Operation and Control of an HVDC Circuit Breaker with Current Flow Control Capability

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INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

Outline

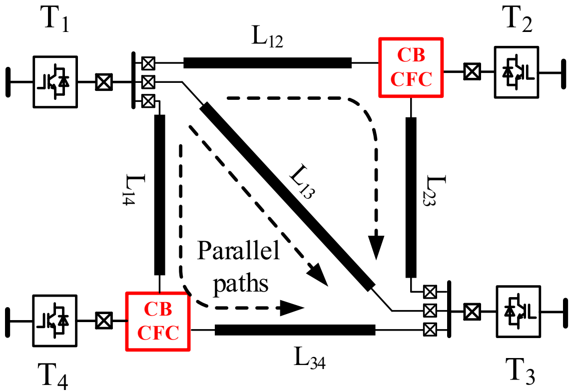
1. Motivations
2. Proposed device
3. Simulation results
4. Conclusion

1. Motivations

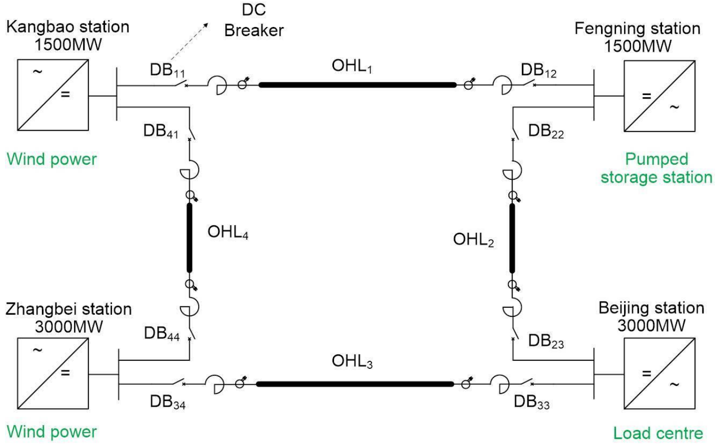
Multi-terminal DC systems

➢ **Multi-terminal HVDC systems**

- Improve system's flexibility
- Improve system's reliability
- Integrate different types of renewable energy



MTDC networks

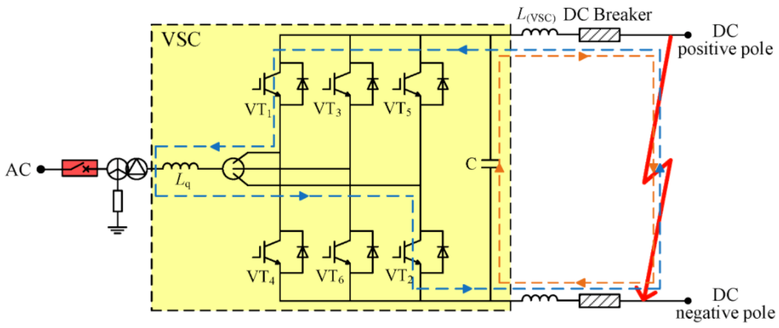


'Zhangbei' ± 500 kV HVDC system for Beijing Olympic Games 2022

[1] G. Tang, H. Pang, Z. He and X. Wei, "Research on Key Technology and Equipment for Zhangbei 500kV DC Grid," in Proc. 2018 International Power Electronics Conference Niigata, 2018, pp. 2343-2351.

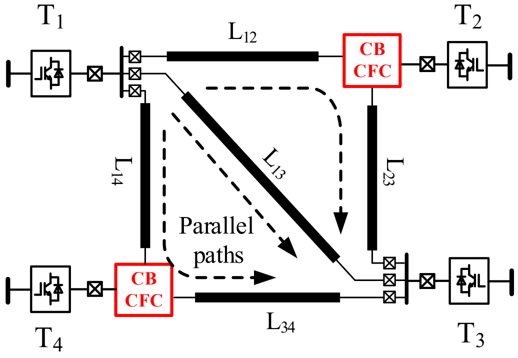
DC fault and Current flow control

- **Challenges of MTDC grids: dc fault**
  - No zero crossings (dc current)
  - High rising rate of current (di/dt)
  - Low capability of overcurrent (IGBTs)



Examples of dc fault for VSC

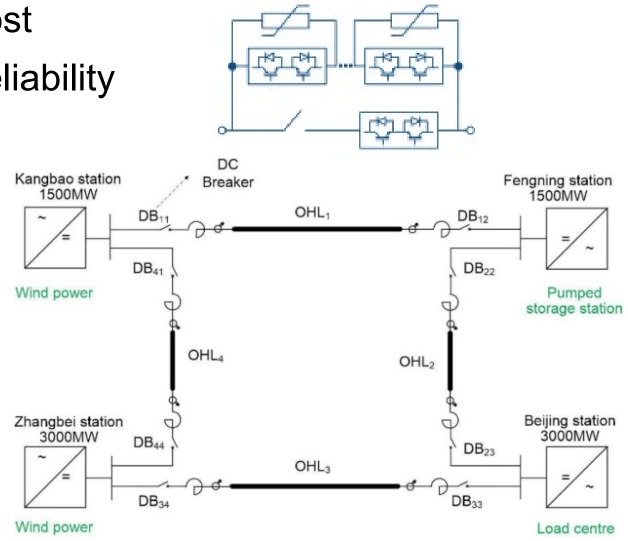
- **Challenges of MTDC grids: Current flow control**
  - Dominated by the resistance of the transmission lines
  - Overloading of transmission lines
  - Limit capacity of power transmission



Four-terminal system

Challenges

- **Challenges for DCCB and CFC**
  - Cost
  - Reliability



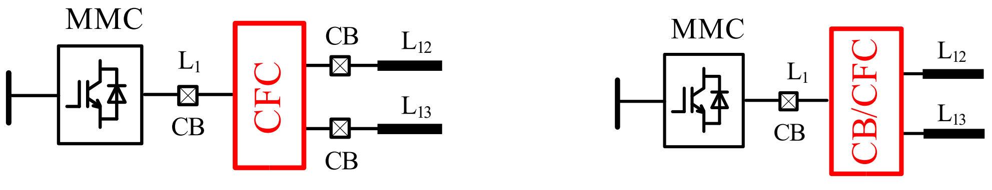
‘Zhangbei’ ± 500 kV HVDC system for Beijing Olympic Games 2022

500 kV HCB developed for Zhangbei project

M. Callavik, A. Blomberg, J. Hafner, and B. Jacobson, “The hybrid HVDC breaker: an innovation breakthrough enabling reliable HVDC grids”, *ABB Grid Systems, Technical Paper*, Nov. 2012.

Solutions

- **Targets**
  - Integrate several CBs and CFC into one device
  - Reduce semiconductors and costs
  - Maintain same function



(a) Separate HCBs and CFC.

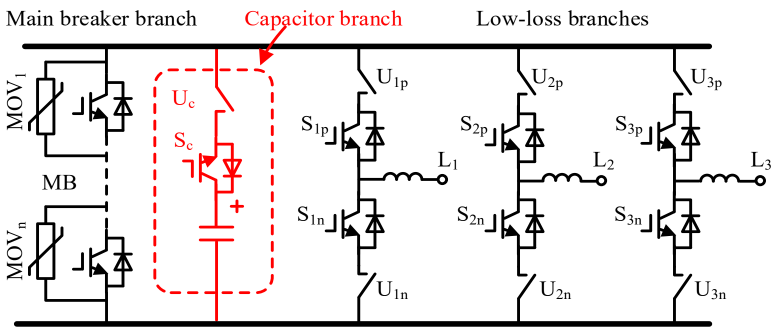
(b) Integrated device.

M. Callavik, A. Blomberg, J. Hafner, and B. Jacobson, "The hybrid HVDC breaker: an innovation breakthrough enabling reliable HVDC grids", *ABB Grid Systems, Technical Paper*, Nov. 2012.

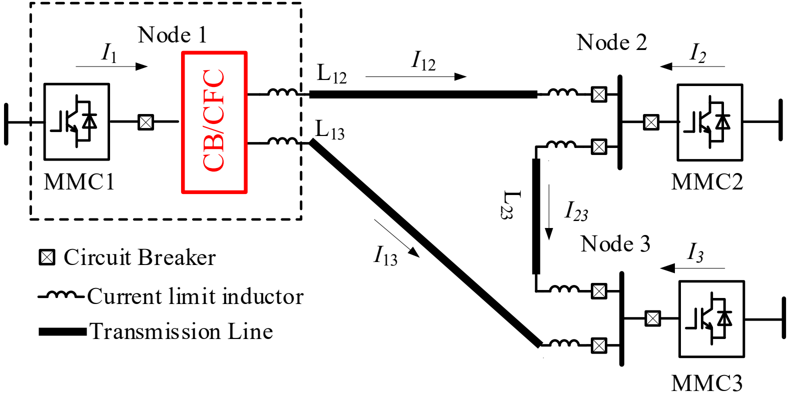
2. Proposed device

Proposed device

- **Topologies**
  - Two CBs and one CFC integrated



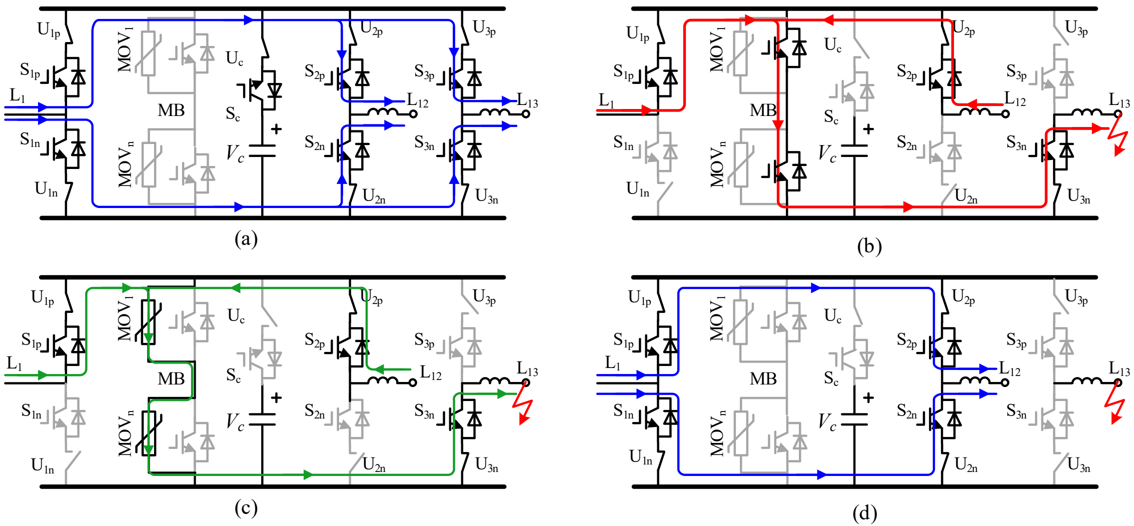
Proposed device (CB/CFC)



System configuration with the CB/CFC

Proposed device

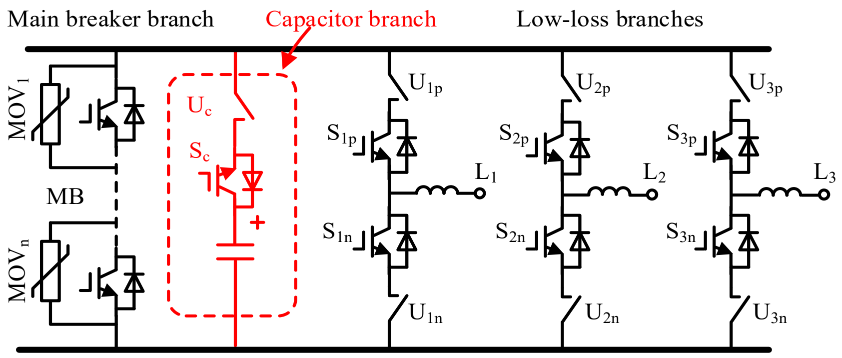
- **DC fault isolating**
  - Four steps



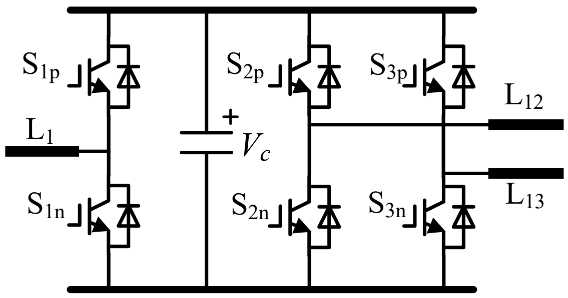
Fault isolation process. (a) Pre-fault. (b) Current commutation. (c) Fault current interruption. (d) Post fault.

Proposed device

➢ **Current flow control**



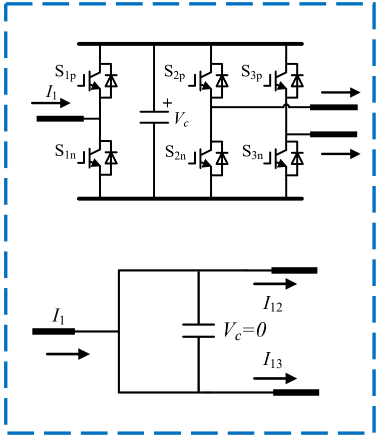
Topology of CB/CFC



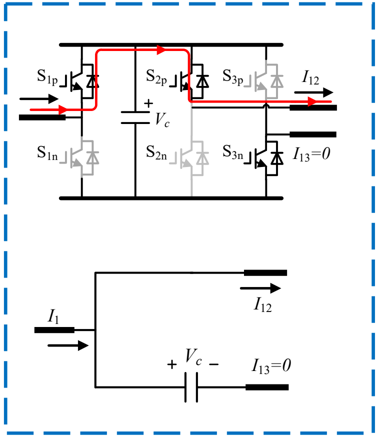
Simplified equivalent circuit as a CFC

Proposed device

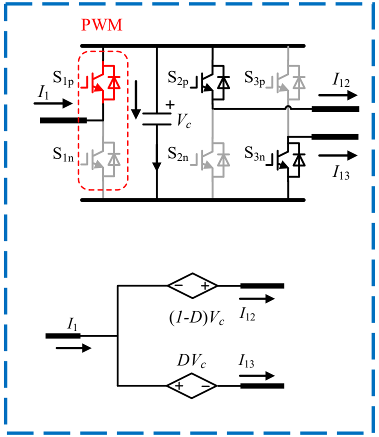
- ➢ **Bypass mode**
- ➢ **Current nulling mode**
- ➢ **Current sharing mode**



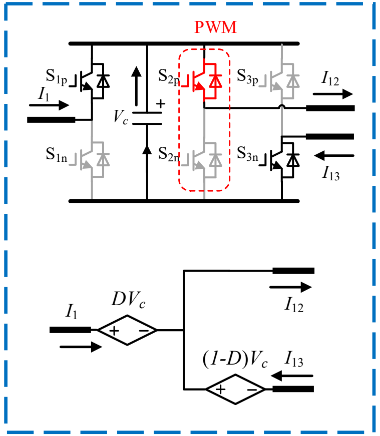
$$I_1 = I_{12} + I_{13}$$



$$I_{12} = I_1, \quad I_{13} = 0$$



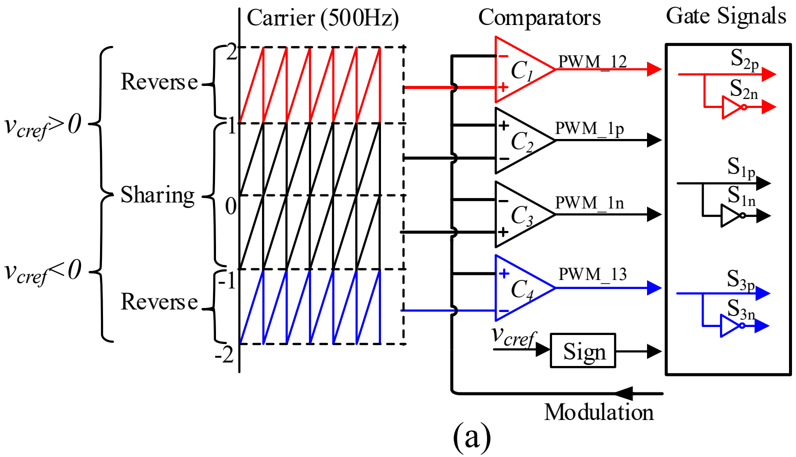
$$I_{12} = I_1 D$$



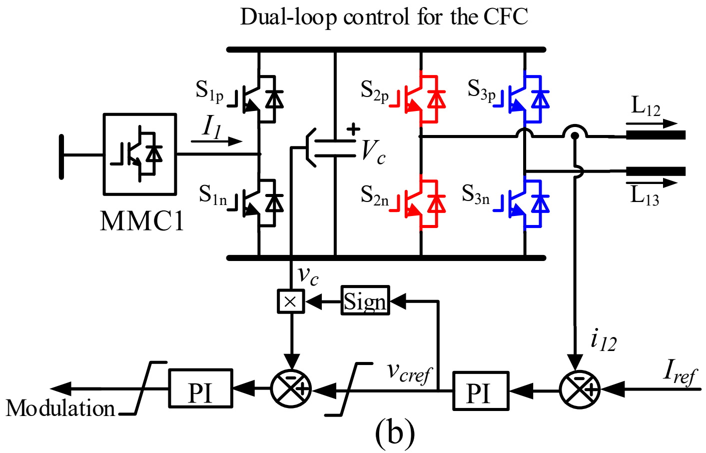
$$I_{12} = I_1 / D$$

Proposed device

- **Control and modulations**



Level-shift modulation



Dual-loop control loop

3. Simulation results

Proposed device

- **System parameters**

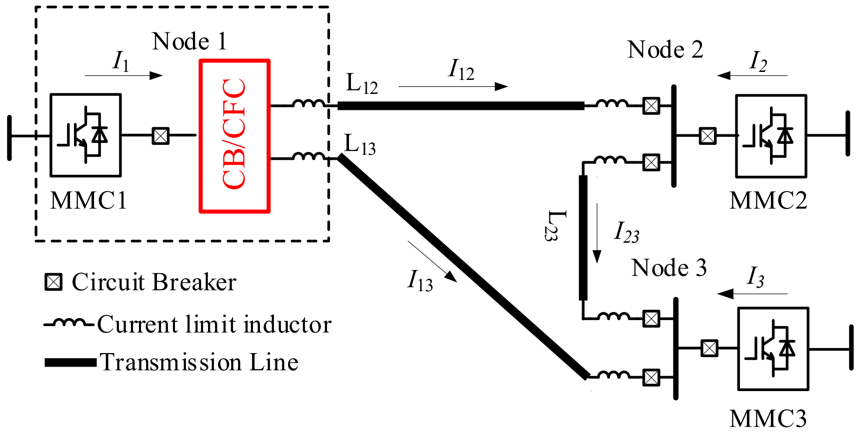
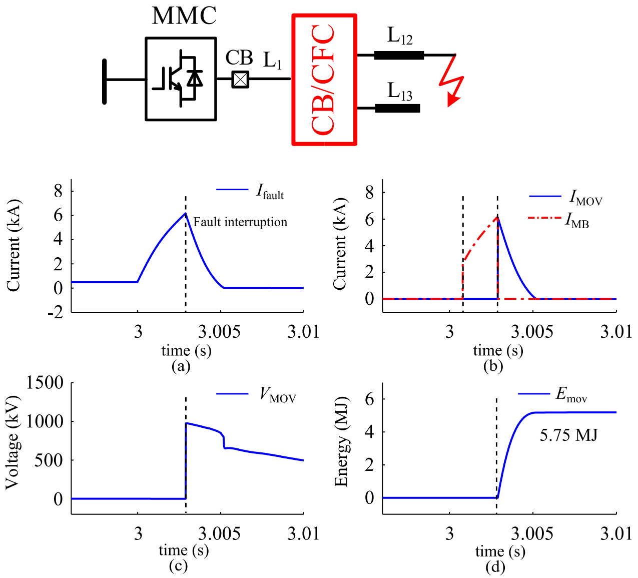


TABLE I
MTDC SYSTEM PARAMETERS

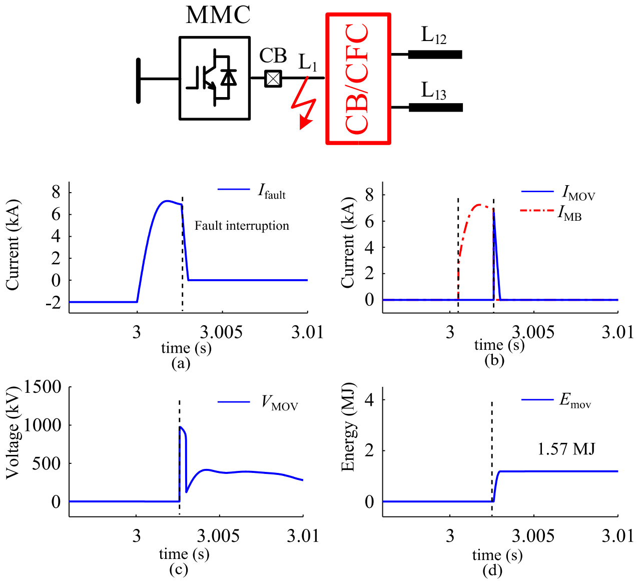
Parameter	Value
Rated dc voltage	500 kV
Rated power MMC1, 2, 3	1000 MW,1000 MW, 1500 MW
Transformer rated capacity	1200 MVA,1200 MVA,1800 MVA
Transformer ratio	500 kV/260 kV
Transformer leakage inductance	0.15 p.u.
Arm inductance	60 mH
SM Capacitor	18 mF
Number of SMs in each arm	250
DC current limiting inductor	300 mH /100 mH
Pi-section (per 40 km)	0.38 Ω, 84.4 mH, 0.46 μF
Capability of transmission line	1.5 kA
Length of Line 12, Line 13, Line 23	200 km, 200 km, 200 km

Proposed device

- **Simulation results of dc fault isolation**



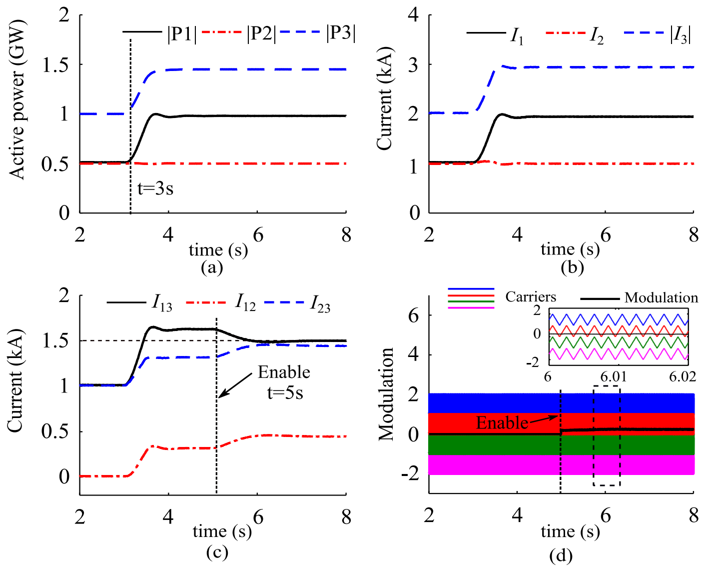
Protection of dc faults at transmission lines. (a) Fault current. (b) Currents of MB and MOV. (c) Voltage of MB. (d) Energy absorbed by the CB/CFC.



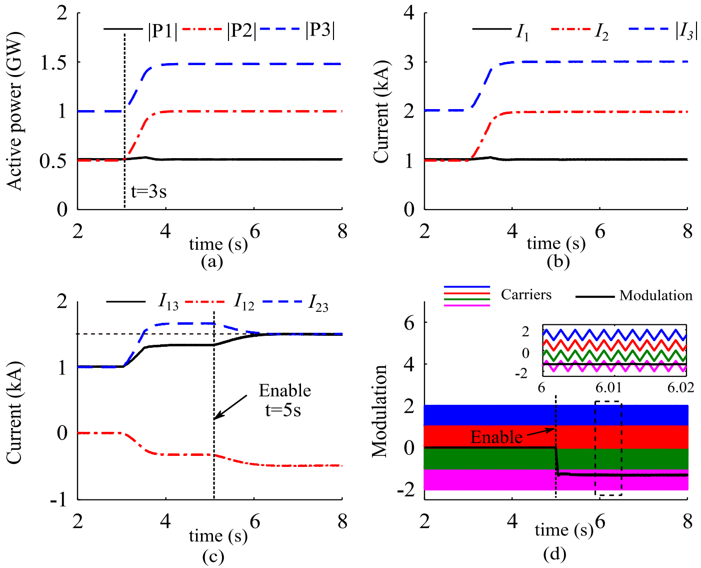
Protection of dc faults at transmission lines. (a) Fault current. (b) Currents of MB and MOV. (c) Voltage of MB. (d) Energy absorbed by the CB/CFC.

Proposed device

➢ **Simulation results of current flow control**



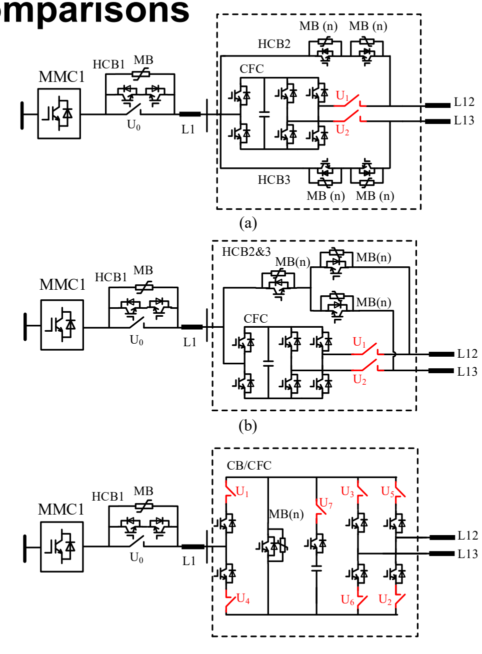
Current reversal mode for CFC operation. (a) Active power of converters. (b) DC currents of converters. (c) Currents of transmission lines. (d) Modulation and carrier signals.



Current reversal mode for CFC operation. (a) Active power of converters. (b) DC currents of converters. (c) Currents of transmission lines. (d) Modulation and carrier signals.

Proposed device

➢ **Comparisons**



Integrated schemes of CFC with HCB. (a) Scheme I: Sharing LCSs.(b) Scheme II: Sharing LCSs and MBs. (c) Scheme III: CB/CFC.

TABLE IV
NUMBER OF HIGH VOLTAGE COMPONENTS

Scheme	No. of IGBTs	No. of UFD Units	No. of MOV Units
I	$4n$+6×4	2	4
II	$3n$+6×4	2	3
III	n+7×4	7	1

Note: n is determined by the residual voltage of MOVs and the cut-off current of the HCBs and n is in the level of hundreds for a 500 kV HCB [29].

TABLE V
COST CALCULATION OF THE MB BRANCH FOR A 500 KV SYSTEM

Scheme	No. of MB units	No. of IGBTs	Costs (Million)
I	4	800×4 = 3200	$ 28.8
II	3	800×3 = 2400	$ 21.6
III	1	800×1= 800	$ 7.2

Note: 400 IGBTs are in series to withstand a transient voltage of 900 kV and 400 IGBTs are in parallel to withstand the fault current. Therefore, 800 IGBTs are considered per MB unit.

4. Conclusion

Conclusion

1. DC protection and current flow control were analysed for MTDC applications
2. The proposed device was described.
3. Simulation results were given to verify the function of the proposed device.

Publications on this topic:

[1] **Wei Liu**, Jun Liang, Carlos Ugalde Loo, Chuanyue Li, Gen Li, Peng Yang. “Level-shift Modulation and Control of a Dual H-bridge Current Flow Controller in Meshed HVDC systems”. ECCE.2019.

[2] **Wei Liu**, Carlos Ugalde Loo, Jun Liang, Chuanyue Li, Frederic. “Modeling and Frequency Analysis of a Dual H-bridge Current Flow Controller in Meshed HVDC Systems”. EPE.2019.

[3] **W. Liu**, C. Li, C. E. Ugalde-Loo, S. Wang, G. Li and J. Liang, “Operation and Control of an HVDC Circuit Breaker with Current Flow Control Capability," *IEEE Journal of Emerging and Selected Topics in Power Electronics* (Early access).

[4] S. Wang, W. Ming, **W. Liu**, C. Li, C. E. Ugalde Loo and J. Liang, "A Multi-Function Integrated Circuit Breaker for DC Grid Applications," *IEEE Transactions on Power Delivery* (Early access).