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MULTI-SCENE OPERATION CONTROL OF HOUSEHOLD MICROGRID BASED ON POWER ROUTER

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ABSTRACT

The promotion of distributed renewable power generation and the development of power electronic converters have promoted the application of DC microgrid in households. In this paper, based on the existing household power structure, a home-based power router is proposed, and according to various operating scenarios in real life, a master-slave control strategy for converting the main control power supply is proposed for different operating conditions in grid-connected mode and island mode. By building the circuit model of household power router, monitoring the voltage fluctuation of DC bus and the power fluctuation of photovoltaic, energy storage, power grid and load, the practical control strategy of microgrid router is verified and analyzed.

Keywords: master-slave control, multi-scene operation, power router, voltage fluctuation

1. INTRODUCTION

In recent years, with the support of policies and the reduction of the cost of related equipment, more and more renewable distributed generations are connected to the grid. The most effective way to utilize distributed renewable energy is "local collection, local storage, and local use" [1], and microgrid is an effective way to integrate and absorb renewable energy [2].

In the existing distribution network, household users are at the end of the distribution network, which is the nearest place to the load. With the access of more and more distributed power generation and energy storage users, micro-grid is established in the unit of family, which forms the autonomous management of energy within the family, reduces the impact on the grid, and even makes flexible interaction [3]. How to effectively integrate distributed generation, energy storage, household load and municipal electricity to form a household microgrid on the basis of the existing household electricity structure is a problem to be solved at present [4]. In recent years, some experts and scholars have put forward the concept of microgrid router [5]. It is an integrated application device of power electronics, which can realize plug-and-play and reliable management of distributed generation and load in microgrid. In this paper, a home-based microgrid router structure based on DC bus structure is proposed, and the master-slave control operation control strategy based on converting the main control power supply is adopted. According to the actual working conditions of different environmental conditions in grid-connected mode and island mode, the physical of optical storage home-based DC microgrid is built by software, and the simulation analysis is carried out.

2. POWER ROUTER

Among many microgrid systems, household microgrid is a very special kind of system. It is the smallest level of the concept of microgrid based on the unit of household users [6]. It integrates household distributed generation and energy storage equipment. While meeting its own electricity demand, it can also interact well with the power grid to maximize the use of renewable energy.

Figure 1 is an intercepted picture of a real distribution network in which the green line is a transformer and the orange Pentagon represents the power load [7]. In the future, with the further popularization of distributed generation and energy storage devices, more and more household microgrids will appear at the end of distribution network. In fact, every household microgrid is a prosumer. If the household users under the same terminal transformer use the power router to transfer surplus electricity in the form of transactions and carry out local absorption, the impact of distributed generation on distribution network can be solved. At present, the author's research group is conducting research on related power routing technology.

In this paper, the operation status of single household microgrid users with power routers is analyzed. Figure 2 shows the structure of the household microgrid system. In the whole system, the power router plays an important role as a node. It can be connected to photovoltaic, energy storage, load, etc. and connected with the power grid to form an independent and complete family microgrid system. In the power router, distributed generation and energy storage equipment are constructed in the form of DC bus, which can be connected with the power grid and traditional household load through only one AC-DC conversion process, thus reducing the energy conversion link and improving the utilization efficiency.

Considering the operation economy of single household microgrid users using power routers, in order to fully absorb the energy that can be generated, the principle of using renewable energy is "first use, then storage, then grid connection", that is, to achieve energy autonomy as far as possible, and then be supported by the grid in case of deficiency or surplus.

3. MULTI-SCENE OPERATION CONTROL

There are two main operating modes in the actual operation of the photovoltaic and storage household microgrid system: grid-connected mode and island mode. Under normal circumstances, the system is in the grid-connected mode, and when the power failure occurs, it is converted to the island mode. In grid-connected mode and island mode, the different operating conditions of photovoltaic, energy storage and load can be subdivided into several. However, regardless of the operating conditions, the power balance of the system must be met. However, no matter what operating conditions, the power balance of the system should be satisfied. The expression of power balance is as follows:

$$CV\frac{dV}{dt} = P_{PV} + P_{Bat} + P_{Load} + P_{Grid} \quad (1)$$

Where P_{PV} is photovoltaic output power, P_{Bat} is energy storage device power, P_{Load} is household load power, P_{Grid} is grid power, C is equivalent bus capacitance and V refers to bus voltage. Power surplus cumulates on bus capacitors and induces bus voltage increase. Similarly, bus voltage drops when system power deficiency occurs.

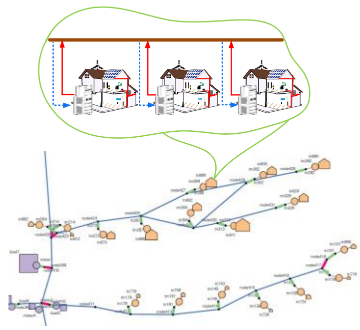

Fig. 1. Distribution network

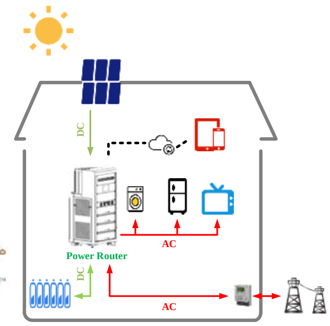

Fig. 2. Household microgrid

3.1 Grid-connected mode

The operation control strategy of master-slave control is adopted in the home microgrid system under the grid-connected mode. In grid-connected mode, photovoltaic always operates in MPPT (Maximum Power Point Tracking) mode due to the existence of two reliable supports of power grid and energy storage. In this case, if the photovoltaic power is greater than the power required by the load, the energy storage battery can continue to charge when the power is not full, then the energy storage battery is used as the main control power supply in the microgrid system, and the energy storage battery is responsible for absorbing the surplus power of photovoltaic power generation and stabilizing the internal DC bus voltage; if the energy storage battery is used as the main control power source, the energy storage battery will absorb the surplus power of photovoltaic power generation When the power is full, the main control unit will be converted, and the grid will act as the main control power supply of the system. It will be responsible for the surplus power of grid-connected inverters and stabilize the DC bus voltage in the system.

When the photovoltaic power is less than the power required by the load, if the energy storage battery is healthy, that is, it can continue to discharge, then the energy storage battery is used as the main control power supply in the microgrid system, and the energy storage battery is responsible for supplementing the difference of photovoltaic power generation and stabilizing the internal DC bus voltage; if the energy storage battery has been exhausted, then switch to the main control unit, the main control power supply of the mains charging system, the grid supply the lack of power, stabilize the DC bus voltage inside the system.

In the grid-connected mode, according to the time as a reference, a total of six scenarios and the switching process between six scenarios are set up. The specific scenarios are shown in Table 1.

Table 1. Grid-connected operation scenario

Time	State	Power balance relation
Sunrise	Photovoltaic power generation begins, and the grid cooperates with discharge.	$P_{PV} + P_{Grid} = P_{Load}$
Morning	The photovoltaic power is abundant and the battery begins to charge.	$P_{PV} = P_{Load} + P_{Bat}$
Afternoon	The battery is full and the surplus power is connected to the internet.	$P_{PV} = P_{Load} + P_{Grid}$
Evening	The photovoltaic power is insufficient and the battery starts to discharge.	$P_{PV} + P_{Bat} = P_{Load}$
Night	Batteries supply load separately.	$P_{Bat} = P_{Load}$
Late night	The battery is exhausted and the utility power is used.	$P_{Grid} = P_{Load}$

3.2 Island mode

Household microgrid system also adopts master-slave control strategy in island mode, but different from grid-connected mode, photovoltaic will not always run in MPPT mode because of the loss of reliable power support, and it will also run in constant voltage mode at a specific time. Constant mode is to reduce photovoltaic power generation processing, to maintain system voltage stability.

When the photovoltaic power is larger than the power required by the load, if the energy storage battery is not full, the surplus power will be absorbed by the energy storage device to stabilize the internal voltage of the system; if the energy storage battery is full, the photovoltaic converter will be converted to the main control power of the system to reduce its own power generation and stabilize the system voltage to meet the needs of the load.

Table 2. Island operation scenario

State	Power balance relation
Photovoltaic has no output and battery discharges.	$P_{Bat} = P_{Load}$
The photovoltaic power is low and the battery cooperates with discharge.	$P_{PV} + P_{Bat} = P_{Load}$
The photovoltaic power is abundant and the surplus electricity is charged for battery.	$P_{PV} = P_{Load} + P_{Bat}$
The battery is full and photovoltaic operates at reduced power.	$P_{PV} = P_{Load}$

When the photovoltaic power is less than the power required by the load, if the battery power is healthy, the battery discharge will supplement the deficiency power and maintain the system stability; if the battery power is insufficient, the load can only be reduced until the system power failure protection.

Considering that the home-based microgrid operates less in island mode and is random, four scenarios and switching processes between them are set up according to the power state of photovoltaic generation. The specific scenarios are shown in Table 2.

4. SIMULATION ANALYSIS

4.1 Mode establishment

Based on the real life scenario, a photovoltaic storage DC micro-grid is built in this paper. The system topology is shown in Figure 3.

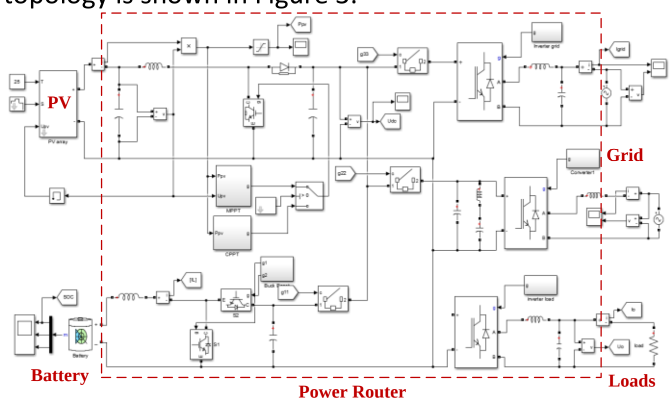

Fig. 3. Topology of household microgrid based on power router

4.2 Result analysis

In grid-connected mode and island mode, the operating conditions described in Tables 1 and 2 are respectively 0.3s. The simulation results show that the steady reference voltage of DC bus is 350 V and the load power is 3 kW. The internal bus voltage in the two modes is shown in Figures 4 and 6, and the power changes of photovoltaic, municipal and energy storage are shown in Figures 5 and 7, respectively.

In grid-connected mode, at 0-0.3s (sunrise), the system starts the MPPT for photovoltaic. Because of the low illumination intensity, photovoltaic and municipal electricity supply load together; at 0.3-0.6s (morning), photovoltaic power has reached the required load, and the surplus electricity is charged for the battery; at 0.6-0.9s (afternoon), the simulated power of the battery withdrawal operation has been full, at 0.6-0.9s (afternoon), the batteries are out of operation and the analog power is full. At this time, the photovoltaic power margin is fed into the grid; at 0.9-1.2s (evening), the photovoltaic power is insufficient, which is supplemented by battery discharge; at 1.2-1.5s (night), there is no photovoltaic power generation, and the supply load of battery discharge alone; at 1.5-1.8s (late night), it is converted to the supply load of municipal electricity.

In island mode, at 0-0.3s, the photovoltaic has no output and the battery discharges separately to supply the load; at 0.3-0.6s, the photovoltaic starts to generate electricity and supply the load together with the battery; at 0.6-0.9s, the photovoltaic power is abundant and the surplus is recharged; at 0.9-1.2s, the photovoltaic power is abundant and the analog battery is full, at this time, the photovoltaic storage is in power-down operation.

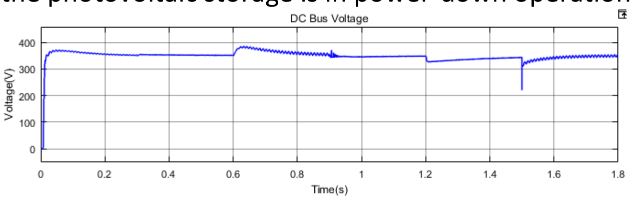

Fig. 4. Bus voltage in grid-connected mode

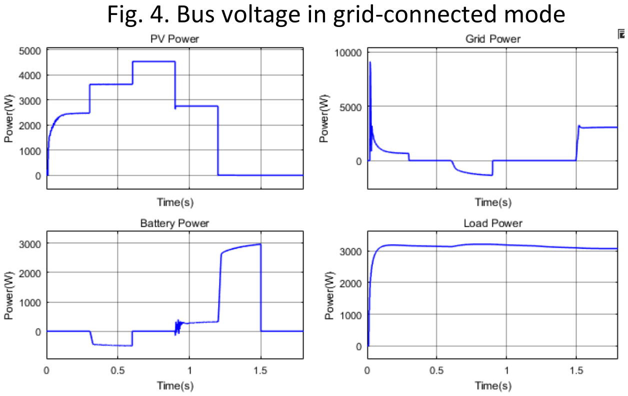

Fig. 5. Power state diagram of grid-connected

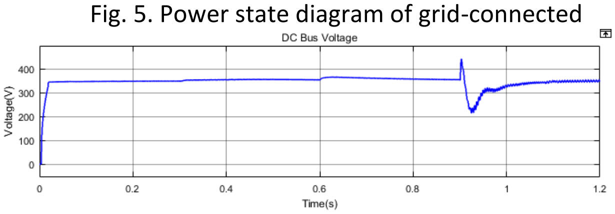

Fig. 6. Bus voltage in island mode

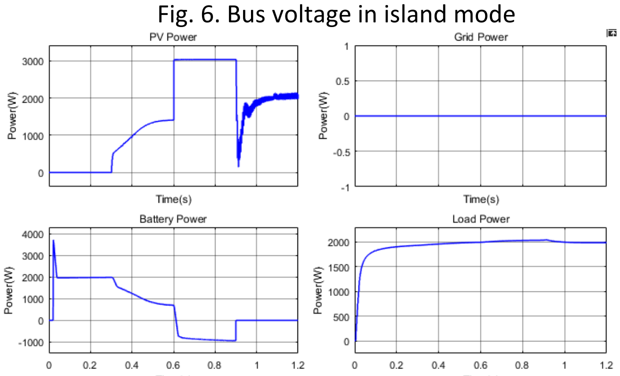

Fig. 7. Power state diagram of island

From the above simulation results of grid-connected mode and island mode, it can be seen that the photovoltaic and storage household DC microgrid system based on control strategy can operate stably in 10 scenarios, and the switching over between 10 scenarios is relatively smooth.

5. CONCLUSIONS

As an effective scheme of distributed generation utilization, microgrid is a hot research topic in the field of power energy. In this context, aiming at the photovoltaic energy storage household users, this paper integrates and builds a household microgrid system through the form of power router, and proposes a master-slave control strategy based on the conversion of the main control power supply, and carries out simulation analysis under various operating conditions. The results show that the microgrid can operate stably and fully absorb renewable energy under grid-connected and islanded operation conditions.

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REFERENCE

[1] Guo H, Wang F, Zhang L J, et al. Intelligent Distributed Energy Network Technology Based on Energy Router [J]. Proceedings of the Chinese Academy of Electrical Engineering, 2016, 36 (12): 3314-3324.

[2] Wang C S, Xu H H. Microgrid Technology and Application [M]. Science Press, 2016.

[3] Li D P, Liu T. Research on Family Smart Microgrid Construction Scheme [J]. China Electric Industry (Technical Edition), 2016, 4 (13): 13-16.

[4] Ashabani S M, Mohamed A R I. New Family of Microgrid Control and Management Strategies in Smart Distribution Grids—Analysis, Comparison and Testing [J]. IEEE Transactions on Power Systems, 2014, 29(5):2257-2269.

[5] Gao F, Li Z, Wang P, et al. Prototype of Smart Energy Router for Distribution DC Grid[C]// European Conference on Power Electronics & Applications. IEEE, 2015.

[6] Xiao J F, Wang P. Multiple Modes Control of Household DC Microgrid with Integration of Various Renewable Energy Sources[C]// Conference of the IEEE Industrial Electronics Society. IEEE, 2014.

[7] Cohen M, GridLAB-D Taxonomy Feeder Graphs [Online]. Available: http://emac.berkeley.edu/gridlabd/taxonomy_graphs/.