Study on Coordination of Resistive SFCLs and Hybrid-Type Circuit Breakers to Protect a HVDC System with LCC and VSC Stations

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Abstract**—**Directing at the robustness increase of a high voltage direct current (HVDC) system with line commutated converter (LCC) and voltage source converter (VSC), this paper proposes a feasible coordination of resistive superconducting fault current limiters (SFCLs) and hybrid DC circuit breakers (HDCBs) to handle the DC line fault. In terms of that the fault interruption involves multi-stages, the coordination time sequence between the SFCL and the HDCB in the LCC/VSC station is elaborated. Using PSCAD, a 320 kV HVDC system is built. Not only changing the SFCL size and the HDCB operation delay is simulated, but also the indexes such as the fault current level, breaking time and dissipated energy are compared. The proposed coordination is verified to be very effective in handling the fault. Especially for the VSC station, it enables to visibly limit the fault current rising, shorten the transient voltage duration, and cause a powerful reduction in the dissipated energy of the HDCB. For the LCC station, the proposed coordination may act as a competitive backup to ensure a timely fault breaking. Thus, the DC fault can be removed more rapidly and reliably.

1. The HVDC configuration and its control strategy

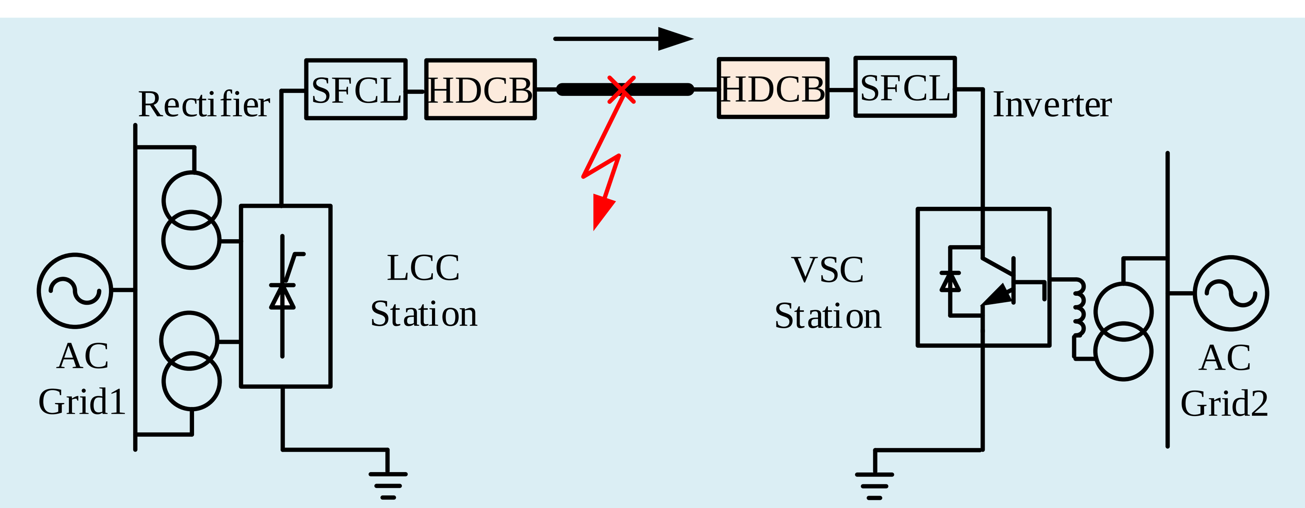

Fig. 1. Schematic configuration of resistive SFCLs and HDCBs in a HVDC system with LCC and VSC stations.

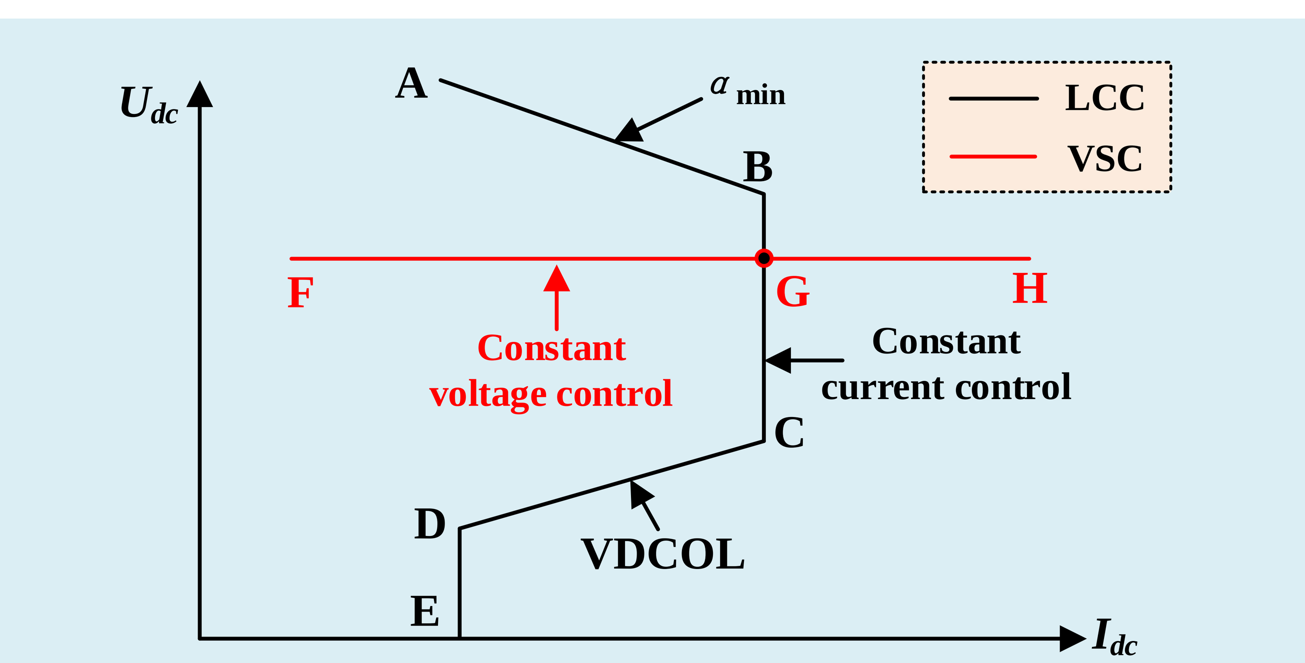

Fig. 2. Control curves of the LCC and VSC stations in the HVDC system.

2. Modeling of the SFCLs and their impacts

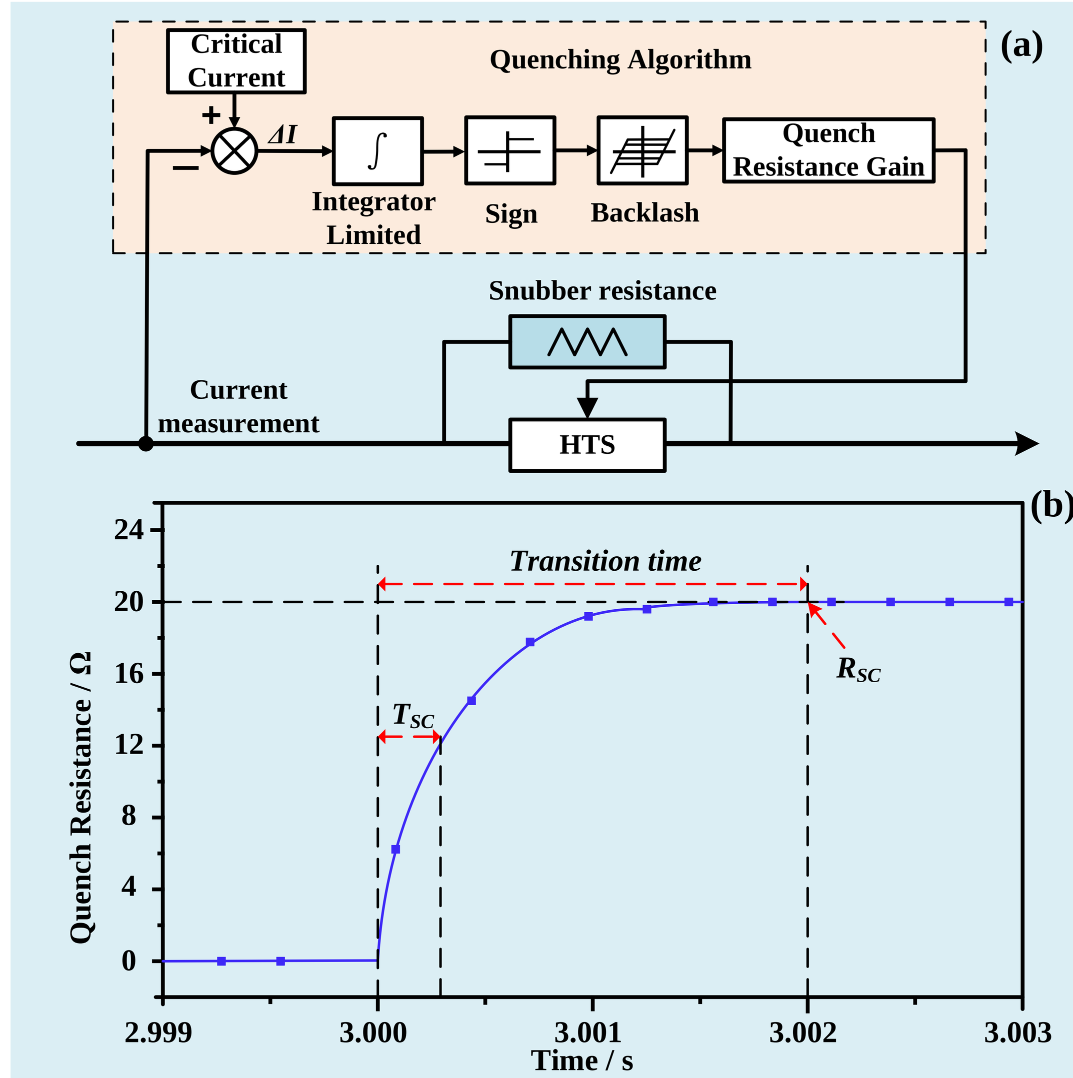

Fig. 3. Description of the designed resistive SFCL. (a) Electrical equivalent model for PSCAD simulation and (b) Quench characteristics..

$$L_{eq-LCC}\,\dot{I}_{f-LCC}=\frac{3\sqrt{2}U_{LCCm}}{\pi T}\cos\alpha-U_g-I_{f-LCC}(R_{SC-LCC}+R_{eq-LCC}+\frac{3X_T}{\pi})$$

$$\begin{cases} L_{eq-VSC}\,\dot{I}_{f-VSC}=U_{dc-VSC}-U_g-I_{f-VSC}(R_{SC-VSC}+R_{eq-VSC}) \\ I_{f-VSC}=-C_{eq-VSC}\,\dot{U}_{dc-VSC} \end{cases}$$

3. Modeling of the HDCBs and their cooperation with the SFCLs to clear the fault

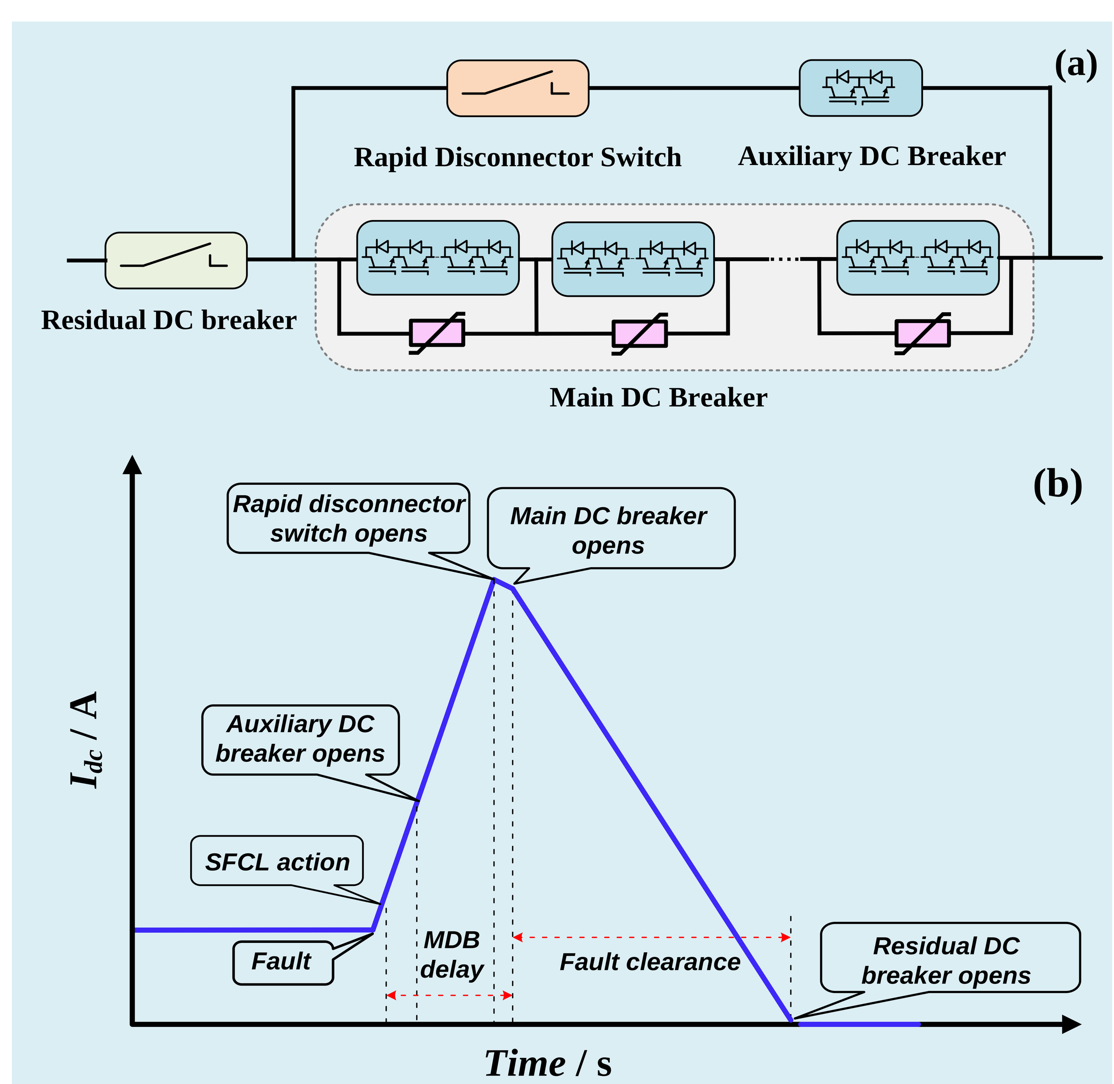

Fig. 4. (a) Topology circuit of the HDCB and (b) interrupting current features.

4. Performance assessment of the SFCLs and HDCBs in the HVDC system with LCC and VSC stations

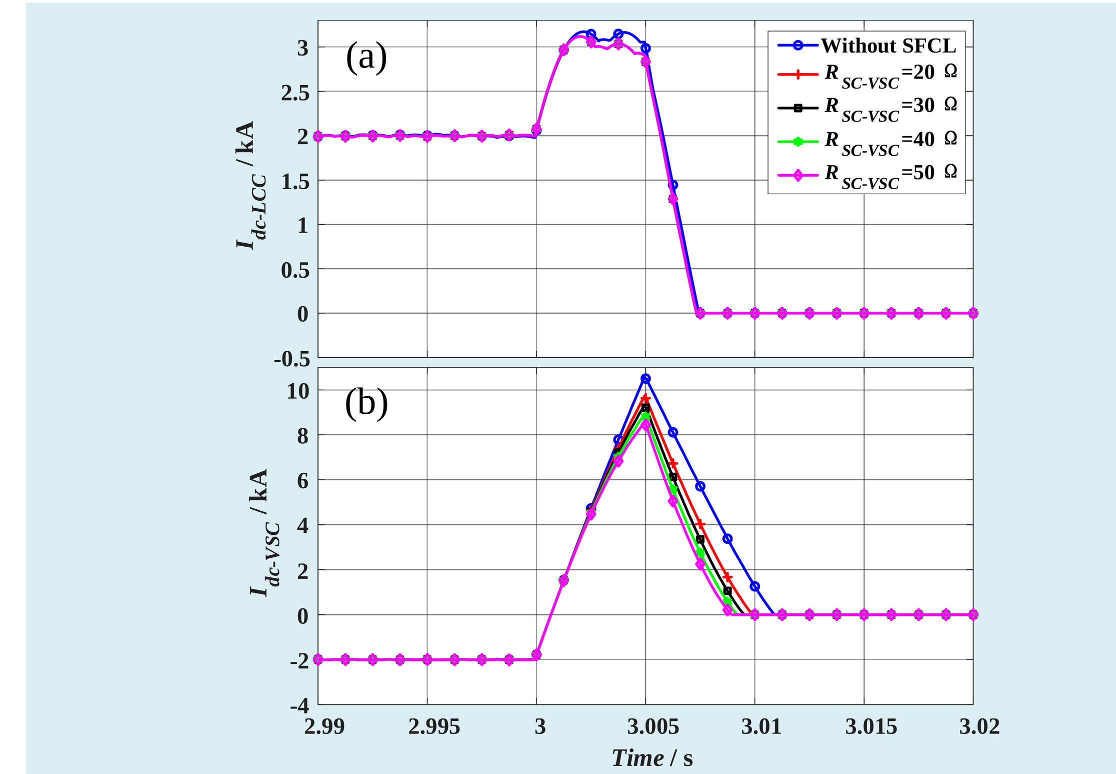

Fig. 5. Fault current response of the HVDC system subject to changing the SFCL size. (a) LCC station and (b) VSC station.

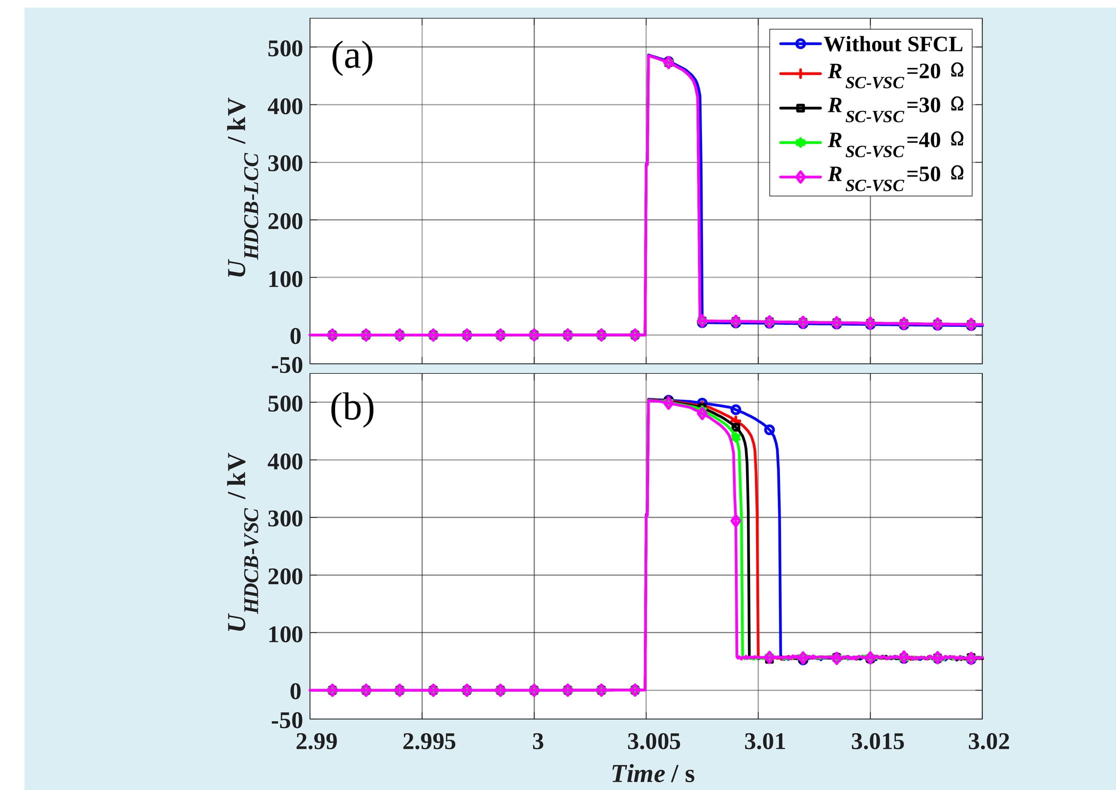

Fig. 6. Transient voltage response of the HDCB subject to changing the SFCL size. (a) LCC station and (b) VSC station.

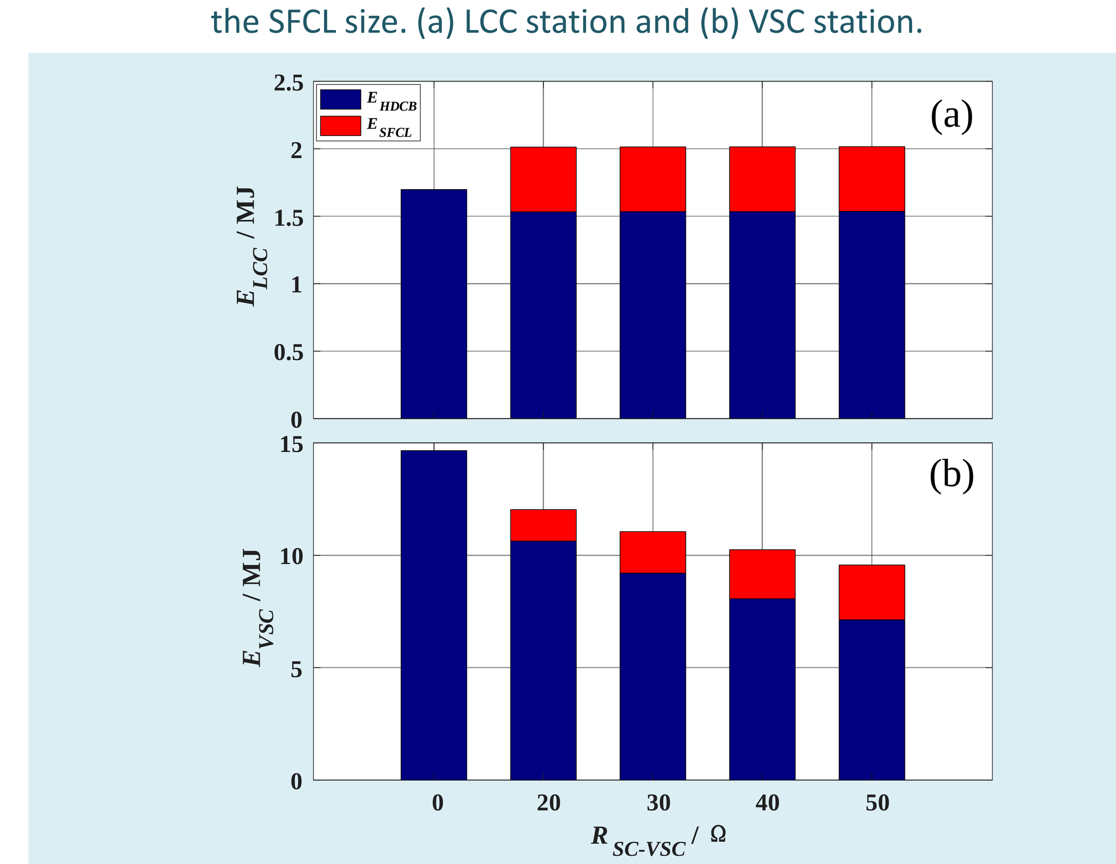

Fig. 7. Dissipated energy of the SFCL and HDCB subject to changing the SFCL size. (a) LCC station and (b) VSC station.

The dissipated energy of the HDCB at the LCC station is reduced from 1.71 MJ to 1.53 MJ after using $R_{SC\text{-}LCC}$ = 50 Ω of the SFCL, which offers an energy dissipation of 0.48 MJ.

The dissipated energy of the HDCB at the VSC station can be obviously decreased with the increase of the SFCL size. In the case of $R_{SC\text{-}VSC}$ = 50 Ω, the HDCB and the SFCL will consume the energy of 7.13 MJ and 2.44 MJ, respectively, and their sum (9.57 MJ) is still much smaller than 14.66 MJ without SFCL.

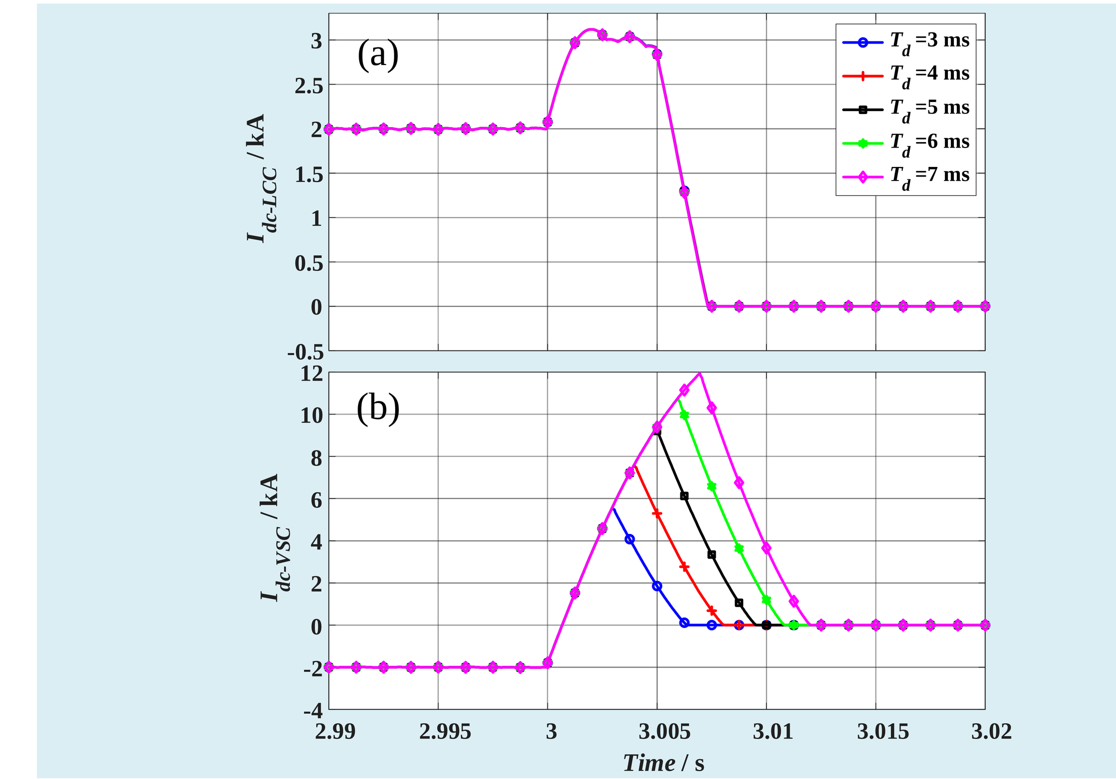

Fig. 8. Fault current response of the HVDC system subject to the change of the MDB delay. (a) LCC station and (b) VSC station.

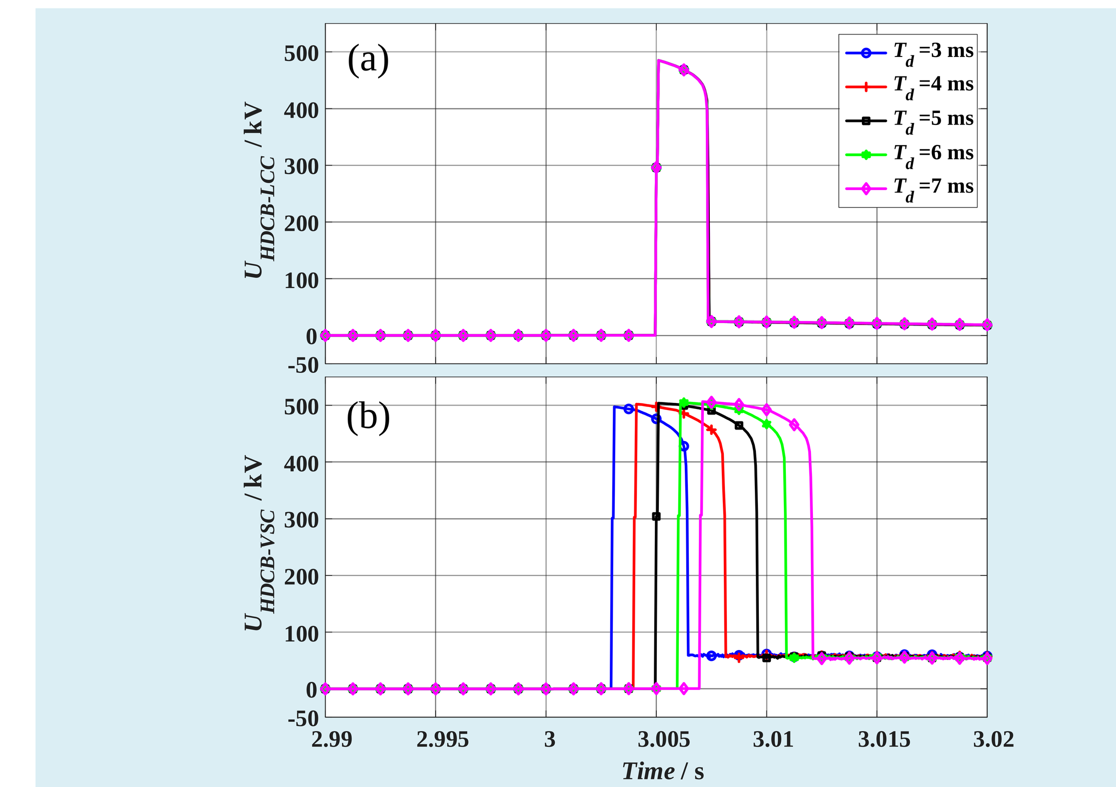

Fig. 9. Transient voltage response of the HDCB subject to the change of the MDB delay. (a) LCC station and (b) VSC station.

Items	Peak of the breaking current	DC fault clearance time	Dissipated energy of the HDCB
T_d = 3 ms	5.57 kA	6.41 ms	4.17 MJ
T_d = 4 ms	7.59 kA	8.12 ms	6.79 MJ
T_d = 5 ms	9.32 kA	9.55 ms	9.21 MJ
T_d = 6 ms	10.76 kA	10.86 ms	11.29 MJ
T_d = 7 ms	11.94 kA	12.05 ms	12.96 MJ

5. Conclusion

This paper explores the coordination of resistive SFCLs and HDCBs in handling the DC line fault of a HVDC system with LCC and VSC stations. On basis of theoretical analysis and simulation assessment, the proposed coordination approach is validated to have favorable validity and suitability. Especially for the VSC station, it is able to powerfully suppress the DC fault current rising, minish the transient voltage duration, and facilitate a significant decrease in the dissipated energy of the HDCB. Concerning the LCC station, the proposed coordination approach can serve as a competitive backup to ensure a timely fault breaking. Thus, the DC fault can be removed more rapidly and reliably, and the system robustness is greatly enhanced.

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