

Research on Battery Energy Storage System Based on User Side

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Abstract. This paper introduces the effect of user side energy storage on the user side and the network side, a battery energy storage system for the user side is designed. The main circuit topology of the battery energy storage system based on the user side is given, the structure is mainly composed of two parts: DC-DC two-way half bridge converter and DC-AC two-way converter, a control strategy combining battery charging and discharging characteristics is proposed to decouple the grid side and the energy storage side, and the block diagram of the charging and discharging control of the energy storage system is given. The simulation results show that the battery energy storage system of the user side can not only realize reactive power compensation of low-voltage distribution network, but also improve the power quality of the users.

1. Introduction

User side power structure is changed in China with continuous development of economy. Power grid load peak-valley difference is increased gradually, which seriously tests safe and stable operation of power grid. In literature [1], it is proposed that distributed energy storage systems are configured in the user side for alleviating the problem of increased load peak-valley difference in the power grid and meeting the requirements of power rational allocation and power grid economic operation. In literature [2], grid side guide electricity prices are combined, and the user side is equipped with a power grid energy management system construction plan actively in order to reduce the cost and operate economically. Intermittent energy consumption and optimization as well as power grid peak cutting and valley filling functions are realized. In literature [3], economic model of user side energy storage device is established under the system of intelligent power grid, and the advantages of adding energy storage device on the user side under the intelligent power grid system is demonstrated through data analysis. In recent years, domestic user side new energy power generation grid connection is emerging gradually. Meanwhile, energy storage system should be configured. User side energy storage system becomes an important trend, and energy storage system becomes an important 'bridge' for connecting user side new energy power grid and grid-side.

In the paper is based on the design of user side energy storage system of lead-carbon battery. Since the cost of the energy storage system is mainly composed of energy storage battery and power



switching system, lead-carbon battery is selected as the medium for energy storage; fewer power electric devices are required in the power switching system. The power switching system is controlled simply through the decoupling controlled by DC/DC and DC/AC, constant current constant voltage charging control of energy storage battery and grid-side active flow direction and reactive compensation are realized.

2. Selection of energy storage battery

The energy storage system is mainly composed of an energy storage battery system and an energy storage power conversion system, wherein power electronic devices are utilized to realize energy two-way flow between the power grid and energy storage battery. The energy storage is an important basic part of the energy storage system.

Currently, energy storage battery categories mainly include lead-acid battery, lithium battery and vanadium battery, etc. Lead-acid battery technology is far ahead of batteries in other categories, and the price is cheap. However, it can not be well used because of its short lifespan and low energy density. The cost of lithium battery is high, the battery management system (BMS) with excellent performance is required for protection. Advantages of lead-acid battery and super capacitor^[4-5] are combined for lead-carbon battery on the basis of lead-acid battery (Tao Zhanliang, Chen Jun. Lead - carbon battery energy storage technology), thereby improving the service life of the battery, and the cycle frequency of battery can reach more than 3000 times under the 60% discharge depth (DOD). The lead-carbon battery is environment-friendly with recycling value and no pollution to the environment.

Table 1. Comparison of the lead-carbon battery and lithium battery

Item	Lead-carbon battery	Lithium iron phosphate	Item	Lead-carbon battery	Lithium iron phosphate
Weight	2.5-time lithium	Light	Safety	Safe	Fire danger
Volume	Large	Small	Pollution and recycling	Recycling value	No recycling value
Specific energy (Wh/L)	86	260	Battery management system	Unnecessary (monitoring)	Excellent
Cycle frequency	≥3000	2000~5000	Price	Cheap	2.5-time lead-carbon

3. Design of power conversion system

3.1. Topology analysis of power conversion system

Figure 1 refers to power conversion system topology. The energy storage battery side is equipped with a DC/DC conversion device. The grid-side is equipped with a AC/DC two-way inversion device.

Power conversion system is divided into two parts: DC/DC two-way conversion circuit unit and DC/AC two-way inverter circuit unit. Conversion power control circuit of the energy storage system can not be directly equipped with a DC/AC two-way inverter structure. Since the inverter circuit output voltage is limited by the inverter circuit structure, the inverter output voltage is not in conformity with the requirements as a result. Meanwhile, the loss of the device will be increased. A grade I DC/DC conversion circuit is added in the DC/AC inverter circuit, which is advantageous to energy storage battery management and DC high voltage bus voltage stability.

The power conversion system mainly includes two operation modes: AC-DC-DC charging mode and DC-DC-AC discharge mode. The AC-DC DC charging mode refers that the energy of the power grid is stored in the energy storage battery. The AC current is rectified and inverted into high-voltage DC current by DC/AC inverter circuit. High voltage DC current is input into the energy storage battery pack through DC/DC conversion module. In the DC-DC-AC charging method, the

energy of the energy storage battery is input into the high voltage DC bus through DC/DC module, and then inverter grid connection is carried out.

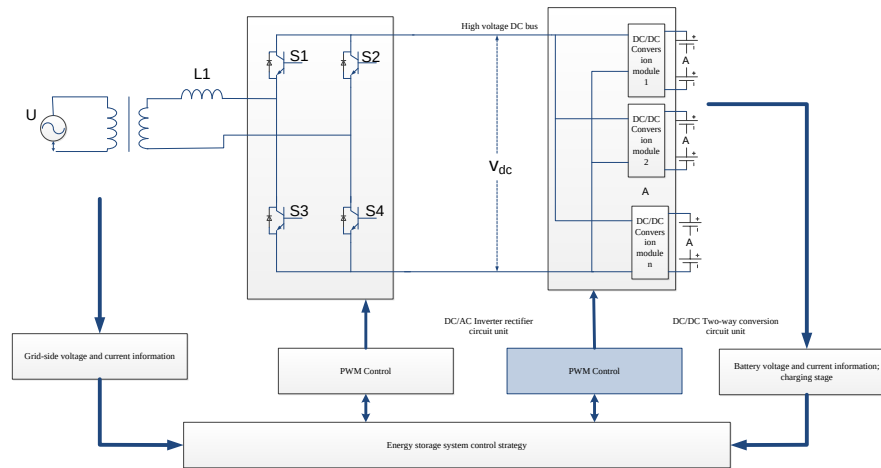


Figure 1. Topology of power conversion system

3.2. DC/DC two-way conversion circuit design and its working principle

DC/DC two-way switching circuit has two-way double-bridge structure and multi-level structure. However, the control algorithm is complex and the cost is high due to excessive switching devices. In the design, a DC/DC two-way half-bridge structure is adopted as shown in figure 2.

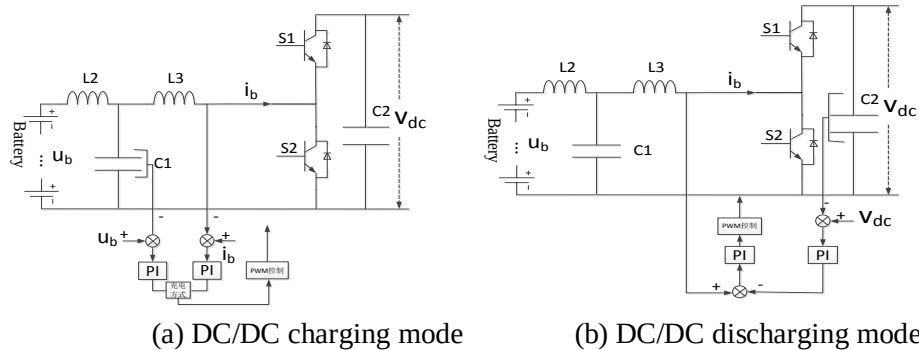


Figure 2. DC/DC two-way half-bridge structure

Independent PWM control is adopted for DC/DC two-way half-bridge structure, which is more reliable than PWM complementary control. PWM complementary control may lead to synchronous conduction of upper and lower bridge arms. Independent PWM control improves the reliability. When battery energy is transmitted to the high voltage DC bus, S1 is conducted, S2 is closed, and DC/DC half bridge structure is changed into a Boost circuit. When the energy storage BATTERY is charged, S1 is closed, S1 is conducted, and DC/DC half bridge structure is changed into a step-down Buck circuit.

DC/DC two-way half-bridge charging control: since constant current-constant voltage (CC - CV) charging mode is always adopted in energy storage battery charging, the charging cycle can be reduced, and the service life of energy storage battery can be extended conveniently. As shown in figure 2 (a), U_b is the reference value of battery voltage, and i_b is the reference value of battery current. In DC/DC charging control, constant current charge and constant voltage charge can be selected according to the charging mode. The current deviation is used for controlling PWM wave during constant current charging. The voltage deviation is used for controlling PWM wave during constant

voltage charging. DC/DC two-way semi-bridge discharge control: figure 2(b) shows that V_{dc} is DC bus voltage. In DC/DC discharge control, current inner loop control and voltage outer ring double-loop control are adopted. The deviation generated by the DC bus voltage is adjusted through PI, which is used for controlling PWM valve with the input end current of the battery.

3.3. AC/DC two-way switching circuit design and its working principle

When DC/AC is operated in the rectifier mode, the equivalent circuit diagram of grid side ac-dc current transforming link is shown in figure 2. In figure 3, U_s , U_{L1} , U and I_{L1} respectively represent AC side voltage, inductance voltage, grid-side voltage and ac side current.

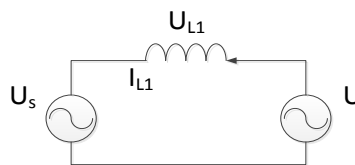


Figure 3. Equivalent circuit diagram of AC-DC current transforming link

It is assumed that the AC side has the same frequency as the AC power grid under the condition of stable operation (the influence of harmonic factor is ignored). The mathematical expression between U and U_s is shown as follows:

$$\dot{U} = j\omega L_1 \dot{I}_{L1} + \dot{U}_s \quad (1)$$

When U and U_s have the same frequency, I_{L1} is the sine wave with the same frequency as the power supply. Under the condition that the electromotive force U voltage of the AC power grid is constant, I_{L1} amplitude and phase are only determined by U_s amplitude and its phase difference with U . The phase difference between I_{L1} and U can be changed by changing the amplitude and phase of U_s , namely the energy transmission direction is changed. Four special circumstances of phase difference between I_{L1} and U are presented in the following figure [6].

The phase difference between I_{L1} and U is 0° in figure 4 (a). The converter absorbs active power from the grid side. In addition, since the included angle is 0° , power factor is 1. The phase difference between I_{L1} and U is 90° in figure 4(b). The converter sends out reactive power to the grid side. In figure 4 (c), the phase difference between I_{L1} and U is 180° , the converter sends active power to the grid side. In figure 4 (d), the phase difference between I_{L1} and U is -90° , and the converter absorbs reactive power from the power grid side.

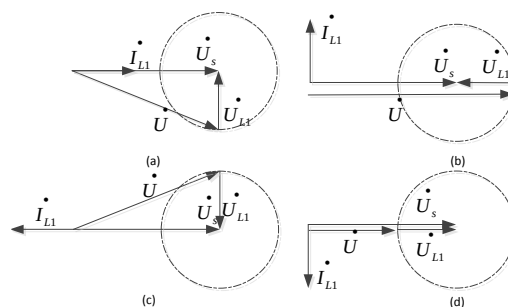


Figure 4. Vector relationship between I_{L1} and U

Reactive power compensation on the grid side is realized in figure (a) and figure (b) through controlling the relationship of phase angle of U and I_{L1} . Charging and discharging of unit power factors on the grid side are realized in figure (b) and figure (d).

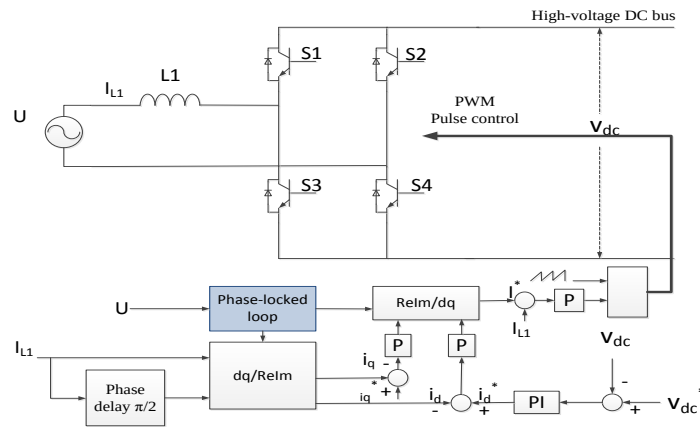


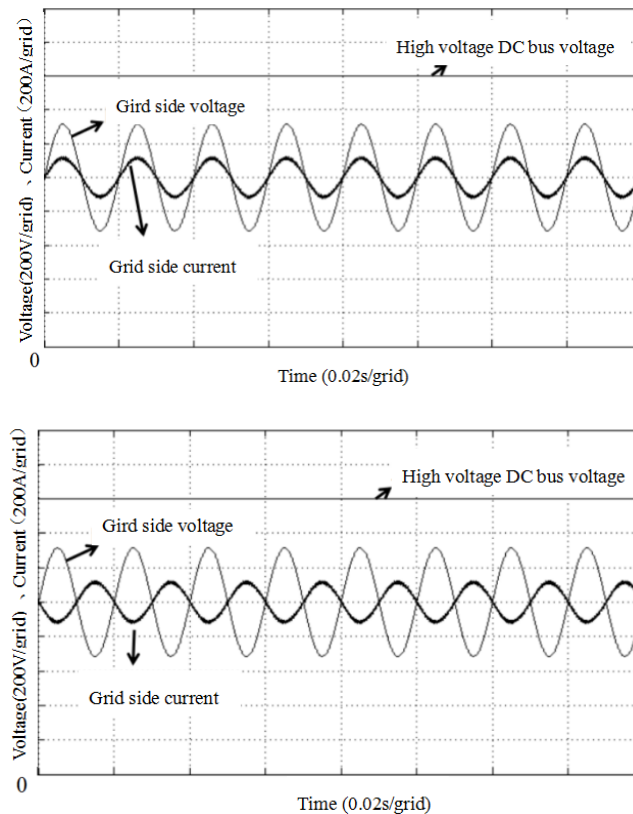
Figure 5. AC/DC rectifying transformation structure

A orthogonal component should be simulated in order to facilitate PI regulation and control of three phase VSR under the synchronous coordinate system. In AC/DC rectifier control link, the collected AC current I_{L1} phase is delayed for 90° to form the required quadrature component. The grid-side measured voltage U , current I_{L1} , simulated current value are converted into active current component i_d and reactive current component i_q through rotational coordinates. The active current component reference variable i_d^* can be obtained from the difference value between the high voltage DC bus DC voltage V_{dc} and the given DC bus voltage V_{dc}^* by PI regulation. Meanwhile, an reactive current component i_q^* is given. Finally, it is measured with the grid side to obtain the difference of the current value I_{L1} . PWM pulse control is formed.

4. Simulation and experimental waveform analysis

The control strategy of user side energy storage system is simulated and verified by Matlab simulink module. Parameter setting of simulation model: the grid-side AC voltage is 380V, the grid-side inductance is 3mH, the filter capacitor is 40 μ F; The voltage of high voltage DC bus is 600V. The DC voltage of the battery pack is 36V, the battery HF inductance is 0.1 mH, and the filter capacitor is 2000 μ F.

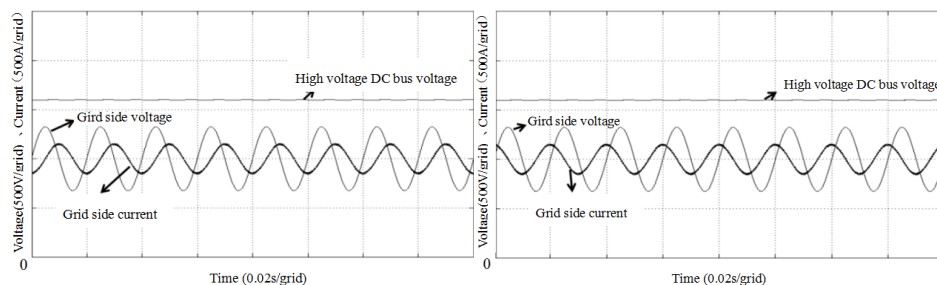
Figure 6 shows a single power operation simulation drawing of power conversion system; FIG. 6 (a) shows a single power charging operation simulation drawing of the Lead-carbon battery. The figure shows that the AC side voltage and AC side current are the same. Figure 6 (b) shows the single power discharging operation simulation drawing of the lead - carbon battery. The figure shows that the phase difference of the AC side voltage and AC side current is 180° .



(a) Lead-carbon battery single power charging operation (b) Lead-carbon battery single power discharging operation

Figure 6. Single power operation stimulation drawing of power exchange system

Figure 7 shows the simulation diagram of reactive power compensation operation of power switching system; Figure 7 (a) shows that the power switching system absorbs inductive reactive power from the grid side, which does not absorb active power. The grid side current in front of grid-side voltage is 90° . Figure 7 (b) shows that the power switching system absorbs capacitive reactive power from the grid side, which does not absorb active power. The grid-side current after the grid-side voltage is 90° .

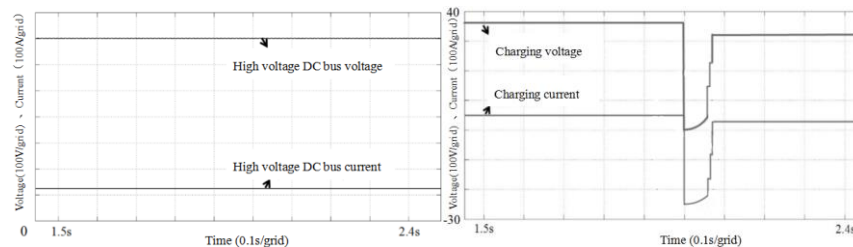


(a) Grid-side absorbs inductive reactive power for operation (b) Grid-side absorbs reactive power for operation

Figure 7. Reactive power compensation running simulation drawing of power exchange system

Figure 8 shows the simulation drawing of the power exchange system for charging the energy storage battery. Figure 8 (b) shows the voltage and current of high voltage DC bus; Figure 8 (b) refers to the constant current charging and constant voltage charging in the charging side. The simulation

lasts for 2s. The charging mode is changed, 5A constant current charging is converted into 32V constant voltage charging. The battery charging curve shows that the battery CC-CV charging mode is controlled through the power exchange system.



(a) High voltage DC bus voltage and current (b) Charging voltage and current of battery

Figure 8. Operation simulation drawing of power exchange system for charging energy storage battery

5. Conclusion

In the paper, 5kW user side energy storage system is designed. The energy storage medium is analyzed in the aspects of economy, security and reapplication. Lead-carbon battery is adopted as the energy storage medium. A virtual phase circuit method is adopted for vector respective control of active component and reactive components of the grid connection current by establishing the topology of user side energy storage system, thereby realizing the control method of reactive power and reactive power decoupling. The simulation experiment results show that the voltage of the high voltage bus user side of the energy storage system is stable with low fluctuation. Four quadrant operation of single-phase grid connection inverter can be realized by the control method, single power charging and discharging can be realized for the energy storage battery. Reactive compensation can be realized on the grid side, thereby improving the user side power supply quality and user power consumption satisfaction. In the paper, a set of feasible user side energy storage system design plan is proposed aiming at the user side energy storage system design of the lead - carbon battery. Feasibility is provided for the access of distributed new energy. It also has certain reference significance for constructing energy storage system of large industrial users.

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