Study of SFCL for multi-terminal HVDC network

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I. INTRODUCTION

In last few years, China has developed a three terminal ±160 kV VSC DC transmission network and a five terminal ±200 kV VSC DC transmission network. A four terminal ±500 kV VSC DC transmission project is under construction. Multi-terminal VSC HVDC power transmission provides enhanced reliability and functionality. It also has the advantage in reducing conversion losses, and resolving the problems of renewable energy integration.

However, there are still some obstacles in promoting multi-terminal VSC HVDC power transmission. One of the major obstacles is the inadequate interrupting capacity of available DC circuit breakers. For a reliable fault isolation in a VSC DC transmission network, to make use of FCLs to compensate the circuit breaker's inability is being considered.

The required functional characteristics of a DC FCL for a multi-terminal VSC HVDC network have significant difference from those of an FCL for an AC power grid. To a satisfactory control of short-circuit fault current in a multi-terminal VSC HVDC network, the FCL not only need to provide a sufficient large resistance during a fault, but also need to provide a sufficient large inductance in the few milliseconds of the fault. A pure resistive FCL may not fit such an application.

Through analyzing the structure of multi-terminal VSC HVDC networks and the transient characteristics of the faults in such systems, we have proposed to use a superconducting FCL(SFCL) in practicing this solution. Otherwise, a conventional FCL may cause too much energy loss during normal power transmission, making the idea unpractical.

We have developed a circuitry structure for an SFCL suitable for multi-terminal VSC HVDC networks. Details of our work are presented in this article.

II. AN FCL SUITABLE FOR MULTI-TERMINAL VSC HVDC NETWORKS

When a fault happens in a multi-terminal VSC HVDC transmission network, the short circuit current goes up very fast and can exceed several tens of times of the rated current of the transmission line in a few milliseconds. These characteristics put forward elevated requirements for the converters, circuit breakers and other primary equipment in terms of the response time and the withstand voltage level. Therefore it is important through the analysis of a multi-terminal VSC HVDC network structure and its fault current characteristic to study the special requirements for an FCL working in such kind of system.

Fig. 1 is the configuration schematic of a four-terminal VSC HVDC network. In this network, a pair of FCLs is installed at each MMC. The topology diagram of the MMC is demonstrated by Fig. 2. We carried out the investigation by comparing the performances of a pure resistive FCL and a pure inductive FCL in this network. The performances of the two FCLs were assessed by computer simulation. The resistance of the resistive FCLs was set to 8 Ω and the inductance of the inductive FCLs was set to 200 mH respectively. The network parameters used in the simulations are listed in TABLE I. In this work, we assumed two cases that one is a pair of the resistive FCLs used and the other is a pair of the inductive FCLs used.
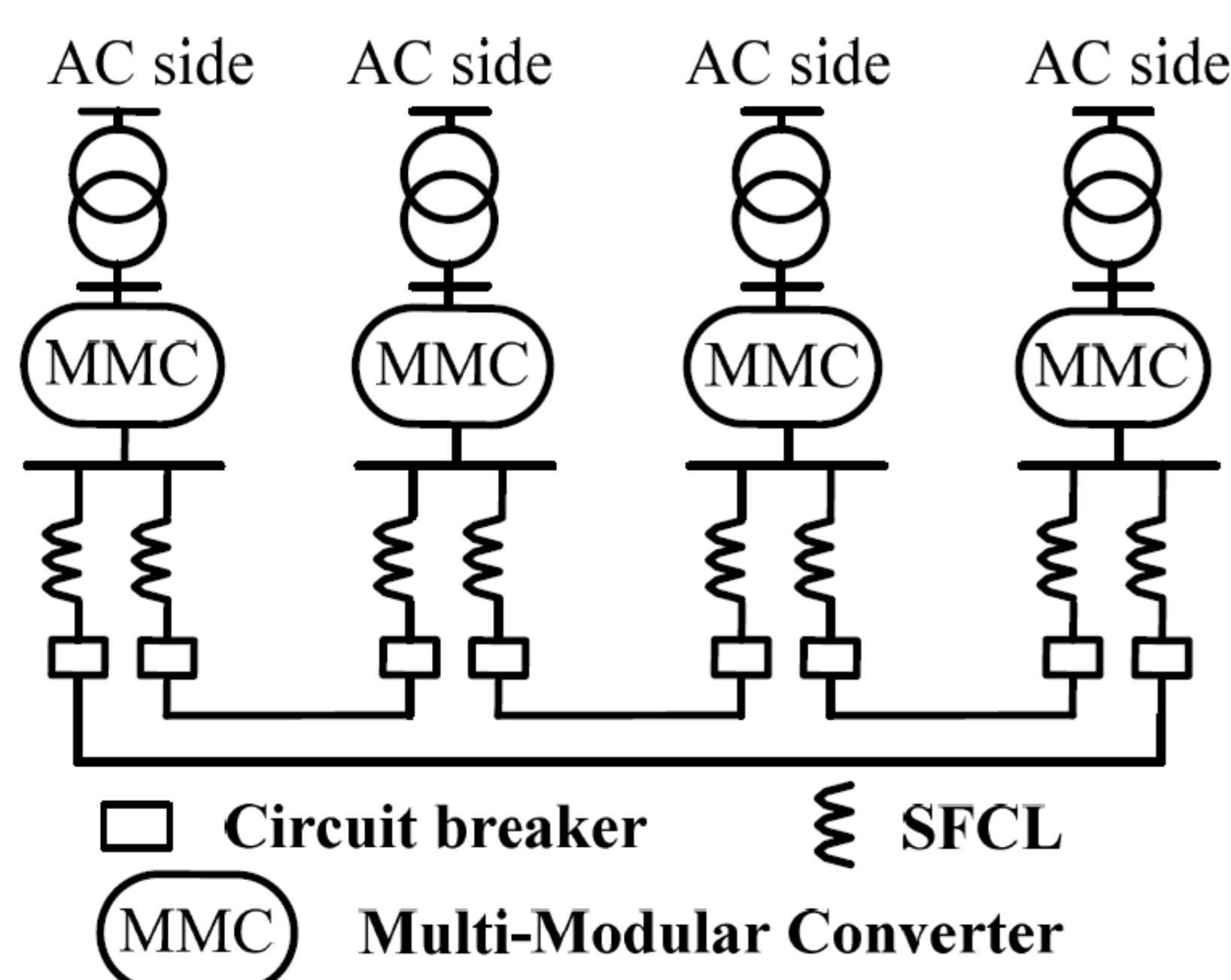

Fig. 1 Schematic for a four-terminal VSC dc network with SFCL installation
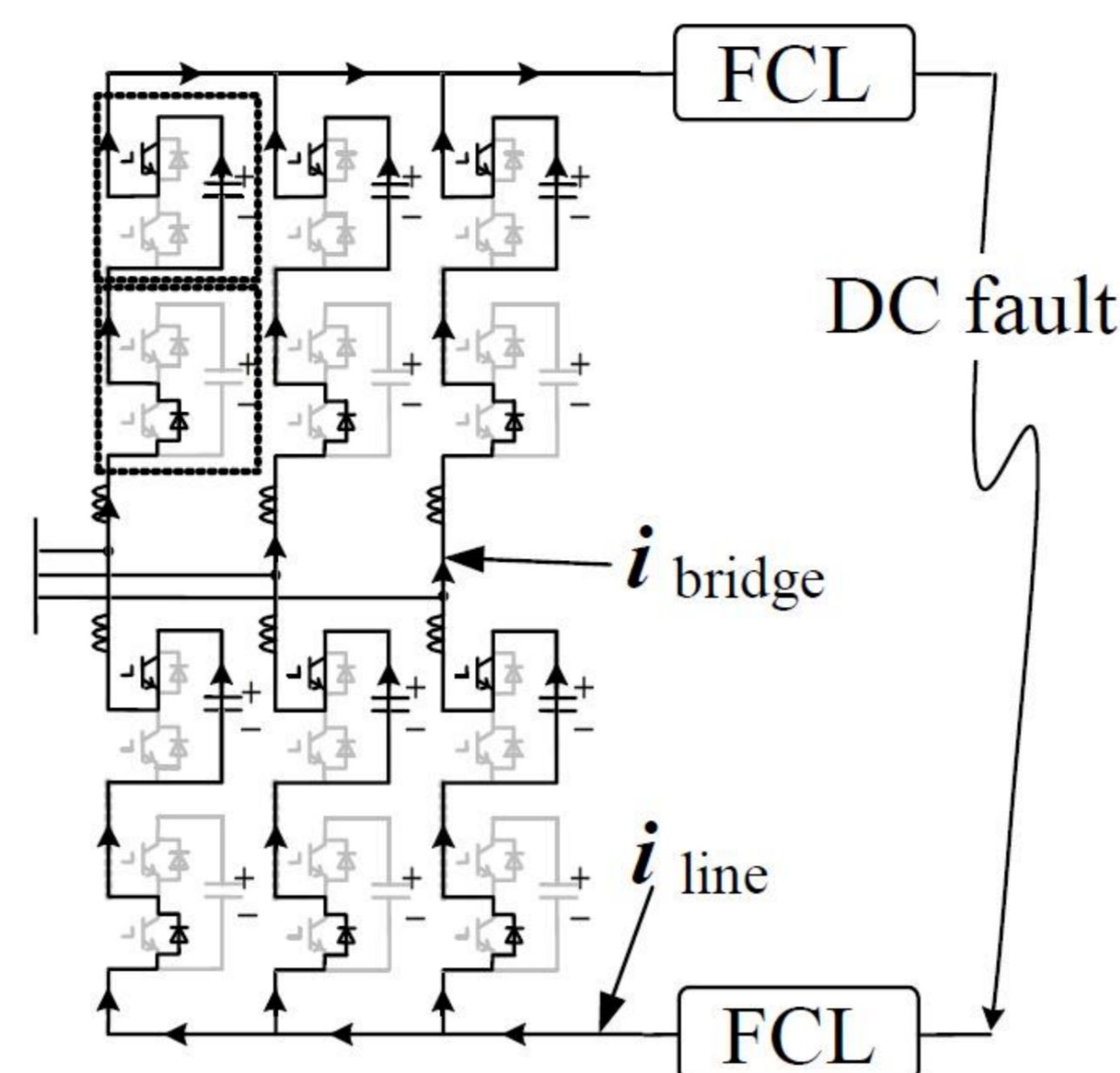

Fig. 2 The MMC topology diagram

TABLE I NETWORK PARAMETERS FOR THE SIMULATION WORK

PARAMETERS	Value
Rated capacity	300MVA
Resistance of the dc line	0.012ohm/km
Inductance of the dc line	1.42mH/km
Rated dc voltage	±200kV
Rated dc current	0.75kA

Fig. 3 gives the comparison of the limited fault current of the transmission line between these two cases. The result shows that the resistive FCLs have better performance in limiting the lasting fault current on the transmission after about 10 milliseconds after the fault while the inductive FCLs is more effective in suppressing the fault current in the early stage of a fault incident. It is clear that adequate resistance is crucial to restrain the lasting fault current in the transmission line.
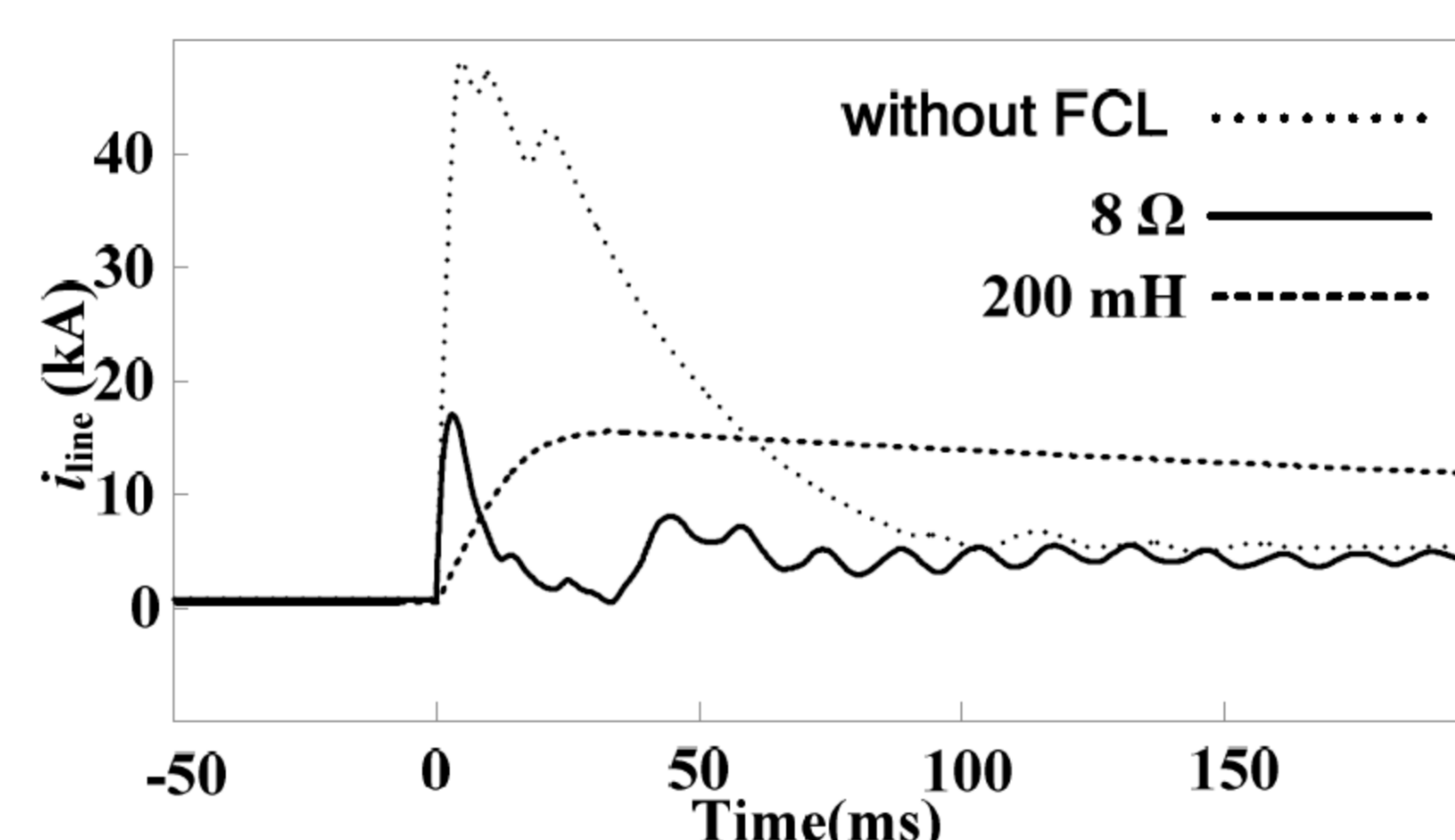

Fig. 3 Fualt currents in the transmission line with resistive and inductive FCLs

Fig. 4 is the comparison of the limited fault current in the MMC's bridge arm between these two cases. It is obvious that the inductive FCL has much more suppressed the fault current in the MMC's bridge. At the first several milliseconds after a fault, an adequate inductance can curb the fast increasing fault current within the threshold current of the bridge arm to avoid the block of the MMC. As the result, the MMC remains controllable during the fault clearance so that it may not need to cut off the ac input and the rest of the network may survive the fault if the circuit breaker functions properly to isolate fault spot with the assistance of an FCL.

From the discussions above, we can conclude what for a multi-terminal VSC HVDC transmission network an effective FCL should be able to throw in both resistance and inductance during fault current limiting. An adequate inductance is required immediately after a fault and then it is necessary to have a sufficient resistance for an effective FCL in a multi-terminal VSC HVDC network.
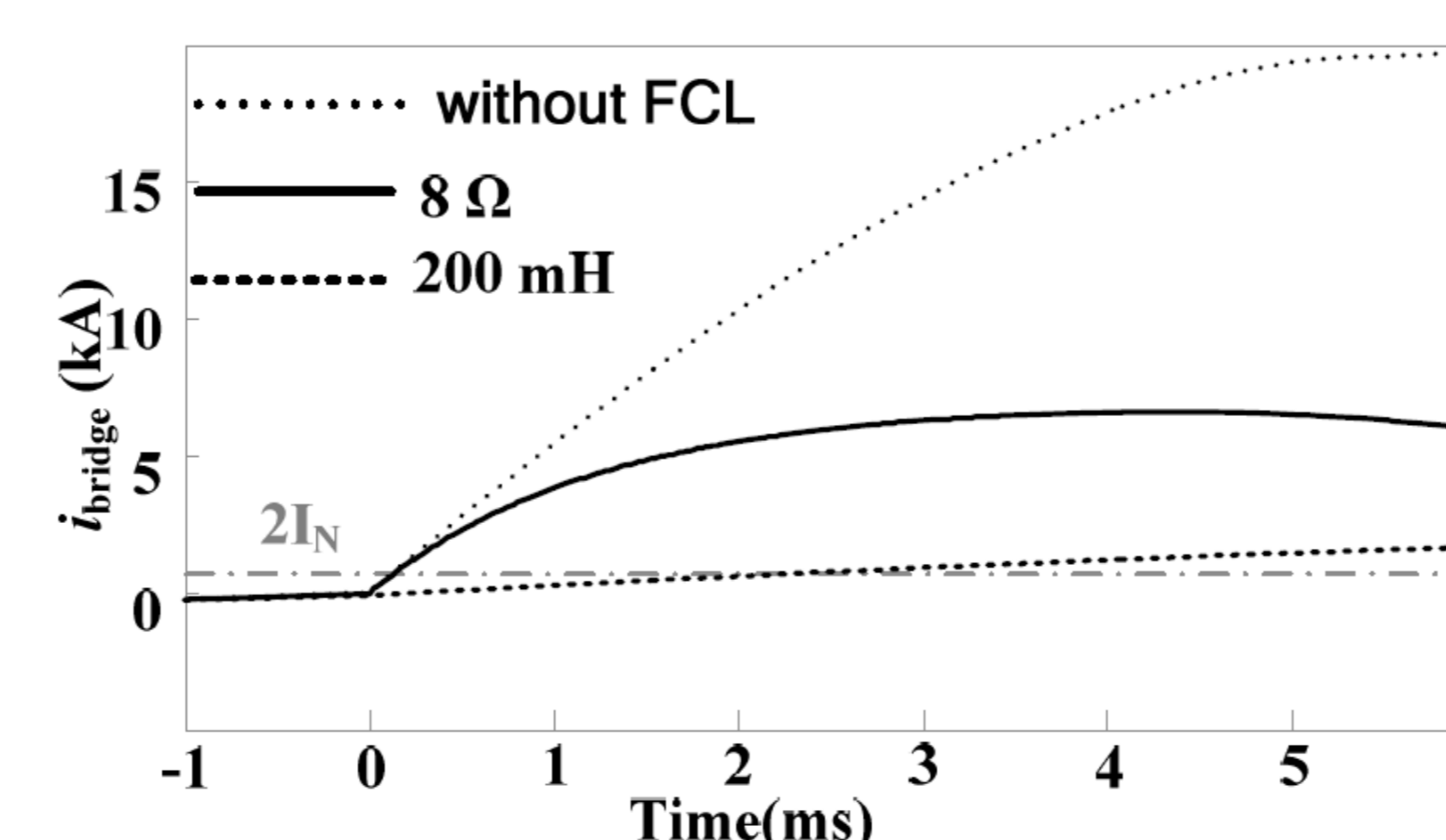

Fig. 4 Fualt currents in the MMC's bridge arm with resistive and inductive FCLs

III. THE CIRCUITRY AND ITS COMPONENTS OF THE SFCL PROPOSED

To satisfy the functional requirements for multi-terminal VSC HVDC network application, we proposed an SFCL configuration demonstrated by fig. 5. The circuitry of the proposed SFCL consists of four major parts, i.e. a superconducting reactor, a shunt, a current limiting resistor, and a high speed switch.
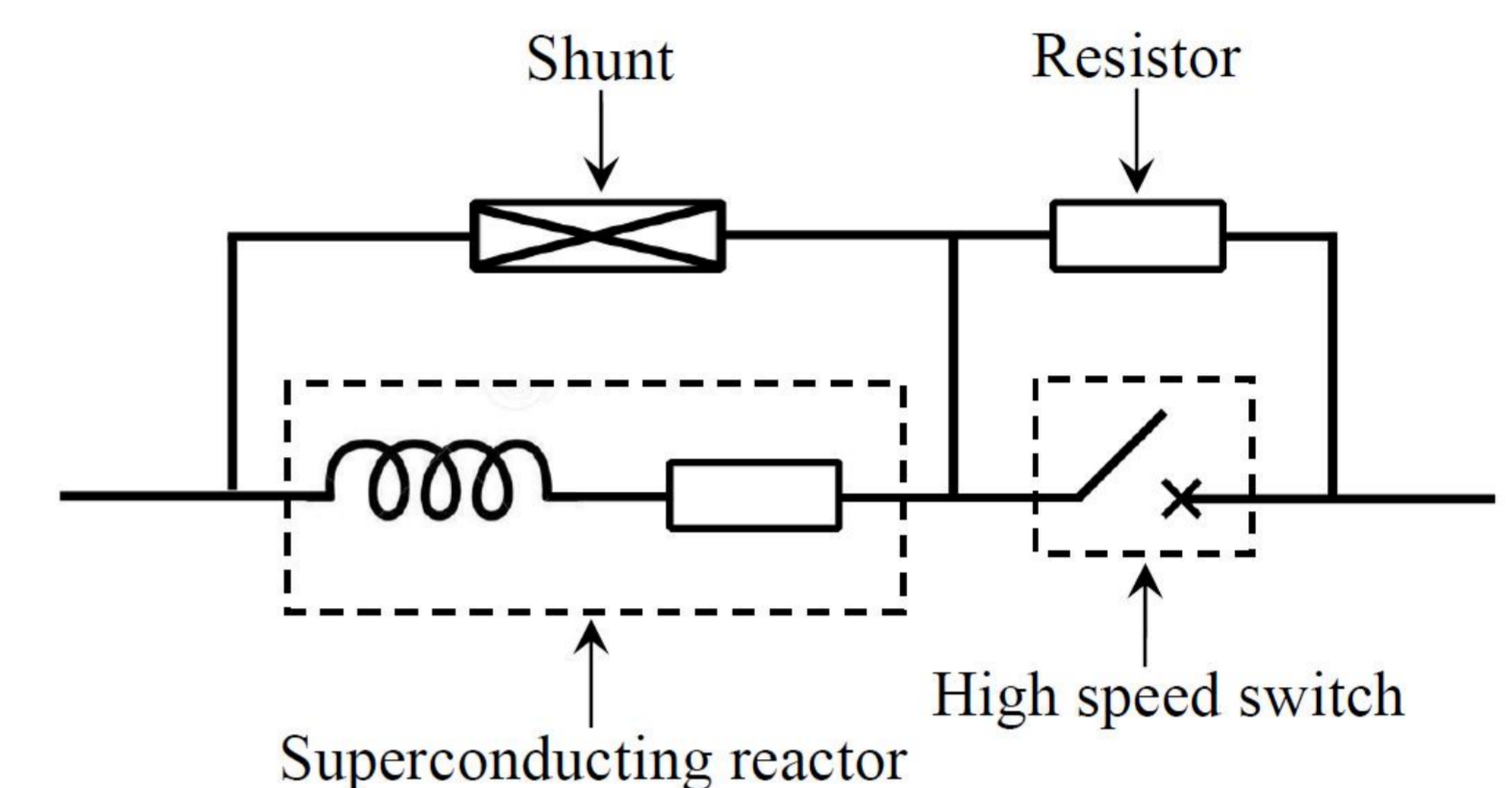

Fig. 5 The proposed SFCL configuration for multi-terminal VSC HVDC network

For a typical multi-terminal VSC HVDC(±100-500 kV) transmission network, the reactor should have an inductance of 100 mH or larger. Conventional reactor with such a capacity will cause significant Joule loss and voltage drop, so the use of superconducting one is an advanced choice.

When a fault takes place in the dc network, the inductance of the superconducting reactor will restrain the rise of fault current in the convertor's bridge arms to prevent the bridge arms from locked in the first several milliseconds of the fault. If the any of bridge arms is locked, the convertor will quit working and the whole network will stop operation. Then, any fault isolation effort becomes meaningless. So the main function of the reactor is to curb the fault current at the early stage of the fault so that the circuit breaker can properly interrupt before the locking of bridge arms. A successful interruption can isolate the fault and have the rest of network keep operation.

As soon as the fault is detected, the high speed switch will break its branch in 2-3 milliseconds and all the current will then go through the current limiting resistor. The superconductor coil of the reactor may quench at some point during the fault. The combined impedance of reactor, the shunt, and the current limiting resistor will then contain the ongoing fault current within the circuit breaker's working capacity.

The shunt may be a resistor or a combination of a resistor and an inductor. Generally, the resistance of the resistor should be about 10 Ω or larger.

A high power resistor should used for the current limiting resistor. The resistance of the resistor should be determined according to the current limiting requirement for the network, likely in the range of 2-3 Ω for most cases.

Since only the minor part of the voltage is on the switch during a fault, it is feasible to use power electronics chips such as IGBTs to build the high speed switch. If necessary, a high power resistor rated 0.5 Ω or smaller may be added to this branch to moderate the difficulties building the high speed switch. The penalty of using the resistor will be the increased transmission loss during normal power transmission.

Air-core reactor with an inductance of 150 mH or larger may have a gigantic size, so we propose to use iron-core reactor which can greatly reduce the size and the cost of the reactor.

With the installation of this kind of SFCLs, during the normal power transmission, there is little negative influence on the DC network since the SFCL would present a very small resistance. When a fault occurs, the SFCLs can effectively control the fault currents both in the MMC's bridge arm in the DC network transmission line. This will prevent the MMC non-necessary blocking and help the circuit breaker work properly. The fault survival rate of a multi-terminal VSC HVDC network can be greatly increased.

IV. SUMMARY

We proposed a new type of SFCL aimed for multi-terminal HVDC applications. The SFCL is able to provide enough inductance needed immediate after a fault to curb the fault current in the MMC's bridge arms and then to provide enough resistance needed for containing the lasting fault current in the DC transmission line. With the installation of this kind of SFCL, the fault survival rate of a multi-terminal VSC HVDC network can be greatly enhanced.