High-Voltage Direct-Current Transmission Systems

Fujin Deng
School of Electrical Engineering
Southeast University
fdeng@seu.edu.cn

Outline

I. HVDC Systems

II. Multi-terminal HVDC Systems

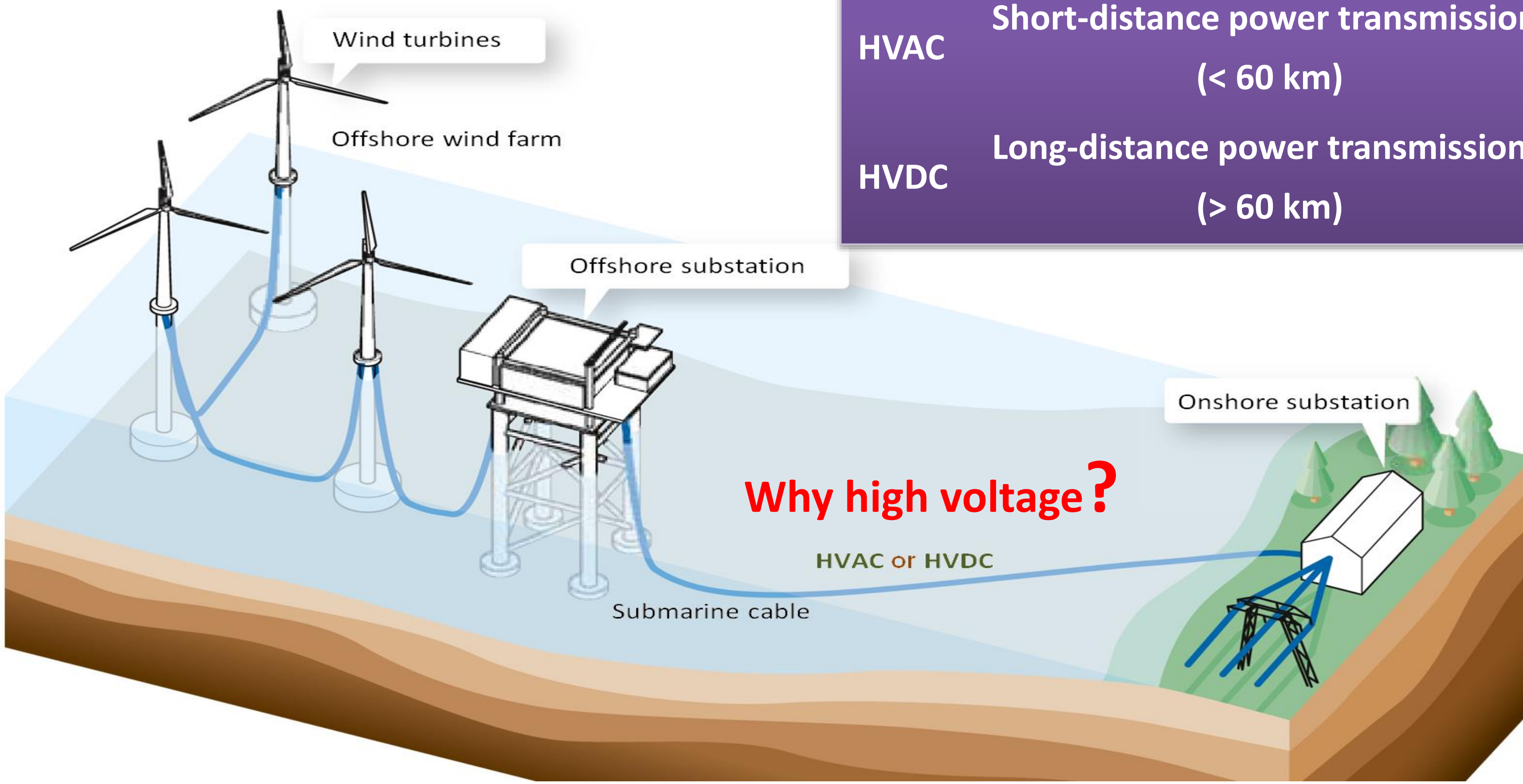
III. DC Grid for Offshore Wind Farms

IV. DC-Line Fault Situations

1 HVDC Transmission System

- ❑ **High Voltage Alternative Current (HVAC) Technology**
- ❑ **High Voltage Direct Current (HVDC) Technology**

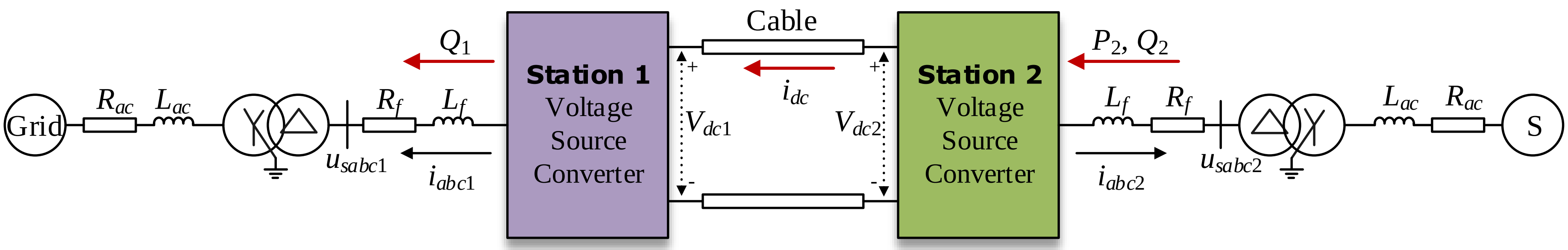
HVAC	Short-distance power transmission (< 60 km)
HVDC	Long-distance power transmission (> 60 km)

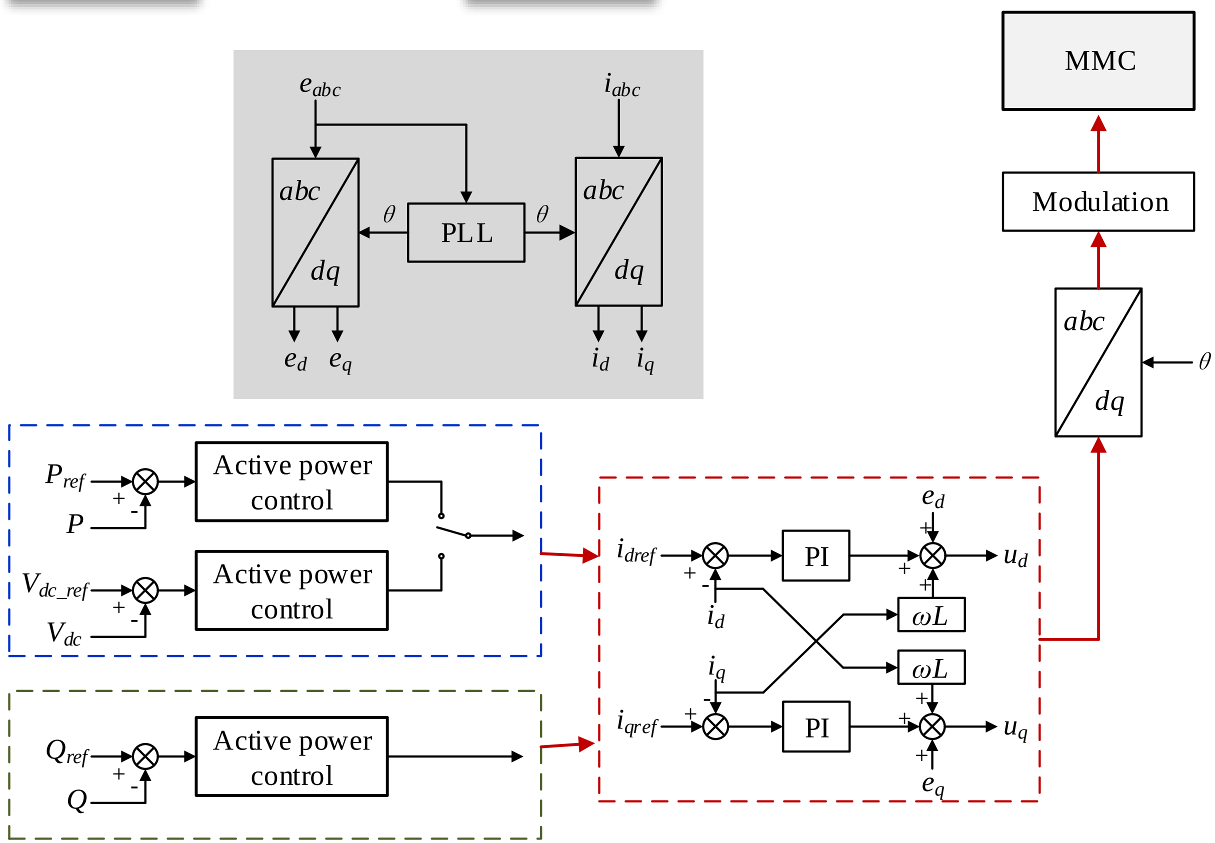


Why high voltage?

HVDC System Configuration

- HVDC System with monopolar configuration

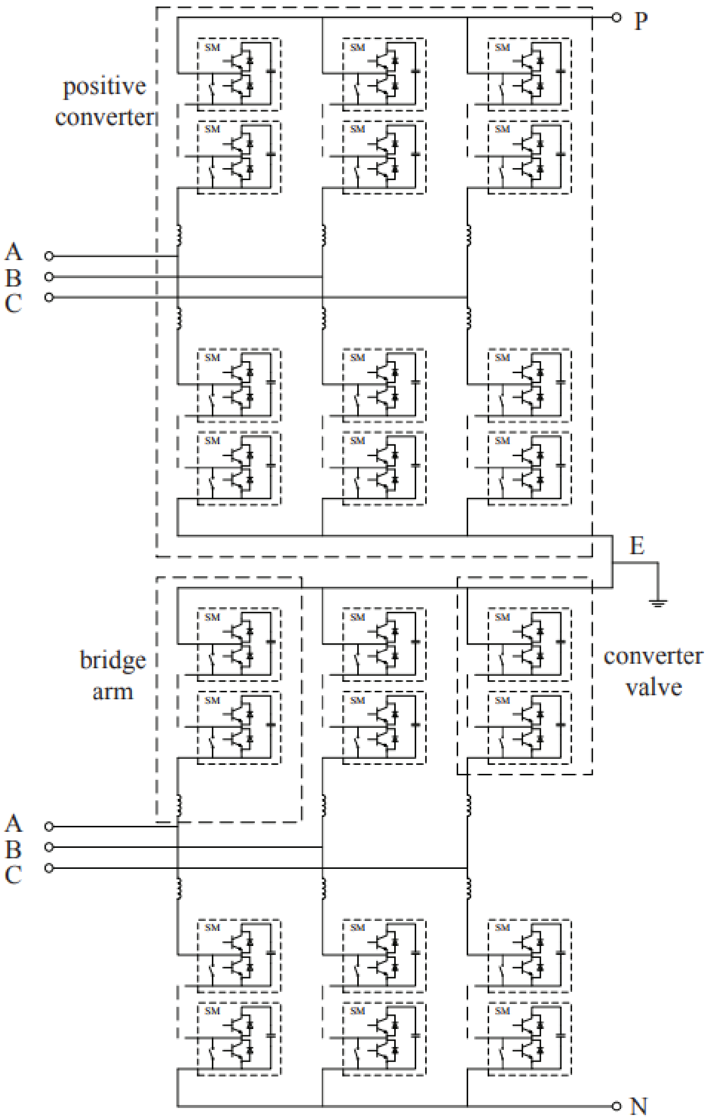




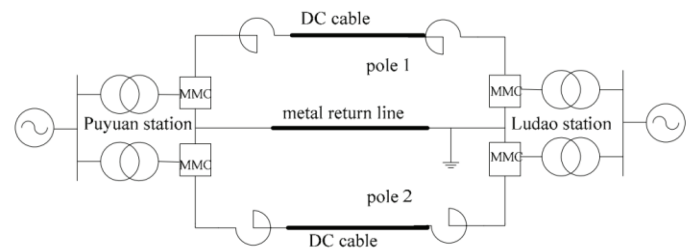
> **Station-1**
> - Keep V_{dc1}
> - Control Q_1
>
> **Station-2**
> - Control P_2
> - Control Q_2

HVDC System Configuration

- Bipolar Configuration

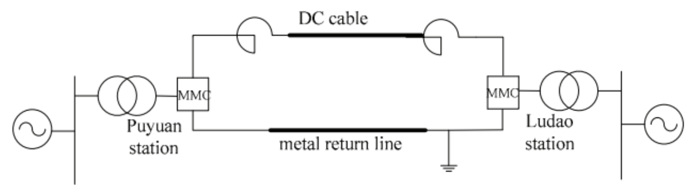


- Operation Mode 1



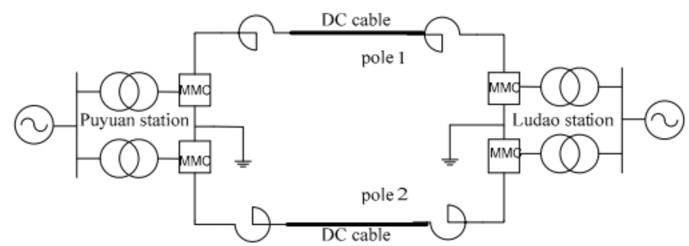
Bipolar operation with metal return line

- Operation Mode 2



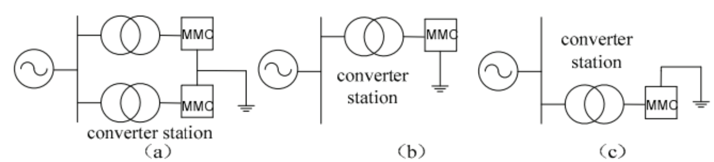
monopolar operation with metal return line

- Operation Mode 3



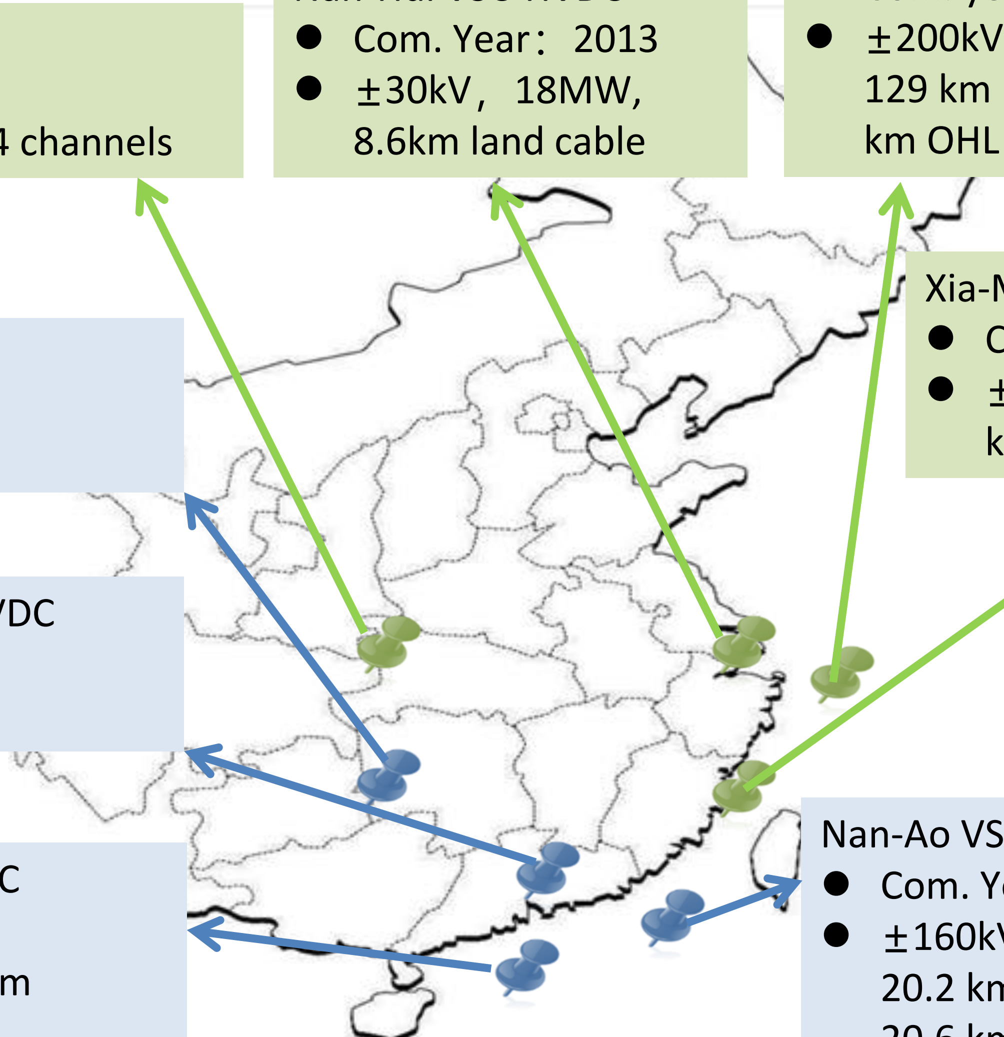
Bipolar operation without metal return line

- Operation Mode 4



Operation as STATCOM

HVDC System Configuration



Yu-e BTB VSC-HVDC
- Com. year： 2017
- ±420kV/1250MW, 4 channels

Nan-Hui VSC-HVDC
- Com. Year： 2013
- ±30kV， 18MW, 8.6km land cable

Zhou-Shan VSC-MTDC
- Com. year： 2014
- ±200kV， 400/300/3×100MW, 129 km submarine cable, 12.5 km OHL

Xia-Men VSC-HVDC
- Com. Year： 2015
- ±320kV， 1000MW, 10.7 km land cable

Luoping BTB VSC-HVDC
- Com. Year, 2016
- ±350kV/1000MW

Guang-Dong BTB VSC-HVDC
- Com. Year： 2019
- planned

Zhong-Hai-You VSC-HVDC
- Com. Year： 2012
- ±10kV， 4MW， 40km submarine cable

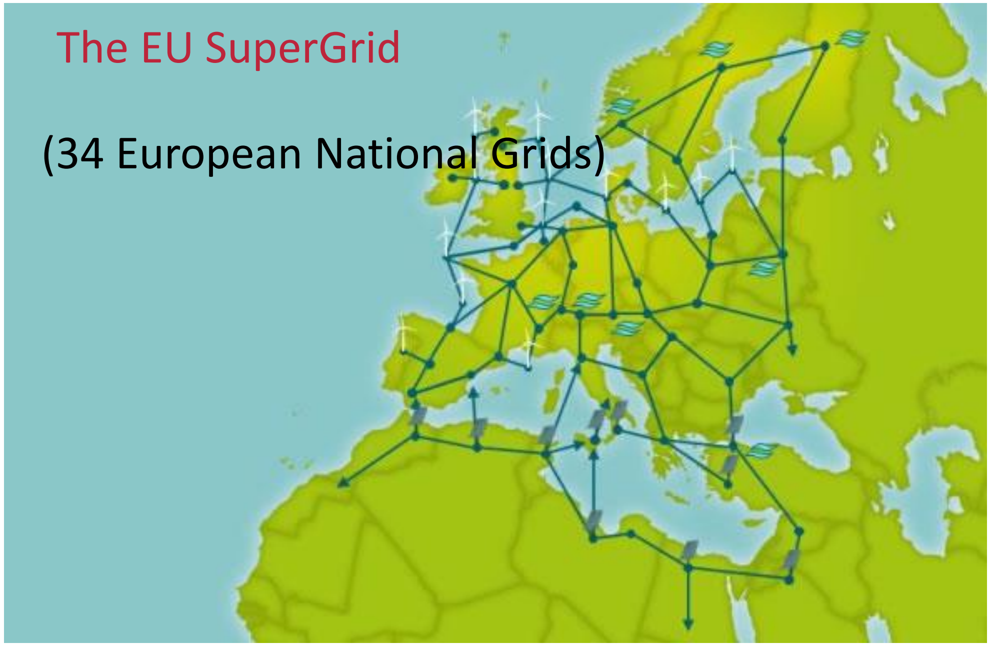
Nan-Ao VSC-MTDC
- Com. Year： 2013
- ±160kV， 200/100/50MW , 20.2 km land/submarine cable, 20.6 km OHL

2 Multi-Terminal VSC-HVDC Systems

Multi-Terminal VSC-HVDC Systems

Why VSC-MTDC ?

- Multiple power supply and multi-drop power;
- Provides additional operation flexibility,
- Redundancy
- High reliability.

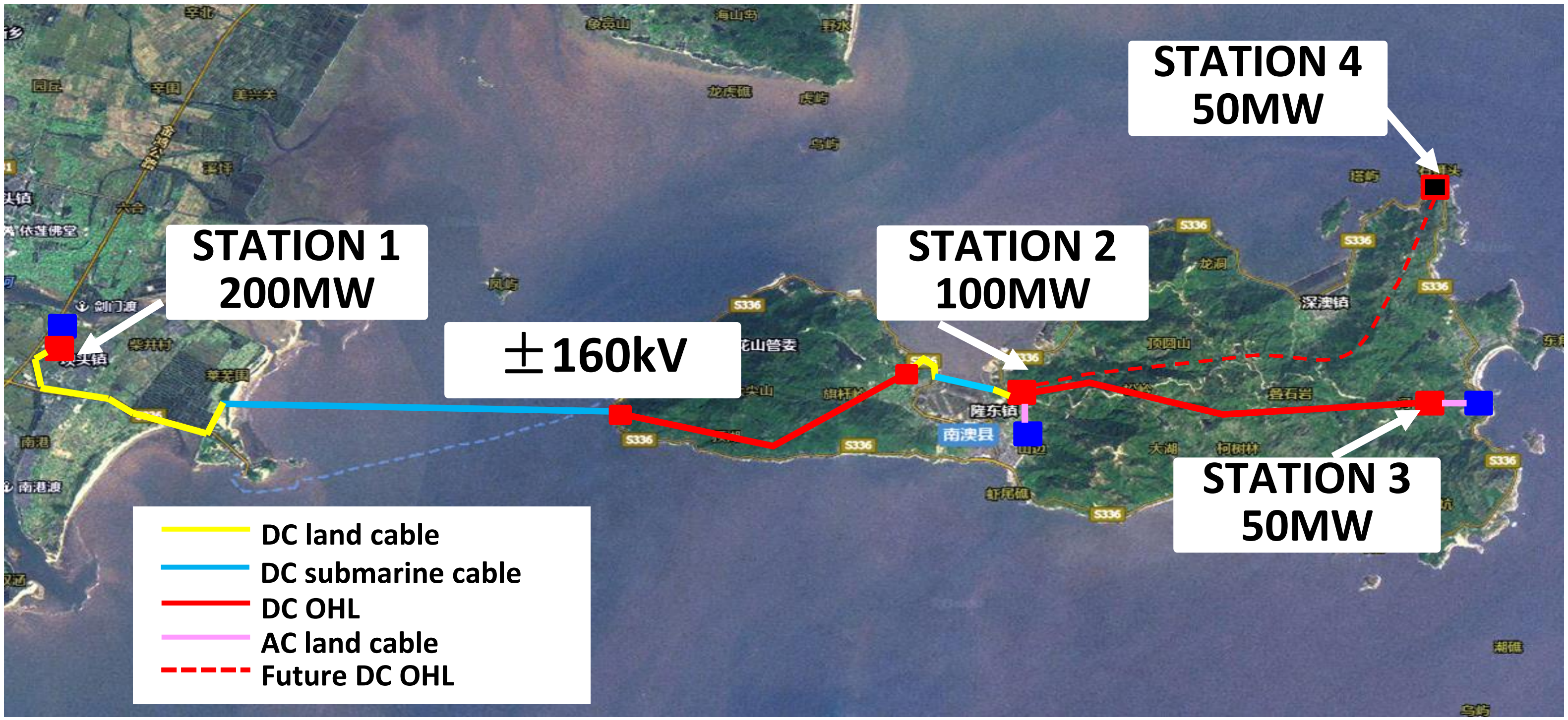


Features

- 2-Terminal System: most existing HVDC systems are point-to-point systems.
- MTDC Systems: DC transmission with 3 or more converter stations.
- For instance, the EU SuperGrid and Nan’ao VSC-MTDC project.

Multi-Terminal VSC-HVDC Systems

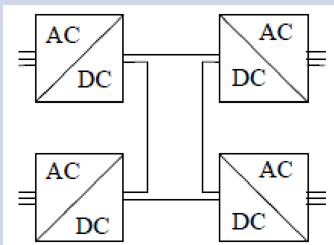
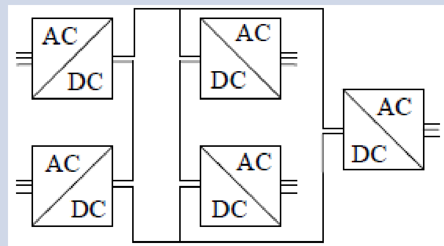
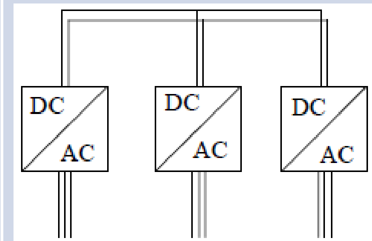
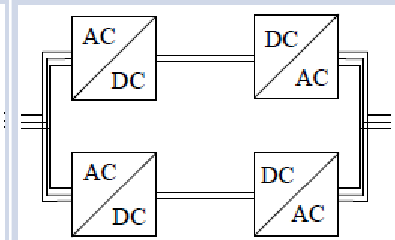
- Nan' ao VSC-MTDC project



R&D	Valve test	Commissioning	Operation
2012-12-30	2013-08-01	2013-10-21	2013-12-25

Multi-Terminal VSC-HVDC Systems

- Multi-Terminal VSC-HVDC Systems Configurations

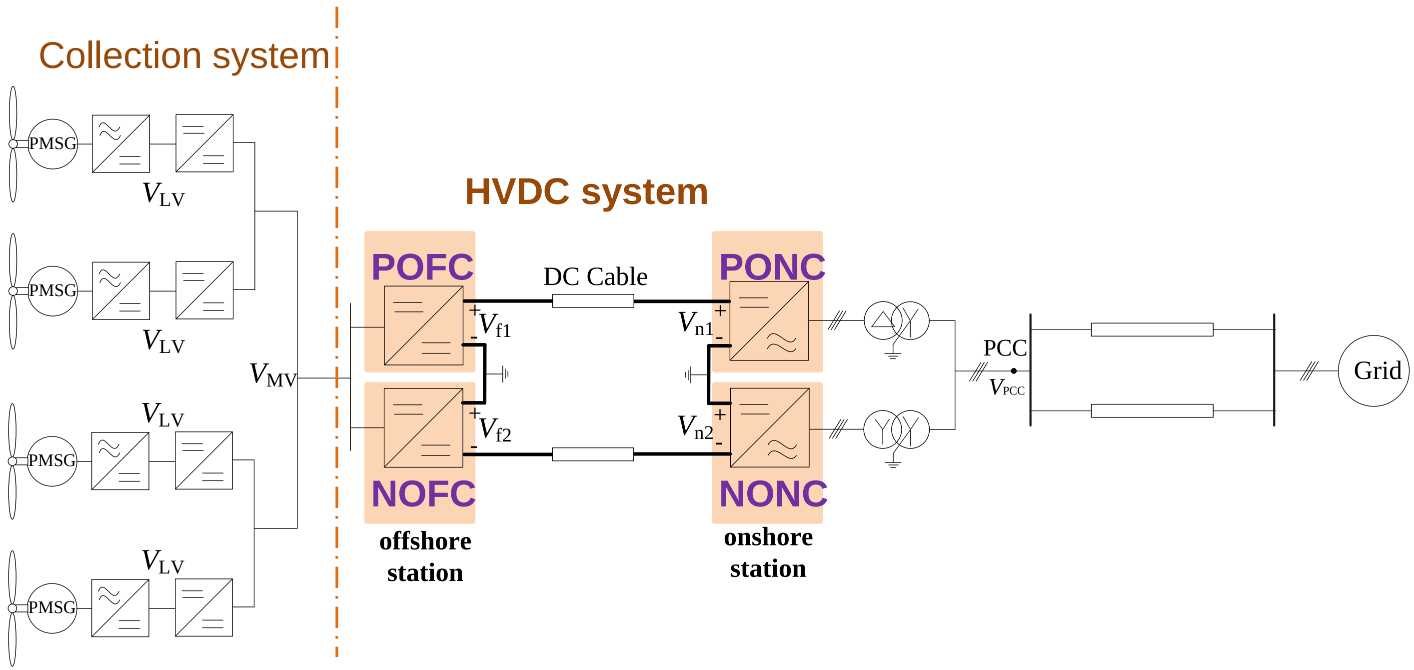
	Series connection	Mixed connection	Radial parallel connection	Ring network parallel connection
Connection Topologies				
Features	● Slow fault recovery, ● Not conducive to the expansion of power grid because of insulation and voltage withstand requirements.		● Fast fault recovery, ● Conducive to power grid expansion, ● High reliability, ● Easy maintenance, ● Flexible operation mode.	
Application	Less		Widely	

3 DC Grid for Offshore Wind Farm

DC Grid

(1) Collection system

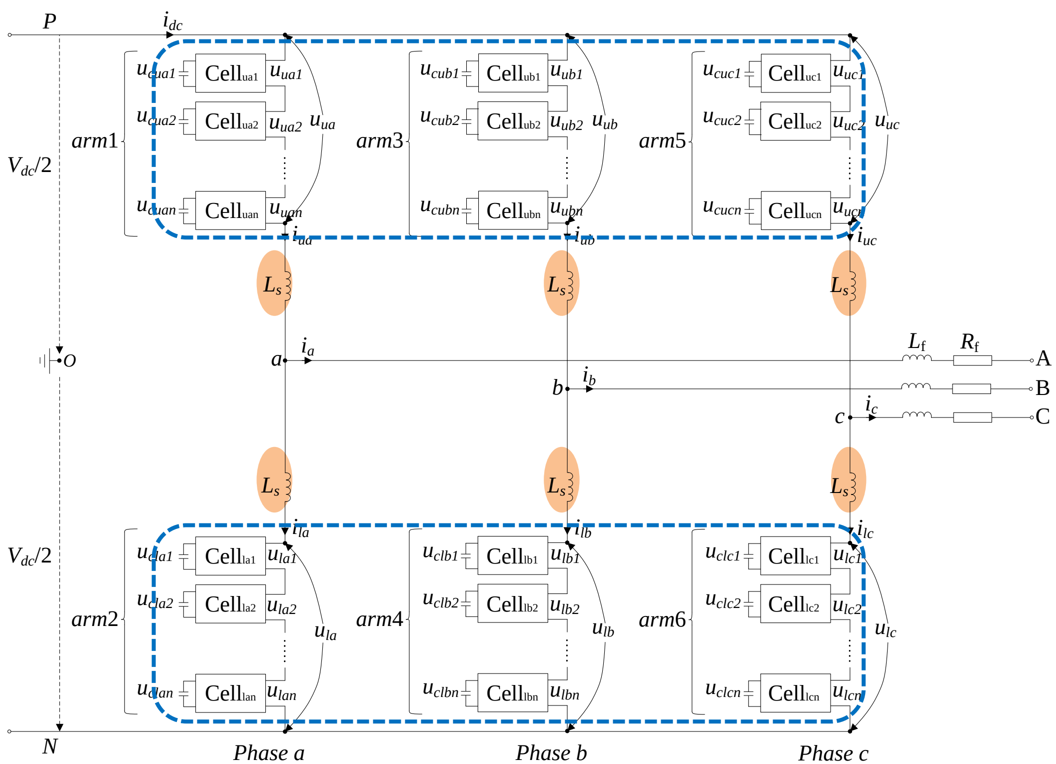
(2) HVDC transmission system



Onshore Converter

MMC for onshore converter

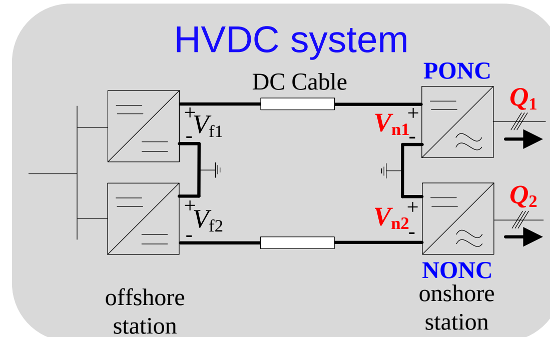
- Multilevel
- Low switching frequency
- Small harmonics
- High reliability

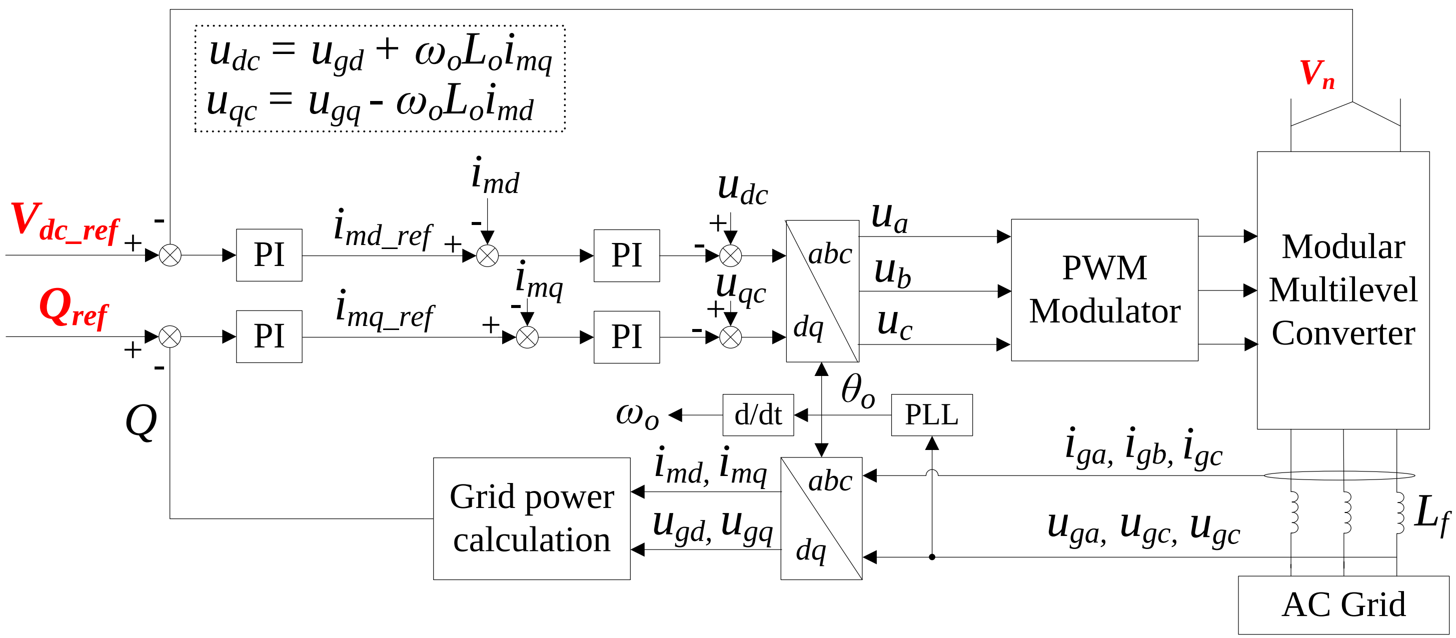


Onshore Converter Control

Onshore converter (POFC & NOFC) control

- DC-link voltage control V_n
- Reactive power control Q

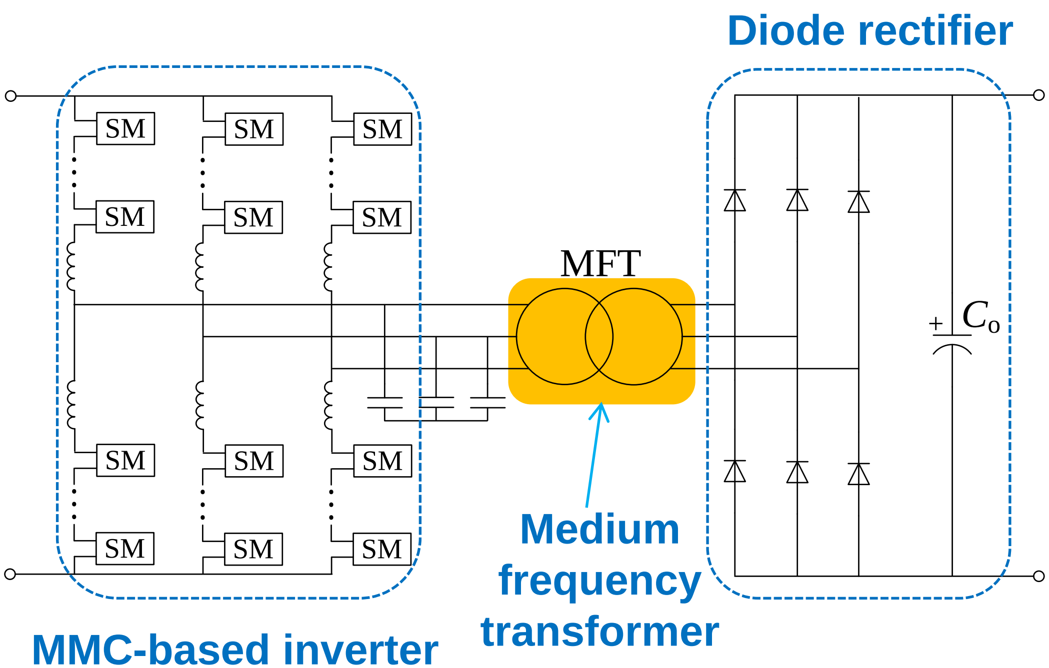




Offshore DC/DC Converter

MMC-based offshore converter

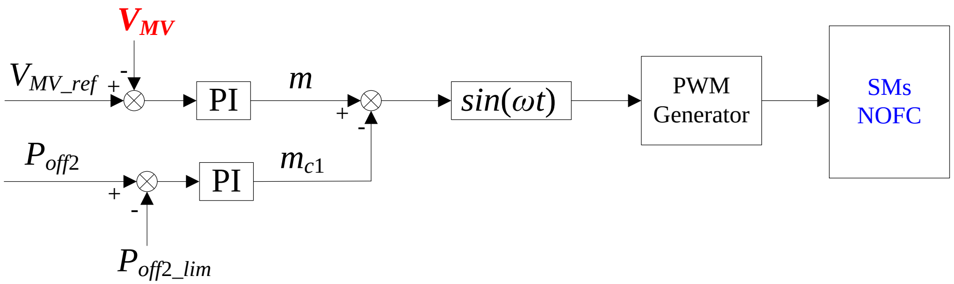
- Isolated DC transformer
- Multilevel configuration
- Medium switching frequency

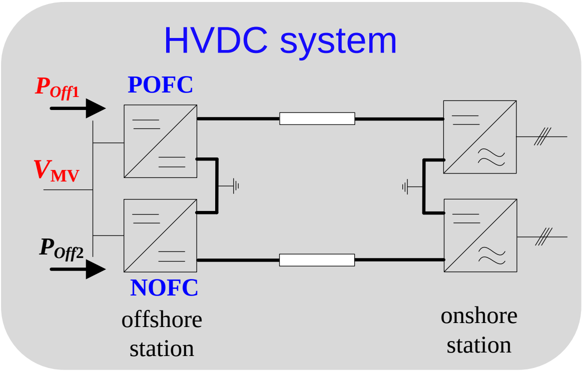


Offshore DC/DC Converter Control

1. Negative Offshore converter (NOFC) control

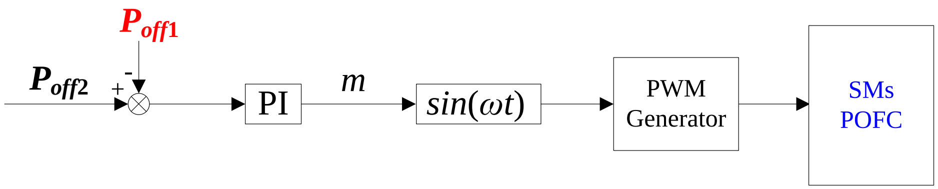
- Collection voltage control V_{MV}





2. Positive Offshore converter (POFC) control

- Power follow control P_{off1}

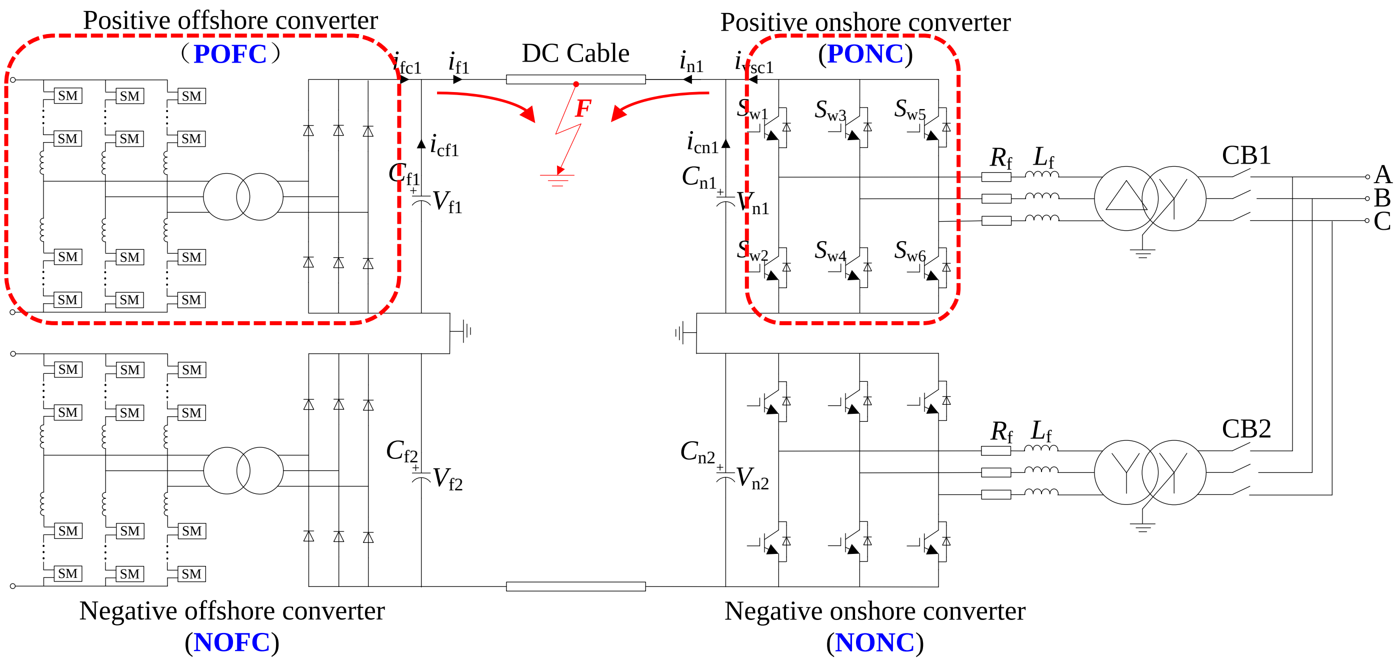


4 DC-Line Fault Situation

HVDC transmission system

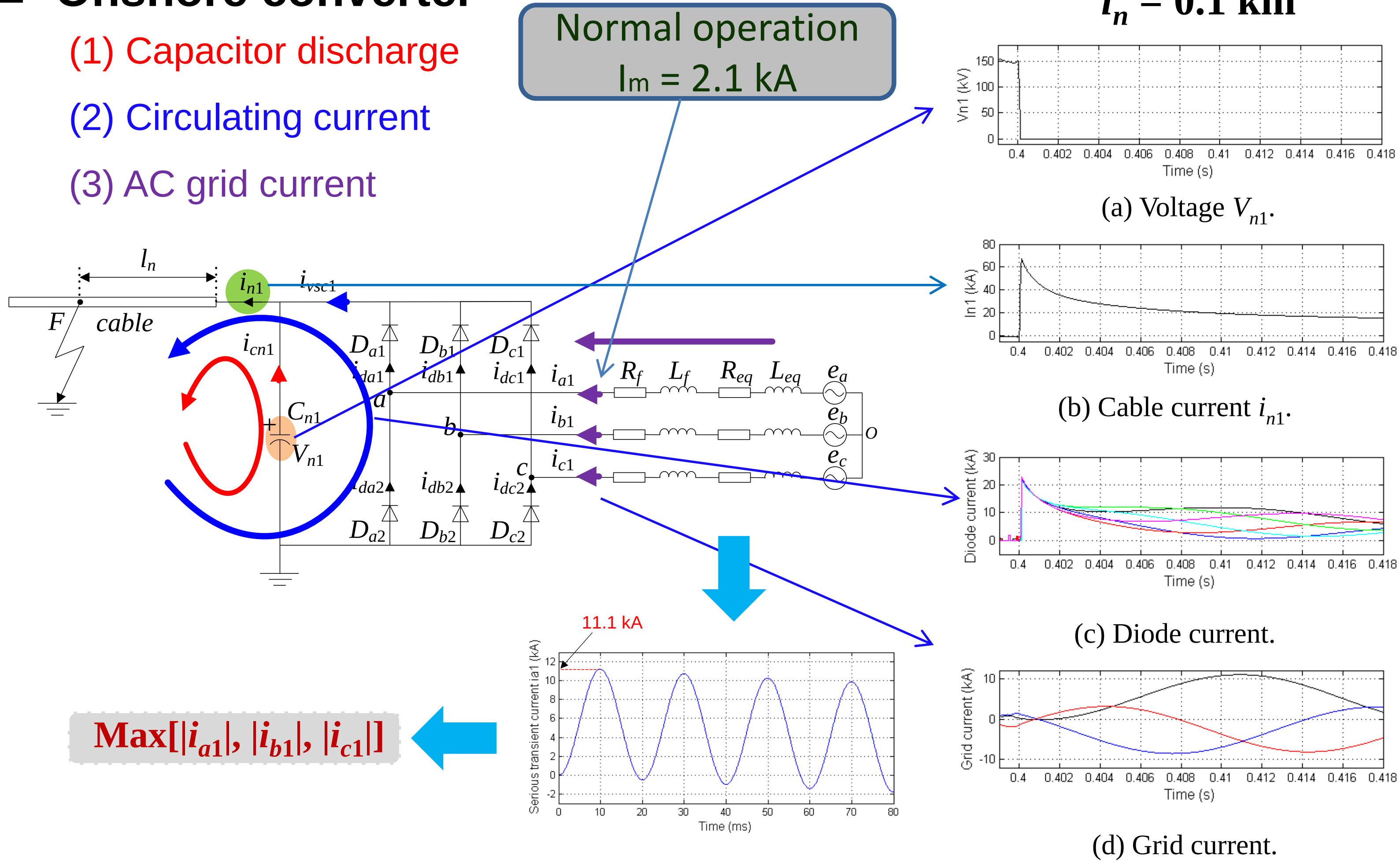
(1) Onshore converter (**PONC** & **NONC**)

(2) Offshore converter (**POFC** & **NOFC**)



Fault Current at Onshore Converter

- **Onshore converter**
  - (1) Capacitor discharge
  - (2) Circulating current
  - (3) AC grid current



(a) Voltage V_{n1}.

(b) Cable current i_{n1}.

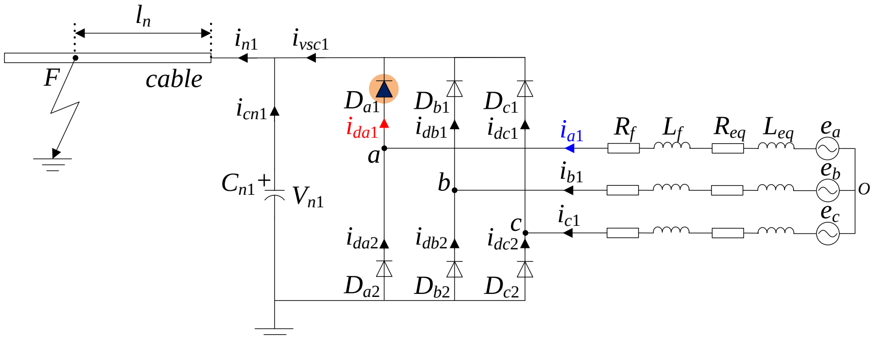
(c) Diode current.

(d) Grid current.

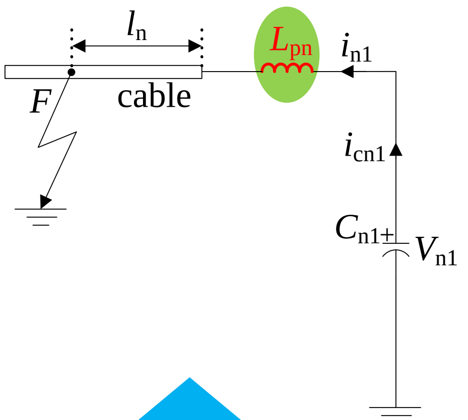
Max[$|i_{a1}|$, $|i_{b1}|$, $|i_{c1}|$]

Protective Inductor for onshore Converter

2. Only one diodes in one leg in condition



Peak value $i_{n1m} = V_{n10}\sqrt{C_{n1}/L_{pn}}$



$i_{dx1} = |i_{x1}|$

$x \in (a, b, c)$

The possible maximum fault current

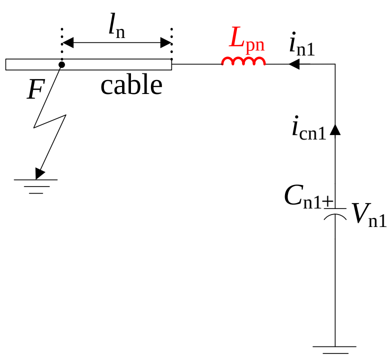
$\text{Max}[i_{n1}] \leq 1.5\ \text{Max}[|i_{a1}|, |i_{b1}|, |i_{c1}|]$

The maximum diode current is

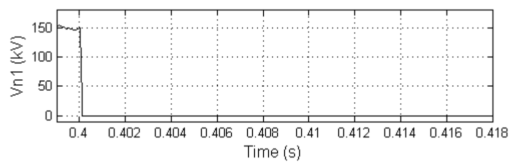
$\boxed{i_{d2\_max} = \text{Max}[|i_{a1}|, |i_{b1}|, |i_{c1}|]}$

$i_{d1\_max} \leq i_{d2\_max}$

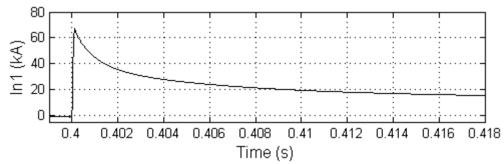
Onshore Converter Performance



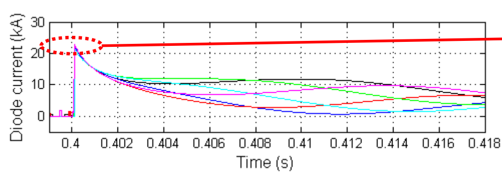
l_n = 0.1 km



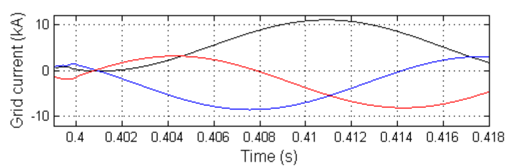
(a) Voltage V_{n1}.



(b) Cable current i_{n1}.



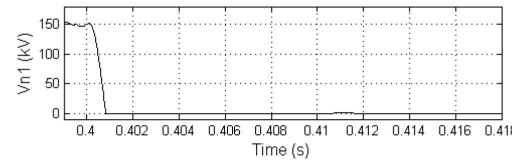
(c) Diode current.



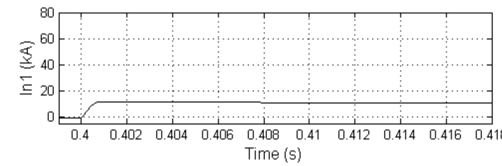
(d) Grid current.

No protection

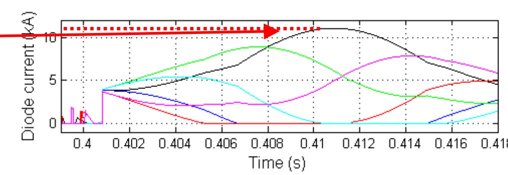
l_n = 0.1 km



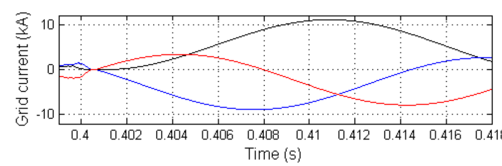
(a) Voltage V_{n1}.



(b) Cable current i_{n1}.



(c) Diode current.



(d) Grid current.

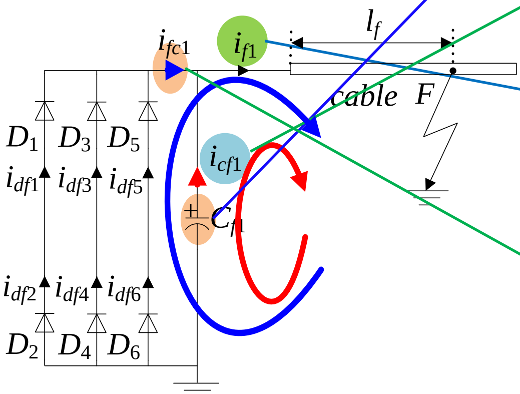
L_{pn}=6.5 mH

Offshore Converter Protection under Faults

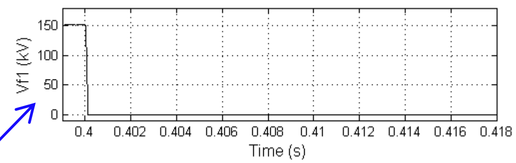
■ Offshore converter

(1) Capacitor discharge

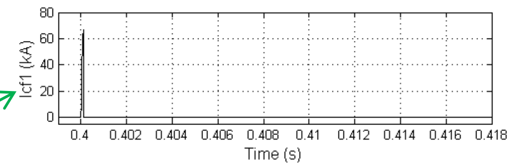
(2) Circulating current



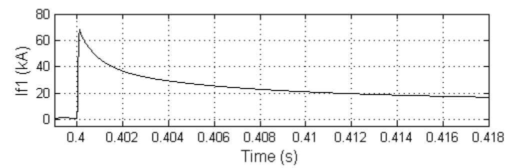
l_n = 0.1 km



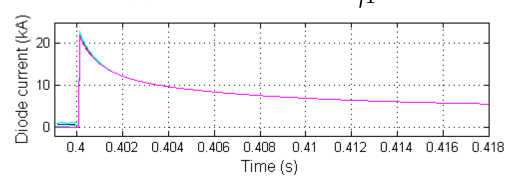
(a) Voltage V_{f1}.



(b) Cable current i_{cf1}.

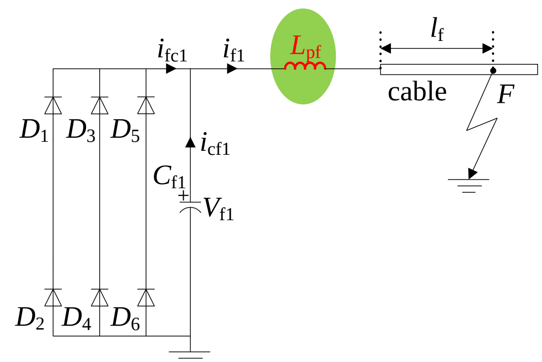


(c) Cable current i_{f1}.



(d) Diode current.

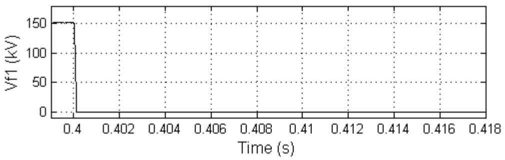
Peak value $i_{cf1}(t) = \sqrt{V_{f10}^2 \dfrac{C_{f1}}{L_{pf}} + I_{f10}^2}$



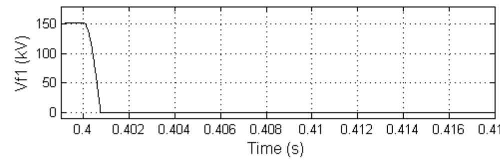
Offshore Converter Performance

l_n = 0.1 km

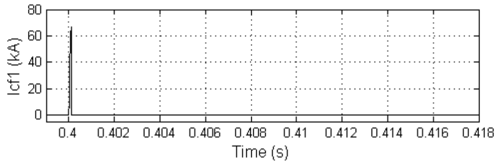
l_n = 0.1 km



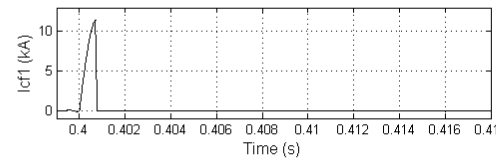
(a) Voltage V_{f1}.



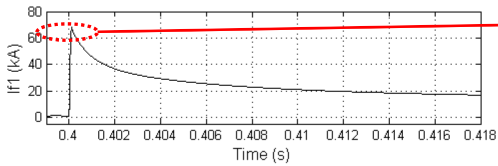
(a) Voltage V_{n1}.



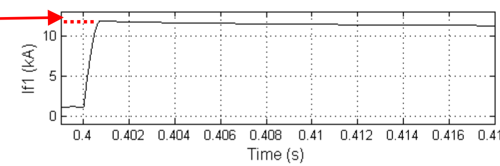
(b) Cable current i_{cf1}.



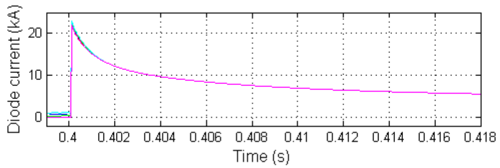
(b) Cable current i_{cf1}.



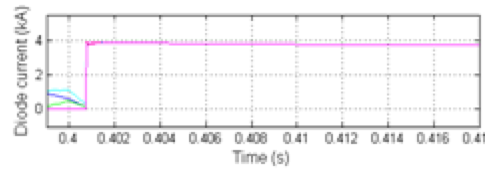
(c) Cable current i_{f1}.



(c) Diode current.



(d) Diode current.



(d) Grid current.

No protection

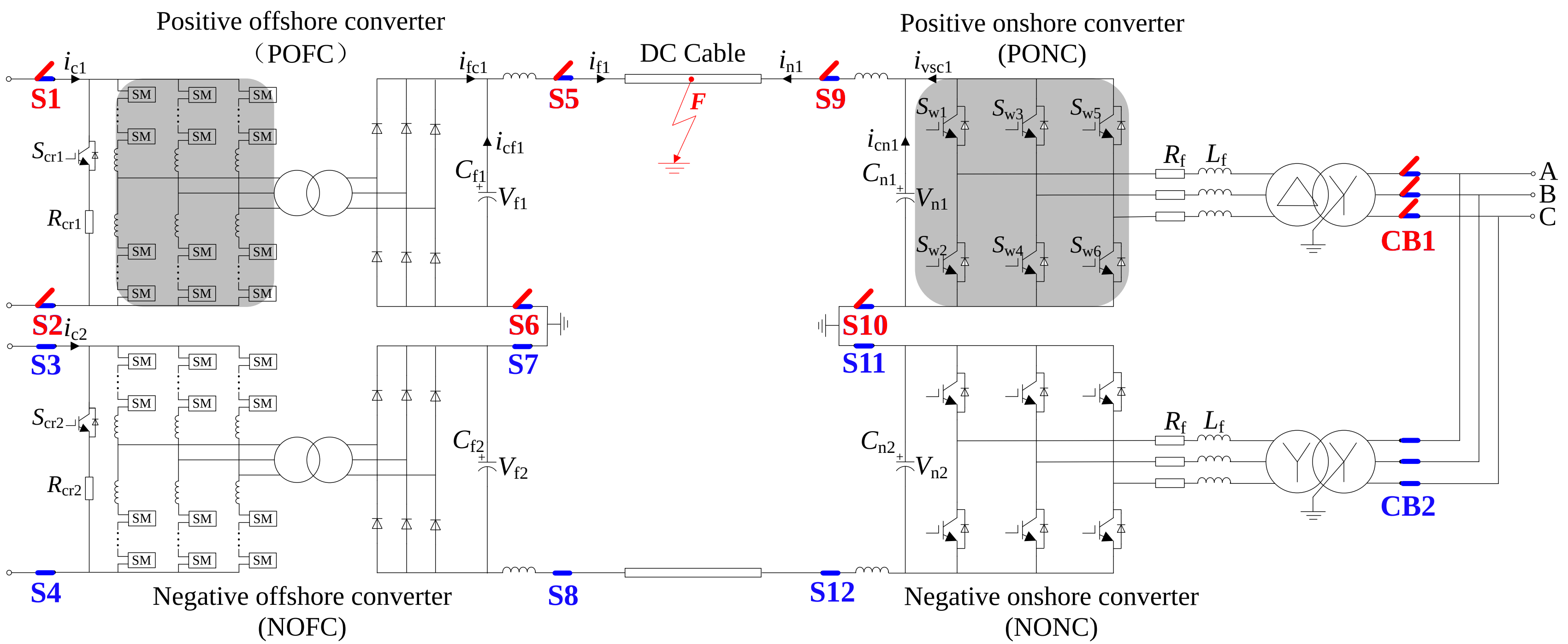
L_{pf}=6.5 mH

Redundancy for HVDC System Faults

■ Redundancy

(1) Redundancy for onshore converter

(2) Redundancy for offshore converter

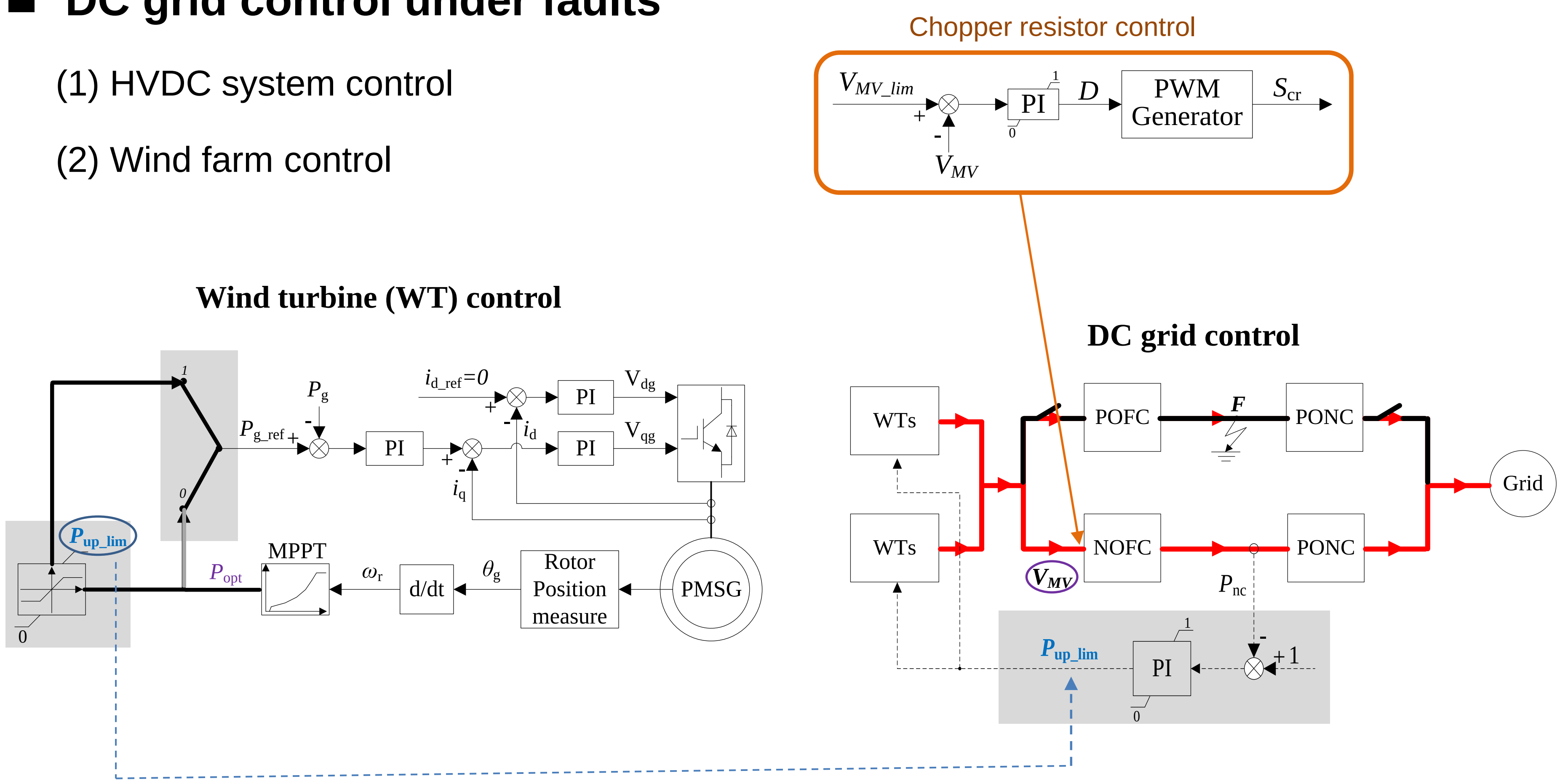


DC Grid Control under Faults

- **DC grid control under faults**

(1) HVDC system control

(2) Wind farm control



Thanks!