Protection Configuration & Scheme for VSC-HVDC Transmission Lines

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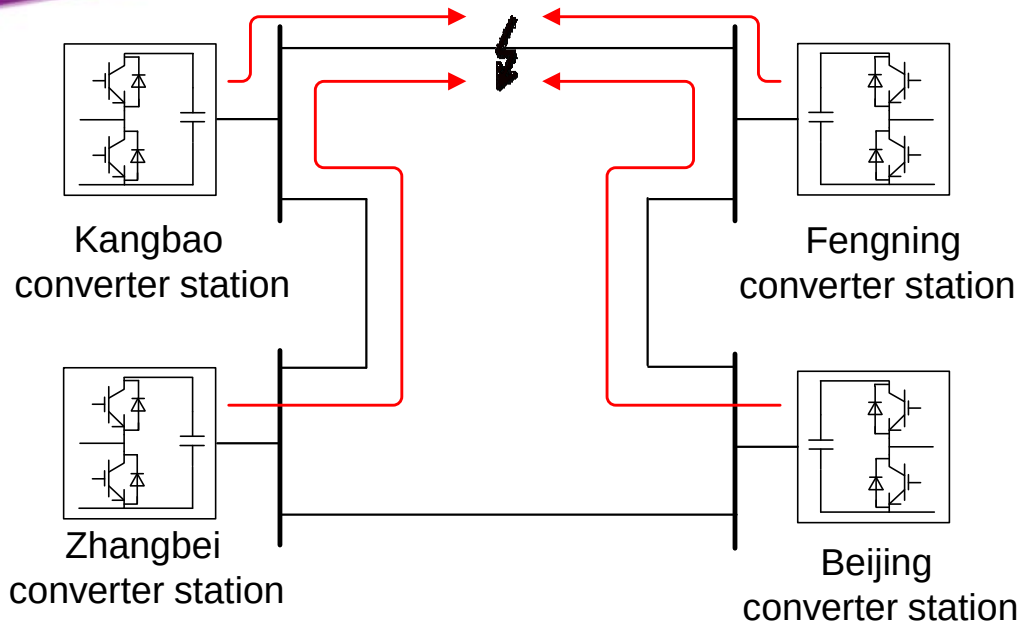
1. Introduction

- SGCC will establish **500kV VSC-HVDC Power Grid** for 2022's Beijing Winter Olympic Games in Zhangbei area.



Fault current in Zhangbei 500kV VSC-HVDC grid

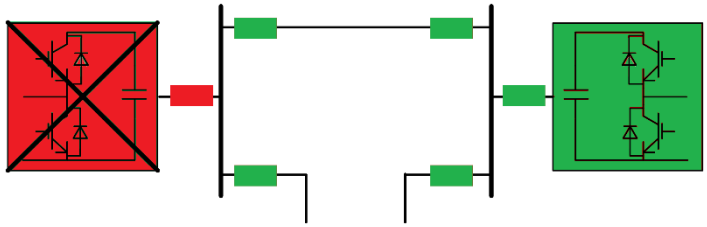
- A short circuit fault at DC side in the grid will immediately lead to severe overcurrent and rapid voltage sag.

- Peak current up to 30kA；
- The rise rate of current in arms up to 3kA/ms；
- DC voltage sag to 80% in 2~3ms.

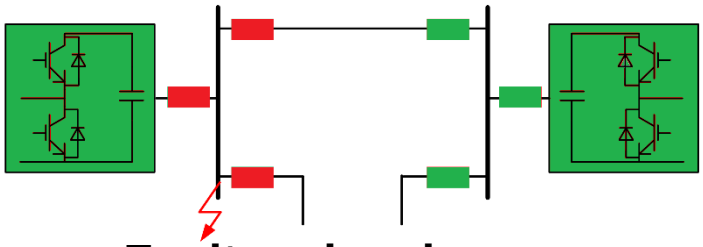
Protection Mode

For a VSC-HVDC power grid

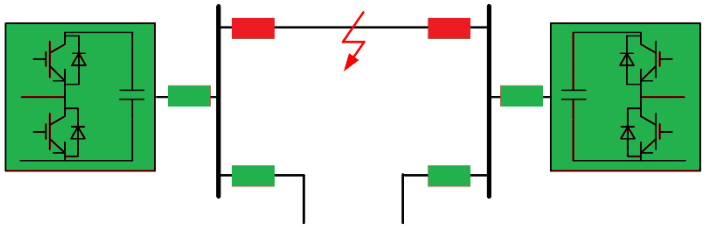
Its fault clearance and protection strategy should be the same as those in AC power grid to try their best to maintain the grid integrity and continuous operation.



Fault in converter—
Trip the breaker connecting the converter



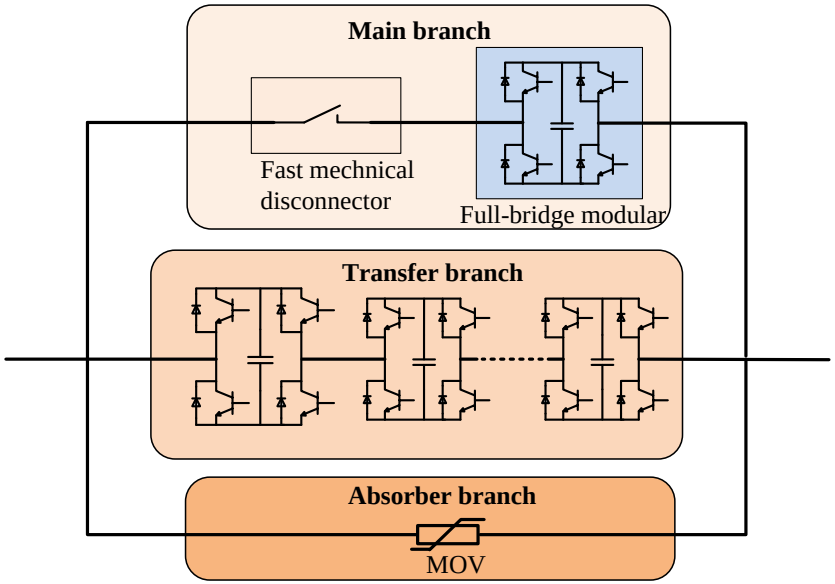
Fault on bus bar—
Trip breakers connecting the bus bar



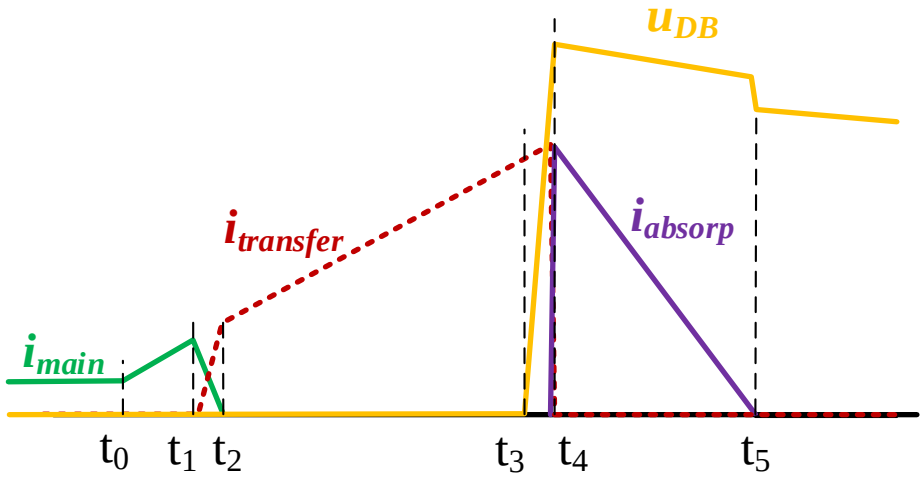
Fault on DC line—
Trip both breakers on DC line

DC Circuit Breaker

- No zero-crossing current. More difficult to cut off DC current than AC current. Difficult to implement DC circuit breaker with large capacity.
- Fortunately, smoothing reactors in DC grid can slow down the rise of short-circuit current. If circuit breaker can operate fast enough, it's possible to cut off the current before it exceeds the ability of circuit breaker.



H-bridge hybrid cascade connection DC circuit breaker topology

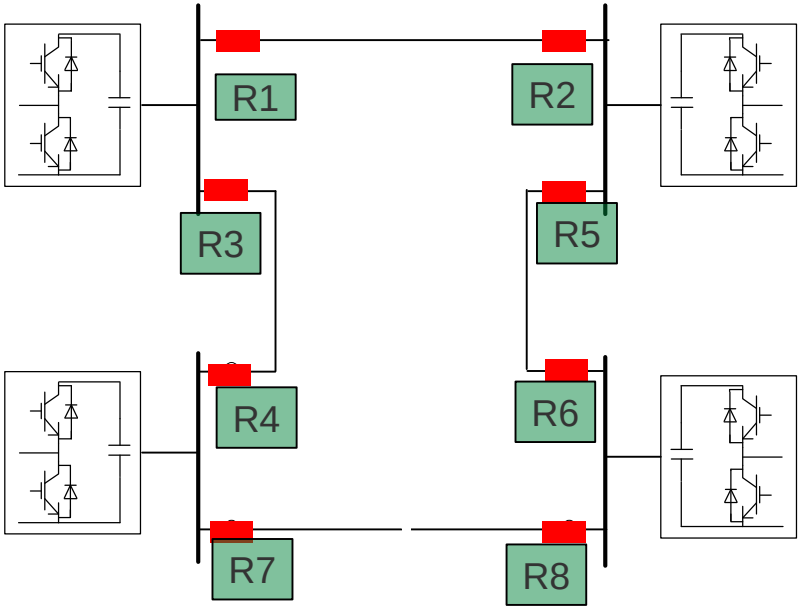


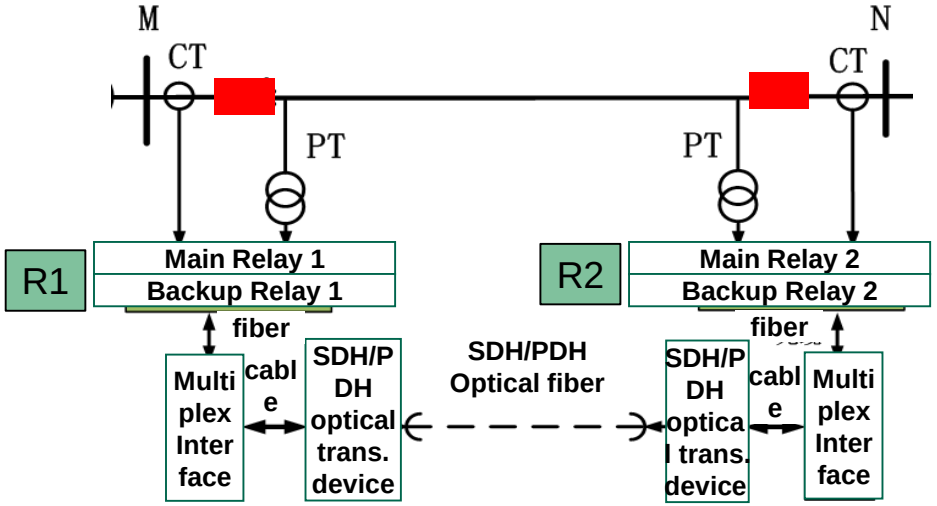
Current in H-bridge hybrid cascade connection DC circuit breaker

Protection Requirements

- The prerequisite for circuit breaker to isolate the fault fast is to send a trip command to it after a fault as fast as possible.
- According to the field requirements, SGCC claims to isolate the fault in VSC-HVDC power grid in less than 6ms, and the operation time of circuit breaker is less than 3ms. That is to say, the protection in DC grid should operate in less than 3ms, which means ultra-high speed.
- In addition, the protection should have high reliability, sensitivity and selectivity.

Protection Configuration of DC lines





- DC circuit breaker should be used in every DC line;
- Every DC circuit breaker should be controlled by one relay.

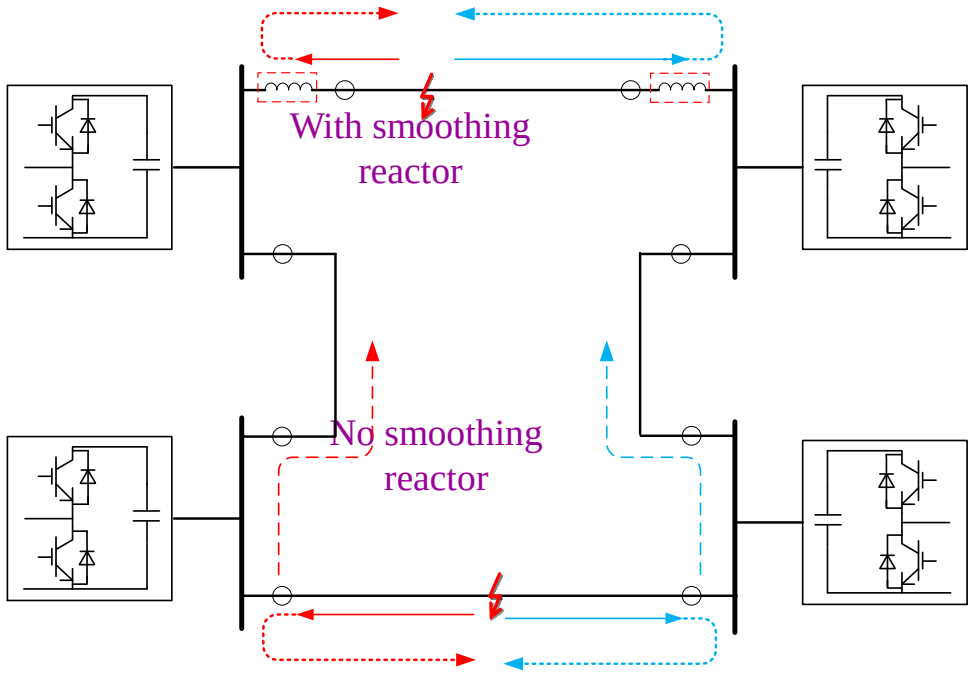
- Each Protection should be configured with：
  - Main protection
  - Backup protections

Protection Configuration of DC lines

- **Main Protection** uses single-end power electrical quantity to ensure the rapidity (operation time is less than 3ms)
  - This is different to the protection scheme in traditional AC line (pilot protection is the main one)
- **Backup Protection** uses pilot directional or differential protection, with almost 20-30ms operation time to ensure the reliability and selectivity.
  - The backup protection is different with AC lines and LCC lines.
  - There is not a impedance relay likes AC Lines.
  - Backup protection cannot and also does not need fast operation due to the impact of transient process after a fault for a LCC DC lines.

3. VSC-HVDC Protection Configuration & Scheme

- **Main Protection**：local data based protection technique (Travelling waves or transient component);
- Backup Protection：Optical pilot differential protection



Travelling waves based propagation in loop DC grid

3. VSC-HVDC Protection Configuration & Scheme

Protection Scheme

Main protection :Single-end Initial TW based protection

- Criterion

  The addition of Reverse waves's WTMM

$$\left|\sum U_{b-\_\mathrm{WTMM}}\right| > U_{set}$$

- Sampling frequency

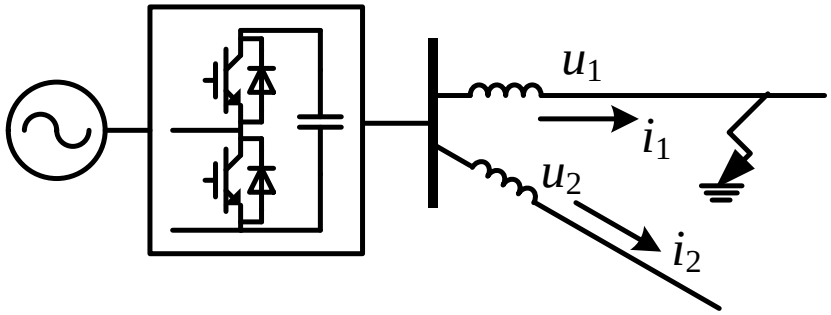
  500kHz

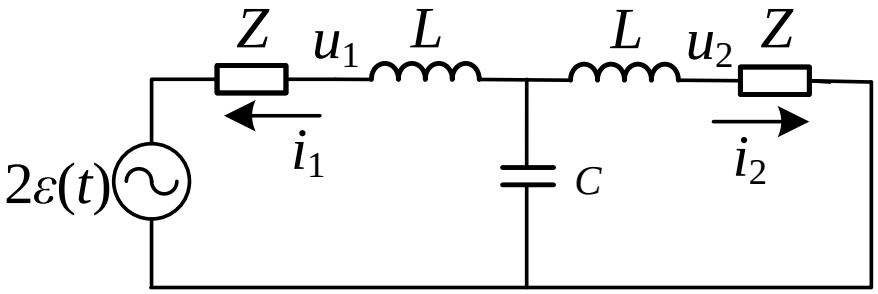
- Multi- scale wavelet transform

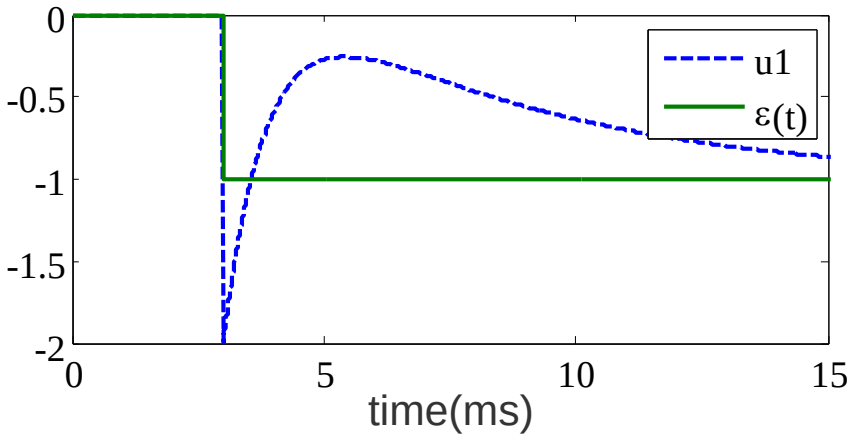
  Ensure the reliability

3. VSC-HVDC Protection Configuration & Scheme

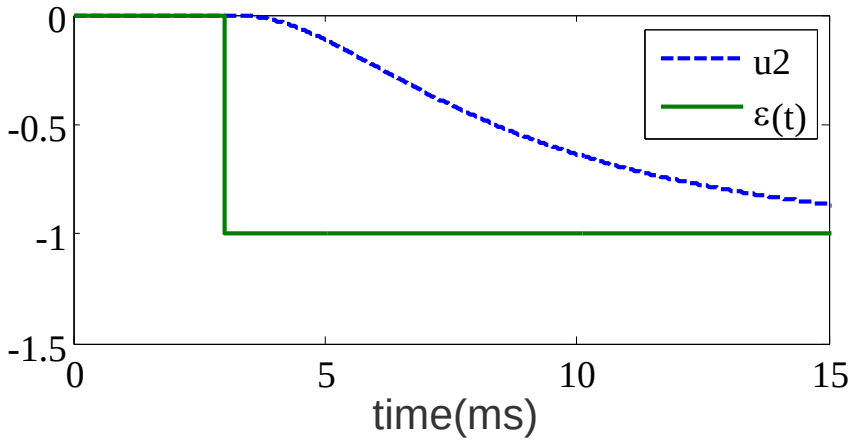
Initial TW based Main Protection







Internal fault



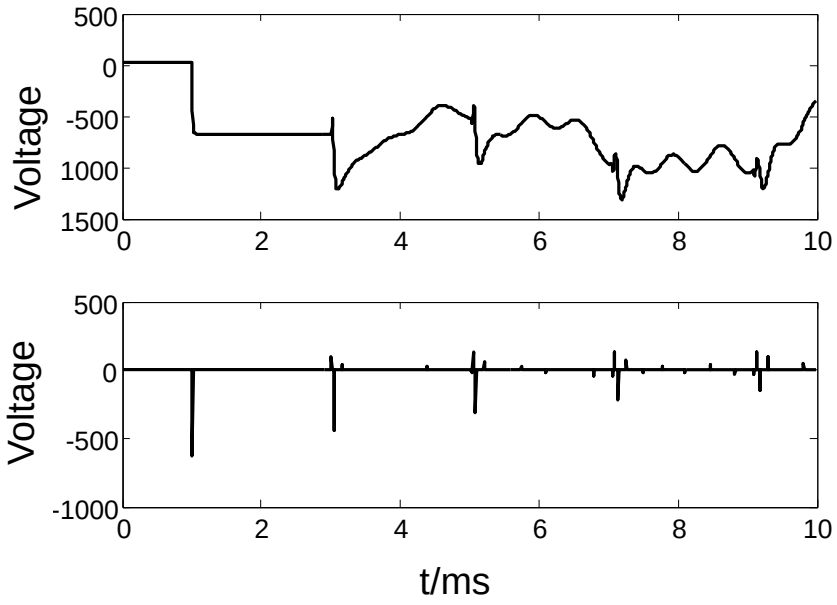
External fault

3. VSC-HVDC Protection Configuration & Scheme

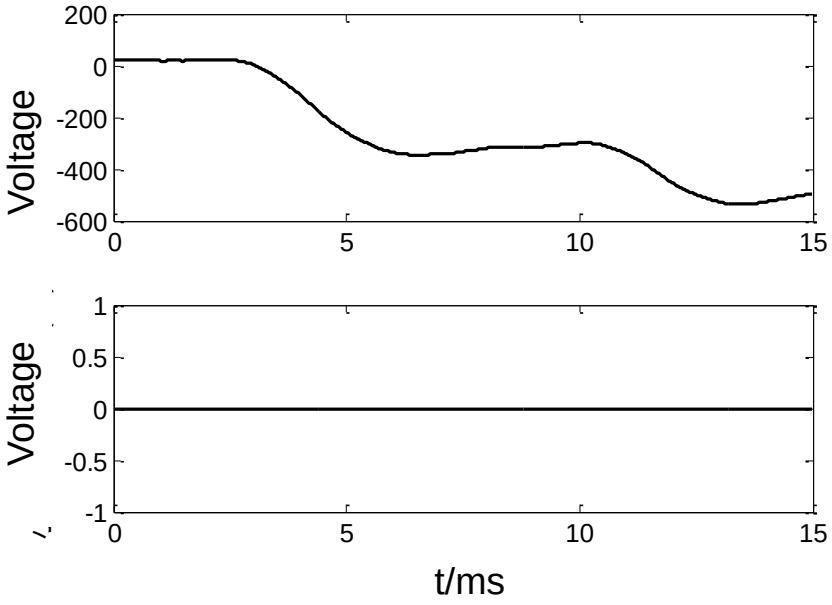
Initial TW based Main Protection

- Simulation result

Internal fault

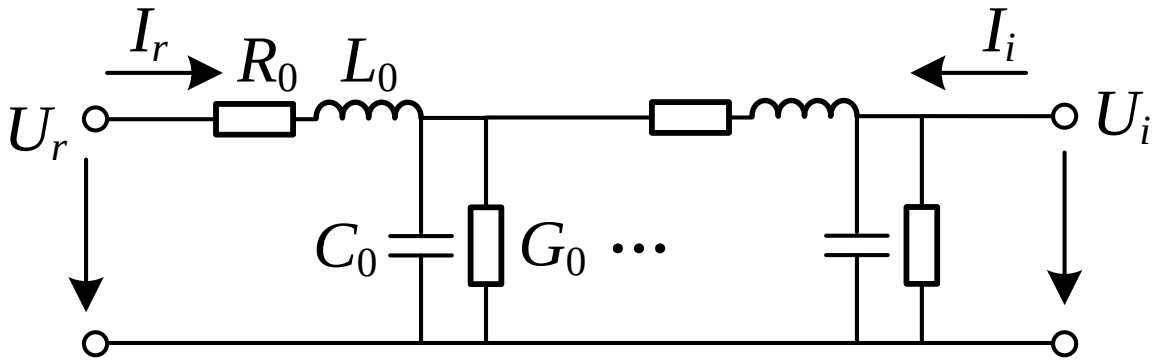


External fault



Protection Scheme

Backup Protection : TW based differential Protection



- Frequency-dependent model

$$\begin{cases} U_r/Z_c - I_r = (U_i/Z_c + I_i)e^{-\gamma l} \\ U_i/Z_c - I_i = (U_r/Z_c + I_r)e^{-\gamma l} \end{cases}$$

- TW differential current in frequency domain

$$\Delta I_1 = U_r/Z_c - I_r - (U_i/Z_c + I_i)e^{-\gamma l} \qquad \Delta I_2 = U_i/Z_c - I_i - (U_r/Z_c + I_r)e^{-\gamma l}$$

- External fault

$$\Delta I_2 = 0 \qquad \Delta I_1 = 0$$

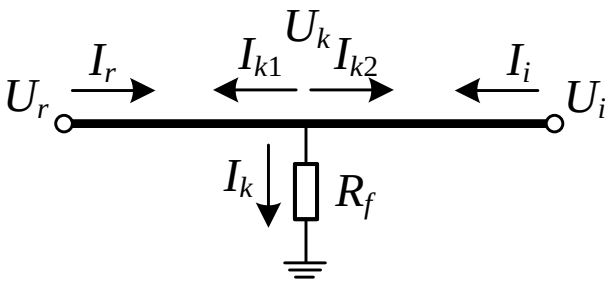
3. VSC-HVDC Protection Configuration & Scheme

TW based differential backup protection

- Internal fault

$$\begin{cases}(U_r/Z_c + I_r)e^{-\gamma l_k} = U_k/Z_c - I_{k1} \\ (U_k/Z_c + I_{k2})e^{-\gamma(l-l_k)} = U_i/Z_c - I_i\end{cases}$$

$$I_{k1} + I_{k2} + I_k = 0$$



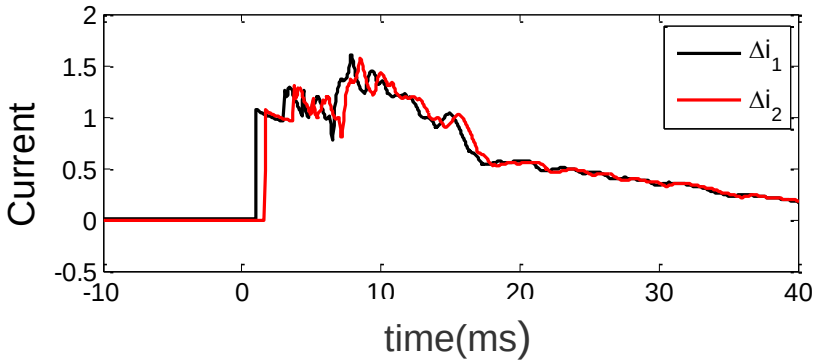
$$\Delta I_1 = (U_r/Z_c - I_r) - (U_i/Z_c + I_i)e^{-\gamma l}$$
$$= -I_k e^{-\gamma l_k}$$

$$\Delta I_2 = (U_i/Z_c - I_i) - (U_r/Z_c + I_r)e^{-\gamma l}$$
$$= -I_k e^{-\gamma(l-l_k)}$$

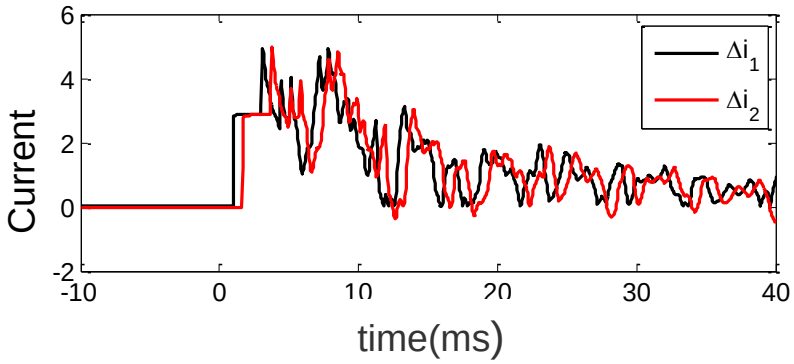
3. VSC-HVDC Protection Configuration & Scheme

TW based differential backup protection

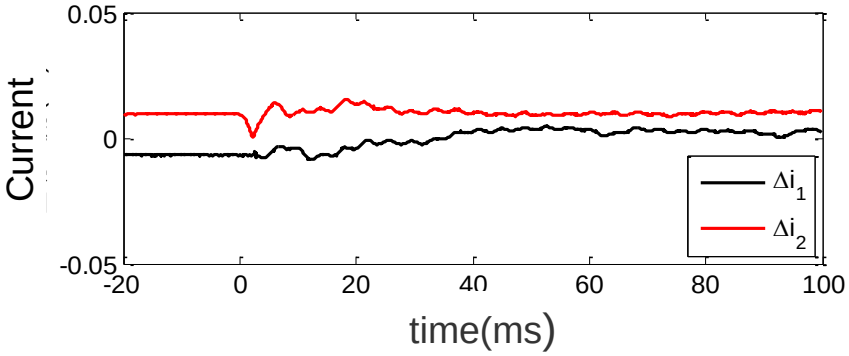
- Internal monopolar fault



- Internal bipolar fault



- External fault



4. Conclusion

- Faults in VSC-HVDC line must be cleared with **Ultra-High Speed** (<3ms).
- Protection for AC transmission lines and LCC HVDC lines can’t meet the requirements of VSC-HVDC lines.
- **Initial Travelling Waves Based Main Protection** is the only possible main protection of VSC-HVDC lines.
- **Travelling Waves Based Differential Protection** is an excellent backup protection of VSC-HVDC lines.

Thanks! & Questions?