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„Protection Schemes for Modular Multilevel Converter Based High Voltage Direct Current Transmission System Converters “

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Motivation

The development of suitable high-voltage DC (HVCD) breakers is an important element in the design of HVDC transmission systems as fault protection in DC systems is more complicated than in AC systems. The lack of zero crossing between DC voltage and current is a serious challenge, making it more difficult to realize insulation and arc extinguishment than in AC systems. Traditional mechanical circuit breakers have long switching times (tens of milliseconds) that make it difficult to meet the protection requirement of a DC system.

In recent years, several new HVDC breakers and relevant protection schemes have been proposed. These topologies and protection schemes have a variety of advantages and disadvantages. This dissertation compares different fault current protection schemes with regard to power loss, switching time, the number of semiconductor elements and so on; proposes a new protection scheme; and discusses the overvoltage protection scheme of insulated-gate bipolar transistors (IGBTs) in multilevel modular converters (MMCs; called random first blocking), With this method, there are many possible fault-current slopes after the first blocking. The threshold current can be determined using this method.

HVDC systems and their protection

Thyristor converters are widely employed as rectifiers in linear constant current (LCC)–based drives to provide an adjustable DC current. A thyristor converter can work in either rectifying or inverting mode. When the fault occurs in LCC HVDC, the thyristors are all blocked. Thyristors can be turned off at the zero crossing point of current.

For two-level and three-level VSCs, large capacitors are installed at the DC side. They smoothen the DC voltage and make sure that the DC side reacts like a voltage source. However, when the DC fault occurs, due to the discharging of the DC link capacitors, substantial overcurrent is generated due to the rapid decrease in DC voltage. On the other hand, when the fault is detected, fully controllable switches are all blocked. However, the anti-paralleled diodes act as an uncontrolled rectifier, which cannot block the fault current.

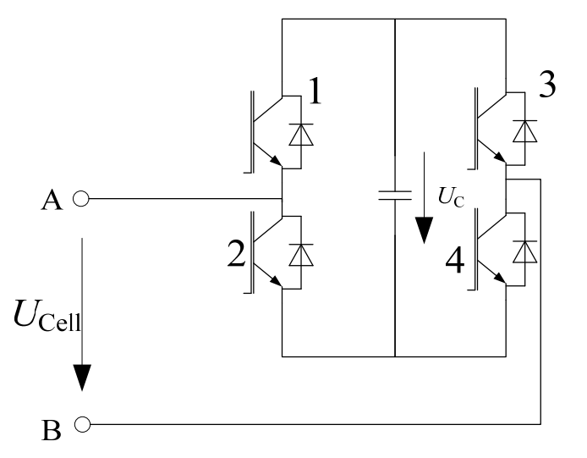
For modular multilevel converter (MMC), because of its modularized structure, it is easy to realize hundreds voltage levels to approximate AC voltage and the THD can be reduced to a great extent. Hence, only small filters are needed or may even be omitted. However, the MMC with half-bridge cannot block the current path during the DC fault, because the diodes act as an uncontrolled rectifier. In order to realize the protection of HVDC system, different protection schemes are proposed.

Protection schemes independent of HVDC converters

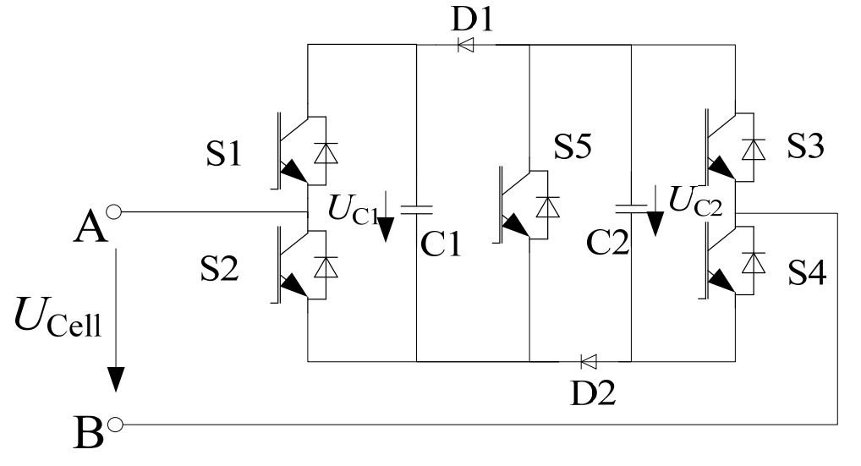
- All-solid HVDC breaker
  - short switching time, the over-current can be limited very fast
  - the conduction loss of semiconductor devices is very large
- Resonant HVDC breaker
  - during normal operation, the resonant HVDC breaker has no extra loss
  - there is always plasma between the contact of the mechanical switch
- Hybrid HVDC breaker
  - low power loss during normal operation, the switching time is limited within several milliseconds
  - the over-current is sometimes too large, and the IGBTs in the main switch must be designed specifically

Protection schemes based on classical MMC converters

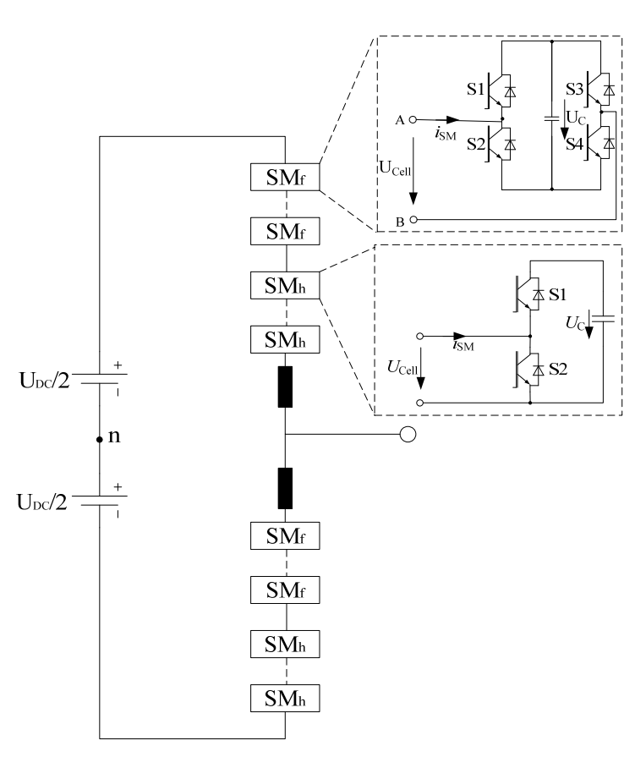
Full bridge sub-module



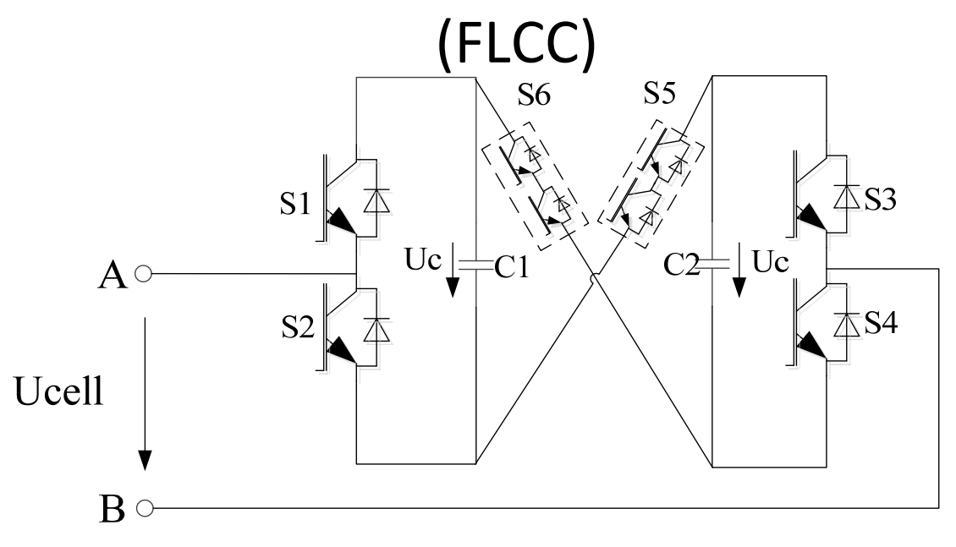
Clamp-double sub-module(CDSM)



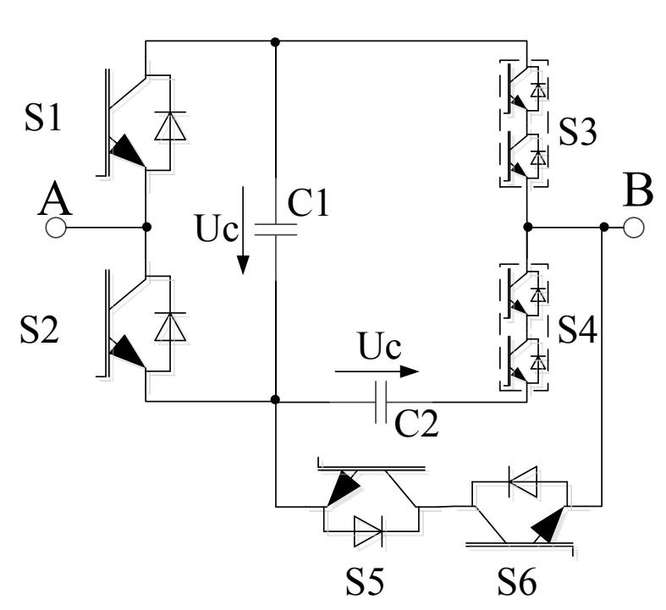
Hybrid MMC



Five-level cross-connected cell type (FLCC)

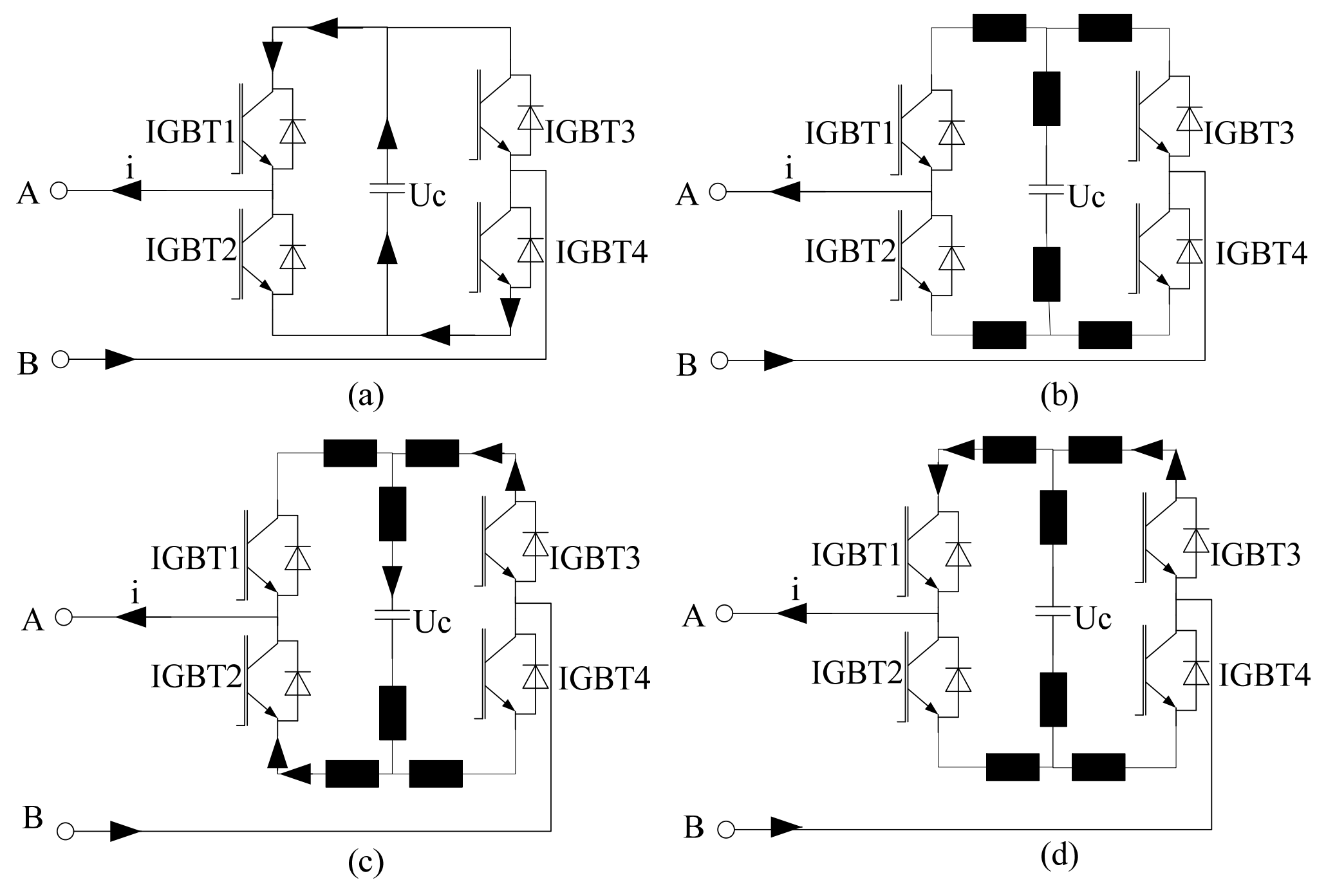


Four-level MMC cell type(FLCT)



Full-bridge (FB) MMCs are the first modified MMCs to block the fault current. However, the hardware cost of FB-MMCs is twice that of HB-MMCs, and the loss power of FB-MMCs is larger than HB-MMCs' as well. In order to block the fault current and solve the problem of high hardware costs and loss power, clamp-double (CD) MMCs have been developed. However, CD-MMCs cannot work under over-modulation. In order to realize fault ride-through capability, lower hardware costs and loss power, and overmodulation, other kinds of MMCs have been invented, including a five-level cross-connected cell type and a four-level MMC cell type; hybrid MMCs are also typical.

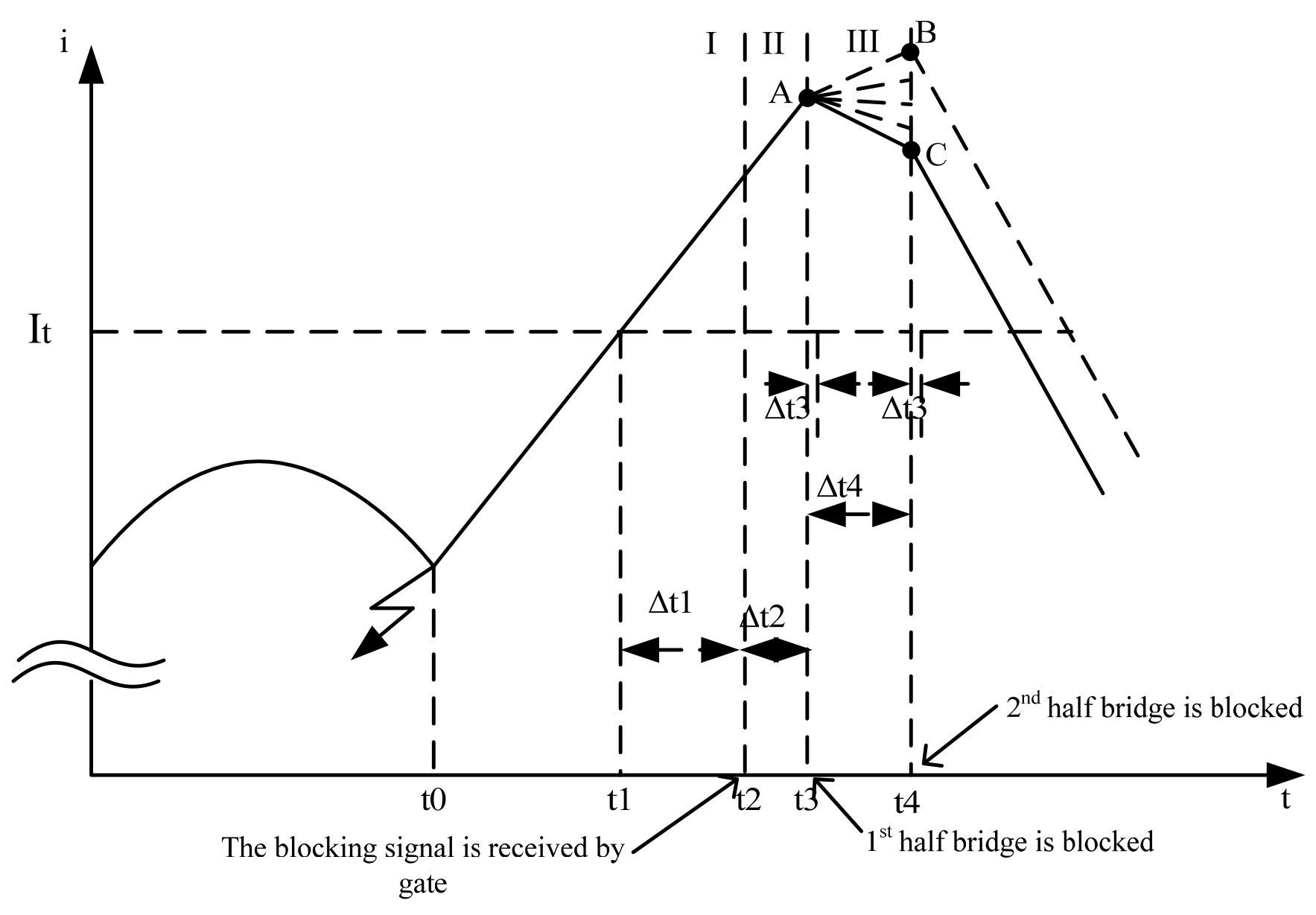
First blocking of FBSM

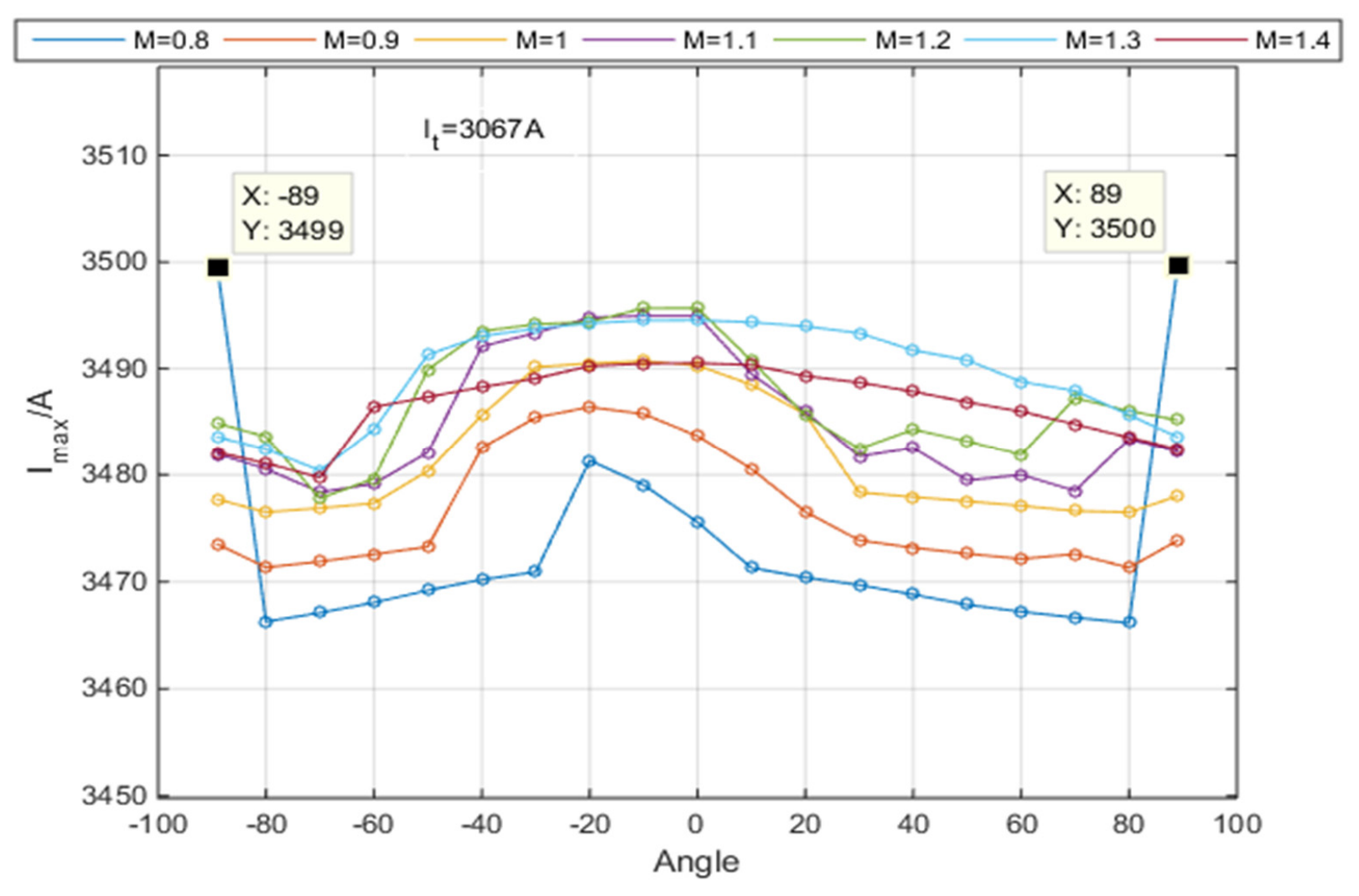


(a) (b) (c) (d)

Due to the stray inductance in the circuit (Fig. (b)), if all IGBTs are blocked simultaneously in each FBSM after the fault, IGBTs will withstand overvoltage (Fig. (c)). In order to reduce the stress of IGBTs, the random first blocking of the right and left sides is used. As illustrated in Fig. (d), if the right side is blocked first, the current will flow through IGBT1 and IGBT3 first. The second blocking will occur shortly thereafter. In this way, the stress of the IGBTs can be reduced.

If the first blocking is random, the output voltages of FBSM after the first blocking may also be random. There are thus many possible output voltages in each arm after the first blocking.





Because the fault current slope is the function of output voltage in each arm, there are a large number of possible fault current slopes after the first blocking. The maximum possible fault current can be calculated.

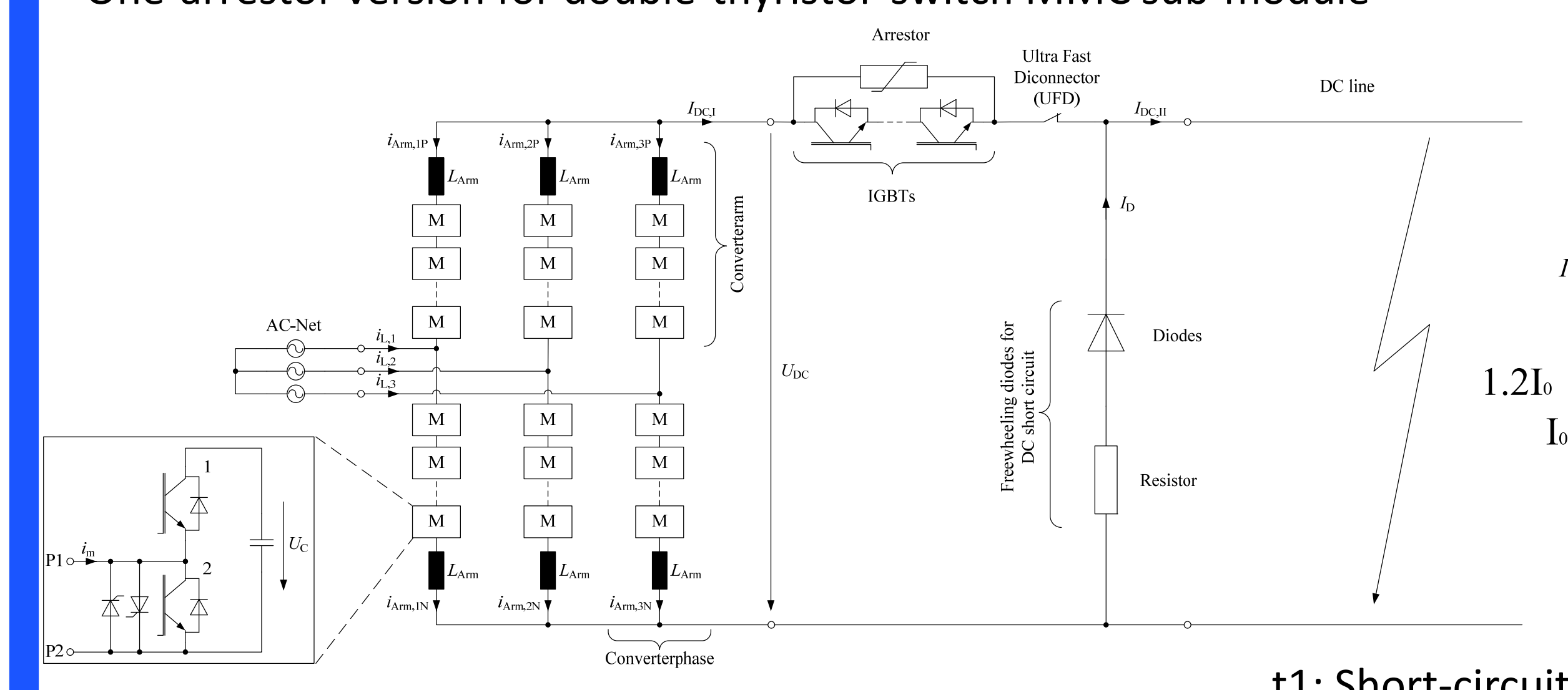
For different cases, the possible maximum fault currents can be calculated. In order to attain a suitable threshold current, the iterative method is used. If the maximum turn-off current of the IGBTs is 3500 A, the threshold current is determined to be 3067 A.

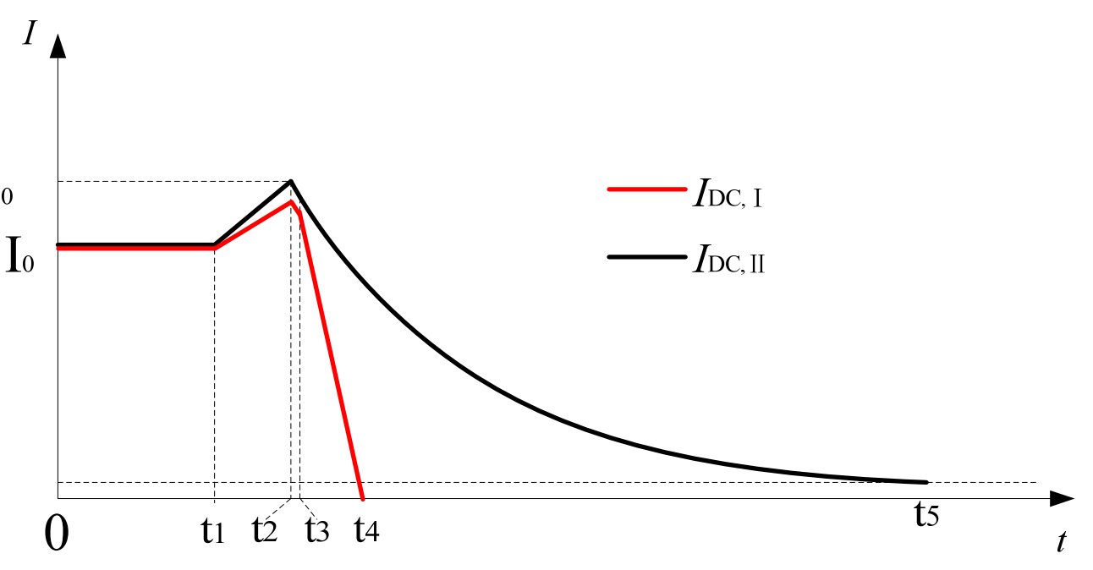
Conclusion

1. Different HVDC breakers have different advantages and disadvantages. The design of HVDC breakers is a trade-off between switching time, loss power and so on.
2. The fault ride-through capability of MMCs leads to large power loss and high hardware costs. MMCs, which can work under overmodulation state, have even greater loss and cost.
3. All MMCs with fault ride-through capability can use the first blocking method to reduce the stress of semiconductor devices. A suitable threshold current can limit the maximum fault current and ensure antidisturbance ability.
4. The new MMC protection scheme combines MMC topology and HVDC breakers, giving it the advantages of these protection schemes.

Protection schemes based on new MMC converters

One-arrestor version for double-thyristor-switch MMC sub-module

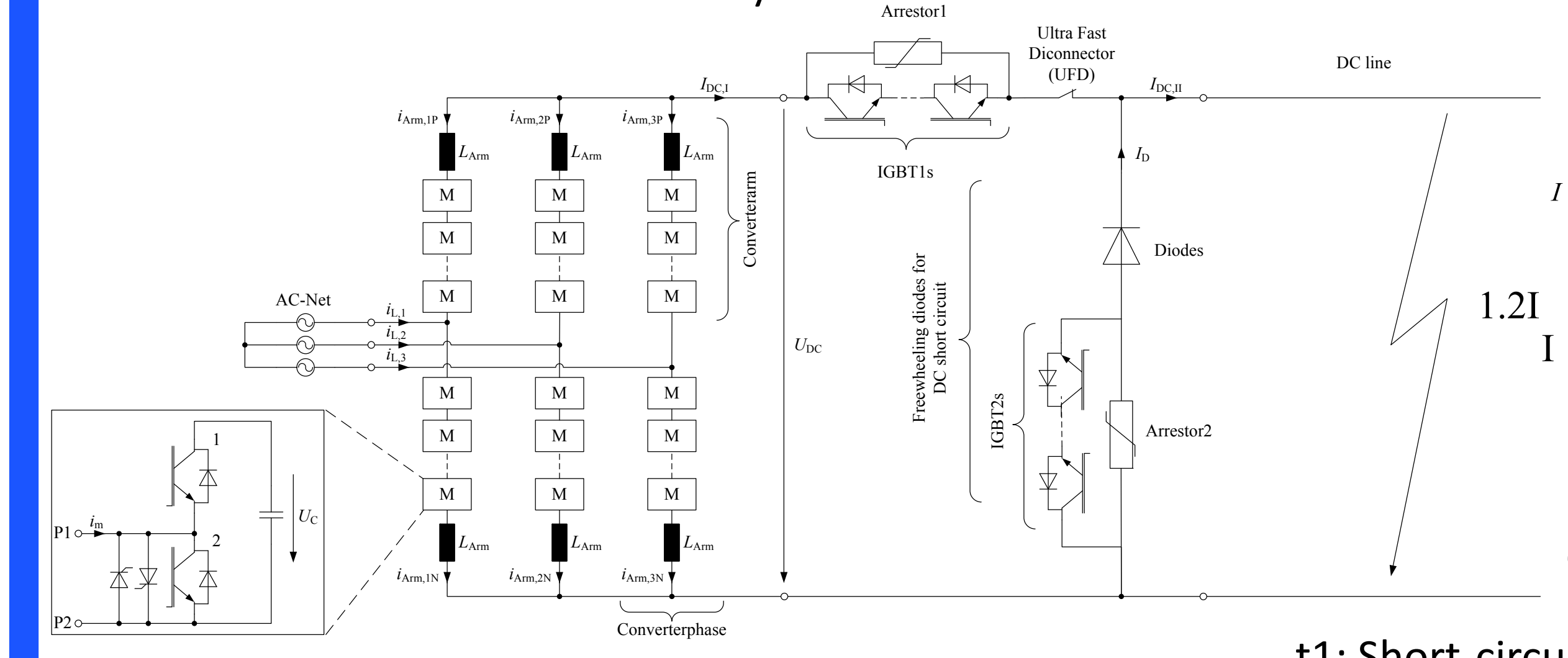


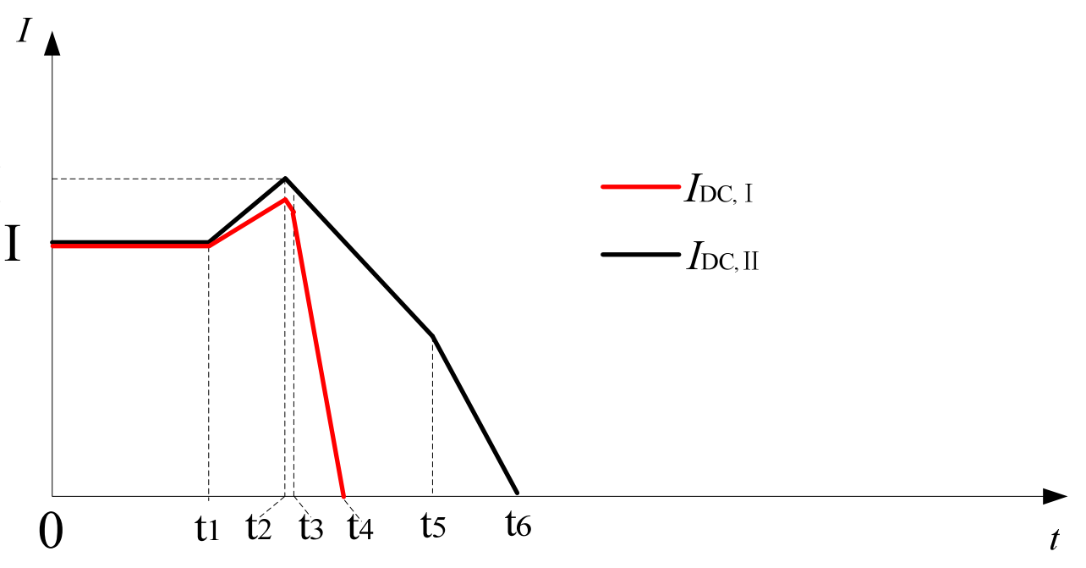


The duration of the AC side short circuit may be limited. However, in extreme cases, the long decay time of the DC fault current may affect the restart of the HVDC system.

t1: Short-circuit fault occurs.
t2: IGBTs in MMCs are blocked; thyristors are turned on.
t3: IGBTs in the main switch are blocked.
t4: Fault current in UFD decays to 0; UFD is turned off.

Two-arrestor version for double-thyristor-switch MMC sub-module

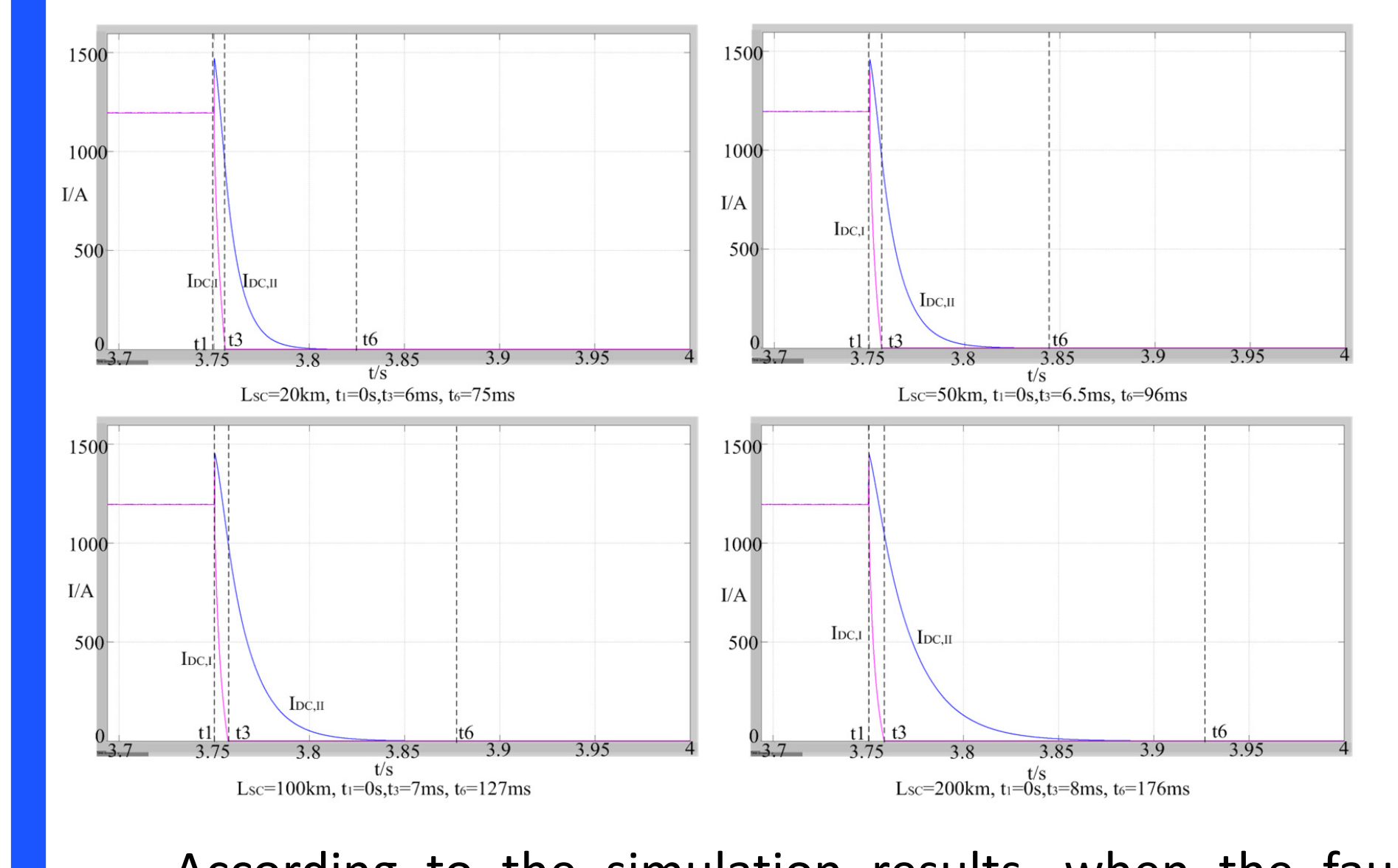




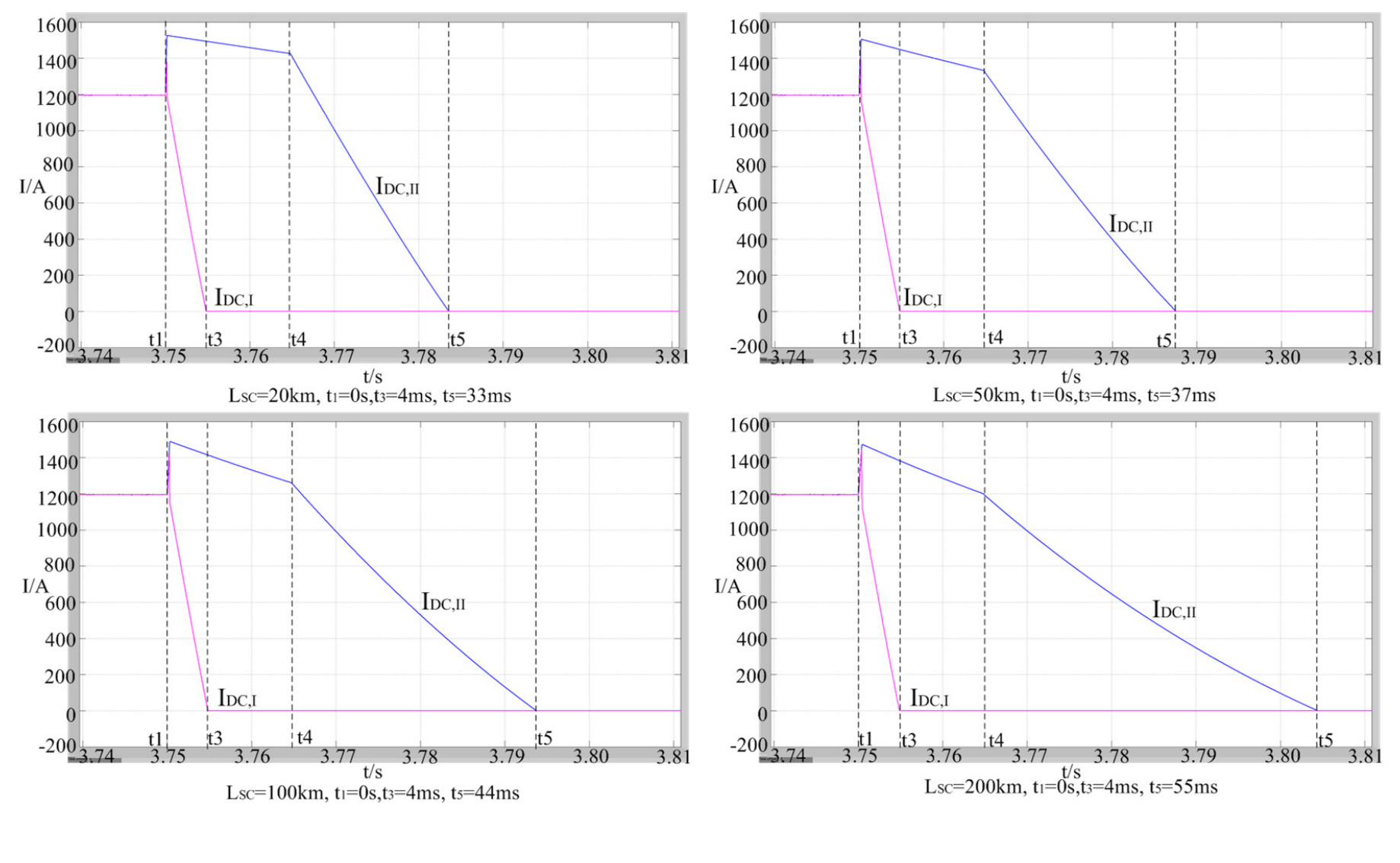
If all IGBT2s are turned off, the fault current will commutate to Arrestor2 and decay rapidly.

t1: Short-circuit fault occurs.
t2: IGBTs in MMC are blocked; thyristors are turned on.
t3: IGBTs in main switch are blocked.
t4: Fault current in UFD decays to 0; UFD is turned off.
t5: IGBT2s in diodes branch are turned off.

Simulation results of one-arrestor version



Simulation results of two-arrestor version



According to the simulation results, when the fault location increases, the fault current decay time also increases. Compared with the one-arrestor version, the two-arrestor version has a shorter fault current decay time.