Cascading Faults and its Protection Strategy for AC/DC Hybrid Power Grid

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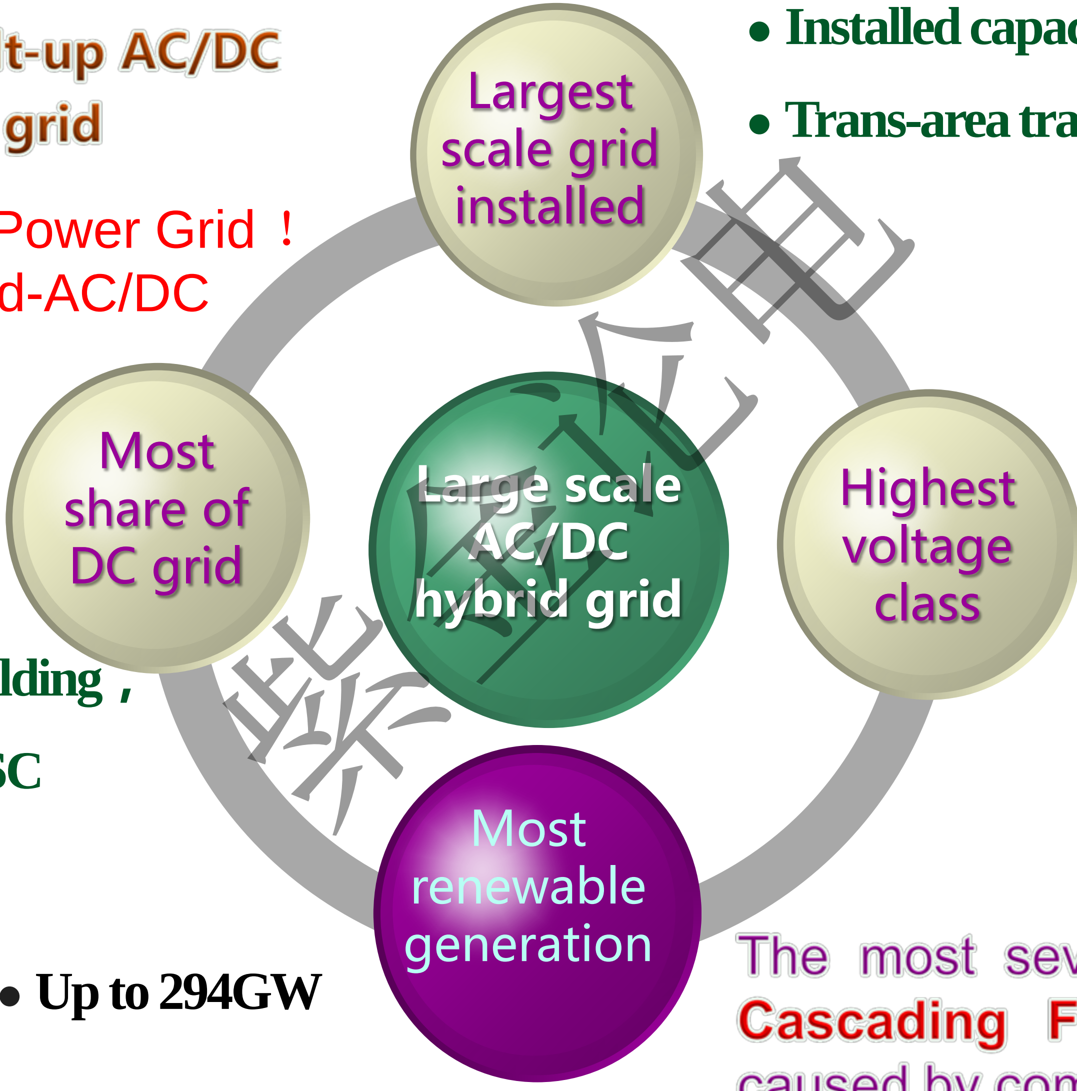
Contents

1. Background

China has built-up AC/DC hybrid power grid

A new form of Power Grid！
DC-AC-AC Grid-AC/DC

- **Installed capacity: 1780GW**
- **Trans-area transmission: 250GW**



- **29 DC lines**
- **DC share to 40%**
- **10 DC lines is building，**
- **Flexible DC，VSC**

- **Up to 294GW**

- **AC: 1000kV**
- **DC: ±800kV**

The most severe challenge is **Cascading Faults**, especially caused by commutation failure.

2. Cascading Faults in AC/DC Hybrid Grid

Cascading Faults

One component faults, resulting in other components/systems fault or abnormal operation in AC/DC Hybrid Power Grid.

Several typical cascading faults cases

- AC Fault → DC Commutation Failure(CF), Consecutive, simultaneous
- AC Fault → CF → Block, monopole / bipolar block
- AC Fault → CF → Block→ DC Power Flow Transfer (PFT) to AC
- AC Fault → CF → Block → DC PFT → AC Cascading trip

2. Cascading Fault in AC/DC Hybrid Grid

The Features of Cascading Faults

- **Be almost a definitive event；**
- **Not caused by hidden fault；**
- **Not only cascading trip；**
- **Even result in blackout, like Brazil 3.21 blackout**

The Cascading Faults is a Frequently Occurring Faults in AC/DC Hybrid Grid.

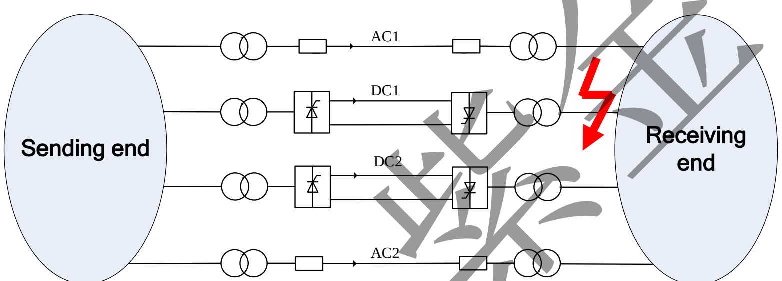
2. Cascading Faults in AC/DC Hybrid Grid

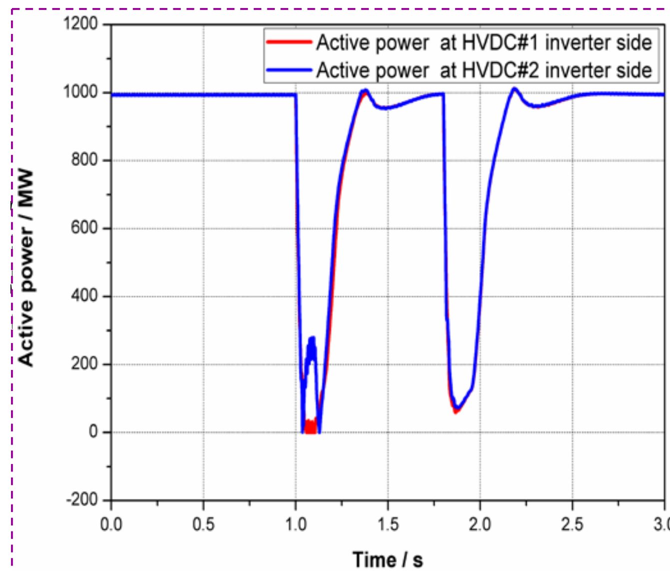
Commutation Failure

Voltage of the bus at inverter station drops (by AC fault or others)

The thyristors can’t to be turned off

The power in DC line drops





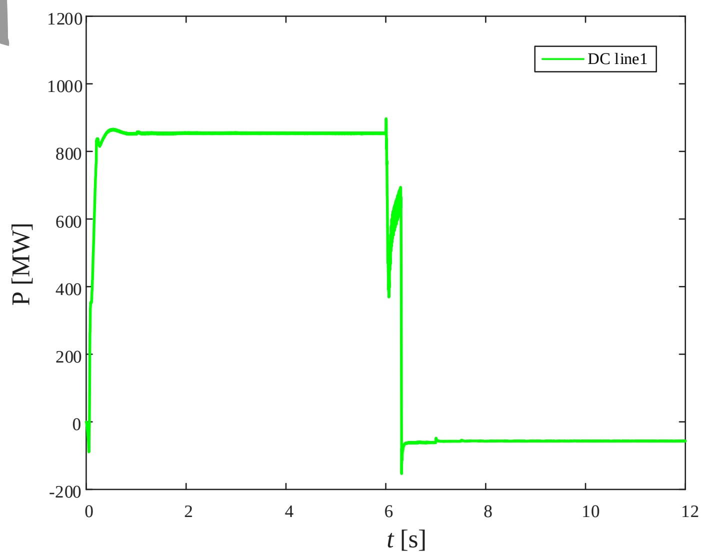
Simultaneous commutation failure
+
Consecutive commutation failure

2. Cascading Fault in AC/DC Hybrid Grid

DC Block

1. Consecutive commutation failure
2. long-last commutation failure
3. over-voltage of bus at converter station

Stop triggering thyristors

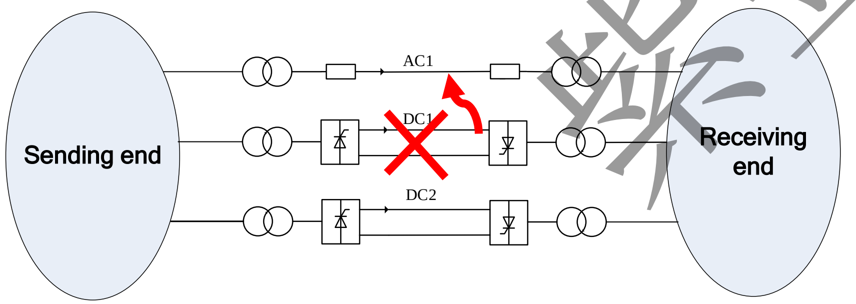


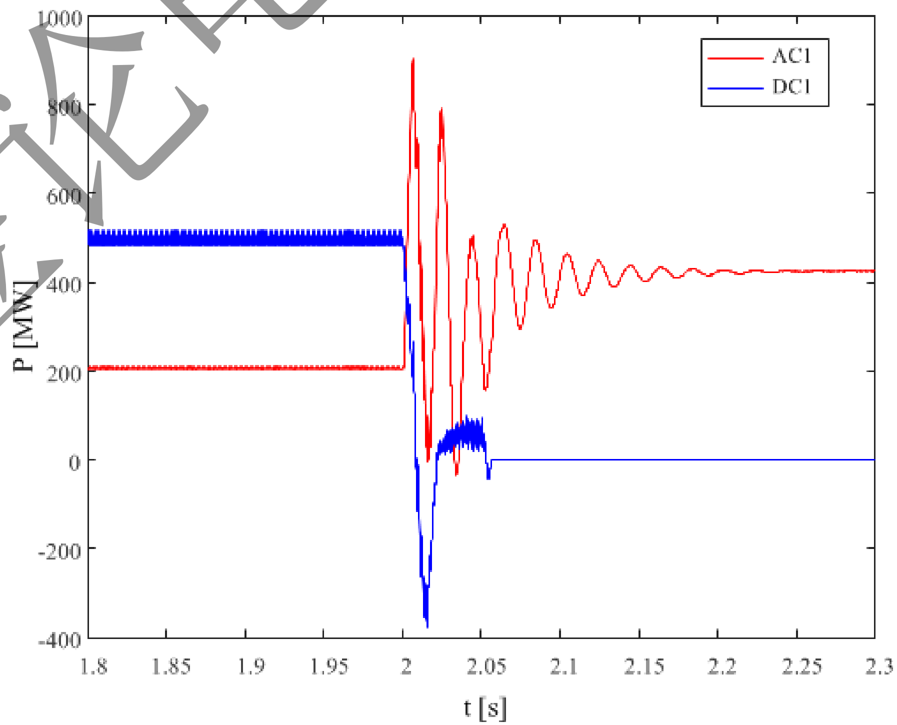
2. Cascading Faults in AC/DC Hybrid Grid

Power Flow Transfer

DC Block

The power in DC line transfers to AC line



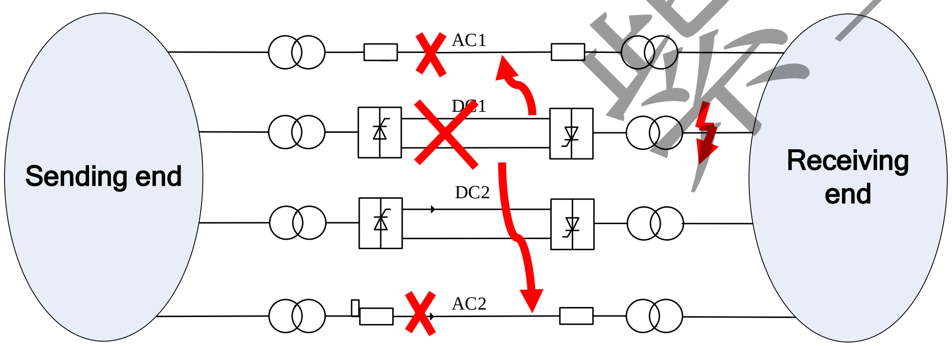


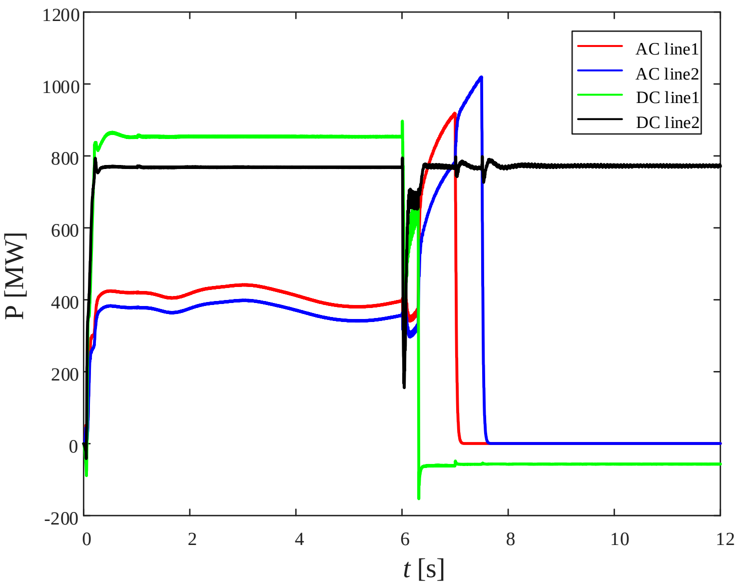
2. Cascading FaultS in AC/DC Hybrid Grid

Cascading Trip of AC lines

DC Power Flow Transfer, AC lines can't afford the power flow

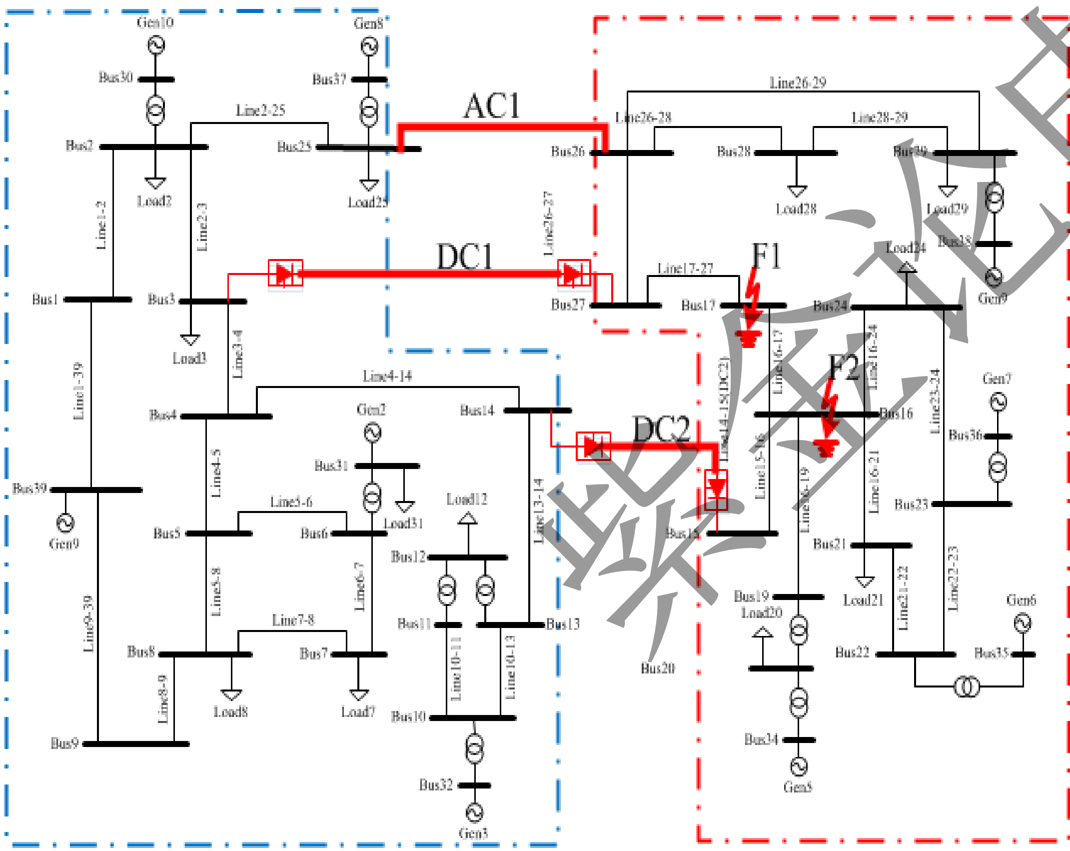
Cascading Trip happens





3. Model and Simulation

Model： Revised IEEE 39-bus (2DC+1AC)



Sending side grid

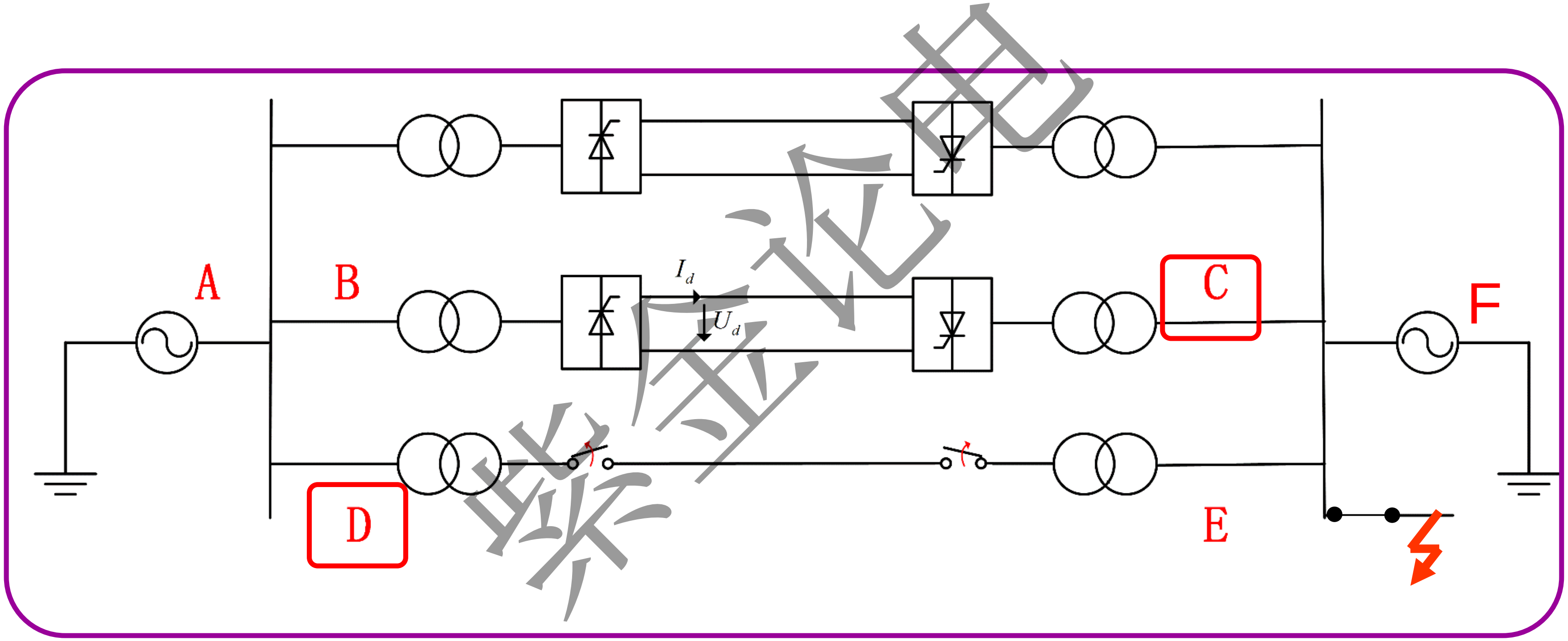
Receiving side grid

An AC/DC hybrid system is built based on IEEE 39-bus system.

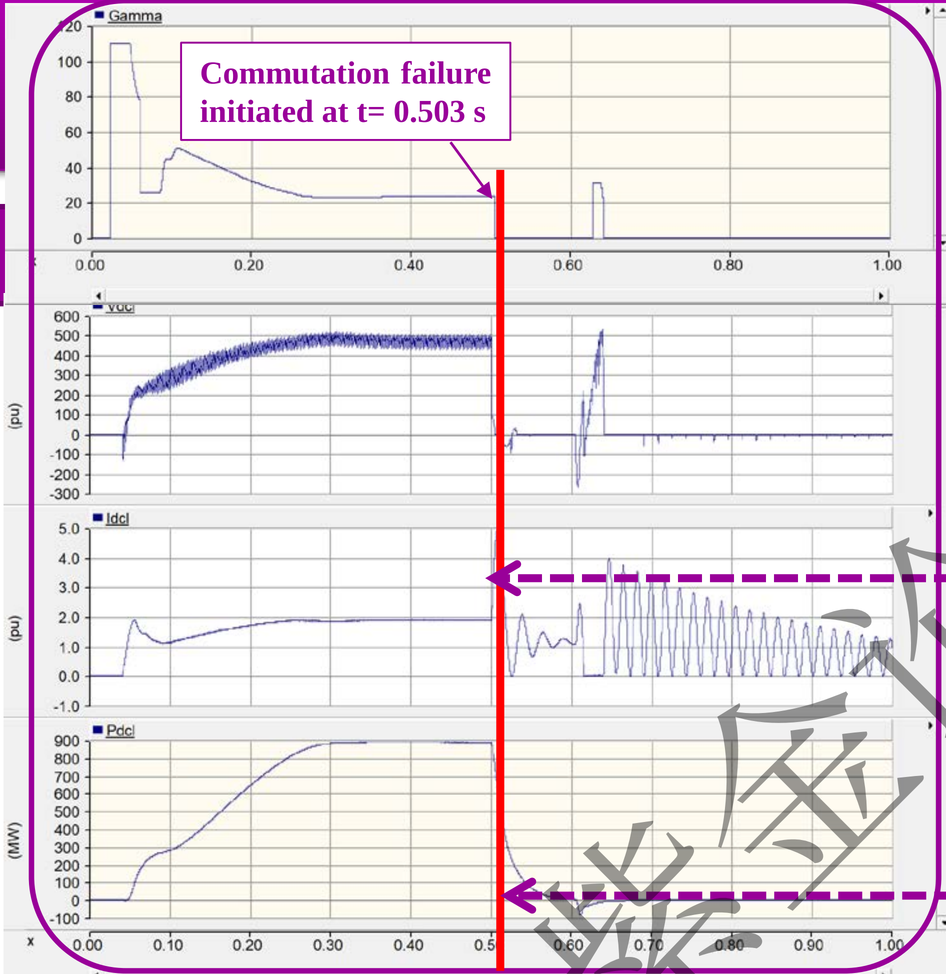
- Bus26 → Bus28, AC1.
- Bus3 → Bus27, DC1.
- Bus14 → Bus15, DC2.
- Two fault points are set in Bus16 (F2) and Bus17 (F1).

3. Model and Simulation

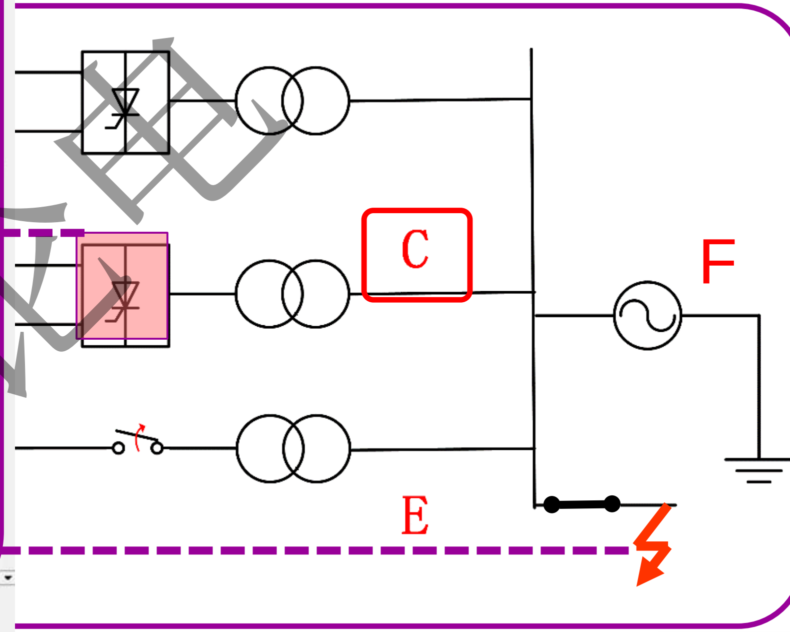
3.1 Simplified Model



3. … on



Extinction angle



t=0.5 s AC fault is initiated

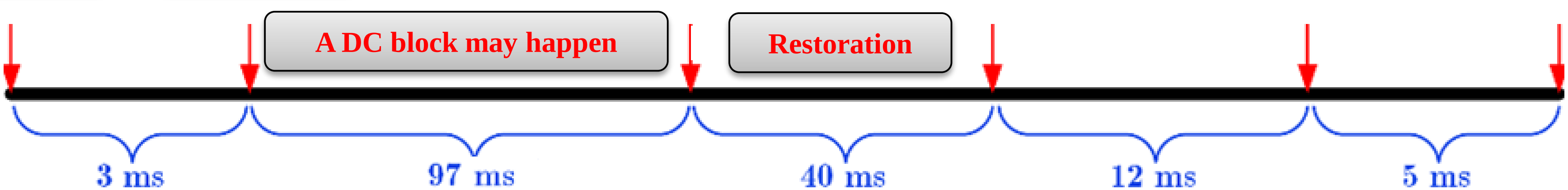
t=0.5 03s Commutation failure is initiated

t=0.6s AC fault is cleared

t=0.64s DC pole blocks

t=0.652 s BRK1 at AC line trips

t=0.657 s BRK2 at AC line trips



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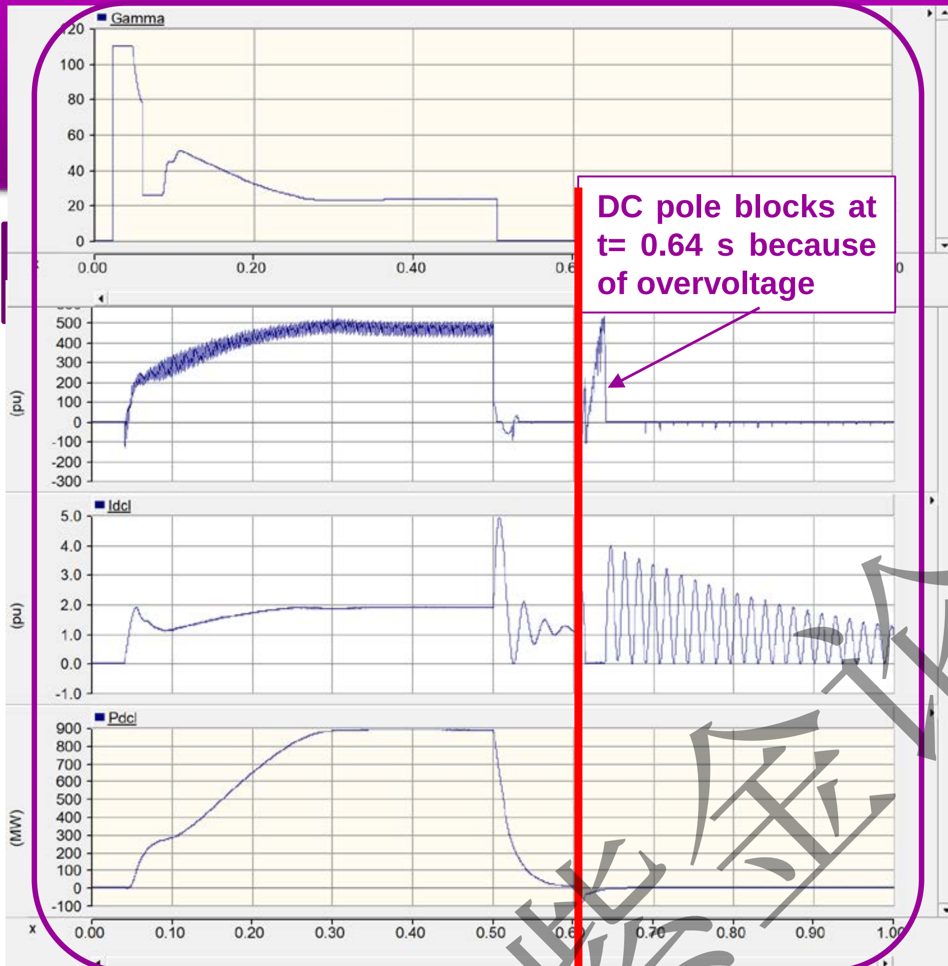

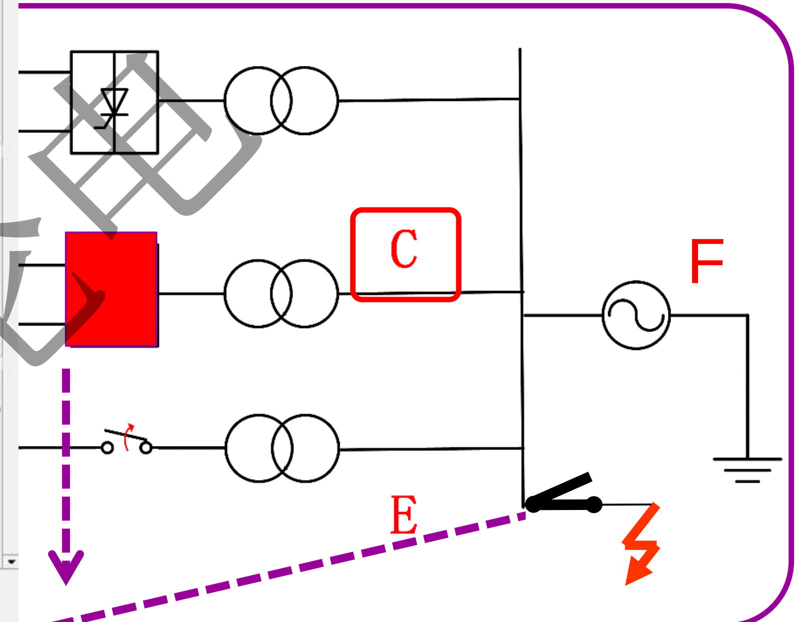

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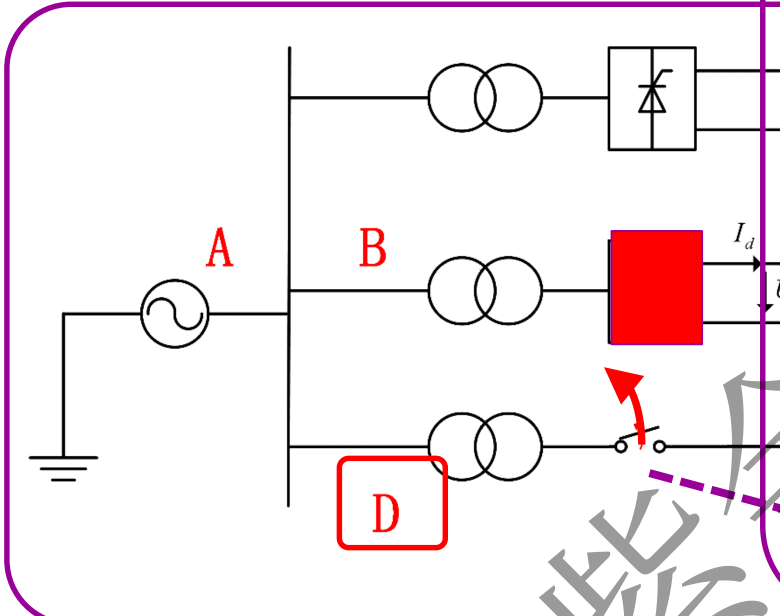
A DC block may happen

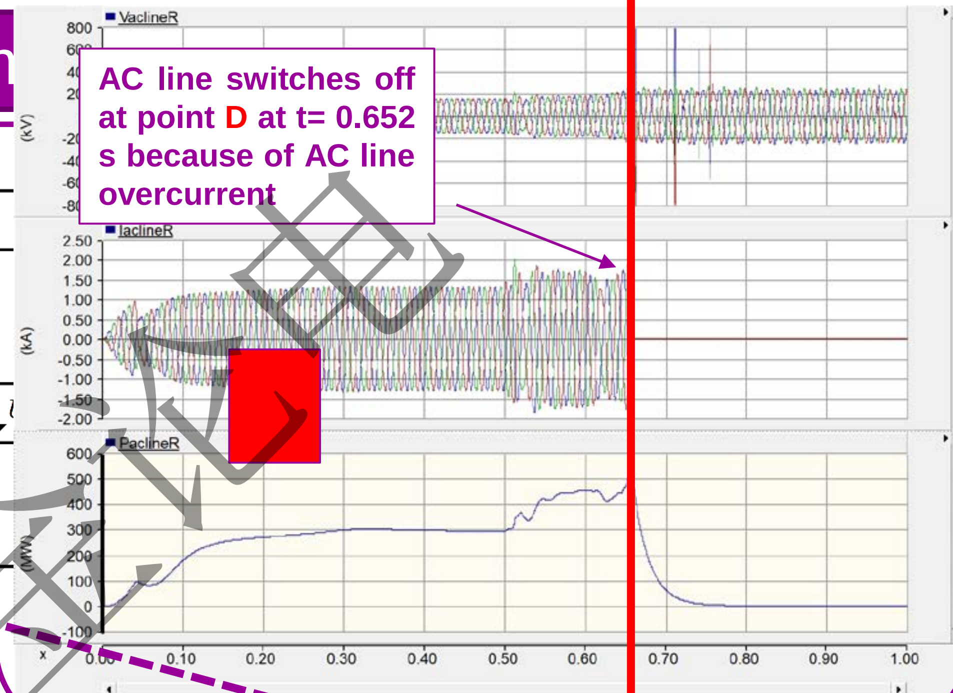
Restoration

3 ms | 97 ms | 40 ms | 12 ms | 5 ms

3. Model and Simulation

3.2 Cascading Faults Sim





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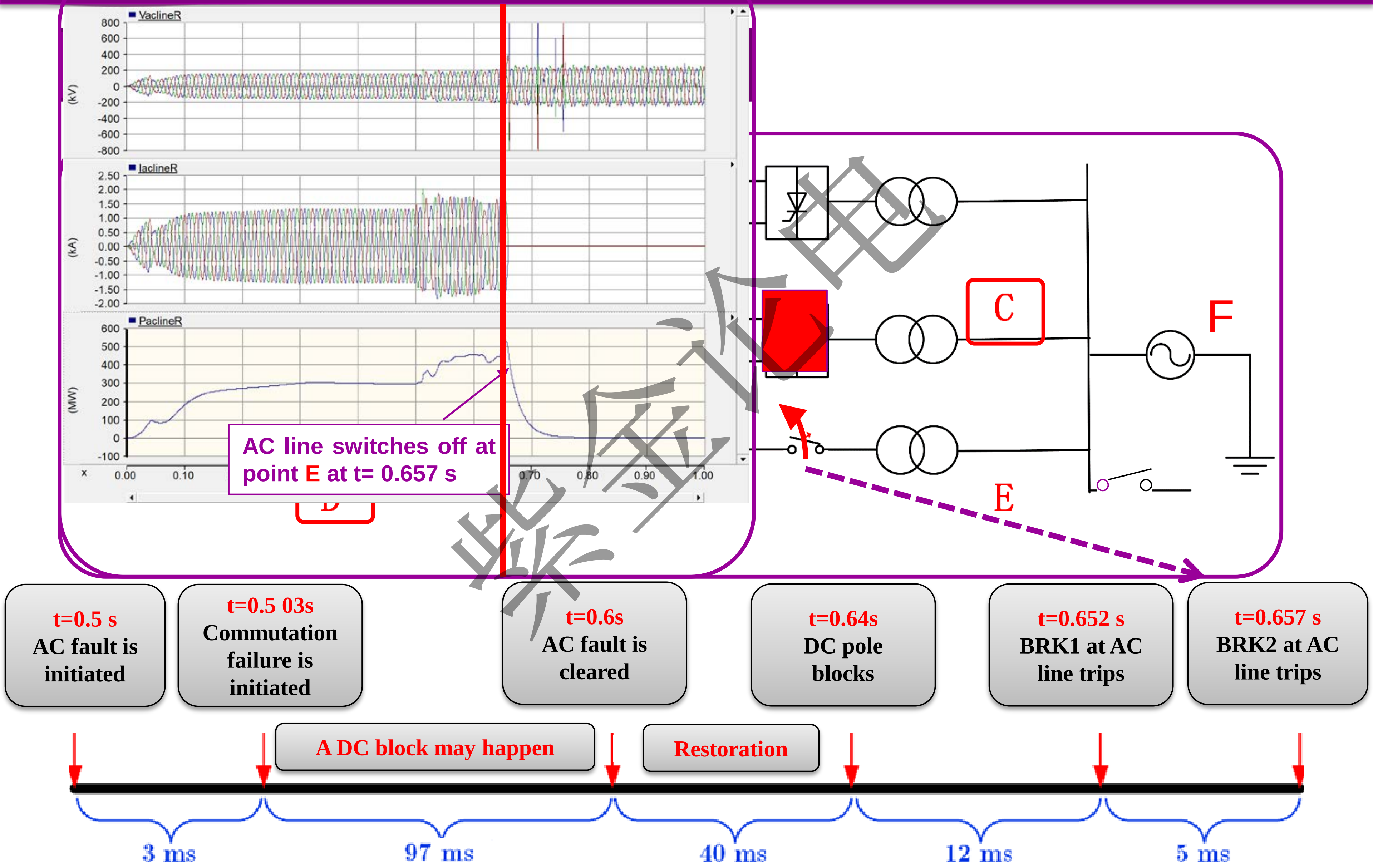

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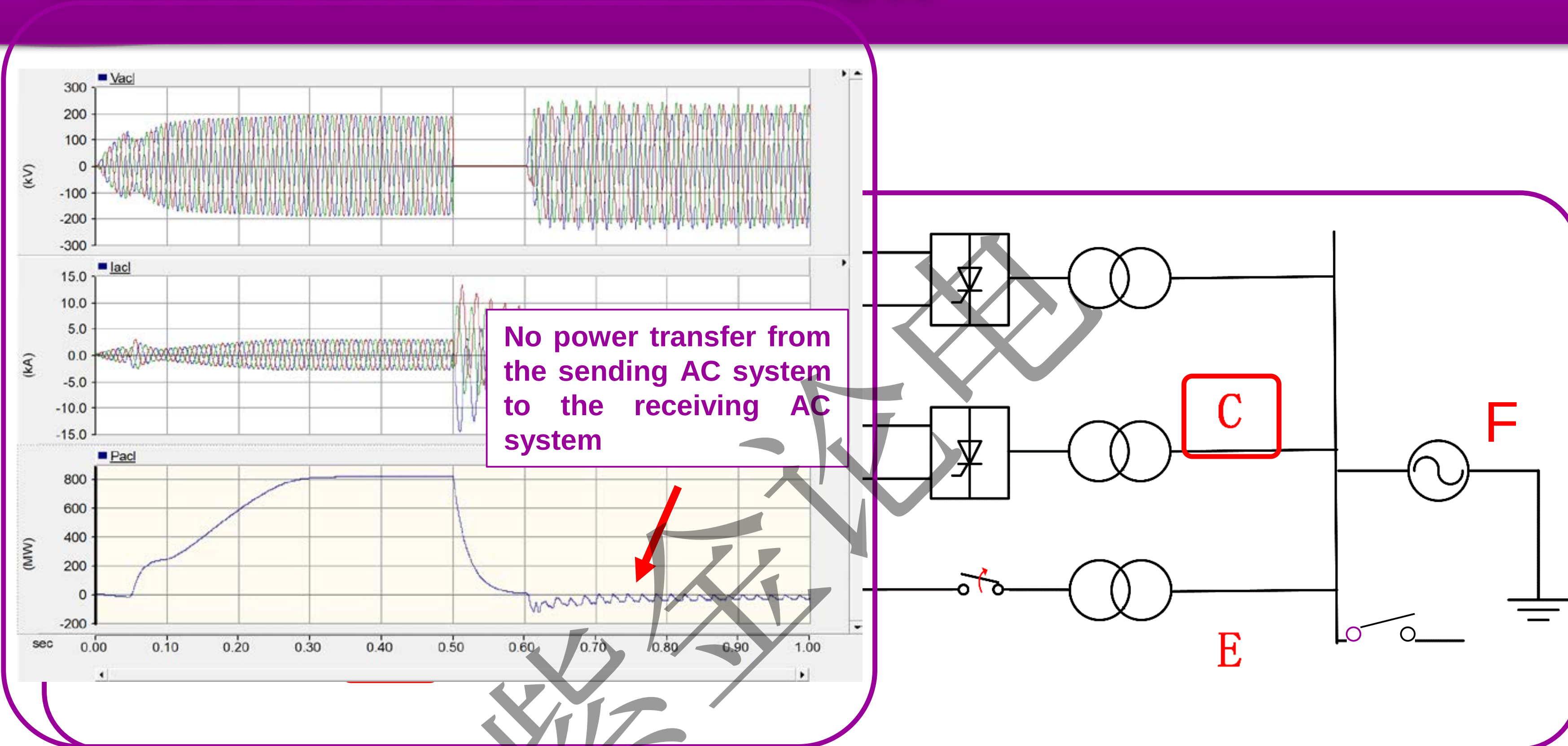

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4. How to prevent the Cascading Fault

4.1 Commutation failure mitigation method

- **Deploy firing angle-based control methods.**

  Advances the firing angle or increases extinction angle.

- **Design a very quick predictive relay.**

  A Relay: should have the ability to clear the fault before DC pole block caused by a long-lasting commutation failure or consecutive commutation failures.

- **Install Fault Current Limiter (FCL).**

  It can prevent any commutation failure within a few microseconds before activation of VDCOL.

- **Apply Voltage Source Converter (VSC) based HVDC**

  There is no commutation failure.

4. How to prevent the Cascading Fault

4.2 Overvoltage prevention approaches

To lower down the DC pole overvoltage using passive Equipment during restoration.

4.3 Strategies for overload of DC line

Make the healthy DC transmission system to undertake part of the power flow transferring from the blocked DC line.

4. How to prevent the Cascading Fault

4.4 Strategies for overload of DC line

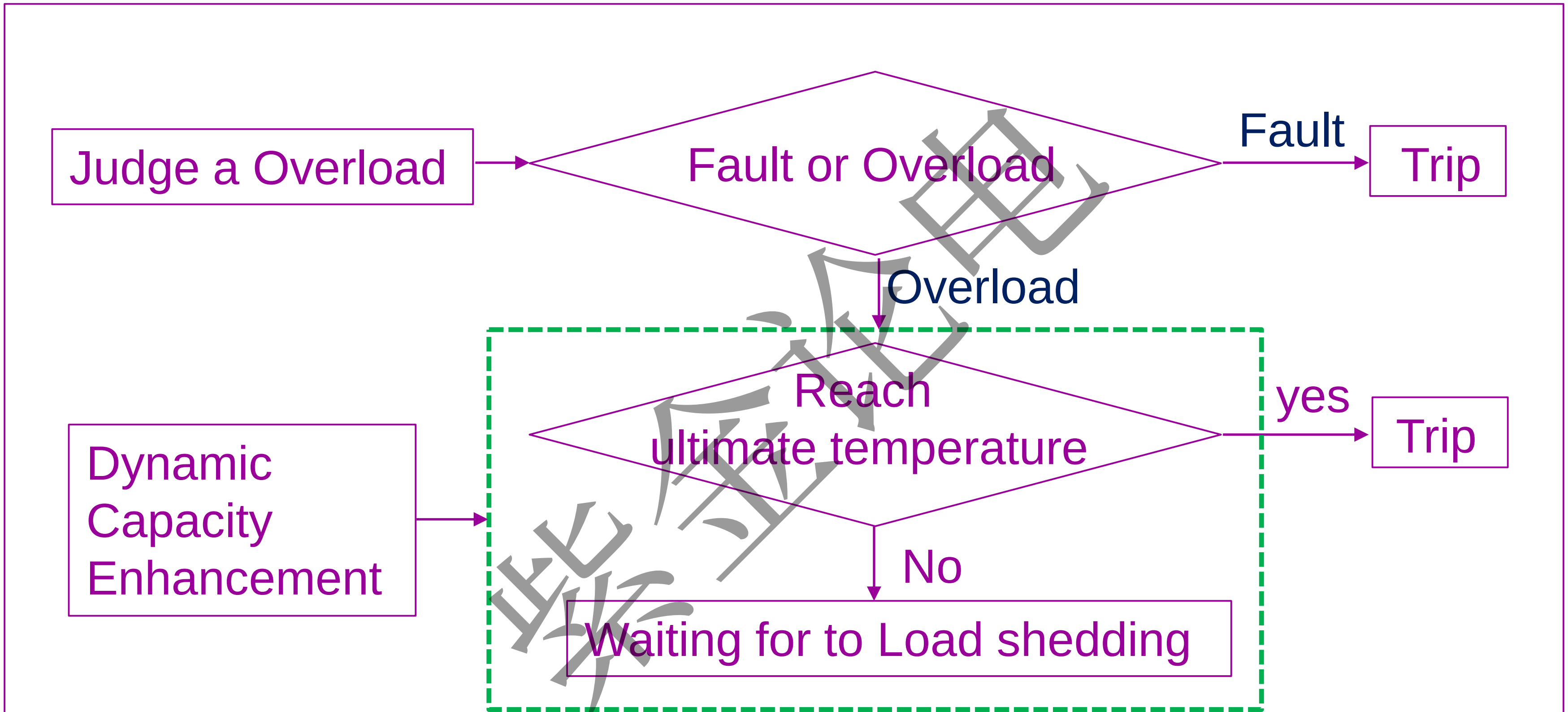
- **Rule**

For a LINE Fault, Protective Relay should trip the LINE;
For a Overload, Protective Relay can't operate

- **Dynamic Thermal Circuit Rating**

Confirm the maximum current carrying capacity of AC line real-timely based on the temperature and heat balance calculation.

Example: Prevent the Cascading



Overload Judgement and Dynamic Capacity Enhancement

Example: Prevent the Cascading

- Relationship between Measurement Impedance and Trevena Equivalent impedance

$$\frac{P+jQ}{\dot{U}}=\dot{I}=\left(\frac{\dot{E}_{thev}-\dot{U}}{Z_{thev}}\right)^{*}\Rightarrow (P+jQ)Z_{thev}^{\;*}=\dot{U}(\dot{E}_{thev}-\dot{U})^{*}$$

- Phase to Phase Zone III

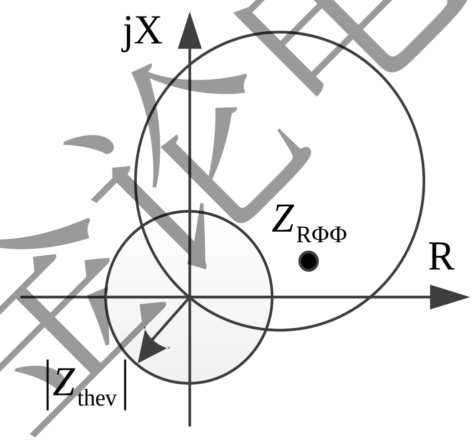
$$\frac{\left|\dot{U}_{\Phi\Phi}/\dot{I}_{\Phi\Phi}\right|}{\left|(\dot{E}_{\Phi\Phi}-\dot{U}_{\Phi\Phi})/\dot{I}_{\Phi\Phi}\right|}>O_{TH1}$$

$$\frac{\left|Z_{R\Phi\Phi}\right|}{\left|Z_{thev}\right|}>O_{TH1}\ (O_{TH1}>1)$$

- Ground Zone III

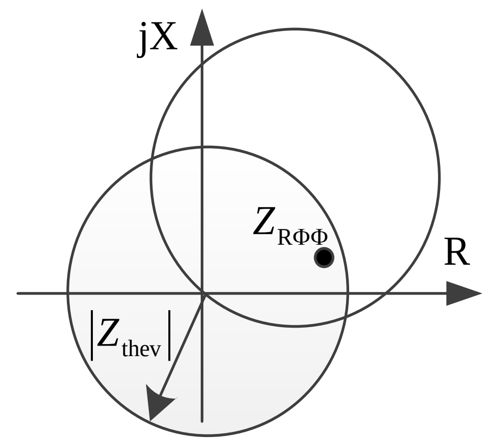
$$\frac{\left|\dot{U}_{\Phi}/(\dot{I}_{\Phi}+3K_0\dot{I}_0)\right|}{\left|(\dot{E}_{\Phi}-\dot{U}_{\Phi})/(\dot{I}_{\Phi}+3K_0\dot{I}_0)\right|}>O_{TH2}$$

$$\frac{\left|Z_{R\Phi}\right|}{\left|Z'_{thev}\right|}>O_{TH2}$$



$$\frac{\left|Z_{R\Phi\Phi}\right|}{\left|Z_{thev}\right|}>O_{TH1}$$

Overload √
Fault ×



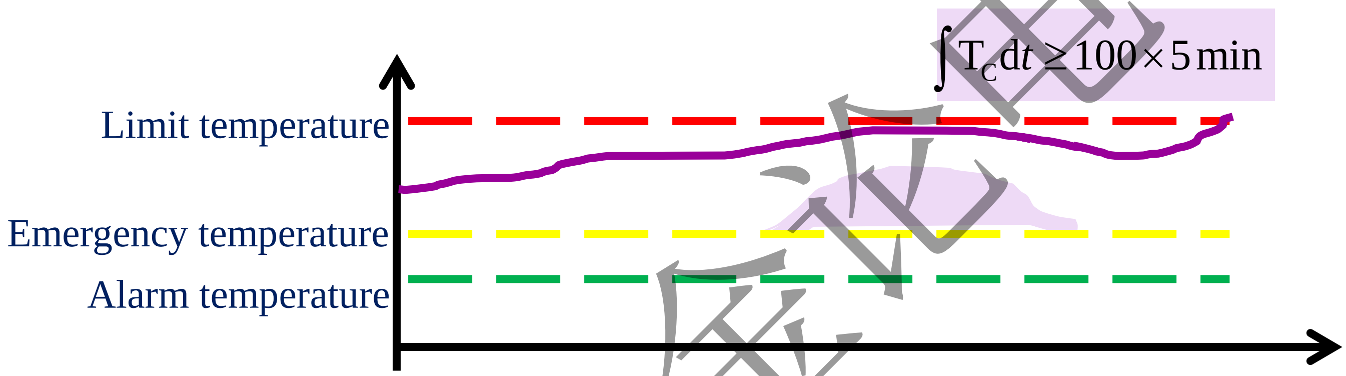
$$\frac{\left|Z_{R\Phi\Phi}\right|}{\left|Z_{thev}\right|}<O_{TH1}$$

Overload ×
Fault √

Example: Prevent the Cascading

Dynamic Capacity Enhancement

- Objective： Protect equipment safety and take account of system safety.
  Monitoring line temperature.



Temperature	Operation
Alarm temp.： Tc>60℃	Estimate support time and upload to dispatch center.
Emergency temp. ： Tc>70℃	Calculate the temperature time product, predict the support time and upload to the dispatching center. When the temperature time product is greater than the setting value, trip.
Limit temp.： Tc>120℃	3s delay then trip.

5. Conclusions

- The large scale **AC-DC Hybrid Grid** is a **New Form of Power GRID** in China and all over the world.
- The **Cascading Fault** is a **Normalization Fault Mode** in AC/DC hybrid power.
- Proper Protection **Strategy and Control Technology** should be studied.
- To prevent the Cascading Faults, Commutation failure mitigation method, Limiting the DC pole overvoltage , Health DC Line take part the load sharing and Overload Judgement are useful.

Thank you !