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IN DEPTH



## Fault-blocking converters for DC networks

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 HVDC  MESHED GRIDS  
 PROTECTION & CONTROL

*DC circuit breakers are not the only solution for multi-terminal DC networks. Another solution could be to use certain types of “fault-blocking” voltage source converters specially adapted to suppress fault currents electronically.*



3 comments



To date, all Voltage Source Converters (VSC) used in HVDC networks are incapable of clearing faults on the DC side of the converter.

“For most of the situations where such converters have been used so far (i.e. point-to-point links using only DC cables), this limitation is not too severe. The other advantages of VSC technology are enough to make up for this shortcoming,” explains Colin Davidson, Alstom’s Chief Technology Officer – HVDC. “However, when multi-terminal DC networks and eventually continent-wide DC grids emerge, these limitations will not be acceptable any longer, because a fault on a single line or cable would black out the entire network. In such cases, the network requires either DC circuit breakers or a special type of VSC that can suppress currents induced by DC network faults.”

## 1 \_\_ From “half-bridge” to “full-bridge”



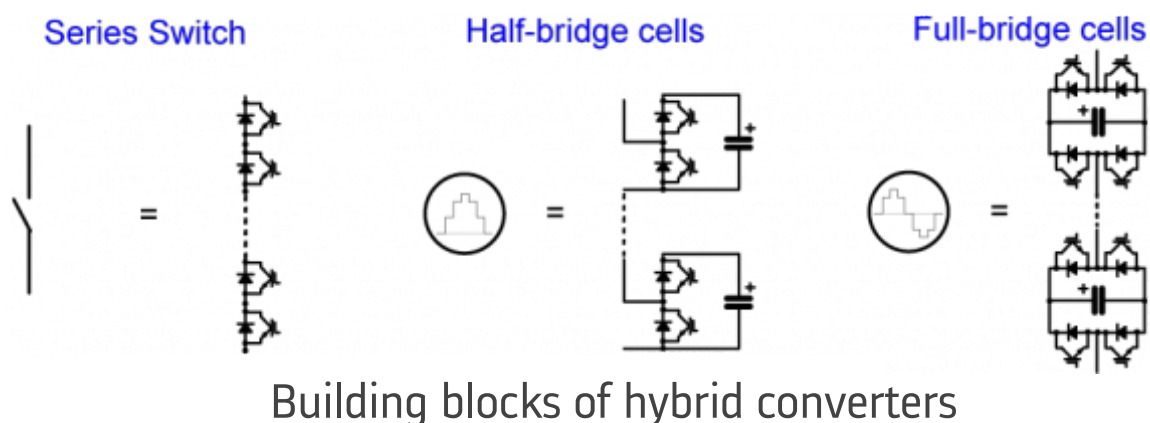
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The most commonly used type of VSC for HVDC today is the “half-bridge” version of the Modular Multi-level Converter (HB-

MMC).

In this circuit, the converter is made up of large numbers of identical submodules, each comprising a large capacitor and two semiconductor switches (IGBTs ). As the HB-MMC cannot suppress currents that occur for faults applied on the DC side of the converter, the usual method for clearing such faults today is to rely on the AC circuit breakers that connect the converter to the AC grid. However, this is – in power electronics terms – very slow, taking 60-100 ms. DC circuit breakers would be much faster. Alstom has established a strong technical position in such DC breaker technology, and solutions based on this should be commercially available in the near future.

“An alternative could be to modify the converter itself so that a DC breaker is not needed,” says Davidson. “This is what the ‘full-bridge’ version of the MMC (FB-MMC) does.”



The FB-MMC, which Alstom was the first manufacturer to propose (in 2009), uses four semiconductor switches instead of two in each submodule. Considered today as a viable short-term option when a VSC is needed for multi-terminal DC networks, the FB-MMC submodule is ready to be used not only in HVDC but also in an updated version of Alstom’s STATCOM offering.

“However, the FB-MMC is not the optimum type of fault-blocking VSC because its cost and power losses are considerably higher than that of an HB-MMC.

To address this shortcoming, Alstom is developing an improved fault-blocking converter, called the Alternate Arm Converter

(AAC).”

(See sidebar.)

## 2 \_\_ A fast disconnecter is also needed



Fault-blocking converters such as the FB-MMC or the AAC would be good solutions for relatively small DC networks with only three or four terminals – as well as for point-to-point schemes using overhead lines, where faults due to lightning strikes can be frequent. Clearance of DC faults in such schemes would require all of the converters feeding into the DC network to be blocked briefly.

The converters can then be de-blocked again shortly after to see if the fault is still present. If it is not, the network can then be re-started. However, if the fault is permanent (as is usually the case with cable faults) then the entire DC network would remain blacked out until maintenance technicians can fix the cable – which may require weeks. However, if a DC network extends over a large geographical area or has a large number of terminals, it becomes a critical element in the whole power transmission system and as such cannot be out of service for an extended time. So, there would be a need for additional means to rapidly isolate the faulted section so that the remaining, healthy part(s) of the DC network can resume operation. “For this we do not need a DC breaker, since the converter has already interrupted the fault current. We just need a ‘fast disconnecter’ that can open rapidly to isolate the faulted section,” points out Davidson.

Traditional disconnectors take several seconds to open, which might be unacceptable in some cases, but there are two known options

to improve the speed. “The first is to use a conventional AC

breaker as a disconnecter; its operating time is around 60-100 ms. The second, which we could call an ultra-fast disconnecter, is to use the mechanical switch that makes up part of a full DC circuit breaker.” Although this might be more costly than the first option, it would be much faster (well under 5 ms) and would be substantially cheaper than providing a complete DC breaker. “The choice between the two would depend on how critical it is to minimise the downtime of the DC network, for instance, whether the DC network is serving a dense urban area with mainly underground cables (where speed is likely to be especially important) or is instead used for long-distance transmission on overhead lines, where speed may be less critical.”

### 3 \_\_ Developing clever detection algorithms



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Controlling the opening of these fast disconnectors requires some clever algorithms. “A common feature for all fault and HVDC equipment types is that, in a steady state, the sum of cable terminal currents should equate to zero, as there are no loads connected along the cable and any current that enters the cable at one end must leave the cable through the other end,” explains Andrzej Adamczyk, Team Coordinator of DC networks. “If a fault occurs, an additional current path appears within the faulty branch and the cable current sum is therefore going to be non-zero – in fact, always positive.” On the other hand, in a healthy branch, as there are still only two terminals through which the current can enter or exit the cable, the cable current sum will remain zero. “However, as the length of transmission lines is typically in the range of tens to hundreds of kilometres, the cable propagation delay may reach several milliseconds and transiently the current sum will be negative in a healthy cable section,” he adds. It is therefore possible to identify whether the fault lies within a given cable



section by looking at the sign of the transient cable current sum: “If the sum has a negative value, the fault is not in that branch; if it is positive, then the fault is located within this section.” Such a detection algorithm has already been validated by testing its operation on a four-terminal meshed HVDC grid, one of the most challenging network topologies from a protection point of view because of the multiple conduction paths for the fault currents.

## 4 \_\_ The Alternate Arm Converter (AAC)



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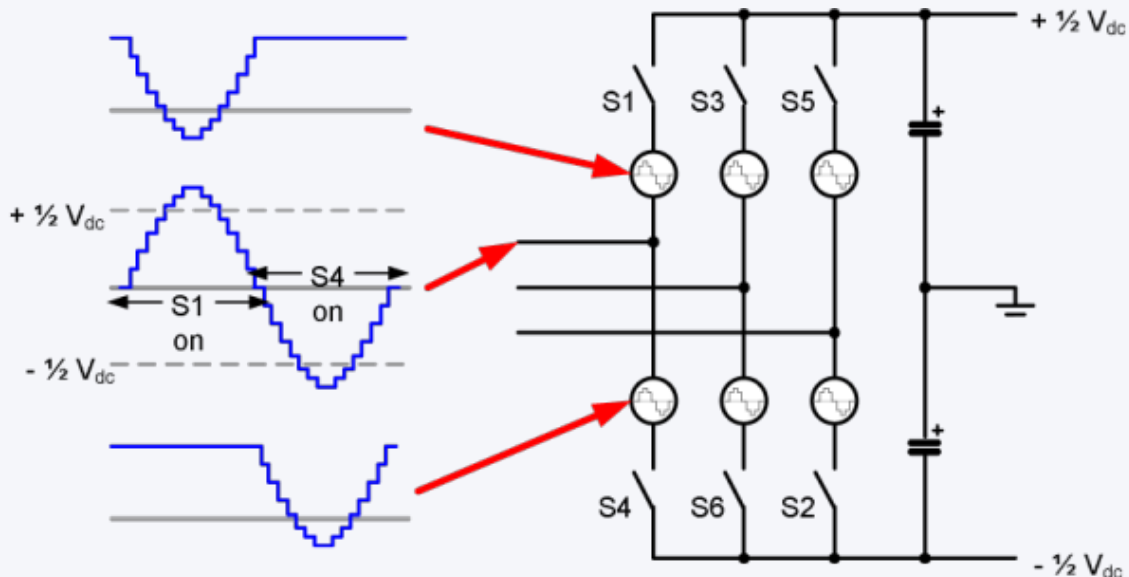
Three questions to Kevin J. Dyke, Alstom’s Research and Technology Department Manager

### **What led to the development of the AAC?**

Unlike a half-bridge modular multi-level converter, also called an HB-MMC, which can produce DC voltage of only one polarity, the full-bridge MMC can produce equal positive and negative DC voltages. It is this capability to produce negative as well as positive DC voltage that lies at the heart of its ability to suppress DC fault currents. But the FB-MMC can produce far more negative DC voltage than is actually needed to clear a fault. This is why a new converter concept, the AAC, has been developed, aimed at providing the ability to clear faults more efficiently using fewer submodules.

## How does the AAC work?

In an MMC, each of the six “valves” needs to contain enough submodules to be able to produce the entire DC voltage, but for much of the time this full voltage rating is not necessary. The AAC removes this requirement by having a separate “director switch” in series with the submodules. The director switch consists of a stack of IGBTs connected in series but it allows the number of submodules to be reduced by almost half. This means the power losses are significantly reduced compared with the FB-MMC and are close to those of the HB-MMC – but with the added benefit of being able to suppress DC fault currents.



Series circuit with wave-shaping circuit on DC side

## Are there other advantages?

A further benefit is that the stack of IGBTs in the director switch is much less bulky than the submodules that it replaces (the submodules contain huge capacitors). So, by minimising the number of submodules we can save space. Moreover, the director switches can be arranged so that in normal operation they turn on and off with both voltage and current at zero (so-called “soft switching”). This means that the director switches have no switching losses and the problems of getting large numbers of IGBTs to work correctly in series are made much easier.

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