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Research on DC Micro-grid system of photovoltaic power generation

Yiming Zheng, Xiaohui Wang

School of Beijing University of Civil Engineering and Architecture, Beijing 100044, China

Corresponding author e-mail: 1373716132@qq.com

Abstract. The use of energy has become a topic of concern, the demand of people for power grows in number or quantity with the development of economy. It is necessary to consider using new forms of power supply-microgrid system for distributed power supply. The power supply mode can not only effectively solve the problem of excessive line loss in the large power grid, but also can increase the reliability of the power supply, and is economical and environmental friendly. With the increasing of DC loads, in order to improve the utilization efficiency, the DC microgrid power supply problems are begin to be researched and integrated with the renewable energy sources. This paper researched the development of microgrid, compared AC microgrid with DC microgrid, summarized the distribution of DC bus voltage level, the DC microgrid network form, the control mode and the main power electronics elements of DC microgrid of photovoltaic power generation system. Today, the DC microgrid system is still in the development stage without uniform voltage level standard, however, it will come into service in the future.

1. Introduction

With the development of community economy and the expansion of power consumption, the Generation of electric energy must be increased to meet the demand. Nevertheless, large-scale power systems, which brings great benefit to society, are potentially dangerous. The CERTS (Consortium for Electric Reliability Technology Solutions) of U.S.A established the concept of micro grid first [1]. Micro grid is a system composed of a micro power and electrical loads, provided important support by the power electronic devices, with electrical and thermal energy of two kinds of energy supply situation. The micro power within the micro grid is controlled as a unit by the large power grid, and it also needs to meet the requirements of the users about the power supply reliability and power quality. The micro grid system includes AC micro network system, DC micro network system and AC / DC Micro-grid system. When the concept of micro grid is just proposed, the first thing that comes to mind is AC micro grid. On the basis of AC distribution network, AC micro grid is easier to be realized, more mature than DC micro grid. AC micro grid is the main form of micro grid, and the basic structure of different types of AC micro grid is similar. Most of them adopt radial grid structure, distributed power supply, energy storage system and loads which are directly connected to the system. The disadvantage of AC micro grid is that each distributed generation unit is more complex to be controlled, and it needs
to consider the factors of frequency, voltage, reactive power and non-synchronization of each heating power supply, while it requires more than one inverter, so it has higher cost.

The DC micro grid system is more efficiency without reactive power compensation. Most distributed power supplies and electrical energy storage devices output direct current, which must be programmed by inverters to allow AC power to be used in the grid, that process reduces the power utilization substantially. When DC power supply is used, there is no harmonic suppression, unbalanced three-phase load, and voltage flicker of the network. The energy loss of transmission line is reduced and there is no instability of AC transmission in DC transmission. The power flow of DC network can be adjusted automatically or manually through the converter station. The multi-section DC topology makes there is only one station in each communication terminal, even if the line fails, it just needs to start the circuit breaker and cut off the fault line.

AC / DC Micro-grid combines a part of advantages of DC micro network and AC Micro-grid.

2. Voltage level of DC micro grid

The design and construction of the DC micro grid are carried out by individual parameter selections of a real project, so no contact potential series standard is reasonable for some DC transmission engineering. The optimization of DC micro grid design and operation can be reached by the local optimum. But for large-scale DC transmission project in China, the randomness of voltage levels will lead to enormous waste of power transmission equipment’s and power generation resources, and at the same time, it is not conducive to transmission equipment.

The standard DC voltage rating can avoid the voltage level out of order, and can reduce the use of the DC/DC converters and the cost and complexity of DC power supply, thus to improve the reliability and safety of power grid. When selecting the DC voltage level, the transmission distance, the transmission power and the DC voltage level of the adjacent DC transmission system are all needed to be considered [2].

References [3] and [4] focus on the low voltage of DC distributed voltage level. The voltage grade of low voltage DC distribution system of civil houses is demonstrated from the view of human safety and equipment safety, and 400V is put forward to be the DC distribution voltage. Reference [5] studies the feasibility of DC distribution system in commercial facilities. Four kinds of DC voltage are discussed in this paper, which are 326V, 230V, 120V and 48V, based on the existing electric power system of Chalmers University Technology, Goteborg, Sweden.

In order to select the most suitable distribution voltage level, the voltage drop and power loss of the system at four voltage levels are calculated respectively. However, there is no clear conclusion that losses are different when different voltage levels are used in different systems. The model is not uniform at home and abroad, and there is no substantive result. Tab. 1 lists the different dc voltage ratings.

| Number | IEC standard/V | Power industry/V | Communication industry/V | Railway power supply system/V | Shipboard power supply system/V | Aviation power supply system/V | Distributed generation/V | AC peak voltage distribution/V |
|--------|----------------|-----------------|--------------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------|-------------------------------|
| 1      | 110            | 110             | 240                      | 600                           | 220                           | 270                           | 300                      | 156                           |
| 2      | 125            | 220             | 270                      | 750                           | 375                           | 450                           | 450                      | 170                           |
| 3      | 220            | 300             | 1500                     | 450                           | 1000                          | 600                           | 326                      | 170                           |
| 4      | 250            | 320             | 700                      | 1500                          | 1000                          | 1000                          | 340                      | 392                           |
| 5      | 440            | 336             | 750                      | 1500                          | 1000                          | 1000                          | 392                      | 491                           |
| 6      | 600            | 250             | 1500                     | 1500                          | 1000                          | 1000                          | 340                      | 491                           |
| 7      | 750            | 380             | 567                      | 567                            | 670                           | 670                           | 848                      | 848                           |
| 8      | 1500           | 400             | 670                      | 670                            | 848                           | 848                           | 848                      | 848                           |
| 9      | 1500           | 400             | 848                      | 848                            | 848                           | 848                           | 848                      | 848                           |
When considering the power supply for residential buildings, the voltage level of DC micro grid should be between 200V-400V [5]. The effective value of single phase voltage is 220V, and the effective value of three phase voltage is 380V in china. The voltage of DC 220V can be compatible with most household appliances, and DC 380V is used in inverter air conditioners, variable frequency refrigerators, frequency conversion appliances, exhaust fans, hair dryers and other single phase load power supply. Reference [7] by Na Shen researched DC micro grid with energy storage, which put forward two voltage levels (300V, 48V) of DC micro grid structure, and it was connected with the power grid through bidirectional inverter, using the grid as a backup for Home DC power supply.

That is to say, the DC bus voltage of micro grid for residential and office is generally maintained between 300V-400V, and it is more special for the micro grid of double DC bus residential structure [6], one level for 170V, while the other is set to 220V to be compatible with most household appliances. There are two buses and two kind of bus voltages in the dual bus structure system. It can be supplied to single phase AC power equipment, such as frequency conversion air conditioner, frequency conversion washing machine or exhaust fan. The dual bus voltages in DC micro grid system with solar power generation are [DC300V, DC48V]. Today, DC micro grid has been put into use in the developed countries such as the United States and Japan [6], and the voltage levels of DC400V and DC380V are more common.

3. Operation modes of DC micro grid and network form
The micro grid system has two operation modes: the isolated network operation and the grid connected operation. The micro grid runs side-by-side with the upper power grid through the tie line, and the two sides are standby for each other. Grid connection means that the micro grid runs in parallel with the power grid of the large unit, that is, there is an electrical connection with the conventional distribution network on the main circuit, commonly called a common connection point. Micro grid operation in accordance with the power exchange mode can be divided into two types of common grid connected and not connected to the system. The micro grid can transmit excess power to the grid using the first one, but the latter is strictly prohibited in micro grid unit delivery-PCC power flowing only from the grid to micro network users.

The structure of DC micro grid is composed of distributed renewable energy generation module, energy storage module and load module. DC micro grid can be divided into three forms: single bus structure, dual bus structure, double bus structure. The single bus structure relies on the single bus to assemble and distribute the electrical energy which can satisfy the demand of load to different voltage levels and is controlled more complicated. Double deck bus structure is a combination of single bus structure and double bus structure, and has been hierarchical designed. It is suitable for voltage level demand of low voltage equipment by reducing the voltage DC380V to DC48V by DC converter, which not only reduces the number of power adapters, but also improves the security and reliability of low-voltage power supply equipment.
Fig. 1 The basic structure of DC micro grid.

The basic structure of DC micro grid is shown in Fig.1, which includes different types of load, several distributed powers, the main energy storage equipment, energy management system, isolating switch, the point of common coupling interface (PCC), power protection device, A B C three feeders and a bus, with the radial network structure.

Various micro power sources need to be connected to the micro grid through power electronic commutation devices, and it is very different from the large grid control, which gives the frequency response of the rotator stabilization system. The micro grid control system must guarantee that the system operated safely and stably under two operation modes: grid connected and isolated network. When the grid connected mode is working, distributed generation units will provide ancillary services to the city in the form of step voltage; when isolated network operation mode is working, the control system based on power electronic commutation technology will control the voltage and frequency in the network, and absorb or supply instantaneous power difference between loads to protect the grid.

4. Control Mode Of DC Micro Grid

Micro grid control is a difficult point. There are many micro powers in the micro grid, so the control center is unable to respond quickly to the changes of the system. It must guarantee that the system can operate safely and stably under both grid connected mode and isolated network mode.

Without the control of frequency and phase of the bus voltage, the control strategy is greatly simplified. The network side converter only needs to control the active component of the current, while the reactive power is given to zero. Whether the micro grid is in active or passive state, the control strategy of the converter in the distribution network side is the same with the coordinated control strategy adopted for the converter on the micro grid side that is constant DC voltage control mode. Distributed control technology and centralized control technology are all derived from the control of AC grid, which can be used in the DC power grid, and can also mix two control methods.

For example, MAS (Multi Agent System) is a collection of multiple agent system [8]. The information among the agents is communicated and coordinated by integrating the agent work, intelligent and flexible in response to changes in working conditions and the needs of the surrounding environment to achieve global control system. The core idea is to solve the large scale complex problem in the whole system through a group of intelligent agent. There are three forms of MAS: centralized MAS, distributed MAS and hybrid MAS. In the centralized mode, the other agents are controlled by an agent with full information, while in the distributed mode by multiple Agent and in hybrid mode by both.
5. DC Micro Grid Equipment’s
A wide range of power electronics interfaces are used between renewable energy sources and Micro-grid. In order to make the output voltage of micro source transformation to meet the requirements of the grid voltage, various converter such as AC-DC, DC-DC, DC-AC, and AC-AC are designed. Combined with the specific application areas, in addition to meeting the requirements of voltage transformation, the corresponding circuit topology is required. The system has the advantages of simple structure and control, high efficiency, high power density, high reliability and low cost.

The main components in the DC micro grid system include:
(1) Converter: The device mainly completes transforming AC to DC, or DC to AC, consisting of a thermistor based Valve Bridge and a transformer with a load regulated shunt.
(2) Flat wave reactor: In the current source converter, a large reactor up to 1.0H is installed corresponding to each phase respectively, and it is mainly used to reduce the harmonic voltage and current of the DC transmission lines, to prevent the inverter commutation failure and the current discontinuous at light load, and to limit the peak current of the rectifier in short circuit of the DC line.
(3) Reactive power supply: The device provides reactive power required for the converter to maintain reactive power balance.
(4) DC cable: The device constitutes a circuit for hard power transmission. If the back to back mode is used, the DC cable can be omitted.
(5) Converters: The inverters used in DC micro grid systems are divided into isolated inverters and non-isolated inverters. Non-isolated inverters are used in photovoltaic grids, while isolated inverters contain one more isolation transformer. The non-isolated inverter can improve the conversion efficiency without the high frequency transformer. It mainly contains Boost, Buck, Buck-Boost, double tube, Buck-Boost and other topologies. Photovoltaic grid connected inverter usually adopts two stage structure, in which the forward DC converter mainly completes the conversion from battery voltage to intermediate bus and MPPT, and the latter is mainly used for the control of incoming battery, DC bus voltage control and island protection.

6. Conclusion
The factors that should be taken into consideration when setting up a DC micro grid are discussed in this paper. When a strong application of DC micro grid system is built, appropriate DG, reasonable structure of grid, suitable bus voltage are needed to be selected according to the load demands. The inverters, flat wave reactor and other hardware equipment can be designed according to the structure of the micro grid, and the energy efficiency should be enhanced by suitable energy storage. After the system frame is built, it needs to be simulated and tested by Mat lab simulation technology to modify the system continuously.
Micro grid is an important part of the smart grid which influence a lot on development of power system in the future. The development of the correct guidance of micro grid can effectively alleviate the problem of energy in the world and make great contribution to the environmental protection of the earth. In addition to technical problems, there also exists some problems, such as no fixed pattern in terms of standards, policies and economy. After solving these problems above, it can be believed that the DC micro grid system of photovoltaic power generation can be widely used in residential and office, and the advantages of micro grid will be given better play. It will bring benefits to society.

To sum up, it is very necessary for China to promote the research of micro grid actively.

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