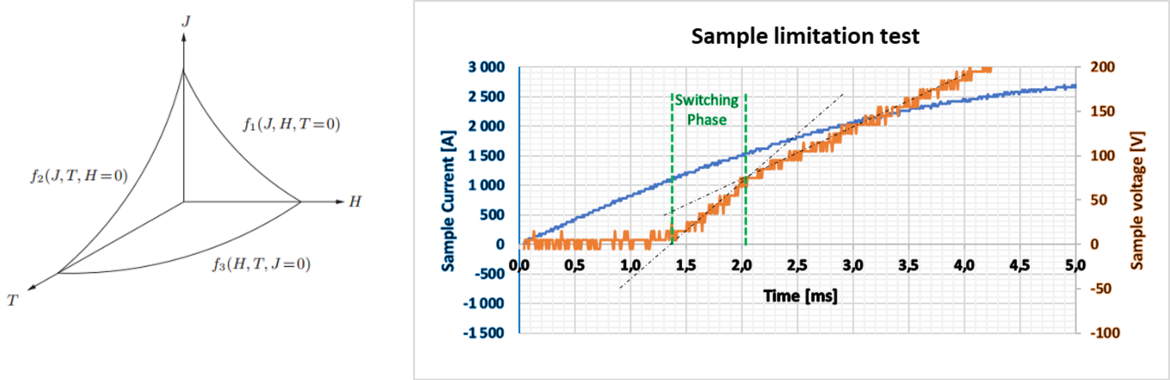
GROUP REF. : A3
COUNTRY : France PREF. SUBJECT : PS1
REGISTRATION NUMBER : **DLG5790** QUESTION N° : 3

As illustrated by the authors of report N° 10357, the use of Resistive Superconductive Fault Current Limiter (RSFCL) has now been experienced since a few years in a high voltage AC substation with clear satisfactory results in terms of current limitation in the events of faults.
This example follows several successful medium voltage AC applications of the RSFCL as well as the installation of a 160 kVdc pilot RSFCL in Nan'Ao converter station.

The basic concept of a RSFCL is to use the property of a superconductive material.
More precisely, the superconductive material can switch from superconductive state to resistive state either when its critical current or its critical temperature or its critical magnetic field is overpassed. This is illustrated by Fig 1(a)



(a) (b)

Fig. 1: (a) illustration of the 3 transition modes of a superconductive material / (b) result of limitation test

For the fault current limitation application, the RSFCL is designed so to be without resistive loss when carrying the rated current and to become resistive when the threshold current commonly named "critical current" is overpassed, consequently heating the conductor and accelerating the transition when overpassing the critical temperature.
The phenomenon is illustrated in Fig 1(b) with a laboratory limitation test on a 1 m long sample conductor: in this example, the critical current is close to 1000 A, until this value is reached, there is no voltage drop between the 2 conductor terminals. The increasing current above this threshold forces the conductor to switch to a resistive state, the duration of this switching phase being less than one ms.

As the conductor becomes resistive, it will have to absorb a certain level of energy depending on the applied voltage and conductor dimensions. For high voltage applications, the order of magnitude of length of conductor is several kilometers per phase or pole in respect to AC or DC application. To limit the size of the RSFCL, the most efficient conductor arrangement is to wind it in shape of pancake. Especially in this application, the switching based on magnetic field is not desired, so a bifilar arrangement is realized so to minimize the pancake inductance.
Nowadays, High Temperature Superconductive (HTS) material can be used and operated around -200°C inside a liquid nitrogen bath. To match the rated voltage as well as the rated current of the system application, pancakes are assembled in parallel and series inside a cryostat where the proper temperature and pressure are controlled.
An example of pancake is shown in Fig 2:

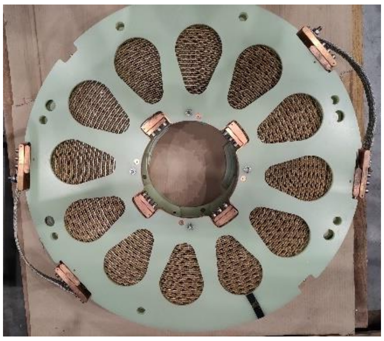


Fig. 2: Example of a bifilar pancake

After this introduction on the working principle, let’s consider the use of the technology in a Multi Terminal DC (MTDC) grid. In that application, the purpose is to protect the grid against a fault reaching several goals:

- achieve selectivity in the fault detection and operation of the DC CB
- avoid converter loss of control during the fault therefore allowing the continuous transfer of power even after the faulty line is isolated
- avoid the use of series reactor that are commonly proposed

The use of the technology is assessed in the benchmark PROMOTioN 4 Terminals MTDC grid with the following main characteristics:

- nominal voltage 500 kVdc / nominal current : 2000 A
- the converter control and auto-protection algorithms are included
- each line extremity incorporates a RSFCL + Mechanical DC CB
- there is no series reactor neither at the converter output nor at the line extremities

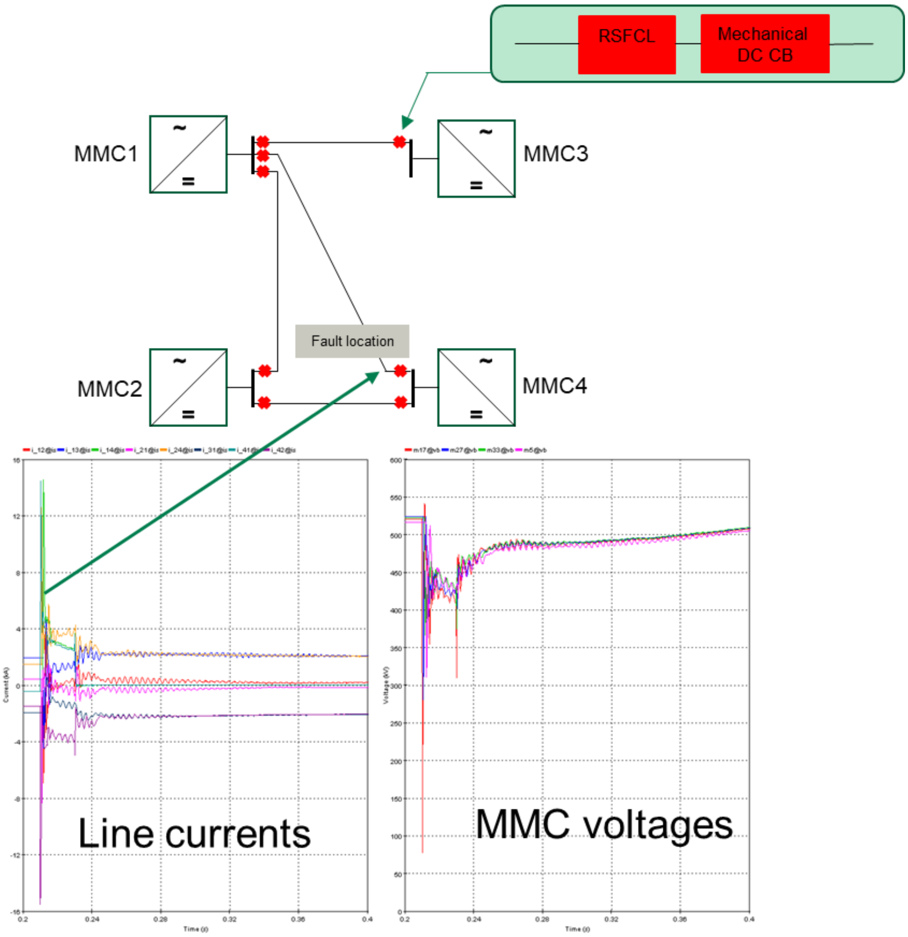


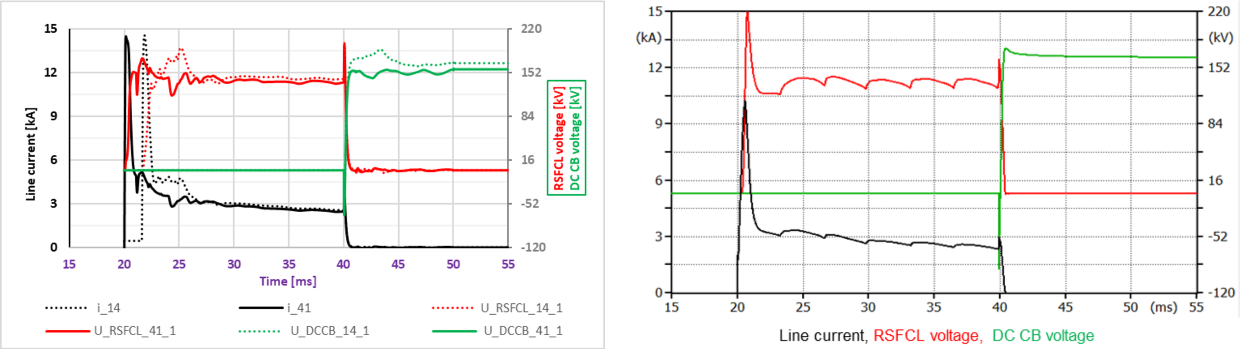
Fig. 3: Illustration of the MTDC grid and fault limitation and interruption process on Line 14

An illustration of the MTDC grid and hypothesis is shown in Fig 3. A fault is simulated and the line currents as well as converter output voltages are illustrated showing the power transfer before the fault (time < 0,21 s), the disturbance before the fault is eliminated by the operation of the DC CBs at both extremities of line 14 and the recovery of power transfer without line 14 after time > 0,22 s. In this example, the impact of the RSFCL is to limit the peak current to 10-15 kAp and limit the current to 1 – 1,5 In for the interruption by the DC CB.

Another aspect to the investigated when introducing a new technology is its validation by laboratory tests. A proposal is to use a diode 6-pulse rectifier with ratings that are consistent with high voltage RSFCL. Such a rectifier was built and is fed by a short circuit generator at Supergrid Institute High Power Laboratory, it can deliver upto 200 kVdc in no load and prospective current upto 40 kA (Fig 4).

Fig. 4: Picture of the rectifier hall in Supergrid Institute High Power Laboratory

Fig 5 shows the comparison of the current and voltage simulation results of one 170 kVdc module of the RSFCL+CB at both extremities of Line 41 of the example MTDC grid and the currents and voltages obtained on the test circuit when testing one 170 kVdc RSFCL+DC CB module.



(a)

(b)

Fig. 5:(a) MTDC grid simulation results on one module of 170 kVdc / (b) Laboratory test simulation results of one module of 170 kVdc

In conclusion, the MTDC grid simulation results show the promising advantages of using a RSFCL+DC CB combination to protect the grid achieving selectivity and keeping the converter control without losing time for power recovery. The feasibility of validating the solution in a High-Power Laboratory equipped with a high power – high voltage 6-pulse rectifier in addition to the relevant dielectric tests to be performed in a high voltage dielectric test laboratory.