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HVDC circuit breakers: driving towards the Supergrid

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 CIRCUIT BREAKERS  HVDC  MESHED GRIDS

An innovative, ultra-fast mechatronic circuit breaker has been specially developed for HVDC networks. It is crucial for protection of the grid and paves the way for continental-scale, meshed DC networks.



2 comments





Grid operators increasingly use high voltage direct current (HVDC) to carry high power efficiently over long distances. A prime reason is that for such high power long-distance links, direct current (DC) is superior to alternating current (AC) because it can transmit power without capacitive or inductive losses.

DC converter stations also improve the stability of the associated AC networks by decoupling the frequency and phase of those networks. HVDC links are therefore very useful in stabilising grids challenged by a growing contribution of power from distributed and intermittent sources such as wind or solar energy.

[Cover picture: GETTY / ThinkStock]

1 __A vital component for interconnected grids



A key element in power networks is the circuit breaker. Its role is to protect the network. It prevents failures and blackouts by rapidly cutting the current in a malfunctioning element (following a lightning strike, or the breakage of an undersea cable, for example). In this way it isolates the fault from the rest of the grid. Circuit breakers are vital to protect complex interconnected grids, be they AC or DC.

Circuit breaker technology for AC grids is generally regarded as mature, and Alstom is among the world leaders in the field. However, there have been few technical answers in the case of DC grids, until now. One major technical challenge is fault current that does not stop rising. “With DC, there is no natural current zero. The DC breaker must perform two duties: first it opposes a voltage to stop the fault current rise and second it absorbs excess energy from the network to bring the current to zero,” explains Wolfgang Grieshaber, research engineer and head of the DC Circuit Breaker & New Solutions group in Alstom Grid’s ARC Technology Centre in Villeurbanne (France). In AC networks, the current is periodically driven through zero (100 times a second for a 50 Hz network), and current zero is the ideal instant to interrupt. “To be used for direct current interruption, the circuit breaker has to perform 10 to 20 times faster than in AC grids.” Current interruption in DC networks must therefore be done very precisely and much more rapidly.

2 __ The Ultra-Fast Mechatronic Circuit Breaker (UFMCB)



Together with partners from various countries, working collaboratively on the European TWENTIES (1) project (see sidebar 1 at the end of this article), Alstom designed a 120 kV DC circuit breaker demonstrator suitable for operation in a meshed network. It underwent a series of specific tests inspired by IEC standards for HVAC breakers. “One technological option was to adapt an existing DC-breaker product that is used in HVDC point-to-point connection,” says Grieshaber. “However, with break times in the range of 27 ms to 40 ms, this type of breaker is relatively slow because its main component is a conventional AC arc chamber.” Another option was to associate power electronics

with an ultra-fast disconnecter. “This is the option that was chosen for the demonstrator because it has low on-state losses, a very short break time and is totally SF₆- free.”

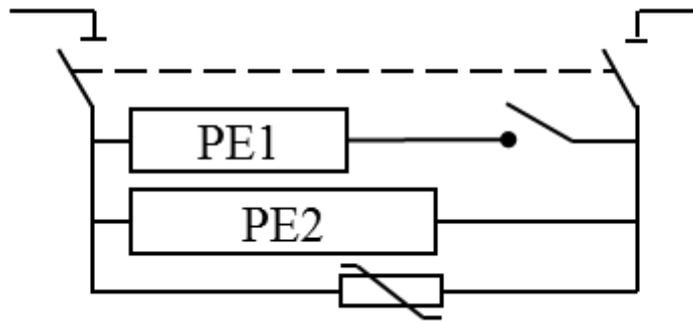
These insights – and three years of R&D – led Alstom to deploy some of its existing technologies as a springboard from which to develop the Ultra-Fast Mechatronic Circuit Breaker (UFMCB), a DC circuit breaker (DC-CB) prototype comprising the following main components arranged in a three-parallel-branch design (see figure below):

- a **mechanical** part, which acts as an ultra-fast disconnecter (interrupter);
- a second part that includes **power electronics components** (capacitors and thyristors) which pilot the current flow in the parallel branches;
- and a **surge arrester** to dissipate the excess energy of the network as part of the interruption.

“The UFMCB’s operating principle is to commutate the current in steps, first from the ‘low impedance branch’ to the ‘auxiliary branch’ and then into the ‘extinguishing branch’; internal breaker commutations are based on generating a reverse current to oppose the network current,” explains Grieshaber.

(1) TWENTIES: Transmission system operation with a large penetration of **W**ind and other renewable electricity sources in **E**lectricity **N**etworks using innovative **T**ools and **I**ntegrated **E**nergy **S**olutions.

Building blocks of the DC-CB. From top to bottom: a two-phase disconnecter, the low-impedance branch consisting of power electronics (PE1) and an ultra-fast disconnecting switch, the auxiliary branch with power electronics (PE2), a surge arrester as energy absorber.



3 __ Full extinction of DC in 5 milliseconds



This innovative technology was first tested on a medium voltage version before scaling it up to the high voltage DC-CB demonstrator. In the future it is expected that this technology will be used for HVDC grids connecting multiple offshore wind farms to the coast. Tests were conducted in close cooperation with RTE, the French power network operator (see sidebar 2 at the end of this article). “During the tests under the real operational constraints of a high voltage DC transmission grid, the prototype successfully interrupted a 5,200 ampere current at 160 kV with full current extinction in 5 milliseconds,” says Grieshaber. All tests were witnessed by independent bodies. The ultimate test, validating the power switching performance, was conducted on November 29, 2013 in the presence of representatives from RTE, Red Electrica España, TenneT and a European Commission project officer.

4 __ A major step in building the Supergrid



Some additional improvements are still needed to enrich or complete the circuit breaker’s functionalities, extend its performance range and facilitate its interface with grids. Even so, this prototype opens the door to the development of Ultra-Fast

Mechatronic Circuit Breakers suitable for any DC transmission voltages.

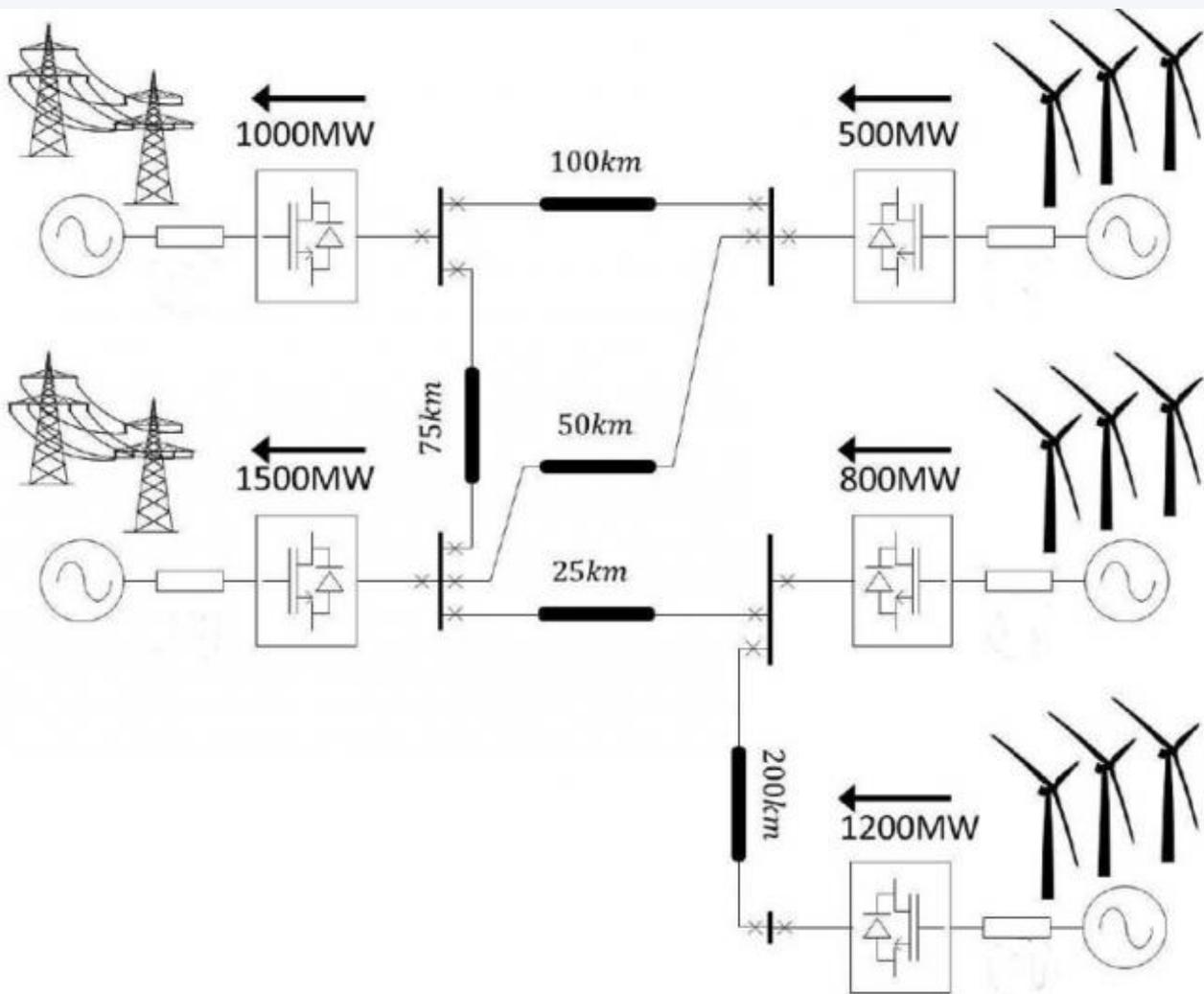
“We see this innovative breaker as a very cost-effective solution, since it offers many advantages such as the ability to partition a network into sub-networks.” As Grieshaber states: “All these results represent a major step towards realising the Supergrid, which will effectively integrate renewable energy sources and enable power trade and bulk supply across continents.”

Why faults occurring in a DC grid must be cleared as fast as possible.

Meshed DC networks are still in the research and development stage, since only point-to-point or radial multi-terminal DC links are in operation so far. Therefore, several possible design strategies can be studied for HVDC networks, depending on integrating existing DC links with different voltages or not. In the latter option, i.e., when the whole network is operated at a single DC voltage level, one possibility is to design a DC grid in the same way as an AC grid: DC substations would be connected together in a meshed configuration, each DC overhead line or cable being protected by a DC breaker at each end. AC generator units and loads would be seen through AC/DC converters whose technology and design could influence the behaviour of the DC grid.

“The similarities stop there,” explains Lucas Violleau, Circuit Breaker Engineering Specialist at RTE, the French power transmission operator. “AC grids can face faults for hundreds of milliseconds before losing their stability, because a large amount of kinetic energy is stored in generator units with high inertia. In a DC grid the energy

reserve is smaller than in AC grids and is only made up from the system capacitance and inductance. When a pole-to-pole fault occurs, the voltage collapses in less than 10 ms. To avoid a complete DC network outage, the fault must be cleared as fast as possible in that period of time. This requires high-performance direct current circuit breakers, especially for meshed DC grids with high short-circuit currents as demonstrated in the TWENTIES project.”



The TWENTIES project: increase the share of renewables

The TWENTIES project was co-funded by the European Commission’s seventh Framework Programme. When

launched in 2010, its objective was to leverage real-life, large-scale demonstrations to pinpoint the benefits of and demonstrate a number of critical technologies by 2013. The technologies in question are those aimed at improving the pan-European transmission network (a.k.a. the 'Supergrid'). At the same time, they will give Europe a capability to include an increasing share of renewables in its energy mix but maintain its level of reliability performance. One of the TWENTIES project demonstrations addressed the technical challenges around the implementation of meshed HVDC networks, which hold the promise of major benefits.



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