2018: 1-1.

[4] Chen C, Wang J, Qiu F. Resilient Distribution System by Microgrids Formation After Natural Disasters[J]. IEEE Transactions on Smart Grid, 2015, 7(2): 958-966.

[5] Song, Nahoak, Lee et al. Energies, Vol. 8, Pages 8371-8390: Optimal Energy Management of Multi-Microgrids with Sequentially Coordinated Operations[J], 2015.

[6] Navya V, Gowthami B, Maheswari C. [IEEE 2017 International Conference on Power and Embedded Drive Control (ICPEDC) - Chennai, India (2017.3.16-2017.3.18)] 2017 International Conference on Power and Embedded Drive Control (ICPEDC) - Video survivallance based face recognition using FLTP[J], 2017: 98-101.

[7] Zhou X, An L, Chen Y et al. A Microgrid Cluster Structure and Its Autonomous Coordination Control Strategy[C]. Annual Conference of the IEEE Industrial Electronics Society, 2017.

[8] Wang B, Sechilariu M, Locment F. Intelligent DC Microgrid With Smart Grid Communications: Control Strategy Consideration and Design[J]. IEEE Transactions on Smart Grid, 2012, 3(4): 2148-2156.

[9] Pipattanasomporn M, Feroze H, RahmanS.Multi-agent systems in a distributed smart grid: Design and implementation[C]. Power Systems Conference & Exposition, 2009.

[10] Huang Y, Mao S. On Quality of Usage Provisioning for Electricity Scheduling in Microgrids[J]. IEEE Systems Journal, 2017, 8(2): 619-628.

[11] Sun W, Zhao C, Wang J et al. Distributed cooperative secondary networked optimal control with packet loss for islanded microgrid[J]. IET Generation, Transmission & Distribution, 2019, 13(20): 4733-4740.

[12] Zeng Z, Peng L. Locality-Driven Parallel Power Grid Optimization[J]. IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, 2009, 28(8): 1190-1200.

[13] Wang B. Intelligent control and power flow optimization of microgrid : energy management strategies[J], 2013.