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# Hybrid HVDC Breaker

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***Abstract:***
*Historical era of HVDC was unable to form HVDC grid even though knowing the merits of HVDC system and main reason behind was that until no HVDC breaker is developed which fulfill the requirement of HVDC grid. Existing mechanical HVDC breakers are capable of interrupting HVDC currents within several tens of milliseconds, but this is too slow to fulfill the requirements of a reliable HVDC grid. HVDC breakers based on semiconductors can easily overcome the limitations of operating speed, but generate large transfer losses, typically in the range of 30 percent of the losses of a voltage source converter station. To overcome these obstacles, scientist developed a hybrid HVDC breaker. The hybrid design has negligible conduction losses, while preserving ultra-fast current interruption capability. This paper will present a detailed description of the hybrid HVDC breaker, its design principles and its operation. The use of semiconductors for electric power circuit breakers instead of conventional breakers remains an ideal when designing fault current interrupters for high power networks. The major problems concerning power semiconductor circuit breakers are the excessive heat losses and their sensitivity to transients. However, conventional breakers are capable of dealing with such matters. A combination of the two methods, or so-called 'hybrid breakers', would appear to be a solution; however, hybrid breakers use separate parallel branches for conducting the main current and interrupting the short-circuit current. Such breakers are intended for protecting direct current (DC) traction systems. In this thesis hybrid switching techniques for current limitation and purely solid- state current interruption are investigated for DC breakers.*

***Key words**: HVDC grid, hybrid, solid state breaker.*

## 1. Introduction

Nowadays, HVDC system becomes more beneficial in bulk power transmission over long distance, but still we are unable to form HVDC grid due to the absence of efficient HVDC breaker. Compared with HVAC grids, active power conduction losses are relatively low and reactive power conduction losses are zero in an HVDC grid. This advantage makes an HVDC grid more attractive. However, the relatively low impedance in HVDC grids is a challenge when a short circuit fault occurs, because the fault penetration is much faster and deeper. Consequently, fast and reliable HVDC breakers are needed to isolate faults and avoid a collapse of the common HVDC grid voltage. Furthermore, maintaining a reasonable level of HVDC voltage is a precondition for the converter station to operate normally. In order to minimize disturbances in converter operation, particularly the operation of stations not connected to the fault line or cable, it is necessary to clear the fault within a few milliseconds.
Semiconductor-based HVDC breakers easily overcome the limitations of operational speed and voltage, but generate large transfer losses - typically in the range of 30 percent of the losses of a voltage source converter station. While existing mechanical HVDC breakers are capable of interrupting HVDC currents within several tens of milliseconds, but this is too slow to fulfil the requirements of a reliable HVDC grid. The hybrid HVDC breaker has been developed to overcome these obstacles. The hybrid HVDC breaker is a combination of mechanical breaker and semiconductor based breaker to fulfill requirement of reliable HVDC grid. Hybrid breaker combines the merits of both breakers.

## 2. System Requirements

Compared with HVAC grids, active power conduction losses are relatively low and reactive power conduction losses are zero in an HVDC grid. An HVDC grid is formed when more than two converter stations are interconnected on the HVDC side via HVDC cables or overhead lines. Each converter station or each terminal of the HVDC grid couples the HVDC grid to an AC grid. In order to maintain the converter`s active and reactive power control capability, it is normally requested that the HVDC voltage be above at least 80 percent of the nominal HVDC voltage. If the converters lose control capability due to low HVDC voltage, the consequences can be voltage collapse in the HVDC grid and high current or voltage stresses for the converter. This can also affect the coupled AC grid voltage. The voltage reduction in other places of the HVDC grid depends mainly on the electrical distance to the fault location and HVDC reactors installed near the converter stations. For an HVDC grid, connected by HVDC cables, a short-circuit fault typically has to be cleared within 5 milliseconds, in order not to disturb converter stations as far away as 200 km, a - significantly different challenge compared to AC fault clearing times. HVDC grid system performance is not the only reason fast HVDC switches are necessary. From the point of view of HVDC breaker design, fast fault current breaking is crucial.

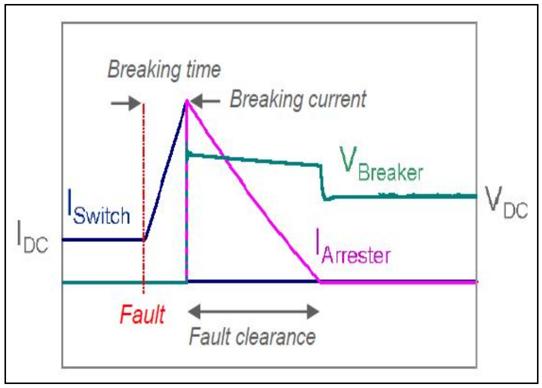


*Figure 1: Electromagnetic Transients, When the Current Is Broken*

Figure 1 shows the electromagnetic transients, when the current is broken. The current starts to rise when the fault occurs. When the switch opens, the current starts to decrease as it is commutated to the arrester. The fault current in the arrester bank establishes a counter voltage, which reduces the fault current to zero by dissipating the fault energy stored in the HVDC reactor and fault current path of the HVDC grid. The protective level of the arrester bank must exceed the HVDC voltage in the HVDC grid.

**3. Hybrid Switching Techniques**

Purely mechanical and solid-state breakers have both positive and negative points. Solid state breakers have ability of ultra speed, but with high switching losses with high cost. Whereas mechanical breaker has low losses, low cost but they are too slow in operation. Integrating solid-state devices with a mechanical breaker in a combination is called the Hybrid Switching Technique. Intentionally, the positive points from each method are retained and the negative points are eliminated. As a result of the fast actions of semiconductors, the moving mechanism of the main contact is critical. The hybrid switching technique is very suitable for limiting currents, especially for repetitive use. Generally, within a hybrid switching system, two different mechanical switches are incorporated; a main breaker and an isolation switch; the main breaker is accompanied by a solid-state switch in parallel. The main breaker provides a path for the continuous current, while the isolation switch allows dielectric separation of the load after a current interruption. The solid-state switch will operate only when the main current has to be interrupted. Fig.3.1 shows the basic components of hybrid switching. A commutation path is connected in parallel with the main breaker; it includes a snubber circuit as a transient suppressor and a voltage limiting element as an energy absorber. During normal operation, the snubber circuit and the voltage limiting element provide high impedance paths. The commutation path is introduced by solid-state switches and only operates during the interruption process. All the switches are controlled by electronic circuits.

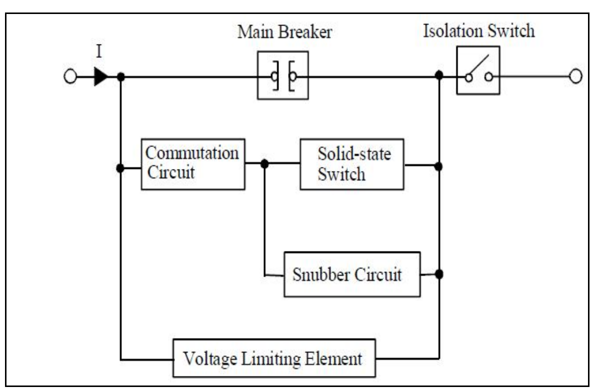


*Figure 2: Basic Components of Hybrid Switching Techniques*

The fact that the reaction times of solid-state switches are much quicker than those of the Mechanical ones means that the mechanical drive of hybrid breakers must be as fast as possible. The higher the rated current, the greater the mass of the mechanism that is needed. Also, the main breaker MB must be able to maintain insulation at the time of the first current-zero event; consequently, a vacuum breaker is most suitable because of its excellent insulating properties after the current-zero. For the development of a high-speed current limiting circuit breaker based on hybrid switching techniques, the features needed are listed below

- Fast main breaker MB opening time.
- Fast current commutation from main breaker to commutating path.
- Limitation of overvoltage during the interruption.

**4. Operating Mechanism**

The hybrid HVDC breaker consists of an additional branch, a bypass formed by a semiconductor-based load commutation switch in series with a fast mechanical dis-connector. The electrical circuit of hybrid breaker is shown in fig. 4.1. The main semiconductor-based HVDC breaker is separated into several sections with individual arrester banks dimensioned for full voltage and current breaking capability, whereas the load commutation switch matches lower voltage and energy capability. After fault clearance, a disconnecting circuit breaker interrupts the residual current and isolates the faulty line from the HVDC grid to protect the arrester banks of the hybrid HVDC breaker from thermal overload.

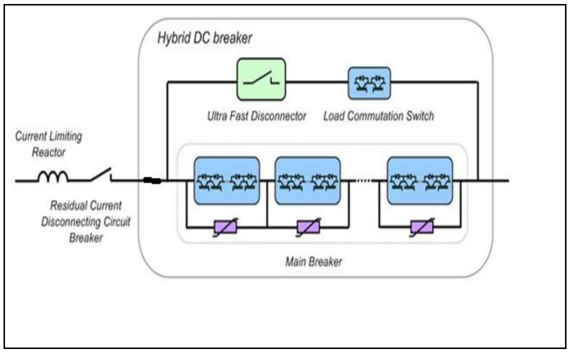


*Figure 3: Hybrid HVDC breaker*

During normal operation the current will only flow through the bypass, and the current in the main breaker is zero. When an HVDC fault occurs, the load commutation switch immediately commutates the current to the main HVDC breaker and the fast dis-connector opens. With the mechanical switch in open position, the main HVDC breaker breaks the current.

The mechanical switch isolates the load commutation switch from the primary voltage across the main HVDC breaker during current breaking. Thus, the required voltage rating of the load commutation switch is significantly reduced. A successful commutation of the line current into the main HVDC breaker path requires a voltage rating of the load commutation switch exceeding the on-state voltage of the main HVDC breaker, which is typically in the kV range for a 320 kV HVDC breaker. The transfer losses of the hybrid HVDC breaker concept are thus significantly reduced to a percentage of the losses incurred by a pure semiconductor breaker. The mechanical switch opens at zero current with low voltage stress, and can thus be realized as a dis-connector with a lightweight contact system. The fast dis-connector will be exposed to the maximum pole-to-pole voltage defined by the protective level of the arrester banks after first being in the open position while the main HVDC breaker opens. Thomson drives result in fast opening times and compact dis-connector design using SF6 as insulating media.

Proactive control of the hybrid HVDC breaker allows it to compensate for the time delay of the fast dis-connector, if the opening time of the dis-connector is less than the time required for selective protection. As explained proactive current commutation is initiated by the Hybrid HVDC breaker`s built-in over-current protection as soon as the HVDC line current exceeds a certain over-current level. The main HVDC breaker delays current breaking until a trip signal of the selected protection is received or the fault line current is close to the maximum breaking current capability of the main HVDC breaker.

To extend the time before the self-protection function of the main HVDC breaker trips the hybrid HVDC breaker, the main HVDC breaker may operate in a current limitation mode prior to current breaking. The main HVDC breaker controls the voltage drop across the HVDC reactor to zero to prevent a further rise in the line current. Pulse mode operation of the main HVDC breaker or sectionalizing the main HVDC breaker as shown in Figure 3 will allow adapting the voltage across the main HVDC breaker to the instantaneous HVDC voltage level of the HVDC grid. The maximum duration of the current limiting mode depends on the energy dissipation capability of the arrester banks.

**5. Advantages and Disadvantages**

Mechanical HVDC breakers are capable of interrupting HVDC currents within several tens of milliseconds, but this is too slow to fulfill the requirements of a reliable HVDC grid. HVDC breakers based on semiconductors can easily overcome the limitations of operating speed, but generate large transfer losses, typically in the range of 30 percent of the losses of a voltage source converter station. To overcome these obstacles, researchers have developed a hybrid HVDC breaker. The Hybrid HVDC breaker has several advantages summarized as follows:

*5.1. Advantages*

- The hybrid design has negligible conduction losses, while preserving ultra-fast current interruption capability.
- The hybrid breaker has relatively low contact resistance and hence low power loss.
- The hybrid breaker has better frequent switching ability.
- They have the good overload capability than mechanically operated breaker.
- Size and volume of the hybrid breaker is lower than the solid state breaker.
- The hybrid contact breaker has good level of contact reliability.

*5.2. Disadvantages*

Hybrid switching devices are also in great demand, especially for DC traction systems, but that will have to be accompanied also by the availability of high power rated semiconductors having turn-on and turn-off times of microseconds. Some of the disadvantages of the hybrid Hvdc breaker are listed below as

- Hybrid breaker has low commutation capacitance.
- It requires additional circuits for triggering and control.
- Higher voltage and current systems may require multi-stage interrupters.
- The need to solve the contact mass problem may push solid-state technology to fulfill the requirements for high current systems.
- The hybrid Hvdc breakers have a relatively higher cost than solid state breaker.

**6. Conclusion**

In this paper a new hybrid HVDC breaker system is reviewed. The use of semiconductors for electric power circuit breakers instead of conventional breakers remains a problematic when designing fault current interrupters for high power networks. The major problem is power semiconductor circuit breakers are the excessive heat losses and their sensitivity to transients. However, conventional breakers are capable of dealing with such matters. A combination of the two methods, or so-called ‘hybrid breakers’, would appear to be a solution; however, hybrid breakers use separate parallel branches for conducting the main current and interrupting the short-circuit current. The hybrid switching technique is very suitable for limiting currents, especially for repetitive use. For DC networks, current limiting devices are necessary for disconnecting faulty circuits rapidly. The hybrid breaker required the fast operating commutation circuit for fast response. The limitation of stored energy in order to produce a current-zero must be accompanied by minimizing the breaker opening time, so that, the time between a fault detection and the contacts opening can be made as short as possible. Therefore, a fast-acting circuit breaker is an important part of the hybrid breaker and for that purpose it uses the fast electrodynamics drives. The interruption of high fault currents requires solving overvoltage problems and taking protective measures.

The hybrid breaker on the other hand, provided fast interruptions, but it introduced high over-voltages because the stored inductive energy was transferred to the commutating capacitor. Those over-voltages would endanger the rectifier and the circuit. Unfortunately, in order to reduce the overvoltage stresses after a fault interruption, high commutation capacitance was required and a passive dissipation path had to be introduced. Therefore, well-designed overvoltage prevention measures (resistor and metal oxide arrester) had to be considered carefully when testing particularly high currents. That’s why the hybrid HVDC breaker opens a new world of HVDC system, thus HVDC grids can now be planned. The next step is to develop the breaker in the real HVDC transmission system to test its behavior under loaded condition.

**7. Future Development**

Until now, the ideal switch has been a figment of the imagination. Switching devices can be developed and constructed having features that approach the ideal switch; however, they can fulfill all practical network requirements and current levels up to the highest voltages. The fact that the solid state breaker is vulnerable means that additional circuits will still be needed. Meanwhile, hybrid switching devices are also in great demand, especially for DC traction systems, but that will have to be accompanied also by the availability of high power rated semiconductors having turn-on and turn-off times of μs. One objective of investigating hybrid breaker concepts was to reduce the costs of the whole breaker and its associated hardware like triggering and control circuits. Reducing the number of parts in a system was also likely to improve its reliability. Increasing the trip level in high-rated nominal current systems, would mean that the commutation capacitance would have to be increased too. The greater the capacitor, the lower the initial voltages that would be needed, and that could reduce the residual voltage and prevent overvoltage problems. However, large capacitance values may be unacceptable economically. Higher voltage and current systems may require multi-stage interrupters. All the time that there is slow progress in applying hybrid breakers for high-rated systems, conventional breakers will continue to be unchallenged for network protection. Even conventional breakers can be improved and updated, but the number of research project is on the decrease.

Further research is still required in order to develop a fast and intelligent monitoring system, to optimize capacitor banks and to model the best energy absorbers. Then, research on superconducting materials will help to motivate the development of fault current limiters, particularly, for the high voltage system. Until they are industrially economic, they will be available only in the laboratory.

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