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Research on high voltage DC transmission system optimal control based on MMC

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ABSTRACT

In high voltage direct current (HVDC) transmission system, modular multilevel converter (MMC) is not satisfactory to maintain the balance of the capacitor voltage and doesn't have the DC side fault ride-through capability. This paper presents that the MMC bridge arm consisting of half bridge module and clamping double sub module in series can reduce the loss of steady state operation and the amount of components. The repetitive predictive control is proposed to suppress the circulation current and balance the capacitor voltage based on the topology of MMC. A related model is built in the PASAD/EMTDC software environment and a repetitive predictive control strategy is developed. The simulation results show that the proposed system not only has the DC side fault ride-through capability, but also carries out the capacitor voltage balancing task and minimizes the circulating currents.

Introduction

The flexible high-voltage-direct-current (HVDC) based on modular multilevel converter (MMC) has been widely accepted because of its good expansibility, high quality output waveform and low switching frequency [1,2].

Nowadays, the hot studies on MMC are mainly focused on the key technology as system modeling, modulation strategy and the design of control system, etc. Correspondingly, in the technical literature, the mathematical model of MMC–HVDC is developed, methods are proposed for space vector pulse width modulation and capacitor balance control on MMC [3–5]. The AC and DC side control method and circulation current mitigation in MMC are investigated [6,7]. The nested loop mechanism of modular multilevel converter topology is proposed in which the output ability of level is increased, and consequently, the amount of sub module and controlling components are reduced, but the DC side fault current cannot be effectively controlled and thus its application field is limited [8] .

The current literatures mentioned that there were two defects in the MMC topological structure: (1) it cannot effectively deal with DC side fault [9]. When the DC side fault occurs, the insulated gate bipolar-trans transistor (IGBT) freewheeling effect of anti-parallel diode is easy to form the energy feedback loop directly connected with AC system fault point [10,11], which needs to disconnect AC circuit breaker for DC isolating switch to work reliably; Due to the slow mechanical response, it may do harm to the system operation [12]. (2) With energy storage capacitor distribution in each sub module, it is difficult to control the equilibrium distribution of capacitance voltage in each sub module. Owing to imbalance energy distribution between the phases, there exists the internal circulation current of converter, which causes the sinusoidal distortion of bridge current and increases the rated current capacity of devices, and consequently, increases the system costs.

In order to solve the existing problems, this paper proposes a new MMC topology called MCH-MMC (Mixed CDSM &HBSM MMC), in which the bridge arm has two sub module groups where half bridge module and clamping double sub module are connected in series. However, there are some shortages, because the energy storage capacitor is distributed in every sub module, which makes it difficult to balance on the voltage. The design method on MMC sub module capacitance parameter is proposed [5], and the control strategy is introduced by an additional switch on capacitor voltage balance, but to monitor and control sub module of switch in very short time, it cause the movement of sub module of switch, which increase the losses of the converter switching. The studies on mechanism of the inner circulation of MMC based on the instantaneous power theory [17,18], that the MMC three-phase circulation is decomposed into two DC component by rotating coordinate in MMC internal mathematical model, and the

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circulating current suppressor is designed. The simulation results show that the method in suppressing the internal circulation of MMC will not affect the output voltage and current. The method is proposed to achieve the suppression effect of the loop current by reasonable selection of the bridge arm inductance and control loop. But the increase of inductance value brings some disadvantages, such as reducing the frequency response speed of the system control and increasing the volume of the device. To solve these problems, the optimal switching state of each MMC unit is selected to suppress the circulating current, and the capacitor voltage is balanced by the redundant switching states.

A repetitive predictive control strategy is developed based on this topology. Simulation results demonstrate that the proposed system not only has the capability to ride through the DC side fault, but also achieves the equilibrium distribution in each sub module capacitance voltage.

The traditional topology of MMC

Half bridge sub-module (HBSM) is widely used in modular multilevel converter; IGBT (T_1, T_2) and anti-parallel diode constitute the Half H Bridge and its structure is shown in Fig. 1. Although the MMC topology has good expansibility, low harmonics, low switching frequency and less favorable trigger, it does not have the DC side fault ride through capability.

Compared with HBSM, clamp double sub module (CDSM) only slightly increases in components and loss and can realize fast self-cleaning in DC fault. As is shown in Fig. 2, by controlling the IGBT trigger signal of CDSM and different operation mode (steady and bypass), the sub module output U_{SM} is achieved as DC capacitor voltage 0, U_c and $2U_c$.

Among them, T_1–T_5 is IGBT, D_1–D_7 is diode, C_1, C_2 is DC capacitor, i_{SM} is bridge current, U_c is DC capacitor voltage, U_{SM} is sub module output voltage. CDSM has the function of DC fault clearing, and it can effectively inherit and transplant the existing MMC–HVDC control strategy, the application of MMC is used to conventional overhead lines. CDSM almost retains all the advantages of HBSM.

The new topology of MCH-MMC

A new topology of MCH-MMC is shown in Fig. 3. The converter is composed of three-phase bridge arm, each phase comprises two converter valve and two commutation reactance. Compared with the traditional topology of MMC, the novelty of the improved topology lies in two sub-module groups in series which comprise respectively of N half bridge sub module (HBSM) and M clamping double sub modules (CDSM) in series. The reactor in each phase arm is to mitigate circulation currents caused by the bridge arm of DC different voltage.

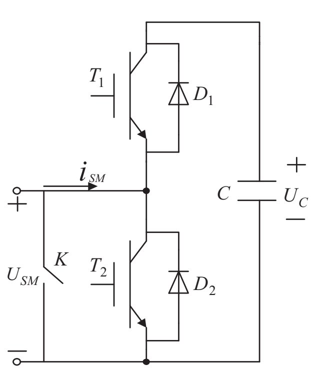

Fig. 1. Structure of one HBSM.

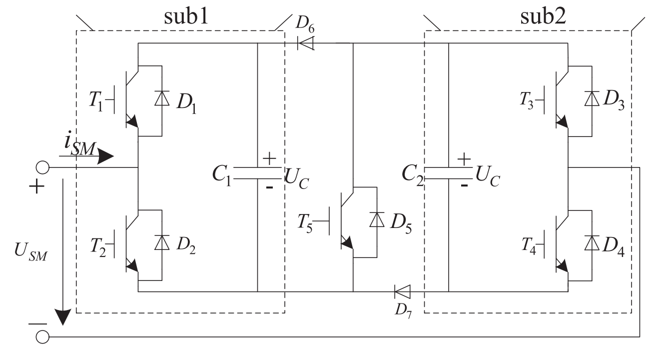

Fig. 2. Structure of one CDSM.

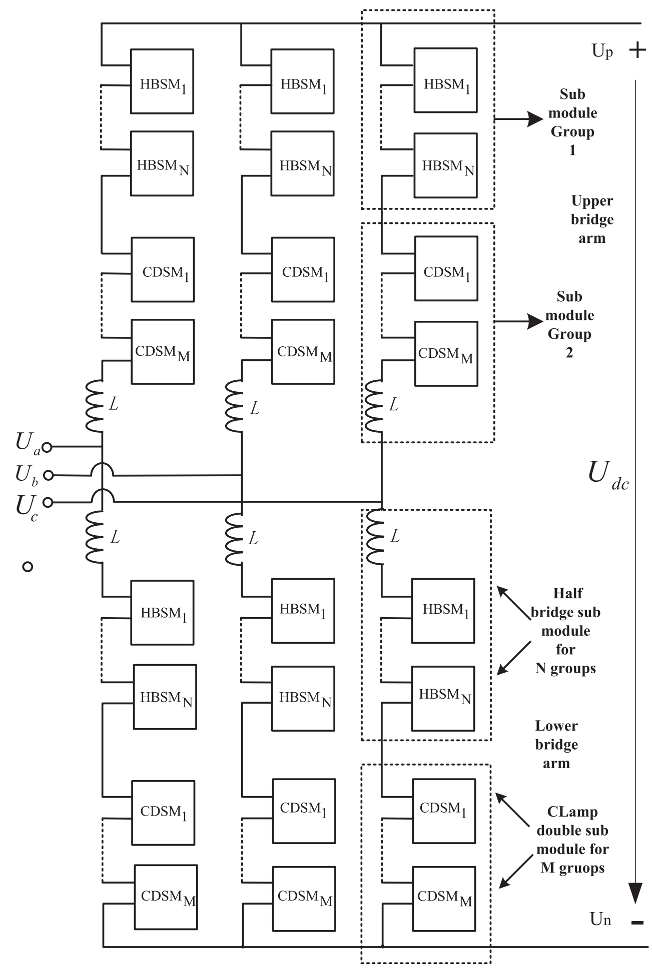

Fig. 3. Improved topology of MCH-MMC.

In order to meet the need of coordinated switching modules, two groups of sub module rating capacitance voltage shall satisfy Eq. (4), which means through coordination with two groups of sub modules, the first group of half bridge sub module capacitance voltage $U_{C\text{-}HB}$ are divided by the second group of clamping capacitance voltage into $2M + 1$ units;

$$U_{C\text{-}HB} = U_{C\text{-}CD}(2M + 1) \tag{1}$$

As shown in Fig. 3, the total number of sub module converter in each bridge arm is expressed as n_{sum}; the output level number of converter $n_{l\text{-}out}$ is expressed as Eq. (2); In order to maintain stable DC voltage, the DC bus voltage of inverter satisfy Eq. (3).