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Droop control Based Seamless Transfer Strategy for Three-phase Converter in Microgrid

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Abstract. This paper proposes a seamless transfer strategy based on the droop control strategy for three-phase converter in microgrid, which consists of the voltage limiter and the frequency limiter. In grid-connected mode, both the two limiters don't work, and the VSC is controlled by PQ control, transmitting constant power between micro-sources and power grid. When the unplanned islanding occurs, the PCC voltage and frequency may exceed the allowable range because the reference of active power and reactive power are not equal to the loads power. Then the voltage limiter and the frequency limiter begin to take effect, ensuring the power supply quality for loads. The difference between the input signal of these two limiter and the output signal will pass through the proportional regulator, and the new references of active power and reactive power can be obtained according to the droop curve. After the islanding detection detects the islanding condition, the control strategy will be changed to the droop control. All the converters can work in parallel and provide the voltage and frequency supply for loads. At last, the simulation results verified the proposed seamless transfer strategy.

1. Introduction

Microgrid is an integrated system which is composed of micro-sources, energy storage system and local loads. It's a new structure of power supply which can make full use of distributed generation (DG) and guarantee the reliable power supply for critical loads [1]. Thus, microgrid has aroused extensive concern for these years. The typical topology of microgrid is shown in Fig.1. DGs and energy storage equipment usually connected to the power grid by three-phase voltage source converter (VSC) [2].

Usually, microgrid has two operation mode, i.e., grid-connected mode and islanding mode. In grid-connected mode, the DGs and energy storage equipment usually work as current sources, and constant power is transmitted between the microgrid and the power grid [3]. In islanding mode, converters in the microgrid are usually controlled by V/f control or droop control, working as voltage sources and providing the voltage and frequency supply for the loads in microgrid [4].

Droop control is widely used to realize the automatic power sharing between different micro-sources without telecommunication lines, especially for parallel converters used in microgrid. The output characteristics of converters controlled by droop control are imitate as the synchronous generator. Several papers have studied droop control, such as [5]-[7].

When the unplanned islanding occurs, in order to realize uninterrupted power supply for critical and sensitive loads in microgrid, seamless transfer strategy for three-phase converter in microgrid is necessary and has also attracted lots of attention. In [8], a control scheme is presented, wherein the micro-source inverter works in voltage control mode amid stand-alone operation. And in current control mode amid grid-connected operation and switches over easily between these two modes during the transition phase. In [9], a soft-start virtual impedance and single loop current feedback control is proposed to transfer between the islanding mode and the grid-connected mode seamlessly. In [10], a transfer strategy based on output current of the three-phase converter with energy storage in the micro-grid is proposed, which consists of an external inductor current loop, a grid voltage loop and an inner inductor current loop.

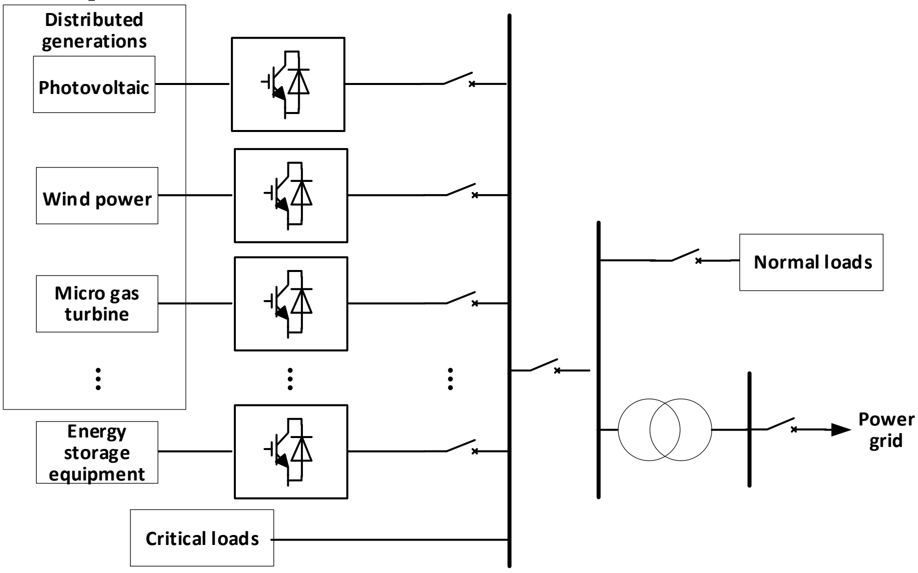


Figure 1. The schematic of typical microgrid

In this paper, a droop control based seamless transfer strategy for three-phase converter in microgrid is proposed. Starting with the typical topology of three-phase converter in microgrid, the principle of droop control method is introduced briefly. Then, according to the characteristics of droop control, the seamless transfer strategy is designed, which contains the voltage limiter and the frequency limiter. The limiters begin to take effect only under the circumstance that the voltage or frequency at the point of common coupling (PCC) exceeds the limit value when the unplanned islanding operation occurs. After the islanding condition is detected by islanding detection techniques, the control strategy can switch to the droop control. All the converters can work in parallel and provide the voltage and frequency supply for loads. At last the simulation verifies the proposed seamless transfer strategy.

2. Droop control strategy

2.1. The topology of three-phase converter in microgrid

The three-phase converter in microgrid is usually used for connecting micro-sources with grid. When the microgrid is operating in grid-connected mode, the converters are controlled by PQ control [11]. PCC voltage is supported by grid. The converters work as current sources, transmitting constant power into the grid. When in islanding mode, there are two kinds of control strategy, master-slave control and peer-to-peer control. The latter control strategy usually adopts droop control mode to control all the converters paralleled in microgrid [12]. The typical topology of converter is shown in Fig. 2.

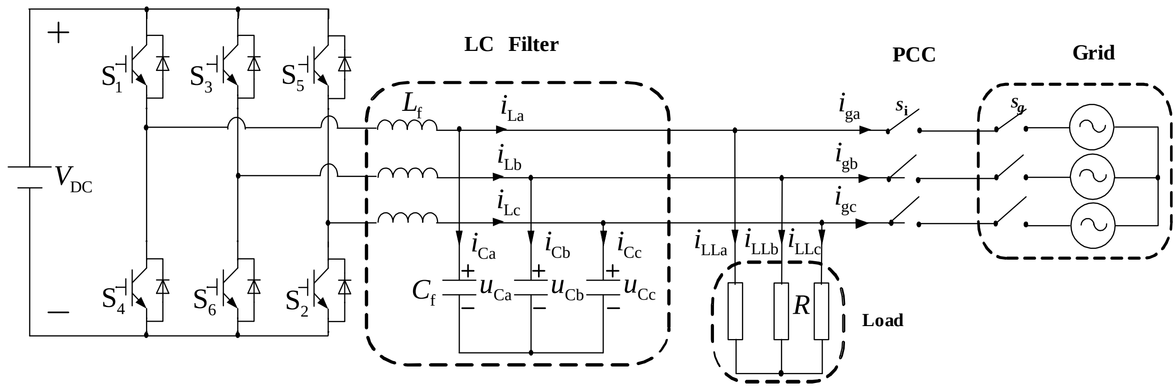


Figure 2. The topology of the typical three-phase converter in microgrid

The micro-source can be equivalent to a constant DC voltage source. V_{DC} is DC voltage. S_1~S_6 are the insulated gate bipolar transistors (IGBT). L_f is AC filter inductance. C_f is AC filter. i_{La}, i_{Lb}, i_{Lc} are the output currents of VSC. i_{LLa}, i_{LLb}, i_{LLc} are the currents in loads. i_{ga}, i_{gb}, i_{gc} are the currents flowing between the power grid and microgrid.

2.2. The relationship of paralleled converters

In Fig.3, the single-phase equivalent circuit of two converters in parallel is shown. Define i as the serial number of converters. E_i is output voltage of converter. R_i and L_i respectively are the resistance and inductance of equivalent line between converters and PCC,. U is PCC voltage. R_L and L_L are the loads' resistance and inductance respectively.

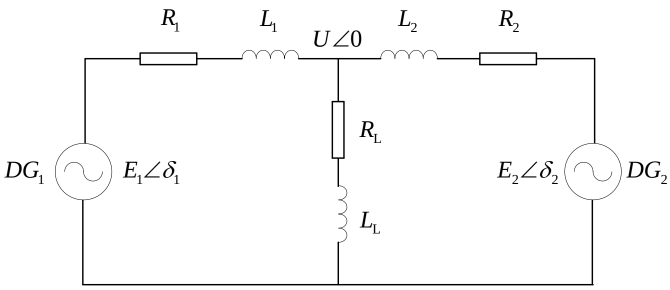


Figure 3. The single-phase equivalent circuit of two converters in parallel

According to Fig.3, the output power of converters can be calculated, as shown in equation (1).

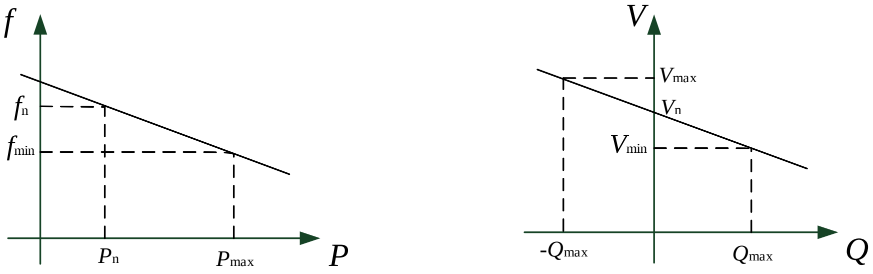
$$\begin{cases} P_i = \dfrac{R_i\left(E_iU\cos\delta_i - U^2\right)}{X_i^2 + R_i^2} + \dfrac{X_iE_iU}{X_i^2 + R_i^2}\sin\delta_i \\ Q_i = \dfrac{X_i\left(E_iU\cos\delta_i - U^2\right)}{X_i^2 + R_i^2} - \dfrac{R_iE_iU}{X_i^2 + R_i^2}\sin\delta_i \end{cases} (\text{i=1,2}) \tag{1}$$

Usually, Li ≥ Ri, and the δi is very small, so the sinδ_i is approximately equal to δ_i. Thus, equation (1) can be simplified, as equation (2) shows.

$$\begin{cases} P_i = \dfrac{E_iU}{X_i}\delta_i \\ Q_i = \dfrac{U\left(E_i - U\right)}{X_i} \end{cases} (\text{i=1,2}) \tag{2}$$

2.3. The principle of droop control

According to equation (2), the active power Pi is related to the phase angle δi, and the reactive power Qi is related to the output voltage of converter. And the phase angle is dependent on the frequency, so the output active power can be controlled by changing the frequency of output voltage. Thus, the P-f droop characteristic and Q-V droop characteristic can be obtained, as shown in Fig.4.



a. Curve of P-f droop characteristics b. Curve of Q-V droop characteristics

Figure 4. The frequency and voltage droop characteristics

Fig.4 can be expressed by equation (3). The output voltage and frequency of converters will be controlled according to the output power. Equation (3) corresponds to the droop control module in Fig.5, in which the control block diagram of droop control is shown.

$$\begin{cases} f = f_o + m\left(P - P_0\right) \\ E = E_o + n\left(Q - Q_0\right) \end{cases} \tag{3}$$

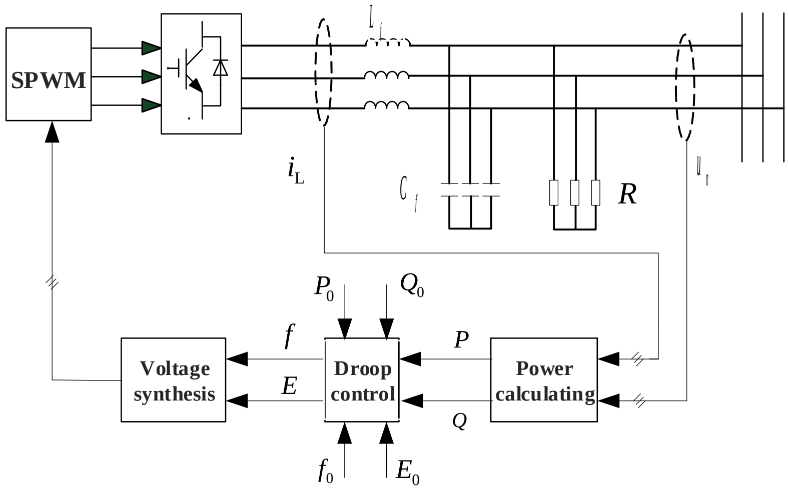


Figure 5. The control block diagram of droop control

3. Proposed seamless transfer strategy

3.1. Basic idea of proposed strategy

When the unplanned islanding operation occurs, because of the time delay of islanding detection technique, the converters in microgrid are still operating in grid-connected mode, controlled by PQ control. If the reference of power is not equal to the loads, the quality of PCC voltage may be damaged, and the critical loads may work improperly even breakdown. In order to prevent this case, the seamless transfer strategy proposed by this paper designs the frequency limiter and voltage limiter, as Fig.4 shows. The difference between the input signal of these two limiters and the output signal will pass through the proportional regulator, and the new reference of active power and reactive power can be obtained according to the droop curve.

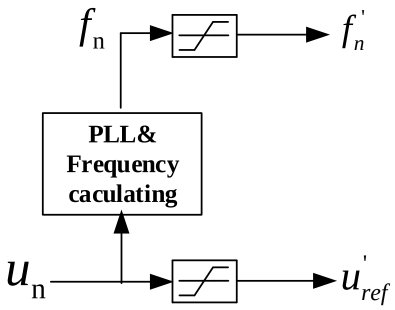


Figure 6. The frequency limiter and voltage limiter

It is necessary to consider the allowable range of frequency fluctuation when designing the limit value of the frequency limiter, as equation (4) shows. $D_{\text{f-max}}$ and $D_{\text{f-min}}$ are the upper limit and lower limit of the frequency limiter respectively. f_n is the acted frequency. Δf is the frequency deviation.

$$\begin{cases} D_{\text{f\_max}} = f_n + \Delta f \\ D_{\text{f\_min}} = f_n - \Delta f \end{cases} \tag{4}$$

The voltage limiter is the key to providing the voltage supply with good quality for loads during the transfer from grid-connected mode to islanding mode. According to IEEE Std_1547 2003 [13], the voltage fluctuation should be within 10% of rated voltage in the case that the rated capacity of converter is lower than 500kVA. So the voltage is designed according to equation (5).

$$\begin{cases} D_{V\_\max} = 110\% V_n \\ D_{V\_\min} = 90\% V_n \end{cases} \tag{5}$$

3.2. The control block diagram

The control block diagram is shown in Fig.5. The part which is in a dotted box is the droop control unit. And the outside part is PQ control unit. The switch between droop control and PQ control can be controlled by the single-pole double-throw (SPDT) switch. When the microgrid is operating in grid-connected mode, the frequency limiter and voltage limiter is ineffective because the PCC voltage and frequency is supported by the power grid. The SPDT selects the PQ control to control the converters. When the unplanned islanding occurs, if the PCC voltage and frequency exceeds the bounds of these two limiters, the reference of voltage and frequency would be the limit values. And the new reference of active power and reactive power can be obtained from the difference between the input signal of these two limiter and the output signal and the droop curve, which is shown in equation (4).

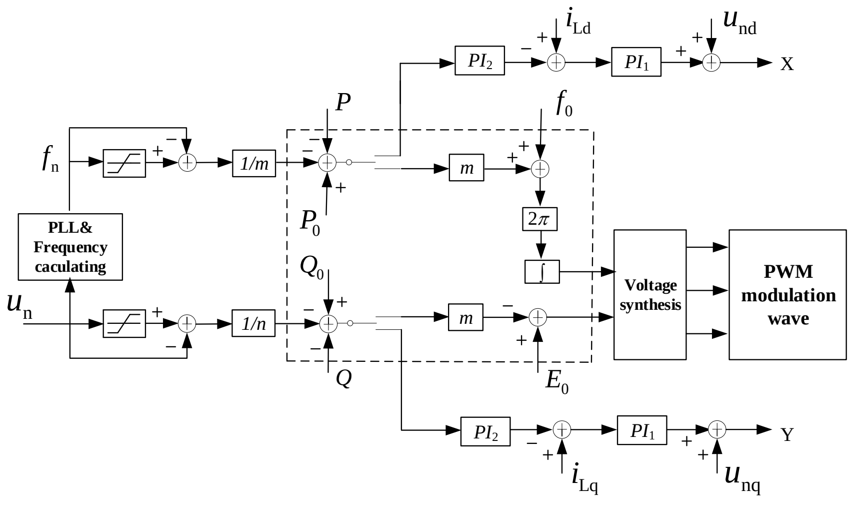


Figure 7. The frequency limiter and voltage limiter

$$\begin{cases} P^* = P_0 - \dfrac{1}{m}\left(f_{\lim} - f_o\right) \\ Q^* = Q_0 - \dfrac{1}{n}\left(E_{\lim} - E\right) \end{cases} \quad (6)$$

In equation (4), $E_{\lim}$ and $f_{\lim}$ are the limit values of the voltage limiter and frequency limiter respectively. P^* and Q^* are the references of active power and reactive power caused by the frequency and voltage fluctuation in unplanned islanding situation. Thus, the output power of converter can be equal to the loads. The PCC voltage and frequency can be guaranteed within the prescribed range.

After the islanding detection technique has detected the islanding condition, the SPDT selects the droop control to control the converters. Thus, the seamless transfer can be realized.

4. Simulation results

The simulation is presented to verify the droop control based seamless transfer strategy for three-phase converter in microgrid. The parameters of the simulation model are shown in Table 1.

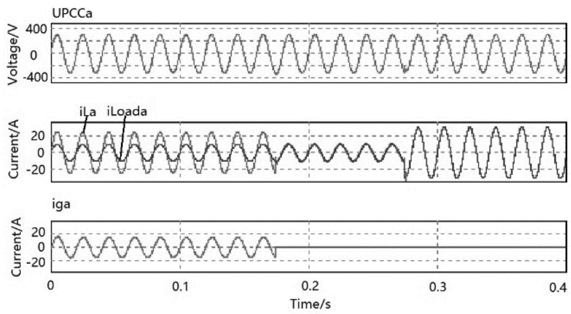
Table 1. The parameter of the main circuit in simulation

Parameter	Value
DC voltage V_{dc}	700V
Filter inductance L_f	3mH
Filter capacitor C_f	20μF
Slope of P-f droop curve m	0.005Hz/W
Slope of Q-V droop curve n	0.0038V/Var
The reference of active power in grid-connected mode P_{ref}	7.75kW
The reference of reactive power in grid-connected mode Q_{ref}	0kVar
loads	30Ω

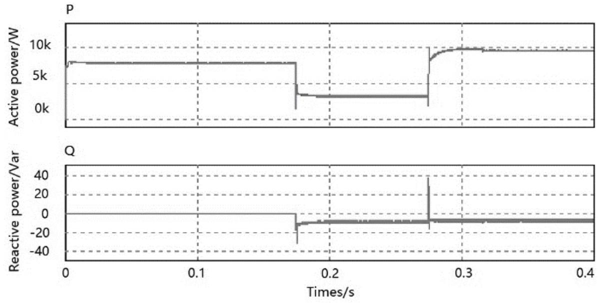
The unplanned islanding occurs at t=0.175s, and the loads are increased at t=0.275s. The results are shown in Fig.7. The PCC voltage, the output current of converter, the load current and the current flowing between power grid and microgrid are shown in Fig.7(a).The output active and reactive power of converter are shown.in Fig.7(b).

Fig.7(a) shows that, after the unplanned islanding occurs, the PCC voltage and frequency are limited within the acceptable range via the seamless transfer strategy. The loads can work properly when the unplanned islanding is occurring. Fig.7(b) shows that the converter can provide the power supply for loads when the unplanned islanding is occurring. And after the islanding detection technology detects the islanding condition, the control strategy can switch over to the droop control. When the loads are increased, the output power of converter can fit the load power by changing the output frequency and voltage of converter in islanding mode.

The simulation results shows that, the droop control based seamless transfer strategy for three-phase converter is useful to realize the seamless transfer between PQ control and droop control. The frequency limiter and voltage limiter can ensure the PCC voltage within the allowable range. The critical loads can work normally in the transfer process. After the control strategy switches over to droop control, the converter can provide the frequency and voltage supply with good quality for loads.



(a) The PCC voltage, output current of converter, the load current and the current flowing between power grid and microgrid



(b) The output active and reactive power of converter

Figure 8. The simulation results

5. Conclusion

This paper proposes a seamless transfer strategy based on droop control for three-phase converter in microgrid, which contains frequency limiter and voltage limiter. When the unplanned islanding occurs, the limiters can ensure the PCC voltage and frequency are within the required range for proper operation of loads. After the islanding detection technique detects the islanding condition, the control strategy switches over to the droop control unit, controlling the converters work as voltage sources and provide the voltage and frequency supply for loads. At last, the seamless transfer strategy is verified by the simulation results.

6. Acknowledgments

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7. References

[1] U. Akram, M. Khalid and S. Shafiq, "An Innovative Hybrid Wind-Solar and Battery-Supercapacitor Microgrid System—Development and Optimization," in IEEE Access, vol. 5, pp. 25897-25912, 2017.

[2] C. Shah, M. Abolhassani and H. Malki, "Fuzzy controlled VSC of battery storage system for seamless transition of microgrid between grid-tied and islanded mode," 2017 International Joint Conference on Neural Networks (IJCNN), Anchorage, AK, 2017, pp. 3224-3227.

[3] Y. Xiaodong, Z. Youbing, W. Guofeng, R. Shuaijie, S. Weiwei and L. Junjie, "Coordinate optimization for grid-connected microgrid considering uncertainties of renewable energy sources and electric vehicles," 2017 29th Chinese Control And Decision Conference (CCDC), Chongqing, 2017, pp. 3224-3231.

[4] D. K. Jeong, H. J. Yun, H. J. Kim, H. S. Kim and J. W. Baek, "Distributed control strategy of DC microgrid for islanding mode operation," 2017 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe), Warsaw, 2017, pp. P.1-P.5.

[5] A. Trivedi and M. Singh, "L_1 Adaptive Droop Control for AC Microgrid with Small Mesh Network," in IEEE Transactions on Industrial Electronics, vol. PP, no. 99, pp. 1-1.

[6] Z. Peng, J. Wang, D. Bi, Y. Dai and Y. Wen, "The Application of Microgrids Based on Droop Control with Coupling Compensation and Inertia," in IEEE Transactions on Sustainable Energy, vol. PP, no. 99, pp. 1-1.

[7] Phuong Le Minh, Hoa Pham Thi Xuan, Duy Hoang Vo Duc and Huy Nguyen Minh, "Control of power in an island microgrid using adaptive droop control," 2017 International Conference on System Science and Engineering (ICSSE), Ho Chi Minh City, 2017, pp. 148-153.

[8] A. H. Kadam, K. Unni and S. Thale, "Control scheme for seamless operating mode transfer of AC microgrid," 2017 IEEE International Conference on Smart Energy Grid Engineering (SEGE), Oshawa, ON, 2017, pp. 123-130.

[9] Y. Chen et al., "Seamless transfer control strategy for three-phase inverter in microgrid," 2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia), Hefei, 2016, pp. 1759-1763.
[10] Y. Wang and G. Zhao, "An output current based seamless transfer control strategy for three-phase converter with energy storage in micro-grid," International Conference on Renewable Power Generation (RPG 2015), Beijing, 2015, pp. 1-6.
[11] D. Zhang and E. Ambikairajah, "De-coupled PQ control for operation of islanded microgrid," 2015 Australasian Universities Power Engineering Conference (AUPEC), Wollongong, NSW, 2015, pp. 1-6.
[12] Jie Feng Hu, Jian Guo Zhu and G. Platt, "A droop control strategy of parallel-inverter-based microgrid," 2011 International Conference on Applied Superconductivity and Electromagnetic Devices, Sydney, NSW, 2011, pp. 188-191.
[13] IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems," in IEEE Std 1547-2003, vol., no., pp.1-28, July 28 2003