Protection Technology for VSC-HVDC Transmission Lines

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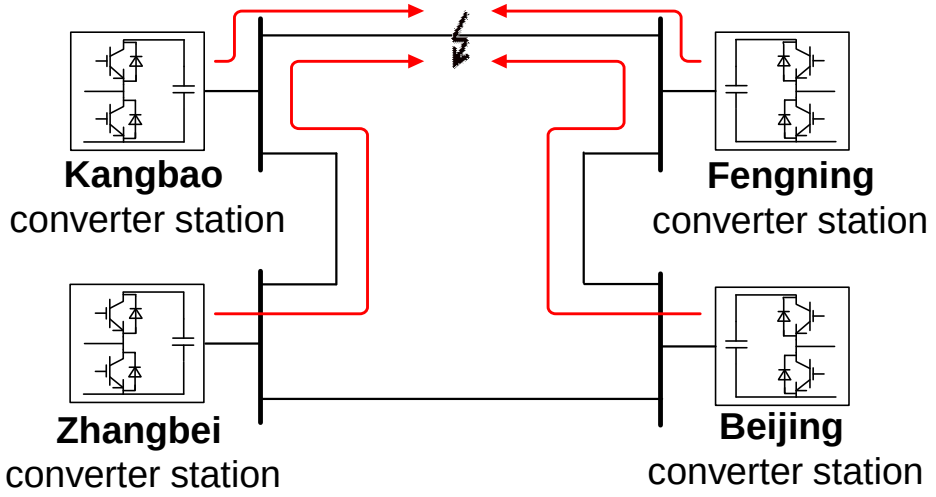
Contents

1. Introduction

Which can flexibly accept the **fluctuating** power

A ±500kV flexible DC power grid is building in Zhangbei by SGCC



Fault current in **ZHANGBEI** 500kV VSC-HVDC grid

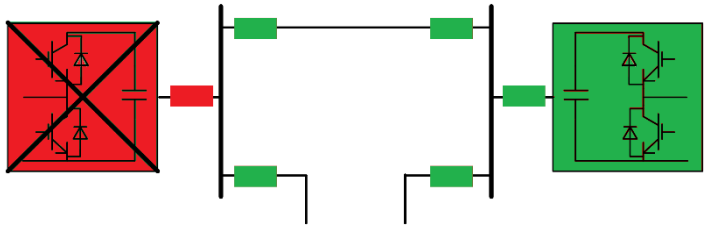
- A short circuit fault at DC side in the grid will immediately lead to severe overcurrent and rapid voltage sag.

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

1. Introduction

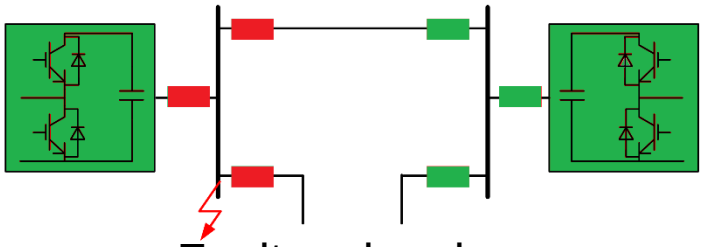
For a VSC-HVDC power grid by Cigre

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



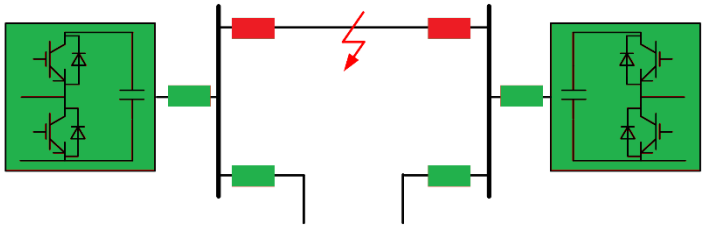
Fault in converter

Trip the breaker connecting the converter



Fault on bus bar

Trip breakers connecting the bus bar

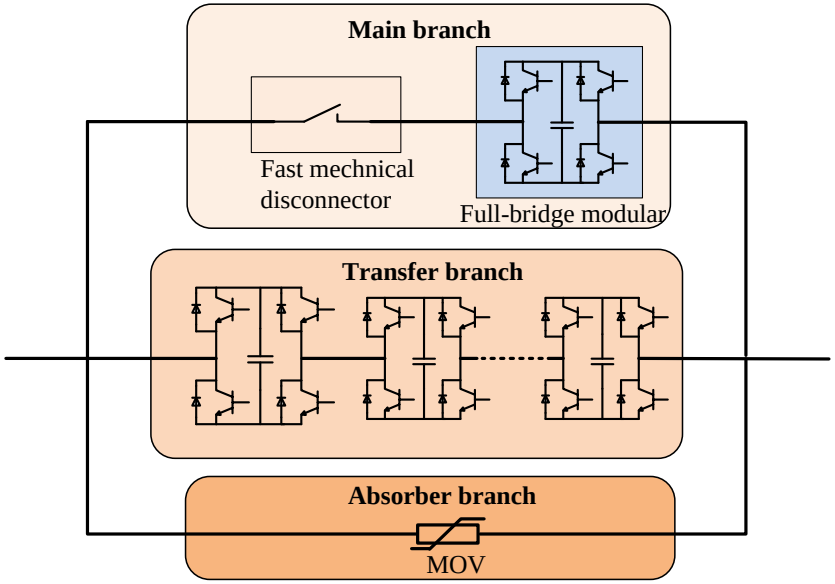


Fault on DC line

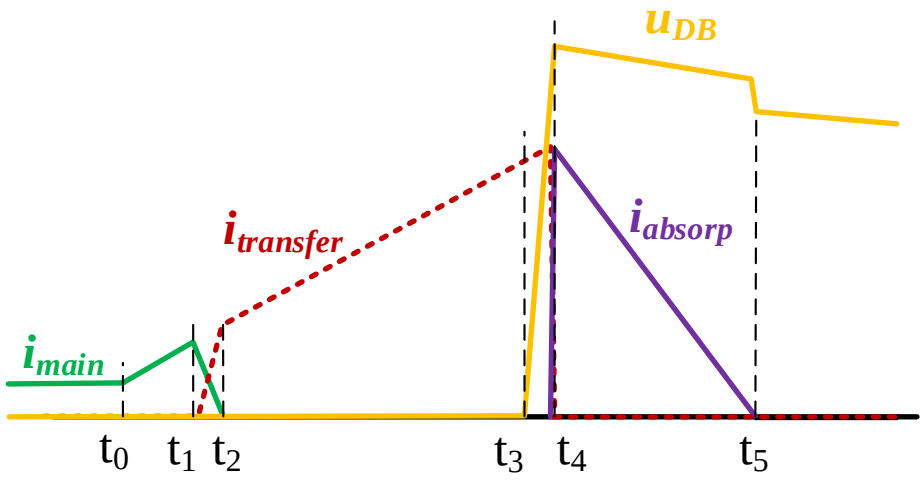
Trip both breakers on DC line

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



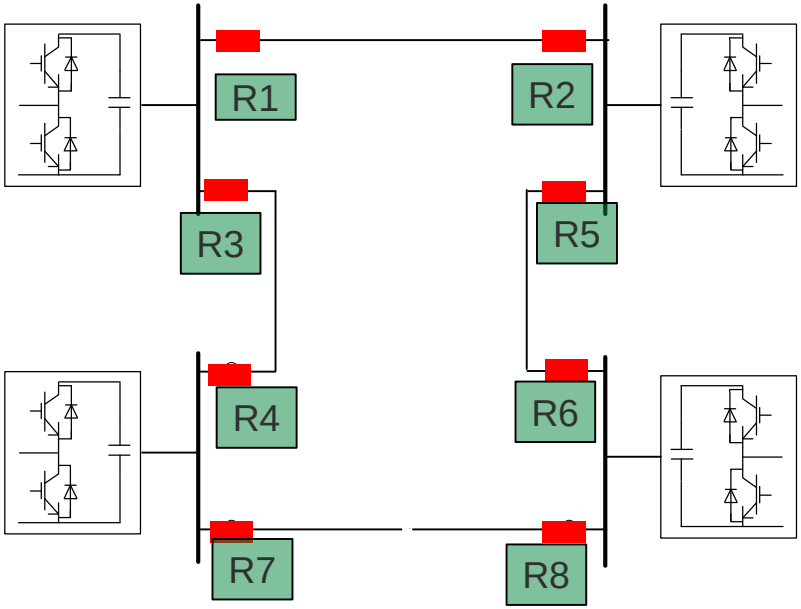
Current in H-bridge hybrid cascade connection DC circuit breaker

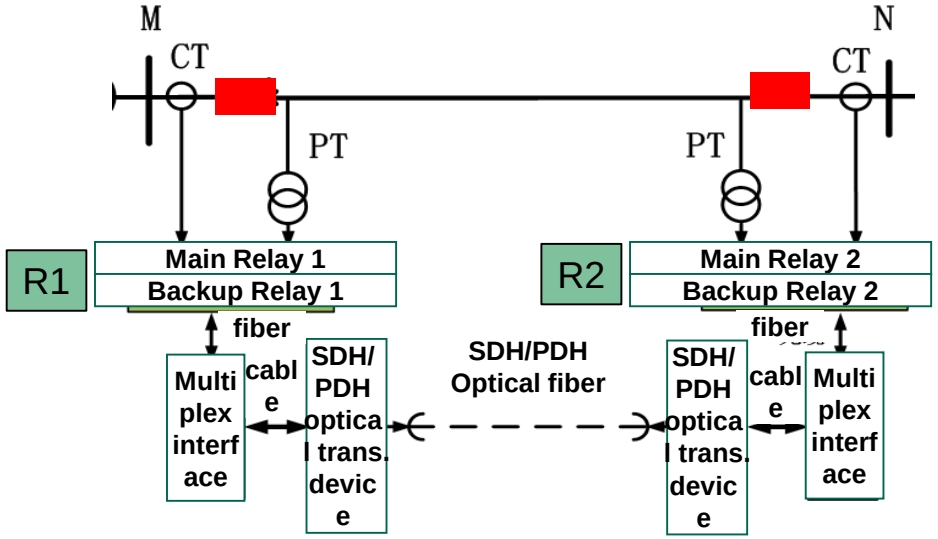
Protection

- 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**.
- Certainly, the protection should have high reliability, sensitivity and selectivity.

3. VSC-HVDC Protection's Configuration & Scheme

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

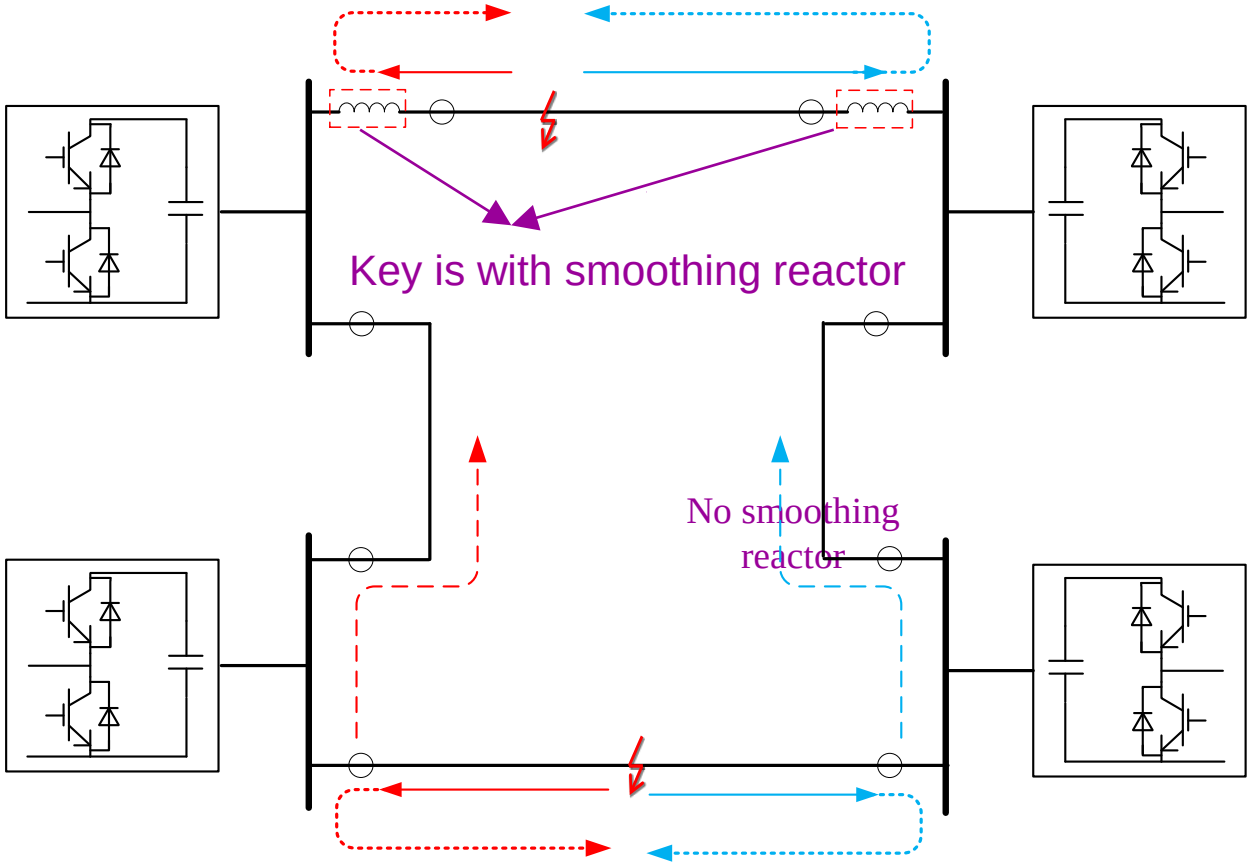
- **Main protection** uses **single-end power electrical quantity** to ensure the rapidity (operation time is less than 3ms)
  - This is different to the protection scheme in traditional AC line (pilot protection is the main one)
- **Backup protection** uses **pilot directional or differential protection**, with almost 20-30ms operation time to ensure the reliability and selectivity.

This is different with AC lines and LCC lines.

- There is not a impedance relay likes AC Lines.
- Backup protection(Current Differential Protection,**800ms**) cannot and also does not need fast operation due to the impact of transient process after a fault on a LCC DC lines.

Protection's Scheme

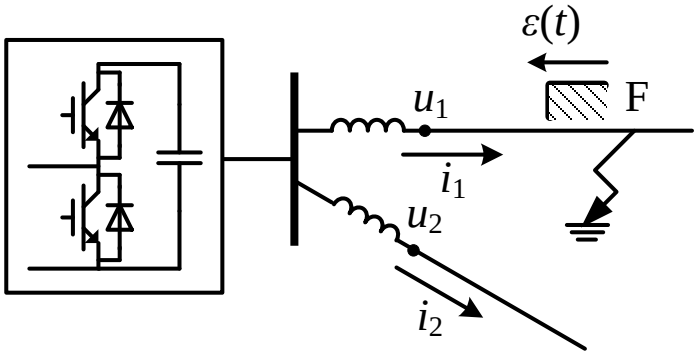
- Main protection: local data based protection technique (Travelling waves and transient component);
- Backup protection: Optical pilot travelling waves differential protection



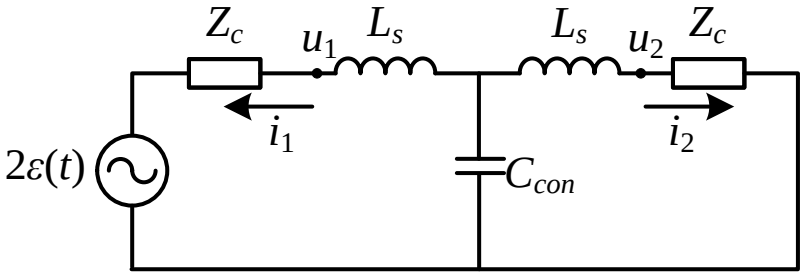
In order to form a border to prevent travelling waves, the smoothing reactor should be deployed in the sides of DC Lines

Travelling wave propagation in loop DC grid

A: Main Protection based on Single end Initial TW

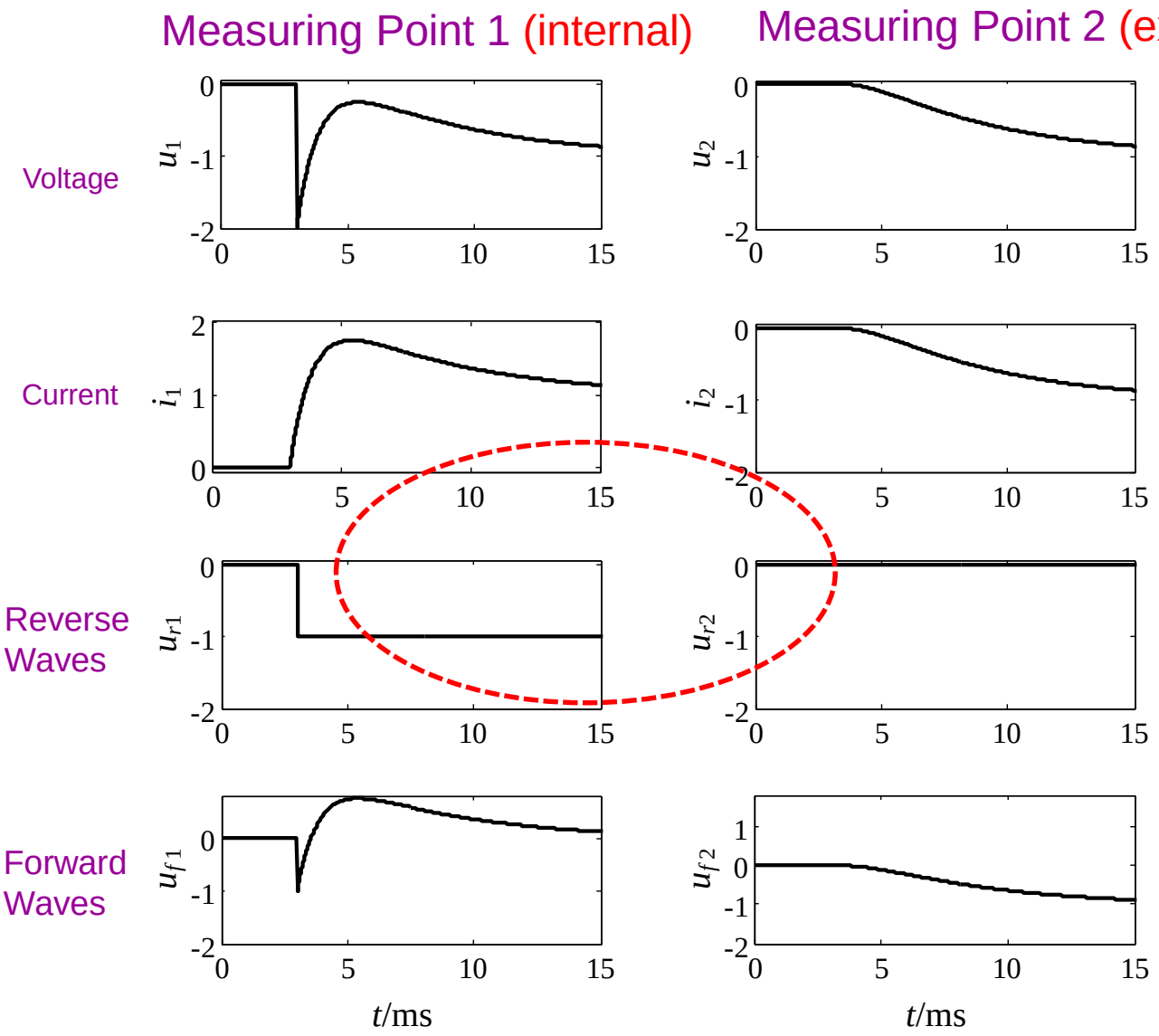


DC line's Boundary



Equivalent Circuit

A: Main Protection based on Single end Initial TW



- **Internal Fault:**

  Reverse Wave

  is very clear

- **External Fault**

  The all of Signal are smooth

A: Main Protection based on Single end Initial TW

Main protection :Single-end Initial Travelling Waves based protection

- Criterion
  - The addition of negative WTMM

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

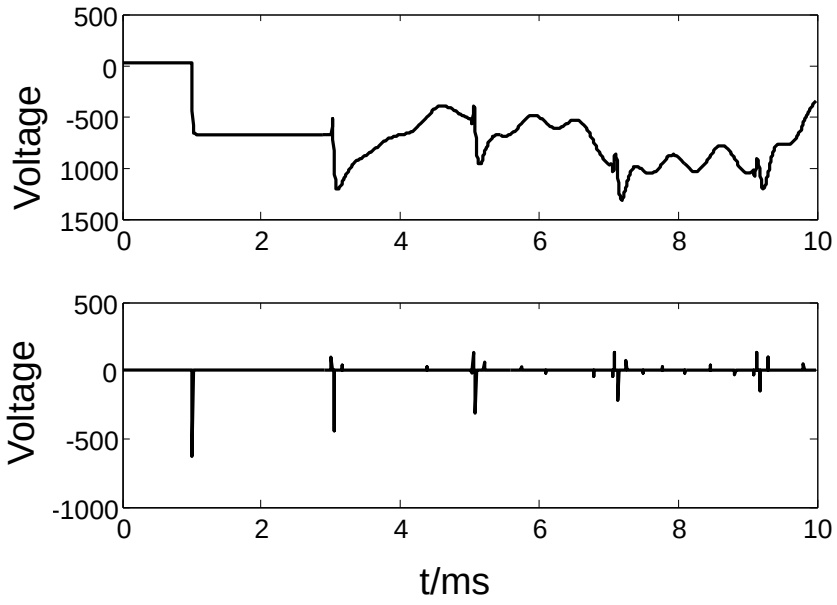
- Sampling frequency
  - 500kHz

- Multi- scale wavelet transform
  - Ensure the reliability

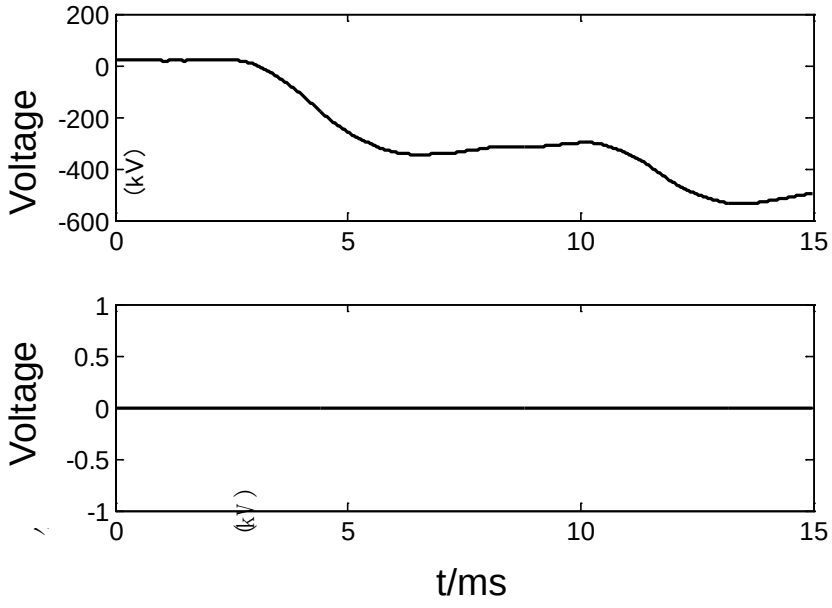
A: Main Protection based on Single end Initial TW

- Simulation result

Internal fault



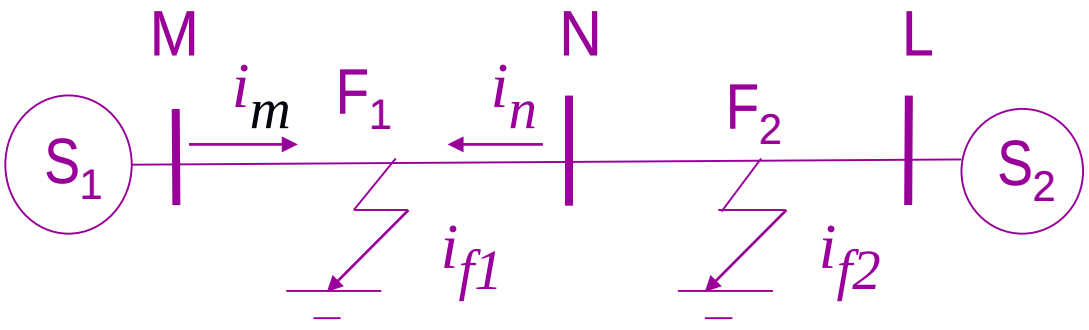
External fault



B: Backup protection based on TW differential protection

Traditional Differential Current based protection

- Current Differential Protection



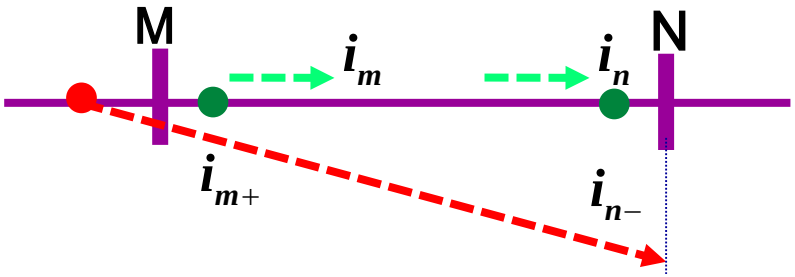
- Nomal& ExternalFault $i_m + i_n = 0$
- Internal Fault $i_m + i_n = i_f$

- Main Protection;
- Generator, transformer and Lines

- **Advantage**
  - Simple KCL
  - Selectivity
  - Reliability
  - Sensitivity
- **Disadvantage**
  - Distributed Capacitance;
  - Time delay

Backup protection :TW differential based protection

For an External Fault



$$i_{m+}(t-\tau)=i_{n-}(t)$$

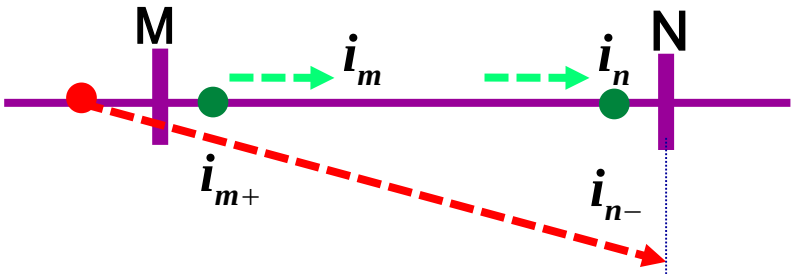
$$i_{m+}(t)=\frac{1}{2}\left[\frac{u_m(t)}{Z_c}+i_m(t)\right]$$

$$i_{n-}(t)=\frac{1}{2}\left[\frac{u_n(t)}{Z_c}-i_n(t)\right]$$

If $\left|i_{m+}(t-\tau)-i_{n-}(t)\right|>i_{set1}$ It's an internal Fault

Backup protection :TW differential based protection

For an External Fault



$$i_{m+}(t-\tau)=i_{n-}(t)$$

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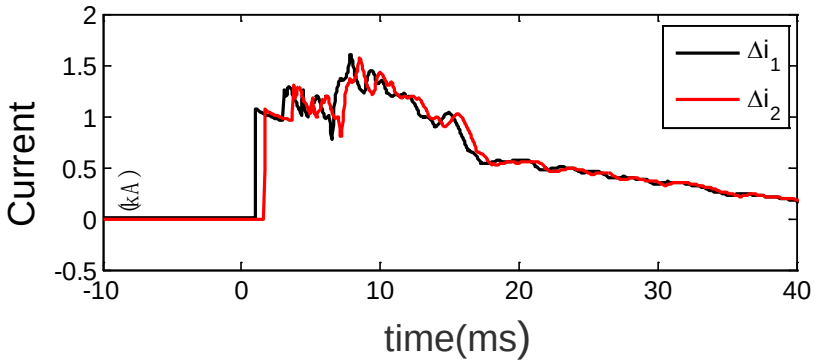
If $\left|i_{m+}(t-\tau)-i_{n-}(t)\right|>i_{set1}$ It's an internal Fault

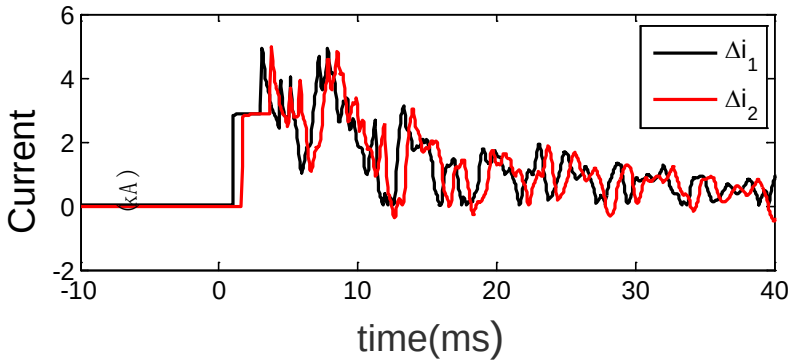
B: Backup protection based on TW differential protection

TW based differential backup protection

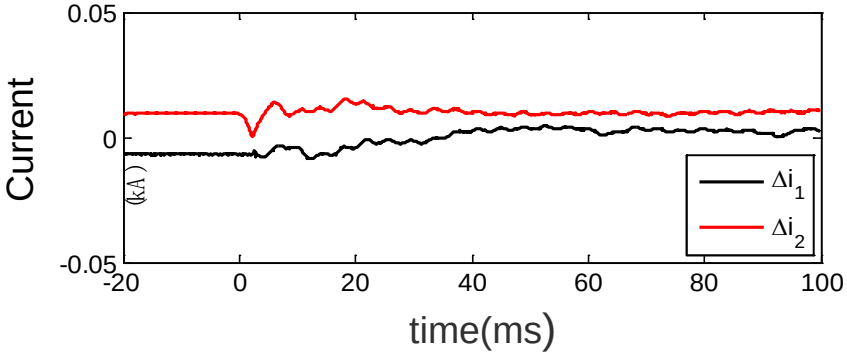
- Internal monopolar fault



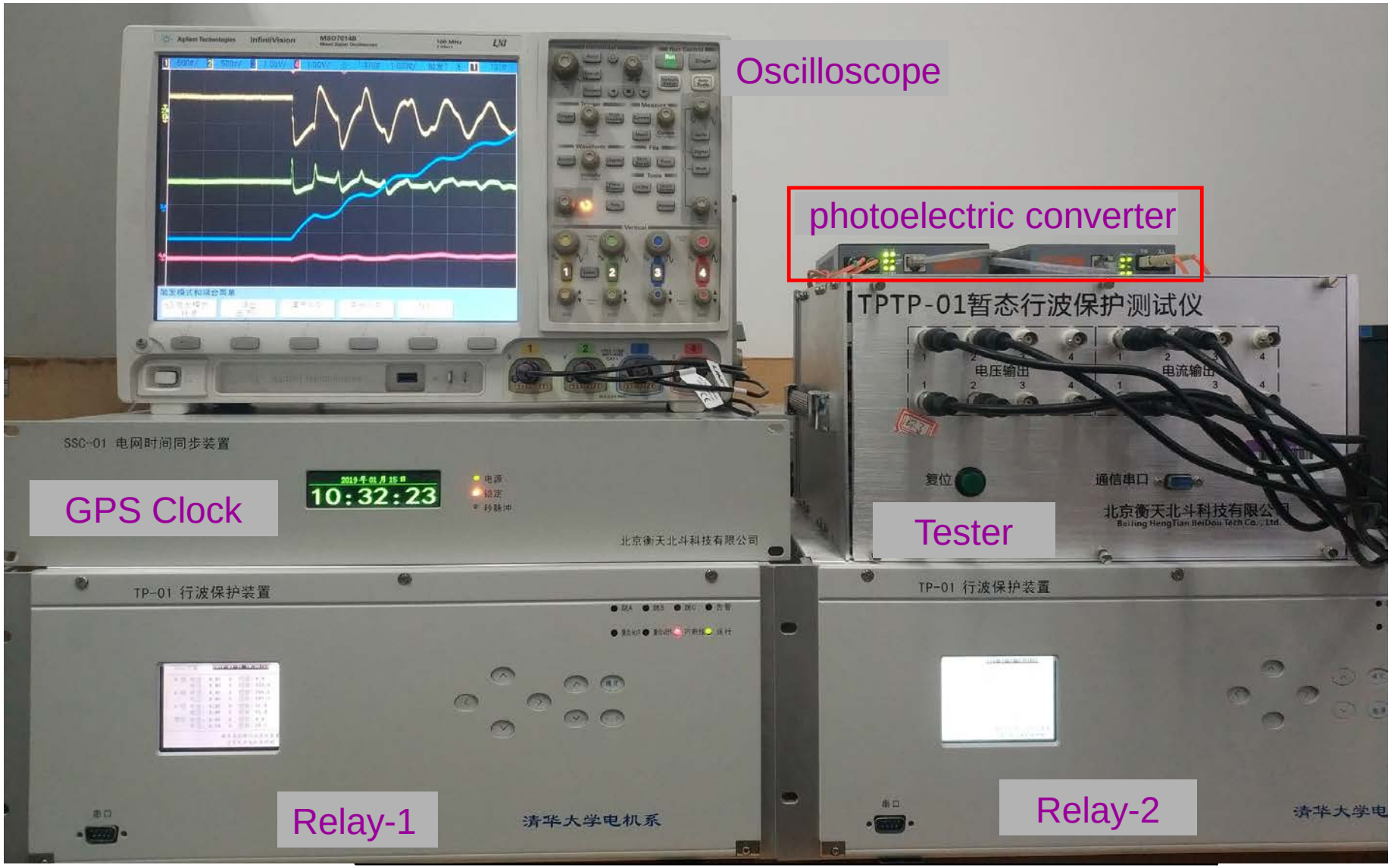
- Internal bipolar fault



- External fault

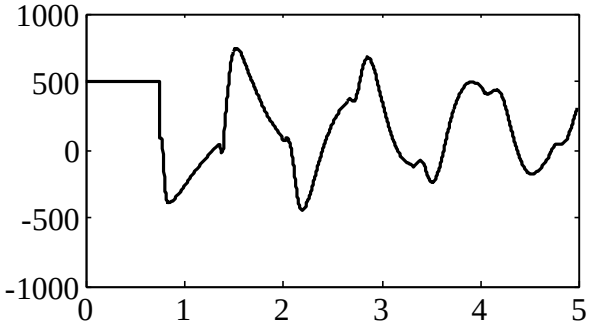


4. Test of Protective Relay

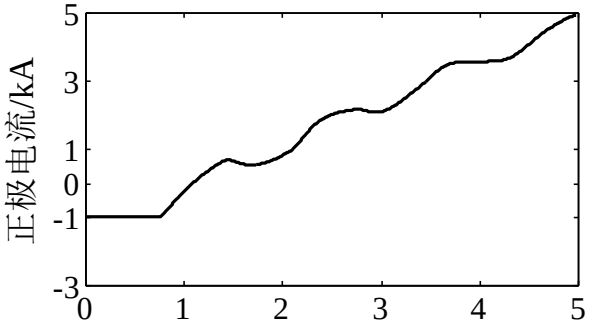


4. Test of Protective Relay

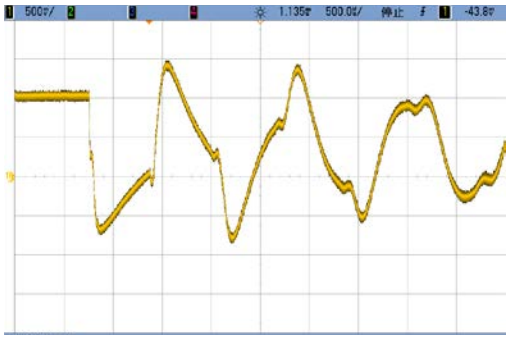
Tester



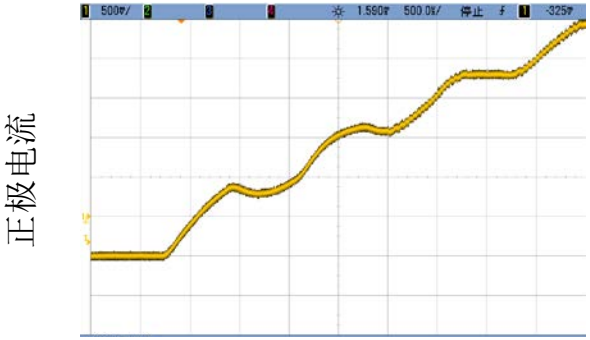
(a) Simulation Voltage



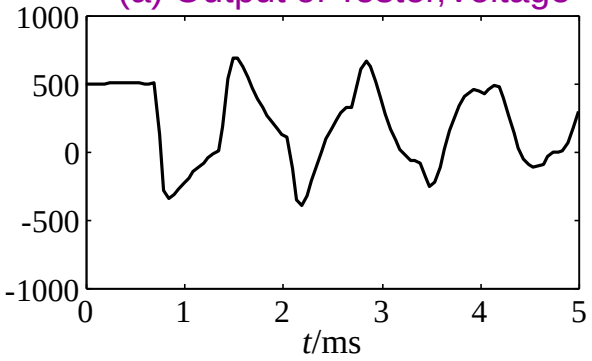
（b）Simulation Current



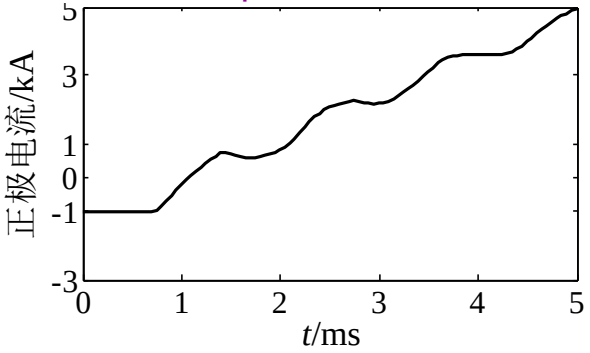
(a) Output of Tester,Voltage



（b）Output of Tester, Current



(a) Record of Relay, voltage

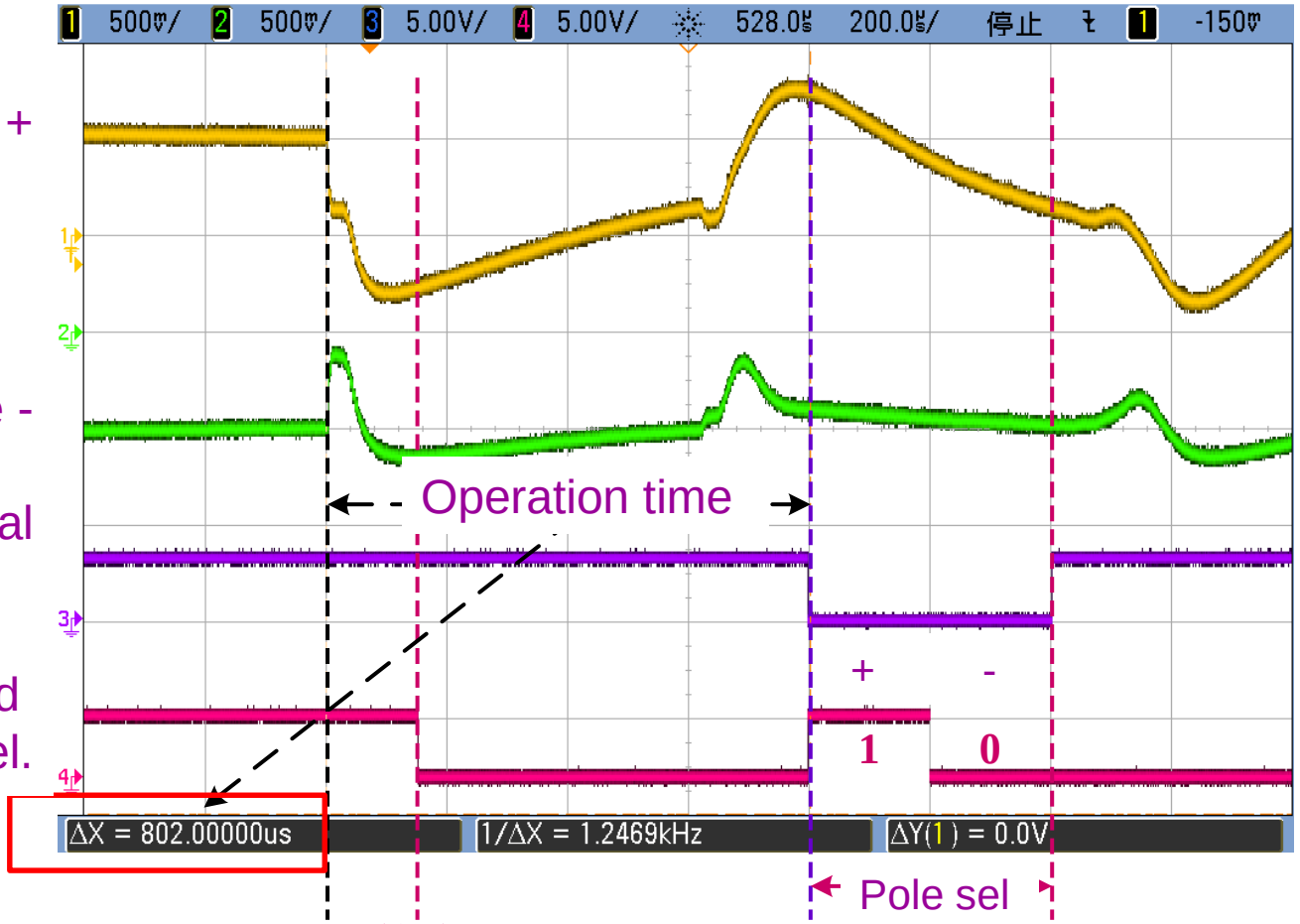


（b）Record of Relay, current

4. Test of Protective Relay

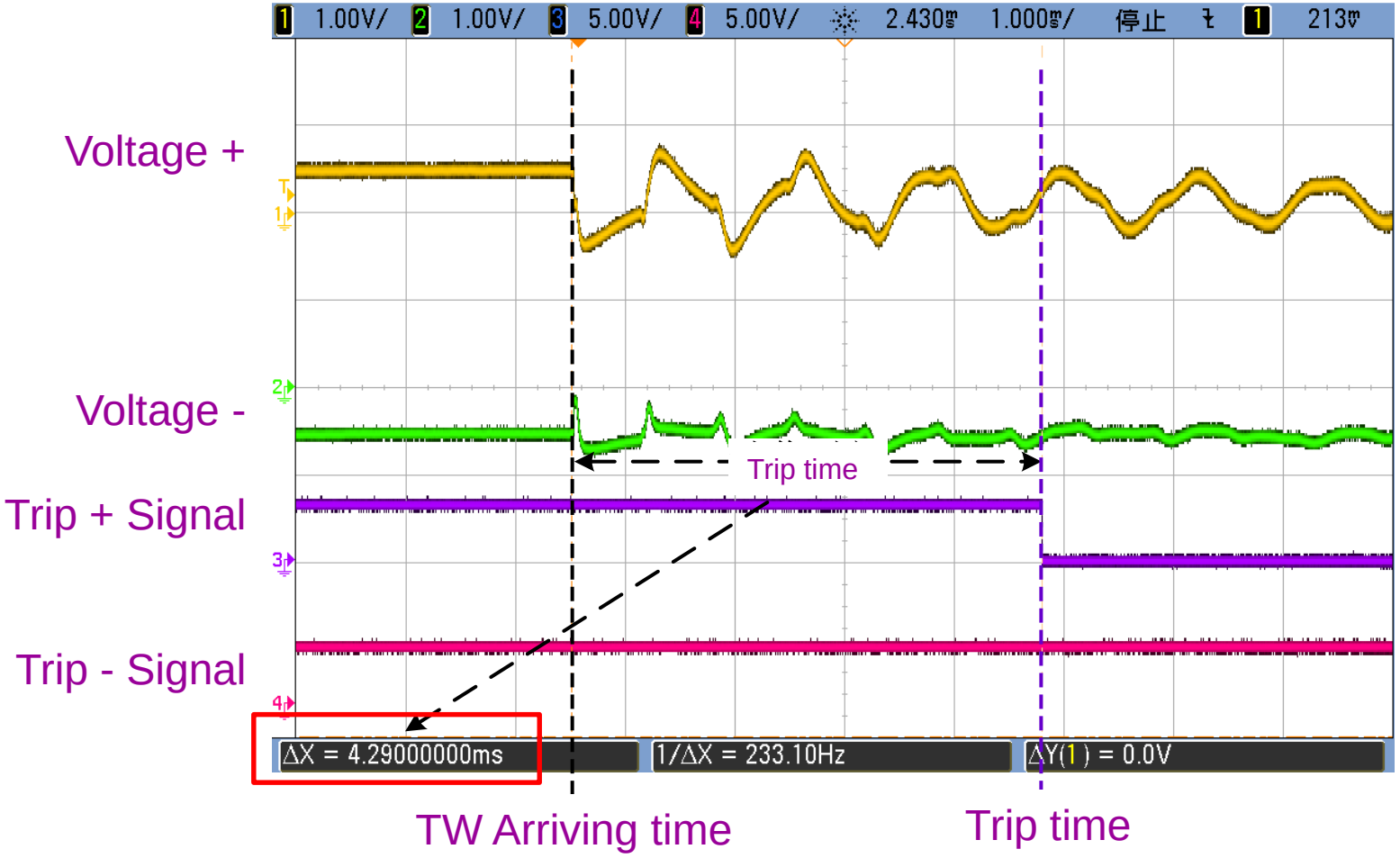
- **Positive Pole internal fault**

Operation time :802μS



4. Test of Protective Relay

- **Positive Pole internal fault**



5. Conclusions

- Faults in VSC-HVDC line will damage power electronic devices and imperil power stability, which requires the protection to operate with **ultra-high speed**.
- Protection for AC transmission lines and traditional HVDC lines can’t meet the requirements of VSC-HVDC lines.
- **Initial travelling waves based protection** is the only possible main protection of VSC-HVDC lines. 1.2ms
- **Travelling waves based differential protection** is an excellent backup protection of VSC-HVDC lines. 5ms

Thanks! & Questions?