Analysis and simulation of multi-station fusion layered structure based on MMC module

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Abstract: In order to solve the problems of low space utilization rate and insufficient power supply reliability of substations, a multi-station fusion technology with substations as the main body and multiple power stations (5G communication base station, electric vehicle charging station, data center and energy storage station) was proposed. In this paper, the layered structure of the new fusion power station with "multi-station fusion" is proposed to clarify the collaborative working mode of various parts in the new fusion power station through the layered structure, so as to prevent equipment failures caused by interlocking control information. At the same time, the topological structure of the energy transfer layer of the new fusion power station is designed, and the MMC module is used in the energy transfer layer for energy transmission. Then the verification procedure, analysis of the circuit feasibility of the output waveform and control of the signal waveform are realized on the hardware circuit.

1. Introduction
"Multi-station fusion" is based on substation, which integrates data center, 5G base station, charging station, energy storage station, etc., to form a new multi-station fusion station. It can realize the integration of information flow, energy flow and business flow, thus improving the comprehensive efficiency of the power grid. New fusion power plant contains data center of data storage, information communication of 5G base stations, energy storage energy storage power station, substation of electrical energy transformation, the fusion together to form more convenient collaborative allocation "energy source - net - lotus" area, thus achieve energy interconnection wisdom and green low carbon city living environment [1-4].

Compared with the traditional substation, the complexity of the power load and the power consumption of the new fusion power station are greatly improved. In the new fusion power station, not only the "charge side" has been increased, such as data center, electric vehicle charging pile, but also the "source side" and "storage side" have been increased, such as the access of wind-view storage. The connection of these fluctuating new energy and energy storage power stations will surely bring greater power fluctuations than the original substation. To deal with these problems, if the traditional power supply mode is extended, it is difficult to ensure the reliability of power supply and energy efficiency. Therefore, it is necessary to design the layered control structure for the new fusion power station, including the centralized control layer, the energy transmission layer, the information
transmission layer and the application layer. The layered control structure can refine the control network of the new fusion power station and clarify its control logic. The layered control structure of the new fusion power station is mainly divided into two control flows, namely information flow and energy flow. The information flow is mainly the detection of operation data and the response strategy to the new fusion power station in the case of emergency. Energy flow is mainly to control the flow direction of electric energy and ensure stable output. In the energy flow, the coordination of "source-network-storage" should be ensured.

In 2002, R. Marquart and A. Lisnica of the Bundeswehr University Munich, Germany, jointly proposed the modular combination multilevel converter [5]. It is composed of multiple power modules and inductance cascaded into the bridge arm. The power balance module adopts full bridge circuit or full bridge circuit. The advantages of MMC module and common multi-level circuit are, firstly, simple circuit structure, low switching frequency and low switching loss. Secondly, MMC circuit can output multi-level waveform, level voltage step is small, the output voltage contains small harmonic component. That is, this paper uses MMC module to carry out energy transmission and conversion in the energy transmission layer.

In this paper, the layered structure of the new fusion power station is designed to clarify the collaborative working mode of various parts in the new fusion power station through the layered structure, so as to prevent the equipment failure caused by the interleaving of control information. At the same time, the topological structure of the energy transfer layer of the fusion power station is designed, and the MMC module is used in the energy transfer layer to reduce the harmonic component and switching loss of the output voltage. Through the verified hardware circuit, the circuit output waveform and control signal waveform is analysed.

2. Layered control structure of new fusion power station

In this paper, the control network of the new fusion power station is divided into four layers: centralized control layer, energy transmission layer, information transmission layer and application layer.

Centralized control layer of the main function is to transmit energy equipment, the application layer of the equipment and the nearby residential area and equipment of the power enterprise information acquisition and detection equipment, and information collected by analysis and calculation, the information of fault and error warning in time and correct, to ensure equipment safety as well as the power supply reliability.

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**Fig. 1 Hierarchical structure of the new fusion power station**

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The energy transmission layer is mainly to realize the transmission of electric energy and convert the fluctuating new energy and the grid-side power supply into the required voltage type through
rectification or inversion. In the energy transfer layer, there are two main modules: MMC module and SST module. The main function of MMC is to convert high voltage into low voltage and realize the conversion of electric energy flow direction. The main function of SST is to realize the conversion of electromagnetic isolation and voltage level. In the case of different loads, the centralized control layer sends MMC and SST through the selection of appropriate control strategies, so as to output corresponding output characteristics.

The application layer mainly contains electricity load, which is divided into three categories: controllable load, uncontrollable load and adjustable load. The controllable load can control the load state, and the load can be reduced when the power consumption peak and the power supply is insufficient without affecting the normal operation of the new fusion power station. Uncontrollable load is the load with high demand for power supply, and the load is not allowed to be in the state of power failure during normal power supply. Adjustable load means that when the power supply pressure is high, the electric energy can be transmitted to other loads through the energy transfer layer to reduce the power supply pressure, and when the power supply pressure is low, the energy can be stored into the load through the energy transfer layer. When these loads are working, the load information is transmitted to the centralized control layer through the information transmission layer for analysis and processing.

In the information transmission layer, data transmission and equipment positioning are mainly carried out through the in-station Internet of Things, 5G base station and Beidou base station, and equipment information of regional residential areas and electricity enterprises are transmitted to the centralized control layer through 5G for data monitoring and processing. The information flow in the station is mainly transmitted by the Internet of Things in the station. In this way, the speed and accuracy of information processing can be greatly accelerated through the two information loops.

The layered control structure of the new fusion power station can clarify the cooperative working mode of each part of the new fusion power station and control the direction of information flow, and make clear the coupling relationship between information flow and energy flow. If there is a fault, it can reduce the difficulty of maintenance and reduce the maintenance time.

The physical topology structure of the energy transmission layer is the core equipment for the energy transmission of the new fusion power station. It is mainly responsible for executing the commands sent by the centralized control layer to transform the output voltage level and frequency, so as to achieve the effect of plug and play, as shown in Figure 2.

Wind power and power grid are used as AC power supply, energy storage and photovoltaic are connected to DC bus, and the AC power supply voltage is converted to DC voltage through a converter. In the energy transfer layer, two voltage channels can be output, one voltage is multi-level AC voltage, one voltage is multi-level DC voltage. According to the different voltage types required, the control methods used in the topology are different. The control mode is performed by centralizing the energy transfer layer under the control layer to achieve the required voltage level and voltage type. To output AC voltage, only the MMC module is required to adopt SPWM modulation strategy and output multi-level AC voltage. To output DC voltage, MMC module only needs to output HF AC pulse signal, and a stable and adjustable DC voltage can be output through SST module.
3. Design and simulation of energy transfer layer MMC module

3.1. MMC topological structure

Although most of the submodules of the traditional MMC module adopt the half-bridge structure, the half-bridge MMC circuit is unable to cope with the emergency situation when the DC bus fails or a submodule of the MMC module fails [6]. Therefore, full-bridge MMC with the ability to pass through DC short circuit faults can cope with such faults in a timely manner. The circuit structure diagram of full-bridge MMC is shown in Figure 3. VD1-VD4 and VD5-VD8 form the double full-bridge control circuit.

![Fig. 3 Full bridge MMC circuit structure](image)

3.2. MMC control algorithm

The low-voltage DC inverter is turned into the pulse signal of SPWM, and finally the SPWM signals of each module are superposed and synthesized to form the power frequency sinusoidal voltage of SPWM. The control chip of MMC circuit designed in this paper adopts STM32 master control chip, and its logic control block diagram is shown in Figure 4.

![Fig. 4 MMC logic control block diagram](image)

When the circuit power is switched on, the main control chip will enter the first stage - initialization stage. Firstly, GPIO and chip peripheral are initialized, and the amplitude M and frequency F of the modulated wave and carrier are set. The amplitude of the modulated wave is generally set to 1.2 times of the amplitude of the carrier. Finally, the specific code of each circuit board is returned through the connection of the circuit hardware, and the master control chip executes the corresponding program through the returned code. Entering the second stage is the circuit synchronization stage, through the connection of the synchronization signal, the working time of the circuit board is unified. The third stage is the output phase of SPWM comparison. Pulse signals of equal amplitude and different width are obtained by comparing the carrier wave and the modulated wave. During the comparison, the comparison times should also be counted to balance the energy of each switch tube, and then the output waveform of each circuit board is superposition and combined. The fourth stage is the clock calibration stage, because each circuit board can not guarantee the exact same, so there must be a certain difference in the received signal and processing signal, so it must be necessary to carry out clock calibration within a certain period. In this paper, the clock is calibrated after 100 cycles, and the final cycle is carried out in the second, third and fourth stages.
3.3. MMC submodule simulation
In this paper, the above theory is verified by hardware circuit, and 2 MMC modules and 4 H Bridges are selected for verification. As shown in Figure 5, position 1 is the 24V switching power supply, position 2 is the battery, position 3 is the MMC circuit driving power supply module, position 4 is the MMC circuit module, position 5 is the high-frequency transformer module, position 6 is the rectifier bridge module, and position 7 is the synchronous signal port.

The switch tube driven optocoupler circuit of the MMC submodule is shown in Figure 6. F1-1 is the PWM output port of the control chip. The control signal is amplified to -9V to +15V voltage signal to drive the MOSFET switch tube through the optocoupler isolation and push-pull amplifier circuit. Figure 7 shows the control waveform of F1-1. It can be seen from the waveform that the control waveform changes according to the sinusoidal law. Since the optocoupler circuit is only used for circuit isolation and amplification, the original control waveform is not changed, that is, the output waveform also presents sinusoidal changes. The MMC submodule needs to superposition the output waveform into a complete multi-level SPWM output, so the control signals of each pair of bridge arms should be superposed as part of the complete SPWM control signal, and the final waveform output is shown in Figure 8 and 9.
The MMC module can not only convert the DC inverter into the required AC voltage, but also convert the high voltage DC into the required DC voltage. As shown in Fig. 10 and 11, the inverter of DC voltage is converted into high-frequency AC voltage for electrical isolation and voltage grade transformation through high-frequency transformer, and the high-frequency AC voltage is rectified into DC voltage through a rectifying bridge. Since there are a variety of DC voltage level equipment in the new fusion plant, high frequency transformers are chosen here to reduce energy consumption.

4. Conclusion
In this paper, the layered structure of the new fusion power station with "multi-station fusion" is designed. Through the centralized control layer, the energy transmission layer, the information transmission layer and the application layer, the collaborative working mode of each part in the new fusion power station is clarified, and the control flow direction of each part is clarified. If the system has problems, the difficulty of equipment maintenance is reduced. At the same time, the topological structure of the energy transmission layer of the new fusion power station is designed, and the MMC module is used to carry out energy transmission in the energy transmission layer. The topology adopts full-bridge MMC structure to deal with DC short circuit fault, and 9 level output can be achieved through SPWM control algorithm. Finally, through simulations on the hardware circuit, the MMC circuit can correctly output 9 level AC voltage and stable DC voltage.

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