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Design and application of microgrid operation control system based on IEC 61850

Wen LU (✉), Yangdong ZHAO, Weixing LI, Hongwei DU

Abstract We consider the microgrid operation control technology including design of microgrid operation control system, MG control device and control strategy. We pay much attention on microgrid operation control device which is core control device. In order to solve the contradiction of quick speed about microgrid operation mode shift and slow speed about the management system, three-layers control architecture based on IEC61850 is designed and adaptive control strategy is used on MG operation control system. The system has been applied in a distributed generation/energy storage power station. The actual operation shows that the system can be effectively and flexibly connected to distribution network.

Keywords Distributed generator, Microgrid, Self-adaptive operation control, *V/f* control, IEC61850

1 Introduction

Distributed generator (DG) has the characteristics of flexible position and dispersion, which adapts to dispersive power demand and resource distribution [1]. However, simple grid-connected operation of large amounts of distributed supplies that are dispersive, in various forms and with different properties will have impact on power grid and its users, bringing bad influence to power quality, system protection and system operation. Integrating DG, load, energy storage and control devices into a microgrid system and presenting this system to power grid as a single and controlled unit can respond to centralized-control signals and coordinate the contradiction between power grid and DG well. But at home there have been no uniform standards for microgrid communication yet, which increased the difficulty in accessing the microgrid to power distribution network for the operation of the microgrid to be controlled [2, 3].

Currently, the two main ways of microgrid control are peer-to-peer control and master-slave control [4–7]. The technology of peer-to-peer control has high requirement for coordination control of DG and is still confined to the laboratory; master-slave control has high requirement for communication, demanding not only reliability but also real-time performance, and considerably relies on computer system and communication, and its timeliness needs to be demonstrated [8, 9]. Master-slave control is further divided into two-layer control or three-layer control, which are used by most pilot projects at home and abroad and lay emphasis on coordinating the operation of DG and load within microgrid [10]. Ref. [11] presents a decentralized control method which makes use of the local information of DG within microgrid. This control method can solve the problems of distributed generator and load within microgrid of being dispersive, but it is unable to take full advantage of the generation complementarities of DG within microgrid. Ref. [14] presents a master-slave control strategy from a microgrid energy management perspective. It relies too heavily on communication and doesn't consider control methods in particular conditions. Ref. [15] presents power management methods and controller design details within microgrid according to output characteristics of different types of DG, but mentions nothing about access control method of microgrid.

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W. LU, W. LI, School of Electrical Engineering and Automation, Harbin Institute of Technology University, Harbin 150001, China
(✉) e-mail: luwen@sgepri.sgcc.com.cn
W. LU, Y. ZHAO, H. DU, State Grid Electric Research Institute, Nanjing 211000, China

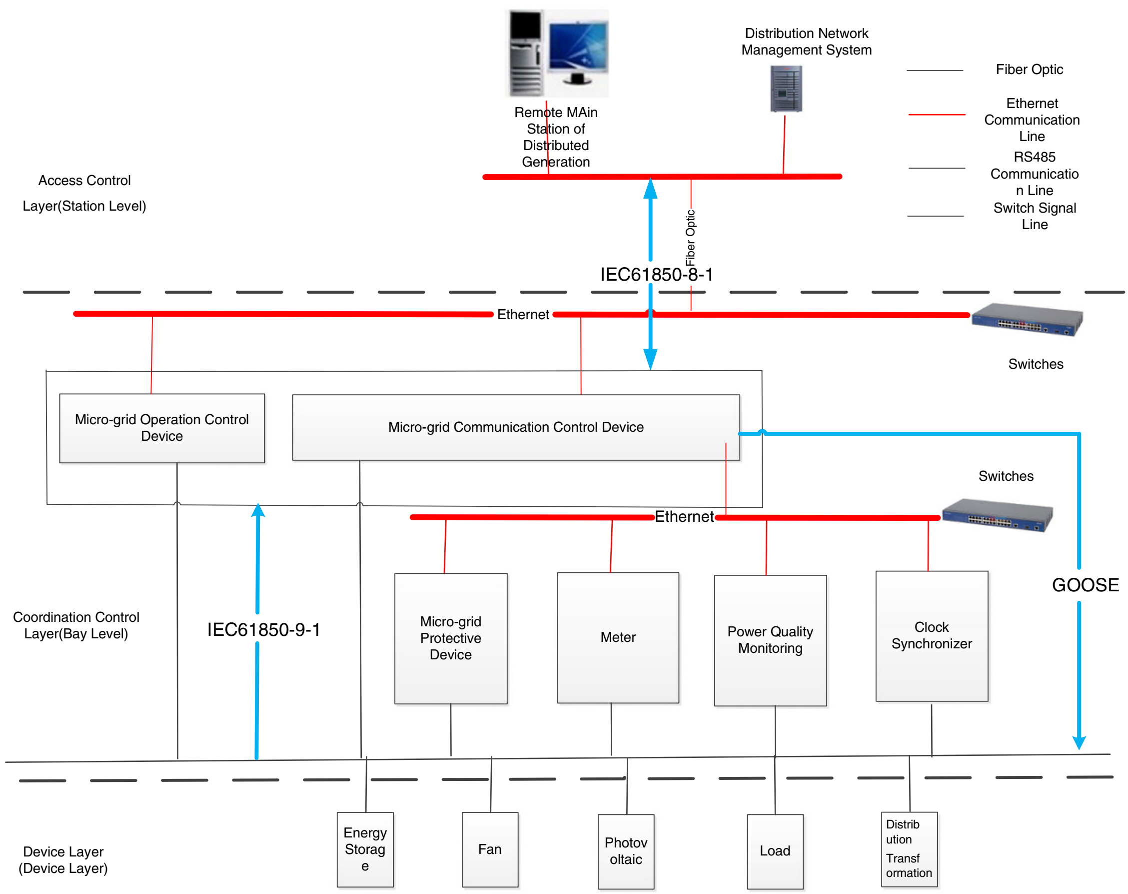

Fig. 1 Three layers control structure based on IEC 61850

On account of the impact of microgrid connection to power distribution network operation and the difficulty in carrying out uniform standards for microgrid communication in a short time, as well as to meet the requirement of future digitalized power system, this paper designs a microgrid operation control system which is based on IEC 61850 using three-layer control mode. In this system, a self-adaptation control strategy is used for controlling microgrid operation, and microgrid operation mode can be quickly switched. This control system can be applied in the microgrid system that has access to power distribution network and solve the problem of low permeability of renewable energy sources. It can also be applied to the microgrid system that operates in an off-grid manner and solve the problems of back-up power important load and difficulty in providing power for remote rural areas.

2 Architecture design of microgrid operation control system

Microgrid access control system adopts three-layer control mode based on IEC 61850, as shown in Fig. 1.

This system contains the access control layer, the coordination control layer and the device layer, uniformly modeled as per standard IEC 61850, which respectively correspond to station level, bay level and process level in IEC 61850. Various DG body equipments and microgrid controller communication adopt uniform communication protocols conforming to the frame system of IEC 61850. Device layer contains photovoltaic power generation, fan, energy storage battery and other equipments such as relevant measurement and control terminals, on-line monitoring devices, etc. Generally, energy storage provides the reference voltage of the microgrid. As to some power-generation equipments that do not support IEC61850, they can get access to coordination control layer via merging unit, thus the device layer can be modeled as per IEC 61850.

The equipments of coordination control layer mainly refers to microgrid operation controller, mainly in charge of sending corresponding control commands to the device layer and delivering execution information of the microgrid to the station layer. The interoperability and interchangeability of the devices will be obtained on bay level for easy interoperability. Microgrid operation controller sends GOOSE messages to intelligent switches. GOOSE messages can at once be sent when the switching value shifts or be sent occasionally when the switching value does not shift.

The access control layer corresponds to the microgrid access control system. It gets microgrid information through the coordination control layer, gets power distribution network information from the distribution network management system and can realize microgrid operation monitoring and control. The information exchange between the coordination control layer and the access control layer adopts the manufacturing messages specification (MMS) mapping defined in IEC 61850-8-1, and supports control services such as “GetMSVCBValues/ SetMSVCBValue”.

Microgrid control system has been completely consistent with IEC 61580 on bay level and station level, but the device layer still can not realize IEC 61850 in full sense, though it is compatible with IEC 61850.

3 Realization of microgrid operation controller

Microgrid operation controller is the core device of microgrid operation control system. In this equipment, the control strategy is realized.

3.1 Platform design

In order to achieve high reliability and control rapidity of the microgrid, microgrid operation controller adopts an embedded real-time design. The hardware platform of microgrid operation controller adopts PCM821 embedded structure design. Its dominant frequency is 800 MHz. It has 8 self-adaptive internet accesses, 18 serial ports, 8 paths in, 4 paths out and 1 memory interface of document object model (DOM). It supports clock synchronization of IEEE 1588 V2.0 and IRIG-B, the RS-232/485/422 mode and the network communication that is based on TCP/IP protocol family, and fully satisfies the needs of massive calculation and Ethernet communication.

The software platform adopts Linux real-time operating system.

3.2 Software design

The program adopts a modular design. Each program module can operate on one machine or more as needed. Data can be exchanged via network communication between modules.

3.3 Function module

The internal relationship of microgrid operation control modules is shown in Fig. 2. Data management module, strategy control module and communication management module are included. Data management module takes charge of collecting, storing and managing status data and history information data of each part. Strategy control module works out the specific controlled quantity of each actuating equipment according to the working condition of the current microgrid and main grid. Communication management module includes access control management and equipment control management. Access control management takes charge of information exchange between the access control master station and the coordination control layer, and accomplishes coordination control of the subsystem of microgrid. Device control management sends controlled quantity down to the actuators of DG, and also collects status messages of the device layer.

4 Self-adaptive control strategy

The operation modes of microgrid varies with different operation conditions. In order to ensure a smooth operation of the microgrid and its flexible access to power distribution network, it is necessary to quickly control the microsource output and smoothly switch the operation mode. In the case of microgrid three-layer control, the above mentioned condition can be realized by means of self-adaptive control.

4.1 Microgrid operation mode

Generally, micro grid has four basic operation modes: normal grid-connected operation mode, the mode of transition from grid-connected operation to isolated-grid operation, isolated-grid operation mode and grid-reconnected mode. Each mode has several sub-modes. The relationship between different modes is shown in Fig. 3.

4.1.1 Normal grid-connected operation mode

Grid-connected operation mode has 4 sub-modes including constant power, variable power, considering peak-load shifting and optimized operation. In normal grid-connected operation, microgrid controller firstly makes generation plans of each DG and charge-discharge plans of energy storage devices according to the generation predication result and load predication result of each DG and the charged state of energy storage units and as required by various sub-modes.

4.1.2 Transition from grid-connected operation to isolated-grid operation

This mode has two sub-modes: planned off-grid and unplanned off-grid. Planned off-grid means that the

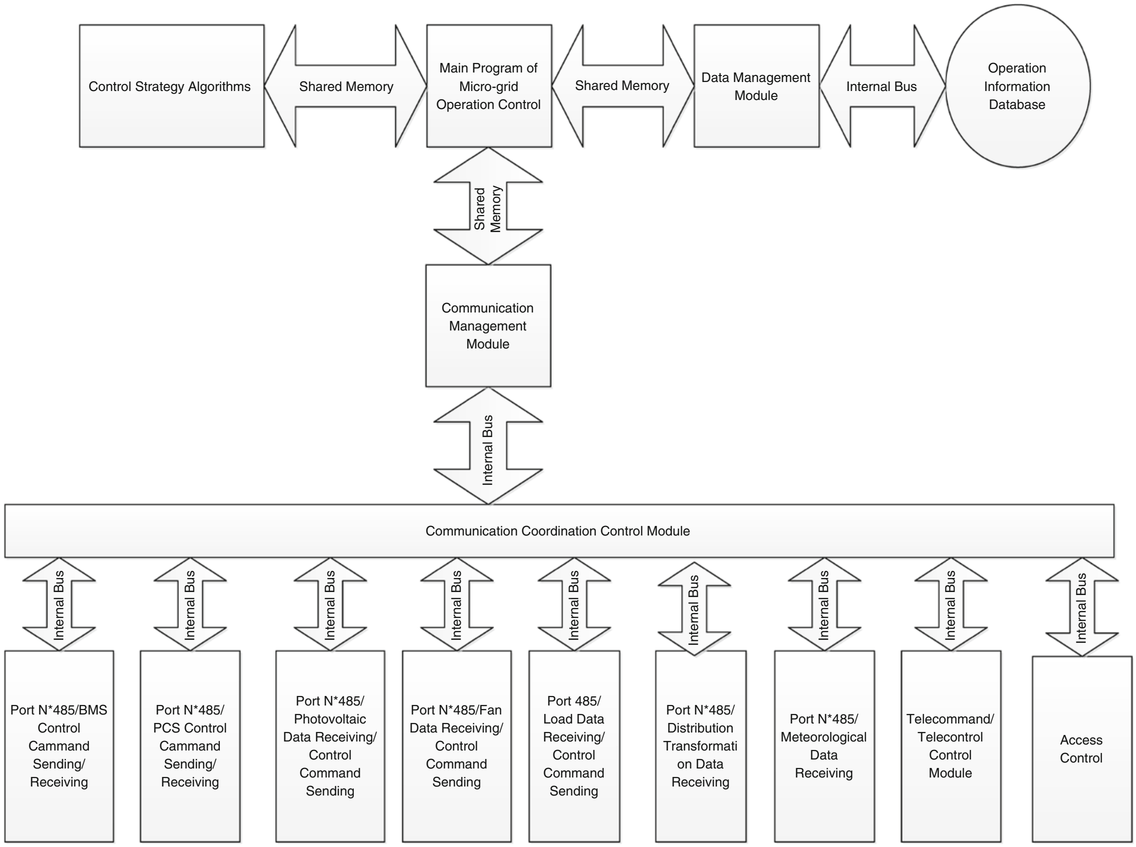

Fig. 2 Model of microgrid control

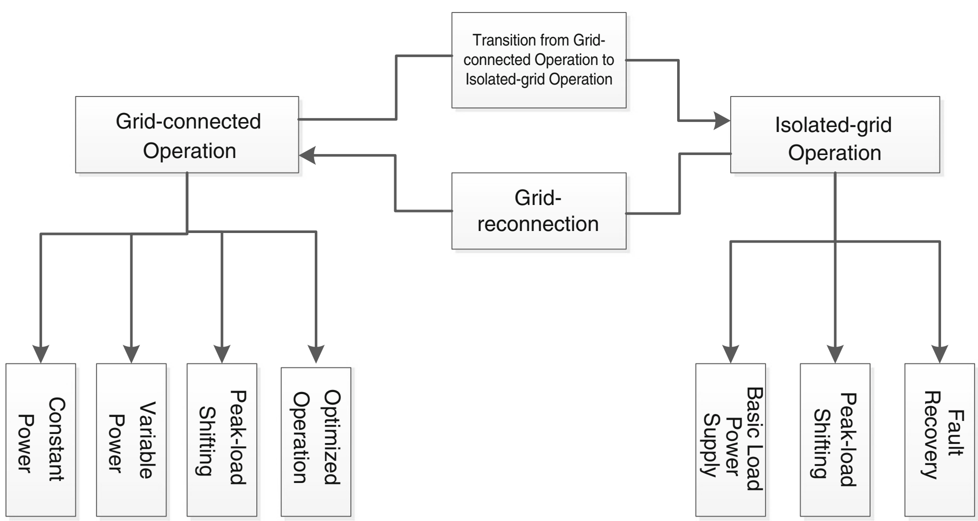

Fig. 3 Control mode of microgrid operation

microgrid controller actively comes to be off-grid according to the command of the access control layer. Unplanned off-grid means that the microgrid passively becomes off-grid due to emergency situations or faults.

4.1.3 Isolated-grid operation mode

In isolated-grid operation mode, the microgrid achieves self-energy balance according to its generation and load

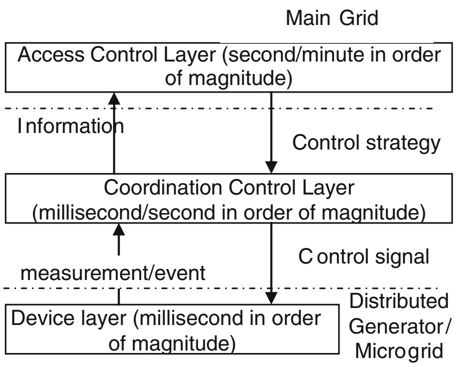

Fig. 4 Three grades control process

state. This mode has three sub-modes: ensuring basic load generator, considering peak-load shifting, and fault recovery.

4.1.4 Grid-reconnected mode

After receiving the command of its parent grid, the micro grid adjusts the voltage amplitude and frequency and reconnects to the power grid.

The operation mode of the micro grid varies with operation condition, and is switched on the basis of certain control strategies when the operation condition changes.

4.2 Self-adaptive control method

Three-layer control structure corresponds to three-layer control process, as shown in Fig. 4. The control of each layer is relatively independent, and takes different response speed according to different response request. Normally, the event responding time of the main station layer is mostly several seconds or minutes, the regulation of the coordination control layer is mostly required to be completed in a second, and the response of the device layer is required to be completed in several milliseconds.

In order to achieve a quick response of the control system, the program uses a message mechanism and each control layer uses the set algorithm of state control to control the state according to the current quantity of state. When the upper or lower layer changes, delivery is done via the message mechanism, and the control layer will process the information according to the priority of the information so as to avoid any delay of task processing caused by waiting. The conditions of normal operation, communication interrupt and island will be respectively analyzed below.

1) Normal operation state. In normal operation state, the access control layer adopts certain control schemes such as setting constant power at the grid connection point, unlimiting power and considering peak-load shifting of distribution network load on the basis of the current working conditions of the microgrid and the main grid, so as to form a control strategy and send it to the coordination control layer. Coordination control layer decomposes the control strategy into control signals to devices according to the measured values and the quantity of state sent by the device layer, and sends these signals to the device layer. The actuators of the device layer ultimately complete the process of control.
2) Communication interrupt condition. As mentioned, the design of this control system does not rely too much on communication system. If there is a communication fault between the main station and the coordination control layer, the access control layer will transfer the control strategy function to the coordination control layer, which leads to two-layer control. When there is a communication fault between the coordination control layer and some device layer DG, the device layer can still make DG control strategies on the basis of the measured values and the quantity of state.
3) Island running. When a fault occurs in the power distribution grid, the microgrid can not remain online operation. When the main station commands the micro grid to be off-grid, the microgrid has to operate independently in order to ensure reliability.

① Active off-grid running. As for the condition of active command, the control process is simpler. After receiving the off-grid control instruction, the coordination control layer sends a message to the load control equipments that the unimportant load may be cut off and the energy storage devices maintain energy balance, according to the generation power and the load power within the micro grid. Then the coordination control layer will convert the control mode of the master controller from PQ control mode to *V*/*f* control mode and trip off the grid-connection switch, thus smoothly switches into the off-grid operation mode.

② Passive Off-grid running. One case is that the coordination control layer obtains the information of grid-connected switch shift at the earliest time. Firstly cut off the unimportant load or start the energy storage devices on the basis of energy balance, so as to maintain energy balance, and at the same time convert the control mode of the master controller from PQ control mode to *V*/*f* control mode so as to complete mode shift. Another case is that the master controller at first detected a fault and starts the islanding protection. The control mode of the master controller is converted from PQ control to *V*/*f* control mode. At the same time, the communication controller sends this message as the highest priority to the coordination

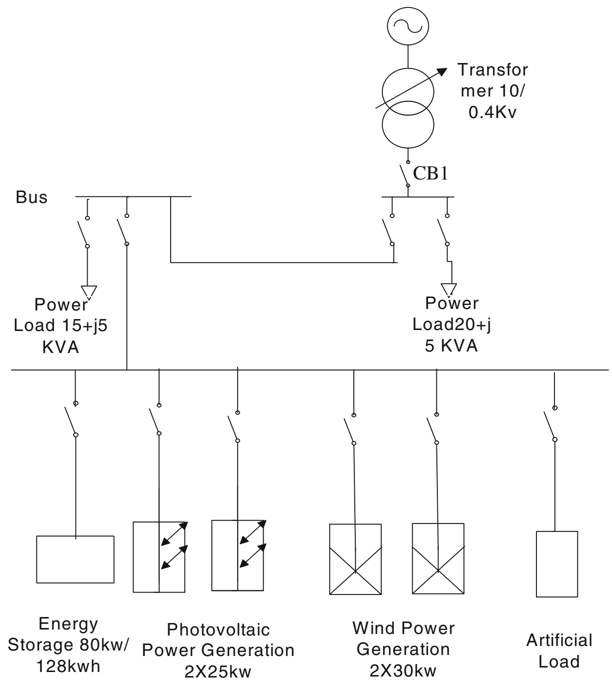

Fig. 5 Village mode for microgrid

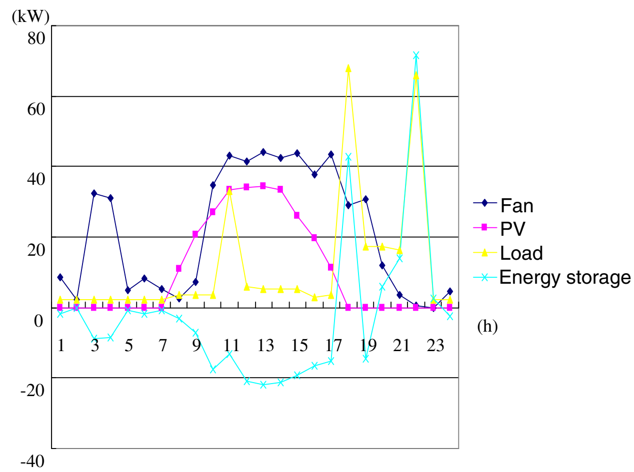

Fig. 6 One typical day of the micro source and load power

control layer, and then takes emergency control measures according to the adaptive control schemes for anticipated incidents, so as to complete mode switch. In the above-mentioned two cases, information will be sent to the control layer after the completion of mode shift, and the access control layer will adopt a global control strategy according to the islanding condition.

The adaptability of state control strategy splendidly accommodates various unexpected accidents or faults of the power distribution grid. The access control layer, the coordination control layer and the device layer of the microgrid take different response speed, which excellently accommodates the rapidity of the mode shift of microgrid operation and the low response speed of the superior dispatching system.

5 Application case

The system is applied in the demonstration project of distributed generation/energy storage and microgrid operation control of Yudaokou Village, Yudaokou Township, Weichang County, Chengde City. The project includes a subsystem of 60 kW photovoltaic power generation, a subsystem of 90 kW wind power generation, a subsystem of 80 kW/128 kWh energy storage, and the village load as shown in Fig. 5. On the one hand, they supply power to the village load. On the other hand, they are connected to the public power distribution network through a 400 V/10 kV distribution transformation. The operation is coordinated under the unified management of microgrid control system.

After the system has been put into operation, the access control system automatically selects corresponding control strategy according to the state of the power grid. The process of self-adaptation control under the three conditions of normal optimized operation, communication interrupt and voltage limit fault will be analyzed below.

5.1 Normal optimized operation

Fig. 6 shows the changes of the output and the load of each micro-source in normal optimized operation. From this figure we can see that the complementation of the output of wind and light can smooth fluctuations in the output of wind and light on the one hand; on the other hand, when the load increases and the output of wind and light is insufficient, the rapid release of the stored energy balances with the over high load of the power distribution network over the period, thus achieves the effect of peak-load shifting.

In this operation process, the access control system of the station level sends out microgrid output plans for the next day based on the load prediction and the working state of the power grid the day before, and makes real-time revisions in the day execution. Generally the revision is made every ten minutes. The microgrid controller of the bay level decomposes the output task to each micro source according to the generation prediction of DG and the generation plan of the main station, and coordinates the operation of each micro source in real time. The regulation period is over ten seconds.

5.2 Communication interrupt condition

In a communication interrupt condition, the microgrid actively comes to be off-grid and operates independently. The energy storage provide reference voltage. *V*/*f* control mode is adopted and the output is regulated in order to provide a power balance within the microgrid system. The each micro-source output can still realize smooth switch by adopting the control strategy of adjustment ratio Droop via inverter.

This process is completed through two-layer control by each micro source of the coordination layer and the device layer under the condition of communication interrupt of the station level.

5.3 Voltage limit fault

If a voltage limit fault occurs in the microgrid, the protection will act rapidly. The fault source will be cut off after tens of milliseconds, emergency control will be executed, at the same time information will be sent to the main station of access control layer. If the device layer passively receives the commands of the station level and the coordination control level, and the fault source is not cut off in time, the scope of fault will be enlarged.

6 Conclusion

By analyzing the operating data of Chengde distributed generation/energy storage and microgrid operation control system in more than two years, it is indicated that the system has the following characteristics:

1) It adopts microgrid hierarchical control system structure and realized full-view monitoring and fine control of the microgrid.
2) It adopts a message mechanism and self-adaptive operation control of the micro grid and realized the intelligence of microgrid control.
3) The operation of this control system does not totally depend on communication. It can realize self-adaptive control strategy in fault conditions.
4) This control system not only attaches importance to reliable and effective use of the micro grid, but also lays emphasis on the coordination of each generation unit, which solves the impact of grid-connected operation of the microgrid on power grid and its consumers.

There are still some aspects deserving further in-depth study.

1) In order to satisfy the safety and reliability requirement of the power distribution network and the constraints of power quality, it is necessary to do more research on the maximum capacity and optimal proportion of the accessible distributed generation, load and energy storage in the distribution network.
2) In order to make the microgrid control more accurate and the fluctuation impact to the power grid smaller, it is necessary to do more research on precise prediction of distributed generators.

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Wen LU received the M.Sc degree in Electrical Engineering from Harbin Institute of Technology University (HIT). He is now a D.Eng. candidate in HIT University and a Senior Engineer in State Grid Electric Research Institute. His research interests include distribution system operation and distributed generation system operation.

Yangdong ZHAO received the M.Sc degree in Electrical Engineering from Wuhan University. He is now a Professorate Senior Engineer in State Grid Electric Research Institute. His research interests include distribution system planning and operation.

Weixing LI received the Ph.D. degree in Electrical Engineering from Harbin Institute of Technology University(HIT). His research interests include power system analysis and operation.

Hongwei DU received the Ph.D. degree in Electrical Engineering from Tianjin University. He is now a Professorate Senior Engineer in State Grid Electric Research Institute. His research interests include distribution system planning and operation.