ICIC Express Letters ICIC International ©2016 ISSN 1881-803X
Volume **10**, Number **2**, February **2016** pp. **447–454**

REACTIVE POWER SHARING USING MULTI-MICROGRID COORDINATION CONTROLLER

Ming Li[1], Jun Wang[1,*], Yanxiang Yang[2], Zhang Sun[1]
Yankun Xia[1] and Ke Chen[1]

[1]Sichuan Province Key Laboratory of Power Electronics Energy-Saving Technologies and Equipment
School of Electrical Engineering and Electronic Information
[2]School of Applied Technology
Xihua University
No. 999, Jinzhou Road, Jinniu District, Chengdu 610039, P. R. China
[*]Corresponding author: wangjun@mail.xhu.edu.cn

Received July 2015; accepted September 2015

Abstract. *The traditional droop control is difficult to achieve the reactive power sharing by droop coefficient influenced by lines impendence differences of multiple microgrid. A reactive power sharing control strategy is presented which modifies the no-load output voltage to decrease reactive power sharing deviations and compensate the voltage of AC feeder based on multi-microgrid coordination controller. It reduces the deviation of reactive power sharing and the magnitude of voltage drop. Simulation results show that the control strategy can achieve the active and reactive power sharing effectively with better stability and excellent dynamic response.*
Keywords: Multi-microgrid, Droop control, Coordination, Reactive power sharing, Voltage drop

1. **Introduction.** The frequency and voltage magnitude droop control is adopted which aims to achieve microgrid power sharing in a decentralized manner. However, affected by the distributed generation (DG) capacity and impedance of the transmission line differences, it is difficult to achieve a rational allocation of reactive power between DG sources and even causes circulating current. The controlling structure of DG is also improved to reduce the magnitude of the deviation of the output voltages of DG to inhibit circulation [3]. In [4], the conventional droop control is improved to reduce the magnitude of the deviation of the output voltages of DG to inhibit circulation. After the output voltage amplitude of inverter is compared with voltage set point, the PI controller will generate the compensation to reduce the deviation of the voltage amplitude. However, it does not take the capacity of each DG into consideration. Besides, the droop control technology with the reference of load-side voltage amplitude is proposed [5]. The scheme adjusts the voltage amplitude of load-side to affect the quality of the microgrid voltage. In [6], the method that increases the compensation of reactive bias and recover voltage has been proposed so as to improve the accuracy of reactive power distribution. Meanwhile, the sync pulse is introduced into controller to help recover the feed voltage so that the control process is complex. The conventional droop control is improved by introducing the multi-loop control structure that is complex to be controlled and difficult to be achieved.

This paper focuses on improving the reactive power sharing in micro-source level control, and presents a simple reactive power sharing compensation scheme to make the conventional droop control structure invariant. The mutual coordination is discussed between DG level control strategy and coordination controller. A compensation method is adopted to recover the AC feeder voltage.

This paper is structured as follows. Section 2 explains the hierarchical control and coordinated control in Multi-microgrid and Section 3 explicates the droop control principle of micro-source level. Section 4 details the proposed reactive power sharing strategy. Its simulation and verification are presented in Section 5 with the conclusion drawn in Section 6.

2. **Coordinated Control of Multiple Microgrid System.** A microgrid consists of several DGs, storage devices, controllable loads, power exchange lines, control system and protection system, which can directly feed into low voltage (LV) as a controllable unit. Currently, in order to improve the energy efficiency of distributed generation, there are projects that multiple sub-microgrid are effectively organized to form a new multi-microgrid by connecting feeder, and they are divided in structure and management. Multi-microgrid managers can manage the microgrid through the hierarchical control in space [1], including system level control, microgrid level control and micro-source level control. The task of system level control includes economic dispatch, scheduling and status of multi-microgrid system, and microgrid level control aims to adjust the microgrid power by coordination controller, and micro-source level control implements prior instruction to rapidly track system set parameters [9,10]. In the hierarchical control, specific task and mutual coordination are used to ensure the justifiability of power sharing and improve the efficiency of multi-microgrid management. In addition, the public feeder voltage of multi-microgrid is supported by distribution network in the grid-connected mode. The reactive power sharing is easy to achieve to the grid-connected mode, so this paper will not repeat the power sharing in the grid-connected mode.

3. **Micro-Source Level Droop Control Strategy.** In an islanded microgrid, the droop control should be generally designed to share the active and reactive power to ensure stable operation of the microgrid [7,11]. The reactive power output of DG can be obtained in (1) as

$$Q = \frac{E^2 - EU\cos\theta}{X} \tag{1}$$

The control formula can be expressed as

$$f = f_0 - mP \tag{2}$$

$$E = E_0 - nQ \tag{3}$$

where f and E are the frequency and amplitude of the actual output voltage of DG, f_0 and E_0 are the frequency and amplitude of the no-load output voltage of DG respectively, and m and n are the droop coefficient of frequency and voltage.

The Q-V droop characteristic is shown in Figure 1 that droop coefficient $n_1 > n_2 > n_3$. It shows that the DG with smaller droop coefficient has larger power capacity.

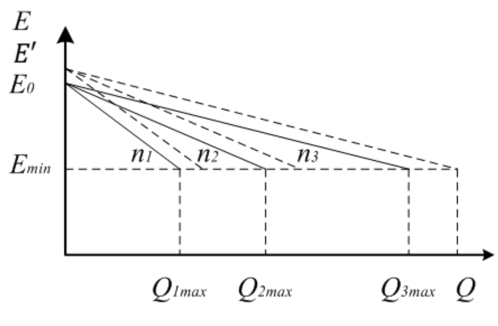

FIGURE 1. Q-V droop characteristic

Equation (3) is brought in Equation (1) as follows. However, nQ is the droop voltage drop which is much smaller than the no-load output voltage generally. Ignoring nQ quadratic term, Q is simplified as

$$Q = \frac{E_0^2 - E_0 U \cos\theta}{X + n(2E_0 - U\cos\theta)} \tag{4}$$

Equation (4) shows that DG reactive power is related to amplitude of unload voltage, amplitude of AC feeder voltage, power angle, transmission reactance and droop coefficient. When the no-load output voltage is adjusted in the conventional droop control, the reactive power output of DG will be changed. It can be noticed that the reactive power output is more than original sharing in the bigger no-load voltage amplitude.

4. **Reactive Power Sharing Strategy.** According to the previous analysis, active power can track the frequency to achieve the active power sharing. The reason is that the system frequency is a global public variable and is consistent at the same time. When the reactive power is shared, the differences of transmission lines and capacity of DG cause the reactive power sharing to inequality, and even circulation, which will increase losses, reduce system efficiency and make an impact on stability of multi-microgrid [8,17].

In order to share the reactive power by droop coefficient, each DG droop voltage drop should be equal and be obtained as

$$n_1 Q_1 = n_2 Q_2 = \ldots = n_i Q_i \tag{5}$$

It is noteworthy that droop voltage drop is not equal in the different impedance microgrid. To compensate for the deviation of droop voltage drop, the method of adjusting no-load voltage set value of droop control is adopted to adapt to changes in reactive power. As shown in Figure 1, improving no-load output voltage can improve the DG reactive output. The less power output appropriately raises no-load output voltage and the larger power output can reduce no-load output voltage to reach DG the reactive power sharing by droop coefficient.

To modify the no-load output voltage of droop control, the introduction of voltage loop in [4] and synchronous pulse mode in [6] changed the original droop structure to regulate the amplitude of no-load output voltage, which needs to modify the original DG controller. It is not involved with reactive power of other DG. This paper presents a simple reactive power sharing and voltage compensation scheme that sets the no-load output voltage through the coordination controller. Calculation of no-load output voltage is separated from the droop control structure which is easy to achieve the reactive power sharing strategy.

In the islanded state of microgrid, reactive power output of DG is always equal to the consumed reactive power. Due to the differences of line impedance and capacity, reactive power output is less than the reactive power that shall be distributed. Meanwhile, more reactive power should be supplied by another DG. Therefore, it is a certain coupling relationship between reactive power of DG and reactive power output of another DG. To reflect the other DG in a certain extent influence to the local distributed power supply, a compensation will be added by the introduction of droop voltage drop of another DG. Finally, the compensation of AC feeder voltage is allowed in the circumstances. The compensation is obtained as

$$E'_{i0} = E_{i0} - \left[\sum_{j=1, j\neq i}^{j=N} (n_i Q_i - n_j Q_j) \right] \tag{6}$$

$$E''_{i0} = E'_{i0} + \Delta U \tag{7}$$

where E_{i0} is the ith no-load output voltage amplitude, E'_{i0} is the ith no-load output voltage amplitude after reactive compensation, N is the number of DG with droop control on the same coordination controller, ΔU is the deviation between AC feeder rated voltage amplitude and actual voltage amplitude, and E''_{i0} is the ith no-load output voltage amplitude after voltage compensation.

In order to ensure the stability of the microgrid system, voltage amplitude must meet the national standard [15], the range of E''_{i0}: $E_{\min} < E''_{i0} < E_{\max}$, and if the value of the calculated voltage is beyond the range, it should be considered whether the reactive power of the load is beyond the maximum load power or not.

Equation (6) is used to improve the system reactive power distribution relationship by droop coefficient. The amplitude of AC voltage feeder are compensated in Equation (7) to restore the AC voltage feeder. After performing Equation (6) and Equation (7) to set no-load output voltage amplitude, coordination controller can set the value of the setting through the communication line to the droop control, and complete the first reactive power sharing. If the reactive power still cannot meet the system requirements for the reactive power sharing or feeder voltage compensation exceeds the specified voltage range, Equation (6) and Equation (7) will continue to regulate voltage and compensate reactive power until the system requirements are reached.

Figure 2 is a block diagram of the system control. The state information is received from micro-source and distribution network. The processing results will be returned to the micro-source controller to complete system coordination and control. In order to facilitate the transmission of each logical node information, IEC61850 standard which is the only global standard in power system and automation field can guarantee the real-time communication of microgrid. The communication system is modeled by the characteristics of microgrid to realize the information interaction [13].

5. **Parameters Selection and Simulation.** Microgrid simulation model is constructed by Matlab/Simulink to verify the effectiveness of the proposed strategy. The microgrid

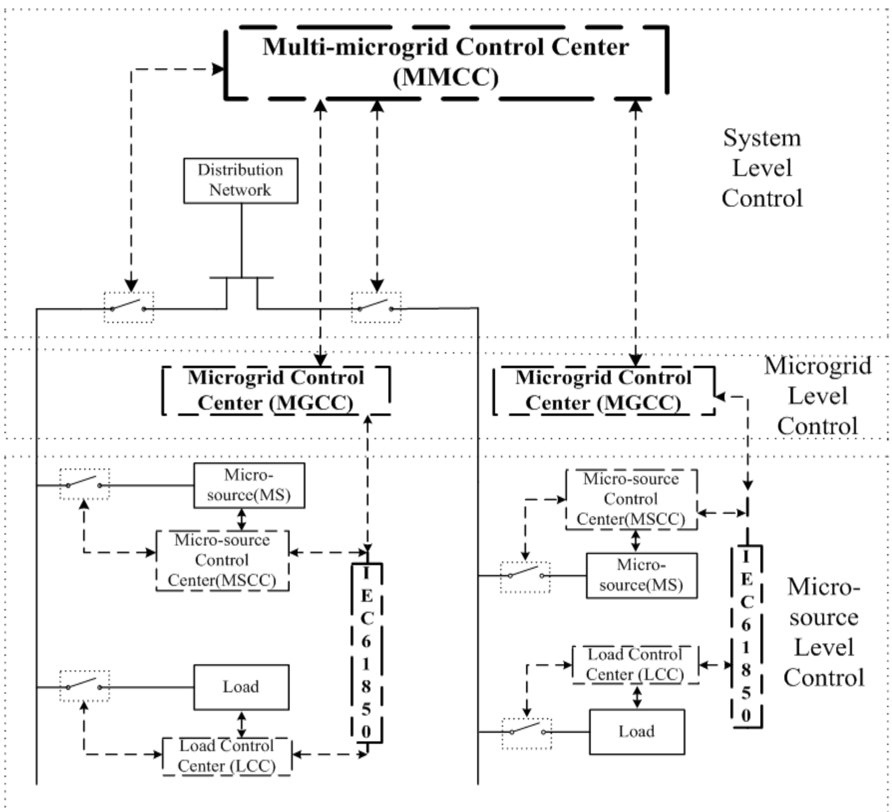

FIGURE 2. Coordination control block diagram

topology is shown in Figure 3. Three distributed power, four load and three transmission lines are included.

In the islanded microgrid, effective value of AC rated voltage is 220V, and frequency is 50Hz. Line and load parameters:

$Z_{L1} = 0.17 + j0.157\Omega$, $Z_{L2} = 0.34 + j0.2826\Omega$, $Z_{L3} = 0.27 + j0.2198\Omega$, $P_1 = P_2 = P_3 =$ 3kW, $P_4 = 25$kW, $Q_4 = 10$kVar.

In Figure 3, each DG adopts droop control, including outlet LC filter and outlet inductance. The filter inductor is 3mH. The filter capacitor is 25uF. The outlet inductance is 1mH. The carrier frequency is 10kHz. To ensure the voltage quality in light load system firstly, the initial set of no-load output voltage amplitude is rated 311V. After setting droop coefficient as shown in Table 1, the system simulation results are shown in Figure 5.

Table 1. DG droop coefficient

Droop coefficient	DG1	DG2	DG3
Active power droop coefficient $m(e^{-5}\text{Hz/W})$	1	2	4
Reactive power droop coefficient $n(e^{-4}\text{V/Var})$	3	5	7

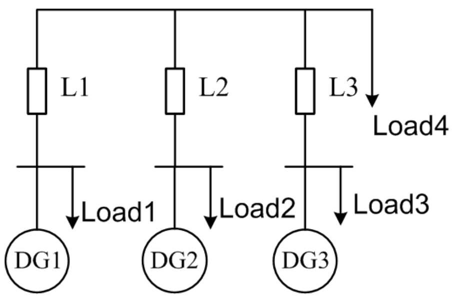

Figure 3. Microgrid simulation topology

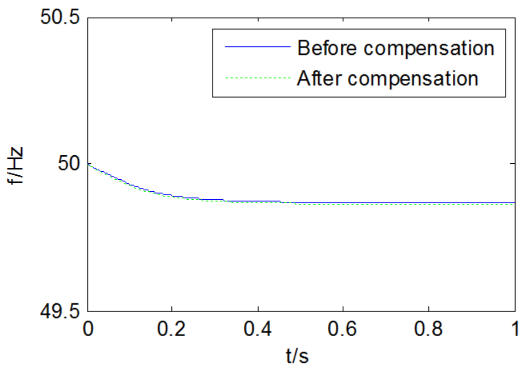

Figure 4. The frequency of AC voltage

Figure 5(a) shows that active power sharing is not affected by the line impedance difference. The smaller droop coefficient is, the more active power sharing is. Figure 5(b) is the reactive power sharing in different lines. As can be seen from figure, reactive power output of DG1 is 1780Var, reactive power output of DG2 is 1860Var, and reactive power output of DG3 is 3360Var. The system is in not accordance with the droop coefficient to share the reactive power. The waveform curve of AC voltage U_a, U_b and U_c is cut. Figure 5(c) is a part of the curve of voltage of AC feeder and shows that the AC feeder voltage drops to about 306V.

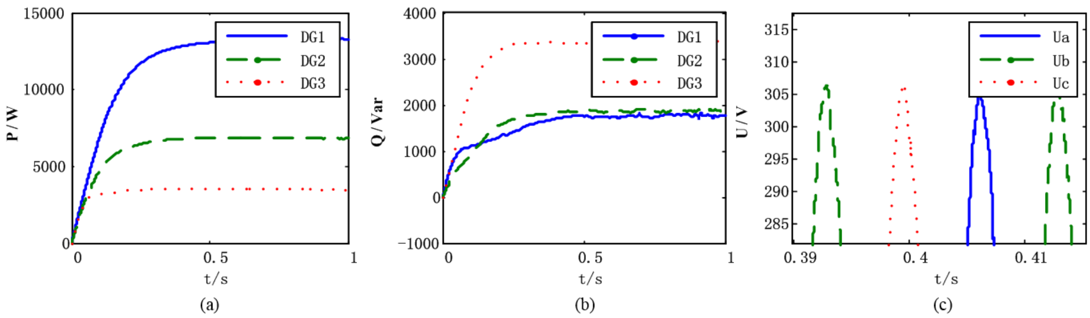

FIGURE 5. Simulation results before compensation: (a) Active power sharing before compensation, (b) Reactive power sharing before compensation, (c) AC feeder voltage before compensation.

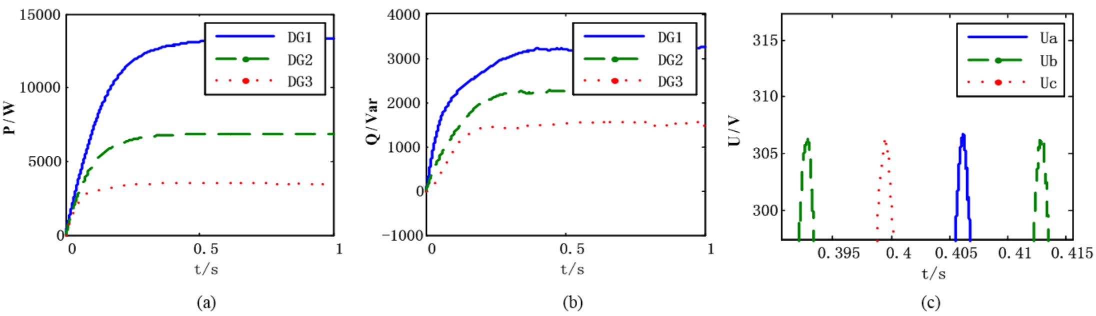

FIGURE 6. Simulation results after power compensation: (a) Active power sharing after power compensation, (b) Reactive power sharing after power compensation, (c) AC feeder voltage after power compensation.

To share the load reactive power properly, no-load output voltage compensation of DG1 is 313.214V, no-load output voltage compensation of DG2 is 312.026V, and no-load output voltage compensation of DG3 is 307.76V, which is calculated by Equation (6). The simulation results are shown in Figure 6. There is little impact on the active power in the reactive power compensation. In Figure 6(b), the reactive droop coefficient is smaller, and the reactive power output is greater. However, it can be seen in Figure 6(c) that amplitude of AC feeder voltage drop has not been improved.

In order to restore the voltage amplitude of the AC feeder, the no-load voltage of DG1 should be set to 318.214V, the no-load voltage of DG2 should be set to 317.026V and the no-load voltage of DG3 should be set to 312.76V. All of them are calculated by coordination controller through Equation (7). The results of simulation are shown in Figure 7, the active and reactive power sharing are reasonable, and the AC feeder voltage amplitude recovers to near nominal 311V.

Before or after the compensation, the microgrid frequency is shown in Figure 4. It can be seen that the system frequency does not exceed the permitted range, and does not have much volatility in the reactive power sharing and voltage restoring.

Multi-microgrid system load will be subject to change to make an effect on the power sharing [16]. Therefore, the active power of load 4 is changed to 20kW, and the reactive power of it is changed to 8kVar. The simulation results are used to verify the impact of the proposed reactive power sharing algorithm. Before the compensation, active power, reactive power and voltage amplitude of AC feeder are shown in Figure 8. Simulation results show that active power has already been reasonable, reactive power are inequitable, and voltage drop is about 3.5V by using Equation (6) and Equation (7) for the reactive power sharing and voltage compensation.

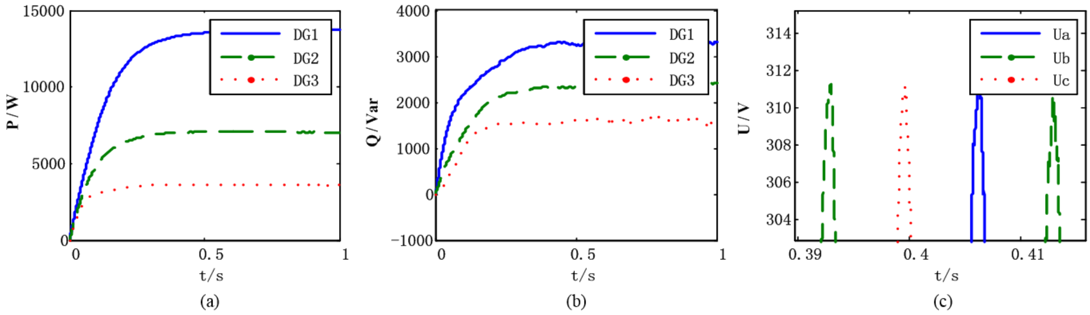

Figure 7. Simulation results after voltage compensation: (a) Active power sharing after voltage compensation, (b) Reactive power sharing after voltage compensation, (c) AC feeder voltage after voltage compensation.

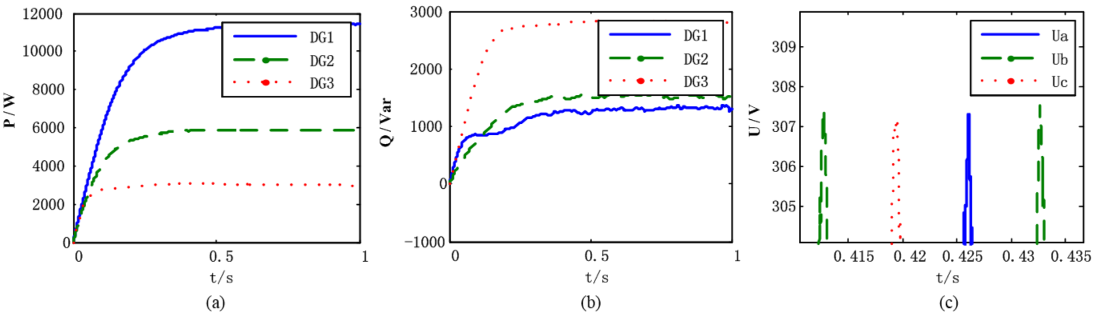

Figure 8. Simulation results after load is changed: (a) Active power sharing after load is changed, (b) Reactive power sharing after load is changed, (c) Voltage of AC feeder after load is changed.

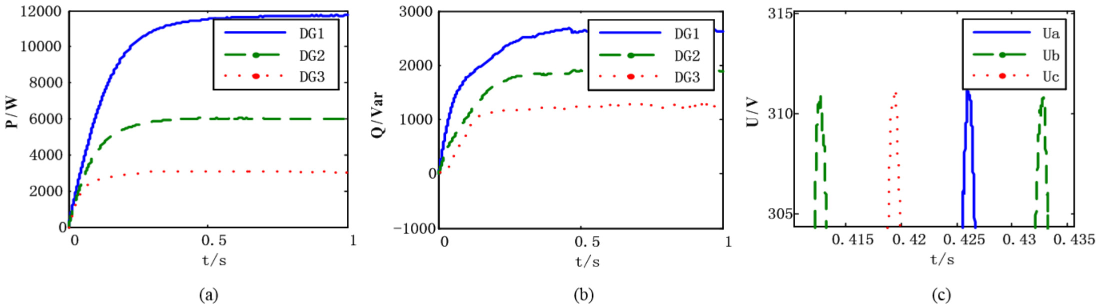

Figure 9. Simulation results after compensation (load is changed): (a) Active power sharing after compensation (load is changed), (b) Reactive power sharing after compensation (load is changed), (c) Voltage of AC feeder after compensation (load is changed).

Figure 9 shows that the active power and the reactive power sharing are achieved by the droop coefficient, and the feeder voltage also restores to the near rated value, after load is changed.

6. **Conclusions.** The approach implemented by an improved multi-microgrid reactive power sharing strategy includes the reactive sharing and recovering from voltage drop. A coordination controller is adopted from multi-microgrid hierarchical control system to modify no-load voltage amplitude of droop control with communication lines. The simulation results verify the effectiveness of the proposed control strategy. The original structure of droop control is not changed by proposed method in which the calculation and

analysis are done in the coordination controller. Therefore, coordinated strategy provides an easy and dynamic response way to efficiently share reactive power and restore voltage drop.

The future research will focus on monitoring and communicating with multi-microgrid, and meanwhile, hardware will be implemented.

Acknowledgment. This work was partially supported by Support Program Fund of Sichuan Provincial Department of Science and Technology (No. 2013GZ0130), and a grant from the Key Equipment Project of Sichuan Provincial Economic and Information Committee (No. [2014]128), and the Innovation Fund of Postgraduate, Xihua University (No. YCJJ2015207), and the Ministry of Education Chunhui Project of China (No. Z2012025), and the Open Research Subject of Key Laboratory of Sichuan Power Electronics Energy-Saving Technologies and Equipment (No. SZJJ2015-064).

REFERENCES

[1] N. C. Zhou, M. Jin, Q. G. Wang, S. Su and Y. T. Yan, Hierarchical coordination control strategy for multi-microgrid system with series and parallel structure, *Automation of Electric Power Systems*, vol.37, no.12, pp.13-18, 2013.

[2] C. S. Wang, Z. X. Xiao and S. X. Wang, Multiple feedback loop control scheme for inverters of the micro source in microgrids, *Transactions of China Electrotechnical Society*, vol.24, no.2, pp.100-107, 2009.

[3] H. G. Xiao, A. Luo, Y. C. Wang, C. M. Tu and Z. K. Shuai, A circulating current control method for paralleled inverters in microgrids, *Proc. of the CSEE*, vol.34, no.19, pp.3098-3104, 2014.

[4] H. Su, W. Cao, J. Sun and D. P. Yang, Micro-grid coordinated control strategy based on improved droop control, *Power System Protection and Control*, vol.42, no.11, pp.92-98, 2014.

[5] X. Ai, P. Jin and Y. Y. Sun, An enhanced reactive sharing control strategy of microgrid, *Power System Protection and Control*, vol.41, no.7, pp.147-155, 2013.

[6] H. Han, Y. Liu, Y. Sun, M. Su and H. B. Shen, An improved control strategy for reactive power sharing in microgrids, *Proc. of the CSEE*, vol.34, no.16, pp.2639-2648, 2014.

[7] C. S. Wang, Y. Li and K. Peng, Overview of typical control methods for grid-connected inverters of distributed generation, *Proc. of the CSU-EPSA*, vol.24, no.2, pp.12-20, 2012.

[8] Q. H. Zhang, A. Luo, Y. D. Chen, C. W. Peng and Z. Q. Peng, Analysis of output impedance for parallel inverters and voltage control strategy, *Transactions of China Electrotechnical Society*, vol.29, no.6, pp.98-105, 2014.

[9] J. Vasiljevska, J. A. Pec, A. S. Lopes and M. A. Matos, Integrated micro-generation, load and energy storage control functionality under the multi micro-grid concept, *Electric Power Systems Research*, vol.95, no.2013, pp.292-301, 2012.

[10] J. Vasiljevska, J. A. Pec, A. S. Lopes and M. A. Matos, Evaluating the impacts of the multi-microgrid concept using multicriteria decision aid, *Electric Power Systems Research*, vol.91, no.2012, pp.44-51, 2012.

[11] X. C. Mu, D. Q. Bi and X. W. Ren, Study on control strategies of a low voltage microgrid, *Automation of Electric Power Systems*, vol.34, no.19, pp.91-96, 2010.

[12] X. F. Yang, J. Su, Z. P. Lv, H. T. Liu and X. Li, Overview on micro-grid technology, *Proc. of the CSEE*, vol.34, no.1, pp.57-70, 2014.

[13] G. W. Li, Y. Z. Zhang, W. S. Huang and Q. Jin, Communication model for IEC 61850 based intelligent monitoring terminal of DER, *Automation of Electric Power Systems*, vol.37, no.10, pp.13-18, 2013.

[14] W. Yu and D. H. Xu, Control scheme of paralleled UPS system based on output virtual resistance, *Proc. of the CSEE*, vol.29, no.24, pp.32-39, 2009.

[15] Z. C. Yang, J. Le, K. P. Liu and X. J. Xie, Study on the standard of the grid-connected microgrids, *Power System Protection and Control*, vol.40, no.2, pp.66-76, 2012.

[16] F. D. Li and M. Wu, An improved control strategy of load distribution in an autonomous microgrid, *Proc. of the CSEE*, vol.31, no.13, pp.18-25, 2011.

[17] J. W. He and Y. W. Li, An enhanced microgrid load demand sharing strategy, *IEEE Trans. Power Electronics*, vol.27, no.9, pp.3984-3995, 2012.