IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition),
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The Prospect of Carbon-Neutrality-Driven Energy & Power and the Possible Application of Superconductor

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Contain

1 Future Energy Structure of China

- China: Carbon Neutrality by 2060;
- To reach this target, >80% of energy consumption would come from renewable & nuclear energy, and electricity would take more than 80% of the total end energy consumption.
- Total CO2 emission would be reduced to 2.5~3.0 billion tons from 13.0 billion tons in 2030.

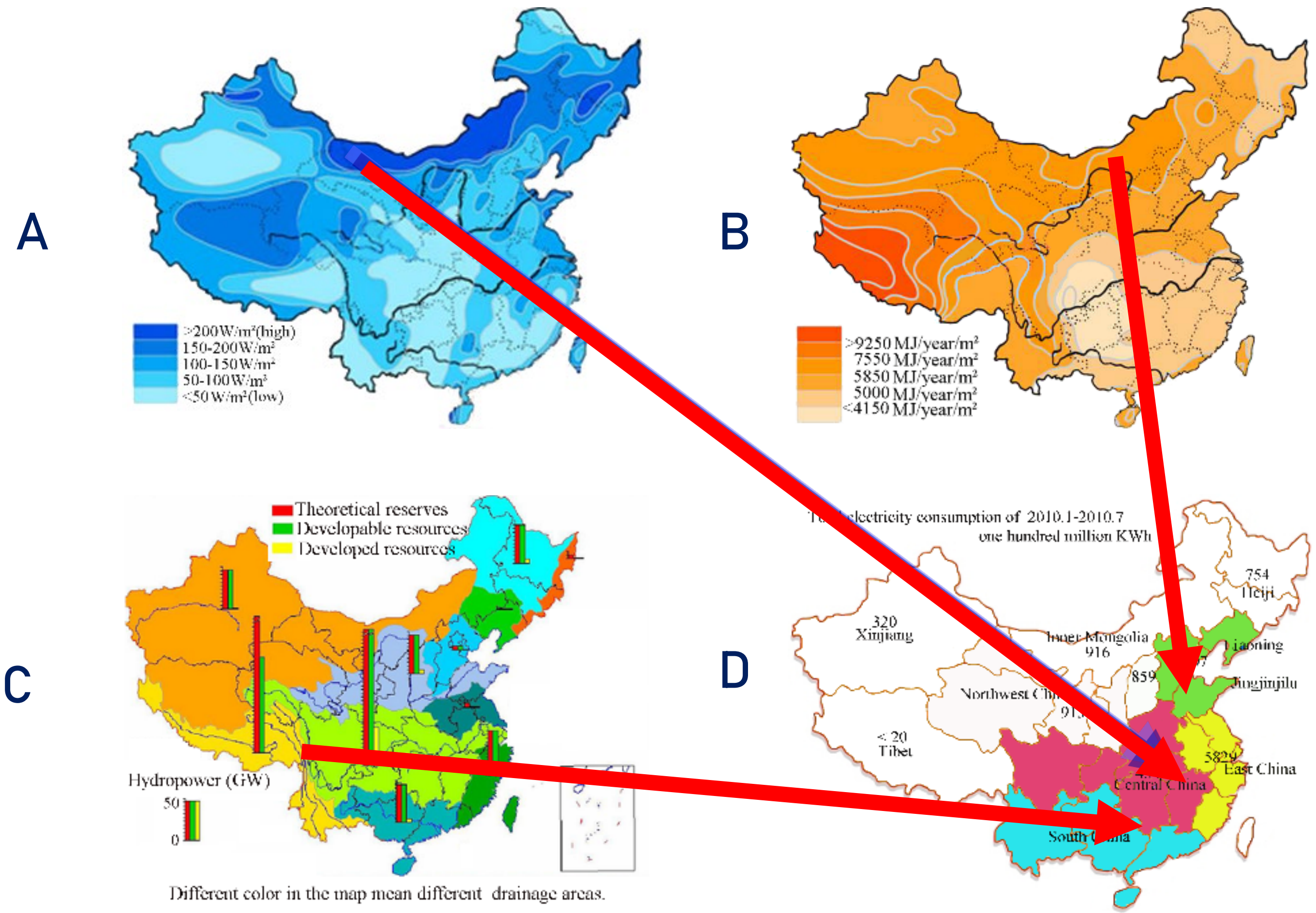
Table 1 Forecast for China's CO2 Emission in 2060

Total CO2 Emission in 2060 (Billion Tons)	For Thermal Power from Gas & Coal (Billion Tons)	For Industry & Building Materials (Billion Tons)	For other Use (Billion Tons)
2.5~3.0	<1.5	<1.0	<0.5

Table 2 Forecast for China's installed power capacity and electricity in 2060

Source of Electricity	Capacity /100GW	Percentage (%)	Electricity Contribution (T-kWh)	Percentage of EC
Thermal Power (gas & coal)	20.0	17.85	3.6	16.36
Hydro Power	6.0	5.35	2.0	9.10
Nuclear Power	2.0	1.785	1.6	7.27
Biomass/Garbage	2.0	1.785	1.0	4.54
Solar Thermal	2.0	1.785	1.0	4.54
Wind Power	16.0	14.285	3.2	14.55
PV Solar Cell	64.0	57.142	9.6	43.64
Total	112.0	100.0	22.0	100.0

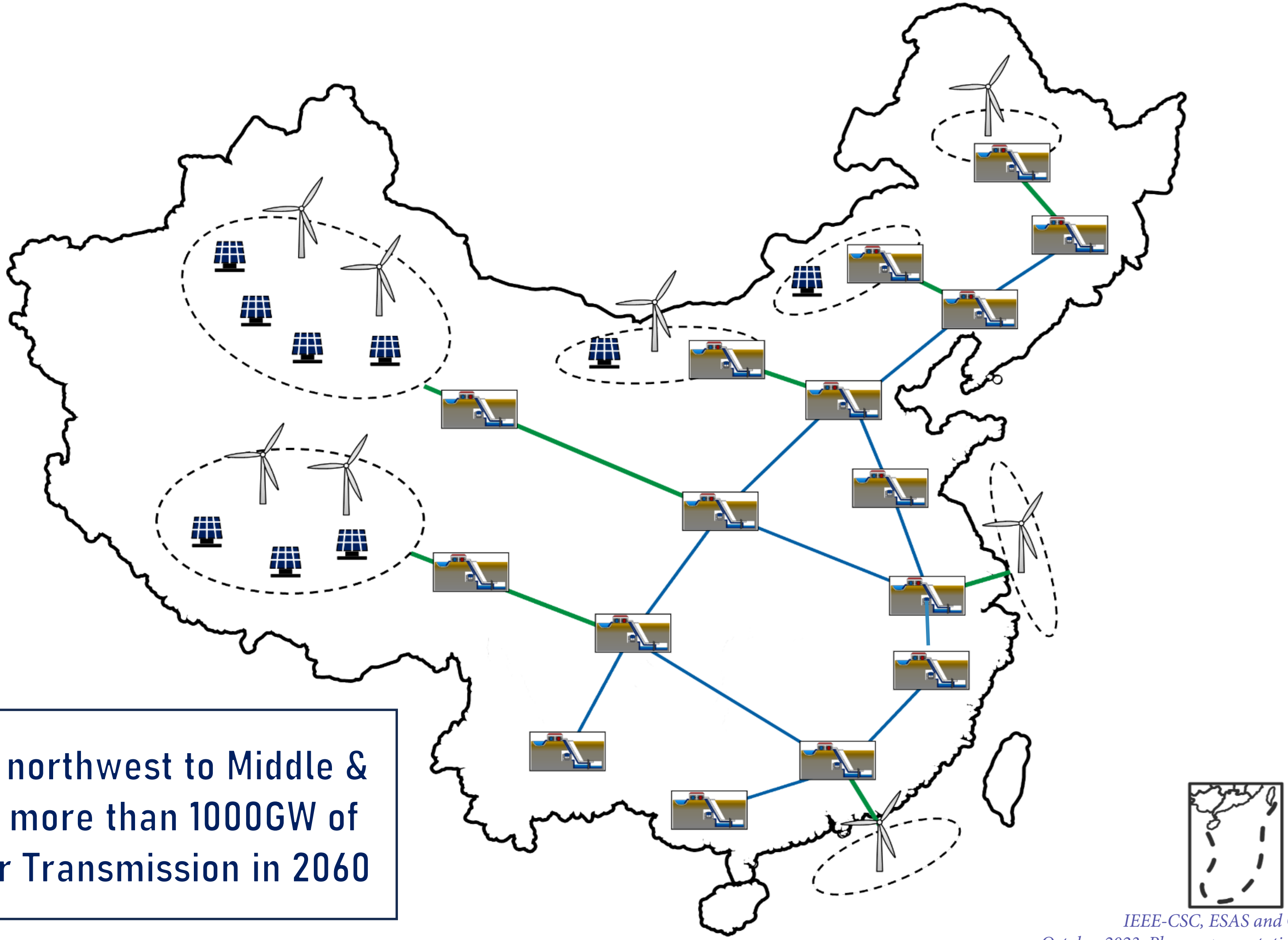
The RE centers are far from Load Centers of China



A-Wind Power, B-Solar Energy, C-Hydropower, D-Load center

2 Challenges for Future Power Grid in China

1) Large amount of electricity/Energy transportation over long distance, and there would be not enough land for overhead power transmission lines.



From northwest to Middle & East, more than 1000GW of Power Transmission in 2060

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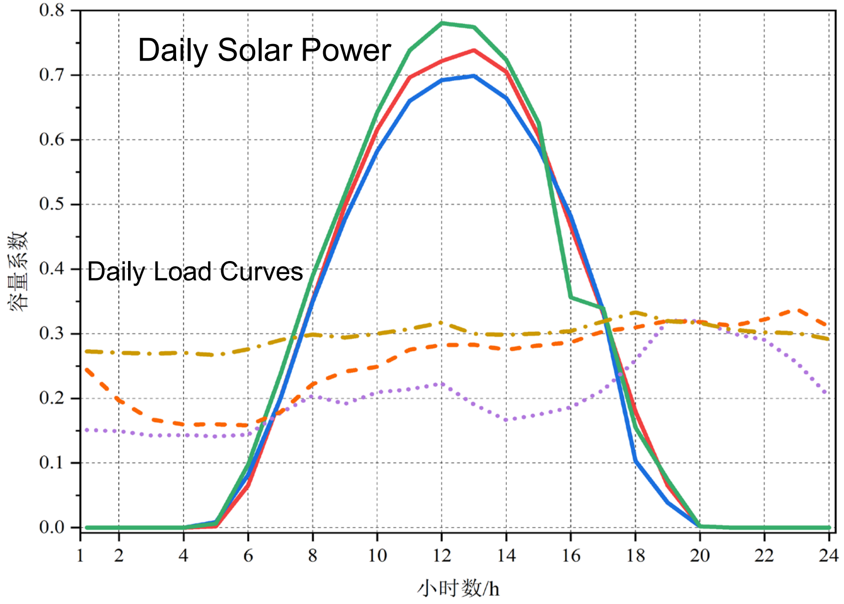
2 Challenges for Future Power Grid in China

2.1) RE——intermittent, volatile, non-schedulable， leading to difficulty in balancing the power & electricity real-timely, hourly, daily, weekly, monthly and seasonally;

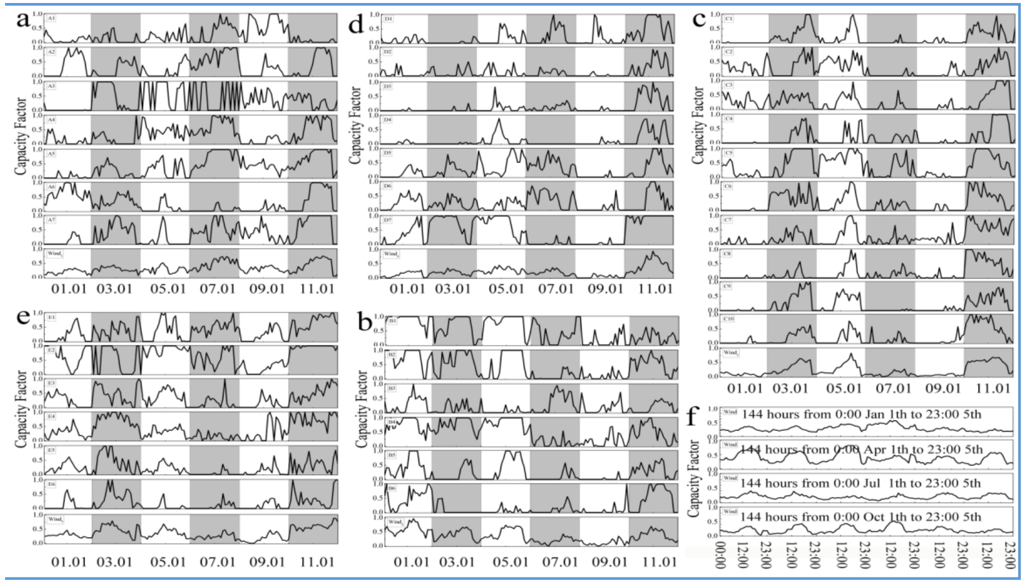
2.2) the significant reduction in synchronous generators leads to a serious shortage of system inertia;

2.3) and thus leading to transient instability of the power system such voltage instability and frequency instability;

Solar Power vs Load Curve



Wind Power Fluctuation Curve



2 Challenges for Future Power Grid in China

3) VSC-HVDC power grid would be a good solution for the transmission of large amount of RE, but it is difficult to deal with the short-circuit fault of VSC-HVDC power grid, because it is required to switch off the fault line without zero-point quickly (within few mill-seconds).

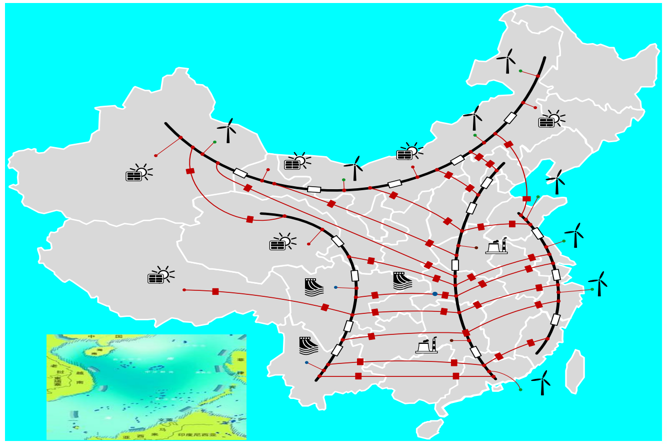
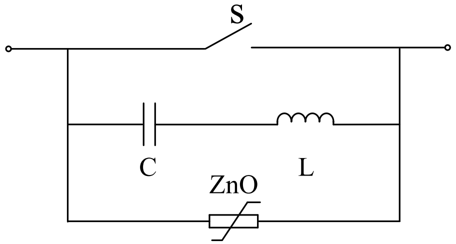


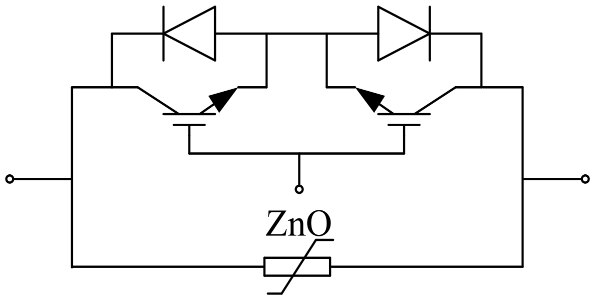
Figure 9: Concept of a "EUMENA Supergrid" based on HVDC power transmission as "Electricity Highways" to complement the conventional AC electricity grid, as developed by TREC in 2003. The symbols for power sources and lines are only sketching typical locations.

VSC-HVDC Power Grid Concept for China & Europe

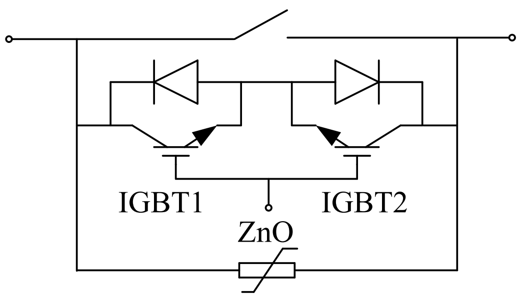
DC Breakers



Mechanical



Solid-State

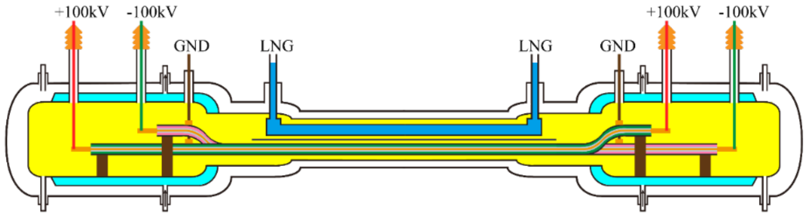


Hybrid

3 Possible solutions from superconductor

1) HVDC power cable or energy pipeline

—high power transmission capacity
—lower losses
—land save

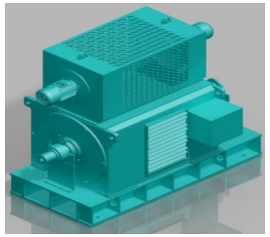


2) SMES

—fast response to requirement
—high power
—output of active and reactive power simultaneously
—Could be used as virtual inertia

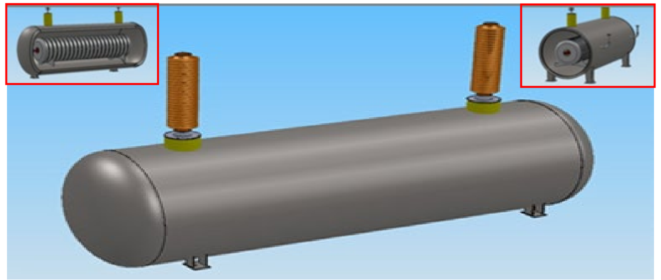
3) Superconducting condenser

—fast compensation of reactive power, especially for wind power farm
—support of Synchronous inertia



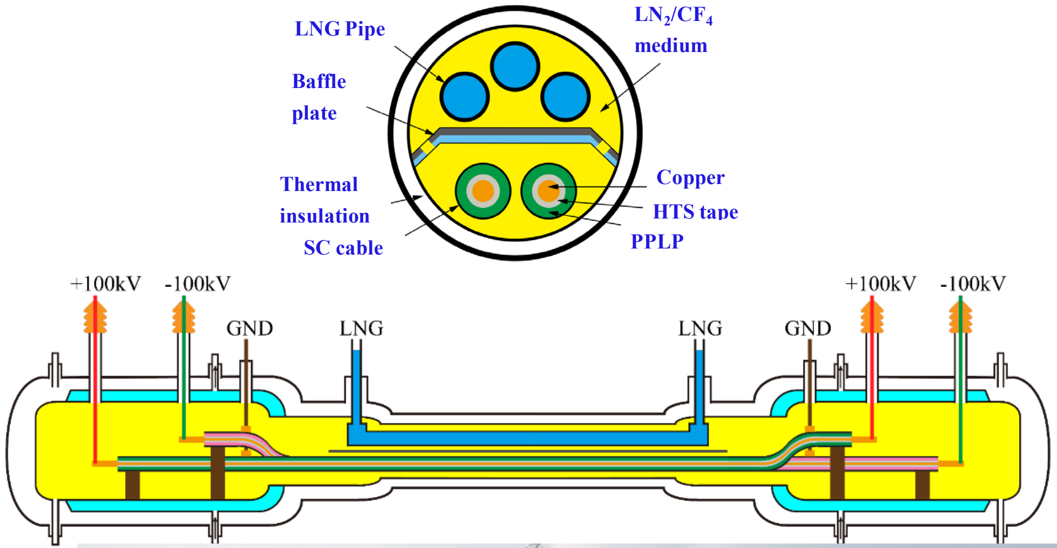
4) DC Fault Current Limiter

—fast response (within 1 ms)
—Design of fast recovery to fit the O-C-O



4 Recent Progress in China—DC Cable & Energy Pipeline

- ±100 kV/1kA superconducting energy pipeline for electricity/LNG transmission in 2021, by IEE and CEPRI



Parameter	Designed value
Operating temperature	85-90K
Operating voltage	±100kV
Operating current	≥1kA@90K
Length of energy pipeline	30m
Transportation rate of liquid fuel	100L/min
Losses	<3W/m

30m, ±100 kV/1 kA Superconducting Energy Pipeline tested at Langfang

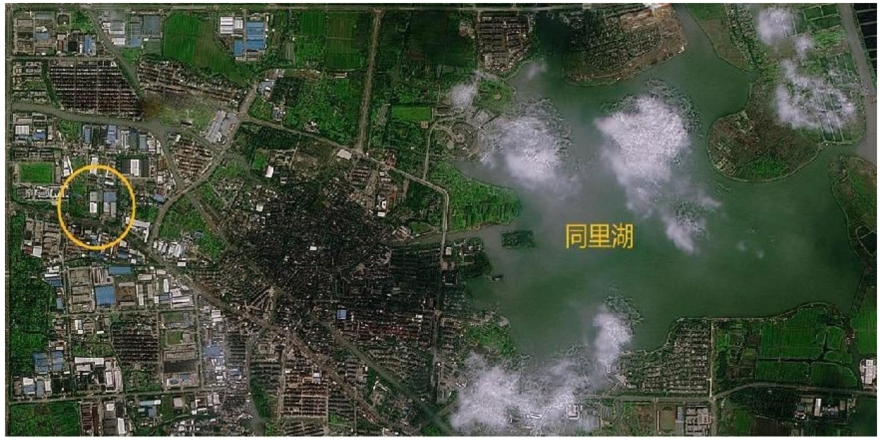
4 Test Results of Energy Pipeline

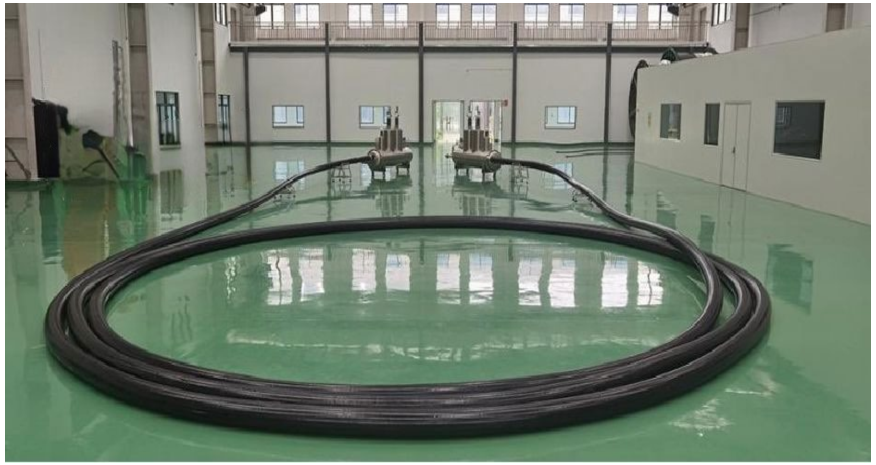
- ±100 kV/1kA superconducting energy pipeline for electricity/LNG transmission in 2021, by IEE and CEPRI

Test results during 24h full power tests.

Recent Progress in China

- Jiangsu Electric Power Corporation and Yongding Group Co., Ltd. developed and tested a 100m, ±375V/4500A DC superconducting cable in 2022, which will be demonstrated in Tongli town, Suzhou City.





100m, ± 375V/4500 A DC Superconducting Cable

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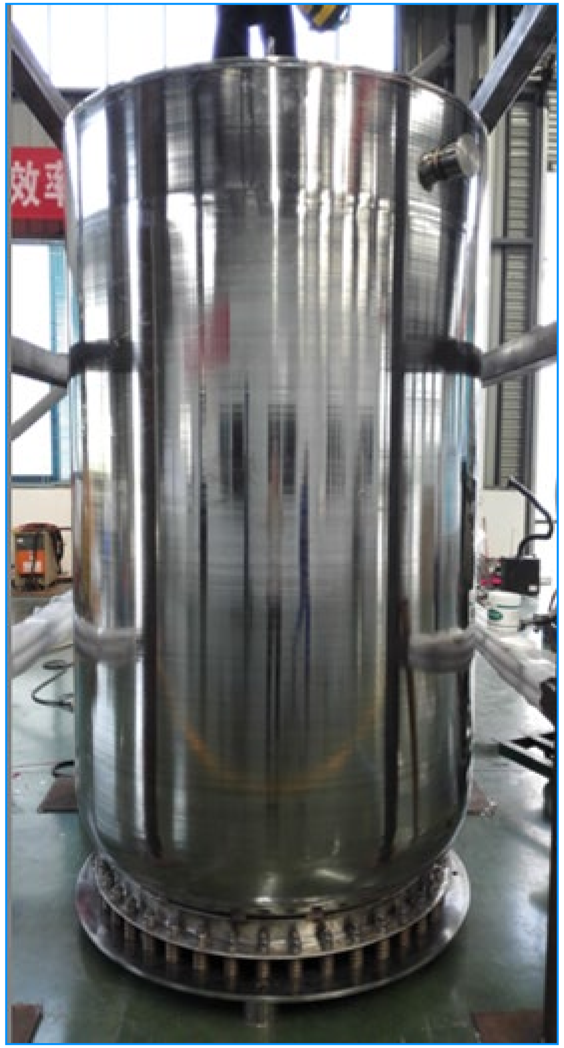
4 Recent Progress in China—SMES

□ 1MJ/1MVA HTS SMES/FCL tested at wind farm, by IEE and Xi'An Electric

Major parameter:
(1)Power rating :1MVA
(2)Energy storage capability: 1MJ
(3)Operational voltage level: 10kV
(4)Fault current limiting rate:≥ 50%
(5)Fault current endurance time:≥100ms
(6)Response time: ≤2ms
(7)Total harmonic distortion:≤5%
(8)Superconducting coil operated at 27K


Superconducting coil

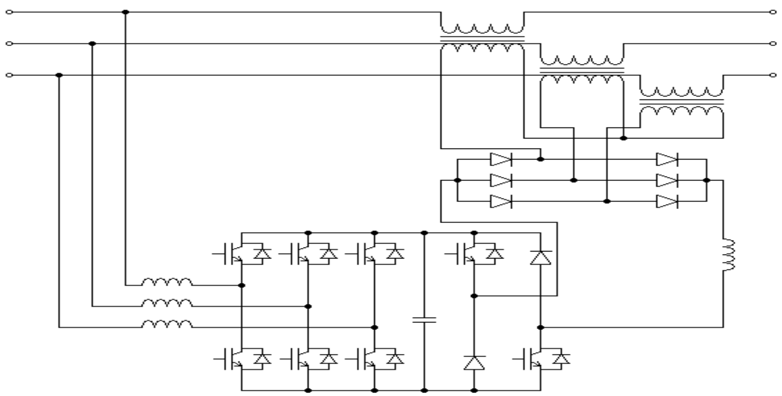



Power conditioning system

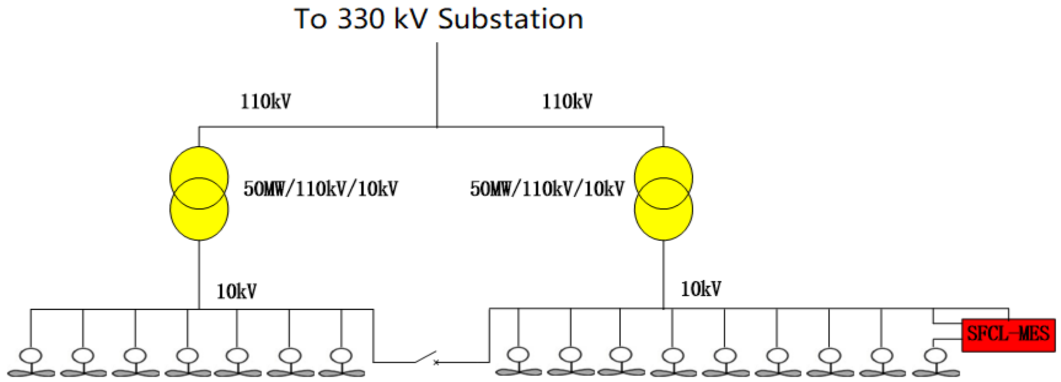
4 Recent Progress in China

- 1MJ/1MVA HTS SMES/FCL tested at wind farm, by IEE and Xi'An Electric

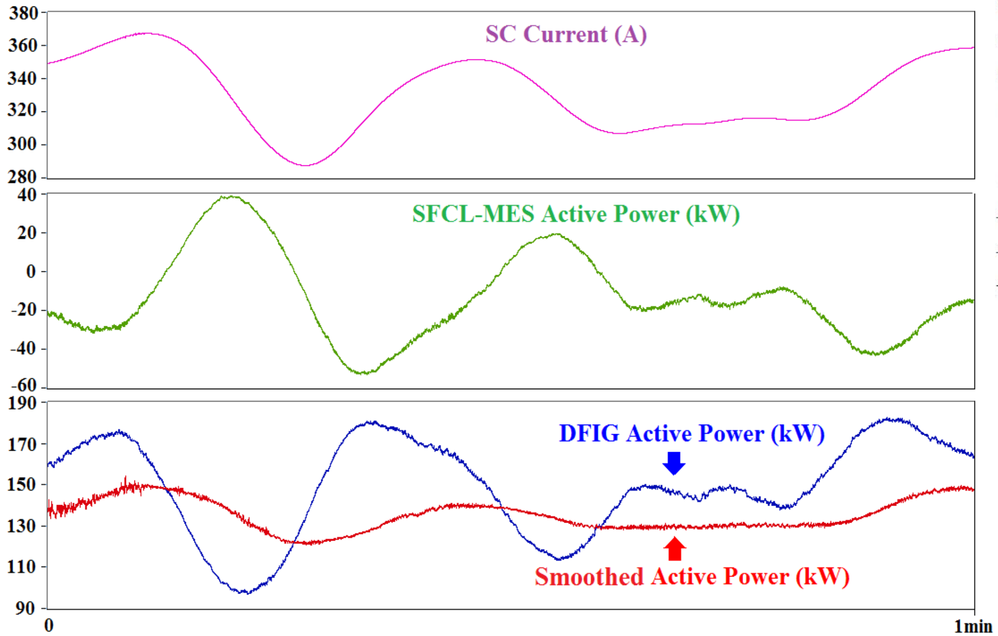
Test results of 1MJ/1MVA SMES/FCL at wind power



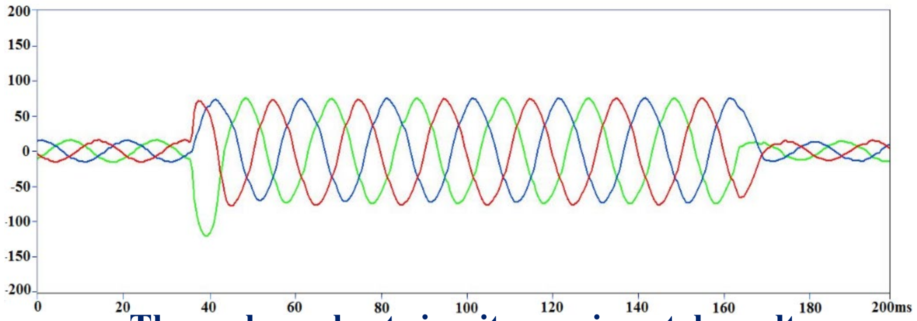
The Schematic diagram of topology of SMES/FCL



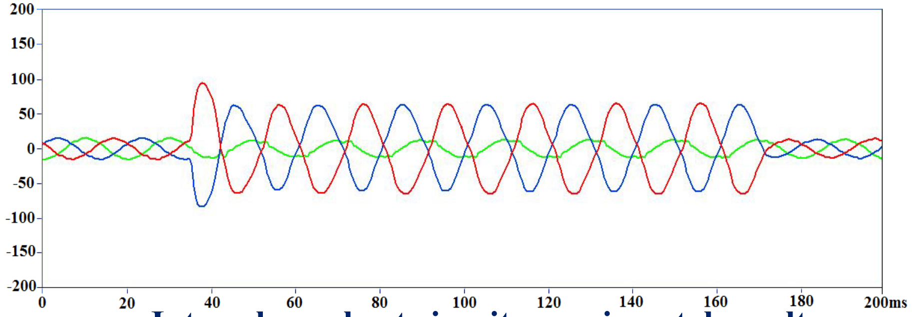
Grid Connection of SMES/FCL in the wind farm



Power smoothing field test results



Three phase short circuit experimental result

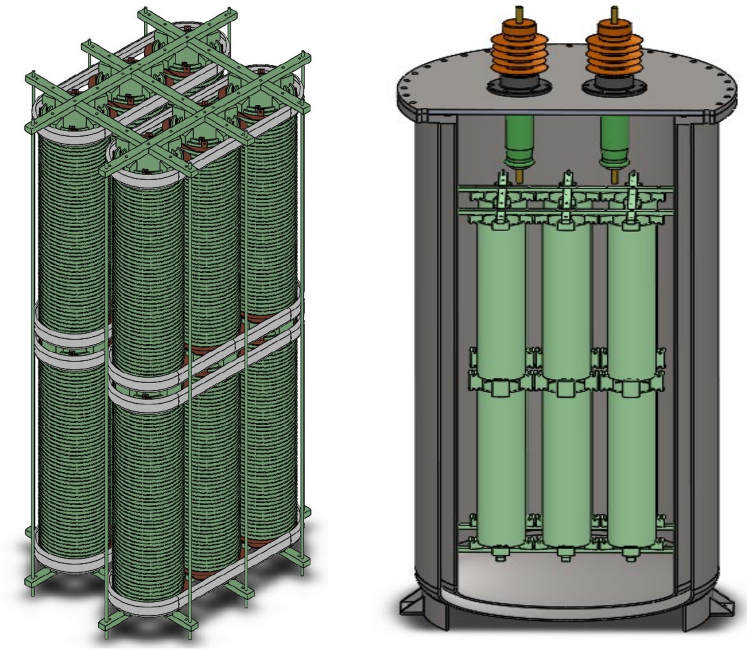


Inter-phase short circuit experimental result

4 Recent Progress in China—DC Fault Current Limiter

Test of A 40kV/2kA DC Fault Current Limiter, by IEE

- The Current Limiter consists of 6X4 modules, the deign is listed at the table.



40kV/2kA DC Fault Current Limiter

Design of the Module

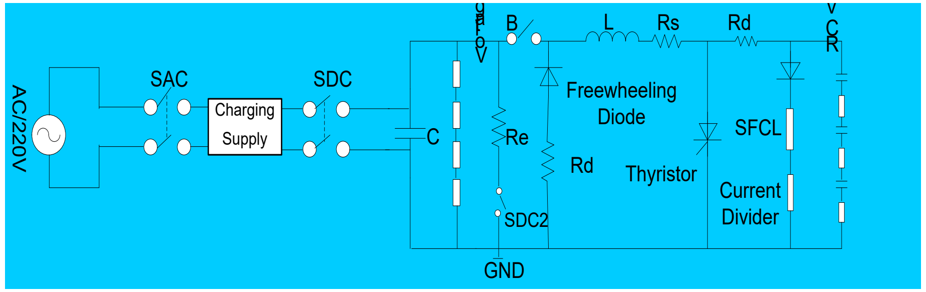
Coil Diameter/mm	176/216
Turns #	52
Height/mm	727
Inter-turn Insulation/mm	1.5
Operation Temperature/K	65-77

Design of the FCL

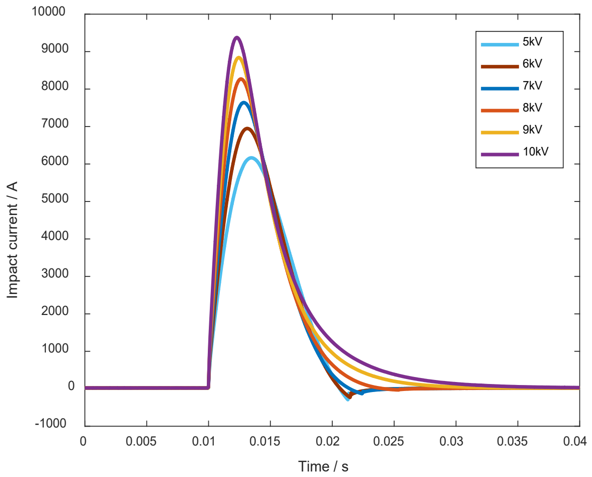
Number of Modules	6X4
Height/mm	1600
Outer Diameter/mm	800
Length of YBCO Tape/m	800
Operation Temp./K	65-77
Pressure at the Dewar	1 atm
Rated Voltage/kV	40
Critical Current/A	1200@77K；2500@65K
Rated Current/A	2000@65K

Fabrication of the Fault Current Limiter

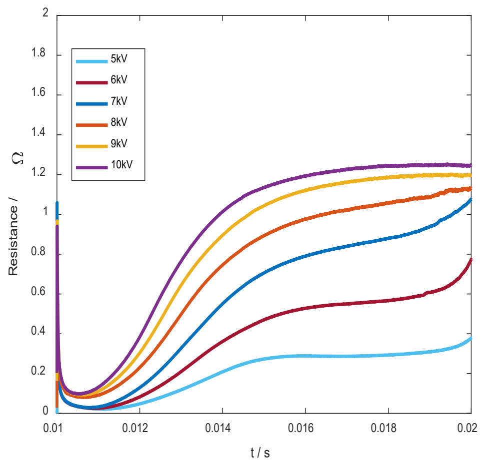
Test of the Fault Current Limiter



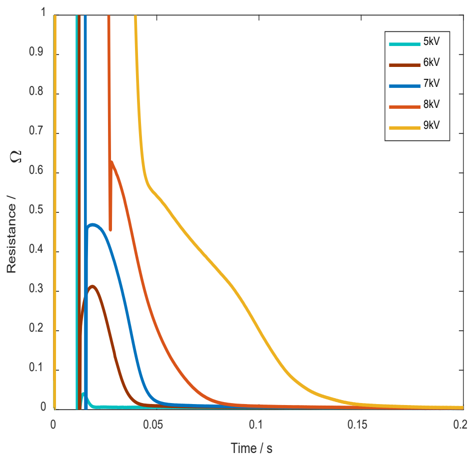
Circuit of the test facility



Impact Current



R-T during current impact

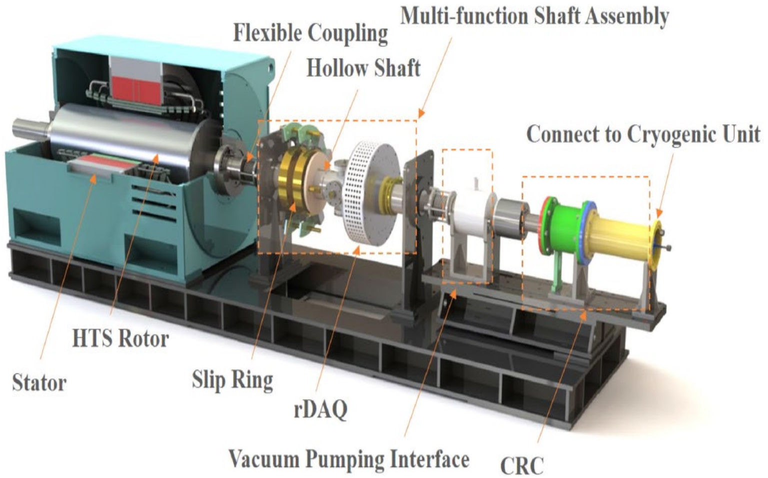


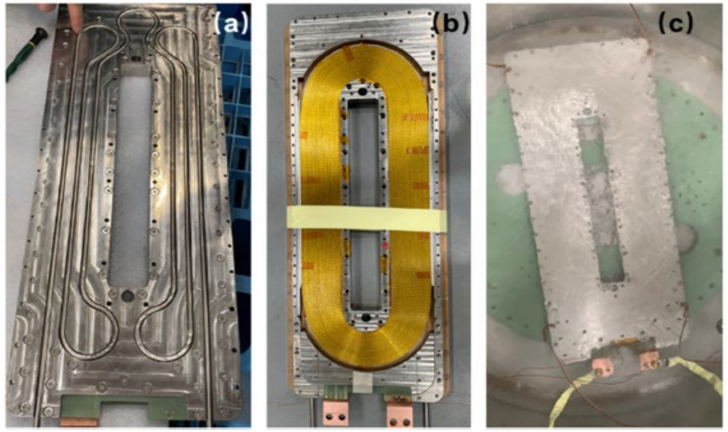
Quench Recovery

The test results show that the FCL could be used to fit O-C-O operation

4 Recent Progress in China—Synchronous condenser

- China Southern Power Grid Corporation: 10 Mvar HTS dynamic synchronous condenser (DSC) Project.
- To initiate the project, a 300 kvar HTS DSC prototype was developed, and excitation and cooling test have been done.





Design parameters:

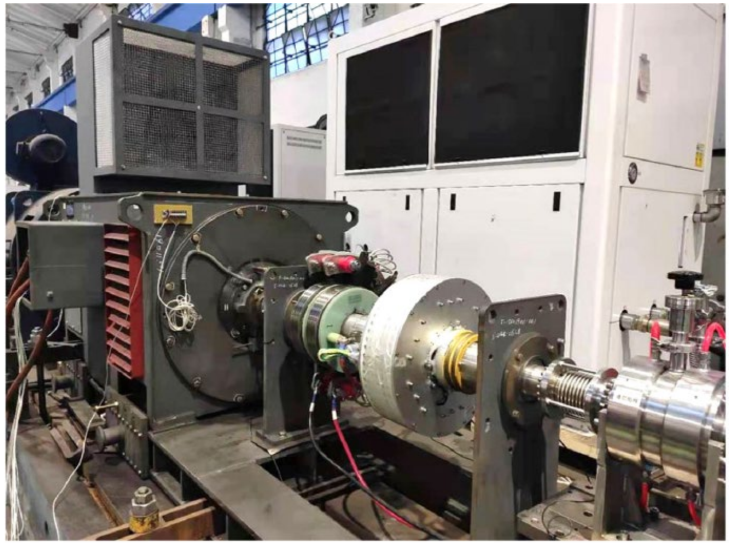
— Rated current: 200A@20-25K;

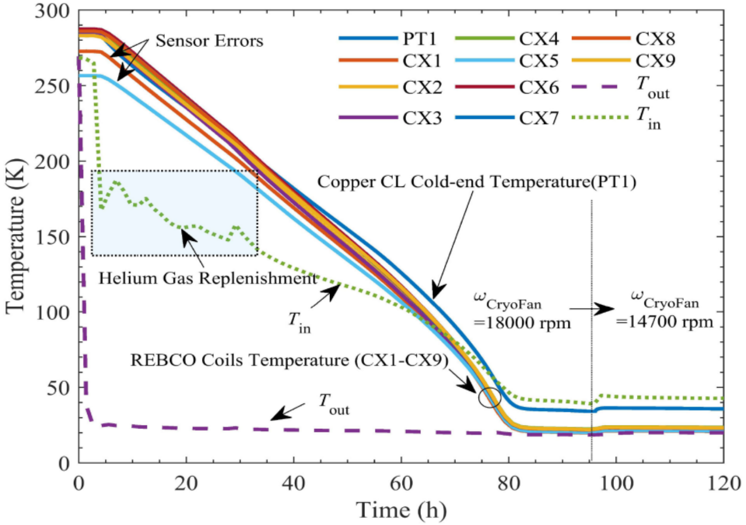
— Rotational speed: 3000rpm

Test results of one pole magnet:

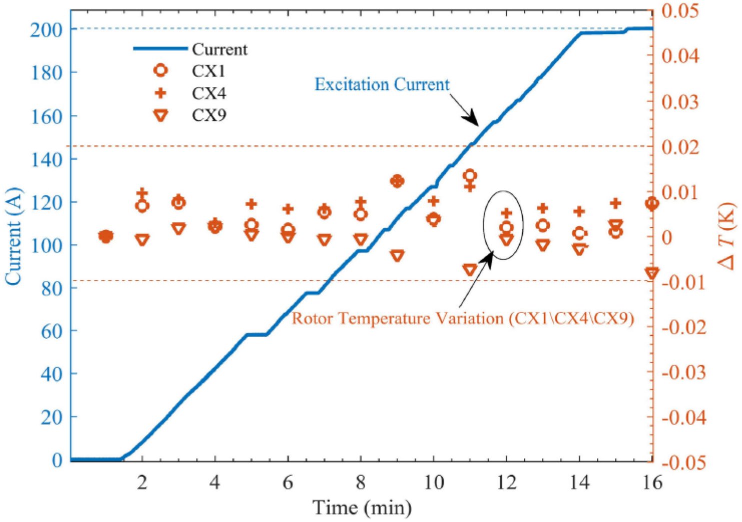
— Critical current: 281A@22 K

Experimental test of HTS synchronous condenser

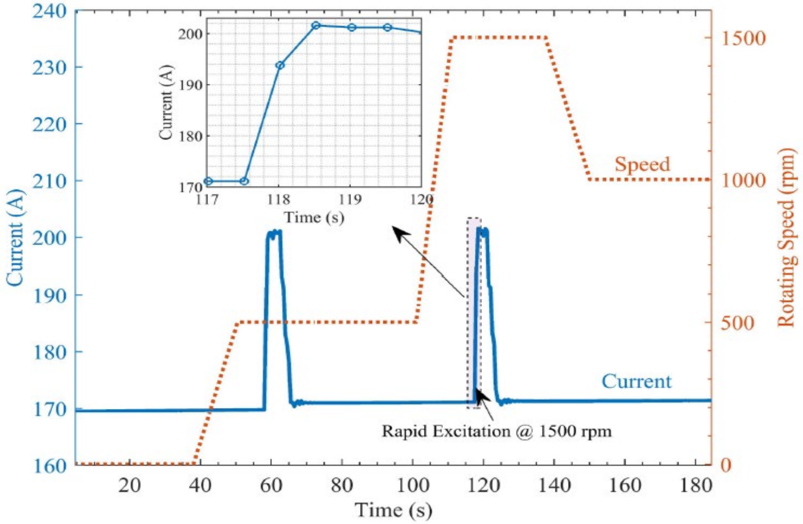




Cooling process of HTS rotor



Static excitation process



Rapid excitations at 500 rpm and 1500 rpm

5 Challenges of superconductor technology for Power

1) Reliability, just like conventional electric power equipment

—long-time operation without maintenance & unattended
—keep intact after surge current & voltage
—after quench, it can recover to operation without maintenance
—it can work outdoor with different weather
—it can recover quickly after power outage is restored
。。。。。。
In general speaking, it may need to be made by Room-Temperature Superconductor?

2) Economy

—Its total cost (including installation) (per kW, or per kW.km, or per MVA etc.) can be as the same level as conventional counterpart
—Operation expenses including annual inspection fee can be acceptable after consideration of its performance over others.

Thank you for your attention