Implementing the protection and control of future HVDC grids

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In a grid topology using HVDC circuit breakers able to provide fast clearance of a DC fault, two main contrasting, yet complementary, solutions appear possible. One would be to apply the same protection philosophy and principles used in AC systems. The second could be the "Open Grid" concept.

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1 __Adapting the AC grid protection philosophy

The principle, philosophy and scheme for protection of HVDC systems can be inherited from AC systems. The greatest challenge is the need for a very short tripping time without losing selectivity, security and sensitivity.

Although HVDC grid protection is still in a development phase (to date no DC circuit breaker is in commercial use in the field), the protection principles of an AC system are still one option for application to an HVDC network. As Sankara Subramanian, head of the Innovation & Technology department at Alstom Grid UK, explains: “A DC breaker that can provide fast clearance of the DC fault will play the key role for isolating the faulty line and devices in the HVDC system. In this context,” he adds, “the philosophy, principle and scheme for protection of HVDC grids may still follow those for AC systems.” However, as with AC system protection, the four requirements of a secure and reliable HVDC system (selectivity, speed, sensitivity and security), “are somewhat in contradiction with each other, and need to be balanced technologically and economically”.

2__Unit versus non-unit protection

Protection can be based on the information and measured voltage and/or current at one end (where the protection is installed) or at both ends. In the first case (one end), it is called a “non-unit protection”; in the second case (both ends), it is a “unit protection”.

In an AC system, the over-current protection and distance protection belong to the non-unit protection category, while the current differential/phase as well as directional comparison belongs to the unit protection category. “The advantage of the non-unit protection is that the communication links and devices are not required,” explains Subramanian. “This not only minimises costs but also means that the speed of the protection is not limited by the communication time delays. Meanwhile the reliability and security are not restrained by communication errors or failure.” On the other hand, non-unit protection has the disadvantage that it cannot provide absolute selectivity.

Another important point is that transmission lines in an HVDC grid are normally longer than those in an AC system: the communication time delay is therefore longer, due to the distance involved. If the line length is longer than the limitation of direct communication, then inter-connection relaying to forward the information is required, which can cause an extra time delay (up to 100 ms for lines over 500 km). "Therefore, in future HVDC grids, the non-unit type is likely to play the dominant role of protection," says Subramanian.

3__Protection algorithm: transient or steady-based?

Protection algorithms are generally formulated by the characteristic difference between internal and external faults. Algorithms based on the characteristic difference of transient voltage or current signals are called "transient-based protection". Those based on the character of steady-state voltage and current signals are called "steady-state-based protection".
Whereas in AC power grids most of the protection systems installed are steady-state based, in HVDC grids the steady-state signal is DC, so the Fourier-based protection does not work; the transient period is also much longer then in an AC system. Therefore, the preferred way of formulating an algorithm for HVDC grid protection of the conventional approach is by employing "transient-based protection".

4__Sampling rate and time window

A very important element for transient-based protection is the time window, which will directly impact the speed of the protection algorithm. It determines the sampling rate such that, within the time window, there should be sufficient samples to detect the faults and determine whether they are internal or external faults. As per IEC 61869-9, the sampling rate for DC grid protection is 96 kHz (96 samples/ms). If we assume that the required time of the total fault clearance should be less than 5 ms, the window length should be less than 0.5 ms. Using the above sampling rate, the decision for an internal or external fault could be made by an algorithm in less than 0.5 ms, which could therefore meet the requirement of HVDC fault clearance.

5 __New algorithms for HVDC grid protection

Based on the above analysis, the only difference between HVDC and AC grid protection schemes would be that non-unit protection would be the primary protection function. However, as for AC, there could be several protection schemes for HVDC grids: the primary protection may be a transient-based direction-over-current relay or a transient-based distance relay plus transient-based high-speed remote trip detection without relying on communications between the ends. The backup protection could be a transient current differential relay or a transient-based directional comparison unit protection or a transient-based distance unit protection plus an aided scheme (a scheme relying on communication between the ends). “All these protection philosophies are presently in the development stage, and there are already several patent applications in this field," Subramanian concludes.

6 __ Open Grid: an alternative approach to HVDC grid protection

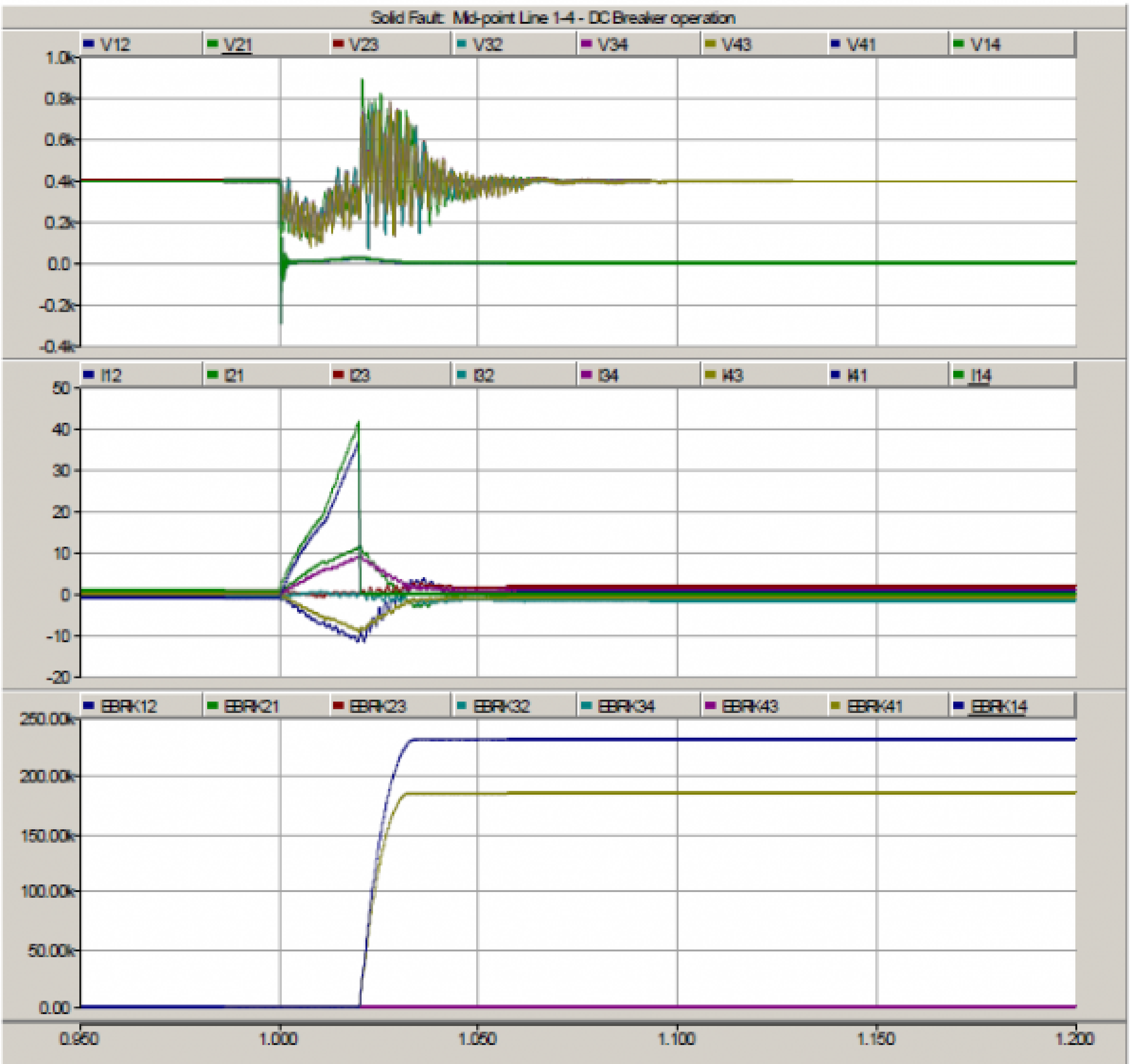
Alstom has also proposed an alternative protection strategy: tripping rapidly based on local measurements without discrimination and then re-closing healthy circuits. This innovative approach may offer practical advantages in terms of building a robust DC/AC grid.

A major hurdle to overcome in the creation of a true HVDC grid, even when the HVDC circuit breaker technology is available, is the protection of the grid. "If the DC grid protection philosophy were to be based on that currently employed in AC grids, then the protection system would need to have the ability to detect the fault, to discriminate that the event is an HVDC grid fault and not an external disturbance, to locate where the fault is on the HVDC grid, and then to send a trip signal to the appropriate HVDC breakers," explains Carl Barker, Alstom HVDC Grids Chief Engineer. "In the event that the fault is real, then this must take place while the DC current is rising towards a steady-state maximum value but before it has reached a level that is beyond the capability of the HVDC breakers to interrupt.

7 __ Fault interruption in a DC grid

Applying the same protection strategy as that used in AC systems – 20 ms detection and discrimination followed by tripping only the DC circuit breakers associated with the fault – results in the line voltages and currents displayed in the figure below (it is assumed that the DC circuit breaker operating time is 5 ms).

"These results show that allowing the fault current to rise over a period of 20 ms and then only using the HVDC circuit breakers associated with the faulted line to clear, imposes a very high current interruption duty on those circuit breakers," says Barker. "On the other hand, reducing the time for detection and discrimination before the HVDC circuit breakers are tripped reduces the time available for fault location."



8__Reversing the protection sequence order

An alternative approach, referred to as "Open Grid", is to reverse the protection sequence order. "This means allowing each HVDC circuit breaker to autonomously trip on detection of a fault without any delays associated with communications or discrimination logic, and then re-closing healthy circuits," explains Barker. This strategy may offer practical advantages in terms of building a robust DC/AC grid: the HVDC circuit breaker opens at a much lower fault current, and the fault, as it propagates rapidly through the network, is "seen" by several breakers that will all open (except those more remote from the fault; they will not have time to "see" it and will therefore remain closed). "The energy requirements of the HVDC circuit breakers could thus be much lower – initial results indicate a reduction of some 95%." This approach significantly reduces the duty on individual circuit breakers, facilitates their rapid opening and is complementary to ongoing HVDC circuit breaker development. Fault location would also be facilitated by this method.

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