MICROGRID COORDINATED CONTROL SYSTEM WITH VSG

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ABSTRACT

The microgrid coordinated control system makes the microgrid to be a controllable and stable power system, which has the great significance to the reliable operation of microgrid system. This paper presents a microgrid distributed coordinated control system, introduces several functions of this control system such as: grid connecting control, islanding control and black start control, and proposes the optimization solution for the issue of slow control speed and low control precision for virtual synchronous generator (VSG). Finally, this paper introduces the microgrid coordinated control system with VSG technology in practical application, Thailand Chiang Mai Ban Khun PEA microgrid project, verifies the feasibility of the proposed system.
***Keywords**—microgrid, coordination control, VSG*

INTRODUCTION

Microgrid is a locally controllable power system composed of distributed generation(DG), energy storage and load, which can be connected to bulk power system and islanding operation[1], and is an autonomous system to realize control, protection and management by itself, furthermore it is an efficient way to make full use of DG. The key factors which influence the stable operation of microgrid system include microgrid coordinated control system (MCCS) and the power conversion system (PCS). The MCCS can control the DG and load quickly while there is a disturbance or the operation mode of the microgrid is changed to ensure that the voltage and frequency of microgrid are maintained within the allowable ranges and the safe and stable operation of microgrid [2].

Normally, microgrid includes a large number of inverter interfaced distributed generators (IIDG). The low inertia and underdamped operation characteristics of the IIDG affect the stable operation of microgrid especially in islanding mode. VSG is one control technology of the PCS, by simulating the inertia of the traditional generator, solves the problems of IIDG mentioned above [3]. PCS based on VSG technology has damping characteristics, which can run in both grid connecting mode and islanding mode, and can improve the anti-interference capability of PCS [4]. However it also has the weak points:

It can't realize the fast and precise control during grid connecting mode as the slow response and low accuracy of power control.

The voltage and frequency control during islanding mode is imprecise, the voltage and frequency varies with the load.

The PCS has a poor overload capacity and can only withstand the current of about 1.2In [5]. So it can't resist the impact of the external power supply access (such as hydropower, diesel generator).

In view of the shortcomings of VSG, this paper introduces a MCCS with VSG, introduces the function of grid connecting control, switching between grid connecting control, islanding control and black start control, etc.

FUNCTION DESIGN OF MCCS

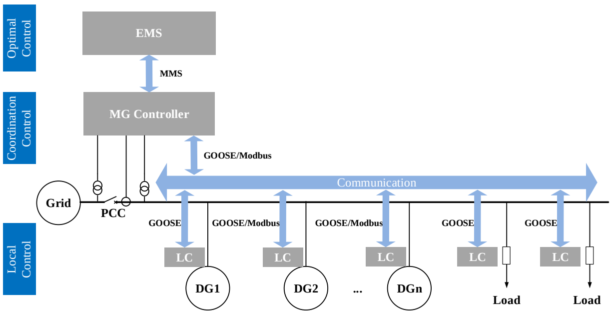

Fig. 1 Control topology of MCCS

The topology of the MCCS is as shown in Fig.1, it includes local control and protection layer, coordinated control and protection layer and optimized control layer [6-7]. Local control layer includes DG, PCS and local controller (LC), when microgrid system has little disturbance or short circuit fault, it can suppress the system fluctuation and restore stable power supply through the fast adjustment of the PCS or the LC. Coordinated control layer includes microgrid controller (MGCC), while the microgrid system has a big disturbance (such as the unscheduled power outage, big scale DG trip during islanding mode, etc.), the MGCC controls the diesel generator, BESS and other DGs, to maintain the voltage and frequency within the allowable range and ensure the safe and stable operation of the microgrid. The optimized control layer includes microgrid energy management system (MEMS), it has the functions of data analysis, energy prediction, load management, optimization operation and economic dispatch for specific applications, to maximize the efficiency of comprehensive utilization of energy in the microgrid.

MGCC is installed near the point of common coupling (PCC). It collects voltage and current at PCC, communicates with DG controllers and LCs, and communicates with MEMS. MGCC receives the analog input from LC, and sends control command to LC. GOOSE is proposed to transmit the control signal which requires high real-time performance, such as the trip signal. If GOOSE function is not supported by the LC, Modbus communication protocol can be used for transmit analog information, binary input and scheduled control command. MGCC uses IEC61850 MMS to communicate with MEMS.

The MCCS provides the function as below:

Grid connecting status control

Due to the active power response of VSG is slow and biased, so if the system requires fast response control in grid connecting mode, such as voltage and frequency fast control, stabilizing the fluctuation of renewable energy, power control at PCC point, PCS should work in PQ control mode. For the situation that no need fast control, due to VSG can operate in both grid connecting and islanding mode, VSG control can avoid the mode switching during the operation mode changing (grid connecting mode to islanding mode or islanding mode to grid connecting mode).

Unscheduled island control

Unscheduled island means that the microgrid turned to island condition due to unscheduled power loss of grid side, to realize the continuously stable operation of the microgrid, the MCCS needs to respond quickly and accurately.

The control flow of unscheduled island is as Fig.2, when unscheduled island happens due to suddenly power loss of grid side, the MGCC detects the island and trips PCC immediately. The success of unscheduled island is mainly determined by the factors as below: fast island detecting, fast trip of PCC breaker, and PCS can withstand the impact during switching process. Any fault of above factors will cause the unscheduled island fail.

Scheduled island control

Scheduled island means that using the scheduled island control function to ensure the uninterrupted power supply of important load in the microgrid area when power grid side has planned for power outage.

If the MGCC receives the scheduled island command, the MGCC will detect the power exchange at PCC, if the power flowing into microgrid is higher than the setting, starting hydro, controlling the PCS or load shedding for unimportant load until the power is lower than the setting; if the power flowing out microgrid is higher than the setting, limiting the power output of DG or shutdown the DG until the power exchange is lower than the setting. After detecting the power exchange is lower than the setting, the MGCC will trip the circuit breaker of PCC.

In case that PQ control is used in grid connecting mode, the control mode of PCS needs switching from PQ control to VSG control, there are two control schemes:

Scheme 1, switching from PQ control to VSG control mode first, then controlling the power exchange of PCC, then waiting for the power exchange within the allowable range, finally tripping the breaker of PCC.

Scheme 2, controlling the power exchange of PCC first, waiting for the power exchange within the allowable range, and then switching from PQ control to VSG control mode, finally tripping the breaker of PCC.

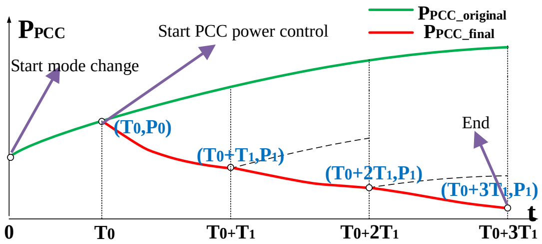

Fig.2 Switching control mode before limit PCC power exchange

Scheme 1 includes several control delay: PQ control switching to VSG control mode has delay T_0; the power control of VSG mode is slow, and the control period T_1 is at seconds' level. As the PV fluctuation inside the microgird is at seconds' level, and leads to the power fluctuation in PCC, so the control period at seconds' level will lead to the issues that it takes several times of power control to limit the power of PCC within the allowable range. As shown in Fig.2, it takes T_0+nT_1 (n means the times of PCC power control). The advantage of scheme 1 is to ensure that the power exchange of the PCC point is little, but it is not suitable for the situation that requires fast control.

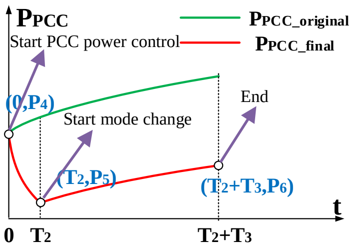

Fig.3 Limiting PCC power exchange before switching control mode

In scheme 2, PQ control mode is used in grid connecting mode, it has the millisecond control response speed, so the control period T_2 is short, at the same time, the control process is at milliseconds' level, the power fluctuation at this period can be ignored, so it needs only once power control to limit the power exchange at PCC. However, the problem of scheme 2 is the mode switching. As shown in Fig.3, there is an oscillation time of T_3 for mode switching, and after that, tripping the breaker of PCC. When the breaker of PCC is tripping, the power of tie line is the fluctuating power during T_3. The advantage of scheme 2 is that the control speed is faster. However the disadvantage is that the power of the PCC point cannot be guaranteed within the pre-setting range.

Island control

Voltage and frequency control

Due to the droop characteristics of VSG, as shown in Fig.4, when the load changes from P_1 to P_2, the frequency in microgrid will fluctuate from f_1 to f_2.So the frequency fluctuates with the fluctuation of the load. The MCCS adjusts the frequency in microgrid constantly, in order to avoid frequent adjustment, MGCC sets the upper and lower threshold trigger frequency, and monitors the real-time frequency. When the frequency is lower than the threshold, a command of Δf_{ref} will be sent to PCS, in order to prevent frequency over adjustment, Δf_{ref} should not be too large. If the frequency is beyond the target after regulation, the frequency will be adjusted again. At the same time, when the frequency is higher than the upper limit threshold, a command of -Δf_{ref} will be sent to PCS.

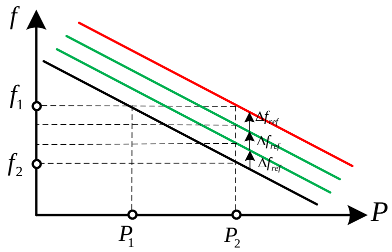

Fig.4 Frequency control scheme during islanding mode

Battery state of charge (SOC) control

The island voltage and frequency are maintained by the PCS, in order to ensure the long-time operation in islanding mode, the battery SOC should be maintained within the specific range. Due to in VSG mode, the output of PCS is decided by load or other sources. If the battery SOC is low, check whether the output of other source can be increased, if not, shedding some unimportant load. If the battery SOC is high, check whether any load has be cut off, if not, reducing the power output of battery, else accessing the load. The output of PV maybe limited during islanding mode, the MGCC determines whether the current operation point of PV is consistent with actual output. If yes, it indicates that PV is limited, and PV output can be increased by modifying the PV operation point.

Parallel control of motor type power supply

When the motor type generator connecting to microgrid, the overcurrent can occur to the PCS trip. As the voltage and frequency in microgrid are decided by the PCS, and the response speed of PCS is faster than motor type generator, PCS can adjust the system voltage and frequency according to the voltage and frequency difference between CB, as shown in Fig.5, to avoid the PCS trip while connecting the generator. Meanwhile, normally the PCS cannot monitor the voltage of the motor type generator side, so a LC can be set to send the voltage and frequency difference to PCS via GOOSE, the communication delay is less than 10ms which can comply with the requirement of control function.

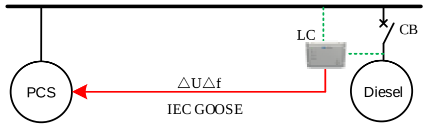

Fig.5 Topology for integrate motor type generator

Switching from islanding to grid connecting

When grid side recovers from faults, in order to restore the power supply of unimportant load in microgrid which has been shedding during islanding mode, microgrid should be switched from islanding to grid connecting. MCCS adjusts the voltage and frequency at PCC until it complies the synchronization condition.
Current mainstream PCS manufacturers have acquire the voltage and frequency on both grid side and microgrid side to realize the synchronization. However, when the PCS is far away from PCC or several PCSs work in parallel at the same time, it cannot be realized through a single PCS. So the control system is still equipped with the synchronization control function at the same time.

PROJECT CASE STUDY

This paper introduces the Thailand first smart microgrid project—Chiangmai Ban Khun Pae microgrid, this microgrid includes 100kWh BESS, 100kWp PV and 90kW hydro generator which can work in grid connecting mode and islanding mode. The MCCS is used in this project with the functions: energy shifting, PV smoothing, black start, switch between grid connecting and islanding, island optimized control function, etc. The PCS is working in VSG mode during islanding mode and MGCC communicates with DGs via GOOSE.

Fig.6 Pictures of the Ban Khun Pae microgrid project

Scheduled islanding control

As shown in Fig.7, after the MGCC received the scheduled islanding command, it will limit the power at PCC, then sending the mode switching command to PCS. In order to avoid the power oscillation produced by the PCS mode switching, MGCC sends the open command to LC via GOOSE after 1s delay (this delay time determined by the performance of PCS), then the breaker in PCC takes about 200ms to trip. The whole switching process takes time about 1.4s.

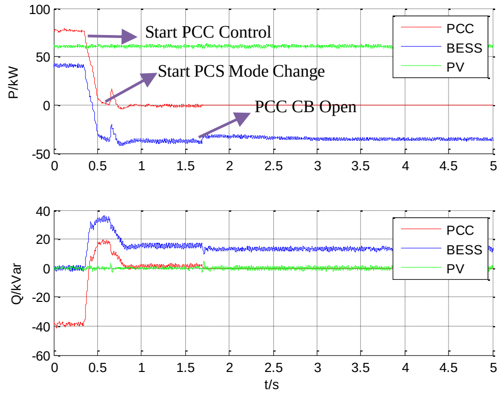

Fig.7 Waveform of scheduled islanding

Switching from islanding to grid connecting

After the MGCC received the grid connecting command, it will adjust the voltage and frequency at PCC point according to the voltage difference and frequency difference, then wait for the synchronization, if the phase difference is less than the setting value 5°, it will close breaker at PCC, the waveform is as below:

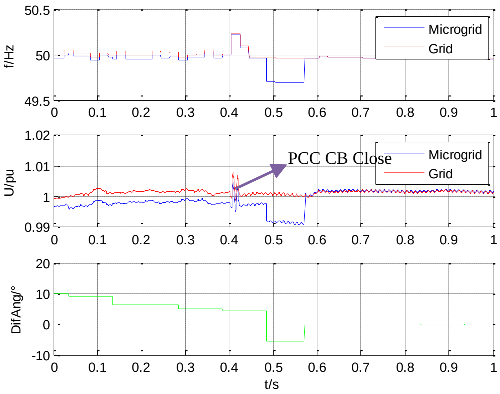

Fig.8 Waveform switching from islanding to grid connecting

Black start

When microgrid is black, MCCS closes the LBS first, then starts the PCS to set up the voltage with load, in order to improve the stability of black start, the voltage increase speed should not be too fast. At the same time, all the protection functions of the MGCC are disabled, to avoid the voltage and frequency protection operating, the waveform is as below:

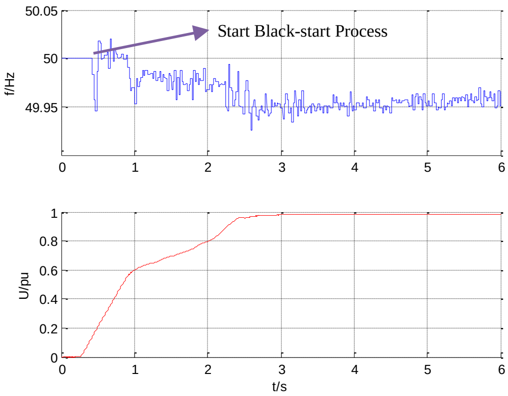

Fig.9 Waveform of black start

CONCLUTION

This paper introduces a hierarchical distributed microgrid coordinated control system, this system has the advantages of high reliability of distributed control system and easy expansion of centralized control system. By effectively coordinated control of different layer, the stable and economic operation of microgrid can be realized. In view of the influence of VSG on microgrid control, the relevant solutions are proposed in this paper. Finally, taking the Ban Khun Pae microgrid as a case, the MCCS is proved to be feasible and can be proposed for other similar microgrid project.

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