Multistage Control of Weak Microgrid with Power Quality Improvement Based on APF

Multistage Control of Weak Microgrid with Power Quality Improvement Based on APF

Hong yang Zhang*, Zhen tang Shi, and Hong yong Du

SINOPEC Dalian Research Institute of Petroleum and Petrochemicals, Power Technology Department, 116045 Dalian, China

pmsm@163.com

Abstract. The power quality of weak microgrid is sensitive due to the nonlinear loads and power electronic devices are applied, and the adjusting automatically compensation function of equipment self is inadequate and ineffective. For this, the control characteristic of active power filter(APF)is studied, and the droop control is analyzed in weak microgrid especially under the isolated island, and the principles of parameter adjustment are proposed. Then the multistage control algorithm of weak microgrid is proposed that improve the power quality and reliability based on APF, the algorithm is that the APF execute multistage filtering process according to the characteristics of harmonic and the other source are designed under droop control scheme, and the constraint condition which considering the THD of load current makes it contributing for the stability and reliability between APF and sources. Further, the mutual influence between multistage control algorithm and transition loads shedding considering different degrees of importance are discussed so that the scheme achieve a higher reliability. Finally, the effectiveness of the control algorithm proposed that taking oil field microgrid as an example in this paper is demonstrated through simulation and analyses.

1. Introduction

With the development of renewable energy and power electronic equipment that the microgrid projects have been used in various occasions, such as coal, petroleum, petrochemical and metallurgical. The power quality problem of microgrid is becoming more and more important factor that affects largely microgrid development and power system security [1-3]. An area of study is to investigate the impact of nonlinear loads and power electronic devices. A control method that separates the control tasks in the frequency domain is proposed under a park microgrid, and power and voltage regulation are distributed through a low-bandwidth communication link [4].Considering current-controlled and voltage-controlled DGs, a novel harmonic control scheme with voltage-controlled method is developed [5].With the energy storage added to a shunt active filter configuration, the control strategy based on the state space pole placement design for the SAFES installed in a microgrid has been developed in [6]. The method through equipment, a hierarchical control structure is proposed that includes primary and secondary to compensate voltage harmonics with inverters and APFs. In addition, two shunt interfacing converters using coordinated are used to realize the voltage and grid current harmonic compensation strategy [7-8].

The treatment of harmonics there are a lot of solutions and schemes [9-12]. A combined system constructed by SVC and SAPF is designed to improve the power quality of island microgrid based on economy and compensation performance [9]. Due to the capacity of semiconductor components is not high, a resonant impedance type hybrid active filter (RITHAF) is proposed for dynamic harmonic current suppression and high capacity reactive compensation in medium and high voltage systems [10].A DSP-based one-cycle control (OCC) filter applied to shunt active power has been presented [11], the proposed APF strategy employs input resistance to control the power factor. A voltage source converter (VSC)-based hybrid power filter compensator (HPFC) scheme with the dispersed wind energy interface is introduced for reactive power compensation and harmonic reduction in distribution grid networks [12].

In the example system of weak microgrid, the DC or AC microgrids with different grid structures are discussed. Low-voltage bipolar-type dc microgrids are proposed for connection with dc output type sources such as photovoltaic (PV) system, fuel cell, and secondary battery [13], moreover, one system for a residential complex is presented as an instance of the dc microgrid. A hybrid ac/dc micro grid and coordination control are proposed to reduce the processes of multiple dc–ac–dc or ac–dc–ac conversions in an individual ac or dc grid in [14], and a small hybrid grid has been modeled and simulated using the simulink in the MATLAB. The primary and secondary control level is provided thronging calculation of unbalance and harmonic distortion indices in [15].The content in [16],low-voltage smart microgrids can also exhibit considerable variation of amplitude and frequency of the voltage supplied to the loads, and a revision of control techniques for harmonic and reactive compensators is also expressed. A seamless operation mode transition control between grid-connected operation and stand-alone operation is proposed, and scenario of a microgrid based on master-slave control is considered [17].Others, a small-signal analysis is presented in [18] in order to analyze the system stability. A unified controller is designed concentrating on multibus microgrid system in [19], the controller contains inner voltage and current loops, also incorporates synchronization algorithms. The APFs are already installed in some microgrids consisting of wind generation and solar energy engineering and other systems, but the characters study and analysis of weak microgrid are not putted forward largely. In this sense, the power quality of weak microgrid is more sensitive and unstable normally.

Rest of the paper is organized as follows. Section 2 presents the control characteristic of APF, and the droop control is analyzed in weak microgrid especially under the isolated island. In section 3, the multistage control algorithm of weak microgrid is proposed. In section 4, the mutual influence and logical order between multistage control algorithm and transition loads shedding are explained. Section 5 is dedicated to the simulation results of the proposed scheme, and the conclusion of this paper is presented in section 6.

2. APF Control Characteristics in Weak Microgrid with Droop Control

The first paragraph after a heading is not indented (Bodytext style). The weak microgrid has many types of topology design and control criterions. The obvious characteristics of small inertia and sensitive load shedding are becoming more harmful to the distribution network or the power grid, so the problems of harmonics and nonlinear loads are the major factor for power quality especially under the isolated island. Fig.1 shows the implementation of typical weak microgrid taking oil field microgrid. For the sake of simplicity, all devices are assumed to satisfy the demands of system and have no more capacity in common, and there are different from power grid with large capacity.

The droop control of weak microgrid can distribute automatically power as synchronous generator, so it is can improve the reliability of load shedding. Hence, the droop control can be expressed as follows:

$$a(\omega^* - \omega) = P^* - P \tag{1}$$

$$b(E^* - E) = Q^* - Q \tag{2}$$

where, E is the amplitude of the inverter of voltage; ω is the frequency of output; P is the power of active; Q is the power of reactive; E^* and ω^* and P^* and Q^* are the reference of designed respectively. Fig.2 illustrates the droop control in weak microgrid. Where a is parameter of active power/frequency, and b is parameter of reactive power/voltage; u_d^* is d-axis voltage reference; u_q^* is q-axis voltage reference; u_d is d-axis voltage ; u_q is q-axis voltage; f_s is frequency reference; $f_s = \omega/2\pi$; U_{ref} is voltage reference.

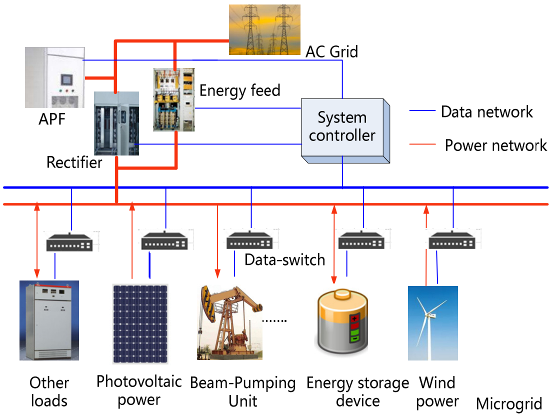

Fig.1 The topology of weak microgrid in oil field

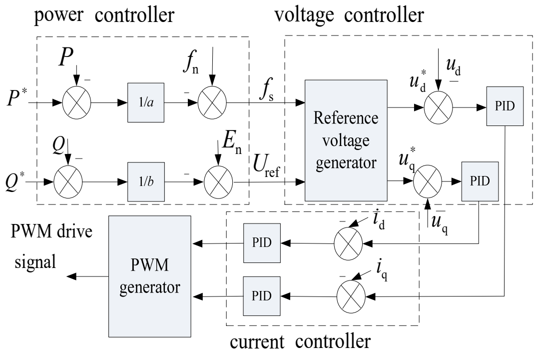

Fig.2 The droop control in weak microgrid

Because a large number of new source converters are connected to the microgrid or distribution network, the grid harmonic problem caused by the nonlinear equipment is becoming more serious, which will bring the fluctuation of reactive power, the increase of line loss, the voltage fluctuation and unbalance. Therefore, the active control cluster control strategy for active filter APF is needed, and it is necessary to be a requirement for large number of energy converters to access the distribution network or microgrid also. In fact, APF is a kind of harmonic suppressor. The main control principle is to measure the harmonic and reactive current, and then compensate the harmonic and reactive current in the power grid with reverse polarity current which given current.

The current controller used in the APF control method studied in this paper is shown in Fig.3. i_{aL} , i_{bL} , i_{cL} are currents of load, i_{qL} , i_{dL} , i^*_{qL} , i^*_{dL} are the load currents and the fundamental currents of the dq axis after the coordinate transformation, i^*_{af} , i^*_{bf} , i^*_{cf} are the given current after the harmonic reverse polarity, respectively.

The control characteristics of APF in weak microgrid with droop control and the principles of parameter adjustment are proposed as follow:

1- Considering the weak microgrid characteristics of dynamic performance and small inertia, the access mode of APF is not adaptive in parallel or cascade.

2- Because of the interaction between droop control and APF control, the parameters adjusting it is very likely to cause system oscillation, in order not to increase the cost of extra hardware, only one parameter can be adjusted at a time for inverter or APF.

3- The error range of frequency affects the ability of harmonic elimination directly, so the threshold can be adjusting dynamically.

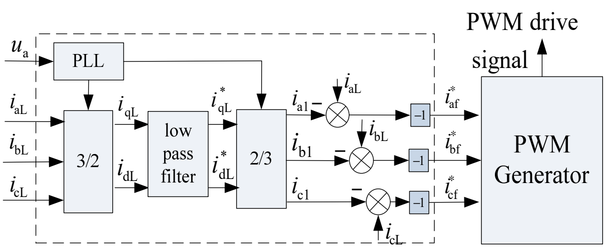

Fig.3 The droop control in weak microgrid

3. Multistage Control Algorithm and Characteristics of Load Shedding

3.1Multistage control algorithm

Fig.4 shows the flowchart of proposed control algorithm. In follow, more explanations and constraint conditions are represented in detail.

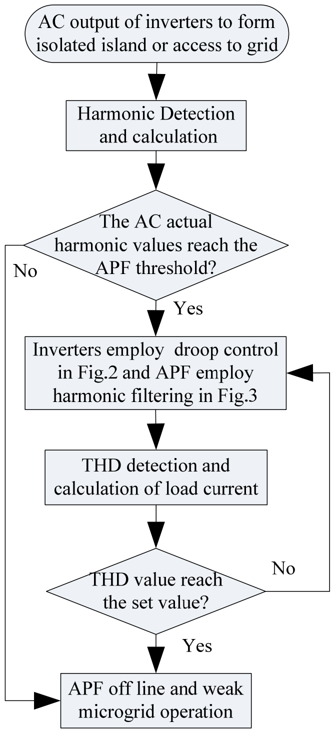

Fig.4. Flowchart of proposed control algorithm

3.2Characteristics of Load Shedding

In order to ensure the security of the microgrid, the characteristics of loads shedding are discussed which considering different degrees of importance. Peak values of voltage and current are the most important index, the constraint conditions for three phase inverter as follow:

$$\begin{cases} i_{\mathrm{q}} = \sqrt{I_{\max}^2 - i_{\mathrm{q}}^2} \\ \dfrac{U_{\mathrm{dcmax}}}{\sqrt{3}} \geq \sqrt{(U_{\mathrm{g}} + \omega_1 L_{\mathrm{g}} i_{\mathrm{q}})^2 - (\omega_1 L_{\mathrm{g}} i_{\mathrm{d}})^2} \end{cases} \tag{3}$$

where I_{gmax} is current limit of inverter, U_{dcmax} is DC bus voltage limit of inverter, i_{d} is d-axis current behind decoupling, i_{q} is q-axis current behind decoupling, L_{g} is reactor inductance, U_{g} Voltage vector amplitude, ω_1 is synchronous angular velocity of grid.

The peak shock caused by load shedding must be satisfied as follow:

1- If the decrease of P_{load} is far smaller than P_{inverter}, and the priority is low, so the volatility of power or peak current is ignored;

2- If the decrease of P_{load} is be close to P_{inverter}, and the priority is low, and the $I_{\mathrm{peak}} < I_{\mathrm{gmax}}$, then the shedding column can be executed. By contraries, if the priority is high or $I_{\mathrm{peak}} > I_{\mathrm{gmax}}$, then the shedding column cannot be executed.

3- In addition to the above two cases, system controller performs loads shedding in ramp.

4. Simulation Result

The simulation and analysis of weak microgrid is performed using Matlab/Simulink. The parameters of inverters and APF are as follow: nominal voltage 380V, nominal frequency 50Hz, APF capacity 20kVA, and load power 10kW, other parameters are not introduce to due to limited space. The droop control is verified through two inverters in weak microgrid(capacity less than 100 kVA under island operation). The curves of active power and reactive power are shown in Fig.5, and the curves of frequency are shown in Fig.6. The active power 10kWand reactive power 10kVar are divided averagely into two parts, the simulation result shows that the droop control meets the design requirements in Fig.2, and load shedding is verified at 1s.

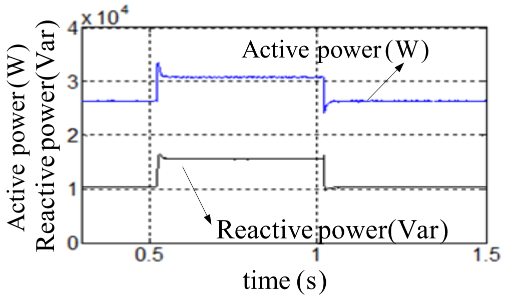

Fig.5. Curves of active power and reactive power

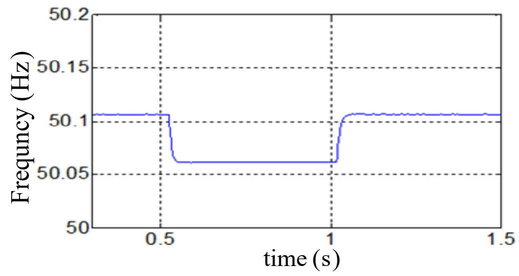

Fig.6. Curve of frequency in droop control

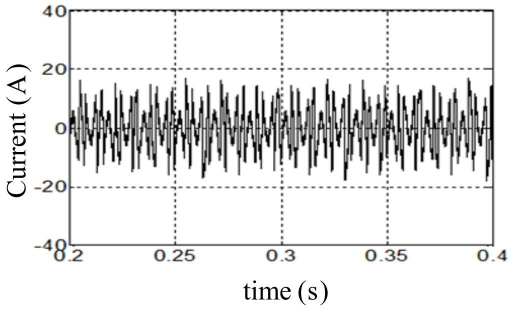

Fig.7. Curve of APF multistage compensation current

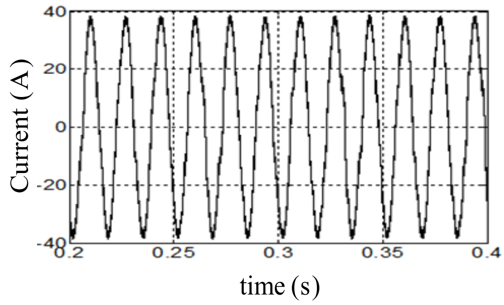

Fig.8. Curve of power grid current after compensation

5. Conclusions

In this paper, the control characteristic of APF and the droop control of weak microgrid are studied. The main conclusions of the paper as follows: (1) The multistage control algorithm is effective that improve the power quality and reliability based on APF; (2) The error range of frequency affects the ability of harmonic elimination directly, so the threshold should be adjusting dynamically; (3) In order to ensure the security of the microgrid, the scheme of loads shedding are required considering different degrees of importance, such as peak values of voltage and current device.

References

[1] Y Li , DM Vilathgamuwa , PC Loh. Microgrid power quality enhancement using a three-phase four-wire grid-interfacing compensator,IEEE Transactions on Industry Applications , 2005, vol.41, no.4, pp.1707-1719.

[2] A Mortezaei , M Simoes , M Savaghebi , J Guerrero , A Al-Durra.Cooperative control of multi-master-slave islanded microgrid with power quality enhancement based on conservative power theory,IEEE Transactions on Smart Grid , 2018,vol.9, no.4, pp.1-12.

[3] C Natesan,SK Ajithan,P Palani,P Kandhasamy. Survey on microgrid: power quality improvement techniques, ISRN Renewable Energy , 2014 : 1-7.

[4] M Prodanovic, T CGreen. High-quality power generation through distributed control of a power park microgrid. IEEE Transactions on Industrial Electronics., 2006, vol.53, no.5, pp. 1471-1482.

[5] He J, Li Y W, Munir M S. A flexible harmonic control approach through voltage-controlled DG–grid interfacing converters[J].IEEE Transactions on Industrial Electronics. 2012, vol.59, no.1, pp. 444-455.

[6] F Carastro ,M Sumner ,P Zanchetta. An enhanced shunt active filter with energy storage for microgrids, IEEE Industry Applications Society Meeting , 2008 :1-7.

[7] MM Hashempour , M Savaghebi , JC Vasquez ,JM Guerrero. A control architecture to coordinate distributed generators and active power filters coexisting in a microgrid, IEEE Transactions on Smart Grid , 2016 , vol.7, no.5, pp.2325-2336.
[8] J He ,B Liang ,YW Li , C Wang. Simultaneous microgrid voltage and current harmonics compensation using coordinated control of dual-interfacing converters. IEEE Transactions on Power Electronics , 2017 , vol.32, no.4 , pp.2647-2660.
[9] X Gao ,L Li , W Chen. Power quality improvement for mircrogrid in islanded mode. Procedia Engineering, 2011 , vol.23, no.5 , pp.174-179.
[10] L Fang , X Xu ,A Luo , Y Li , C Tu . Control strategy and characteristic analysis of hybrid active power filters with the resonant impedance principle. Journal of Power Electronics , 2012 , vol.12 , no. 6, pp.935-946.
[11] AS Lock , ERCD Silva ,ME Elbuluk , DA Fernandes.An APF-OCC strategy for common-mode current rejection. IEEE Transactions on Industry Applications , 2016 , vol.52 , no. 6 , pp.4935-4945.
[12] AM Sharaf , W Wang , IH Altas. A novel hybrid active filter compensator for stabilization of wind-utility grid interface scheme, International Transactions on Electrical Energy Systems, 2010 , vol.20 , no. 3, pp.306-326.
[13] H Kakigano , Y Miura , T Ise.Low-voltage bipolar-type DC microgrid for super high quality distribution,IEEE Transactions on Power Electronics , 2010 , vol.25, no.12 , pp.3066-3075.
[14] X Liu , P Wang , PC Loh, A hybrid. AC/DC microgrid and its coordination control,IEEE Transactions on Smart Grid , 2011 , vol.2 , no.2, pp.278-286.
[15] M. Savaghebi, A. Jalilian, J. C. Vasquez, and J. Guerrero, Secondary control for voltage quality enhancement in microgrids, IEEE Transactions Smart Grid, 2012,vol. 3, no. 4, pp. 1893-1902.
[16] P. Tenti, P. Matavelli and H. K. M. Paredes, Conservative power theory, a framework to approach control and accountability issues in smart microgrids, IEEE Transactions Power Electron., 2011,pp. 664-673.
[17] CS Wang , XL Li , L Guo ,YW Li. A seamless operation mode transition control strategy for a microgrid based on master-slave control,Science China.Technological Sciences , 2012 , vol.55, no.6, pp.1644-1654.
[18] JM Guerrero , JC Vasquez , J Matas ,M Castilla ,LGD Vicuna. Control strategy for flexible microgrid based on parallel line-Interactive UPS systems, IEEE Transactions on Industrial Electronics , 2009 , vol.56, no. 3, pp.726-736.
[19] Y Li , DM Vilathgamuwa , PC Loh, Design. analysis, and real-time testing of a controller for multibus microgrid system, IEEE Transactions on Power Electronics , 2004 , vol.19 ,no.5, pp.1195-1204.