Analysis and Selection of Switch for Double Modes Inverter in Micro-grid System

Zilong Yang, Hua Liao, Chunsheng Wu, Honghua Xu
Institute of electrical engineering, Chinese Academy of Science, China

Abstract — Double modes inverters, as the interface devices between the micro-grid system and public grid, plays an important role in the distributed generation system. In order to realize the connection and disconnection between double modes inverter and public grid, an intelligent switch is necessary. The switch is used to detect the status of grid and inverter, adjust the frequency, amplitude and phase of inverter, realize seamless transition. Three types of switch were introduced in this project, CB-based, SSR-based, and IGBT-based switch. The configuration, performance and application of these switches are analyzed in this paper. The state machine which was used to control the transitions operation between grid-connected mode and stand-alone mode also was illustrated.

Index terms — distributed generation system, micro-grid, switch, double modes inverter, mode transition

I. INTRODUCTION

Proliferation of distributed resource (DR) units in the form of distributed generation (DG), distributed storage (DS), or a hybrid of DG and DS units has brought about the concept of micro-grid [1–3]. A micro-grid is defined as a cluster of DR units and loads, serviced by a distribution system, and can operate in 1) the grid-connected mode, 2) the islanded (autonomous) mode, and 3) ride-through between the two modes. Therefore micro-grid system is utility-interactive system.

In order to implement the utility-interactive function, a switch should be installed between grid and inverter to make sure that the micro-grid connect and disconnect with public grid flexibly and quickly. Unlike general switch only connecting and disconnecting two or more relative component part, this special switch was designed as multi-function model. It can realize 1) detect the operation status of grid and inverter, include frequency, amplitude and phase of micro-grid and public-grid, 2) fast response and disconnection performance when there is fault in public grid, 3) exactly and fast connection micro-grid and public-grid when synchronization of the island and the utility.

There are three basic types of components can realize the switch function, they are circuit breakers (CB), silicon-controlled rectifiers (SSR), and insulated gate bipolar transistors (IGBT). CB-based switch has been widely used in converter system, SSR-based switch is used on some double modes inverter, especially single phase system [4-6], there are not any IGBT-based switch manufacturers except some laboratory applied it in prototype [7]. The main difference between these switches is the switching speeds. Switching speed is defined as the clearing time for a disturbance that can affect loads. The high speed switch is inclined to be adopted.

In this paper, simple system architecture is present to define the function of each component. Switch is introduced to realize the grid-interactive. In order to select an appropriate switch, three type of switch was analyzed and compared, and IGBT-based switch is finally determined to apply on the system. The transition procedure is formulated to control the operation of switch. Finally, the experiment results verify the serviceability of IGBT-based switch and validity of the transition procedure.

II. MICRO-GRID SYSTEM ARCHITECTURE

This architecture, shown in figure 1, leads to a simpler overall system design, but it include all of basic components in Micro-grid system.

In this simple Micro-grid system, dual mode DG inverter is the core component that can seamlessly operate in grid-connected and islanded modes of operation. When grid-connected mode, the inverter is operated in current-control mode, the current injected into grid should be regulated to fellow the reference. In the islanded mode, the inverter is operated as a voltage source. The inverter is operated to regulate the voltage across the load, and steady sine-voltage is expected.

The input of dual mode inverter was DC power source, including energy storage device and PV array with DC/DC converter. The PV array was the source of power energy, and then DC/DC converter regulates the DC current to charge lead-acid batteries. Lead-acid batteries as common energy storage device are used in this system, it maintain the dual mode inverter to power local load when Micro-grid system operated in islanded mode. The batteries are charged by means of DC/DC converter and dual mode inverter.

Such a Micro-grid system requires a switch to connect or disconnect from the grid so the critical loads can provide power in an islanded configuration. When grid is fault, the switch should open rapidly to make sure the load and inverter keep continuous work. The speed of the switch to disconnect from the grid and the capability to seamlessly transition between grid-connected and islanded operation would determine the power quality, as seen by the loads in the island.

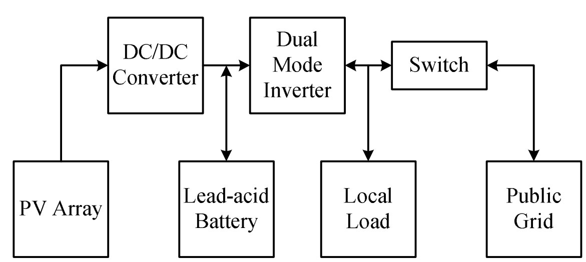


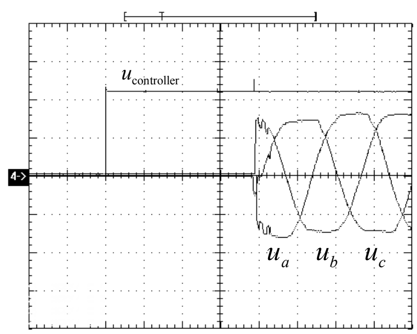
Figure 1. Micro-grid system architecture

III. ANALYSIS AND COMPARISON OF SWITCH

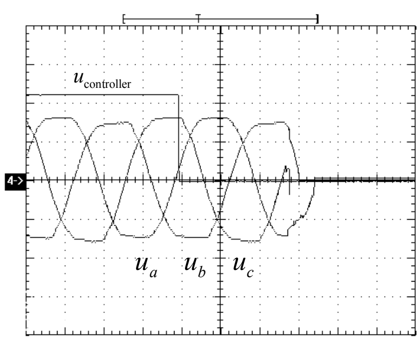
An interconnection with the grid that meets the application requirements described in the Micro-grid architecture requires a flexible hardware concept that is switch. There are three types of switches have been investigated, and the differences between the varieties of switch are based on the speed with which it can respond.

A. CB-based switch

The CB-based switch can respond in 20-100ms and is the predominant variety of utility interconnection device being stalled. The switch can separate Micro-grid system with public grid absolutely in the electrical connections, but can not separate inverter from grid quickly enough which may resulted in overload for grid-connected inverter in case of power failure. The delay time of different CB is different from their capability and structure. The response waveform of relay "JQX-38F", shown in figure 2, illuminate that the delay time is 20ms and the three contact point are not synchronous. Because the respond time of CB-based switch is too long, it is not suitable for the double modes inverter to realize seamlessly transform between stand-alone and grid-connected mode, but it is acceptable for the insensitive load, the architecture is shown in figure 3.



(a) Turn on



(b)Turn off

Fig. 2. Experiment waveform of CB-based switch

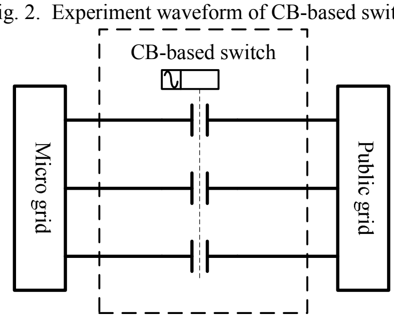


Fig. 3. IGBT-based switch architecture

B. SSR-based switch

The SCR-based switch can respond in one-half cycle (10ms) to one cycle (20ms) in 50Hz grids. Figure 4 shows the configuration of SCR-based switch. Solid State Relays (SSR) is a typical SCR-based switch. Because of the nature of the electronic control circuitry, it is possible to delay the turn-on of SSR until the next voltage zero of the AC supply, and meanwhile it will turn off at the current zero after the removal of the control signal.

Although these functions make the control system simply and reduce the surge of current when switching, there are some problem to prevent this switch applying on the Micro-grid system. The first one is the possibility that SSR refuse to turn on when the inverter mode transfer the operation mode because the time of cross zero point may not occur. It maybe happens when the voltages of Micro-grid and public grid synchronous very exactly, then SSR almost bears no voltage difference, saying nothing of cross zero point. The second reason is the SCR-based switches can not turn-on or turn-off synchronously in three-phase Micro-grid system, because the phase difference of voltage and current. Figure 4 (a) and (b) shows the delay time when turning on and turning off. Therefore Micro-grid system which has SCR-based switch may not implement seamless transitions.

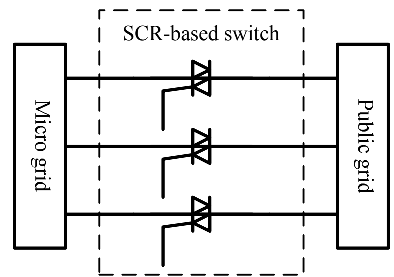
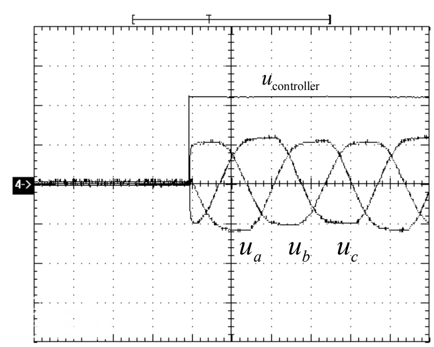
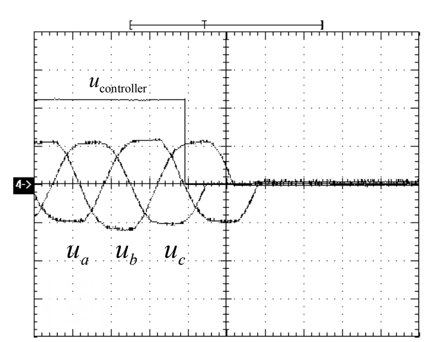


Fig. 4. SCR-based switch



(a) Turn on



(b) Turn off

Fig. 5. SCR-based switch

C. IGBT-based switch

The IGBT-based switch can respond in shorter time (10us), the switching speed is enough fast to meet the pace of double modes inverter requirements. The system requires system with bidirectional voltage and current blocking capability. As IGBT has not the capability of blocking reverse voltage, it is necessary to connect four diodes and one IGBT in actual application, which is shown in figure 6. Such IGBT-based switch can realize flexible and quickly control of connection, disconnection. There is no voltage impact on the load and grid because the transition time is very short. Then the seamless transfer problem in Micro-grid system is easy to be solved. The status transition of turning on and turning off are shown in figure 7 (a) and (b). The voltage waveforms of load when turning on the switch showed in figure 7 (a) keep clear without any oscillations, and so do the turning off in figure 7 (b). There are also no delay time like CB-based or SSR-based switch waveforms in figure 2 (b) and figure 5 (b).

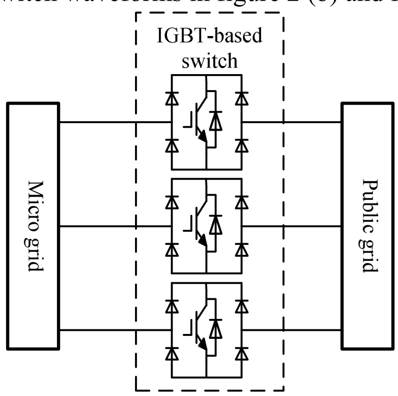
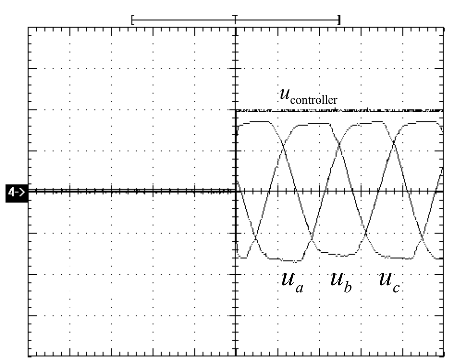
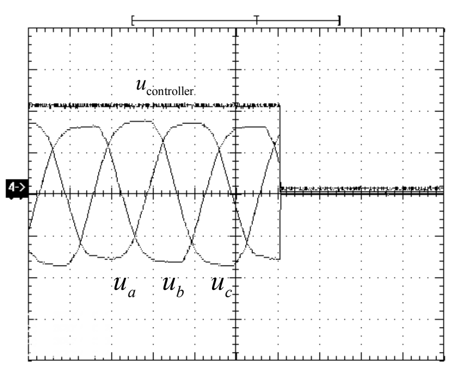


Fig. 6. IGBT-based switch



(a) Turn on



(b) Turn off

Fig. 7. SCR-based switch

IV. The Operation Principle of Switch

Base on the analysis of three types of switches, IGBT-based switch is selected in Micro-grid system to connect and disconnect public grid. In an actual IGBT-based switch system, there are not only IGBTs and rectifier diodes, but also some auxiliary components, such as a controller with diagnostic and monitoring functions, communication processors, voltage and current sensing devices, protection/absorption circuit, bypass and isolate CBs, and so on.

The switch model aggregates the control functions in a DSP. It evaluates all inputs to achieve interconnection protection, to evaluate ambient power quality, and to turn on and turn off the IGBTs following a reasonable operational procedure to realize seamlessly transition. The operational procedure is designed in this paper. The primary operating states of the switch are to connect the public grid and Micro-grid or to stay disconnected. A number of the other control states are used for the startup sequence, faults, and operation isolate CBs. The procedure of the switch when operating is described below.

A. Islanded mode to grid-connection mode

Assume that initially there is a fault on the grid and the inverter is operating in the voltage-controlled mode with the switch open. When the fault on the grid is cleared and reconnection is required, the phase and amplitude of the Micro-grid voltage (maintained by the inverter) may not match those of public grid voltage. It is necessary that both the magnitude and phases of the Micro-grid's voltage should be adjusted to keep synchronous with grid before the switch can be turned on to reconnect the inverter to the utility. Thus, the steps to be performed in this phase of the algorithm can be summarized as follows:

1. Detect that the grid is normally operating, turn on the isolate CBs. Then Micro-grid and public grid are connected with a turning off IGBT-based switch.

2. Switch model send the public grid's parameters to inverter model, include frequency, amplitude and angle difference. Inverter adjusts its output voltage to match the magnitude and frequency of the grid voltage.

3. The angle difference between Micro-grid and public grid change following slip frequency f_s.

$$f_s = f_{Micro-grid} - f_{public-grid} \tag{1}$$

Because the frequency of Micro-grid and public grid is about 50Hz, slip frequency is no more than 2Hz for normal status. When the angle difference is near zero, switch is controlled to turn-on.

4. Switch model sends switch status message to inverter at once. The inverter changes the operation mode from islanded to grid-connection.

B. Grid-connection mode to Islanded mode

Assume that initially the inverter is operating in the grid-connection mode. Once there is a fault on the grid, the controller diagnoses it and turns off the switch as soon as possible. The steps to be performed in the transition can be summarized as follows:

1. Detect a fault on the grid. The judge algorithm should be reliable and quickly, and have anti-islanding function. It is better to combine the frequency diagnoses and amplitude diagnoses.

2. Give a turn off signal to the switch once there is fault happened in grid. Controller monitors the magnitude and phase of the load voltage.
3. When the inverter receives the status message from switch model, transfer the inverter to an islanded operation mode, with the voltage reference being derived from the load voltage.

V. Experimental Results

A prototype was built in the laboratory to evaluate the performance of the proposed transition procedure. The block diagram of the circuit is shown in figure 8. The static performance was studied and meets the project requirements, for both the islanded and grid-connected modes. The detail of static performance is not involved in this paper. The dynamic response of the inverter under transient conditions of mode changes on inverter and status changes of switch is illustrated. The transition from grid-connection to islanded status is shown in figure 9. The transition from islanded to grid-connection status is shown in figure 10.

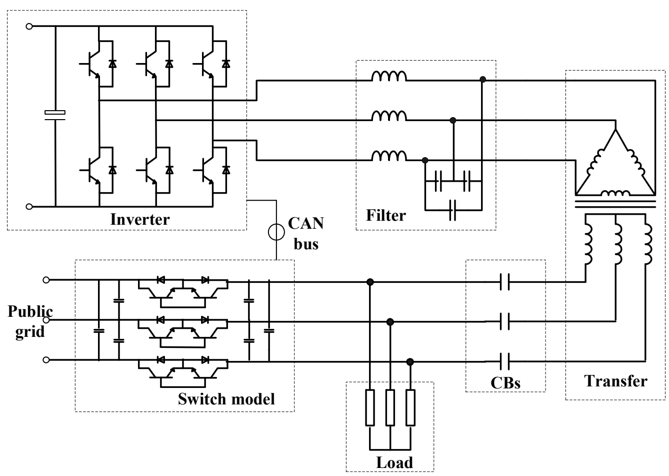


Fig. 8. System block diagram

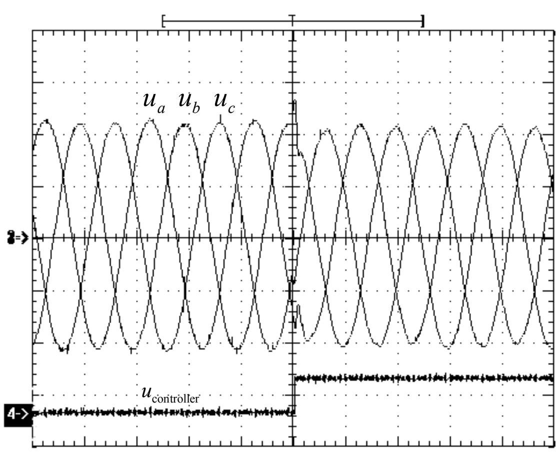


Fig. 9. Transition from grid-connection to islanded mode

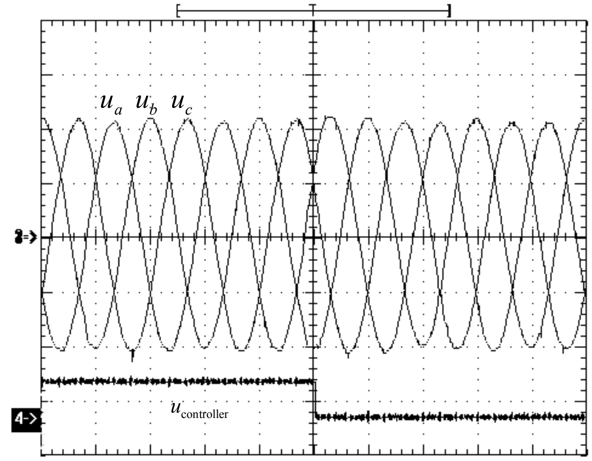


Fig. 10. Transition from islanded to grid-connection mode

VI. Conclusion

Three type of switch, which used in Micro-grid system, are analyzed in this paper. CB-based switch has long and random response time, so it isn't applied on the fast switch circuit. SSR-based switch can't turn off synchronously in three-phase system. IGBT-based switch is the most acceptable for the double mode inverter.

In order to realize the transitions between two modes, this project design a state transition procedure to control the operation of switch for the Micro-grid system. Furthermore the experimental results through a 10kVA three-phase double mode inverter will illustrated and verify the performance the IGBT-based switch and transition procedure.

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