Preprints of the 19th World Congress
The International Federation of Automatic Control
Cape Town, South Africa. August 24-29, 2014

Research on Dynamic Process of DC Micro-grid under Hierarchical Control

Zheng Lee*. Shouzhen Zhu*. Jinghong Zheng*. Dae Hee Choi*.Ling Wei*.

**State Key Lab of Power Systems, Dept. of Electrical Engineering, Tsinghua University*
Haidian District, Beijing, 100084 China (Tel:010-62783378 ;e-mail:lizheng901224@163.com).

Abstract: In this paper, an improved hierarchical control strategy of DC micro-grid is given. The micro-grid has a hierarchical bus, a grid-connected AC/DC converter, a voltage level converter, interface converters for PV and battery modules, etc. By controlling these converters, the system can work in and switch between two modes: grid-connected and islanded. In grid-connected mode, the DC bus voltage remains stable mainly by the controlling system of grid-connected converter. In islanded mode, in order to maintain the power balance, I-U droop control is used in battery energy storage system uses. The paper confirms the current control strategy is effective.

In this paper, voltage and power fluctuation when system operates in different dynamic processes is also discussed, and its regularity is summarized. Through the study of dynamic process and the analysis of system dynamic characteristics, the paper tries to give the improvement method in order to enhance fault resistance, and improve the stability of the system.

Keywords: DC system; micro-grid; hierarchical control strategy; dynamic processes; non-intentional islanding

1. INTRODUCTION

As problems of energy and environment are becoming more and more serious, technology of distributed energy resources (DER) is developing rapidly. In order to improve the using efficiency of DER, people put forward the concept of micro-grid. Generally, micro-grid contains micro source, energy storage system, load components, interface converters and other devices. As a new kind of structure which can achieve self-protection and self-management, micro-grid is able to build better control strategy and make the electricity network more intelligent by appropriate use of micro source and energy storage devices. Generally, we require that micro-grid works under and switches smoothly between two modes: grid-connected and islanded.

At present, the main form of micro-grid is AC micro-grid. While another concept, is to connect load, energy storage and other components together through DC bus or network. It is called DC micro-grid. Two kinds of micro-grid structure are shown in Fig. 1.

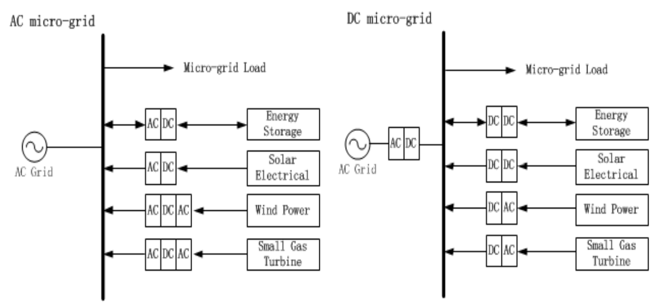

Fig. 1. AC and DC micro-grid.

Compared with AC micro-grid, there're fewer power electronic converters in DC micro-grid, which makes the structure simpler, and energy efficiency higher. The space-charging effect reduces corona loss and radio interference in DC micro-grid. Furthermore, DC micro-grid only needs to consider the DC bus voltage and internal power balance, regardless of frequency control, which makes control easier and stability higher.

At present, researchers have studied quite a few about connecting methods, bus voltage, control strategy of distributed modules and other aspects of DC micro-grid. However, as a series of basic problems are essentially different between AC and DC systems, there are many aspects to be studied. These aspects include: DC standards, multi-source coordination, technology of distributed network, typical dynamic processes, protection methods and policy change caused by distributed generation, etc. There have been a lot of research production about the structure of DC micro-grid, this paper complements the study about multi-source coordination, especially typical dynamic processes.

2. STRUCTURE AND CONTROL METHOD OF THE SYSTEM

2.1 Main Structure of the System

The structure of DC micro-grid this paper builds under MATLAB/SIMULINK is shown in Fig.2.

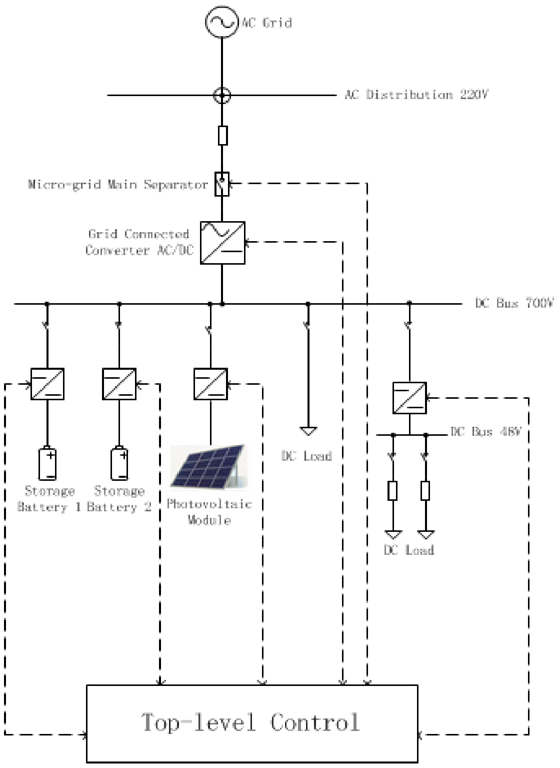

Fig. 2. Structure of DC micro-grid

The main separator and AC/DC converter connects 380V AC distribution network and micro-grid, which contains hierarchical bus, a PV module, two sets of battery storage, DC loads and voltage converter, etc. This paper uses hierarchical control for the system: the bottom level mainly controls power-electronic converters using basic methods, while the top level realizes coordination control of source, battery, grid-connecting converter for the control strategy.

2.2 *Control of PV Module*

Photovoltaic battery generates electricity mainly by photovoltaic effect. The output DC voltage of PV module is generally lower than bus voltage of micro-grid, therefore, Boost DC/DC converter is selected. We use Duty Cycle Perturbation and Observation Method for MPPT. Control model is shown in Fig.3.

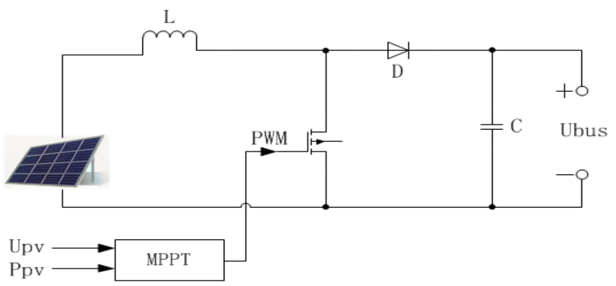

Fig. 3. Control model of PV

2.3 *Control of Battery Module*

We choose lead-acid battery in this paper. Bidirectional DC/DC interface converter and current closed-loop control are used. When grid voltage becomes lower, electricity goes from battery to grid; when voltage gets higher, electricity goes from grid to battery. In fact, considering the internal resistance, the voltage of battery will change during dynamic processes. But the amplitude could be ignored. Circuit diagram and I-U droop curve when micro-grid is islanded is shown in Fig.4 and Fig.5.

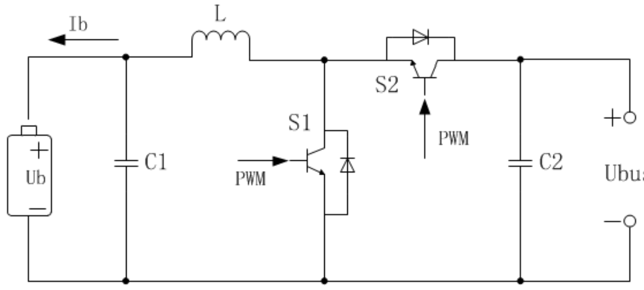

Fig. 4. Battery control circuit

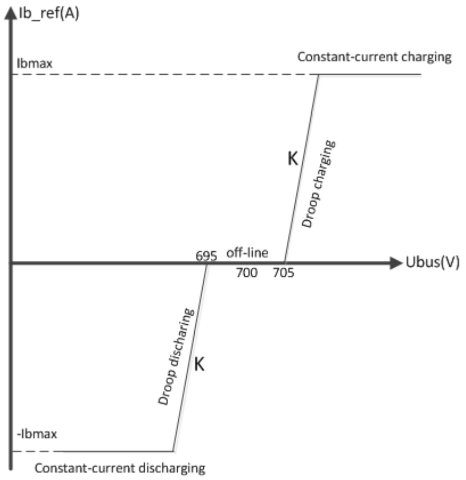

Fig. 5. Battery control droop curve

2.4 *Control of Grid-connected Converter*

In order to realize bidirectional flow of energy, this paper selects three-phase voltage source PWM converter. The converter uses DQ decoupling control method, as is shown in Fig.6. Considering the principle of conservation of energy, stability of P equals to stability of bus voltage, while Q=0, means that AC power factor is 0, so the micro-grid can be regarded as a resistance when grid-connected.

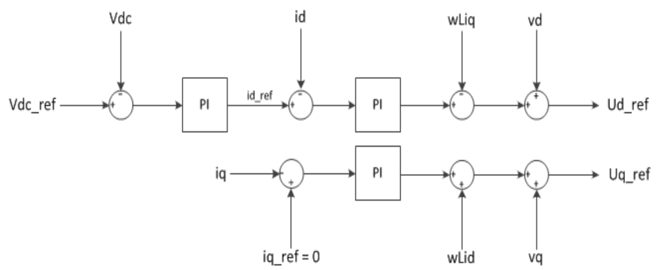

Fig. 6. DQ decoupling control method

2.5 *Control Method of the System*

Control method of the system is shown in Table 1. For extreme cases when bus voltage gets lower or higher than critical value, over voltage protection is needed. But this point is within the scope of this paper.

Table 1. Control strategy of the system

Work mode	Bus voltage	Grid-connected converter	Battery	PV
Grid-connected	U>700V	Active inverter	50A current charge	MPPT
	U<700V	Rectifier	50A current charge	MPPT
Islanded	U>710V	Off-line	200A current charge	MPPT
	705V<U<710V		Droop charge	MPPT
	695V<U<705V		Off-line	MPPT
	690V<U<695V		Droop discharge	MPPT
	U<690V		200A current discharge	MPPT

2.6 *Verification of Control Strategy*

Fig.7 shows the simulation result of DC micro-grid when grid-connected, while Fig.8 is when system works in islanded mode. The load comes to a sudden change at 0.4s and 0.7s.

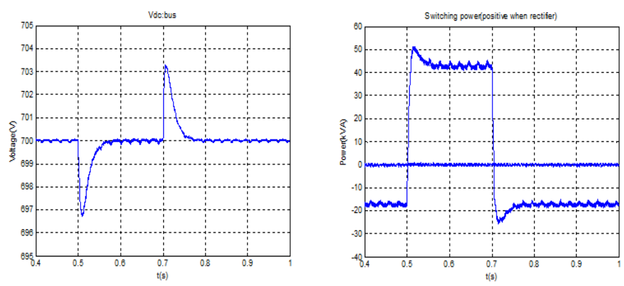

Fig. 7. DC voltage and switching P,Q when grid-connected

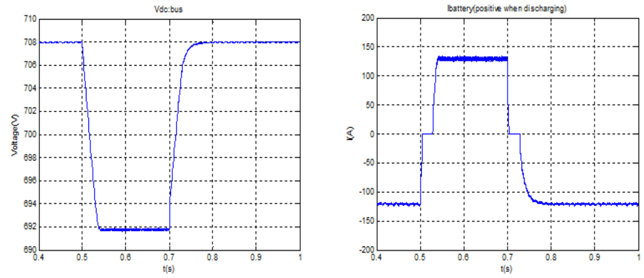

Fig. 8. DC voltage and battery current when islanded

It could be seen that, under the control strategy shown in Table 1, DC micro-grid is able to maintain its stability of voltage and power.

3. STUDY ON DYNAMIC PROCESSES OF DC MICRO-GRID

This section describes several kinds of dynamic process when DC micro-grid is working. Analysis is mainly done about change regulation of the process and primary factor that influences the system.

3.1 *Short-circuit Faults in AC Side*

The short-circuit faults in ac side of grid-connected converter, mainly cause the drop of ac voltage. Assuming that Uac is the ratio of ac voltage during fault and at steady state, which is generally between 0 and 1. Typical dynamic process of dc bus voltage is shown in Fig.9.

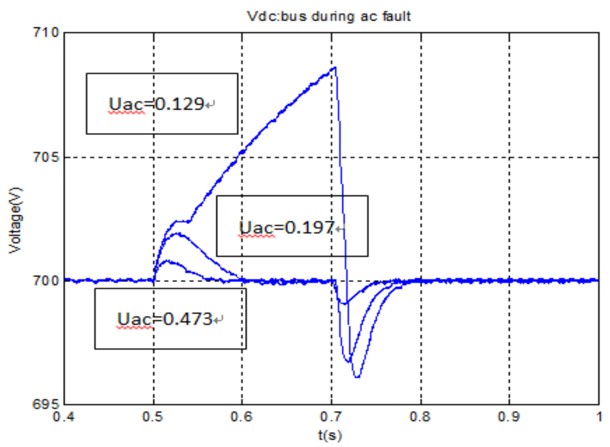

Fig. 9. AC short-circuit fault: dc bus voltage

When the change of Uac is small, the system will restore stability during faults. However, when the change is too big, the dc bus voltage will diverge. When actual system is working, people hope the system can return to the steady state during faults, instead of divergence of voltage. We can define an important parameter "Uo" as follows: "Uo" is a critical value when a short-circuit fault happens in ac side. When Uac>Uo, the voltage of dc bus will restore stability during short-circuit, otherwise, the voltage will diverge.

Simulation results show that, "Uo" increases when the power flow between ac and dc grid increases before islanding .

3.2 Non-intentional Islanding Process

When micro-grid is connected with ac grid, non-intentional islanding is defined as a dynamic process caused by sudden break between micro-grid and ac grid. The reason of the break is indeterminism. This paper does not discuss the principle of island detection, only assuming that it takes some time. During that time micro-grid is uncontrollable. Fig.10-12 show the comparison of islanding process when changing capacitance to ground, load power and maximum current of battery "Ibmax". Study results are shown as follows.

(1) In dynamic process, the rate of voltage change is negatively correlated with capacitance to ground;

(2) During island detection, the rate of voltage raising and lowering is positively correlated with the power flow between ac and dc grid before islanding. However, the rate of voltage recovery is positively correlated with the imbalance of power ΔP;

(3) The rate of voltage recovery is positively correlated with "Ibmax".

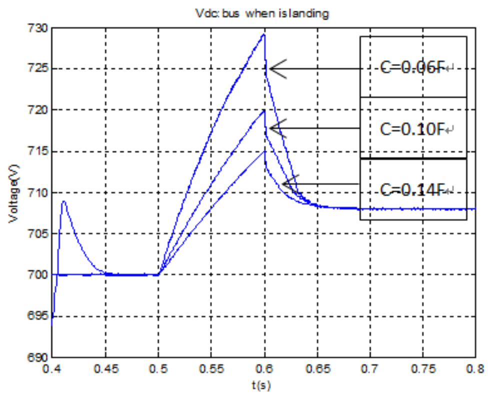

Fig. 10. Islanding process when changing C

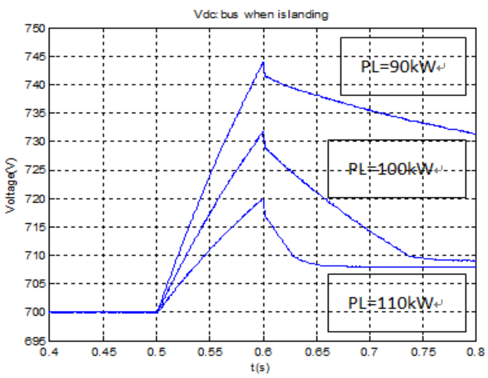

Fig. 11. Islanding process when changing PL

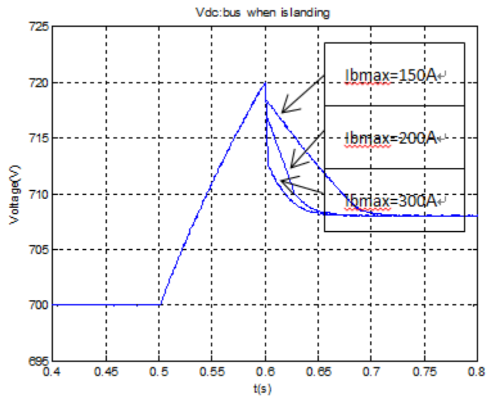

Fig. 12. Islanding process when changing Ibmax

4. CONCLUSION

In order to ensure that the DC micro-grid can work stably both in grid-connected mode and islanded mode, the control strategy of distributed modules is given in this paper. Through the summary and analysis of a series of dynamic processes, this paper gives some factors to consider when designing micro-grids.

(1) According to the situation of DC micro-grid, determine the critical value of Uo. It is an important reference of the strategy of network protection.

(2) According to the capacity of distributed power and load, select appropriate batteries, while keeping a certain margin of Ibmax.

(3) Measure the capacitance to ground of the network, add compensation when it is not enough.

5. Acknowledgements

This work is supported by National High-tech R&D Program of China (863 Program) (2014AA051902).

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