Journal of Power and Energy Engineering, 2015, 3, 128-135
Published Online April 2015 in SciRes. http://www.scirp.org/journal/jpee
http://dx.doi.org/10.4236/jpee.2015.34019

Micro-Grid Smooth Switchover Method Based on Controller State Following

Yang Fu, Lisha Huang, Jingjing Zhao

Shanghai University of Electric Power, Shanghai, China
Email: mfudong@126.com, lisa0706@live.cn, jjzhao_sh@163.com

Received January 2015

Abstract

Micro-grid smooth switchover between different operation modes is important for steady operation and reliable power supply of micro-grid. In order to reduce the transient fluctuation of voltage and frequency during switchover, this paper proposed a new switchover method based on controller state following. When transferring to island mode, the control method for inverter of storage device changed from PQ control to V/f control. Before switchover, the output of V/f controller is always following the output of PQ controller. So that the sudden change of output is avoided at the moment of switchover. A micro-grid model with photovoltaic and battery is built on DIgSILENT Power Factory simulation software, to simulate micro-grid switchover from grid-connected mode to island mode. Results show this method can effectively suppress the transient fluctuation of voltage and frequency, and reduce the influence of transient process on power grid. This conclusion has important practical significance on micro-grid smooth switchover from grid-connected mode to island mode.

Keywords

Micro-Grid, Smooth Switchover, Controller State Following

1. Introduction

As fossil fuel supply becomes steadily tighter and electricity demand continues to grow, distributed generation technology based on renewable energy are beginning to attract wide attention. Distributed generation will undoubtedly be strong complement and effective support to bulk power grids, and be a trend of future power system development [1] [2]. To give full play to the advantages of distributed power generation technology, one or more distributed power (DG), energy storage device and controllable load form a micro-grid according to certain topological structure. Grid-connected mode is when micro-grid is connected to the main grid and island mode is when micro-grid is isolated from the main grid. Both are normal operation status of micro-grid. Proper control strategy is key to the steady operation of micro-grid [3] [4]. Micro-grid smooth switchover between grid-connected mode and island mode is the emphasis and difficulty of micro-grid control strategy research and is important for steady operation and reliable power supply of micro-grid.

At present, many experts and scholars at home and abroad have studied on the smooth switchover control

How to cite this paper: Fu, Y., Huang, L.S. and Zhao, J.J. (2015) Micro-Grid Smooth Switchover Method Based on Controller State Following. *Journal of Power and Energy Engineering*, **3**, 128-135. http://dx.doi.org/10.4236/jpee.2015.34019

strategy of micro-grid. In [5] takes the integrated energy storage device composed of super capacitor and battery as the main power supply during the island mode of micro-grid, where proper control of charge and discharge of the integrated device can realize smooth switchover of micro-grid. In [6] a bi-directional inverter is used to switch the control method of storage device changed from PQ control to V/f control, stabilizing voltage and frequency of micro-grid in island mode and realizing smooth switchover between two operation modes. It is the common smooth switchover strategy. However, this strategy neglects the non-synchronization of controller switchover and mode switchover, and will easily cause overshoot current and voltage fluctuation during the switch process. To avoid this situation, a voltage and current weighted control strategy without increasing system complexity is presented in [7], achieving seamless switchover, but power shortage in the process of switchover from grid-connected mode to island mode is not considered.

In the process of mode switchover especial the switch moment, the non-synchronization of controller switchover and mode switchover as well as unbalanced power between DGs and loads may lead to large fluctuation of voltage and current, causing negative impacts on micro-grid stable operation. Moreover, serious consequences like frequency instability and voltage collapse might happen. In order to decrease transient fluctuation of voltage and frequency in the process of switchover, this paper proposed a micro-grid smooth switchover method based on controller state following and built a micro-grid model on DIgSILENT Power Factory simulation software to verify the effectiveness of proposed method.

2. Control Strategy of Micro-Grid

2.1. Micro-Grid Configuration

Figure 1 shows the micro-grid configuration of study case. Photovoltaic and battery as distributed generators access to 10 kV grid through inverters and transformers, and supply power to loads in micro-grid. Load C and Load D are linked to low voltage side of 0.4 kV, and are supplied by photovoltaic and battery directly. In grid-connected mode, the control method for inverters of photovoltaic and battery is PQ control and DGs generate rated power. Voltage and frequency of micro-grid is supported by the grid. When micro-grid disconnects from the grid and transfers to island mode, the control method for inverters of battery changes from PQ control to V/f control and that of photovoltaic maintains the same. At the moment, loads in micro-grid are only supplied by DGs and battery provides support of voltage and frequency for micro-grid as main power source.

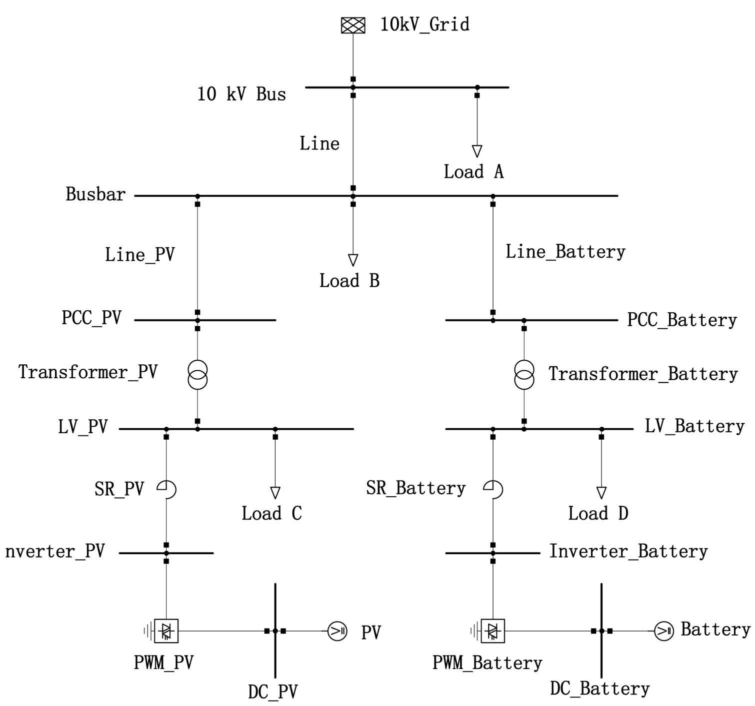

Figure 1. Micro-grid configuration.

2.2. Control Modes for DGs

PQ control diagram and V/f control diagram are as given in **Figure 2** and **Figure 3** respectively [8]. PQ control takes dual-loop control structure. The internal loop is power control, which ensures power output always tracking reference power. The inner loop is current PI control, which controls the pulse width modulated signal of inverter. V/f control has a multi-loop feedback control structure including power loop, voltage loop and current loop. The current loop takes d-axis reference current i_{dref} and q-axis reference current i_{qref} from power loop and voltage loop respectively. In power loop, the reference active power follows the change of frequency. V/f control can adjust the reference power of DGs according to the voltage and frequency of micro-grid.

3. Method Based on Controller State Following

Figure 4 shows the traditional switch method of the controllers of battery inverter when micro-grid transfers from grid-connected mode into island mode. During grid-connected mode, K_1 is closed and K_2 is open. The battery takes PQ control mode. When micro-grid disconnects with the grid, K_1 opens and K_2 closes, so the control mode switches into V/f mode. The generated reference current i_{dref}, i_{qref} becomes different and flows into the current control loop. But this traditional switch method of controllers will lead to great transient fluctuations at switch momentdue to the difference between outputs of two controllers. In grid-connected mode, the PQ controller outputs a control signal which flows into the current controlloop, while the output of V/f controller is zero. When transferring into island mode, PQ controller is out of operation and V/f controller takes over it. The input signal of current controlloop instantaneously becomes 0, which leads to the transient fluctuation of voltage and frequency of micro-grid during switchover.

To avoid the above situation happens, this paper proposed a new switch method based on controller state following, as shown in **Figure 5**. In grid-connected mode, K_1 and K_4 are closed while K_2 and K_3 open. The battery takes PQ control. The difference between outputs of V/f controller and PQ controller is designed as a negative feedback to be put into V/f controller. Through the non-differential control of PI module inside V/f controller, the output of V/f controller always follows the output of PQ controller. When the operation mode switches into

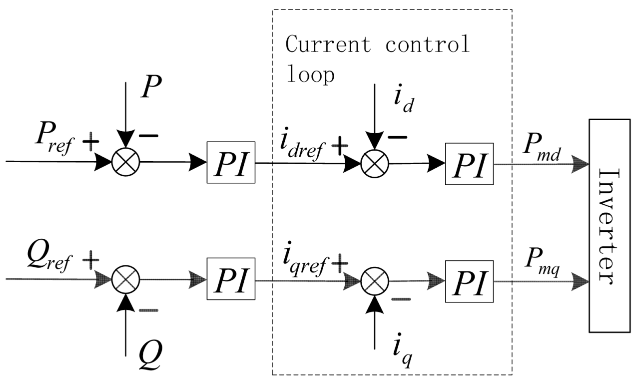

Figure 2. PQ control diagram.

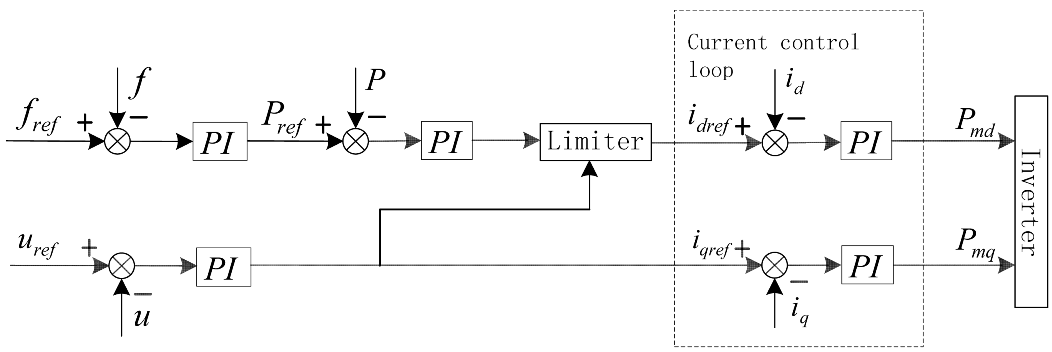

Figure 3. V/f control diagram.

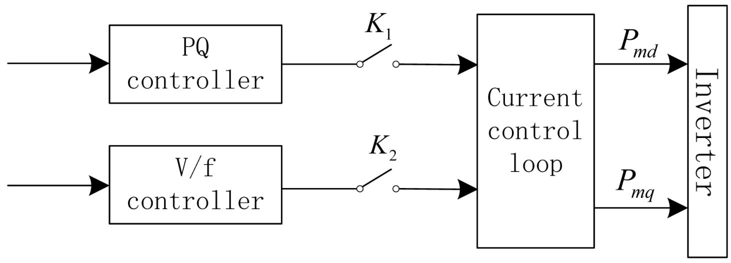

Figure 4. Traditional switch method of controllers.

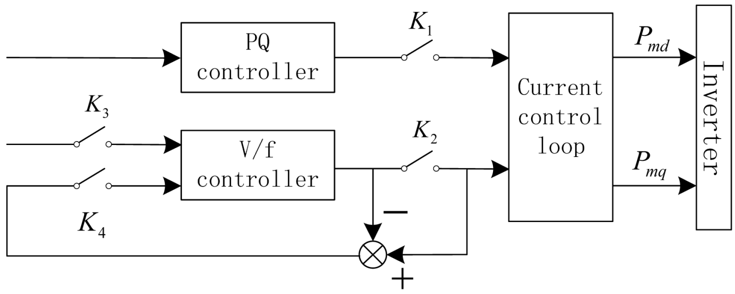

Figure 5. Switch method based on controller state following.

island mode, K_1 and K_4 open and K_2 and K_3 close. The PQ controller is out of operation and battery takes V/f control. In this way the sudden change of input of current control loop is avoided at switch moment and the smooth switchover of operation mode is realized in micro-grid [9].

4. Simulation and Analysis

The DIgSILENT Power Factory simulation software is used to develop a time-domain simulation model of the study case of **Figure 1**. DGs' parameters, loads' parameters and control parameters of control models are given in Appendix. At initial state when t = 0 - 1 s, micro-grid connects with grid. At t = 1 s, disconnection occurs between micro-grid and grid. Micro-grid comes into island mode.

4.1. Steady State Process

Table 1 shows the power flow distribution of micro-grid under grid-connected mode and island mode.

It can be seen from **Table 1**, when micro-grid is in grid-connected mode, Both DGs and the distribution grid offered power to the loads, and the DGs generated rated power. The active power produced by DG sonly can't meet the demand of loads, so the rest part was supplied by the grid. The grid delivered 0.5 MW active power to the micro-grid, the extra 0.5 Mvar reactive power produced by DG was transmitted to the grid through the connection. At this moment, the grid worked to keep the power balance in the micro-grid and maintain the stability of voltage and frequency of micro-grid. After the operation mode switched into the island mode, micro-grid and the grid were disconnected, and there was no longer any power exchange between the grid and micro-grid. The control mode of battery inverter was changed from PQ control to V/f control to adjust the active and reactive power output as the goal to keep the grid voltage and frequency stabile. Then the active power output of the battery increased from 2 MW to 2.5 MW, reactive power declined from 0.5 Mvar to zero. Meanwhile, micro-grid still kept its balance state of power.

The simulation result of power flow in micro-grid is the same with or without the proposed control method of smooth switchover, and the method based on the controller state following has no impact on the steady process of micro-grid.

4.2. Transient Process

The comparison of power output curves of PV and battery before and after the control method improvement are

Table 1. Power flow distribution of micro-grid under grid-connected mode and island mode.

Operation Mode		Grid-connected mode		Island mode	
		Active power/MW	Reactive power/Mvar	Active power/MW	Reactive power/Mvar
Source	PV	2	0.5	2	0.5
	Battery	2	0.5	**2.5**	**0**
	Grid	0.5	−0.5	0	0
Power Production		**4.5**	**0.5**	**4.5**	**0.5**
Load	A	−1.5	−0.2	−1.5	−0.2
	B	−1	−0.1	−1	−0.1
	C	−1	−0.1	−1	−0.1
	D	−1	−0.1	−1	−0.1
Power Comsumption		**−4.5**	**−0.5**	**−4.5**	**−0.5**

shown in **Figure 6** and **Figure 7**. In order to see the frequency change clearly, the abscissa was shorten scope in the graph to amplify the curve for better observation.

It is shown in **Figure 6** and **Figure 7**, before the improvement, the fluctuation of output power of PV and battery is more severe than after, especially at the mode switch moment. After taking the smooth switch control method based on controller state following, the power output of DGs change less, but the steady-state power remains the same in island mode. The improvement suppresses the transient fluctuation during switching process which may lead to negative effect on the equipment in the micro-grid. There is a close connection between DG power fluctuations and the fluctuation of micro-grid voltage and frequency, therefore the improvement of control method also has a good effect on the improvement of the stability of voltage and frequency.

The comparison of micro-grid voltage and frequency curves before and after the control method improvement are shown in **Figure 8**.

From **Figure 8** it can be seen that, before the improvement of control method, there appeared transient fluctuations of both voltage and frequency in the micro-grid, the maximum voltage range is more than 15%, the frequency range is up to 4%. After a short wave, the inverter of the battery takes V/f control to stabilize the voltage and frequency, and adjust the active reactive power output to keep balance of power within the micro-grid. When comes into steady state of island operation, micro-grid voltage and frequency are back to normal. Therefore, although there is a certain power deficiency, the grid still has the ability to keep stable voltage and frequency after island. However the fluctuations of voltage and frequency are too bigger to pose a threat to the safety of equipment within the micro-grid, and will affect the stable operation of the micro-grid. After the improvement, the smooth switch control method based on controller state following reduces the voltage and frequency fluctuations. the lowest point of voltage and frequency are picked up. The maximum scope of voltage fluctuation is reduced from 15% to about 2%, while the maximum frequency fluctuations is reduced from 4% to less than 1%. This leads to great improvement on the transient process of micro-grid significantly. In addition, the duration of frequency fluctuation is reduced after the improvement, and this is helpful to the transient stability of the micro grid.

5. Conclusions

This paper proposed a new control strategy for smooth switchover of micro-grid based on controller state following. By analysis of simulation results, conclusions are given as follows:

1) V/f control of battery has ability to keep steady voltage and frequency of micro-grid in island mode, but traditional way of switchover of controllers has negative influence on stability of micro-grid during switchover process.

2) Micro-grid smooth switchover method based on controller state following can smooth active and reactive output of DGs at switch moment and enhance stability of voltage and frequency of micro-grid.

3) The proposed method can effectively suppress the transient fluctuation of voltage and frequency, and reduce the transient time to diminish impact on micro-grid and improve its stability and reliability.

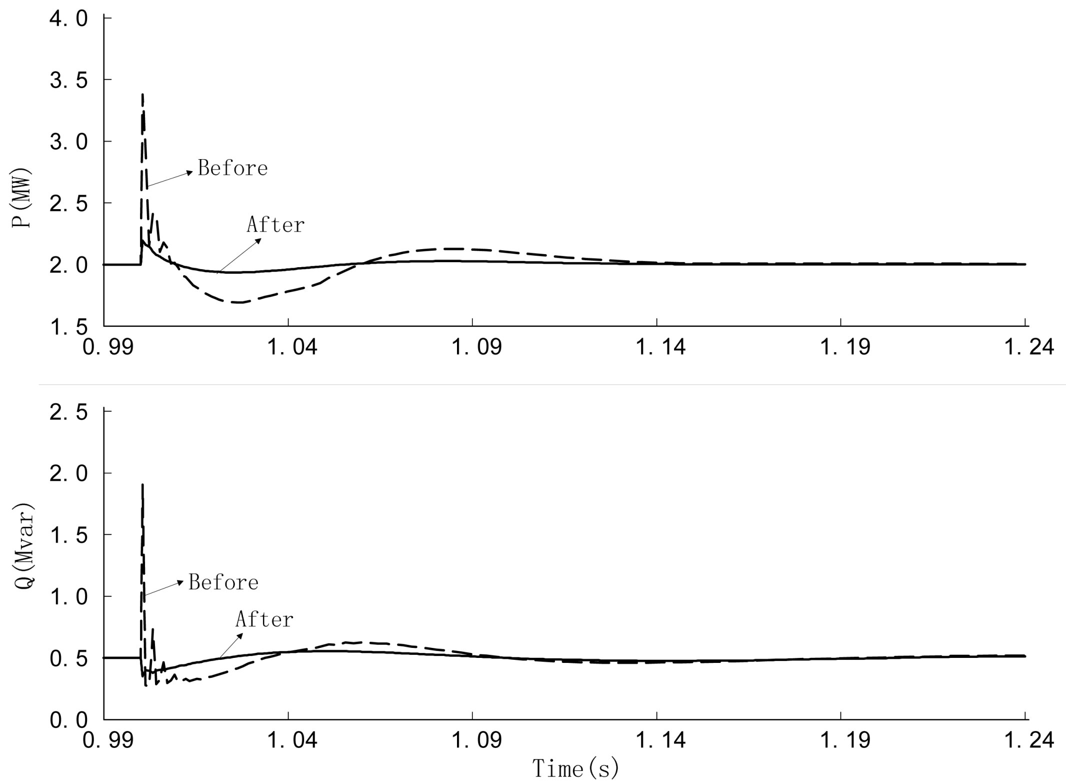

Figure 6. Power output of PV.

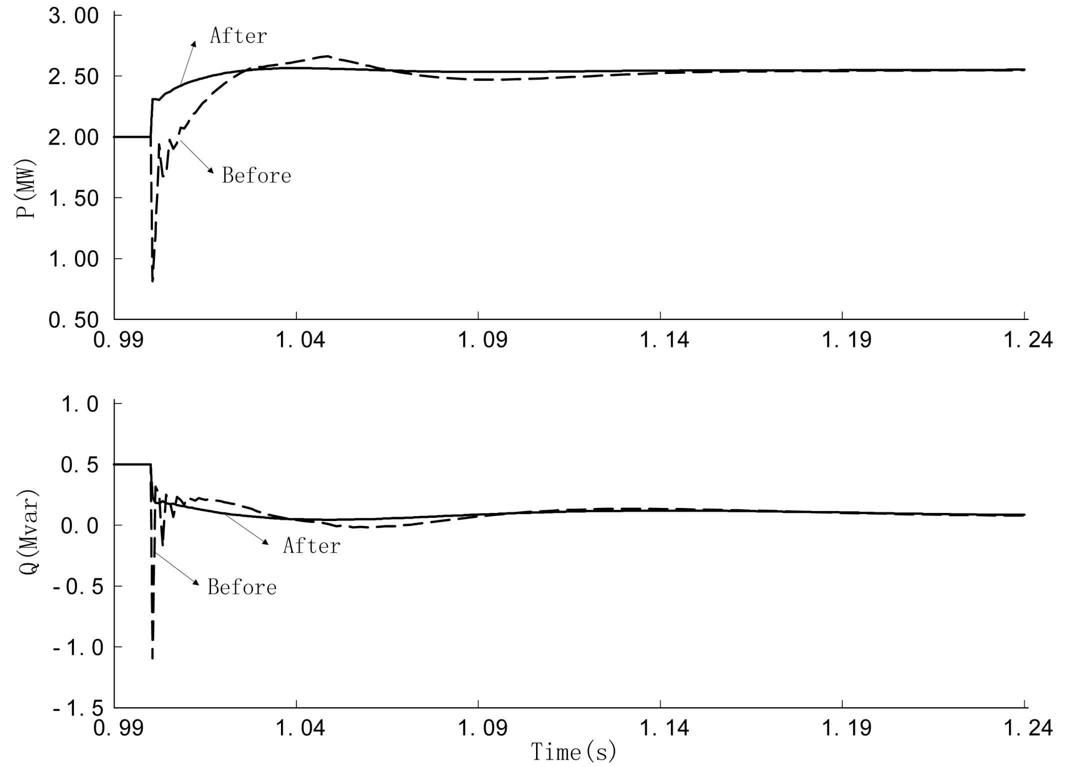

Figure 7. Power output of battery.

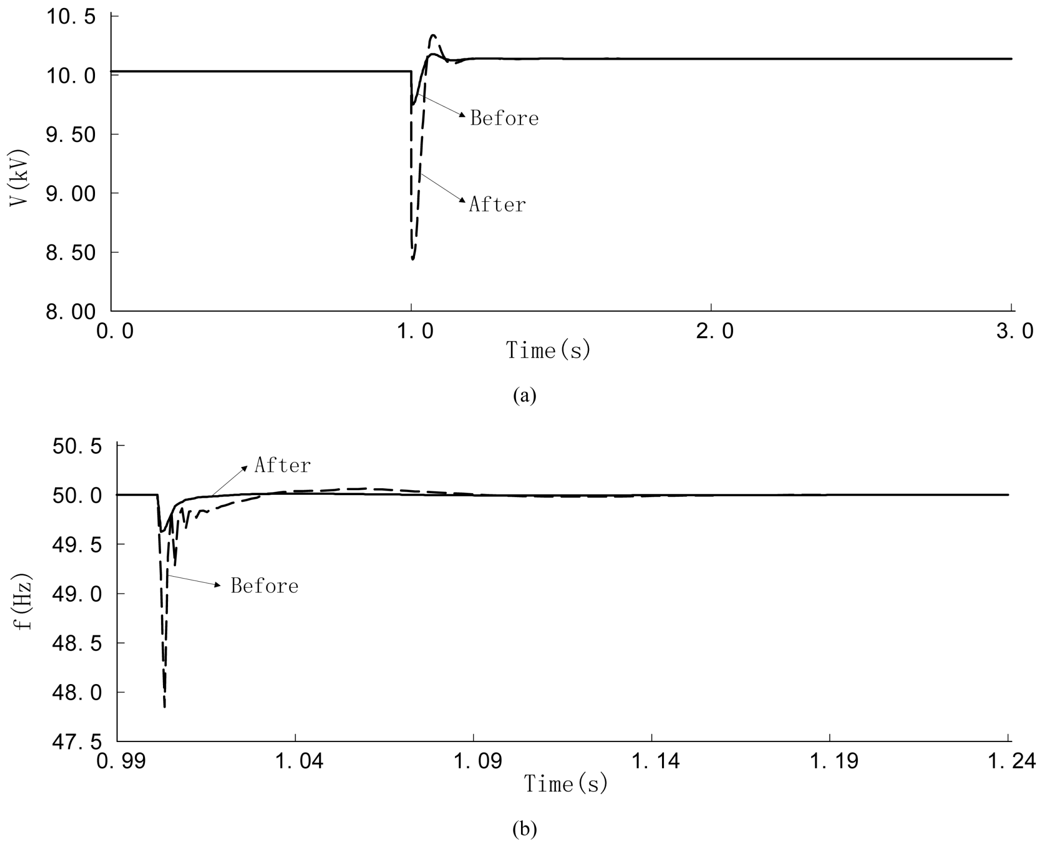

Figure 8. Microgrid voltage and frequency. (a) Micro-grid voltage. (b) Micro-grid frequency.

4) Micro-grid smooth switchover method based on controller state following has no influence on steady state process of micro-grid.

Acknowledgements

The authors gratefully acknowledge the financial support by Shanghai Green Energy Grid Connected Technology Engineering Research Center (No. 13DZ2251900) and Shanghai Key Technology R&D Program (No. 13160500800).

References

[1] Wu, X., Yin, X.G., Wei, Q., *et al*. (2013) Research on Microgrid and Its Application in China. *Energy and Power Engineering*, **5**, 171-176. http://dx.doi.org/10.4236/epe.2013.54B033

[2] Zhou, X.X., Chen, S.Y. and Lu, Z.X. (2013) Review and Prospect for Power System Development and Related Technologies: A Concept of Three-Generation Power Systems. *Proceedings of the CSEE*, **33**, 1-11.

[3] Ariyasinghe, M. and Hemapala, K. (2013) Microgrid Test-Beds and Its Control Strategies. *Smart Grid and Renewable Energy*, **4**, 11-17. http://dx.doi.org/10.4236/sgre.2013.41002

[4] Turner, G., Kelley, P.J. and Storm, L.C. (2014) Design and Active Control of a Microgrid Testbed. *IEEE Transactions on Smart Grid*, **40**, 1432-1436.

[5] Wang, X.H. and Zhang, C.J. (2012) Study of Control Strategy for Seamless Transfer of Grid-Connected Distributed Generation Systems. *Transactions of China Electrotechnical Society*, **27**, 217-222.

[6] Yang, Z.G., Wang, C.S. and Che, Y.B. (2009) A Small-Scale Microgrid System with Flexible Modes of Operation. *Automation of Electric Power Systems*, **33**, 89-92.

[7] Liu, Z.W., Xia, W.B. and Liu, M.B. (2013) Control Method and Strategy for Smooth Switchover of Micro-Grid Operation Modes Based on Complex Energy Storage. *Power System Technology*, **27**, 906-913.

[8] Ren, B.Y., Tong, X.Q., Tian, S., *et al.* (2010) Research on the Control Strategy of Inverters in the Micro-Grid. *Power and Energy Engineering Conference* (*APPEEC*), *Asia-Pacific*, Chengdu, 28-31March 2010, 1-4. http://dx.doi.org/10.1109/APPEEC.2010.5448341

[9] Zhao, D.M., Zhang, N. and Liu, Y.H. (2013) Synthetical Control Strategy for Smooth Switching between Grid-Connected and Islanded Operation Modes of Microgrid Based on Energy Storage System. *Power System Technology*, **37**, 301-306.

Appendix

1) Reference power of DGs:
PV: P_{ref} =2 MW, Q_{ref} = 0.5 Mvar
Battery: P_{ref} =2 MW, Q_{ref} = 0.5 Mvar
2) Constant power of loads:
P_A=1.5MW,Q_A=0.2Mvar
P_B = 1 MW, Q_B = 0.1 Mvar
P_C = 1 MW,Q_C = 0.1 Mvar
P_D = 1 MW, Q_D = 0.1 Mvar
3) Parameters of controllers:
a) PQ control:
PI parameters for Active power loop: K_P = 0.5, K_I = 0.01
PI parameters for Reactive power loop: K_P = 0.5, K_I = 0.01
PI parameters for Current control loop: K_P = 0.5, K_I = 0.02
b) V/f control:
PI parameters for Frequency loop: K_P = 2, K_I = 1
PI parameters for Active power loop: K_P = 0.5, K_I = 0.01
PI parameters for Voltage loop: K_P = 1, K_I = 0.005
PI parameters for Current control loop: K_P = 0.5, K_I = 0.02