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Study on Micro-Grid Power Storage Converter

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Abstract

In the micro-grid, power storage converter is played as a interface between the battery pack and grid electricity storage device, to achieve a two-way exchange of energy. In this paper, the research and development of power storage converter can realize multiple sets of independent control of the battery, flexible configuration of the system capacity and flexible cutting of the battery pack. Structural design uses multi-level topology. It contains 15 non-isolated half-bridge parallel bi-directional DC / DC converter. Control strategy designed to be grid inverter adopts SVPWM control technology. DC / DC converter designed to improve the droop control strategy based on environmental design. The high-power energy storage converter product this paper designed have completed the charge and discharge related droop control and Full power grid experiment. The charge and discharge currents accurately track the current instruction and the grid efficiently is more than 95%. It verified the rationality and effectiveness of the design and is the important part of the optical storage and solar power generation systems.

Keywords: *Battery energy storage system, Energy conversion system, Droop control, DC / DC converter*

1. Introduction

With the great development of new energy industry, now there have been some new problems and challenges highlighted in the new energy generation and net consumptive problems. Wind, solar energy is an intermittent presence of random, intermittent characteristics, resulting in artificially difficult to accurately predict power, winds power, and photovoltaic power plants is difficult to provide continuous and stable power [1-7]. In wind farms, photovoltaic power plants around supporting the energy storage system can be added to balance wind power, active power output of photovoltaic power fluctuations, the power output of new energy curve as expected output, so you can minimize the difficulty of grid scheduling for more new energy generation and networks to create conditions for the smooth[8-9].

With the rise of micro-grid technologies, whether the Micro-grid system has enough capacity to accept a variety of disturbed power is the decisive factor of system interconnection efficiency. As energy storage system of the micro grid, batteries play an important role in micro grid interconnection technology. Battery exchanges energy with power grid by energy conversion system, and stored energy or release energy in accordance with the actual situation. Energy conversion system plays a role as a connection between the battery and power grids as the interface to achieve the two-way exchange of energy between the battery and power grid. The essence of the energy conversion system is the storage of high-power converter[10-15]. The energy storage converter this paper researched and developed can realize separate control of multiple sets of batteries and freely configurable switching capacity. DC / DC converter using droop control had overcome the uncontrollable problem of unable to create intermediate DC voltage and charge-discharge voltage when the off-grid work in the conventional constant-current control and fixed DC bus voltage control. Eventually developed products

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verified the rationality of the design by droop control the charging and discharging experiments and grid efficiency experiment.

2. Structure and Characteristics of Energy Storage Converter

Battery energy storage system architecture diagram shown in Figure1, the system mainly by the battery and management systems and energy conversion system (Power Conversion System, PCS) two parts.Energy conversion system with battery power by switching energy, according to the actual need to store energy or release energy. As the energy conversion system interface between the battery pack and the power grid is actually high-power power electronic converters, later in the energy conversion system (PCS) refers specifically to the storage converter.

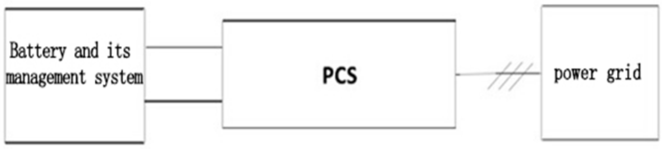


Figure 1. Battery Energy Storage System Structure

In practical applications, due to the single cell voltage is low, a small capacity, so that the battery energy storage system by a plurality of cells are connected in parallel to string together, constitute the battery clusters to meet the energy storage system and the battery voltage capacity requirements. In the discharge state, the battery pack DC power, the converter through an energy storage transformation, the DC power back into AC power grid[16-20]. Similarly, in the charged state, the storage of energy conversion by the converter, the AC power is converted into direct current energy to charge the battery. By storage converter control strategy designed to achieve the charge of the battery pack / discharge management, network-side load power smoothing, islanding operation and other functions. After 90 years of the 20th century, with the development of power electronic devices in order to represent IGBT switching device has a drive power is small, fast switching speed, on-state voltage drop of small features, a modern power electronics technology leading components, making high voltage level, the application of large capacity PCS device becomes a reality[21-25]. Storage converter topologies are many kinds of forms more varied, but are mainly converter system constituted by a plurality of switching devices. Accumulator acts as a converter connected between the battery and the power grid interface between the battery and the energy to achieve bidirectional power switching, in the form of more varied. According to its topology, can be divided into single-stage and multi-stage type categories.

3. High-Power Energy Storage Converter Topologies

Single stage topology storage converter, which only consists of a DC / AC link, namely a PWM rectifier. Its working principle is, the energy stored in the battery pack through a PWM rectifier DC-AC inverter, converting alternating current feedback network; conversely AC power AC-DC rectifier be changed by the PWM rectifier is converted into direct current stored in the battery group [26-28]. PWM rectifier can operate in the state rectifier or inverter state in order to achieve two-way flow of power. In order to ensure the normal operation of the PWM, generally parallel to constitute a single battery string voltage is high enough batteries. Advantages of single-stage topology is a simple structure, the control method is simple, energy storage converter low loss, high energy conversion efficiency. However, in practical applications, a single-stage topology, there are some drawbacks:

1) The lack of storage capacity of the system configuration flexibility.

2) The battery voltage operating range is small.

3) The flow characteristics of the battery pack are bad.

Single-stage type storage converter can control the entire battery charge / discharge current of the total, the control unit cannot be set battery charge / discharge current due to the internal resistance of the battery between the groups do not completely equal, the entire battery charging / total current discharge is unevenly distributed between the respective battery groups, causing the flow characteristics are not good between the battery pack.

Since the capacity of the single stage type energy storage converter topology cannot be changed at any time, the energy storage system output voltage is unstable and poor flow characteristics, as a part of the light complementary storage system.

The energy storage this paper researched and developed need to realize the multiple sets of independent control of the battery, flexible configuration of the system capacity and flexible cutting of the battery pack, so storage converter designed for multi-level topology. The storage converter contains 15 parallel bi-directional DC/DC converters and a PWM converter. Compared with only a DC / AC aspects of a single-stage topology, the multilevel topology has one more DC/DC link. Multi-stage type storage converter (as shown in Figure 2) first let the DC power the battery produced go through the DC/DC converter to boost the voltage, and then supply PWM converter as a DC-side input voltage, input power after the inverter. Otherwise, the AC power grid generated will be rectified to a DC voltage through PWM converter, then buck through the DC/DC converter to get the charging voltage of the battery. This is designed to make the working voltage through the DC/DC conversion have a wide range of operation.

The advantage of this topology is that the battery pack voltage operating range is wider. After the battery voltage DC / DC converter to convert the voltage rating of the battery required reducing the operating voltage range, the battery can achieve a wide range of operation. Compared with the single-stage type, the presence of multi-stage topologies weaknesses, including: a converter the increased DC / DC link, the energy conversion efficiency of the entire system is reduced; the same time as an increase in the device, consider the DC / DC coordinate converter, PWM rectifier fit between problem, increase the complexity of the control.

In the multi-stage topology, based DC / DC converter topology types can be divided into non-isolated topology and isolated topologies two categories. Isolated topology contains high frequency transformer, DC / DC converter through step-up transformer, and can achieve electrical isolation between the battery pack and the power grid, but due to the introduction of high-frequency transformer reduces the energy conversion efficiency, while increasing converter design cost. Isolated bidirectional DC / DC converter including topology, and an organic combination of these topologies Forward, flyback, push-pull, bridge and so on. Isolated topologies each have their own characteristics, and have different scope.

Non-isolated since no high-frequency transformer, its structure is simple, less desired device, small size, low cost, high reliability and high overall energy conversion efficiency, control is relatively simple. However, their existence ratio is not too large, the battery pack cannot be electrically isolated from the grid, particularly when the grid is a problem that may interfere with cell passages, is not conducive to stable operation of the safety of the battery pack. Non-isolated bidirectional DC / DC converters typically include half-bridge, full-bridge type, and three main cascade topology.

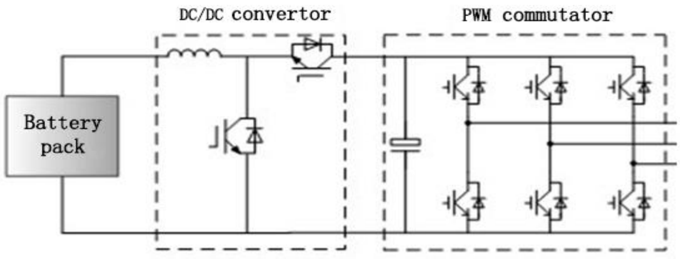


Figure 2. Double Stage Converter Typical Topology for BESS

The DC/DC converter this paper researched and developed adopts non-isolated topology and contains high frequency transformer. DC/DC converter boosts the voltage through transformer and can realize the electrical isolation between the battery and power grid at the same time. Each set of batteries connected to the DC side in the middle by a bi-directional DC/DC converter respectively, then filtered through DC/DC links and connected to the grid after the transformer. This topology has some advantages:

(1) Can access multiple sets of batteries.Each battery pack can realize the multiple set of battery charge/discharge control independently through independent DC/DC link control.

(2) The battery pack has wide working voltage range.

(3) Circulation between the battery pack can be avoided.

(4) Can realize the flexible configuration of the entire battery energy storage system capacity and flexible switching of the battery pack.

4. High-Power Energy Storage Converter Control Strategy

Storage converter control strategies for energy storage converter control method of each part, we study the constant current control, given the DC bus voltage control, droop control three control strategies, and finally selected the droop control strategy. Battery energy storage system consists of DC / DC control and DC / AC controls two parts. The need for both control methods were designed to coordinate both control objectives through the upper controller, so that the two good cooperation in order to implement the entire storage converter control strategy.

Grid converter (three-phase VSR) the main control objectives are twofold: First, to ensure the stability of the intermediate DC voltage, DC link voltage stability is a prerequisite for PWM converter to work properly, which is achieved by controlling the input current of; the second is to ensure good input specific, nearly sinusoidal input current that is small harmonic content to meet the power factor requirements.

At present, the most commonly used three-phase VSR control strategy is based on the dual-loop control coordinate transformation theory, methods based on different coordinate directional control strategies can be divided into grid-side voltage and based on virtual flux based control strategy. Network-based control strategy to estimate and side voltage grid voltage detection is based, including voltage-oriented control (Voltage oriented control, VOC) and Direct Power Control (Direct power control, DPC).

Directional control voltage dual closed-loop structure of the intermediate DC voltage outer ring, the inner side of the current network to the grid voltage space vector direction as a reference, and directional control of the current direction, the closed-loop output can and space vector pulse width modulation (SVPWM) interface, after the conversion of the pulse width modulation pulse signal.

Grid converter (three-phase VSR) in two-phase synchronous rotating coordinate system (d, q) under the current equation is:

$$\begin{cases} u_d = e_d + \omega L i_d - R i_d - L \dfrac{d i_d}{dt} \\ u_q = e_q - \omega L i_d - R i_d - L \dfrac{d i_q}{dt} \end{cases} \quad (1)$$

Grid inverter SVPWM control technology is based on the converter to control the space voltage vector switching converter of a new control method, which once came to widespread attention, has become a hot topic. Three-phase voltage-type PWM rectifier bridge arm has turned upper arm or lower arm turned two states, the state of the switching device and the output voltage as shown in Table 1.

Table 1. Voltage Vector in Different Switch State

S_a	S_b	S_c	U_{a0}	U_{b0}	U_{c0}
0	0	0	0	0	0
0	0	1	$-\frac{1}{3}U_{dc}$	$-\frac{1}{3}U_{dc}$	$\frac{2}{3}U_{dc}$
0	1	0	$-\frac{1}{3}U_{dc}$	$\frac{2}{3}U_{dc}$	$-\frac{1}{3}U_{dc}$
0	1	1	$-\frac{2}{3}U_{dc}$	$\frac{1}{3}U_{dc}$	$\frac{1}{3}U_{dc}$
1	0	0	$\frac{2}{3}U_{dc}$	$-\frac{1}{3}U_{dc}$	$-\frac{1}{3}U_{dc}$
1	0	1	$\frac{1}{3}U_{dc}$	$-\frac{2}{3}U_{dc}$	$\frac{1}{3}U_{dc}$
1	1	0	$\frac{1}{3}U_{dc}$	$\frac{1}{3}U_{dc}$	$-\frac{2}{3}U_{dc}$
1	1	1	0	0	0

Table, we can see that the analysis of three-phase voltage-type PWM rectifier AC side voltage different switch combinations can use a space voltage vector in the two-phase stationary coordinate system (α , β) under representation. Eight kinds of switching states corresponding to the eight basic voltage vectors, wherein the vector is a modulo six non-zero voltage vector $2U_{dc}/3$, two vectors are zero vectors.

High-power energy storage converter control contains grid converter control and DC / DC converter control link. Grid inverter SVPWM control technology has been relatively mature, here we don't make detailed introduction. This paper mainly introduces the droop control strategy for DC/DC converter technology.

DC/DC converter can keep a constant charge/discharge current according to the instruction in the traditional constant current control mode. But the intermediate dc voltage is maintained by the grid converter, the grid converter is unable to establish the intermediate DC voltage when off-grid. That is to say,it cannot be applicated in off-grid state. The charge/discharge current is in a state of uncontrollable in another kind of dc bus voltage control method. Aiming at the problems of the above two methods, this paper has designed the droop control method for bi-directional DC/DC converters .This method can realize the off-grid operation and ensure a relatively controlled charge/discharge current simultaneously.

Droop control principle is based on "the U_{dc-p} " droop curve designed to determine the output power of DC/DC converter. Droop control contains the sagging charging mode and the vertical discharging mode. In the case of the battery voltage knowable,to determine the output power of DC/DC converter is to determine the instruction value of output current.

Droop control strategy is designed by prolapsed curve to get different current instructions based on different. As changes, the current instruction is constantly changing. Finally it achieves a dynamic balance. At this time, the system power is balanced, and U_{dc} stabilized at a certain voltage value within the allowable voltage range. In this paper, the design of the working range of intermediate dc voltage U_{dc} is 720v to 880v. Voltage fluctuation range is relatively narrow. Droop curve slope is bigger. Adjusted performance degrades and stability deteriorates. Thus this paper presents an improved droop characteristic curve in Figure3. The interval in the charging and discharging is multiplexed. Therefore, the required voltage regulation range greatly reduced. But the U_{dc} and charging /discharging instruction value is no longer a one-to-one relationship. At this point, it needs the higher system to release the initial charging and discharging state.

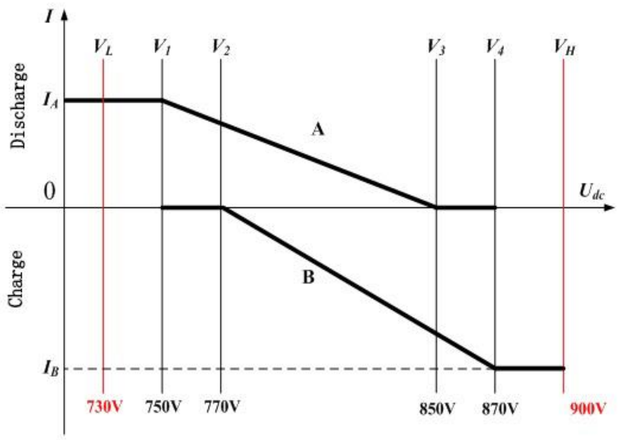


Figure 3. Schematic Diagram of Actual Droop Control

Sagging discharge mode (A)

When $U_{dc} \leq$ V1, it discharges according to the current benchmark.

When V1<U_{dc} <V3, it adjusts the discharge current according to the Linear A based on different.

When V3<U_{dc} < V4, the discharge current is zero, and it stops discharging. It is in the standby state.

When U_{dc} ≥V4, it automatically switches to "droop charge mode" and charges according to the reference current.

Sagging charging mode (B)

When U_{dc} ≥ V4, it discharges according to the current benchmark.

WhenV2<U_{dc} <V4, it adjusts the charge current according to the Linear B based on different.

WhenV1<U_{dc} <V2, the charge current is zero, and it stops charging. It is in the standby state.

When U_{dc} ≤V1, it automatically switches to "droop discharge mode" and it discharges according to the reference current.

As can be seen, the voltage range of a discharge state (V3~ V4) and the voltage range of the state of charge (V1~ V2) play a role in the voltage of the dead band. In fact, assuming the battery energy storage system discharging power is P1 and charging power is P2 .and are determined by the control target of superior micro-grid monitoring and dispatching system. Assuming the number of branches can be put into operation is n and the SOC values of the corresponding battery is S_i, I=1~n. From this, each of branches discharge / charge reference current can be calculated. When calculating value and set value, P1 and P2 needs to have a certain margin compared with the actual. As the following formal:

$$\begin{cases} I_{iA} = \dfrac{P_1}{U_{bati}} \bullet \dfrac{S_1}{\sum\limits_{m=1}^{n} S_m} \\ I_{iB} = \dfrac{P_2}{U_{bati}} \bullet \dfrac{1-S_i}{\sum\limits_{m-1}^{n} (1-S_m)} \end{cases} \tag{2}$$

Then, calculate the discharge / charge current reference current of all the branches. Droop control has many advantages in practical applications. On the one hand, it not only can be run in the state grid, can also run in off-grid state. On the other hand, it can reasonably allocates the various branches of power according to SOC of the battery pack to achieve effectively control of input/output power of each branch and relatively control of charge / discharge current .

5. High-Power Energy Storage Converter Test

Droop control controlled test is a test to verify the storage converter performance. Make the DC source output voltage 650V and grid converter work in double closed loop mode and to determine whether to implement droop control by adjusting the intermediate DC voltage and measuring the charge / discharge current size of DC/DC channel. To adjust the size of and make it increases from 760 to 860, and then decreases. DC/DC channel works in discharge mode and prolapsed charging mode. Wherein the discharge current of the reference current is set to 10 and the discharge current of the reference current is set to 5. To measure the average charge / discharge current of the inductor as Table 2 and the discharge direction is positive.

Table 2. Charge / Discharge Current in Different Dc-Bus Voltage

U_{dc} /V	760	780	800	820	840	860
I/A	9	6.67	5.2	3.02	1.04	0.1
U_{dc} /V	870	860	850	830	790	770
I/A	-5	-4.51	-4.1	-2.93	-1.05	-0.23

The data in Table 2 can make 2 curves. Compared with the actual droop curve in Figure 3 as Figure 4, the curve of A and B is drooping curve with benchmark discharge current 10 and the charging current 5. Figure 1 is obtained by changing from 760 to 860 of and figure is obtained by changing from 860 to 760. From Figure 4, it can be seen that the actual current track sag curve substantially and has achieved the objectives of the droop control.

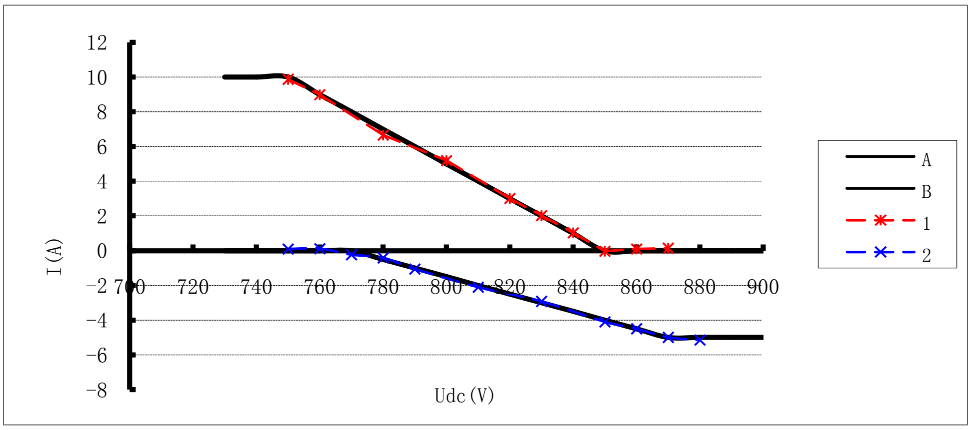
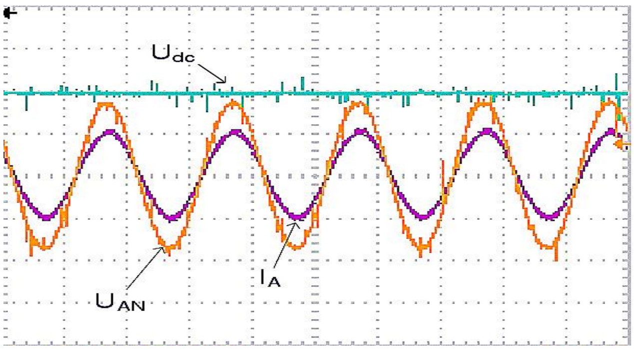
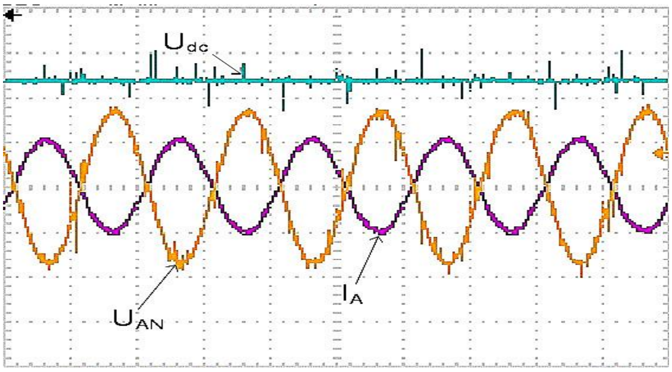


Figure 4. Charge / Discharge Current in Droop Control Mode

Make the DC source output voltage is 650. The stored energy converter is in the droop mode. Charge/discharge the grid with the power of 100kW. DC/DC control charge/discharge current according to droop mode. Waveform is as shown in Figure 5. The discharging current reference current is set at 15, and the charging current reference current is set at 10.



(a) Sagging Discharge



(b) Sagging Charging

Figure 5. Experimental Waveforms in Droop Control Mode

Among them, CH1: A phase voltage in the grid (200 V/cell); CH2: Intermediate DC voltage (200 V/cell); CH3: A phase current (200A/cell).Time horizontal 10ms / cell, a current to flow to the grid as the positive direction. Time horizontal is10ms / cell, and define a current flowing to the grid as the positive direction. Figure5 (a) is the discharge waveform. Grid inverter discharges to the grid with 100kW.As can be seen from the waveform the A-phase current and voltage are the same phase. Power factor is close to +1.Compared with the constant current mode U_{dc} is no longer stable at 850V in this case but changes according to the power change. Since the energy the grid inverter inputs/outputs to the intermediate DC side determines the DC/DC converter charge/discharge current size. Then determining U_{dc} according to the prolapsed curve. In order to accurately calculate the value U_{dc} . Its efficiency is 95.75% after calculating considering the wastage of the grid inverter here. Then the absorption of energy from the middle to the DC side is:

$$P_{总} = 100 \big/ 0.9575 = 105 \ kW \tag{3}$$

$$P = \frac{105kW}{15} = 7kW \tag{4}$$

$$I_b = \frac{P}{U_{bat}} = \frac{7kW}{650V} = 10.77A \tag{5}$$

According to droop curve to calculate in discharge state when

$$I_b = 10.25A \tag{6}$$

$$U_{dc} = 850 - \frac{10.77}{15}(850 - 750) = 778V \tag{7}$$

The U at this time should be stable at 778v. From Figure 5 (a) can be seen U_{dc} is about 780V and it is consistent with the calculation. Figure 5 (b) is a waveform in the state of charge. Grid inverter charges to the DC source with 100 kW. As can be seen from the waveform, a phase current and phase voltage waveform is reverse. Power factor is close to -1.Due to the efficiency of the parallel converter is 95% and the losses are about 5%. The actual energy flowing into the intermediate DC side is about 95 kW. So:

$$P = \frac{95kW}{15} = 6.33kW \tag{8}$$

$$I_b = \frac{P}{U_{bat}} = \frac{6.33kW}{650V} = 9.74A \tag{9}$$

According to sag curve I_b= 9.74A when in discharging state,

$$U_{dc} = 770 + \frac{9.74}{10}(870 - 770) = 867V \tag{10}$$

From Figure 5 (b) can be seen that U_{dc} is about 865V, and it is consistent with the calculation.

Efficiency is one of the important indicators to measure current transformer design, the stored energy converter using efficiency experiment and using the platform for single-channel DC/DC channel efficiency experiments, as the 15 channels' structure are exactly the same, so we can be thought of 15 road channel efficiency at the same as the 1 road channel efficiency. In the charge for working state, the dc source for output voltage U_{bat} is 650v, in the case of different current, and measured efficiency, specific data as shown in Table 3. Figure 6 is efficiency the under the condition of different charging current I_b. It can be seen in efficiency increased gradually along with the increase of current I_b, I_b is 20 at a maximum, the U_{bat} is 650 v, U_{dc} = 850 v when the efficiency of 98.45%.

Table 3. The Efficiency of DC / DC Converters in Different Discharge Current

Charging Current $I_b(A)_{RMS}$	5.49	10.63	12.72	15.84	20.95
Efficiency	93.04	96.74	97.44	98.08	98.45

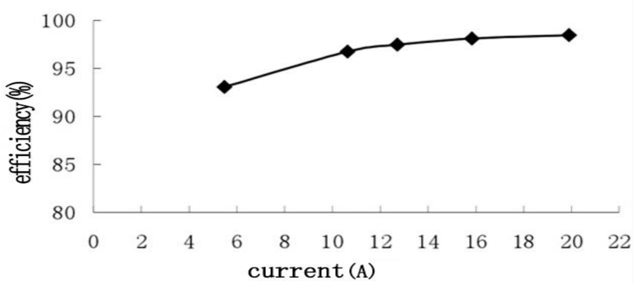


Figure 6. The Efficiency of DC / DC Converters in Different Discharge Current

On grid inverter efficiency experiments conducted, this time in the middle of DC current source and grid side converter is directly connected, both U_{dc} are set in 850V, in crossfeed state. Measured grid inverter input power 106 kW, output power 101.5kW, efficiency is 95.75%. Above all,we can calculate the whole energy storage efficiency of the converter is 98.46%, 95.75%, 94.27%.

6. Conclusion

The distributed power in the micro grid has is random, intermittent and not stable, so it needs high power energy storage equipment to serve as its complement. This paper has developed a high-power energy storage converter and achieved bi-directional exchange of energy .We aimed at that batteries serve as energy storage devices in micro-grid system.

In this paper, the research and development of power storage converter can realize multiple sets of independent control of the battery, flexible configuration of the system capacity and flexible cutting of the battery pack. Structural design uses mufti-level topology. Control strategy designed to be grid converter adopts SVPWM control technology. DC / DC converter designed to improve the droop control strategy based on environmental design. In this paper, the design of high power converter product has completed droop control charge and discharge and storage full power grid experiment. Charge and discharge current accurate track instruction current grid and the efficiency is more than 95%. This paper has verified the rationality and effectiveness of the design. The product 100 kv bidirectional converter has become a light complementary storage energy storage is an important part of power system. This paper is funded by "2014 Annual colleges and universities excellent talents support program of Liaoning Province "

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