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A Survey of Control Stratedy Based on Cascaded H-bridge Power Conversion System

Jing-Hua ZHOU[a], Xiang JI[b], Xiao-Wei ZHANG[c] and Ya-Ai CHEN[d]

Inverter Technologies Engineering Research Center of Beijing (North China University of Technology),Shijingshan District,Beijing,100144,China

[a]zjh@NCUT.edu.cn, [b]jixiang417206787@163.com, [c]zxw@NCUT.edu.cn, [d]cya@NCUT.edu.cn

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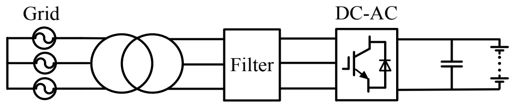
Abstract. The fluctuation and intermittence of renewable energy sources power poses a great challenge to the stable operation of power system, which needs power conversion system(PCS) to provide spare power to achieve dynamic balance of supply and demand for the power grid. Cascaded H-bridge converter is a main topology structure for the application for high voltage large capacity grid, which is combined with different energy storage media, having broad application space in the large capacity storage places. This paper introduces the topology of cascaded H-bridge PCS, expounds the various control strategies under different energy storage media and mainly analyzes and evaluates the various control methods, whose respective advantages and disadvantages are also summarized, providing reference for the theory research and practical application.

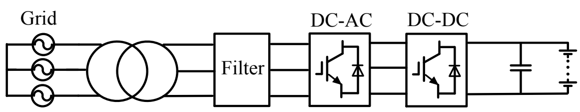
Introduction

Today's renewable energy generation and its grid access rate is increasing. But because of this intermittent energy output power has a greater volatility and uncertainty, so as to the stable operation of the grid has brought great challenges. Energy storage power conversion system has become an important part of the power system, commitment to energy storage system and power between the two-way energy transfer task [1].

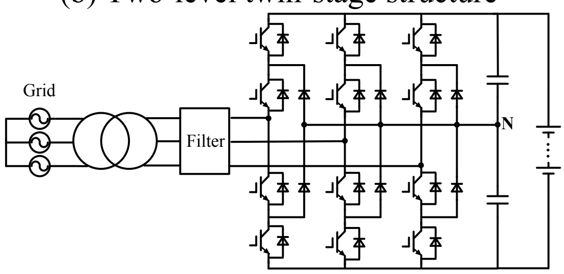
PCS topology is divided into traditional two-level, three-level and cascade type. Several common PCS converter topologies are shown in Figure 1. These topologies are simple and easy to control, but there are many problems in high-voltage and high-capacity applications. For the two-level PCS structure of its shortcomings: the system cost is high, the device bulky, large switching losses, the need for complex dynamic voltage equalization circuit. These problems also appear in the three-level PCS, thus limiting the traditional PCS in high-voltage high-capacity applications.



(a) Two-level single-stage structure



(b) Two-level twin-stage structure



(c) Three-level structure

Fig.1. Traditional topology structure of PCS

With the storage capacity and scale more and more large, cascade H-bridge PCS is more popular because of its strong scalability, redundancy is good, no power transformer can be directly connected to the characteristics of high-voltage distribution network and other concerns. Considering the characteristics of different energy storage media, the energy type represented by the battery or the power type storage medium represented by the super capacitor is combined with the cascade type converter to form the high voltage and large capacity energy storage device.However, cascading PCS will encounter many problems in the application. In [2] , the problems of cascade energy storage system in practical application are summarized in detail. In order to ensure that the cascade PCS is working properly, it must maintain a dynamic balance with the power delivered by the AC grid, so it is necessary to effectively control the output power. Each power unit of the different switching losses will lead to battery charge state (State of Charge, SOC) is not balanced or super capacitor group voltage is not balanced, it is necessary to the entire energy storage system equilibrium control strategy to study.

Based on the research results of scholars at home and abroad for many years, this paper first introduces the multi-level cascade H-bridge PCS topology in recent years, then analyzes and compares its advantages and disadvantages. And then lists the current relevant literature proposed by the control strategy. This paper can provide reference for the future research of cascade H-bridge energy storage power conversion system.

1 Cascaded H-bridge PCS Topology

In general, the cascade energy storage system consists of energy storage media and PCS two parts, the general structure shown in Figure 2. Each phase is made up of *n* power cell, and the energy storage unit can be a battery or a super capacitor. The cascaded PCS inverter side is connected directly to the medium to high voltage grid via a filter inductor.

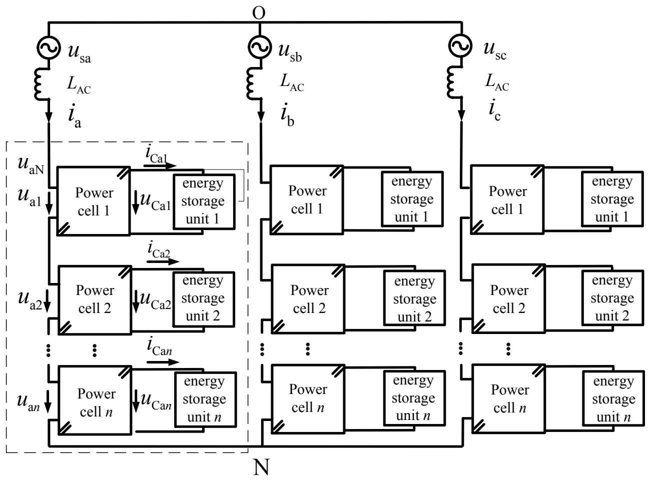


Fig.2. General structure diagram of cascaded energy storage system

In Fig. 2, the topology of the various cascaded PCS units is different depending on the power unit structure. In [3], the half-bridge with bi-directional switch on each side of the power unit has a full-bridge structure with one-way switch on the energy storage medium. The topology is shown in Fig. 3, adding the isolation transformer to the storage medium and the grid side to further reduce the DC side of the voltage requirements, and the grid current ripple smaller. But each module within the complex structure, more switching devices, control strategy is complex, less efficient.

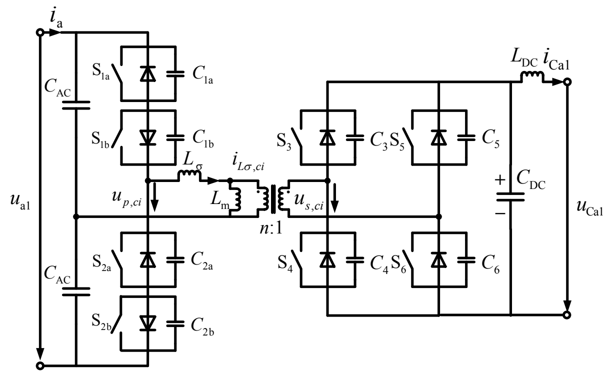


Fig.3. Cascaded half-bridges converter cell topology structure

[4] proposed a single-stage cascade H-bridge converter, as shown in Figure 4. Compared with the structure shown in Fig. 3, the power switch device is small, the structure is simple and easy to modular design, and easy to implement PWM control mode. However, since the unit modules of the chain structure do not have a common DC bus, this results in a two-multiple frequency fluctuation of power that adversely affects battery performance and operation.

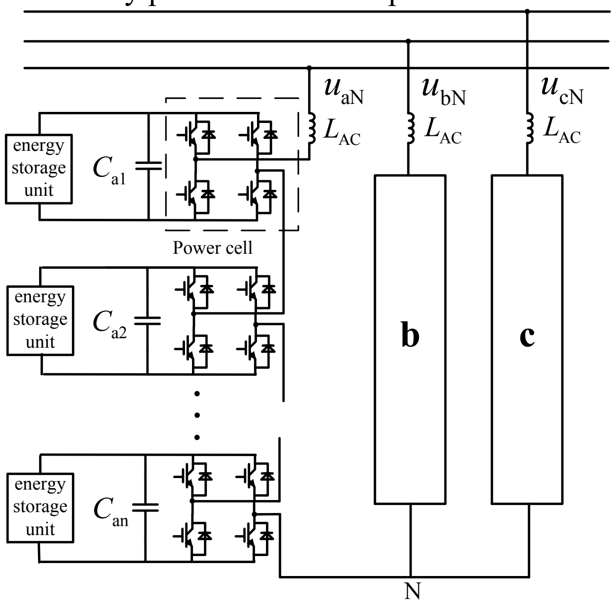


Fig.4 Circuit configuration of cascaded H-bridge with unidirectional converters

Similar to this structure, [5] proposed a two-stage cascade H-bridge converter, as shown in Figure 5. Compared with the single-stage cascade H-bridge converter shown in Fig. 4, each power unit increases the DC/DC link, which can effectively control the charge and discharge current and reduce the charge and discharge state caused by the change DC side voltage change. In this paper, the control strategy of cascade H-bridge PCS system is introduced in Figure 4.

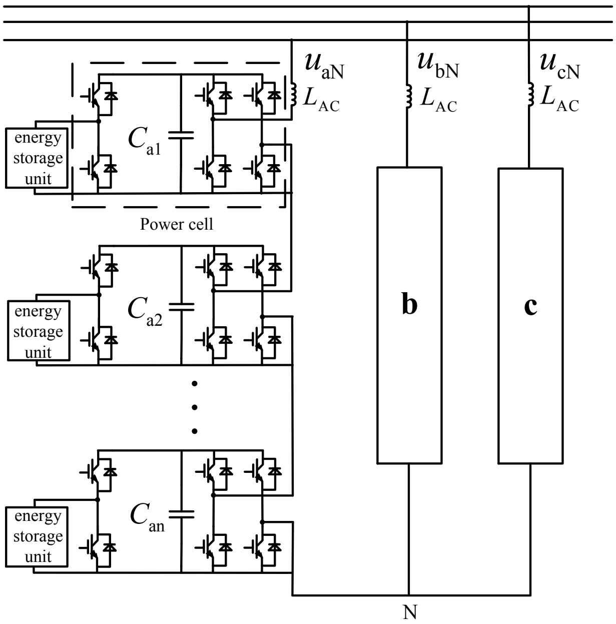


Fig.5. Circuit configuration of cascaded H-bridge with bidirectional converters

2 Cascade H-bridge PCS Control Strategy

2.1 System power control

[6] on the cascade PCS system-level power control strategy for in-depth study, the control block diagram shown in Figure 6. Based on the instantaneous power theory, the current feedforward decoupling strategy based on PI regulator is used to obtain the instantaneous active power and reactive power control as the outer ring, and the load current is controlled as the inner ring. Double closed-loop control strategy and produces a cascade of PCS's total modulation voltage signal u_{aN}^*、u_{bN}^* and u_{cN}^* per phase。

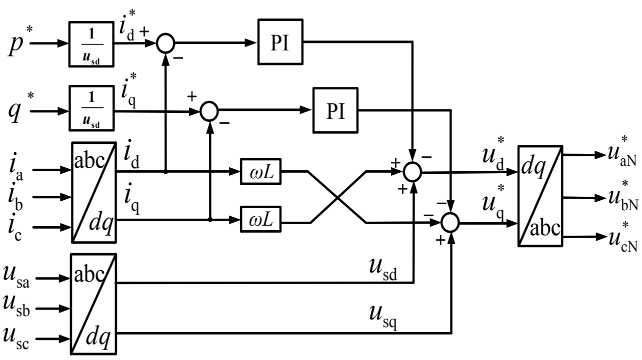


Fig.6. Instantaneous power control block diagram based on decoupled current control

On the basis of the [6]，[7] uses the proportional resonant (PR) regulator, directly in the static coordinate system to achieve the instantaneous power without static control. According to the instantaneous power theory, we can get the relationship between the instantaneous active power p^* and the instantaneous reactive power q^* in the α-β coordinate system and the command currents i_α^* and i_β^*:

$$\begin{cases} i_\alpha^* = \dfrac{u_{s\alpha}}{u_{s\alpha}^2 + u_{s\beta}^2} p^* + \dfrac{u_{s\beta}}{u_{s\alpha}^2 + u_{s\beta}^2} q^* \\ i_\beta^* = \dfrac{u_{s\beta}}{u_{s\alpha}^2 + u_{s\beta}^2} p^* + \dfrac{u_{s\alpha}}{u_{s\alpha}^2 + u_{s\beta}^2} q^* \end{cases} \tag{1}$$

Based on the PR regulator of the instantaneous power control block diagram shown in Figure 7, the final phase of the total modulation voltage signal u_{aN}^{*}、u_{bN}^{*}和u_{cN}^{*}。

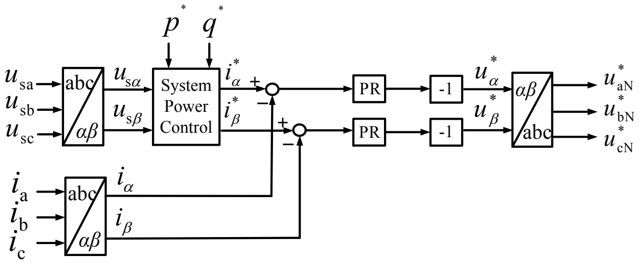


Fig.7. Instantaneous power control block diagram based on PR regulator

2.2 Balancing Control

Equalization control is divided into phase equalization and phase power unit equalization. According to the charge and discharge characteristics of different storage media, the equilibrium strategy is common but slightly different.

2.2.1 Clustered Balancing Control

For the cascade type PCS of the storage medium as the battery, [8] proposed an SOC equalization strategy applied to the cascade multi-level structure of the electric vehicle, and the switching mode exchange method is used to realize the equilibrium of the phase charge state. In [9], it is proposed to use zero sequence voltage injection method to ensure the balance of multi-level STATCOM phase-to-phase DC voltage in three-phase unbalanced condition, and give the principle explanation of zero sequence voltage injection method. On this basis, the [4] by injecting zero sequence voltage to fine-tune the modulation wave, effectively achieve clustered balancing SOC equalization control, the control block diagram shown in Figure 8.

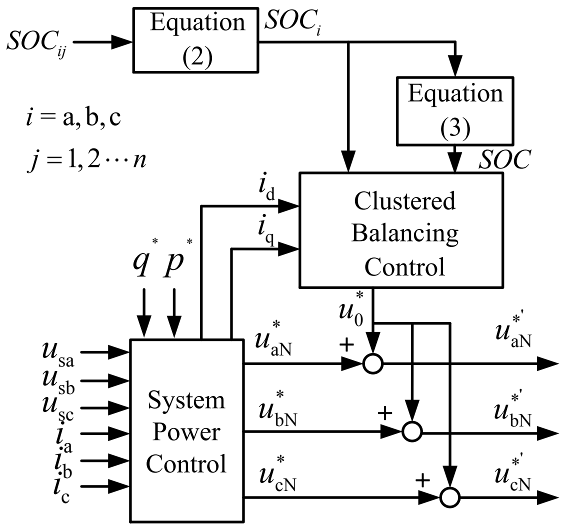


Fig.8. Integral control block diagram for cascaded BESS with unidirectional converters

The clustered balancing SOC equalization control is mainly to keep the SOC mean of each phase equal, that is, *SOC*a = *SOC*b = *SOC*c. The control idea is to add an extra power to each phase by injecting the zero sequence voltage. The additional power is used to realize the SOC clustered balancing. Figure 9 shows its zero sequence voltage vector analysis, where δ represents the power factor angle. The three-phase voltage changes the modulation voltage signal of each phase by adding a zero sequence component u_0^{*}, that is, $u_{\mathrm{aN}}^{*'}$, $u_{\mathrm{bN}}^{*'}$ and $u_{\mathrm{cN}}^{*'}$. Therefore, as long as the appropriate selection of the zero sequence voltage amplitude and phase angle, that is able to achieve the purpose of SOC clustered balancing.

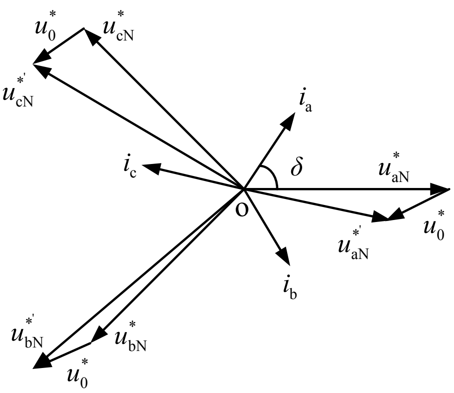


Fig.9. Zero-sequence-voltage injection vector

In order to construct the zero sequence voltage u_0^* superimposed on Fig. 9, the three-phase inter-phase imbalance Δ*SOC*a, Δ*SOC*b and Δ*SOC*c are subjected to equal-power CLARK transformation to obtain the amplitude and phase angle *γ* of the general vector **Δ***SOC*, and then the current vector Phase angle *δ*, and finally get the required zero sequence voltage[6]. According to the SOC difference on the amplitude of each phase modulation wave fine-tuning, so that the difference between the power unit of the battery pack to absorb or release different power, by adjusting the final phase of the SOC have reached the average, that is, control. Figure 10 shows the zero-sequence voltage generation for phase-to-phase SOC equalization control.

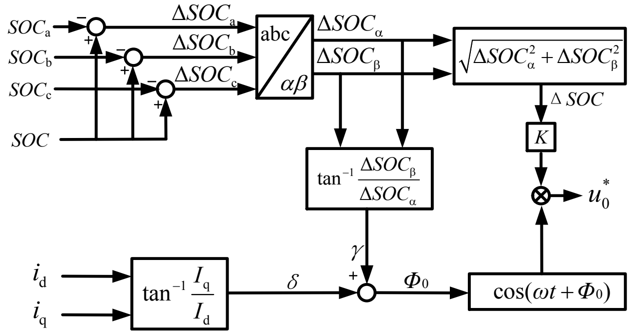


Fig.10 Formation of the zero-sequence-voltage used to achieve clustered SOC-balancing control

where

$$\begin{bmatrix} SOC_a \\ SOC_b \\ SOC_c \end{bmatrix} = \frac{1}{n}\begin{bmatrix} SOC_{a1} + SOC_{a2} + \cdots & {}_{\_n} \\ SOC_{b1} + SOC_{b2} + \cdots & {}_{\_n} \\ SOC_{c1} + SOC_{c2} + \cdots & {}_{\_n} \end{bmatrix} \tag{2}$$

$$SOC = \frac{1}{3}\left(SOC_a + SOC_b + SOC_c\right) \tag{3}$$

Then the expression of the zero sequence voltage is given:

$$u_0^* = K \cdot \Delta SOC \cdot \cos(\omega t + \Phi_0)\,. \tag{4}$$

Where *K* is the proportional gain; $\Phi_0=\delta+\gamma$。

For the cascade type PCS with energy storage medium as super capacitor, the [10] has carried on the thorough research to its phase-to-phase voltage equalization strategy, also uses the modulation wave trimming method to change the total power distribution among the three phases, the difference is the injection The pattern is to construct the voltage required for each phase according to the voltage imbalance of each phase, as shown in Fig. 11, where u_{0a}, u_{0b} and u_{0c} are the equalized voltage signals superimposed on each phase. This phase separation method is to control the three-phase converter as three separate single-phase converters.

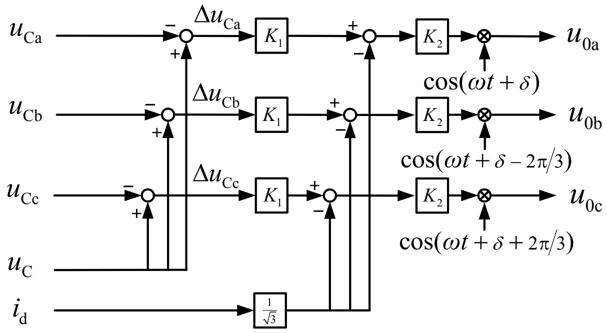


Fig.11. Formation of the additional voltage used to achieve clustered voltage-balancing control

To a phase, for example, a superimposed voltage signal:

$$u_{0a} = K_2(K_1\Delta u_{Ca} - i_d/\sqrt{3})\cos(\omega t+\delta). \tag{3}$$

Where $K1$, $K2$ for the proportional gain。

2.2.2 Individual Balancing Control

The phase SOC equalization control is responsible for the SOC balance of each phase cell within the power cell, a phase such as $SOCa1 = SOCa2 = \cdots = SOCan$, which eventually achieves all battery SOC balance. In [11], the triangular wave of each cell carrier is constructed by combining the state of charge of the battery of each power unit. The multi-carrier phase shift modulation strategy is used to achieve a positive correlation between the output power of each power cell and its own battery pack. In order to achieve the purpose of reducing the SOC deviation between the battery cells, the ultimate realization of the phase balance. Through the analysis of the effectiveness of the control strategy, it is found that this method has different control effect on SOC-V curves of different energy storage batteries. For lithium titanate and lead-acid batteries, SOC tolerance range, balance, for the lithium iron phosphate battery control effect is not ideal. In [4] and [10], the internal and external equalization of the single-stage tandem energy storage system composed of the battery and the super capacitor is studied respectively. The basic voltage is used to realize the phase balance of the battery super capacitor bank. Since the current flowing through the cascaded H-bridge transform system is the same, the overall control idea is to achieve the equalization of the power unit per phase, that is, the output voltage $u_{aN}^{*'}/n$ by changing the modulation voltage of each power element, $u_{aN}^{*'}/n$、$u_{bN}^{*'}/n$ and $u_{cN}^{*'}/n$, respectively, the corresponding basic components u_{1aj}、u_{1bj} and u_{1cj}, the voltage component control block diagram shown in Figure 12.

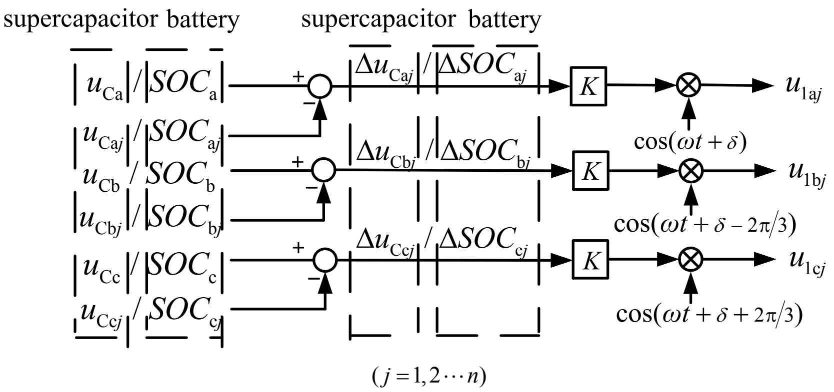


Fig.12. Formation of the fundamental-frequency voltage used to achieve individual SOC-balancing control of battery pack and voltage- balancing control of super supercapacitorstack

The experimental results verify that this control method can ensure the balance between each power unit, the maximum protection of the energy storage battery pack and super capacitor group, to extend its service life. But did not consider the three-phase voltage imbalance.

As mentioned earlier, the traditional phase-shifted SPWM control of cascaded H-bridge can only achieve synchronous charge and discharge, and [12] proposed a new differential charge-discharge control strategy. When a battery SOC is detected to be unbalanced The SHE-PWM control mode is used to switch to the phase-shifted SPWM control when the SOC is equalized. This control mode is different from the modulation method of the modulation wave fine tuning, and the phase shift SPWM can be automatically completed only by satisfying the switching condition And SHE-PWM control mode of mutual switching. Simulation results show that this method can not only realize the SOC balance of the battery, but also improve the output voltage waveform and improve the power quality. Although this method is based on isolated cascade energy storage system, but for single-stage cascad.

Conclusion

This paper focuses on the control strategy of cascade H-bridge energy storage power conversion system. The control strategy can be divided into system-level power control and equalization control under autonomous mode, With the further development of energy storage technology, fully integrated and play a variety of energy storage media advantages, cascade hybrid energy storage is a promising research direction, will further promote the application of cascade PCS. In terms of its control strategy, the current control method has been relatively mature, but only applies to the normal operation of the grid conditions, non-ideal power grid and power grid failure under the conditions of operation control strategy to be further studied. In order to improve the economic efficiency of the energy storage system, it is necessary to study the multi-function application mode, and it is relatively easy to realize the multi-function application with obvious time-sharing characteristic, and the coordination strategy of the composite function needs to be studied.

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