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A Smoothing Control Strategy between Grid-connected Mode and Off-grid Mode for Smart Microgrid and Its Design

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Abstract—**In this paper, the characteristics of typical smart microgrid are analyzed and the key technology of smoothing coordinated control method is studied. Moreover, in order to obtain a smooth switch between grid-connected mode to off-grid mode, a smoothing control method is proposed and realized. The technology include a synchronization detection method which is based on the leading angle algorithm, a fast power balance control technology based on GOOSE communication technology and a control strategy based on XML language. Based on this technologies, the smoothing coordinated control strategy is realized. The RTDS simulation platform is established and the result is verified.**

Keywords—microgrid; grid-connected mode; off-grid mode; GOOSE communication

I. INTRODUCTION

The distributed generation has the advantage of effective, green, economic and flexible, it is a important supplement to the large power grid. But due to the volatility and intermittency feature of the DG, the access of large-scale DG will have a significant impact on the security of the grid. However the Microgrid which are composed of distributed generation (DG), distributed storage (DS), and loads has the features of self-healing, self-control and self-management, [1] it is the inevitable choice to deal with large-scale access of DG. So research on smart microgrid technology lays foundation for solving the problem mentioned above[2-4].

Microgrid can operate in grid-connected mode or off-grid mode. "Grid-connected mode" means that the microgrid is connected to the main grid. "Off- grid mode" means that the microgrid could continue to supply the local loads independently even after the system is separated from the main grid. Then the system will become a self-powered grid. When microgrid switch between grid-connected mode and off-grid mode, the key point is how to realize a smoothing transition. In this paper, the control mechanism between grid-connected mode and off-grid is studied and a smoothing control strategy is proposed. Moreover, The RTDS simulation platform is established and the smoothing control strategy is verified, the result shows that it achieved smoothing switch effect between grid-connected mode and off-grid mode successfully.

II. THE SMOOTHING CONTROL STRATEGY BETWEEN GRID-CONNECTED MODE AND OFF-GRID MODE

The microgrid has two kinds of operation mode, when the large grid is in normal state, it operates in grid-connected mode. When a fault is happened in the large grid, the grid-connected breaker is off and the microgid operates in off-grid mode. So there has a switch between the two kinds of mode. When the microgrid needs to switch from grid-connected state to off-grid mode, the key point is how to control the power balance fastly to guarantee the power supplied by the DG. When the microgrid needs to switch from off-connected state to grid-connected, the key point is how to control the breaker closed in the synchronization phase with the large grid to reduce the impact.

A. The Asynchronization Detection Method for Microgrid

When the microgrid is running in the off-grid mode, the frequency and phase between the grid and the microgrid is inconsistent. In order to minimize impact when connected in to the grid, the main point is how to control the breaker close at the time that the angle difference is close to zero. So, a asynchronization detection method based on the leading angle algorithm is proposed. The method is as follows:

Collecting the voltage of the grid Ua and the voltage of the microgrid Usa, and calculate the amptitute, frequency, angle both of the grid and the microgrid using the discrete Fourier transform (DFT) algorithm. The DFT formula is as follows:

$$a_k = \frac{2}{N}\sum_{n=0}^{N-1} x(n)\cos(\frac{2\pi}{N}kn) \tag{1}$$

$$b_k = \frac{2}{N}\sum_{n=0}^{N-1} x(n)\sin(\frac{2\pi}{N}kn) \tag{2}$$

Where, N is the sample pointis a whole wave, k is the number of harmonics. From the formula(1) and (2), we can derive the amptitute(A) and angle(ϕ_k), as follows:

$$A_k = \sqrt{a_k^2 + b_k^2} \tag{3}$$

$$\varphi_k = arctg(-\frac{b_k}{a_k})\ (a_k > 0) \tag{4}$$

$$\varphi_k = arctg(-\frac{b_k}{a_k}) + \pi(a_k < 0) \tag{5}$$

Judging if the frequency and voltage are in the normal range.

Proposing a constant leading time asynchronization principle, calculate the leading-angle (shown in formula 6).

$$\delta_{yj} = \omega_{si} T_{dq} + \frac{1}{2}\frac{\Delta\omega_{si}}{\Delta t} T_{dq}^2 \tag{6}$$

Where: δ_{yj} is the leading angle, T_{dq} is the leading time; ω_{si} is the angle slip of the grid-connection point ; $\frac{\Delta\omega_{si}}{\Delta t}$ is the angle slip acceleration of the grid-connection point.

The advantage of this principle is that it derives the leading-angle according to the angle difference between the grid and microgrid and the time that cost from the closing signal to the breaker closing. So, the closing signal will be sent before the leading-angle to ensure the minimum impact to the grid.

B. Fast Power Balance Control Based on GOOSE Communication

The fast power balance control technology plays a great significant role in switching between grid-connected mode and off-grid mode. Microgrid can operate in off-grid mode after the breaker is separated only it reaches power balance in the whole system. This paper manages to propose a power balance control technology with fast GOOSE communication mechanism[5-7].

GOOSE is a fast message transmission mechanism in IEC61850 standard. In order to ensure the instantaneity of communication, GOOSE message transmission directly maps to ISO/IEC8802.3 frame instead of MMS mapping, which supports IEEE802.1Q priority tag and VLAN coding. The header of IEEE802.1Q occupies 4 bytes, including TPID (whichoccupies 2bytes) and TCI (which occupies 2 bytes). TCI includes priority tag, which occupies 3 bits and can be set with different priority. The use of IEEE802.1Q protocol ensures the priority of GOOSE packet transmission. At the same time, the retransmission mechanism ensures the reliability of the GOOSE message in application layer[8].

To realize the fast power balance control technology, it requires to control the power balance in real time. The technology of fast power balance control succeeds to adjust the output or input power of DGs, DSs and the loads. What's more, according to GOOSE communication mechanism, all GOOSE packets are sent at a high speed and the delay will be less than ms level, thus it ensures the power balance before the breaker at the PCC is separated.

C. A Smoothing Control Strategy Based on XML Language

To realize the smooth switch between grid-connected mode to off-grid mode, it requires a control center that coordinate the operation of each sequential control in the system. According to the actual microgrid, there may be many different kinds of network structure and operation modes in microgrid system, a large-scale of microgrid system may consist of a lot of sub-microgrids, so there are many different coordinate control strategies for different microgrid structure[8-10]. In order to make it convenient for the implementation of the projects, this paper introduces a smoothing control strategy with standard XML language.

The smoothing control strategy based on XML is generated by the configuration tool, which includes the topology structure of the microgrid and the control sequence for the storage, load and breaker at the PCC. The XML file will be parsed and loaded automatically, which is more convenient and standard to realize different control strategies. The instance of strategy based on XML language is as follows:

<?xmlversion="1.0"encoding="utf-8"?>

<config>

<DGNode Index = "0x0100"attribute =”DG" desc="1# PV" cap=”500kW”/>

<DGNode Index = "0x0101"attribute =”DG" desc="2# PV" cap=”500kW”/>

<DGNode Index = "0x0103"attribute =”DG" desc="3# FAN" cap=”750kW”/>

<DGNode Index = "0x0104"attribute =”DG" desc="4#Battery PCS" cap=”500kW”/> <DGNode Index = "0x0105"attribute =”DG" desc="5# capacity" cap=”500kW”/>

< LineNode Index = " 0x0200" attribute =”LineBus" desc="1#Line"/>

< BreakNode Index = " 0x0300" attribute =”Breaker" desc="1#Breaker"/>

<LoadNode Index= "0x0400" attribute =”Load” desc="1#Load"/>

< LoadNode Index ="0x0401" attribute =”Load” desc="2#Load"/>

< tripMode index=”0x0300” condition ="Trip&State=0x01"optime="20000ms"desc="PCC1 ">

<Action operate = "0x02"index = "0x0400"delay ="0"desc=" 1#Load control"/>

<Action operate = "0x02"index = "0x0401"delay ="0"desc="2#Load control"/>

<Action operate = "0x01"index = "0x0104"delay ="0"desc="4#Battery PCSmode control"/>

</tripMode>

</Config>

The smoothing control strategy of microgrid mentioned above is mainly composed of two parts: the configure describe and control sequence, which are introduced in detail as follows:

In the configure describe , there are four different nodes: ”DG node”, “Line node”, “Load node” and “Breaker node”, where DG node contains the index number, attribute , description information and capacity, it includes wind turbine, photovoltaic and battery. “Line node” contains the index number, attribute and description information of the line. “Load node” contains the index number, attribute and description information of the load. “Break node” contains the index number, attribute and description information of the break.

2. The realization of the switch control of the microgrid: It includes the “tripMode” and the” Action”, the “tripMode” determines the trip of the execution of this strategy, "index" defines the index of the node, "condition" defines the trip condition,"optime" defines the operation time,the time unit is ms. The “action” dscribes the execution steps of the control strategy, at first, the 1#load and 2#load is cut off., then the PCS is controlled from P/Q mode to V/f mode, "operate", "index" and "delay" are used to define the method, objective and delay of the operation respectively.

The time sequence for the control strategy is as follows: after the fault is detected, the switching process from grid-connected mode to off-grid mode begins and the coordinate control strategy is trigged. The fast power balance is excuted and. Thus, a smooth transition from grid-connected mode to off-gridmode is achieved.

III. RTDS Simulation Verification

The Smoothing Control Strategy are verified through a RTDS simulation, which simulates an actual project.

A. *Simulation Platform*

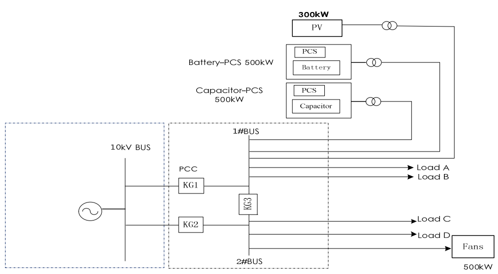

FIGURE I. THE SIMULATION PLATFORM

The basic data of equipment model in RTDS experiment is as follows:

No	Equipment	arameter
1	Battery-PCS	500kW
2	Capacitor-PCS	500kW
3	Fans	500kW
4	PV	300kW

TABLE I. THE EQUIPMENT MODE IN RTDS EXPERIMENT

The RTDS experiment simulates different occur time and point of the connection to the grid, in which the smooth transition between grid-connected mode and off-grid mode is successfully verified.

B. *Simulation Result*

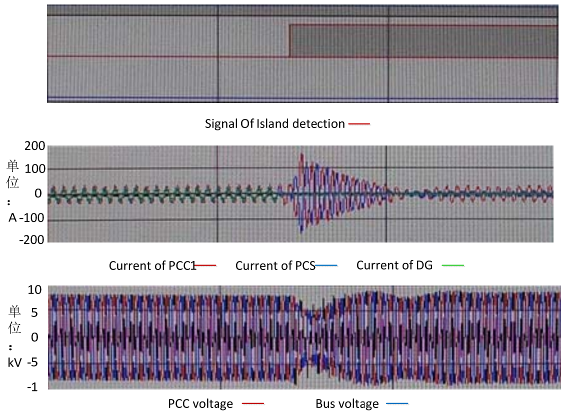

FIGURE II. THE RTDS SIMULATION RESULT

As is shown in Fig. 2, the smoothing control strategy is trigged to set the control sequence and balance the power flow within the whole system during the switching process from grid-connected mode to off-grid mode. Then after about 100ms, the balanced power at the PCC is achieved and the microgrid manages to switch to off-grid operation mode through disconnecting the breaker at the PCC. From the bus voltage of the microgrid it could be seen that after the switching process, the voltage is quite stable and suffer nearly no fluctuations. Thus, the smooth transition from grid-connected mode to off-grid mode is successfully achieved. The result shows that the smooth switching from grid-connected mode to off-grid mode is guaranteed within just 3 cycle waves without power off.

IV. Conclusion

This paper focus on the smoothing switch between grid-connected mode and off-grid mode. It propose a smoothing control strategy which includes a asynchronization detection method based on the leading angle algorithm, a fast power balance control technology based on GOOSE communication technology and a smoothing control strategy based on XML language. The RTDS simulation has been done and verified its effect.

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