High Power Conversion Technology for High Voltage DC Transmission Application

Proven technology to transmission and connection



Dr. Guangfu Tang
Global Energy Interconnection Research Institute (GEIRI)

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1. Background

2. Line Commutated Converter Technology

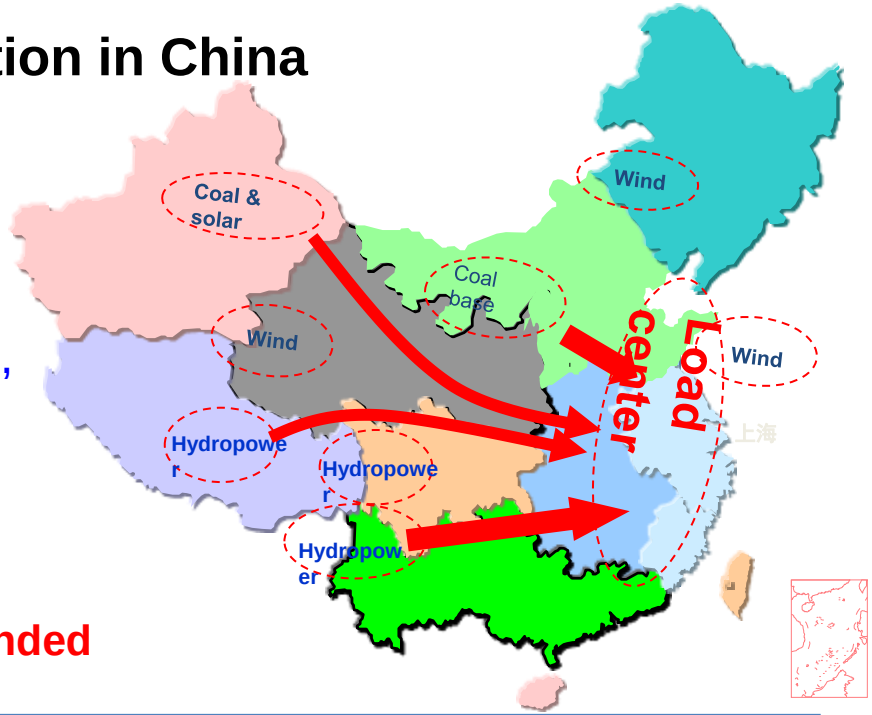
3. Voltage Sourced Converter Technology

4. Conversion Technology for MTDC and DC Grid

Demand for large scale power transmission

Energy resource and load distribution in China

- 76% of coal in North and Northwest
- 80% of hydropower in Southwest
- All inland wind in North
- 70%+ of load in Central and Eastern parts, distances in-between reaching up to 2000+km

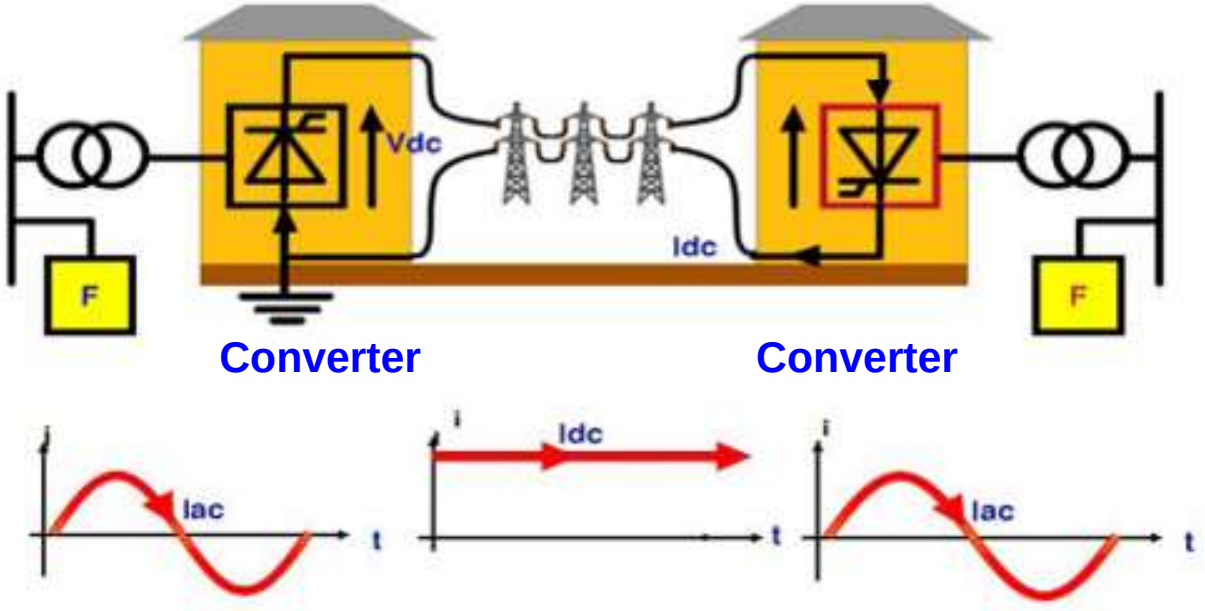


High power transmission technology is demanded

China's population (billion)	Annual power generation per capita(kWh)	Total installed capacity (10^8 kW)/Annual power output (10^8 kWh)	Installed coal-fired generation(TW)/ratio	Renewable installed (excl. water) (TW)	West-to-East Project capacity (10^8 kW) /electricity(10^{12} kWh)
1.33	3500	/4.65	0.745/80%	-	-
1.4	5000	14.9/7	0.98/70%	0.126	3.84/1.82
1.4	7000	24/9.8	1.1/55%	0.6	5.85/2.43
1.5	9000	37.5/13.5	1.2/44%	1.5	8.35/2.86
1.5	10000	40.5/15	1.2/40%	1.75	8.98/3.18

What is the LCC-HVDC ?

- LCC-HVDC is the primary solution for long distance and high power transmission by employing the line commutated converter (LCC)
- Ultra HVDC(UHVDC) is referred to the DC voltage level of ±800kV and above
- A UHVDC project, rated at ±800kV/5000A, can transmit electrical power over 8,000 MW, with a distance of more than 2000km



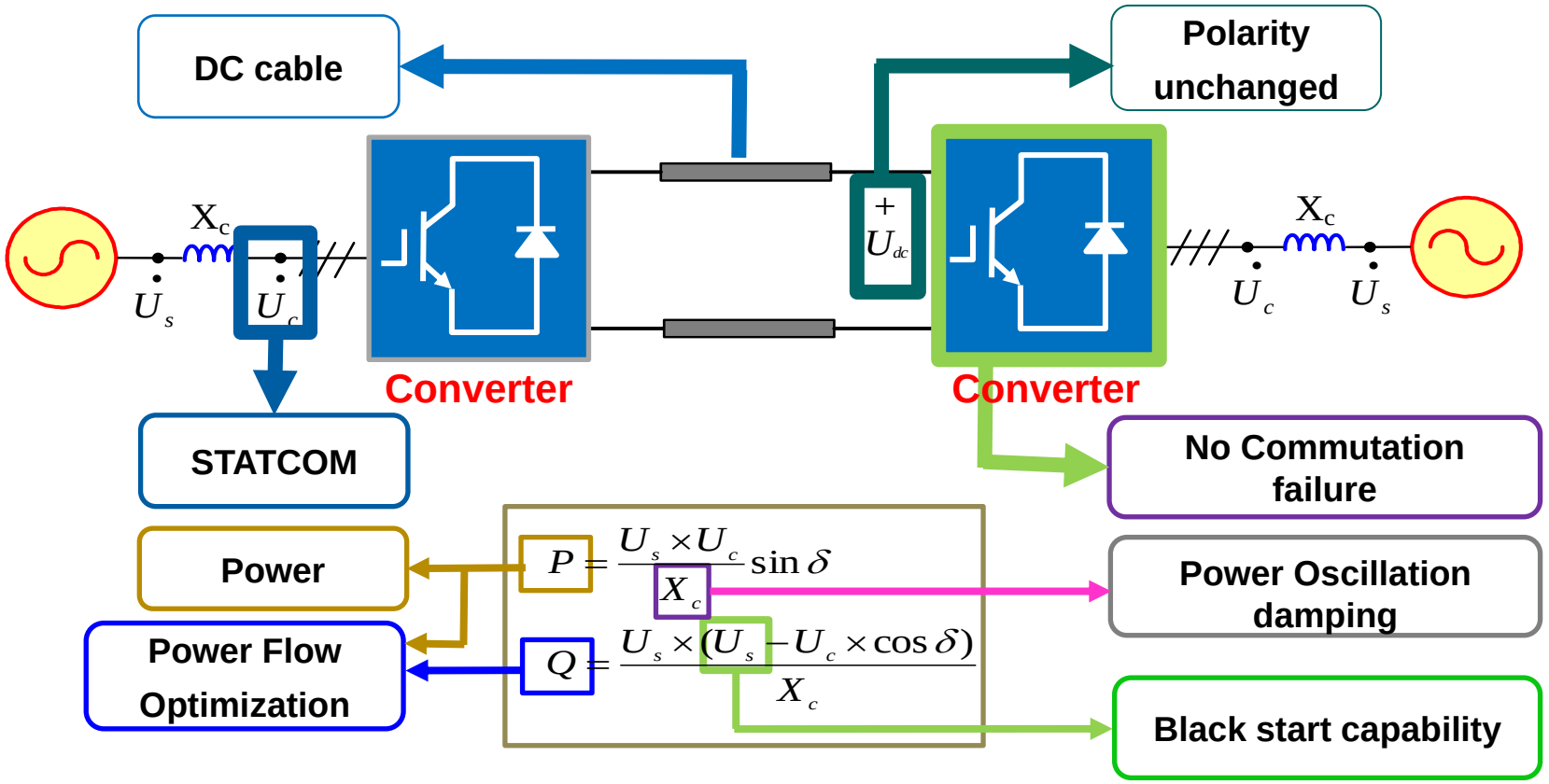
LCC-HVDC transmission system

Demand for flexible power transmission

- Most of the wind and solar power distributed in west of China, renewable energy generation will rise up to more than 30% of the generated electricity
- East of China has large offshore wind resource (about 200GW) , it evoke to be effectively integrated into the mainland network
- The weak power grids, such as those in islands and remote areas, need more flexible power transmission

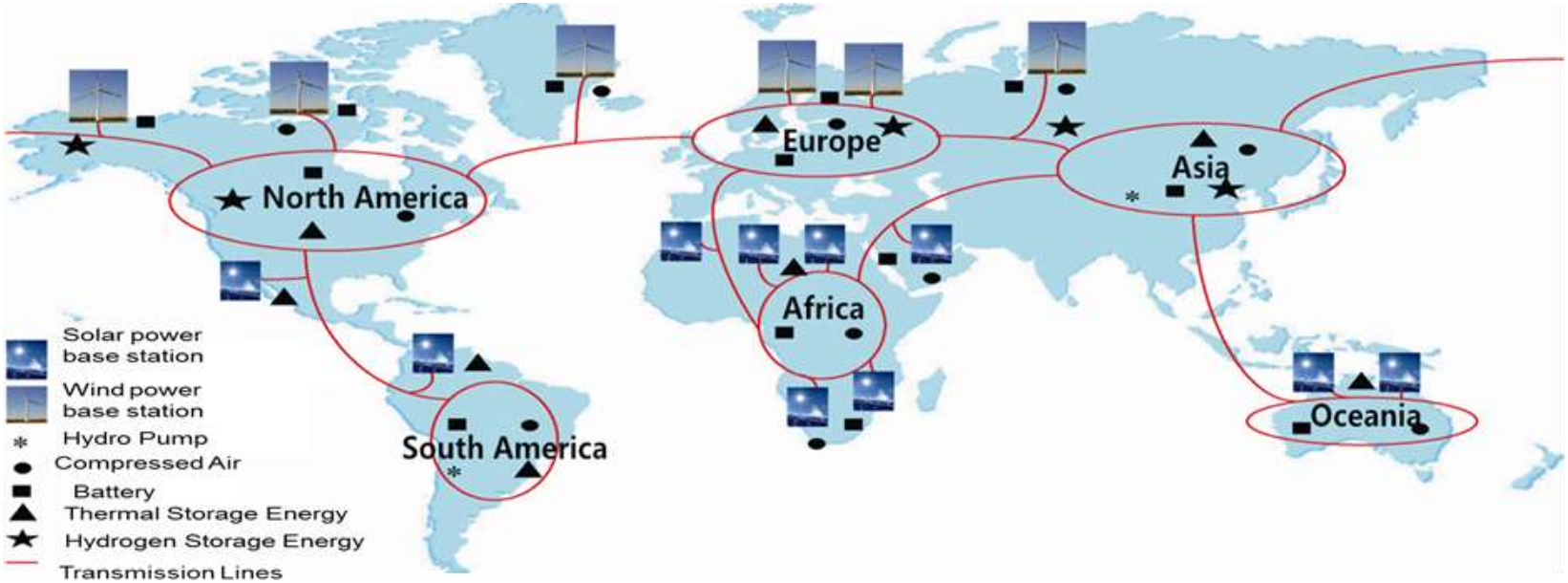
What is the VSC-HVDC ?

- VSC-HVDC is a new type of HVDC transmission technology based on voltage sourced converter (VSC)
- It has the capability of independent control of both active and reactive power by changing the phase angle and amplitude of the converter



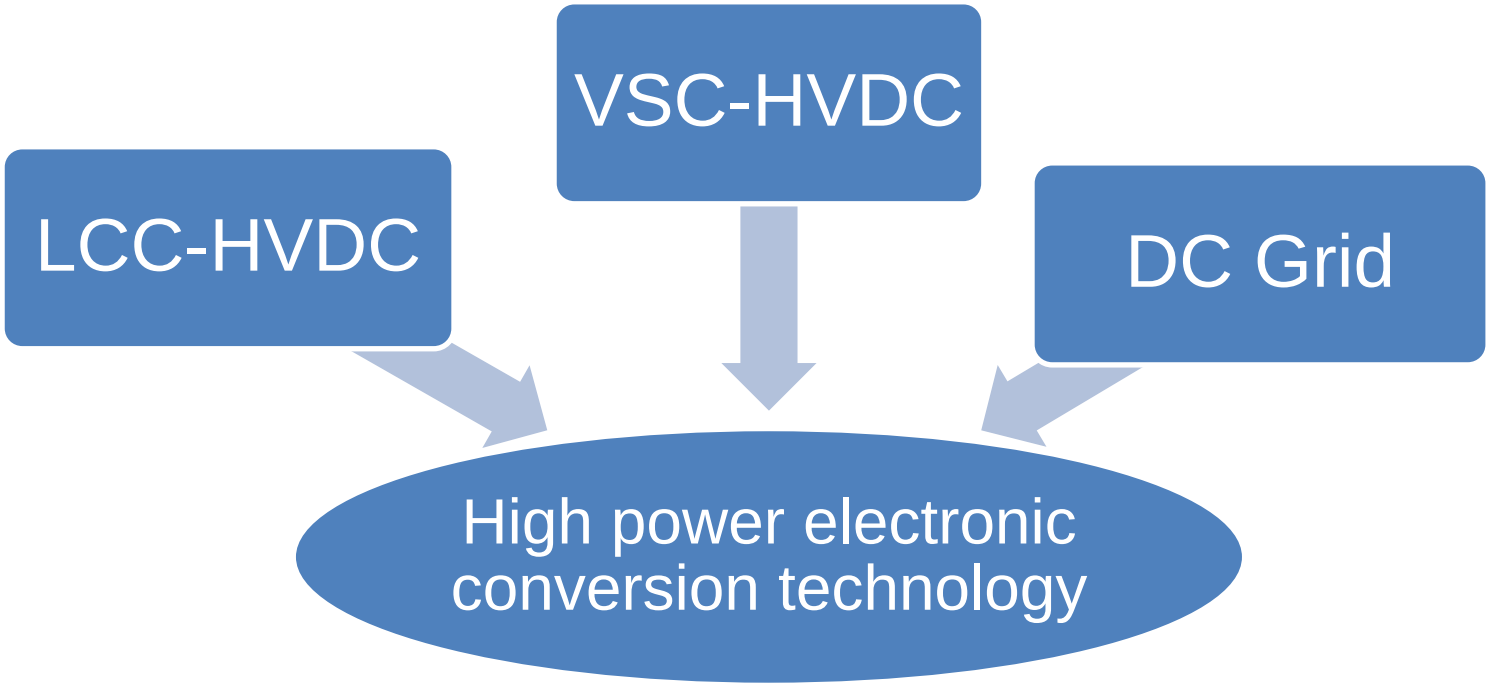
What is the DC Grid ?

- More renewable energy, such as offshore wind power, hydropower and solar power, will be integrated into power network all over the world
- DC grid can provide power complementary for output fluctuations of renewable energy, and ensure efficient integration and flexible transfer of wind energy from a wide geographical area.



High Power Conversion Technology

High voltage DC transmission employ high power electronics technology to step up/down voltage and convert electrical power to achieve energy efficient, flexible, long-distance transmission.



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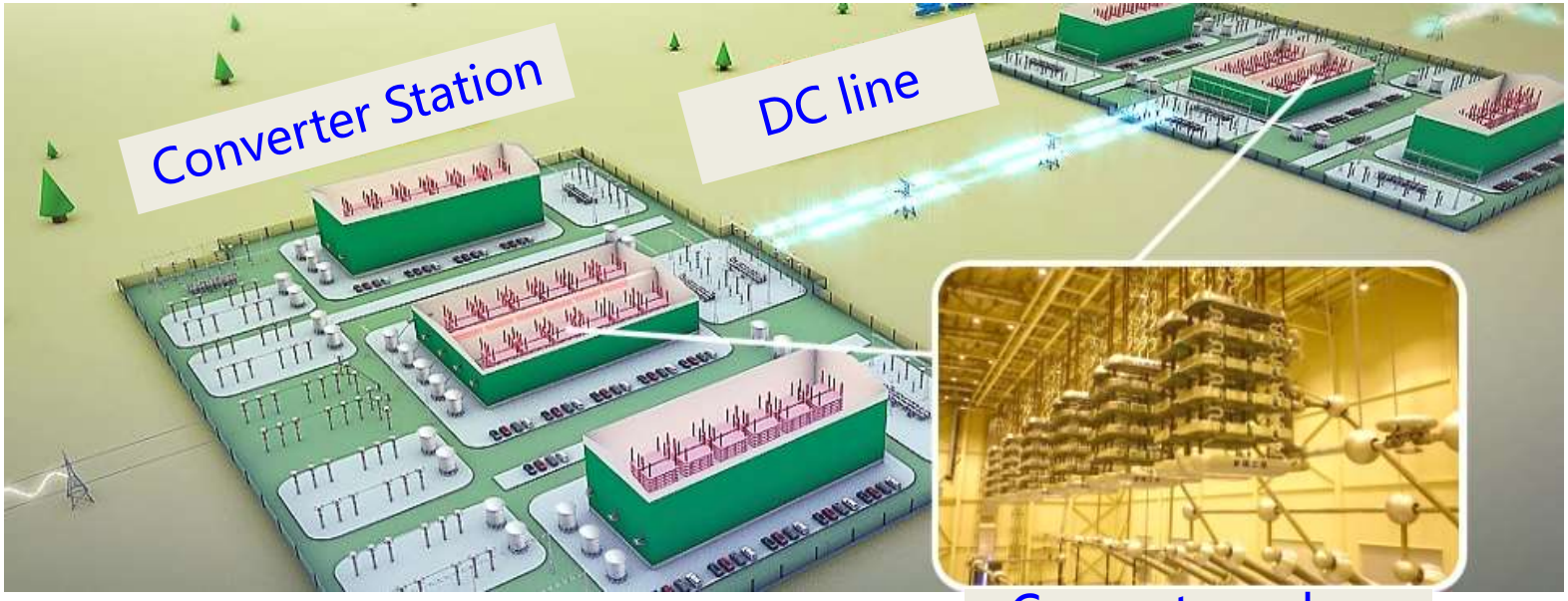
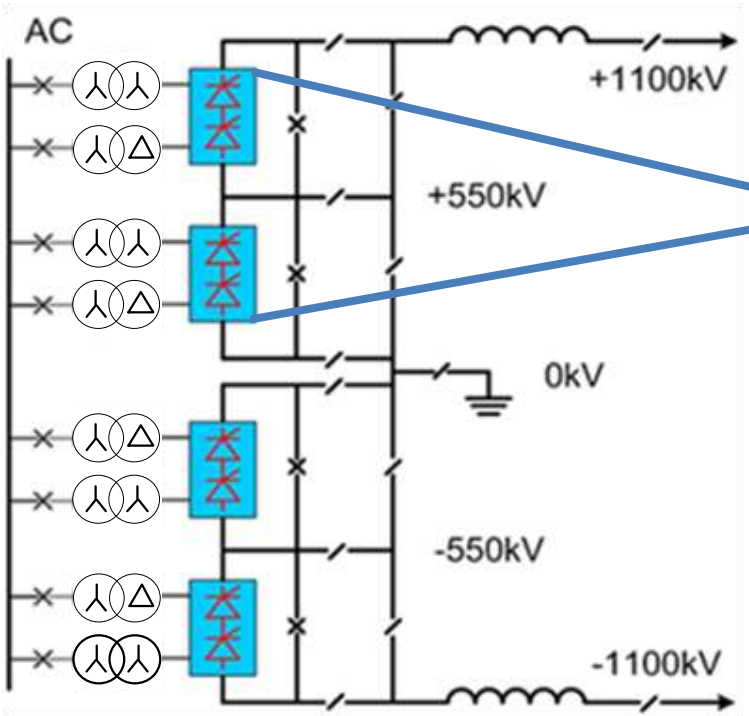
LCC-HVDC System

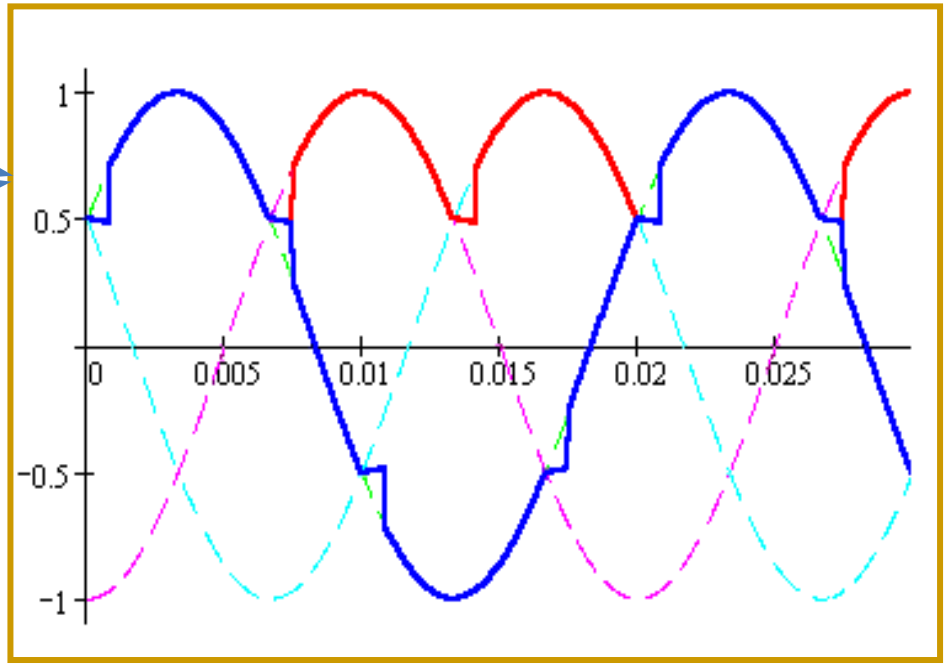
- LCC-HVDC converts AC to DC power and then transmitted to the load center, where the DC power will be converted back to the AC power to supply the load
- Due to the high power rating of each HVDC project, it poses a very high requirement on the reliability of the converter
- The possibility of each converter experiences unpredictable failures should stay below once per 10 years



Conversion principle of LCC

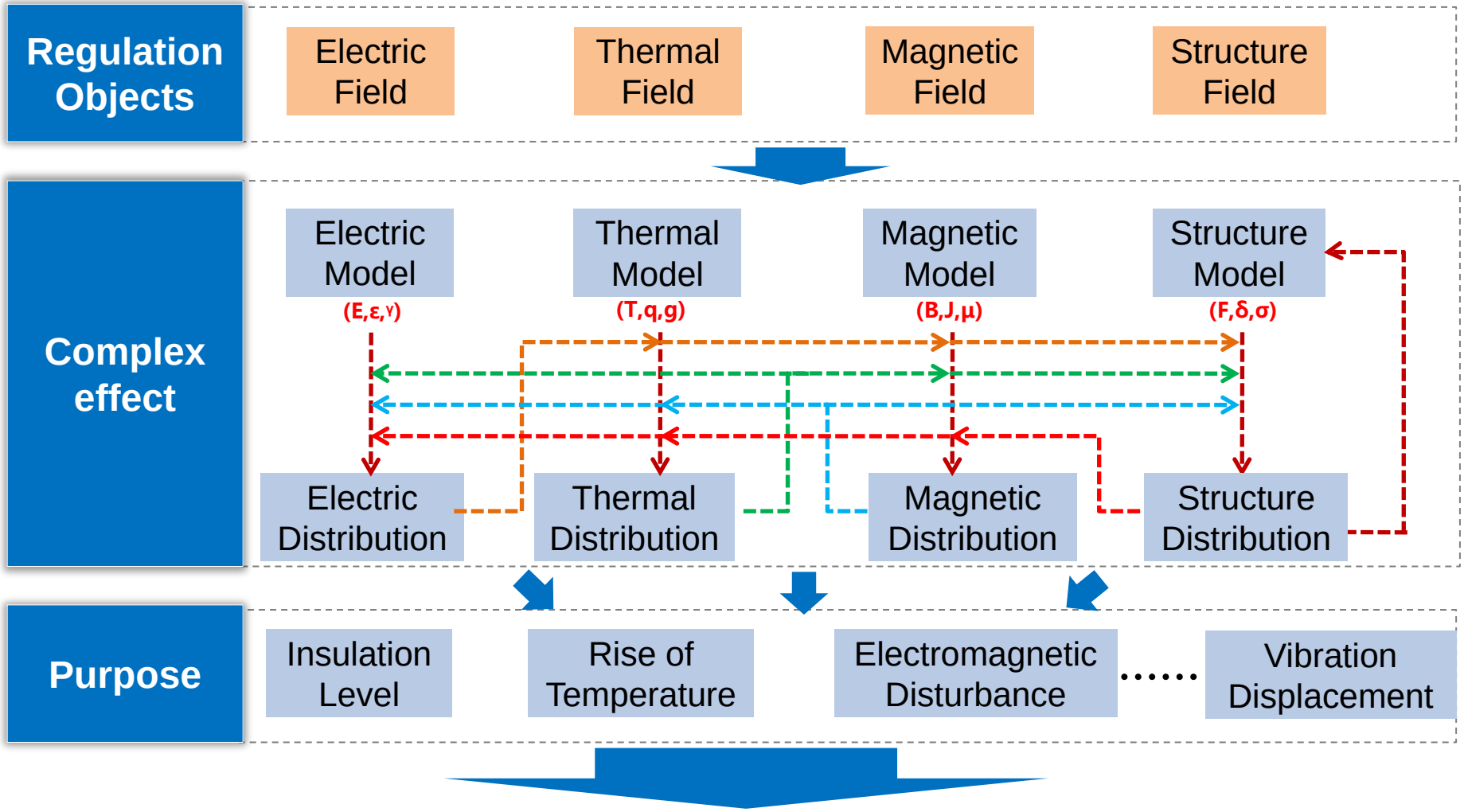
- Single 12-pulse design for <660kV HVDC applications
- Double 12-pulse design for >800kV UHVDC applications to limit the height of the valve towers





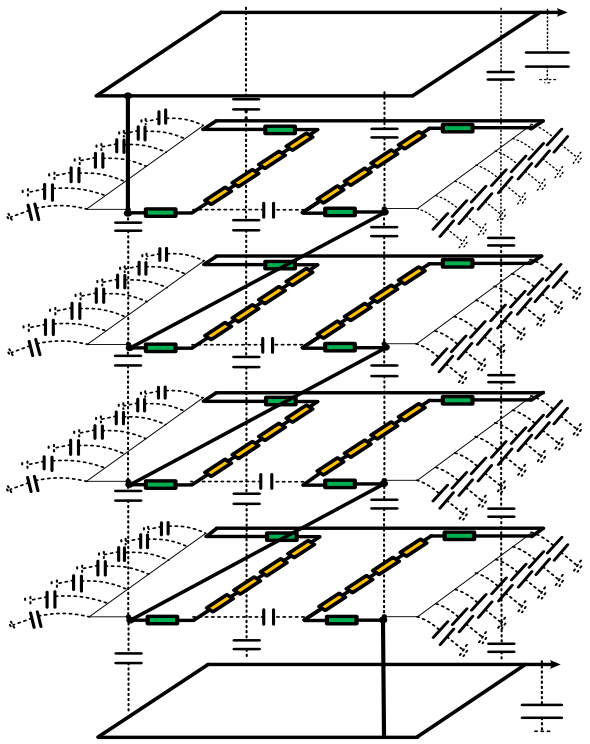
Valve voltage of the rectifier side

Method of Matrix Multi-physics Regulation

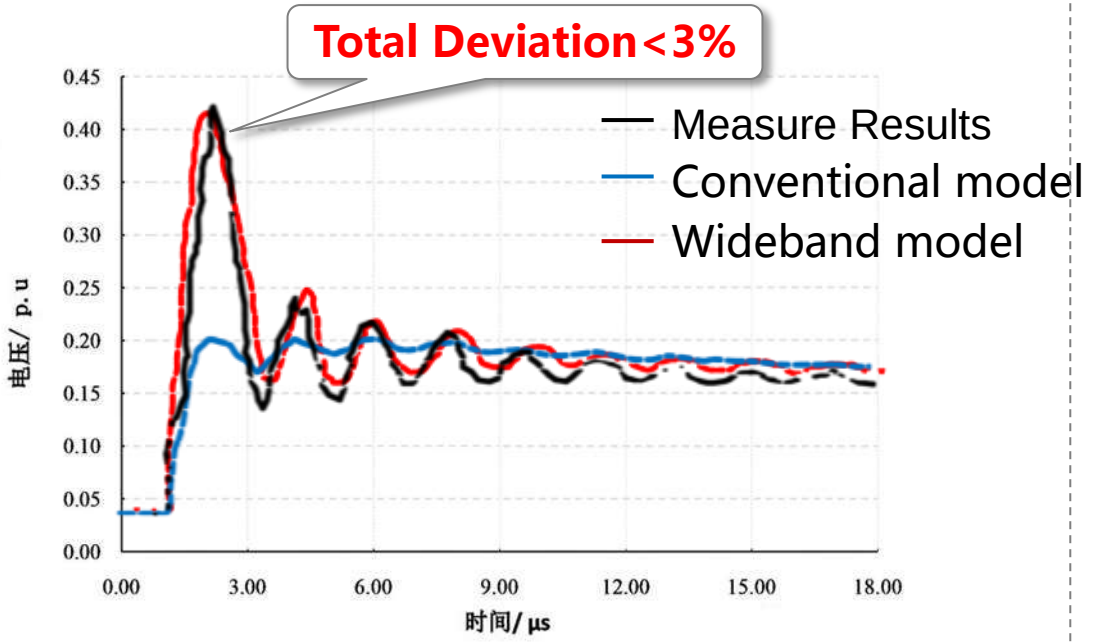


Multi-physics field of converter valve is regulated comprehensively

Wideband Modeling of Converter Valves



Wideband Model of Converter Valves

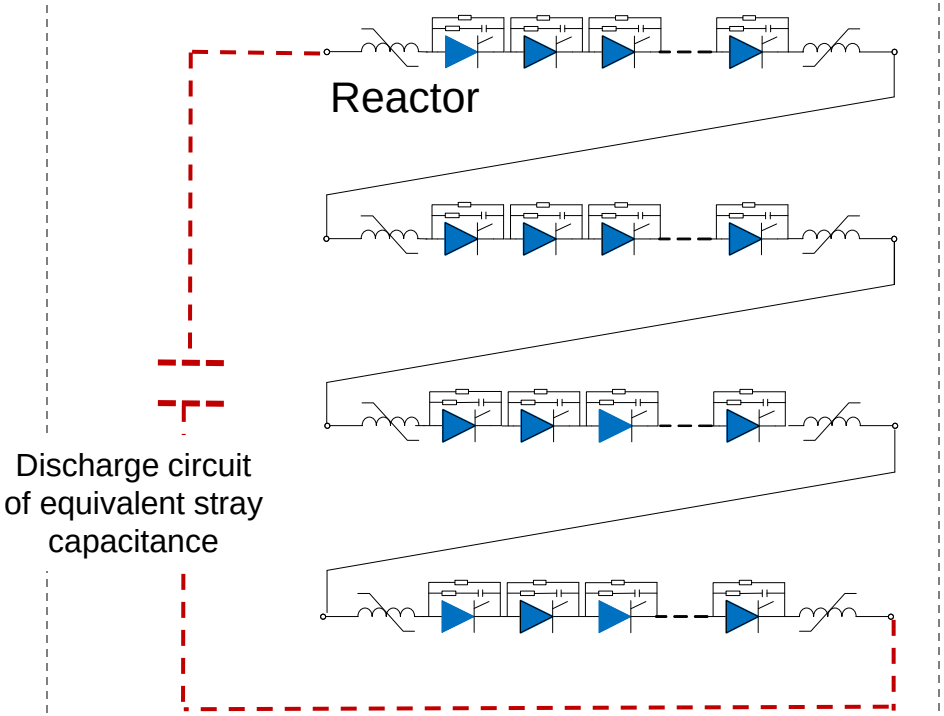


	Switching Impulse	Lightning Impulse	Steep Impulse
Wideband Model	0.95%	2.2%	3%

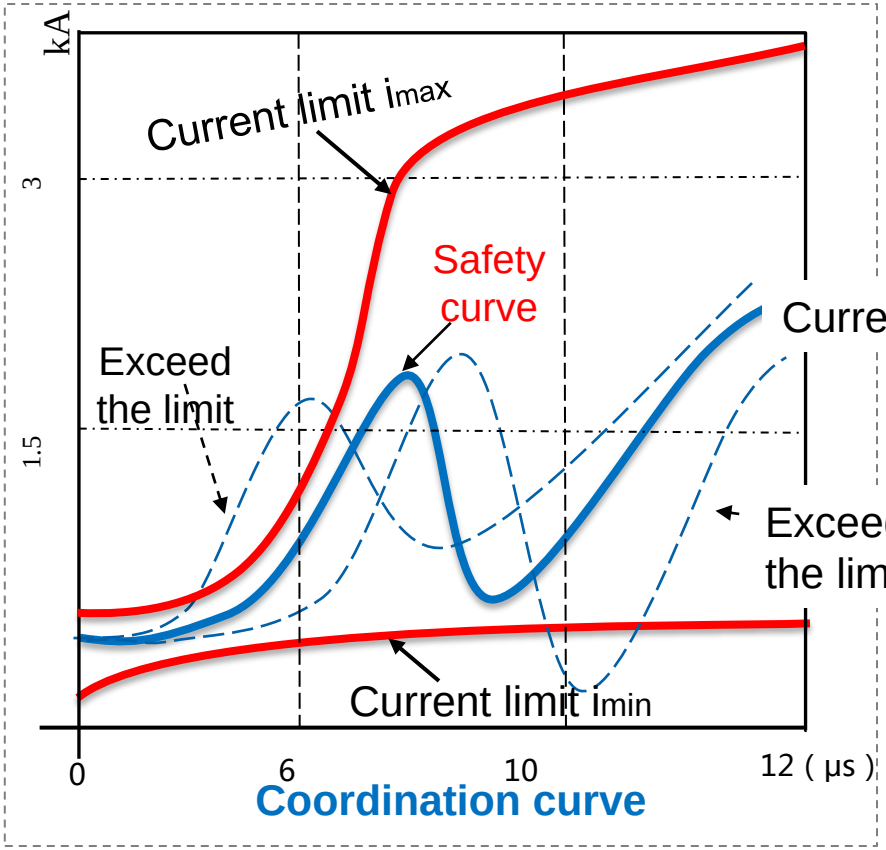
Deviation between wideband model and measured results

The influence of stray capacitances to transient voltage distribution of thyristor is obtained.

Coordination of Thyristor and Reactor



Scale series thyristor discharge opening



Coordination curve

Opening security boundary of 6 inches thyristor : the current in turn-on stage reduces from 500A to 3000A within 5μs

Puzzle of series thyristor opening reliability is solved.

Thyristor Trigger Monitor(TTM) of Valve

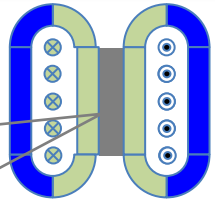
- Real-time triggering, protection and detection is completed by TTM, which suffers from many electromagnetic interference.
- According to statistics, failures caused by electromagnetic compatibility problems accounts for about 80% of the total failures of the converter valve in China's HVDC projects.
- Under harsh electromagnetic environment, a converter valve trigger control system is developed, which can trigger and monitor thyristor reliably at a high voltage.

Performance	Thyristor trigger synchronization	Mean time between failures	Bit error rate	Adaptive protection
Parameter	**500ns**	**50400h**	**10^{-12}**	**YES**

Key Components and Modules of Converter Valve

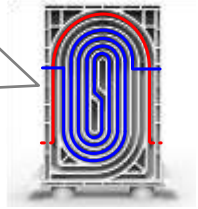
Key components

- Temperature control
- Electromagnetic control
- Balance of loss
- Electromagnetic vibration suppression



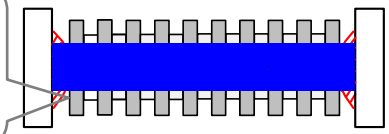
Asymmetrical saturated reactor

- Temperature regulation
- Water tube structures
- Power density
- Electric corrosion



Integrated water-cooled resistor

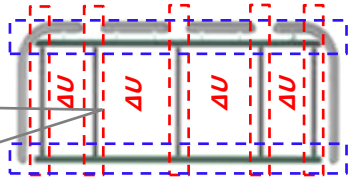
- Temperature control
- Balanced of electric field
- Contact resistance control



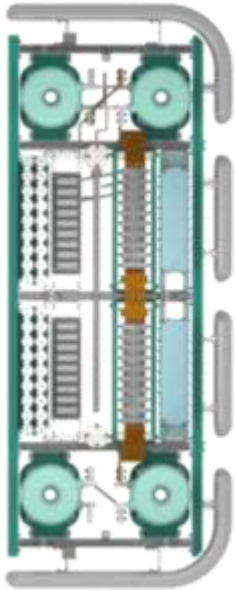
Adaptive press-fit mechanism of Series thyristor

Modules of converter valve

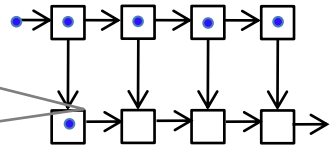
Electric Field
Structure Field



Valve module frame



Thermal Field
Fluid Field



Cooling circuit

Electric Field
Thermal Field

Inlet / outlet pipe

performance	Magnetostrictive force	The maximum temperature	Thyristor press Force	Contact resistance
Parameter	175N	68℃	180kN	1μΩ

The power density of components is increased, while the electromagnetic vibration and temperature are reduced

Equipment

Converter valve for LCC-HVDC

Valve Base Electronics

UHVDC Projects in Service

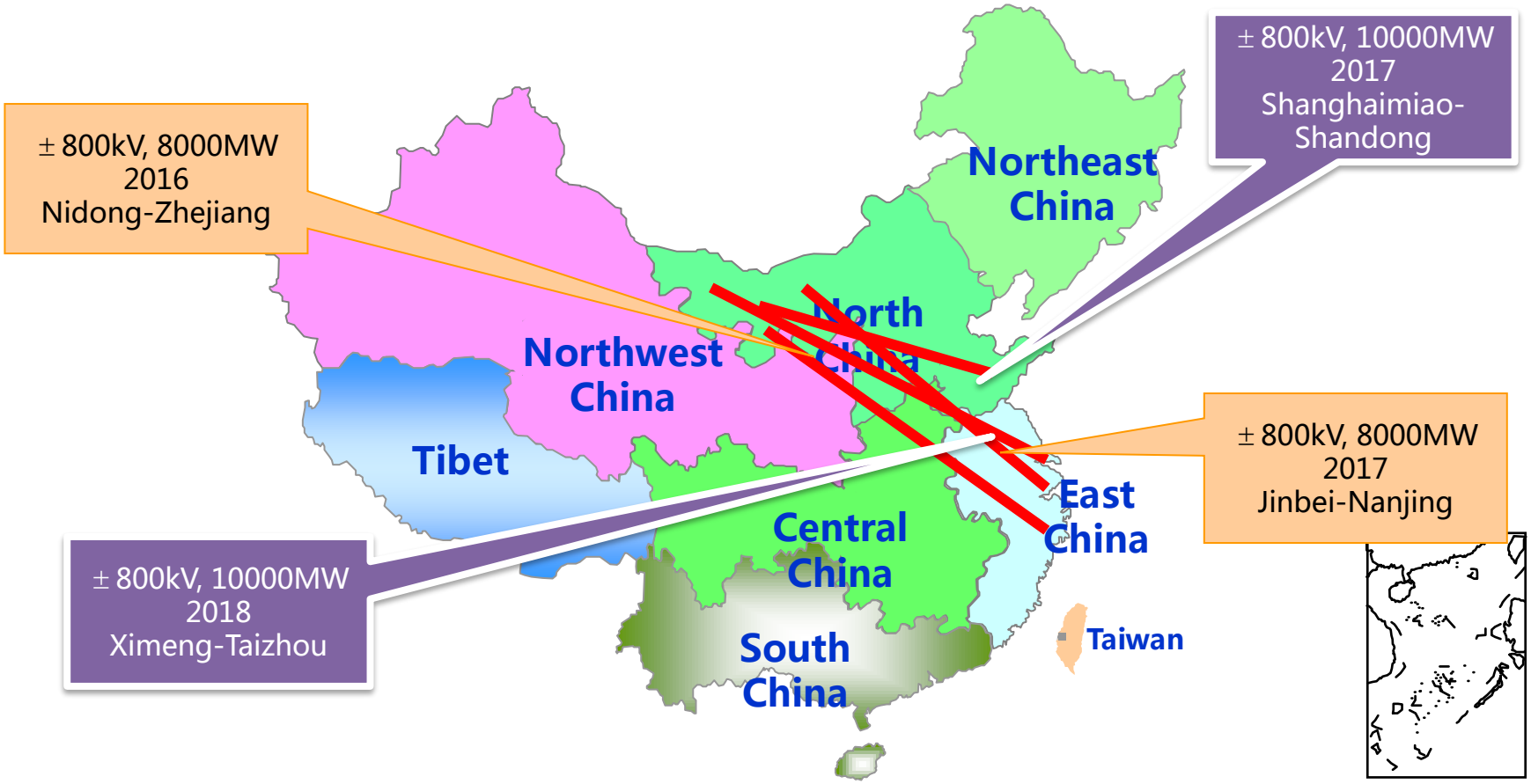
- 5 commissioned UHVDC transmission projects in China
- Realized large-scale long-distance power transmission from western renewable energy bases to eastern load centers

Project	Yun-Guang	Xiang-Shang	Jin-Su	Ha-Zheng	Xi-Zhe
Commissioning	2010	2010	2012	2013	2014
Rated capacity (MW)	5000	6200	7200	8000	8000
Rated voltage (kV)	±800	±800	±800	±800	±800
Rated current (A)	3000	4000	4500	5000	5000
Distance(km)	1373	1907	2100	2210	1722

UHVDC transmission projects in service

Ongoing UHVDC Projects

- 4 UHVDC transmission projects are being constructed in China, two of them reaching up to ±800kV/10,000MW



Ongoing ±800kV/6250A UHVDC Project

Shanghaimiao-Shandong Project

- The world's first ±800kV/10GW UHVDC project
- Commercial operation is scheduled at the end of 2017

Project route

- DC voltage: ±800kV
- DC current: 6250A
- Capacity: 10000MW
- Transmission distance: 1238km
- Execution period: 2015 to 2017

Ongoing ±1100kV UHVDC Project

Zhundong-Wannan Project

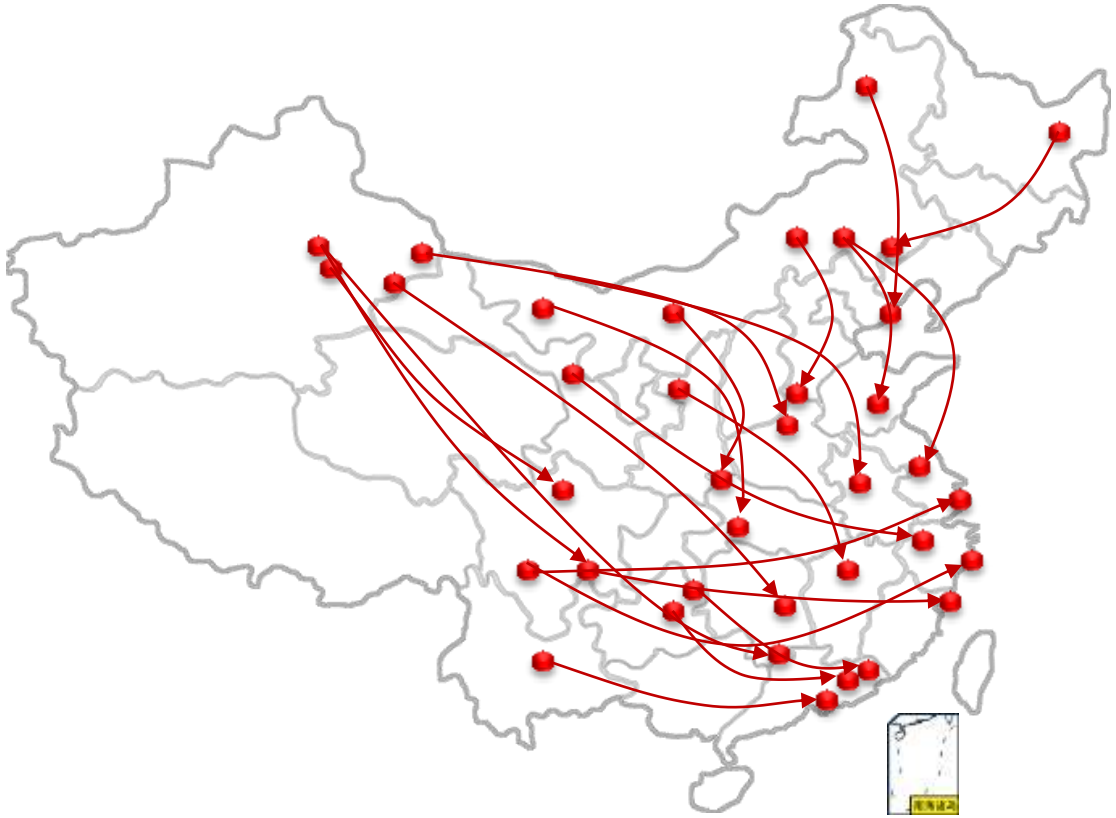
- The first ±1100 KV DC project in the world
- Transmission capacity reaching 12GW and over a distance of 3324 km
- Construction began in 2015 and to be commissioned in 2018

Project route

±1100kV UHVDC valve

Prospects

By 2020, China will build more than 20 HVDC projects, a wide range of power transmission and optimal allocation of resources will be implemented



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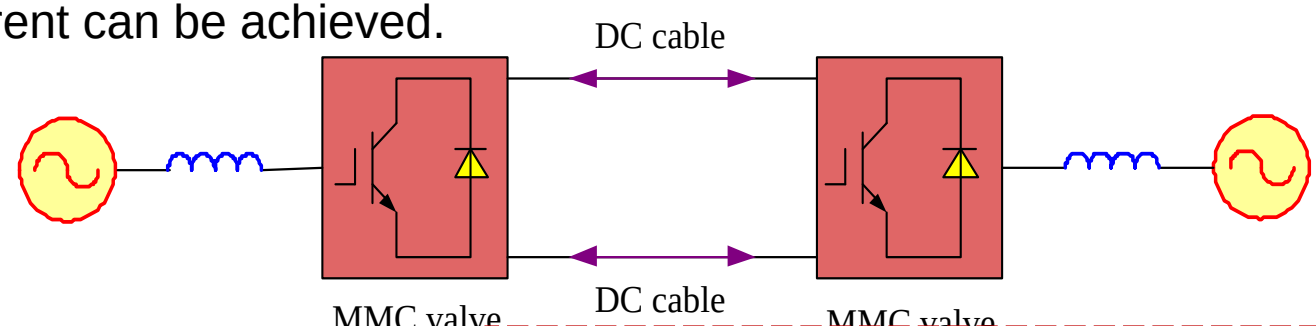
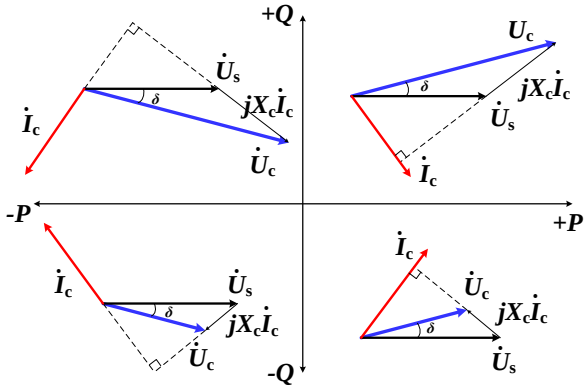
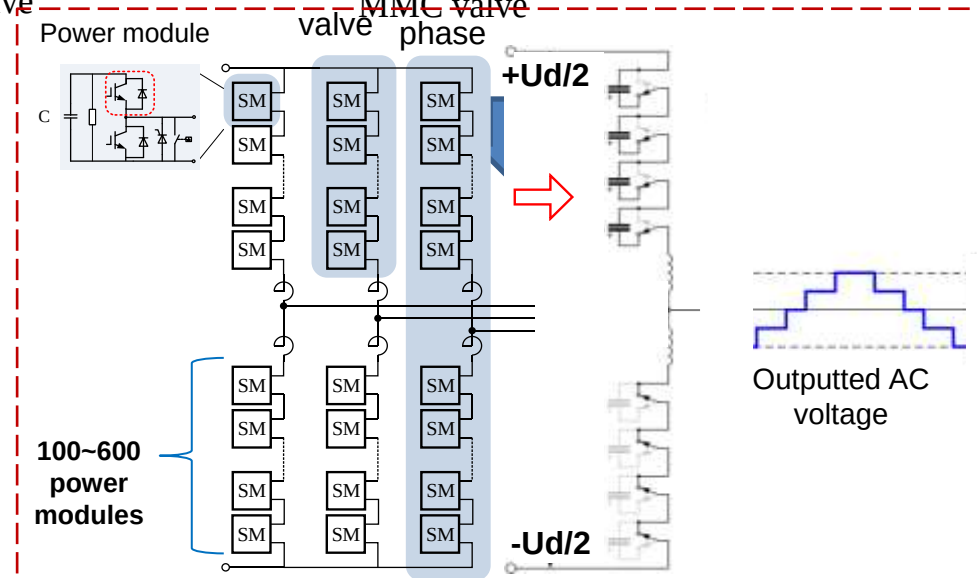
Modular multilevel converter based HVDC

- Voltage sourced converter based HVDC project adopted MMC as the primary topology, so called MMC-HVDC
- In MMC HVDC, by switching in/out a large amount of power modules, a desired sinusoidal waveform can be obtained in the AC side from the DC side voltage source. In this way, the purposes of power conversion and regulation of voltage and current can be achieved.



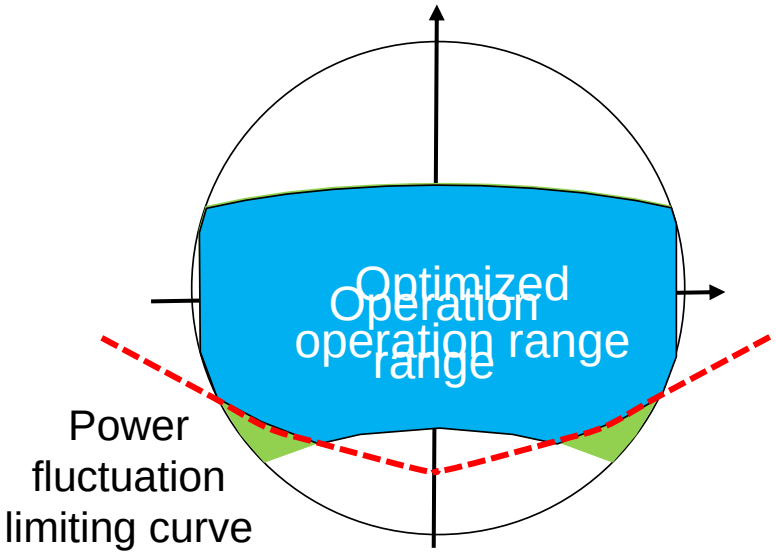


vectors of VSC outputting

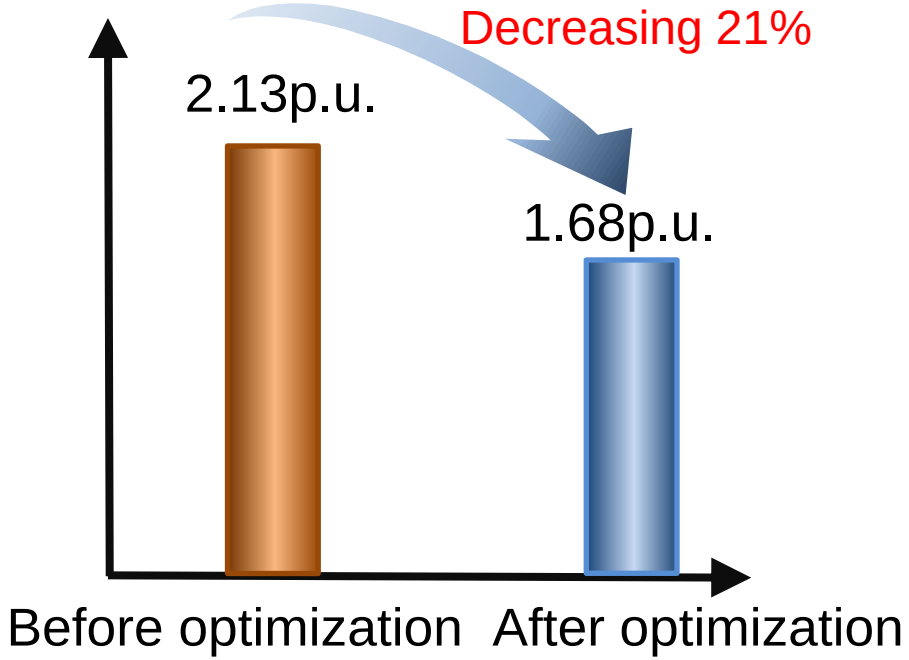


Power exchange mechanism between AC and DC

- Power exchange mechanism and energy coupling is important for MMC between the interconnected AC and DC system
- Precise dynamic performance describing method and system designing method of MMC



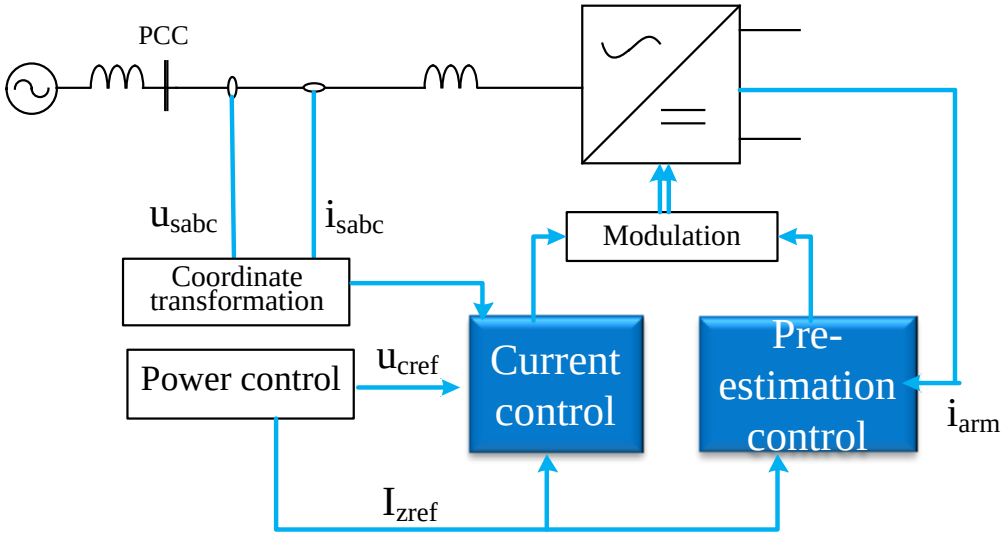
Designing of MMC operation range



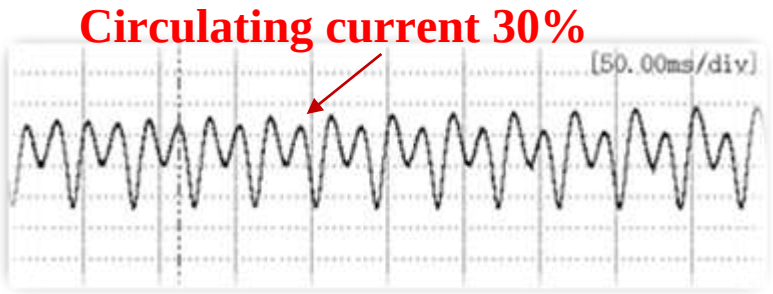
Over voltage and insulation level
（based on rated DC voltage）

Balancing control technologies of MMC

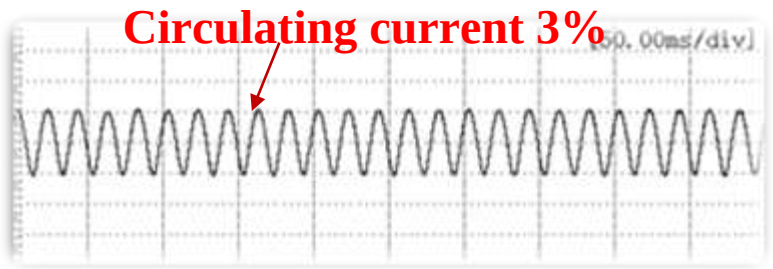
- The "reconstruction" of energy inside the converter has been carried out to realize the conversion between AC system and DC system by using the independent control of thousands of power modules
- The comprehensive dispatching technologies among power units, converter valve, AC system , DC system have been obtained.



Multi level current balancing control



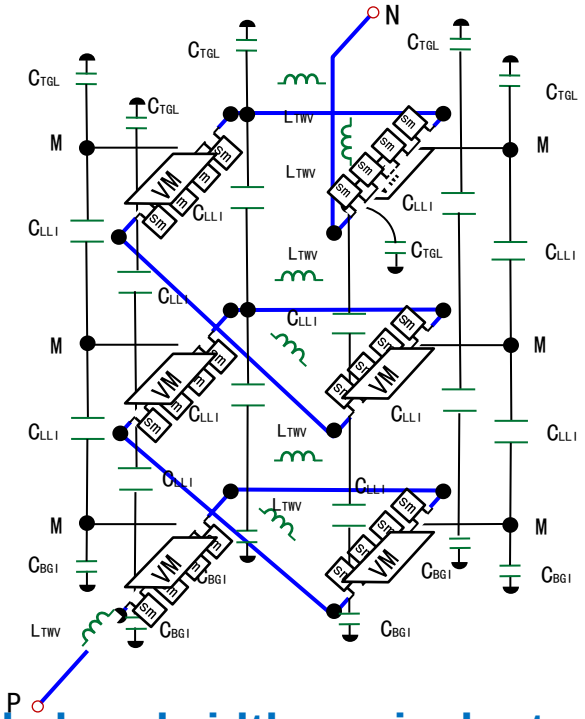
Without current balancing control



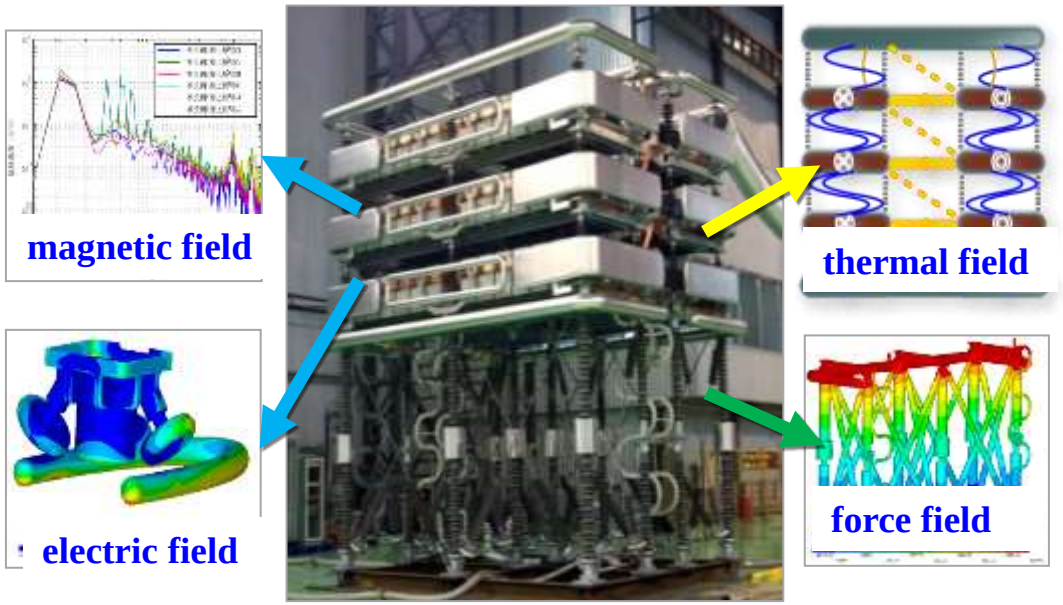
With current balancing control

Multi-field stresses balancing method of converter

- Wide bandwidth （ 50Hz~1MHz ） equivalent model has been established.
- The balancing state among the magnetic, thermal, electric, and force field of converter have been realized by studying the transmitting mechanism and the distribution of the electronic press of the converter.



Wide bandwidth equivalent model of converter



Multi-field balancing state of converter valve

Development of converter valve

- The power module of MMC has been developed.
- The converter valve of the MMC has been constructed with the advantages of high modularity, low power loss, and excellent voltage capacity expansion.

Power sub-module

±320kV/1000 MW converter valve

±200kV/400 MW converter valve

±30kV/20 MW converter valve

Valve hall of MMC-HVDC

Nanhui wind farm plant integration

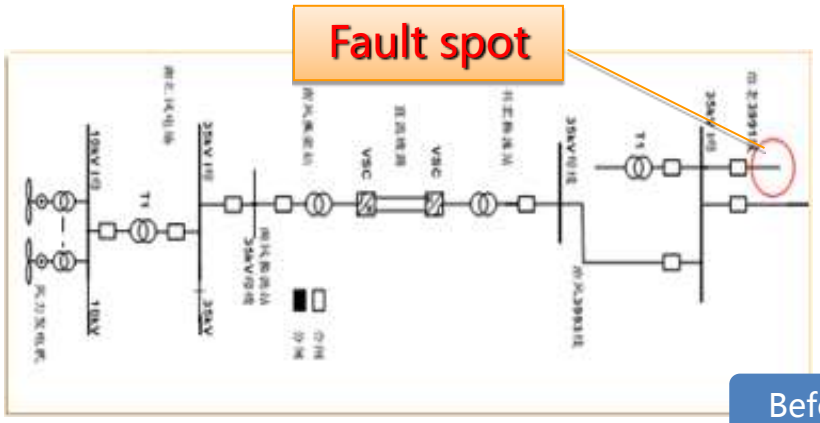
Target

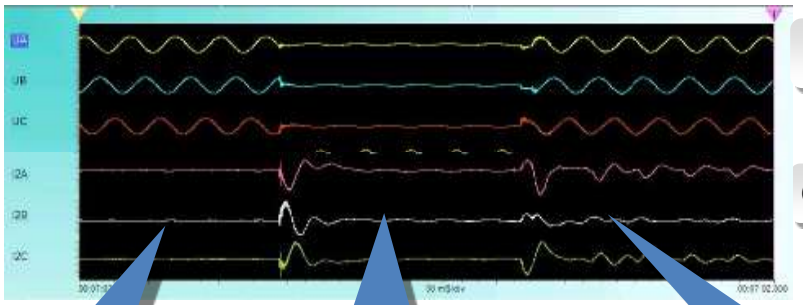
- Integrate wind power plant into power network
- Improve the wind farm fault ride-through capability

Overview

- The first VSC-HVDC project in China
- The trips of wind power plant had been reduced more than 54%

Commission	July, 2011
Rated capacity	20MW
AC voltage	35kV
DC voltage	±30kV
Converter Topology	MMC





Before fault

Low voltage

Fault recovery

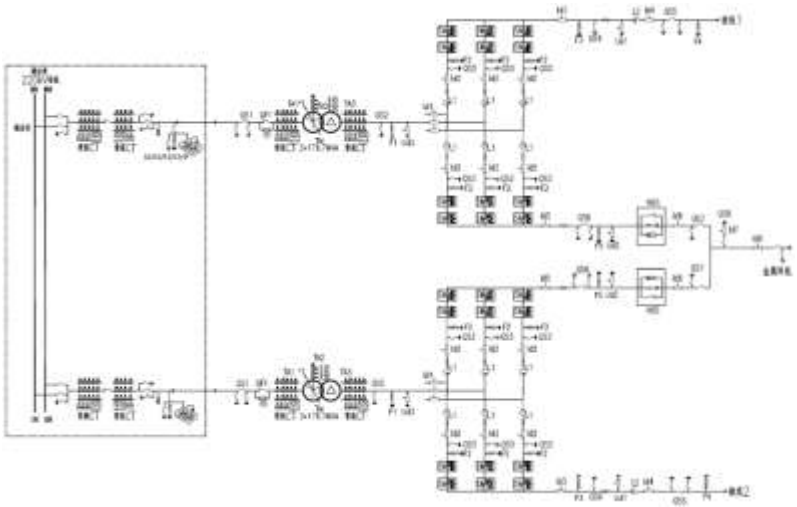
Xiamen island power supplying

Target

- To meet increasing power demand of Xiamen island
- Small station footprint
- Submarine cable
- High transmission capability

Overview

- Rated at ±320kV/1000MW, bipolar topology
- Put into commercial operation at the end of 2015



bipolar topology of converter station

Commission	Dec, 2015
Rated capacity	1000MW
AC voltage	220kV
DC voltage	±320kV
Converter Topology	MMC

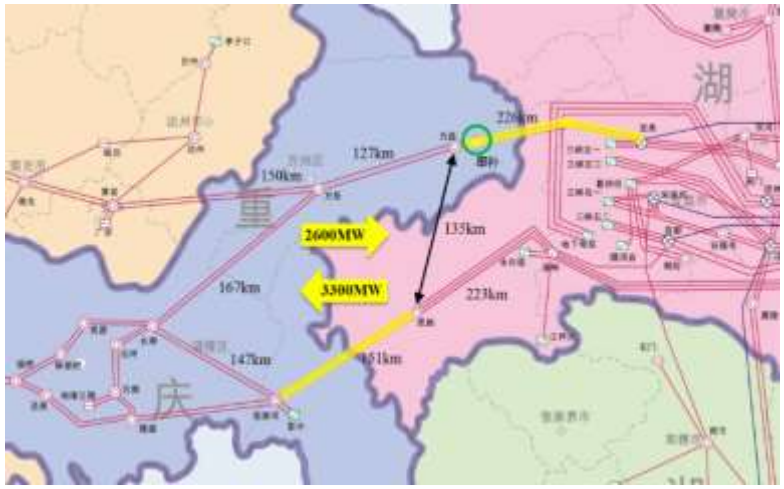
Yu’e back-to-back power grid interconnection

Target

- Asynchronous AC power system interconnection
- Improve stability of the weak power network

Overview

- Yu’e project consists of 4 back-to-back system, one of them is rated with ±420kV/1250MW.
- It is scheduled to commission at the end of 2017.



Yu’e btb interconnection

Commission	2017
Rated capacity	1250MW
AC voltage	500kV
DC voltage	±420kV
Converter Topology	MMC

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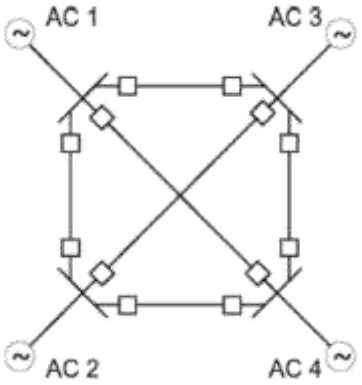
MTDC and DC Grid

- DC grid is a DC transmission and distribution system composed by multiple converters, transmission lines, DC circuit breakers, transformers and so on.
- DC grid can be used for large-scale renewable energy integration, cities and island power supply, distribution network construction, etc.

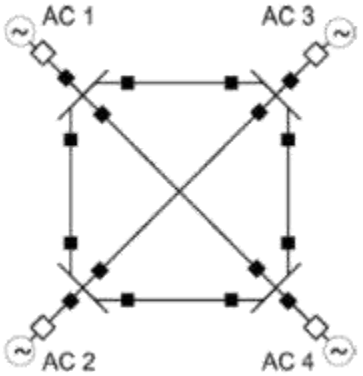
MTDC



vs.

□ : converter
■ : DC circuit breaker

DC grid



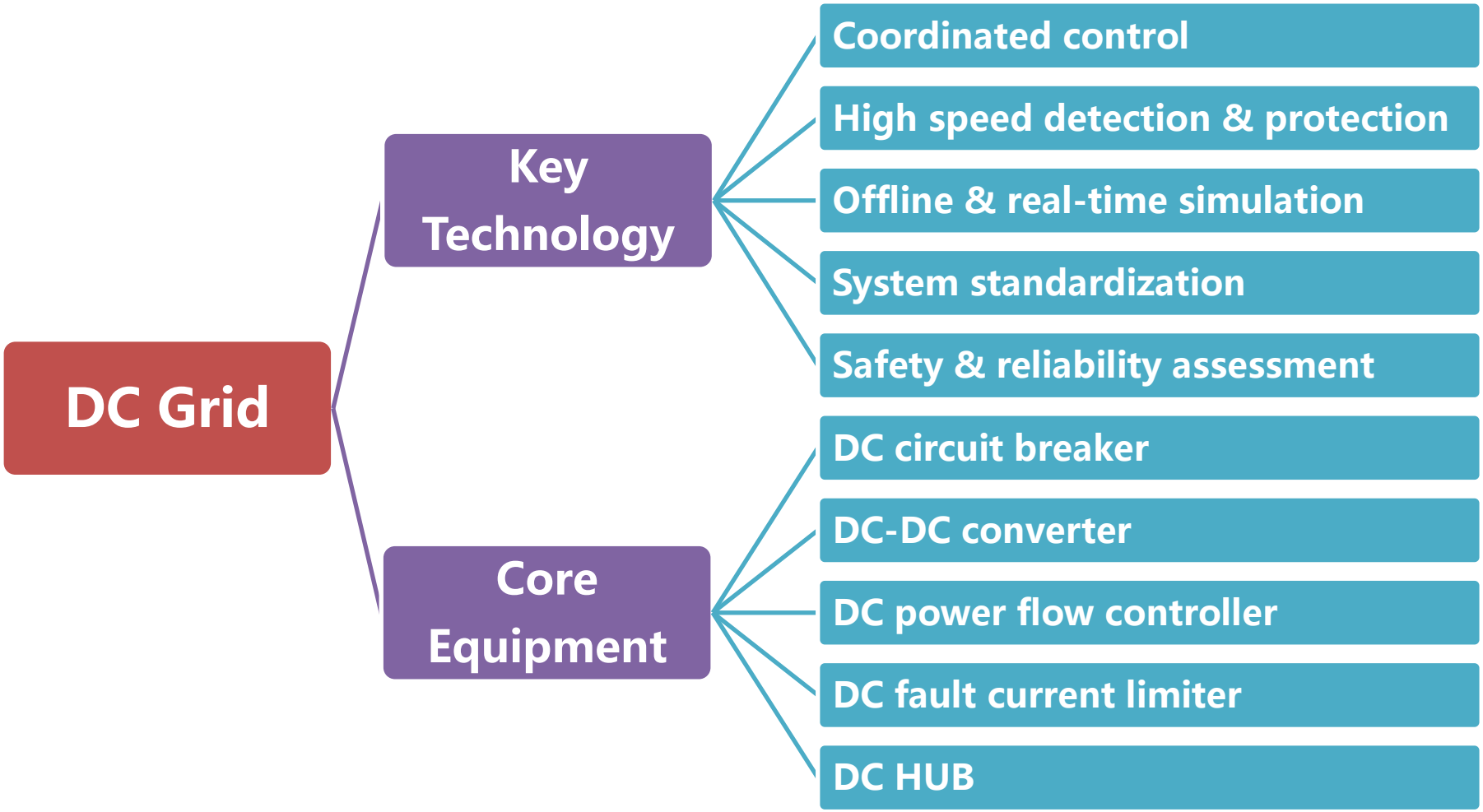
Multi-terminal DC (MTDC)：

- ☼ Relying on converters for DC connections, i.e. meshes at AC sides not DC sides
- ☼ It is not a real "DC grid"
- ☼ Large amount of converters → costly
- ☼ No need of DC breakers

DC Grid：

- ☼ Multi-DC lines from each DC busbar
- ☼ DC connections via DC lines
- ☼ Real "DC meshes" → real DC grid
- ☼ Requiring DC breakers to clear DC faults

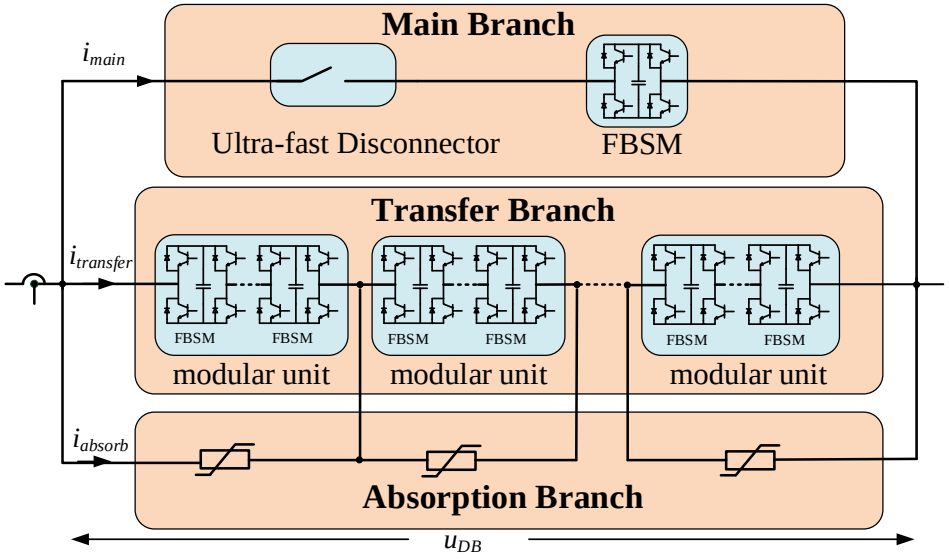
DC Grid Technology and Equipment



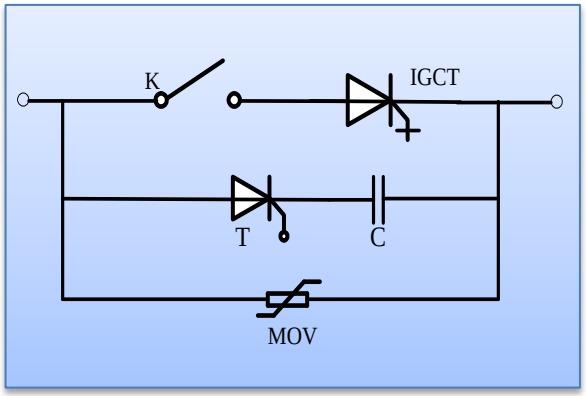
DC Breaker

- The breaking time of the DC breaker (DCB) used in DC grid should be less than several ms, and the breaking current should be more than 10kA, and it also should have the function of bidirectional breaking and re-closing.

- Considering the aspects of breaking ability, hybrid structure is recommended.



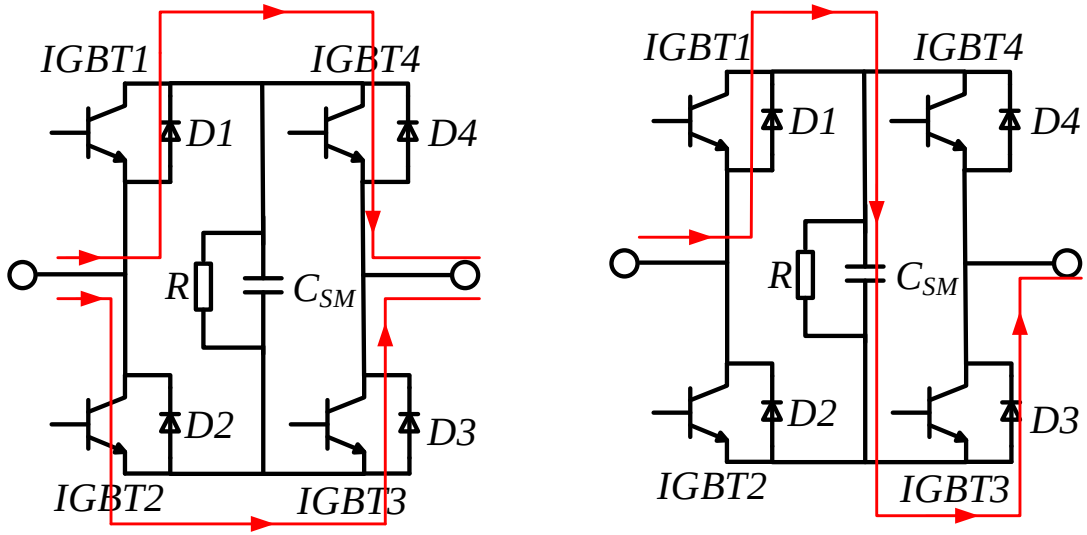
Full controllable hybrid topology



Half controllable hybrid topology

DC Breaker

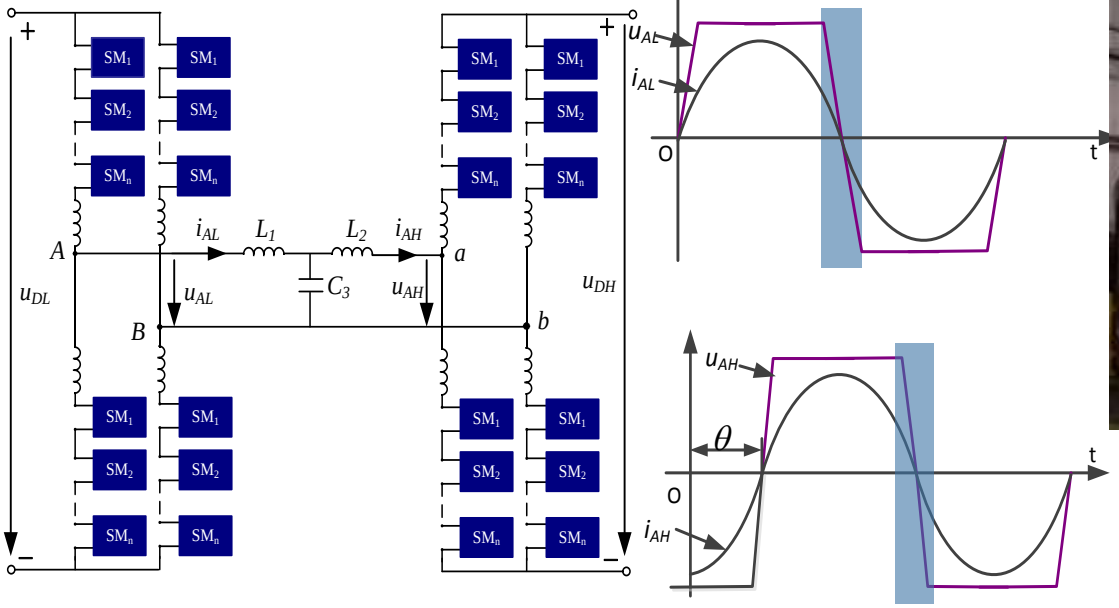
- The FBSM of Full controllable hybrid DCB has two operating states, provides a bidirectional current path and double the current breaking capability compared to one IGBT
- The capacitor ensures soft turn-off and reduces IGBT voltage stresses
- A counter-voltage across the IGBT is established



The operating states of FBSM

DC/DC Converters

- LCL resonance type MMC based DC/DC converter realizes the zero output of reactive power for two sides of MMC, and realizes approximate zero current switch for two sides of MMC
- Develop the 3MW 10kV/20kV LCL resonance type DC/DC converter prototype



LCL-M2DC converter

Zero current switch

DC/DC converter prototype

Zhoushan Multi-terminal DC Project

Target

- Integration of offshore wind farm
- Reliable power supply to Zhoushan islands

Overview

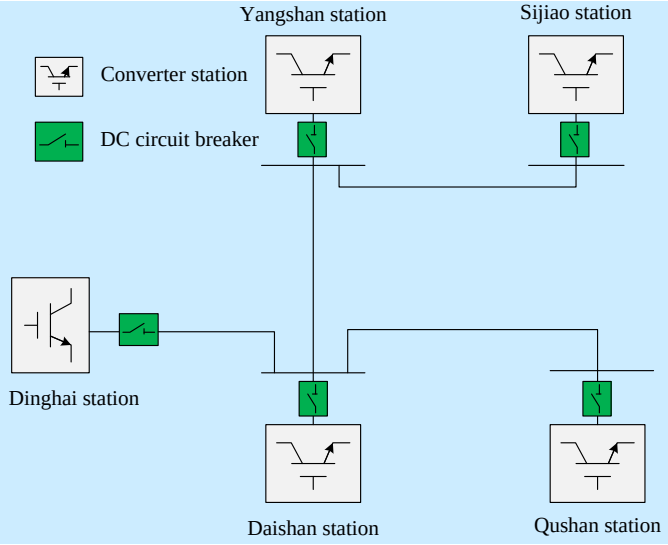
- The largest converter station has a capacity of 400MW and the DC voltage is ±200kV
- It is commissioned on July 2014.

Commission	July, 2014
Rated capacity	400/200/100/100/100MW
AC voltage	220kV
DC voltage	±200kV
Converter Topology	MMC

Zhoushan Multi-terminal DC Project

DC breaker application in Zhoushan project

- 200kV hybrid DC breaker is applying in ZhouShan five-terminal project
- It would increase the reliability by fast dc-line fault isolation and achieve converter station “hot plug-in or plug-out”
- It is scheduled to put into operation at the end of 2016



ZhouShan demonstration

200kV DC Breaker (15kA/3ms)

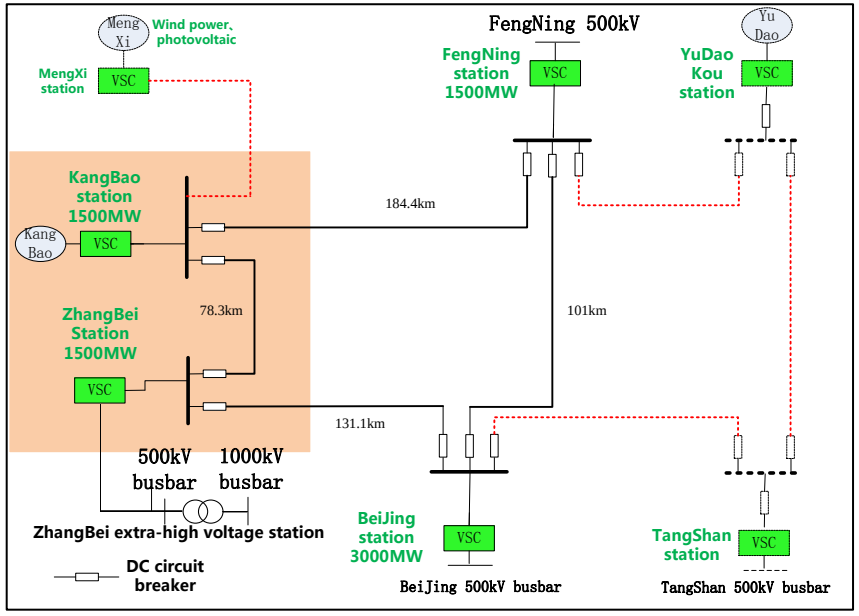
The Zhangbei DC Grid Project

Target

- Develop power fluctuations suppressed strategy to cope with the case when 100% renewable energy integration into the distribution and transmission networks

Overview

- 4-terminal DC power grid based on overhead line
- Rated DC voltage is ±500kV



Topology of ZhangBei 4-terminal DC grid

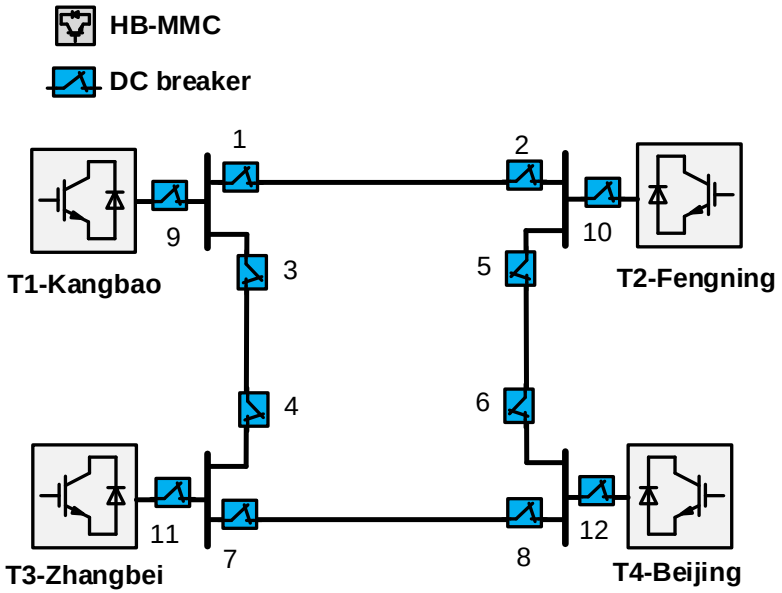
	BeiJing	ZhangBei	KangBao	FengNing
Rated Voltage(kV)	±500	±500	±500	±500
Rated Power(MW)	3000	3000	1500	1500
Rated DC current (A)	3000	3000	1500	1500
Phase current (A)	2100	2100	1050	1050

System parameters of ZhangBei project

The Zhangbei DC Grid Project

System scheme for Zhangbei project

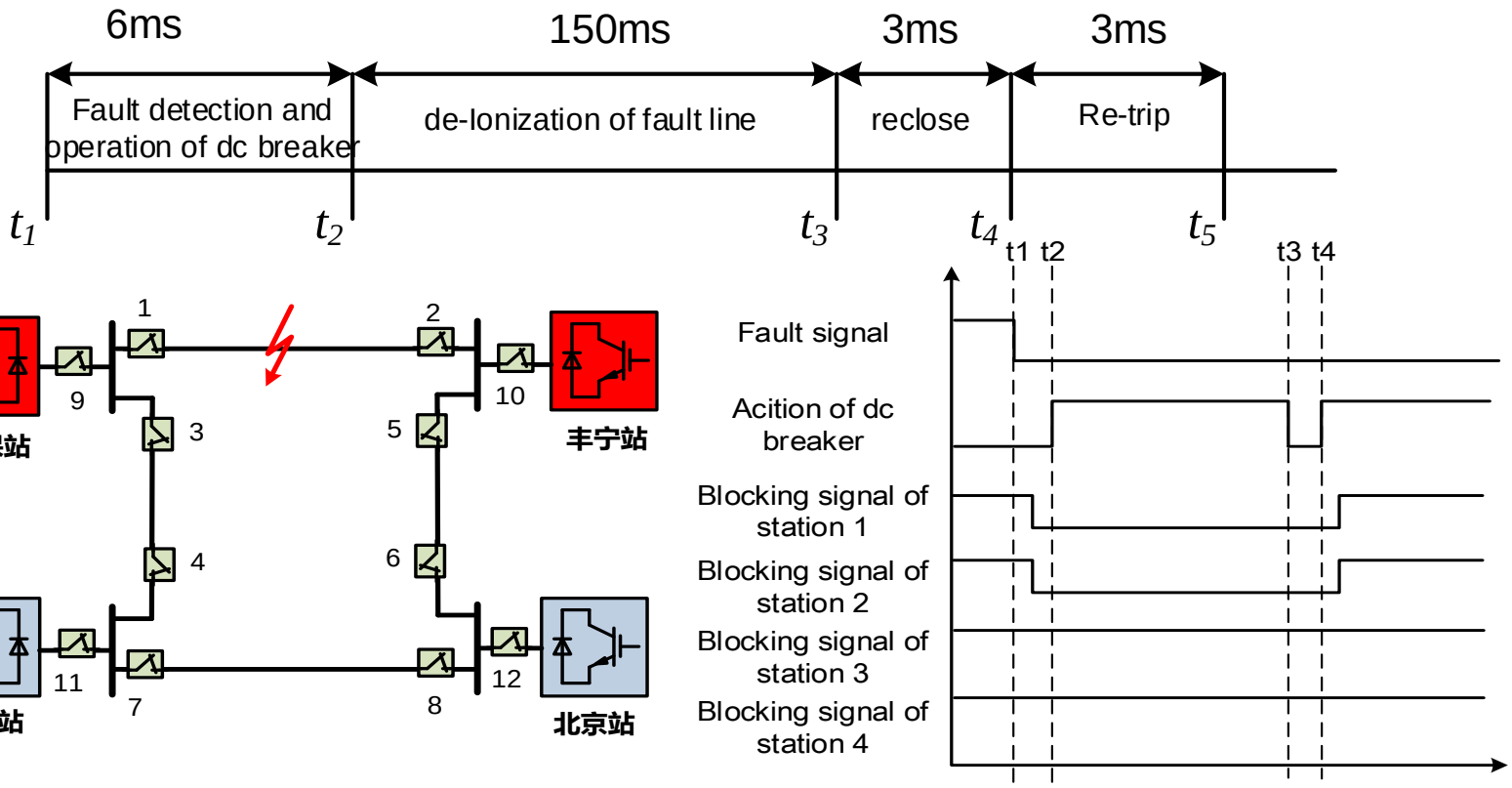
- The project adopts “Half Bridge MMC + DC Breaker” scheme
- Scheme achieves fault isolation and system recovery by DC breakers
- System recovery need to consider the re-closure because of the use of overhead line



Half Bridge MMC + DC Breaker Configuration

The Zhangbei DC Grid Project

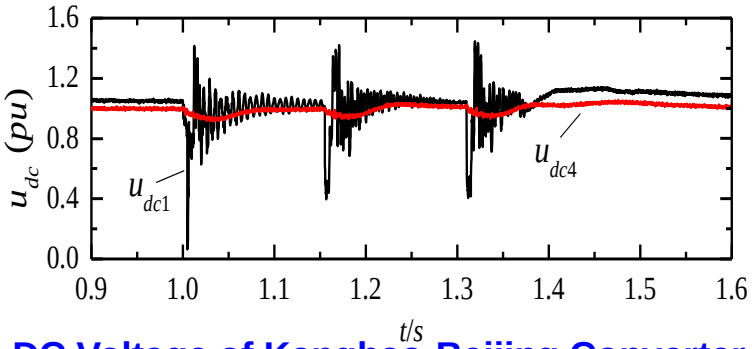
- Since the present DC breaker and DC fault detection technologies still cannot fulfill the requirement of no converter blocking, scheme allows the converters close to the fault to block, but the DC Grid should not stop operation.
- According to the study result, it is necessary to cut off the fault within 6 milliseconds.



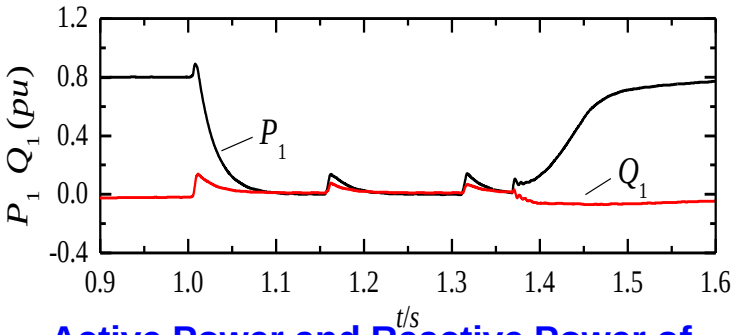
The Zhangbei DC Grid Project

Simulation Result of permanent fault on Kangbao-Fengning line

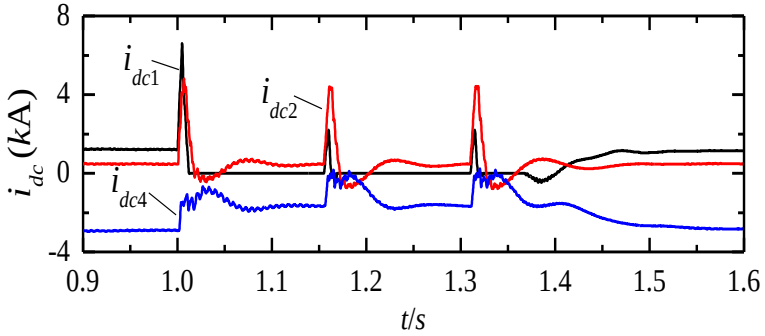
- Converter Stations far from the fault maintain the voltage of DC Grid, and guarantee the continuous running of DC Grid.
- The blocked converter station could de-block and recover to normal operation if the fault is cleared.



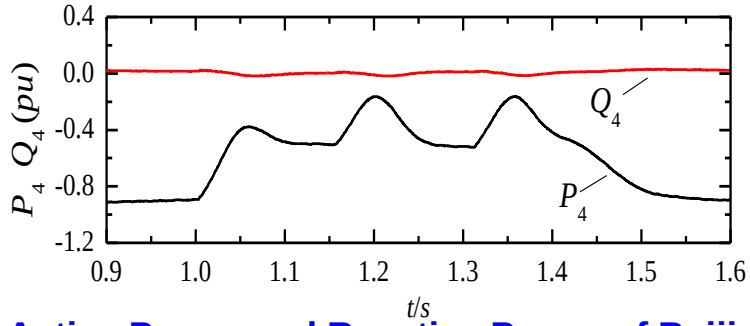
DC Voltage of Kangbao-Beijing Converter Station



Active Power and Reactive Power of Kangbao Converter Station



DC Current of the Converter Station



Active Power and Reactive Power of Beijing Converter Station

Conclusion

- High power electronics conversion technology is the important solution to large-scale energy transmission and connection
- In the future, LCC-HVDC technology will develop toward ultra high voltage. It is expected that the capacity will exceed 10 GW and solve the issue of mega-power transmission with distance over 2000 km.
- VSC-HVDC technology with its flexibility for solving a high proportion of renewable
- DC grid constituted by VSC-HVDC, is very forward-looking technologies, it will play an important role in supporting energy structure change all over the world

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GLOBAL ENERGY INTERCONNECTION RESEARCH INSTITUTE

Thanks for your attention !

Dr. Guangfu Tang

E-mail: gftang@geiri.sgcc.com.cn