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# A new topology for current limiting HVDC circuit breaker☆

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ABSTRACT

With the high voltage direct current Transmission (HVDC) booming, HVDC grid has received wide attention. As an essential component in HVDC grid, high voltage direct current circuit breakers (DCCB) requires urgent and intensive study. A novel topology for current limiting DCCB (CL-DCCB) is proposed in this paper. The topology consists of several units which are divided into two classes: main circuit breaker (MCB) and branch circuit breakers (BCBs). The number of inductor branches can be flexibly selected to enhance the current limiting effect. The CL-DCCB can start current limiting operation when a suspected fault occurs. When the detection circuit reveals what has happened, it can be determined whether to implement breaking operation or recover to normal state. This mode allows longer fault detection time and circuit breaker operation delay while guaranteeing the fault current within the maximum limit of the system. Finally, Simulation model and experiment prototype are built to study the design criteria for CL-DCCB. It is observed that the maximum detection delay can be extended to 12 ms. Moreover, the current limiting effect can be enhanced when the number of inductor branches or the inductance of each branch is increased.

## 1. Introduction

DC grid is a new type of power transmission system, which is obtained from voltage-source converter (VSC) type HVDC [1,2]. It interconnects multiple AC and DC systems with higher reliability due to its redundant DC lines. DC grid technology is especially suitable for large-scale wind power or photovoltaic and other new energy integration, which is the future direction of DC transmission technology [3,4]. China is building a demonstration project named as Zhangbei DC grid. The project is designed for the collection and transportation of large-scale wind power, photovoltaic, energy storage, and other energy forms. The rated voltage of this DC grid is ± 500 kV, with approximately 648 km overhead transmission lines [5].

Due to the low damping of DC system and no zero crossing point of the DC current, it is difficult to isolate the DC fault. Especially in large-scale power grid. Take a scenario of DC grid shown in Fig. 1 as an example, the DC grid is divided into two parts by a DC-DC converter. The upper part $C_1$-$C_4$ is a cyclic and radiation mixed connection structure. The lower part is a point-to-point DC system. Obviously, the normal operation of the whole network will be hardest hit if the fault cannot be cleared in time.

One way to solve this problem is to use novel MMC sub-modules (SMs) with DC fault clearance capability [6,7]. Once short circuit fault occurs, the fault current discharge path can be blocked by blocking MMC SMs. Finally, the mechanical switch can be used to interrupt the fault line, thus, the system fault characteristics can be greatly improved. However, the novel SMs will inevitably increase the cost and power loss of MMC. More importantly, all the converter station must be blocked under fault condition. Thus, the loss of power transmission capacity will affect the normal and stable operation of the whole grid. Taking Fig. 1 as an example, if a short-circuit fault occurs in the transmission line among converter station $C_1$-$C_4$, all these converter station should be blocked, then mechanical switch can be used to isolate faulty lines when the fault current drops to zero. The outage of those converter stations means a quick stop of electricity transmission in the whole grid, which is unacceptable.

The DC-DC converter can also be configured in the grid to isolate the DC fault, and the high frequency transformer of the DC-DC converter is undoubtedly a good isolating device. Through the control of the DC-DC, the fault can be isolated quickly. However, the configuration of DC-DC in the grid is limited with the issue of cost and power loss, thus the protection area of the grid is limited [8,9].

SCFCL is featured with good current limiting effects and fast response, but the technology is not yet mature, and expensive [10,11].

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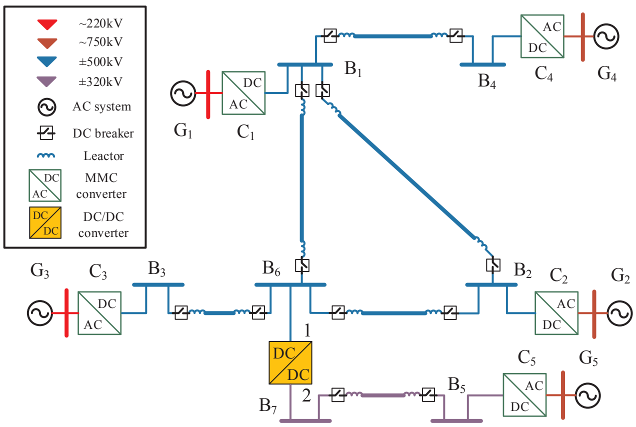


**Fig. 1.** A typical structure of DC grid.

Moreover, it does not have the fault isolation ability. It still relies on other equipment to cut off the DC fault current.

The DCCB is a relatively safe solution because it can be flexibly arranged at any point in the grid and can interrupt the fault circuit without affecting the operation of the converter and the normal DC line [12]. The hybrid DCCB has been deeply studied by [13]. The design idea of this type DCCB is to close the mechanical switch under normal condition to reduce the on-state power loss. The power electronic branch only works under the condition of fault status. A 320 kV/2kA hybrid DCCB is manufactured by ABB, Ltd., in 2012, as shown in Fig. 2. On the fault status, firstly, block all the IGBTs of branch 1 and trigger all the IGBTs of branch 2, the fault current will be transferred from branch 1 to branch 2; secondly, open the UFD (ultra-fast disconnector) of branch 1 when the fault current in this branch is attenuated to zero; thirdly, close the IGBTs of branch 2 when the UFD is fully opened, then the fault current will be transferred to the MOA and attenuated to zero quickly.

However, the fault current may rise to the maximum limit of the IGBTs in hybrid DCCB under the condition of larger capacity transmission occasion. Increasing the current limiting reactance can avoid this problem but will affect the dynamic characteristics of the system. Therefore, many fault detection methods are unable to meet the needs of DC grid protection due to the time delay, which can only be used as backup protection strategies. A feasible fault protection strategy in DC grid: the measured ROCOV [14], can meet the needs of rapidity. But in some cases it may cause misjudgment. In the case of small resistance short circuit occasion, a local line fault may be mistaken as a remote line fault, because the local ROCOV value may be lower than the critical threshold value to discriminate local and remote fault, and the misjudgment cannot be amended through communication due to high delay. At the same time, the fault current rising-rate is still too large. If the current limiting operation cannot be taken in time, the fault current will exceed the maximum breaking capacity of DCCB, and further lead to the outage of the DC grid. Thus, this type of hybrid DCCB cannot fully meet the need of DC grid.

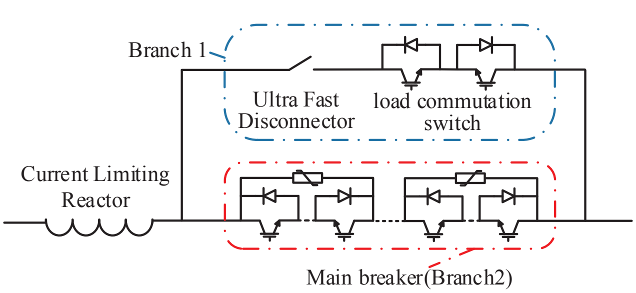


**Fig. 2.** Generic structure of hybrid DCCB developed by ABB.

The feasibility of future DC grids depends largely on their capabilities to withstand DC faults. In order to overcome the problems mentioned above, a novel DCCB topology with current limiting capability is proposed in this paper. It has modular characteristics. Therefore, the number of branches can be flexibly configured to increase the current limiting effect while reducing the current value of each branch to adapt large current condition. Because of its flexible current limiting ability, it can better cooperate with the ROCOV fault detection method and improve the system's reliability.

The rest of this paper is organized as follows. The topology and working principle are introduced in Section 2. The equivalent circuit diagram of the topology and the current limiting mechanism are also studied in this Section. The comparative analysis of the typical DCCB solutions is detailed in Section 3. To verify the validity and the feasibility of the proposed CL-DCCB, the simulation studies in PSCAD/EMTDC and experiment validation are presented in Section 4. Finally, the conclusions are given in Section 5.

## 2. Topology and working principle

### 2.1. Derivation of the topology

The proposed CL-DCCB consists of MCB and BCBs, as shown in Fig. 3(a), where $L$ represents the reactors. The MCB includes three branches: branch 1 is a low loss branch, branch 2 is a power electronic branch, branch 3 is an energy absorption circuit, as shown in Fig. 3(b). where, power electronic branch can break fault current rapidly. The function of energy absorption circuit is to protect the IGBTs from overvoltage, which consists of MOA (metal oxide arrestor). It should be noted that IGBT modules displayed in Fig. 3(b) have been configured with equalizing circuit to prevent partial overvoltage [15–17]. Considering that each IGBT is configured with a diode rectifier circuit, the fault current is converted to the same direction. Therefore, the MCB can be able to cut bidirectional current on the premise of half the usage amount of IGBTs.

The topology of BCB is shown in Fig. 3(c), which includes three branches: branch 1 is a low loss branch, which is composed of UFD and several IGBTs, branch 2 is composed of capacitor banks, branch 3 is an energy absorption circuit.

### 2.2. Working principle

With issue to MCB, when conducting UFD and all the IGBTs in branch 1 and blocking all the IGBTs in branch 2, the MCB will run under low power loss mode. As path A in Fig. 4(a). In order to quicken the breaking speed, fault current path should always be transferred to branch 2 when a suspect fault occurs. Then breaking operation can be executed quickly when the fault is determined. The process can be described in detail as follows: firstly, trigger all the IGBTs in branch 2 and then block all the IGBTs in branch 1; secondly, open the UFD in branch 1 when the current in this branch drops to zero. The current path in this working mode is shown as path B. If the fault is confirmed, the breaking operation can be executed by blocking all the IGBTs in branch 2. As the current is interrupted by these IGBTs, the overvoltage will be induced by system inductance, then the fault current will be transferred to MOA when the over-voltage value exceeds the protection voltage of the MOA, as current path C in Fig. 4(a).

Due to the function of the diode rectifier bridge, unidirectional arrangement of the IGBTs can meet the requirement of the bidirectional breaking operation. The forward and reverse current paths are shown in Fig. 4(b) separately. Considering that the capacity and cost characteristics of diodes under the same parameters are obviously better than that of IGBTs, and the halve of IGBTs can also reduce the static and dynamic voltage balancing circuit, which can effectively reduce the system cost.

For the BCB, the UFD and IGBTs of branch 1 are conducted under