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The Research of Super Capacitor and Battery Hybrid Energy Storage System with the THIPWM

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Abstract: It has to be considered that dynamic performance of Super Capacitor and Battery hybrid energy storage system is poor and the output waveform of AC voltage distorted seriously. The Third Harmonic Injection PWM (THIPWM) with the three-level inverter, which has a excellent performance to improve the dynamic performance of the super capacitor and battery, gathers information from ends of the DC output voltage or current and the total current of the DC side to solve the problem of unbalanced neutral line voltage of three-level inverter .It also keeps super capacitor and battery controlled smoothly during the operation, and reduces the final output waveform distortion index. The simulation results verify the practicality and correctness of the three-level inverter topology and its control algorithm.

Keywords: Three-level inverter, Hybrid energy storage, Voltage unbalance, THIPWM.

1. Introduction

With the development of Microgrid technology, a single energy storage device can not meet the needs of users. The Hybrid Energy Storage System (HESS) will become a new focus in the future [1, 6, 7]. The development of Power Electronics Technology is faster and faster so that the multi-level inverter achieves higher power density, efficiency, static and dynamic performance.

HESS is necessary not only to ensure the stable operation of the two modes of the Microgrid, but also to ensure the smooth control of the two energy storage device, which always has the problem of the voltage waveform distortion and poor dynamic performance. Three-level inverter compared with two-level inverter can reduce the loss of the switching device, decrease the AC side harmonic pollution and improve the static and dynamic performance [3-4]. In summary, it presents a Third Harmonic Injection Pulse Width Modulation (THIPWM) method in this paper [8-10], using a three-level inverter instead of the two-level converter in the circuit to improve the performance indicators of system and the output voltage waveform. The common control algorithm of three-level inverter is the zero-sequence voltage injection and space vector modulation (SVM) PWM method [3, 4], which cause some problems that the DC voltage utilization rate is low, and the output voltage has a greater fluctuation when modulation ratio is fixed. However, if the modulated wave of the phase voltage is injected in the third harmonic, the DC voltage utilization will be improved effectively. At same time, the output voltage fluctuations will be reduced [2, 8]. The THIPWM is a method that superimposed sinusoidal modulation wave in the phase voltage with an appropriate third frequency doubling harmonic. For the reason, the output phase voltage of the inverter has the same harmonic components and phase after

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modulation, which can eliminate each other when they synthesize into the line voltage [9, 10]. Therefore, it can eliminate the harmonic components of the traditional harmonic injection left in the PWM and reduce the harmonic quality problems.

2. System Structure

The Microgrid composed of renewable energy generation unit and the energy storage device is shown in Fig. 1. The switch is used to control the connected/isolated mode of Microgrid. The power generation unit is used to generate electricity, and the hybrid energy storage device comprised of a super capacitor (SC) and a battery (BAT) is used to absorb/supply the power.

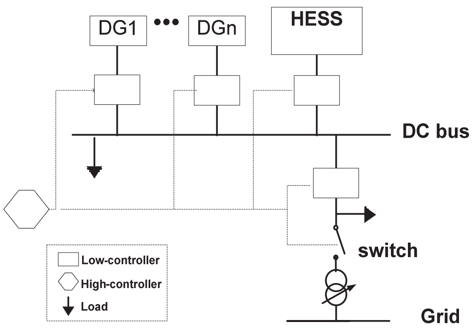

Fig. 1. The structure of the system.

3. Control Algorithm

3.1. Topology

The structure of SC and BAT HESS is shown in Fig. 2. The HESS is used to the voltage sources, which connected with the three-level inverter directly. The capacitor plays a role in filtering. The storage devices are used to filter the effect of the switch.

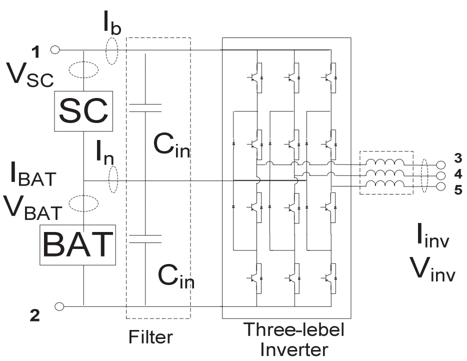

Fig. 2. The topology of three-level inverter.

3.2. The Detail of Algorithm

The control algorithm has to be designed to work well in the two modes, connected or isolated.

When the switch u , u_p locates on Position 1 (see Fig. 3), the system works in Island Mode. The Microgrid is controlled by U/f, and the collected AC voltage will be transformed to a vector under the two-phase rotating, V_d and V_q . There are two control loops in the control algorithm, an inner one for the current and an outer one for the voltage. The THIPWM generates the switching signals d_{abc} .

When the switch u , u_p locates on Position 2 (see Fig. 3), the system works in Connected Mode. The Microgrid is controlled by P/Q. The collected AC voltage will be transform to a vector to obtained active and reactive power under the two-phase rotating. The THIPWM generates the switching signals d_{abc} .

The carrier is an isosceles triangle. By sampling the BAT and SC at both ends of the DC output voltage and current and the total current of the DC-side, the current reference $i_{\text{BAT*}}$ can be calculated. Then it will be compared with i_{BAT} before modulating by PI controller. Time point of intersection is obtained between the wave and the carrier. So that, it can control the signal "on" or "off" and 27 switch states of three-level inverter [5].

The phase voltage is injected with the harmonic of time-frequency spectrum as follow:

$$\begin{aligned}&\mathrm{F}_1(wt) = \\&= 1.1547\sin(wt) + 0.1962\sin(3wt) \\&+0.0253\sin(9wt)-0.0162\sin(15wt)\end{aligned} \quad (1)$$

The specific construction method of the three standard sine waves u_{an} , u_{bn} and u_{cn} is as follow:

$$u_{\text{n}} = -\frac{\max(u_{\text{an}}, u_{\text{bn}}, u_{\text{cn}}) + \min(u_{\text{an}}, u_{\text{bn}}, u_{\text{cn}})}{2} \quad (2)$$

u_n as the injected harmonic wave is superimposed on the three-phase modulation, as follow:

$$\begin{aligned}u_{\text{a}} &= u_{\text{an}} + u_{\text{n}} \\ u_{\text{b}} &= u_{\text{bn}} + u_{\text{n}} \\ u_{\text{c}} &= u_{\text{cn}} + u_{\text{n}}\end{aligned} \quad (3)$$

u_{an} , u_{bn} and u_{cn} are the synthesis of injected harmonic of the time-frequency spectrum. By Fourier decomposition of the formulas (2), the same expression of the formula (1) can be obtained when taking the 15th harmonics. The formula (2) and the formula (3) are the full form of the harmonic of third-time-frequency spectrum, other forms are approximate.

V_{12} (see Fig. 3) is the DC bus voltage:

$$V_{12} = V_{\text{sc}} + V_{\text{BAT}} \quad (4)$$

P_{dc} (see Fig. 3) is the total power of the DC side:

$$P_{dc} = V_{sc} \cdot I_b + V_{BAT} \cdot I_{BAT} - V_{BAT} \cdot I_n \tag{5}$$

The power variation of the system is divided into two parts by the low-pass filter according to the frequency. The low-frequency is absorbed by the BAT; the high-frequency is absorbed by the SC. $P_{dc}*$ is the total power out of the low-pass filter.

The modulated signal offset limit module is used to control the current variation Δi_{BAT} (see Fig. 3). It can be calculated as follow:

$$\Delta I_{BAT} = I_{BAT}{}^{*} - I_{BAT} = \frac{P_{dc}*}{V_{BAT}} - I_{BAT} \tag{6}$$

In summary, the control algorithm of three-level inverter is as shown in Fig. 3.

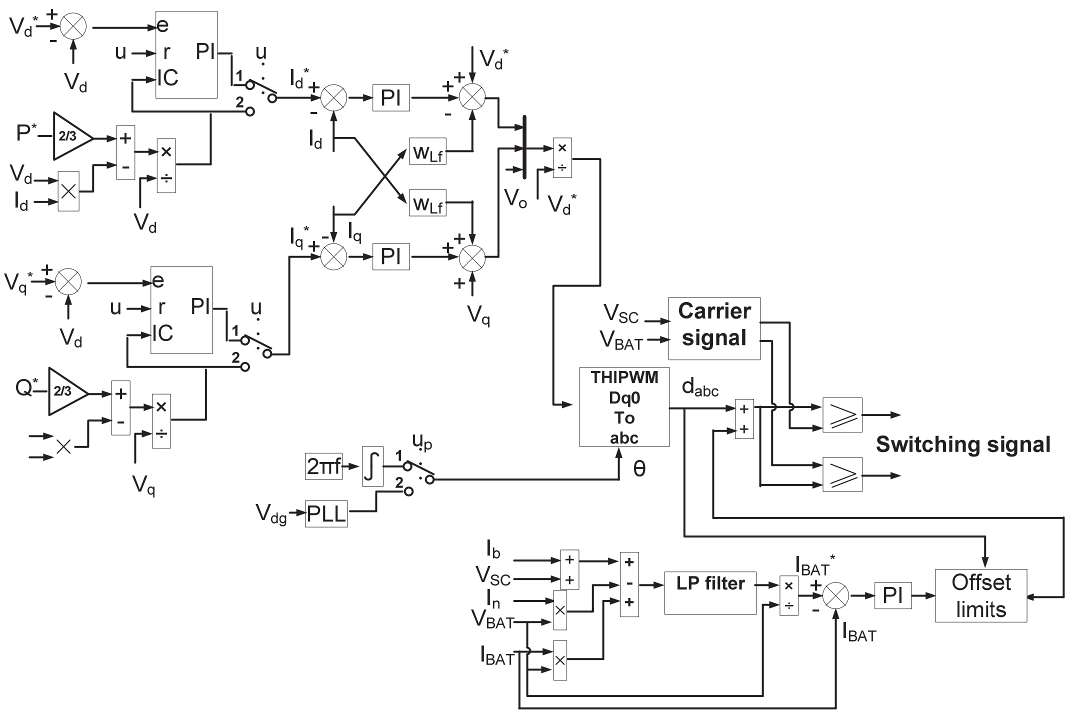

Fig. 3. The control algorithm of three-level inverter.

4. Simulink Result

Fig. 4 is a system simulation diagram. The power generation unit as a variable DC power supply is directly connected to the DC bus. The three-level inverter for converting alternating into direct current, and make the system controlled smoothly. The switch is used to control the connected or isolated mode of the Microgrid. The system contains two loads, one is the main load connected to the Microgrid, the other is minor load connected to the Grid.

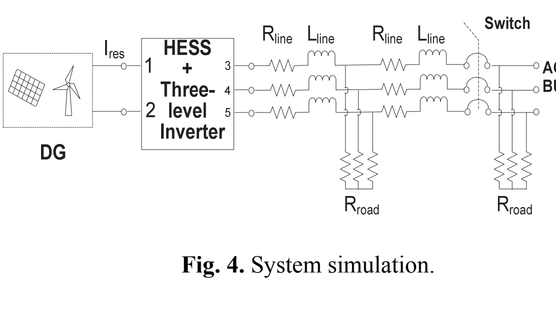

Fig. 4. System simulation.

The simulation parameters are shown as follows: the capacity of HESS is 15KVA (capacity of battery is 100A•h, the rated voltage is 240 V; the CS is 15 F, the rated voltage is 360 V), the load active power is 15 kW, reactive power is 20 kvar. R_{line}= 7.6 mΩ, R_{road}= 15 Ω, L_{line}= 66.53 μH, C_{in}= 10 mF.

The simulation results of the DC bus are shown in Fig. 5 indicates that the time when the switch is closed. It is clear that the THIPWM has improved convergence rates and less overshoot than SVM, and enhance the stability of system.

When separated from the Grid, the process of the current variation of the energy storage unit is similar both SVM and THIPWM (see Fig. 6 and Fig. 7). At the point 0, both of the current of inverter increases suddenly which causes the DC bus voltage reduced. However, the SC-side has a rapid response with a large peak current inject to the DC bus when it changed. The BAT-side is no any change (see Fig. 6). It can be proved that the SC can respond quickly to the DC bus in unexpected situations. The output current of BAT-side increased after the interference elimination, in order that the power can supplied to the new load. However, they also have some differences. Fig. 6 shows that the current of inverter with SVM has a larger oscillation compared with the THIPWM (see Fig. 7). The impact of the AC side voltage can be seen in both Fig. 8 and Fig. 9. Fig. 8 is the output phase voltage waveform with SVM, Fig. 9 is the output phase voltage waveform with THIPWM. It can be seen the fluctuations of the output voltage decreases. The THD is 3.68 %-4.96 % in SVM and 2.39 %-3.57 % in THIPWM.

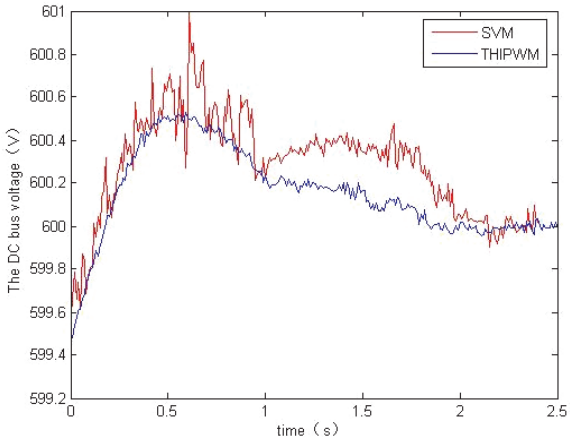

Fig. 5. The comparison of two control algorithms.

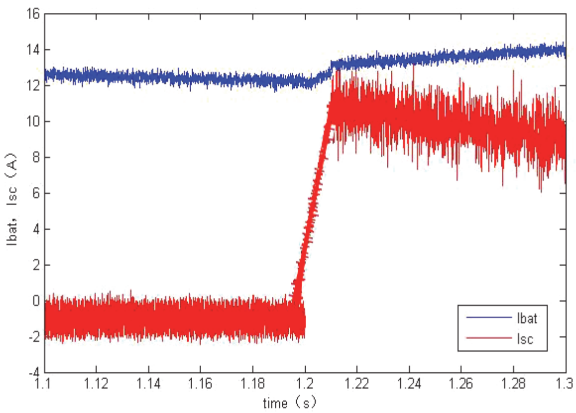

Fig. 6. Current waveform of SVM.

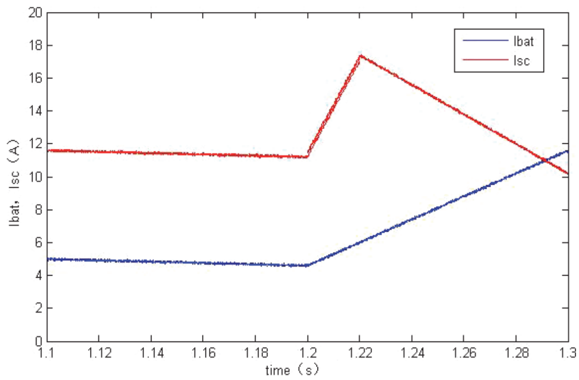

Fig. 7. Current waveform of THIPWM.

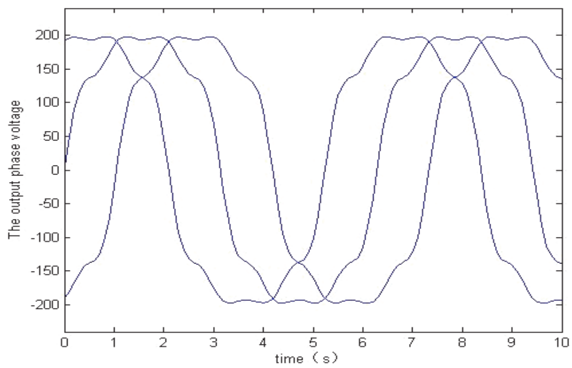

Fig. 8. Output phase voltage of SVM.

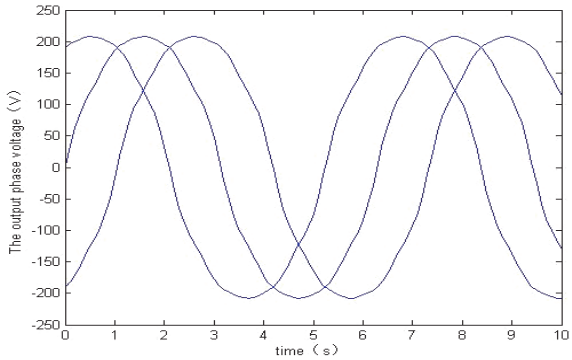

Fig. 9. Output phase voltage of THIPWM.

5. Conclusions

Single energy storage has been replaced gradually by the HESS to be a part of the Microgrid system. The use of HESS combines the advantages of the two energy storage devices to achieve complementary performance. However, we have to consider the control algorithm under two modes of Microgrid in order to make sure the smooth control process. Therefore, the THIPWM is put forward with the voltage-current double-loop control to minimize harmonics and improve the utilization and dynamic performance of the DC bus voltage. The use of the three-level inverter also improves the steady-state and transient performance of the system. The simulation results show that the THIPWM can not only fully meet the smooth control of SC and BAT but also the need of process of mode switching for energy storage in the operation of Microgrid.

References

[1]. Chen Wei, Shi Jing, Ren Li, *et al.*, Composite usage of Muti-type Energy Storage Technologies in Microgrid, *Automation of Electric Power System*, 34, 1, 2010, pp. 112-115.

[2]. Sun Xiaofeng, Gu Herong, Wang Liqiao, *et al.*, High frequency switching inverter and the grid, *China Machine Press*, Bei Jing, 2011.

[3]. Song Wensheng, Feng Xiao-Yun, A pulse width

modulation scheme with zero-sequence voltage injection for single phase three-level NPC Rectifier, in *Proceedings of the CSEE*, 31, 36, 2011, pp. 16-24.
[4]. Song Qiang, Liu Wenhua, Yan Gangui, *et al.*, A Neutral-Point Potential balancing algorithm for three-level NPC inverters by using an alytically injected zero-sequence voltage, in *Proceedings of the CSEE*, 24, 5, 2004.
[5]. Dou Zhenlan, Zhang Tongzhuang, Ling Yu, SVPWM and neutral-point-potential balance control of three-1evel NPC, *Electric Power Automation Equipment*, 28, 2, 2008, pp. 65-79.
[6]. Zhang Guoju, Tang Xisheng, Qi Zhiping, Application of hybrid energy storage system of super-capacitors and batteries in a Microgrids, *Automation of Electric Power System,* 34, 12, 2010, pp. 85-89.
[7]. Zhang Ye, Guo Li, Jia Hongjie, *et al.*, An energy management method of hybrid energy storage system based on smoothing control, *Automation of Electric Power Systems,* 36, 16, 2012, pp. 36-41.
[8]. A. Etxeberria, I. Vechiu, H. Camblong, J. M. Vinassa, Comparison of three topologies and controls of a hybrid energy storage system for microgrids, *Energy Conversion and Management*, 54, 2012, pp. 113–121.
[9]. M. F. M Sabri, M. H. Husin, I. N. Othman, Development of 5-bit, 4-Inputs PWM Generator on FPGA through VHDL Programming, in *Proceedings of the International Conference on Advances Science and Contemporary Engineering 2012*, *Procedia Engineering,* 50, 2012, pp. 486-493.
[10]. Zhao Guopeng, Han Minxiao, DC voltage design and corresponding compensation performance analysis or static var generator, *Electrical Power and Energy Systems*, 43, 2012, pp. 501-513.