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New Multi-function Composite Device Researching in Micro-grid

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Abstract

In the view of economic conditions to improve the Micro-grid quality, paper puts forward a new type multifunctional composite device. Combination the consistent characteristics of the main circuit structure from micro-grid energy storage battery and active power filter, combining the two components of multifunctional composite device, with corresponding control to achieve a variety of functions. This paper analyzes the working principle of the energy storage battery and active power filter, with the comparative analysis of its structural features, given the composite principle, derived the mathematical model of composite device, by containing harmonic suppression link power decoupled control method to achieve effective control. Simulation shows that the composite device effectively adjusting the active power and reactive power and harmonic suppression of Micro-grid, verify the rationality and validity of the composite device.

Keywords*: multi-function composite device, micro-grid, energy storage battery, APF*

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1. Introduction

As a supplement of large-scale power grid, Micro-grid plays a more and more important role in power system. But with numerous of nonlinear power electronic members coming into the Micro-grid, which will inevitably bring a large number of harmonics, the power quality has been seriously polluted. Active power filter (APF) is considered to be one of the most effective devices for harmonic suppression [1], which can track of harmonic suppression and reactive power compensation in real-time [2]. Installation of Energy storage battery can make Micro-grid from rigid to flexible, but its function has not been fully utilized in the practical application, even many times in the idle state. Therefore, APF and Energy storage battery research has very practical value and significance.

The Reference [3] gives a multifunctional control strategy of battery energy storage system, not only make the device maintaining Micro-grid power balance, but also control the harmonic current and harmonic voltage. It equivalent to the unified power quality conditioner role, but the implementation of device is very difficult; The Reference [4] makes the large capacity at power generator and the energy storage device into integration, using the power converter topology and switching strategy control, to increase and enhance the static var generator performance, the device is mainly used for High Voltage System. Reference [5] studies on superconducting coil and a lithium battery capacitance combined SVG-APF, which can prevent voltage collapse induced by Choke Domino Effect; it can also be harmonic elimination. But the device of DC side to the installation of the superconducting coil or lithium battery, which costs too much. Based on the research above, the energy storage battery and active power filter combination consider in a grid environment, so implementation "one machine can be more function", the device can balance the active power and reactive power, harmonic suppression purposes of Micro-grid. In addition, composite device can improve the energy storage battery utilization rate, and achieve together more easily, also, low costs.

2. Energy Storage Battery and APF

2.1. Energy Storage Battery

Figure 1 is a common structure of micro-grid, which mainly composed of a main generator, distributed power, energy storage battery and loads. Energy storage battery includes

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an energy storage device and an inverter bridge. When the micro-grid working connected in power network, it can absorb excess energy; When islanding operation, it can raise the dynamic response speed of micro-grid through the energy output, also keeps the balance of the active power and reactive power regulation of micro-grid, ensure a stable operation of power network [6].

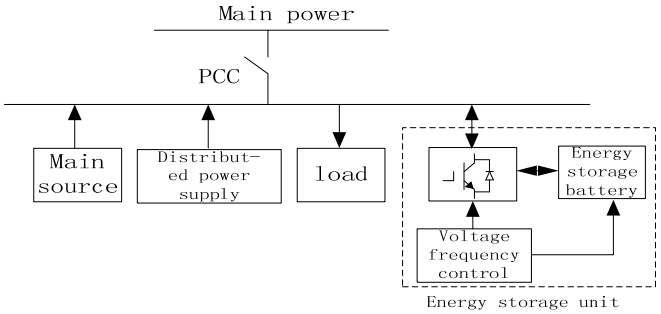


Figure 1. Structure of Typical Micro-grid

Do as an interface circuit which connects the energy storage device to micro-grid, inverter bridge can realize the energy storage device DC energy and electric energy flow between each other. Proper adjustment of converter to control the energy storage battery voltage amplitude and phase angle, then can realize the exchange of the active power and reactive power between energy storage battery and micro-grid system [7].

2.2. Active Power Filter

The working principle of Active power filter can be seen in the literature [8]. The APF structure of the main circuit is similar to the energy storage battery, the only difference is that the DC side of APF is capacitor, but the energy storage battery is DC power. Compared with energy storage battery, APF control is more complex, also its higher real-time requirement. First detecting signal of current and voltage, then a series of complicated operation, finally obtains the instruction signal, selecting a suitable modulation to drive inverter output a set of harmonic current, which is the same amplitude, contrary phase to the direction of the current signal to eliminate the harmonic.

3. Principle and Mathematical Model of Composite Device

3.1. Composite Device Principle

The main function of APF is restraining harmonics and compensating reactive power. Most cases, APF works in the characteristics of harmonic suppression, if compensating reactive power at the same time will cost more. From the analysis before, the output from energy storage battery is DC, it need a large capacity inverter to transform it into three-phase alternating current. Contrasting the two structures, the main circuit structure are similar, both including voltage inverter, DC side voltage and so on.

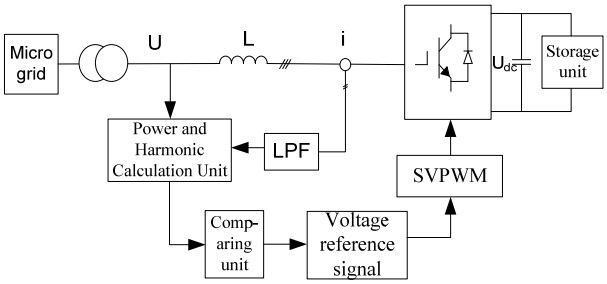


Figure 2. Frame Diagram of Composite Device

Figure 2 is a block diagram of the combined device. The energy storage battery and DC side capacitor are installed in parallel, then output by the inverter. Detection of the micro-grid voltage and current input to the Power and Harmonic Calculation Unit, calculate the corresponding signal, then the signal is compared with a given value, finally compare the output of the command signal that three-phase voltage reference signal, using voltage space vector control method control the inverters.

3.2. Composite Device Model

Figure 3 is a topology of the device, the structure can be built according to its model [11-12].

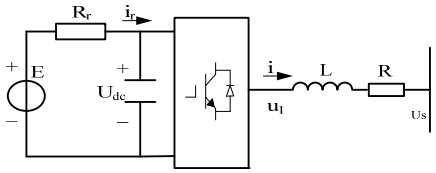


Figure 3. Structure of Composite Device Topology

Where, E is the battery voltage, Suppose R_r, I_r are the composite device equivalent resistance of internal and the output current, U_{dc} is voltage of smoothing capacitor C, L is output inductor.

More over, three phase bridge under the structure of two-level, hypothesis AC voltage and current respectively are U_{1a}, U_{1b}, U_{1c}, I_A, I_B, I_C, and modulation ratio $m=u_1/u_{dc}$.

From Kirchhoff's voltage law, there is:

$$U_{dc} = E - R_r i_r \tag{1}$$

Assume the initial phase of U_s is 0, phase difference between U_1 and U_s is δ. By voltage law at AC side, there is:

$$L\frac{di}{dt} = u_1 - u_s - Ri \tag{2}$$

By energy conservation, there is:

$$E i_r - R_r i_r^{\,2} - \frac{d}{dt}(\frac{1}{2}C U_{dc}^{\,2}) = u_{1a} i_a + u_{1b} i_b + u_{1c} i_c \tag{3}$$

From the above, we can obtain the actual DC side voltage equation.

$$\frac{dU_{dc}}{dt} = -\frac{m}{C} i_a \sin(\omega t + \delta) - \frac{m}{C} i_b \sin(\omega t - \frac{2\pi}{3} + \delta) - \frac{m}{C} i_c \sin(\omega t + \frac{2\pi}{3} + \delta) + \frac{E}{CR_r} - \frac{U_{dc}}{CR_r} \tag{4}$$

Where, ω is the angular frequency of d-q rotating frame, which is the same with the three-phase voltage.

The mathematical model for device is:

$$\frac{d}{dt}\begin{pmatrix} i_a \\ i_b \\ i_c \\ U_{dc} \end{pmatrix} = \begin{pmatrix} -\frac{R}{L} & 0 & 0 & \frac{\sqrt{2}m}{L} s_1 \\ 0 & -\frac{R}{L} & 0 & \frac{\sqrt{2}m}{L} s_2 \\ 0 & 0 & -\frac{R}{L} & \frac{\sqrt{2}m}{L} s_3 \\ -\frac{m s_1}{C} & -\frac{m s_2}{C} & -\frac{m s_3}{C} & -\frac{1}{CR_r} \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \\ U_{dc} \end{pmatrix} - \begin{pmatrix} \frac{\sqrt{2}u_s}{L}\lambda_1 \\ \frac{\sqrt{2}u_s}{L}\lambda_2 \\ \frac{\sqrt{2}u_s}{L}\lambda_3 \\ 1 \\ -\frac{E}{CR_r} \end{pmatrix} \tag{5}$$

Where, $s_1 = \sin(\omega t + \delta)$, $s_2 = \sin(\omega t - \frac{2\pi}{3} + \delta)$, $s_3 = \sin(\omega t + \frac{2\pi}{3} + \delta)$, $l_k (k = 1, 2, 3)$ is lagging δ angle than the corresponding S_k.

On the type of Park transformation and further calculation, can realize active and reactive expression [13].

$$\begin{cases} P = \frac{3\sqrt{2}}{2} U_s i_q \\ Q = \frac{3U_s^2}{2R} \sin 2\delta \end{cases} \quad (6)$$

4. Composite Device Control Strategy

Combined with the characteristics of the whole device, not only get the function of energy storage battery to control active and reactive power, but realize the harmonic suppression function of APF.

There are two operation modes for micro-grid: parallel operating and island operating. So, control methods device also divide two kinds. Figure 4 is the block diagram of P-Q decomposition control, which containing harmonic suppression links in micro-grid when working in parallel operation. P, Q in the diagram were active power and reactive power value after the calculation of the tested, i^*_{abc} is the signal of harmonic instruction current. Modulation mode select the Space Vector Pulse Width Modulation (SVPWM), the modulation can reduce switching loss and improve the utilization ratio of DC voltage [14].

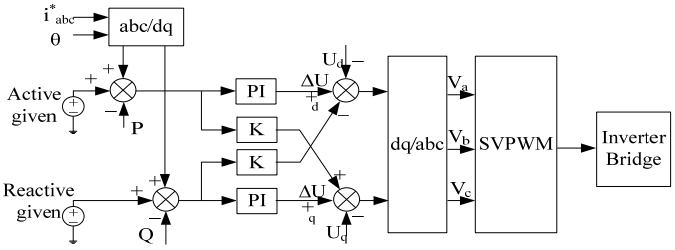


Figure 4. Block Diagram of P-Q Decoupling Control with Harmonic Suppression Links

5. Simulation Analysis

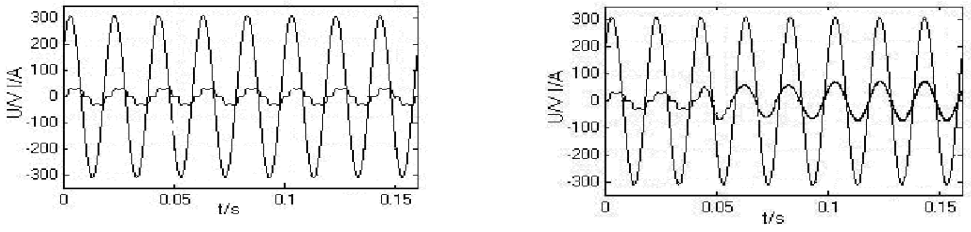
Simulation of the device is based on the MATLAB 7.1, The main circuit of simulation system is shown in Figure 2. For convenience, the energy storage battery is equivalent to the DC source when establish the simulation system, the system impedance is negligible. The simulation parameters are set as shown in Table 1.

Table 1. Simulation System Parameter

Parameter	value
Line voltage of the system u/V	380
Grid frequency f/Hz	50
Inductance L/mH	0.5
DC side capacitor C/uF	6800
Battery output voltage u/V	750
Resistance R/Ω	0.2

In the process of simulation, the control system based on the instantaneous reactive power method of i_p-i_q to detect the harmonic current, and generate a compensation current instruction, DC side voltage will not be controlled in the process of simulation.

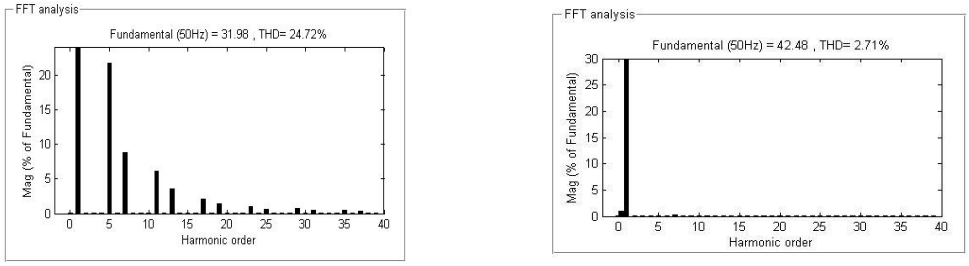
The simulation result of harmonic suppression is shown in Figure 5. From the diagram, the current of system is serious distortion before the 0.03s, current and voltage also does not have the same phase. Input device in the 0.03s, it can quickly track the current changes, realize harmonic compensation effectively. Current in 0.05s has essentially become a sine wave, and in the same phase with the voltage phase, the effect is obvious.



(a) before compensation (b) after compensation

Figure 5. Voltage and Current Wave Compensation and Simulation Images from Phase A

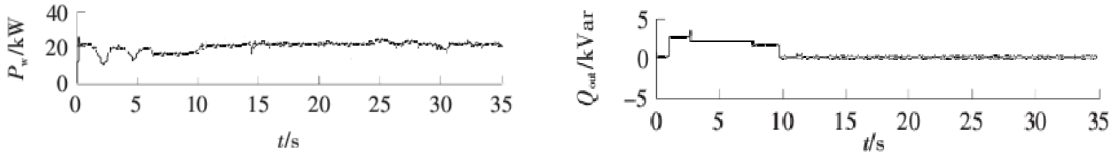
Figure 6 is the harmonic current compensation and spectrum analysis of phase A. From the graph we can see, the current distortion rate was 24.72% before the compensation, while the compensation can reduce to 2.71% after the compensation.



(a) before compensation (b) after compensation

Figure 6. Harmonic Current Spectrum Analysis before and after Compensation in Phase A

Figure 7 is the chart of adjusting micro-grid fluctuation effect by the composite device. Micro-grid occurs active power vacancy before the 10s, reactive power also fluctuate. The composite device inputs in the 10s, it can be seen that the active power fluctuate reduced significantly, basically stable at 20kW, reactive power regulation tends to 0.



(a) active power (b) reactive power

Figure 7. The Regulation of Active Power and Reactive Power Simulation Effect Diagram

6. Conclusion

A new multi-function composite device is researched under the condition of Micro-grid in this paper, which realize the energy storage battery connect to the DC side with active power

filter, to achieve a variety of functions. The device can not only control the micro harmonics, but balance the active power and reactive power of micro-grid. This paper from the energy storage battery and active power filter structure and the composite principle, derived the dynamic mathematical model of composite system, application of SVPWM control method, improve the precision and speed of control, simulation verify the composite device is reasonable and effective.

Acknowledgments

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