A Novel Submodule Applied in HVDC Hybrid DC Breaker Topology

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Abstract. In recent years, with the vigorous development of power electronic technology, renewable energy sources such as wind power and solar energy utilization efficiency continuing to improve, and the application scale expanding unceasingly, DC power grid technology and the development of multiterminal HVDC has become a key link of transmission technology in our country. As the key equipment of biulding DC system, The direct current breaker need to be optimized on the aspect of topology,to promote the development of dc transmission. This article puts forward a new type of submodule which can be applicated in hybrid DC breaker. After a brief review of DC circuit breaker research status, the paper will give the topology structure, and analyzes its working principle. Then, verification and electrical stress calculation will be done in Saber Sketch simulation. Based on this, two other present scheme will be introduced, and finally a comparison will be made between the diffent scheme. As is concluded, the novel submodule can save the power elctronic device cost effectively

1 Introduction

Large-scale renewable energy access, transportation, and consumption request interconnectino and complementary with load, energy storage, thermal power, hydropower and other energy in Internet more quickly and widely, this means that the traditional power grid structure, electric equipment and operation mode will be subject to severe challenges. Constructing cross-regional dc grid, is the inevitable development trend in today's power transmission system.[1-2]

In the recent double side DC transmission system, when failure occurs in certain transmission line, the protection strategy is cutting off protection switch in the converter valve, or cutting off nearby AC breaker, which will stop the entire transmission system of power transmission, so as to achieve the aim of protecting grid system. But in multiterminal HVDC system, the strategy will greatly reduce the transmission efficiency and the stability of the system. We hope that when failure occurs on the transmission line, the faults will be cut off quickly and specifically, to ensure the normal operation of other transmission line. Therefore, DC circuit breaker is important equipment in the future dc power grid.

On the aspect of high voltage hybrid DC circuit breaker, there are corperations and research institudes have made development in the recent years[3-11].In 2012,ABB Corp has developed a 320kV hybrid DC breaker full-scale prototype based on press-pack IGBT, the turn off current is 9kA,and fault duration time is 2ms[6-8].In 2013,Alstom Corp has developed a 120kV hybrid DC breaker full-scale prototype which can turn off 7.5kA fault current[9].At the end of 2013,State Grid Corperation of China successfully developed a 200kV hybrid DC breaker ,which can turn off 15kA fault within 3ms[10-11].

In this paper, a novel high voltage hybrid DC circuit breaker topology will be proposed. This topology is based on Diode and IGBT which is called “Diode Full-bridge submodule, DFS”. The auxiliary branch can be made by many DFS in series. This novel topology can not only maintain existing performance, but also reduce the cost by 20%~30%.In the first part of paper, the structure and working principle will be introduced, and then verificate the circuit breaker working process in simulation soft. In the second part of paper, two other present scheme will be introduced, and finally a comparison will be made between the DFS scheme, Anti-series scheme and IGBT full-bridge scheme.

2 The Structure and working prinple of novel topology

2.1 Topology structure

The novel high voltage hybrid DC circuit breaker topology structure is shown in Fig.1.Main branch is composed of fast mechanical switch and little DFS, which will flow the normal working current. Auxiliary branch is composed of series DFS. the DFS structure is shown in Fig.2

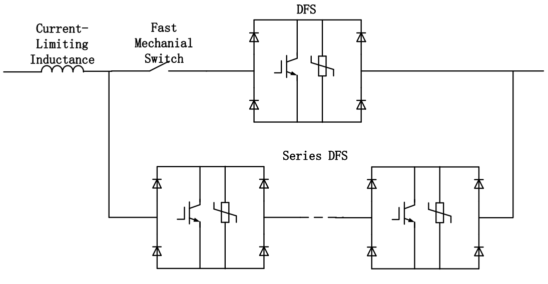


Fig.1 New Type Hybrid DC Breaker Topology

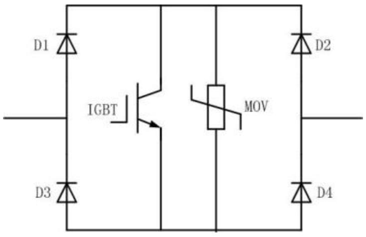


Fig.2 Diode Full-bridge Submodule Topology

In the DFS topology,D1,D2,D3,D4 is Diode. When DFS begins to conduct fault current from left to right, the current path is D1-IGBT-D4.When DFS begins to turn off, the current path is D1-MOV-D4.In turn, when DFS begins to conduct fault current from right to left, the current path is D2-IGBT-D3.And when DFS begins to turn off, the current path is D2-MOV-D3.So the double-side fault current can be turned off in DFS topology. The Fig.3 is waveforms of DC circuit breaker based on the DFS. Ia means normal working current value, Ib means equipment protection start value, Ic means circuit breaker turn off current value.i_main means main branch current,i_zy means auxiliary branch current, and i_arr means arrestor branch current.

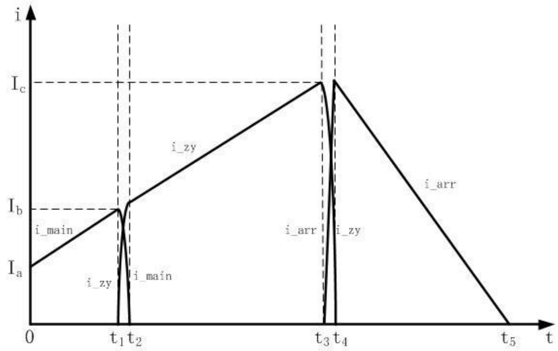
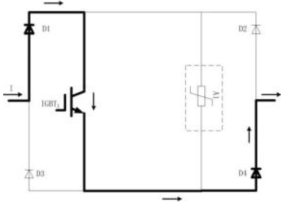


Fig.3 The DC breaker waveform based on DFS

2.2 Working principle

Suppose the current flow left to right: When DC transmission line is on normal working state, the current flow through the main branch. The number of DFS on main branch could not be too much because DFS here only endure the total IGBT Vce(sat) on the auxiliary branch, which is several hundreds of volt, and fast mechanial switch has been open when IGBT on the auxiliary turn off.

When the fault happens in the transmission line and fault current rise to the set value, the DFS on main branch should be turned off. Meanwhile, the DFS on auxiliary branch are turned on, so the current transfer from main branch to auxiliary branch, as is shown in Fig.4.



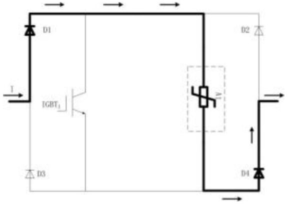


Fig.4 Turn-on process of DFS **Fig.5** Turn-off process of DFS

After several millsecond, the fast mechanical switch has restored insulating ability. After that, DFS on the auxiliary can be turned off, which results in the voltage on current limiting inductance rise rapidly, until the operate voltage of arrestor. Then the fault current will flow through the arrestor, which absorb the fault energy. Until the fault energy and fault current fall down to zero, the disconneter open, and working process is over, as is shown in Fig.5.

When the fault current flow in anti-direction, the working principle is similar, as is shown if Fig.6.

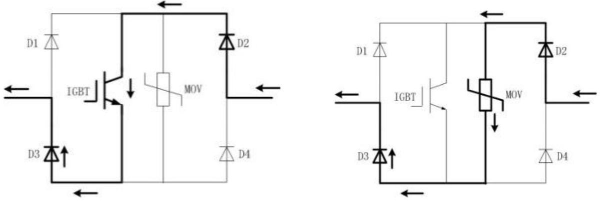


Fig.6 Turn-on and Turn-off process of DFS when current anti flow.

2.3 Simulation analysis

In order to verify the working principle and performance, and calculate the electric stress in IGBT in auxiliary branch, the simulation work has been done in Saber Sketch. First of all, ABB 4.5kV/2kA press-pack IGBT has been modeled in Saber Sketch according to the datasheet. Then, the simulation has run in the situation of 35kV transimission line.

Tab.1 The related simulation parameter in Saber

Parameter	Value
Udc/kV	35
Ls/mH	18
Rs/Ω	35
Irating/kA	1
Iset/kA	1.3
Isc/kA	5
tsc/ms	2
IGBT numbers	18

According to the simulation results, the electric stress of IGBT in DFS on auxiliary branch has been studied as follows:

(1)Commutation process: When fault current reach the set value, the commutation process begins. Actually, the IGBT on auxiliary branch will turn on first, after several us delay time, the IGBT on the main branch will turn off. This is because if IGBT on auxiliary branch hasn't been turned on in time when IGBT on main branch has been turned off, there will be a pulse voltage across the IGBT on both branch, which will bring damage on power electronic devices. In the commutation process, the max di/dt rate is 0.8kA/us, IGBT device turn on in the situation of load shorted, so this process could be also called the “Over Current Turn-on process”, as is shown in Fig.7.During this process, the current distribution of IGBT chips will be diverse because of the inconsistency of press distribution inside press-pack IGBT and stray inductance between chips and thus, the reliability of device will be reduced[16-17].

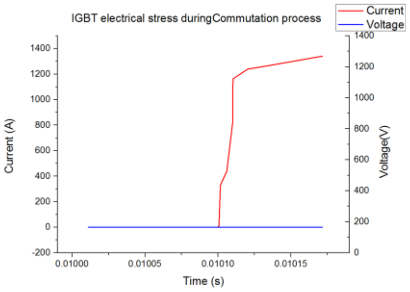


Fig.7 The current and voltage waveform in single IGBT device during commutation process.

(2)Current rise process: When the commutation process is over, the fault current will keep rising cause fast mechanical switch need several millseconds to restore insulating ability. The current rise rate depends on current-limiting inductance, and the voltage across IGBT on auxiliary branch is IGBT saturated voltage Vce(sat).In this process, for the purpose of utilize IGBT current turn off capability as much as possible, the fault current will rise from set value to near saturated current Ice(sat),which is 5-6 times the rating current. Therefore, the temperature inside IGBT device will rise because of the conduction loss. So the demand for IGBT device work in this situation and maintain reliability is the important request of device design[18].

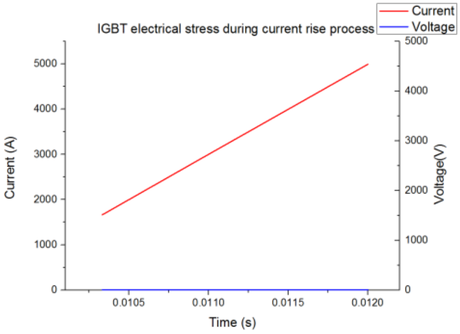


Fig.8 The current and voltage waveform in single IGBT device during current rising process.

(3)Turn-off process: After fast mechanical switch restored insulating ability, IGBT on auxiliary branch can be triggered to turn off. The turn-off current valus is 5-6 times rating curent, the current change rate is 0.5kA/us, voltage change rate is 0.2kV/us. During the turn-off process, IGBT device will suffer large electrical and thermal stress, and transient temperature will rise, which will raise the harsh demand of IGBT device application reliability[19-22].

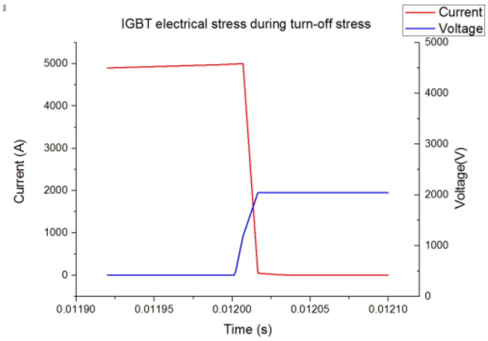


Fig.9 The current and voltage waveform in single IGBT device during interrupted process

3 The Comparison of Different Hybrid DC Breaker

3.1 Other two present main topology

(1)Anti-series Submodule Scheme: The topology based on anti-series submodule is shown in Fig.10 and Fig.11,which is applied in ABB Corp’s scheme in 320kV/9kA Hybrid DC breaker. This topology is composed of three paralelled branch: branch one is main branch, branch two is auxiliary branch and branch three is arrestor branch. Main branch is composed of fast mechanical switch and little anti-series submodule, which is used for conduct normal working current. Auxiliary branch is composed of many series anti-series submodule, which is used for turn off fault current. Arrestor branch is composed of many paralelled arrestor, which is used for absorbing the short energy.

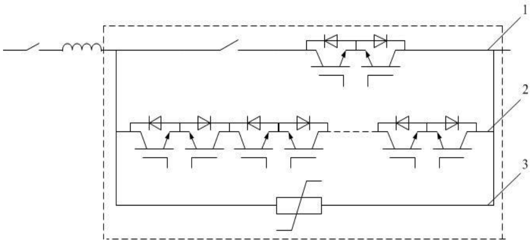


Fig.10 Hybrid DC Breaker Topology based on anti-series submodule

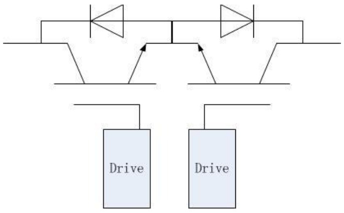


Fig.11 Anti-series submodule structure

(2)IGBT Full-Bridge Submodule Scheme(FBS):The topology based on FBS is shown in Fig.12 and Fig.13,which is applied in State Grid Corp in China in 2013 for 200kV/15kA Hybrid DC breaker scheme.This topology is also composed of three paralelled branch,the structure and working principle is similar to anti-series submodule scheme, and the difference is anti-series submodule is replaced by FBS,and it can turn off doubled fault current.

3.2 Comparison of three submodule scheme

As is verified in Saber Sketch simulation, there is little difference of electrical and thermal stress in single IGBT between three diffent submodule. The main difference exists in cost. The Diode Full-Bridge Submodule(DFS) contains one IGBT device,one IGBT drive and four power diodes; The Anti-series Submodule(AS) contains two IGBT devices, two IGBT drives and two power diodes;The IGBT Full-Bridge Submodule(FBS) contains four IGBT devices, four IGBT drives and four power diodes. Because the FBS scheme can be simply equivalent to two paralelled IGBT branch, so we reduce half the IGBT device, drive and power diode in FBS module for comparison in the same performance.

Due to the different price of IGBT device, drive and power diode between different model and manufacturers, we make the comparison using the unit of “Diode number”, as is shown in Tab.2.

Tab.2 The price comparison between three submodule using the unit of “Diode number”.

“Diode” price	DFS	AS	FBS
1IGBT+1Drive=2Diode	6	6	6
1IGBT+1Drive=3Diode	7	8	8
1IGBT+1Drive=4Diode	8	10	10
……	……	……	……
1IGBT+1Drive=+1Diode	+1	+2	+2

We can infer from the Tab.2 that, if the price of 1 IGBT device and 1drive is higher, or, the price of 1 Diode is lower then the hybrid DC circuit breaker scheme used DFS will save more cost. According the present market price, we estimate that 1 IGBT + 1 Drive = 4 Diode, that is, DFS will save around 20% cost.

4 Conclusion

DC power grid based on flexible HVDC technology application prospect became bright and clear. as one of the technical bottleneck, DC circuit breaker research has developed rapidly. Based on this ,this article first bring a novel Diode Full-Bridge submodule, which is composed of four power diode and 1IGBT.Then we verify the working principle of the hybrid DC circuit breaker using FBS in 35kV transmission line in Saber Sketch. Finally, we compare DFS with Anti-series Submodule(AS,ABB Corp)and IGBT Full-Bridge Submodule(FBS,SGCC).On the one hand, the performance in the three submodule is around the same; On the other hand ,DFS will save 20%~30% cost from the aspect of power electronic device.

Acknowledgement

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