The Present Status and Prospective of the power transmission by Superconductors in China

Liye Xiao

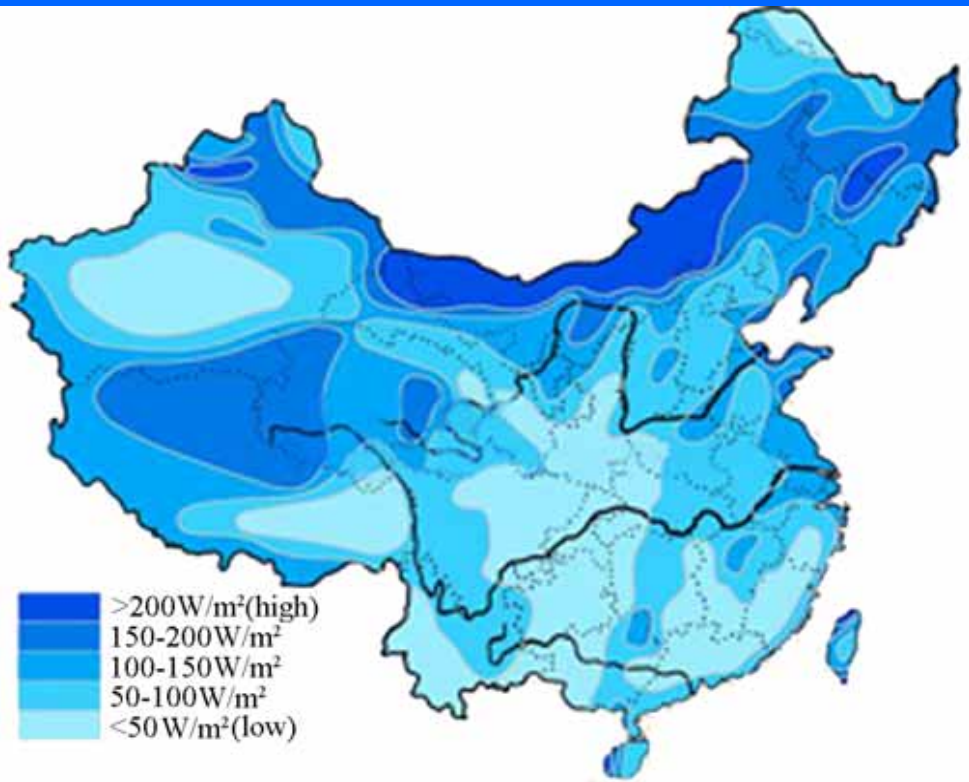
Institute of Electrical Engineering
Chinese Academy of Sciences

IASS, Germany, May 12-13, 2011

Contents

- Distribution of Renewable Energy in China;
- Distribution of load in China;
- Architecture and operation mode of the future transmission grid;
- Energy transmission by superconductor;
- Development status of the superconducting cable in China;
- Summary.

Distribution of renewable energy in China
— Wind Power

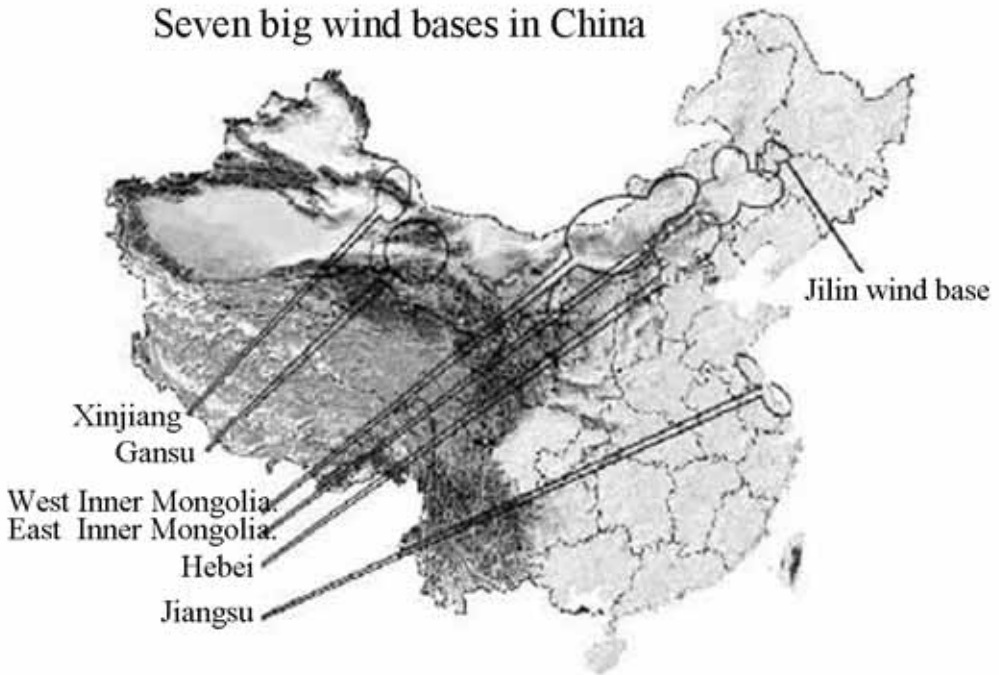


Distribution of wind power resources in China

Areas with rich wind resources

(1)Northern areas:
Average: 200~300 W/m^2,
local: over 500 W/m^2.

(2) Southeast Coastal areas:
~ 150 W/m^2.



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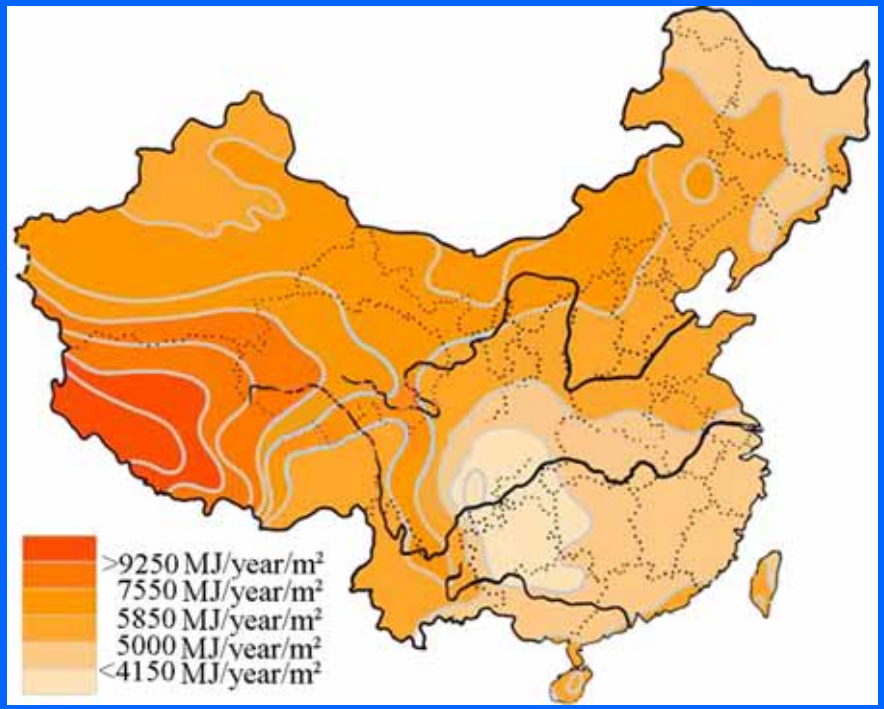
Distribution of renewable energy in China — Solar energy



Distribution of solar energy in China

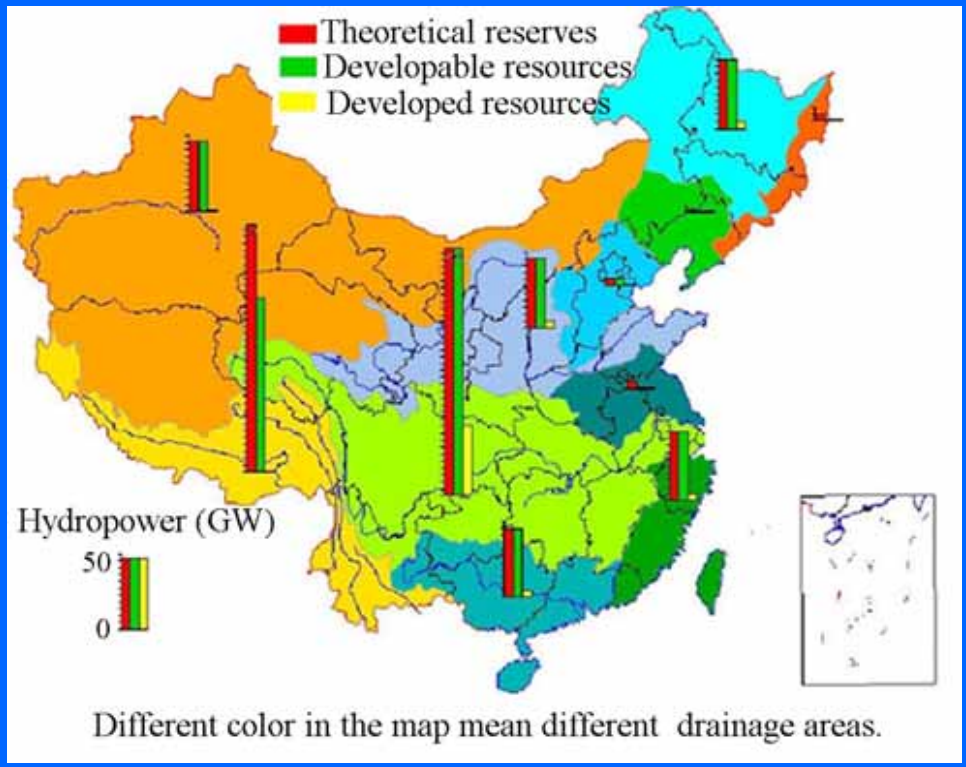
The high irradiation areas:

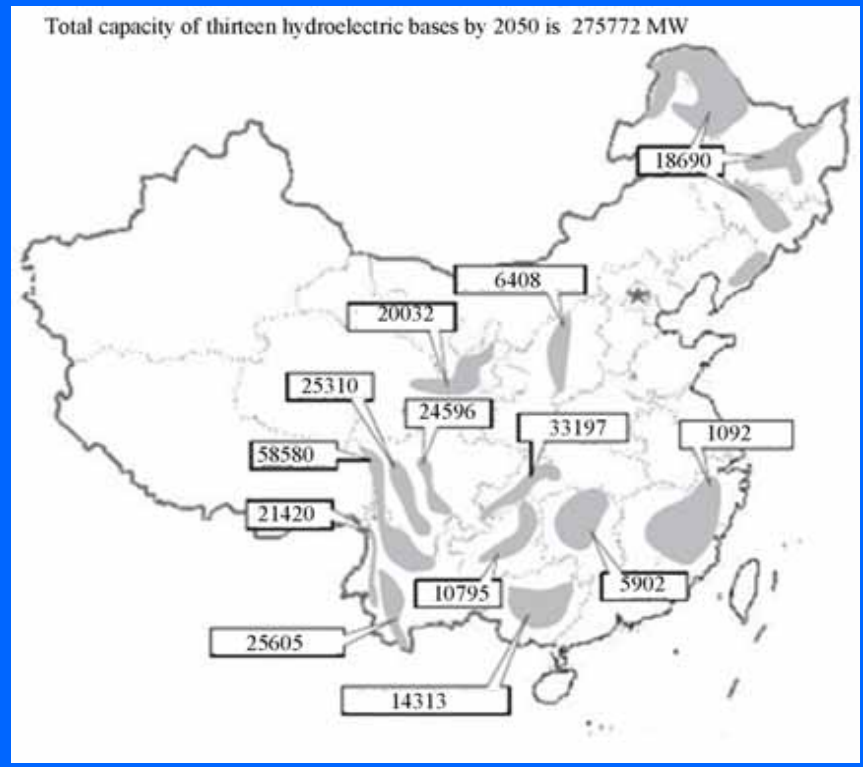
(1) The west region, such as, Tibet, Xingjiang and Qinghai;

(2)The north region, such as Inner Mongolia, Shanxi, Gansu, Ningxia, Hebei;

Annual hours of sunlight is about 3000 h, and the annual irradiation amount is more than 5800 MJ/m^2.

Distribution of renewable energy in China — Hydropower

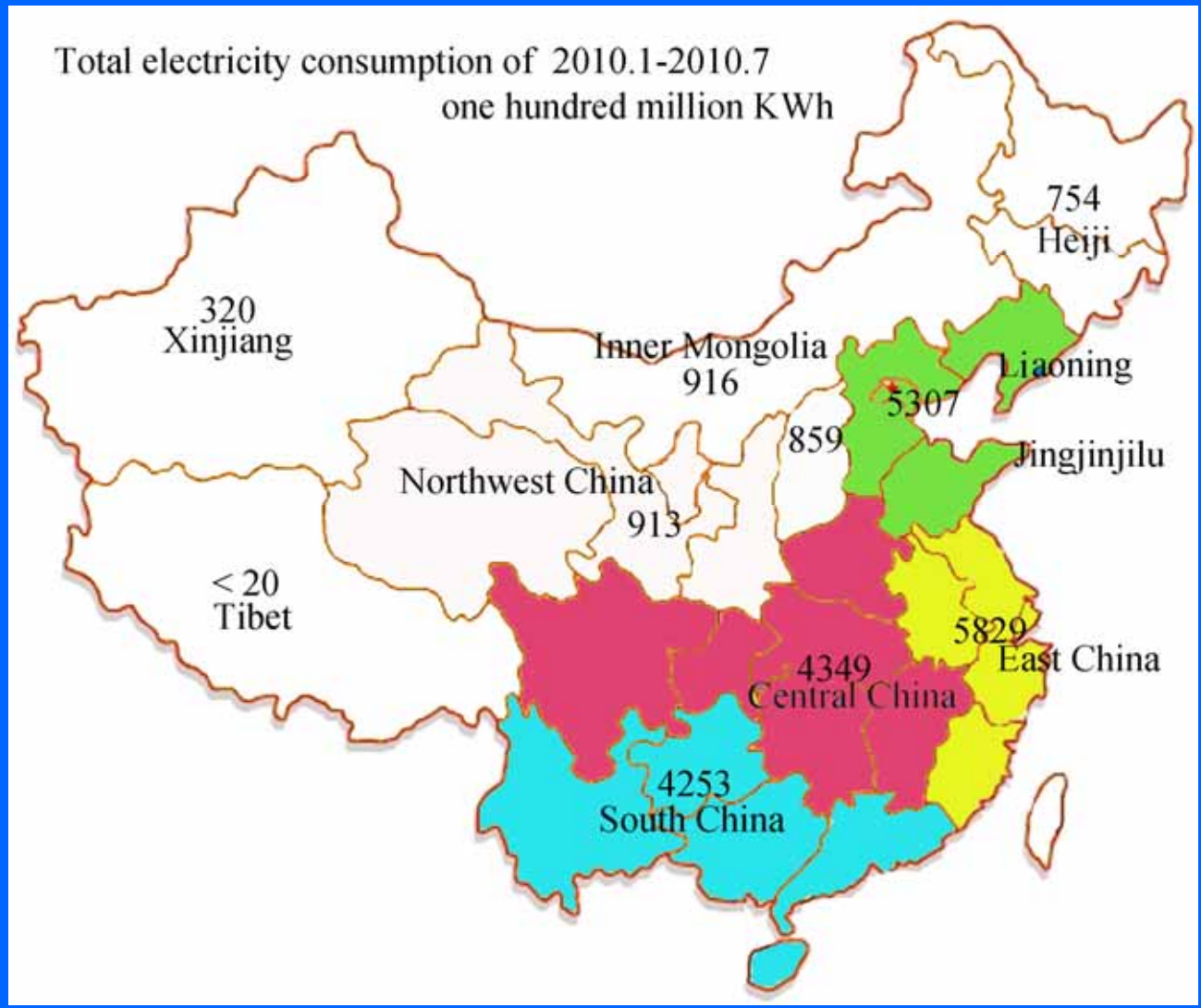




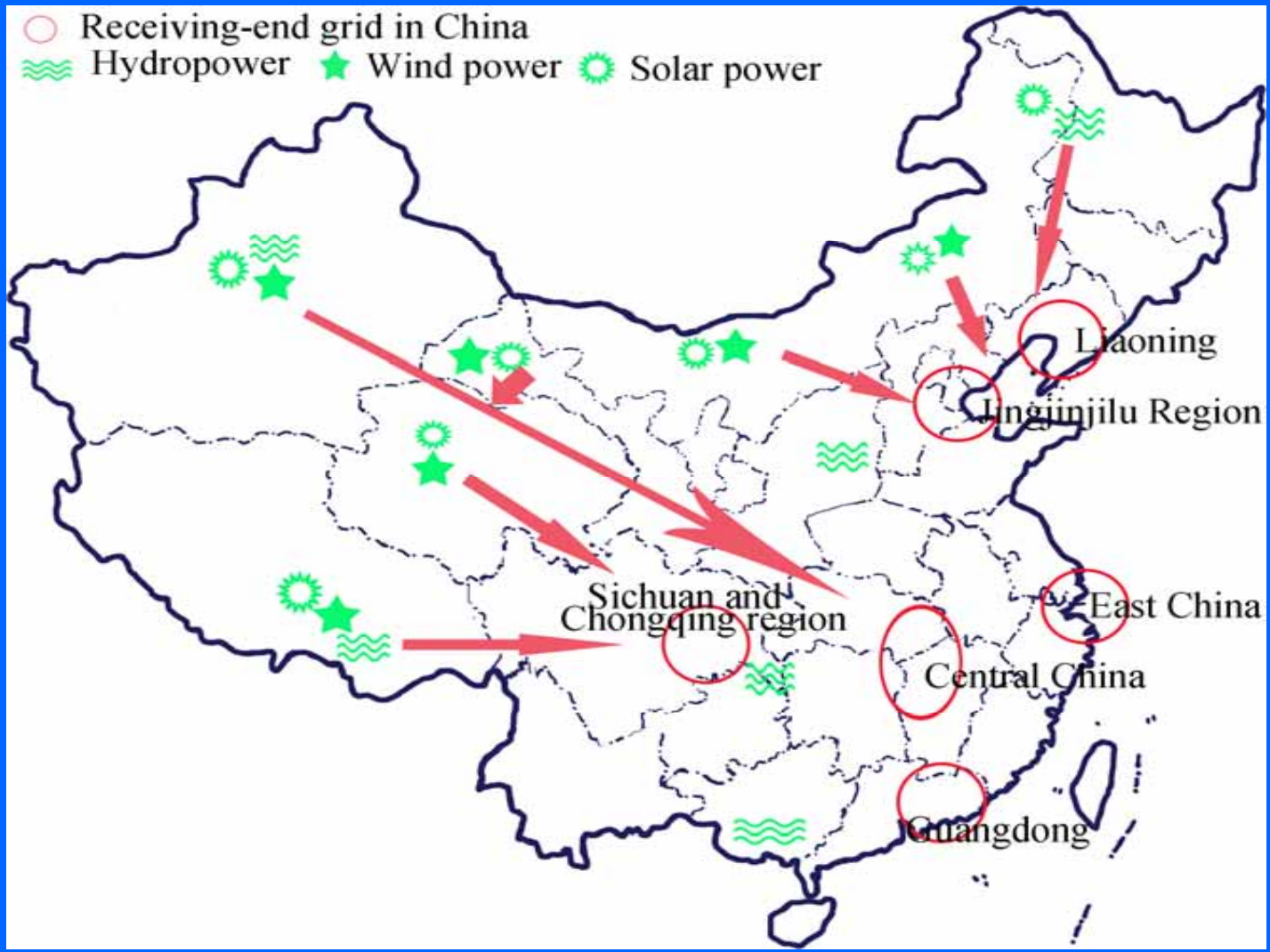
The hydropower distribution:

(1) Southwest region, such as, Sichuan, Yunnan, Guangxi and Guizhou;
(2) The west region, such as Gansu and Qinghai;

Distribution of power load in China



Power transmission of China in the future

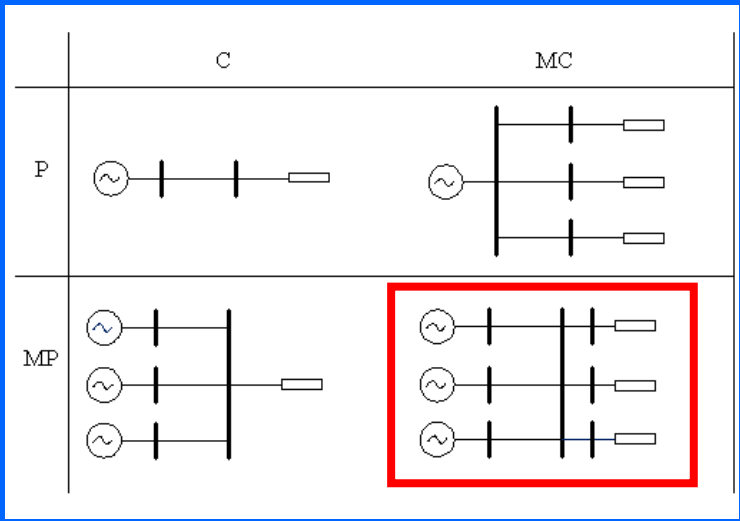


Architecture of Operation Mode of Future Grid

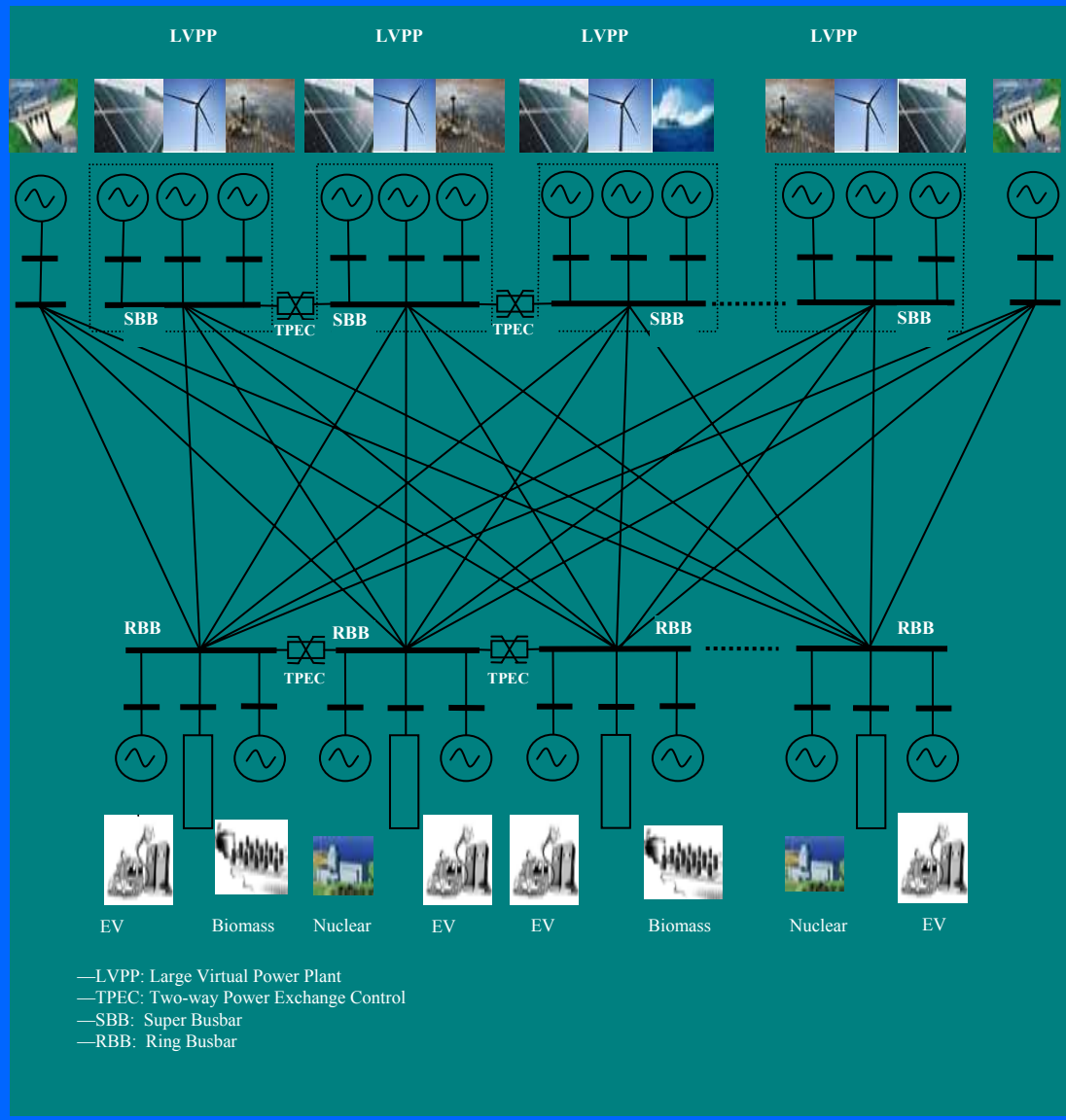
1、The complementaries of renewable energies in wide area:
Solar, wind, biomass, Hydro, and EV;

2、Intelligent use of the renewables:
Power-packing: Virtual Power Plant;
Cloud-Powering;

3、HVDC
SBB, RBB, Long distance transport



Power Transmission Mode



Architecture of Future Grid

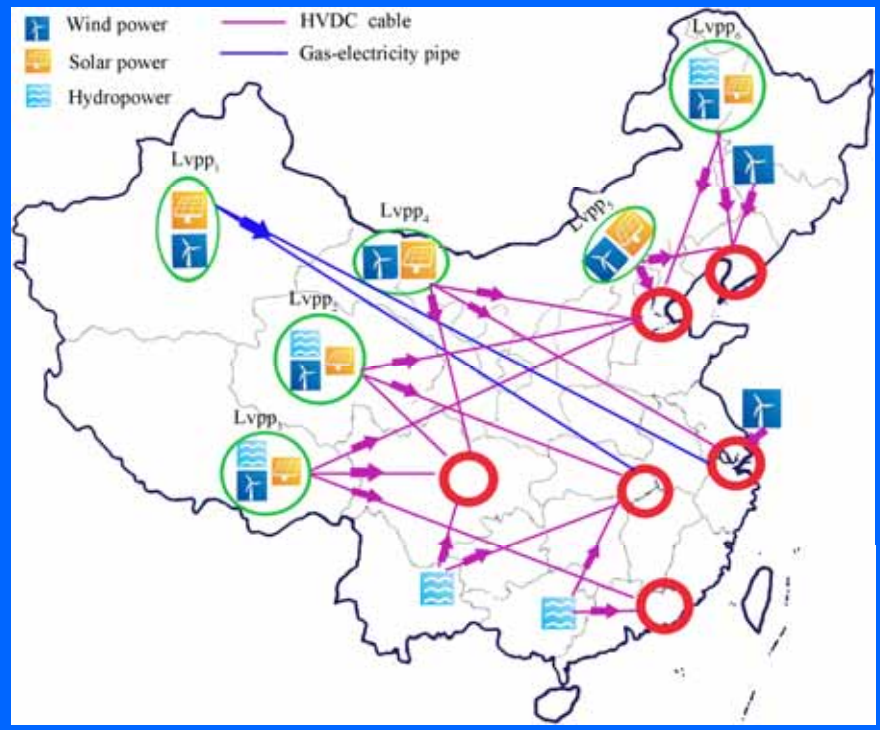
Energy Transmission by Superconductor

1、**Super Busbar (SBB)：**
Power Capacity: tens of Giga-Watts
Length: hundreds to 1000 km

2、**Ring Busbar (RBB)：**
Power Capacity: tens of Giga-Watts
Length: hundreds to 1000 km

3、**Long Distance HVDC**
Capacity: 5~10 Giga-watts
Length: 1000-3000 km

4、**Energy Pipeline**
Transport LNG and Electric Power
Length: 1000-3000 km



Some Technical Issues for DC transport by Superconductor

1、HTS wires by:
YBCO @ 77 K
HgBCO @ 110 K (LNG temperature) ?

2、Low Heat loss Cryogenic Envelope
Joint for the envelope

3、High efficiency Refrigeration system with high reliability
Cryogenic station

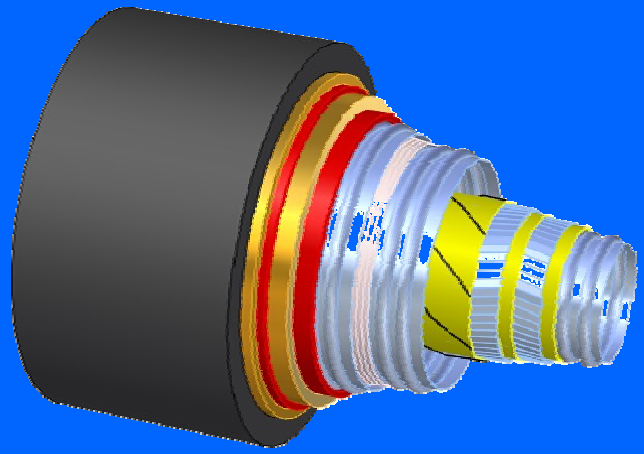
4、Dielectric at Low temperature

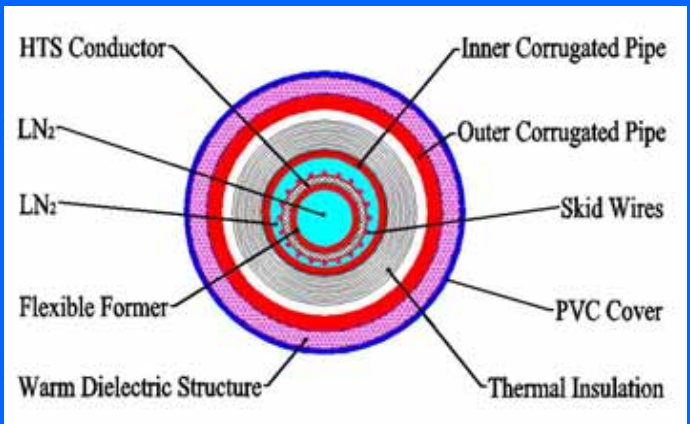
5、Multiple-terminal HVDC technology
HVDC Switch
DC-FACTS

6、Fabrication for flexible & robust HTS cable with large capacity

HTS Power Cables 75m/10.5kV/1.5kA@IEE

Parameter	Value
Outer diameter of former (mm)	32.7
Outer diameter of conductor (mm)	34.6
Number of conductor layer	2
Number of tapes in conductor	36
Outer diameter of skid wires (mm)	39.0
Inner/outer diameter of envelope (mm)	49.5/92.0
Thickness of warm dielectric (mm)	4.5
Thickness of copper shield (mm)	0.4
Thickness of PVC cover (mm)	5.0
Outer diameter of cable (mm)	117





HTS Power Cables 75m/10.5kV/1.5kA@IEE

Energized: Dec., 2004 Operation time: more than 7000h.;
Critical current of the 75m HTS power: up to 5000A;
Joint resistance: as low as $10^{-7}\Omega$.

HTS Power Cables

30m/35kV/2kA@Inno

Subject	Specification	Subject	Specification
Mode of Cable	Three single phase, Outdoor	**Dielectric Type**	Warm(XLPE, 11.8mm)
Length	33.5m (flange to flange)	**Outer Diameter of Cable**	112mm
Rated Voltage	35kV	**Installation Bending Angle**	90°
Rated Current	2kA(rms)	**Operating Temperature**	72~76K
Shortcut Current	20kA/2S	**Cooling Fluid**	LN2

HTS Power Cables

30m/35kV/2kA@Inno

❑Installation:

•Puji Substation, Yunnan, transmitting electricity to 4 industrial customers (including 2 metallurgical refineries) and about 100,000 residential population.

❑Current Status:

❑has delivered more than 680,000,000kW.h electricity to the customers.

HTS DC Power Cables 360m/10kA@IEE

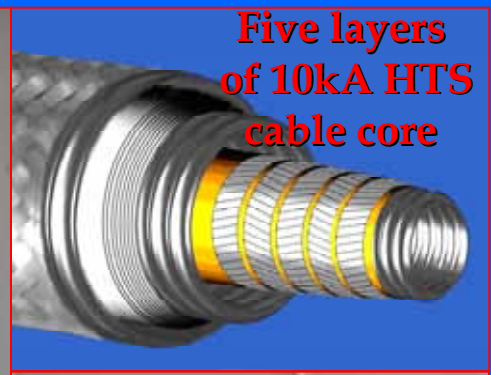
Power cable	Type	Length	Voltage	Current	Status
Bixby, US	AC, CD	200m	13.2kV	3.0kA	Energized 2006
Albany, US	AC, CD	350m	34.5kV	0.8kA	First stage 2006 Second stage 2008
LIPA, US	AC, CD	600m	138kV	2.4kA	Energized 2008
New Orleans, US	AC, CD	1760m	13.8kV	2.0kA	N/A
Amsterdam, Netherlands	AC, CD	6000m	50kV	3.0kA	N/A
Seoul, Korea	AC, CD	800m	22.9kV	1.25kA	Energized 2010
IEECAS, China	DC, WD	360m	1.3kV	10.0kA	Energized 2011

360m DC HTS power cable: the highest transportation current in the world

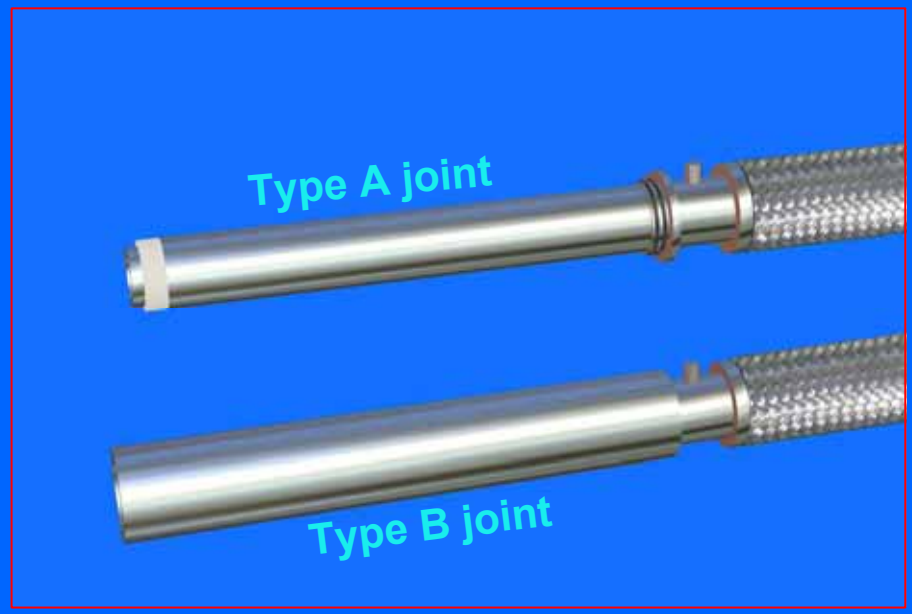
10kA HTS Cable: the design parameters

No.	Items	Parameters
1	**Total length of the DC HTS power cable**	362.4m
2	**Total length of the cryogenic envelope / LN_2 flow pipe**	350.1m / 367.4m
3	**Length / out diameter of the termination**	6.15m / 325mm
4	**Out diameter of the DC HTS power cable**	151mm
5	**Layers of the cable core**	5
6	**Winding angle of the cable core**	15^0 (with difference for each layer)
7	**Total length of the HTS tapes used**	46km
8	**Heat loss of the cryogenic envelope / LN_2 flow pipe**	≤2W/m / ≤1.0W/m
9	**Segmentations of the cryogenic envelope / LN_2 flow pipe**	Totally 8 segments
10	**Dielectric type**	Warm dielectric
11	**Total hest loss of the DC HTS power cable system**	2487W
12	**Refrigeration type / capacity**	LN_2 circulation / 4kW@77K
13	**Designed critical current**	≥12,500A
14	**Rated current**	≥10,000A
15	**Rated voltage**	1300V
16	**Minimum bending radius**	≥3.0m

The conductor for the cable



The cryogenic envelope for the cable

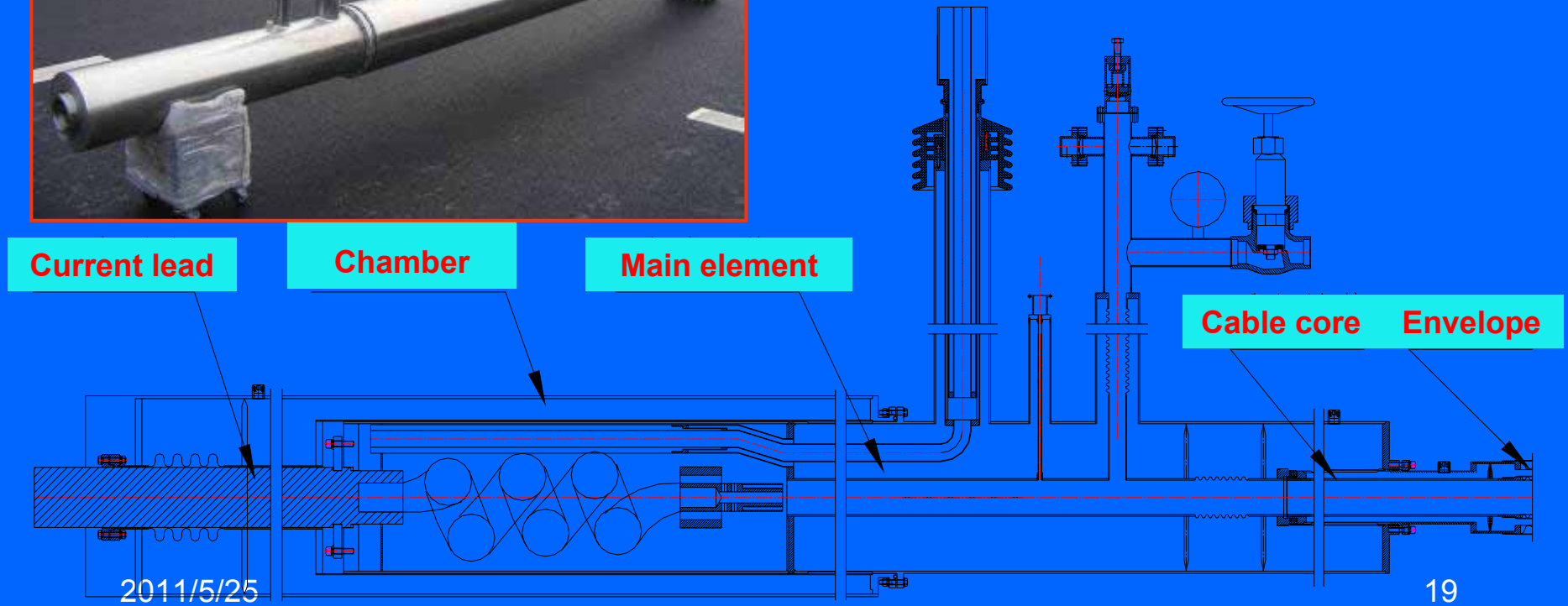


- The cryogenic envelope has been divided into 8 segments;
- Each segment has a standardized joint at both ends;
- Just inserts type A joint into type B joint when integration;
- This design and assembly is a good way for long-distance HTS cables.

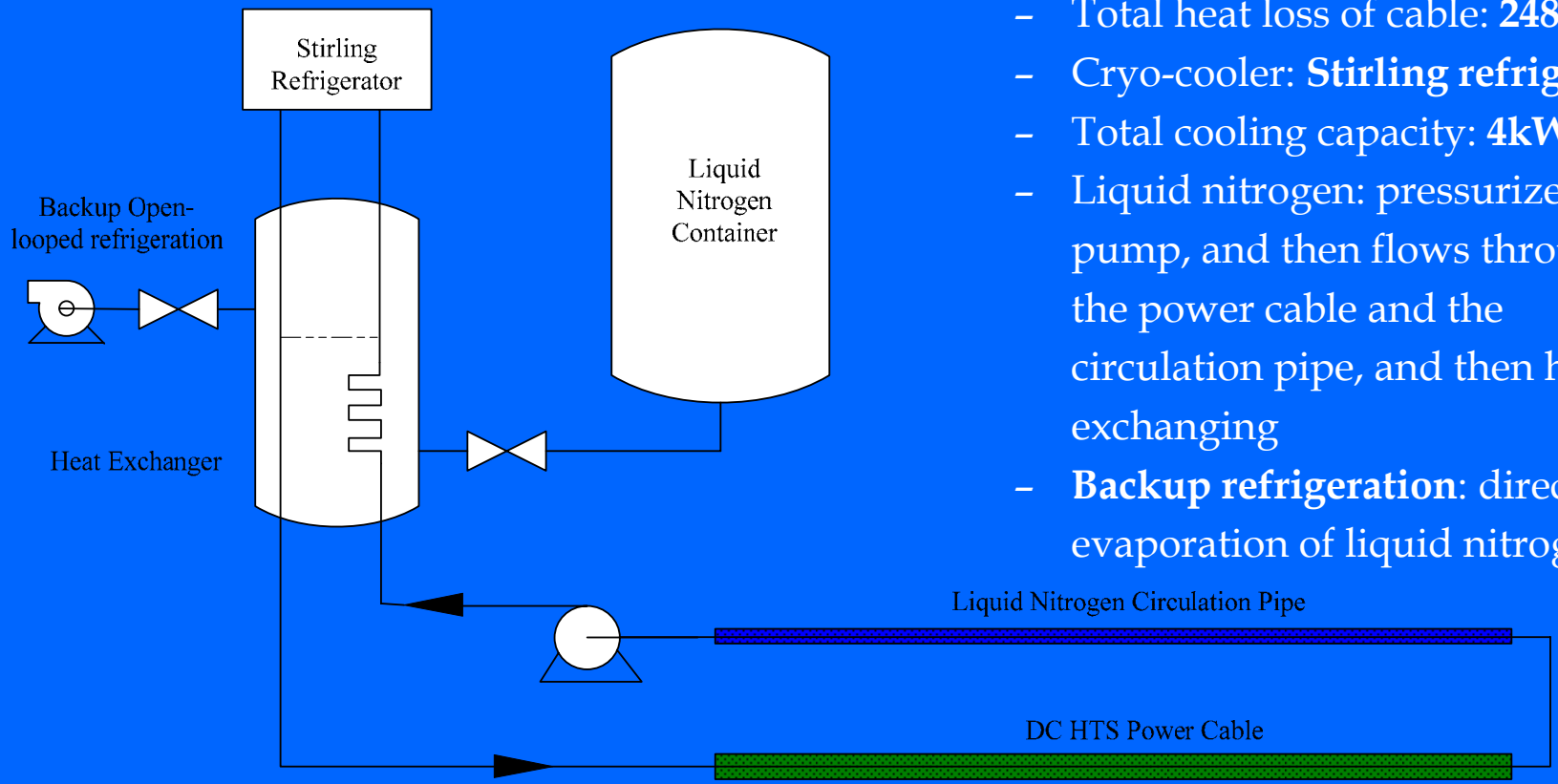
The termination for the cable

— Modularization: each functional part is independent;

— Three functional parts: the main element, current lead, chamber.



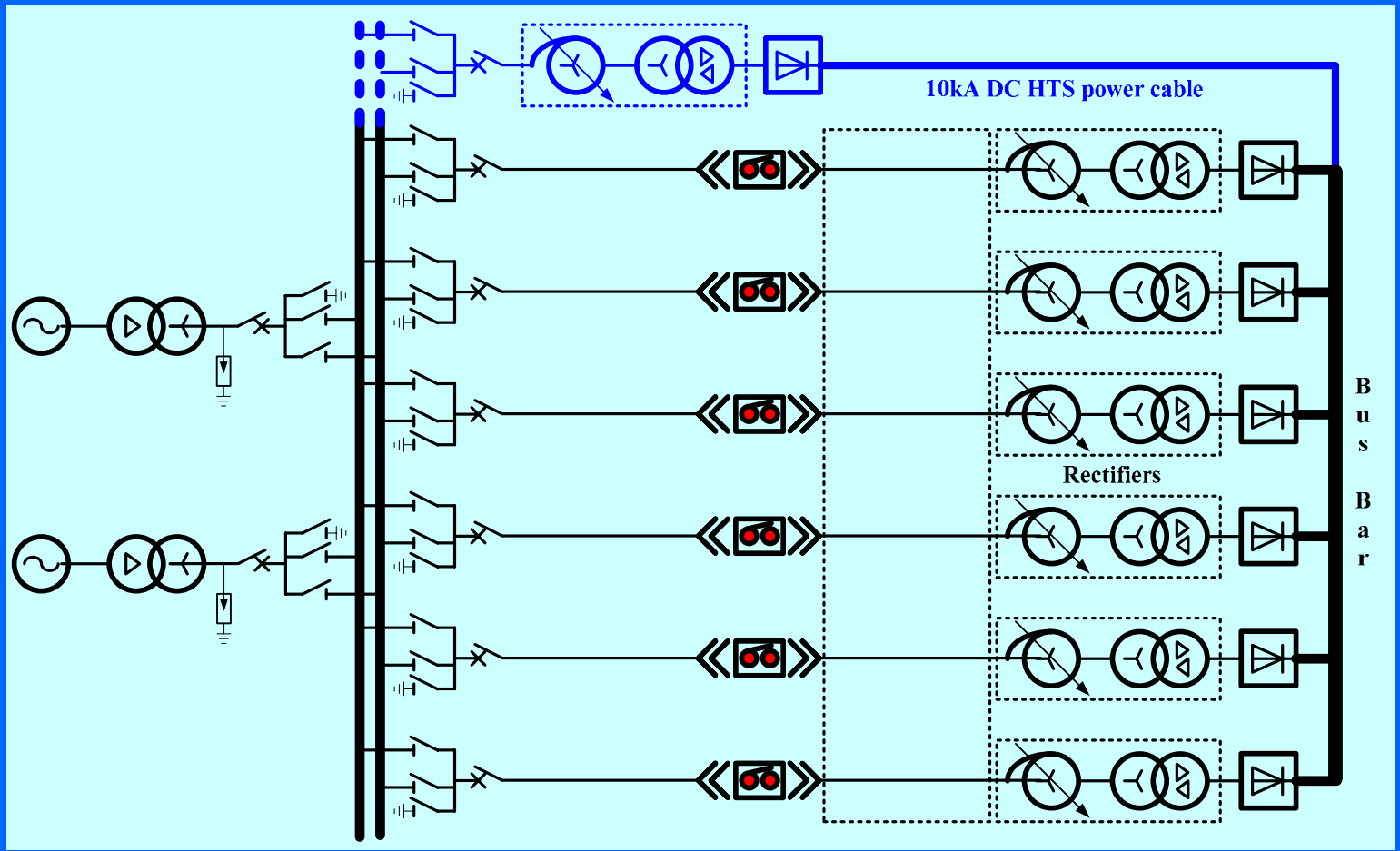
The refrigeration system



- For the refrigeration
  - Total heat loss of cable: **2487W**
  - Cryo-cooler: **Stirling refrigerator**
  - Total cooling capacity: **4kW@77K**
  - Liquid nitrogen: pressurized by a pump, and then flows through the power cable and the circulation pipe, and then heat exchanging
  - **Backup refrigeration**: direct evaporation of liquid nitrogen

Closed loop and Stirling refrigerator will be employed for the DC cable

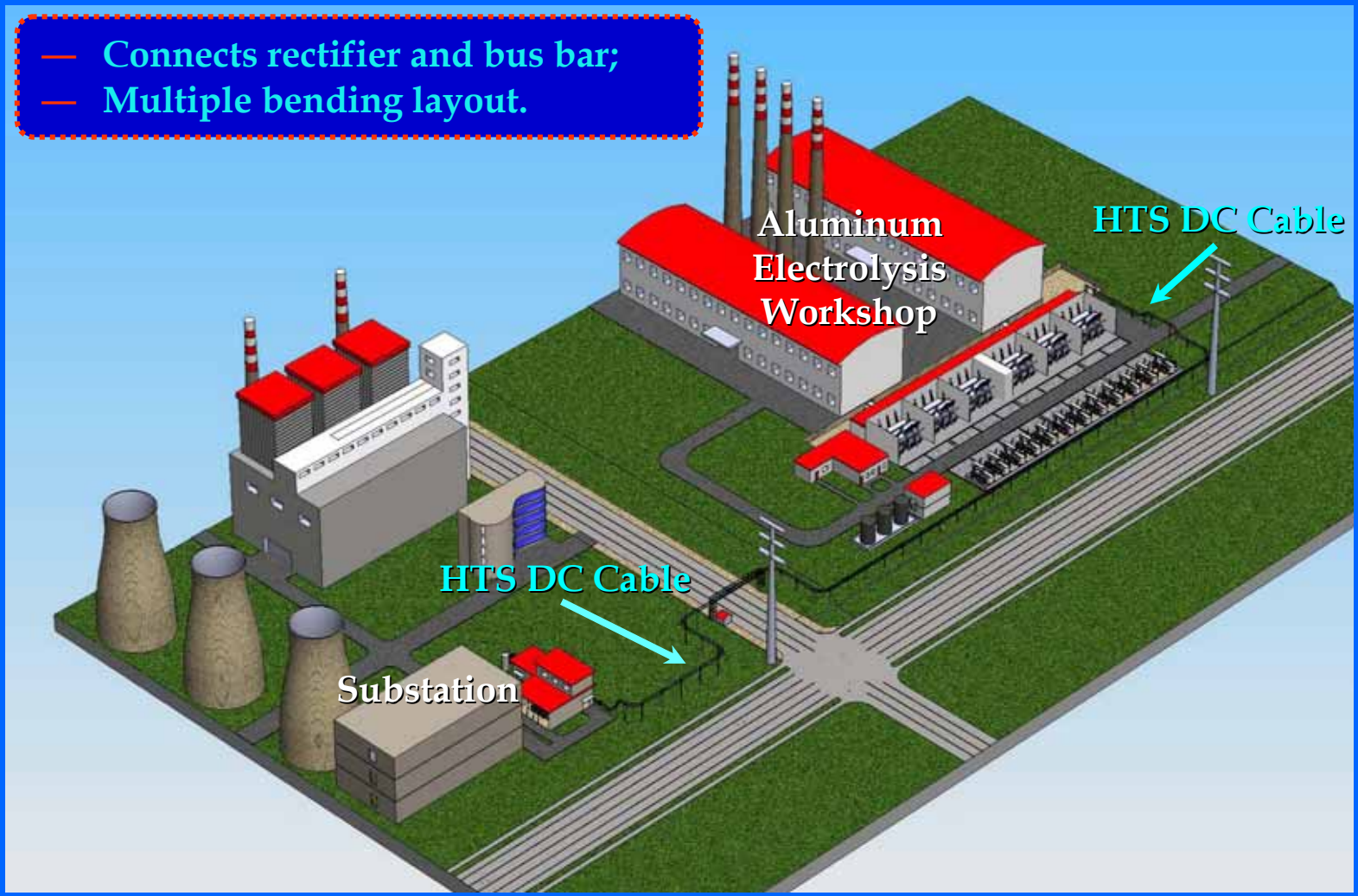
The HTS DC cable will be connected to the busbar for a alumina electrolyzer



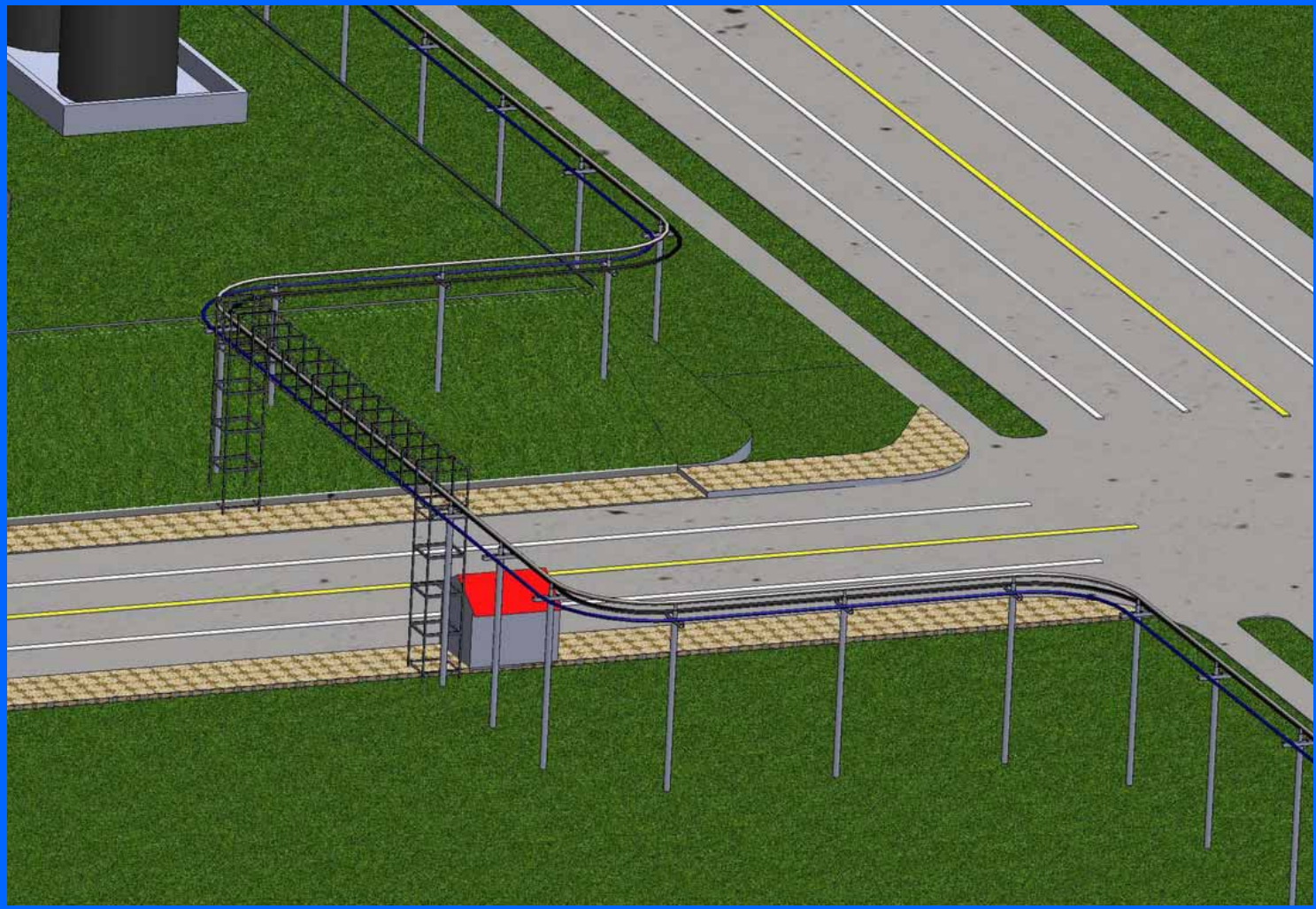
Location of the DC cable: **connects the rectifier with the bus bar**

Overview of the layout of HTS DC cable

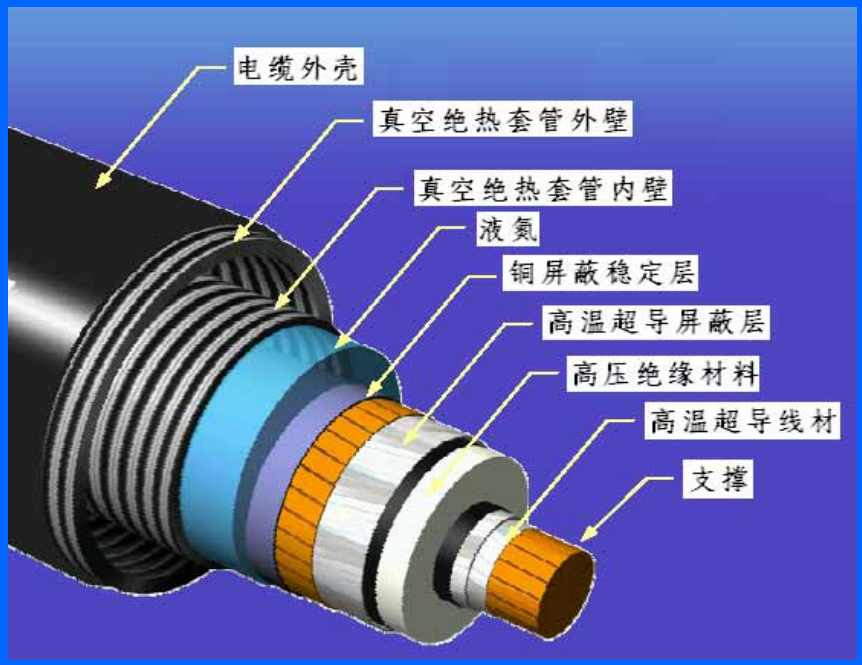
- Connects rectifier and bus bar;
- Multiple bending layout.



Overview of the layout of HTS DC cable



HTS Cable Project @ State Grid Company — A Plan

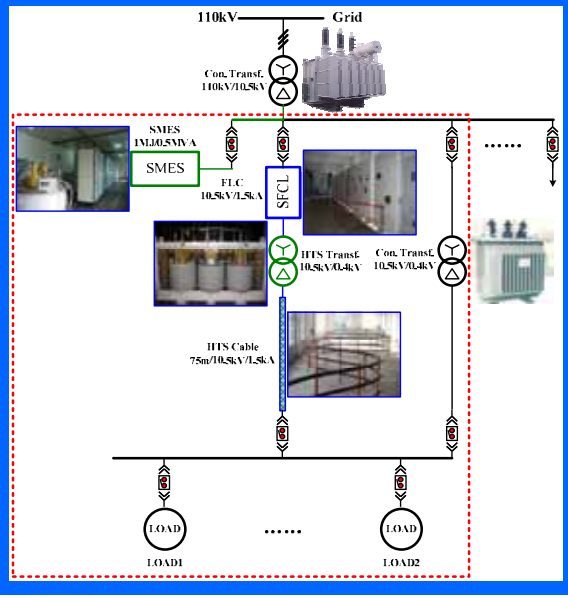


The 110 kV HTS Power Cable

The 110 kV HTS Power Cable

Cable type	three phase AC
Cable structure	CD
Cable length	~1km
Rated voltage	110kV
Max voltage	126kV
Impulse withstand voltage	550kV
AC withstand voltage	160kV, 30min
Rated current	2~3kA

A 10 kV Superconducting Substation @ IEE



- **Superconducting FCL:**
  - Suppress Fault current;
  - Enhance dynamic stability and reliability of the gird;
  - Increase transmission capacity;
  - Prolong life of the equipment.
- **HTS Power Cable:**
  - Lower transmission loss;
  - Increase transmission capacity.
- **SMES:**
  - Quick power compensation;
  - Improve power quality;
  - Uninterrupted power.
- **HTS Power Transformer:**
  - Lower Operational loss;
  - Increase unit capacity.

The superconducting substation has been energized in the beginning of February, 2011

Demonstration of a 10 kV HTS Substation

1MJ/0.5MVA SMES

10kV HTS FCL

10kV/400V/630kVA
HTS Transformer

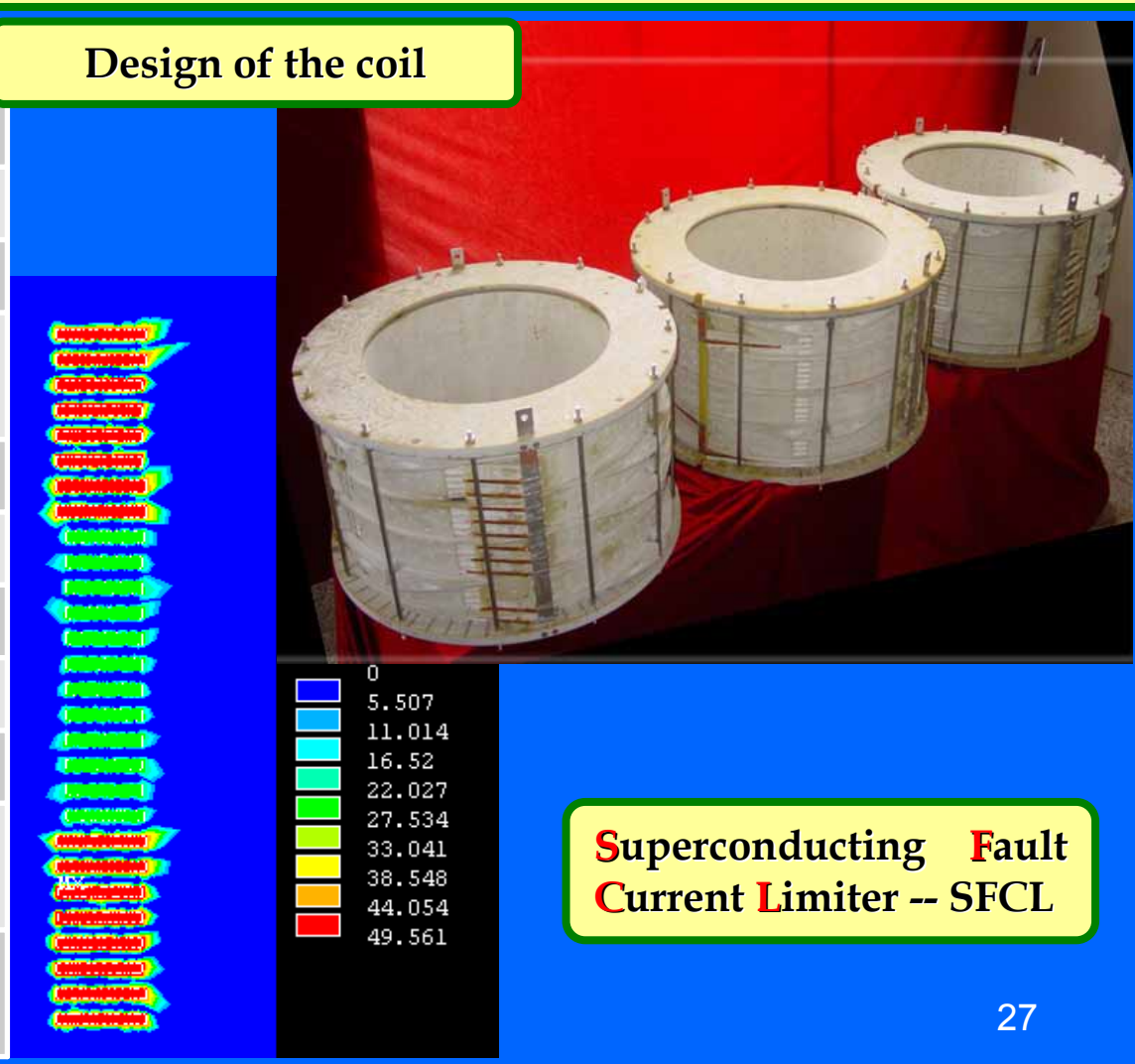
75m/10kV/1.5kA
HTS Power Cable

The 10 kV Fault Current Limiter

Jointly developed at the Institute of Electrical Engineering, CAS, et al.

Parameters	Value
Inner Diameter	492-502mm
Outer Diameter	580mm
Height	361.6mm
Number of Pancakes	14
HTS Tapes	2856.8m
Inductance	6.24mH
Insulator	kapton
Ic@77K	600A
Iop	450A
Central Magnetic Field	1000Gs
Maximum Magnetic Field	1434Gs

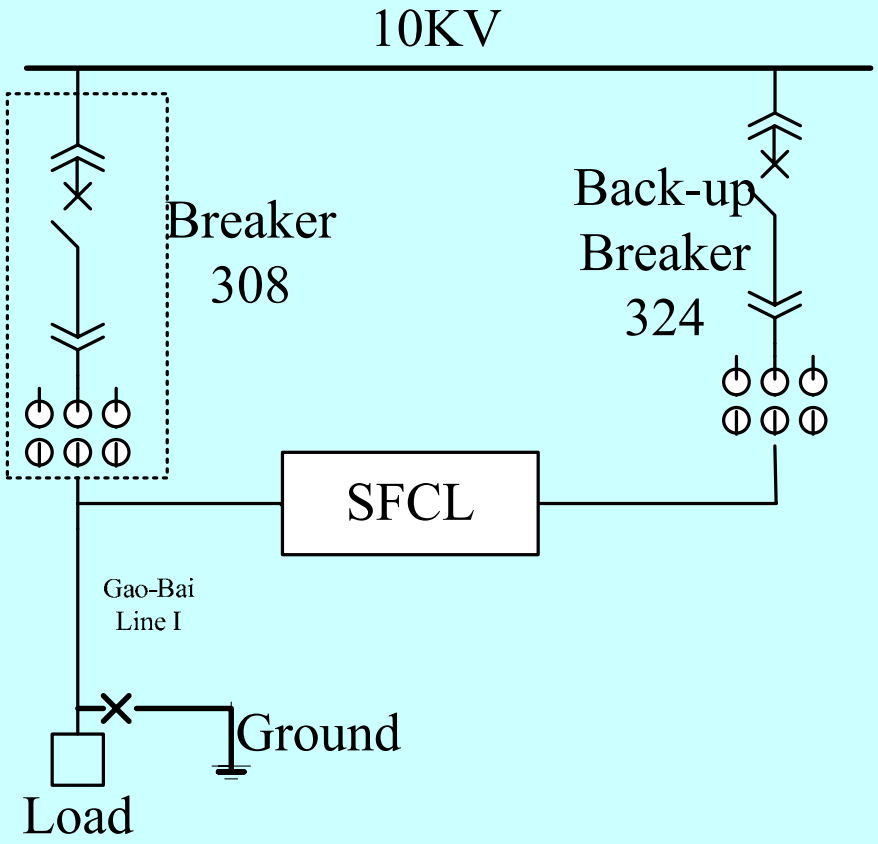
Design of the coil



Superconducting **F**ault **C**urrent **L**imiter -- SFCL

The 10 kV Fault Current Limiter

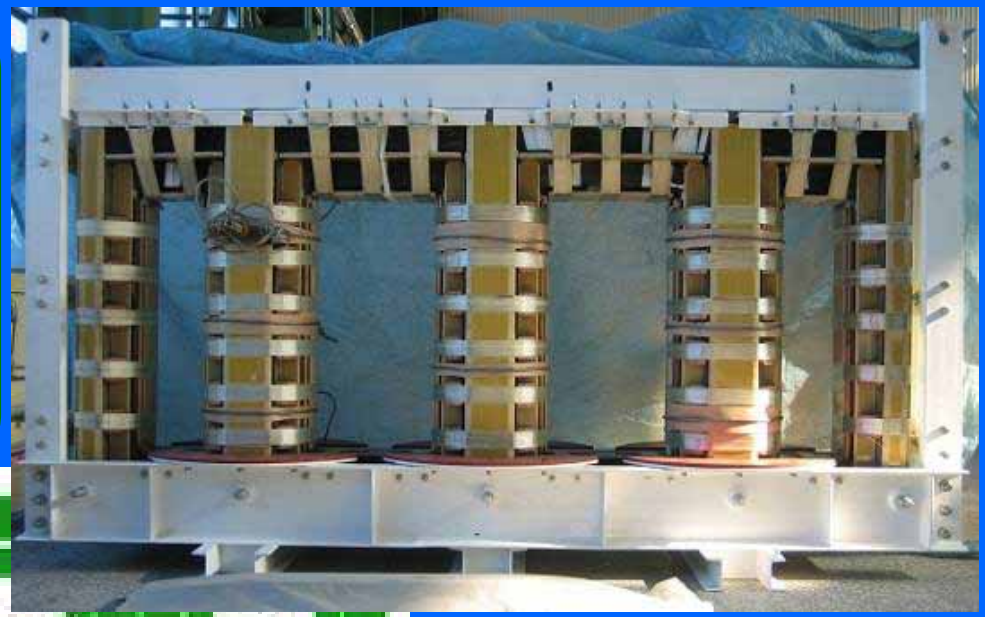
Improved bridge type SFCL

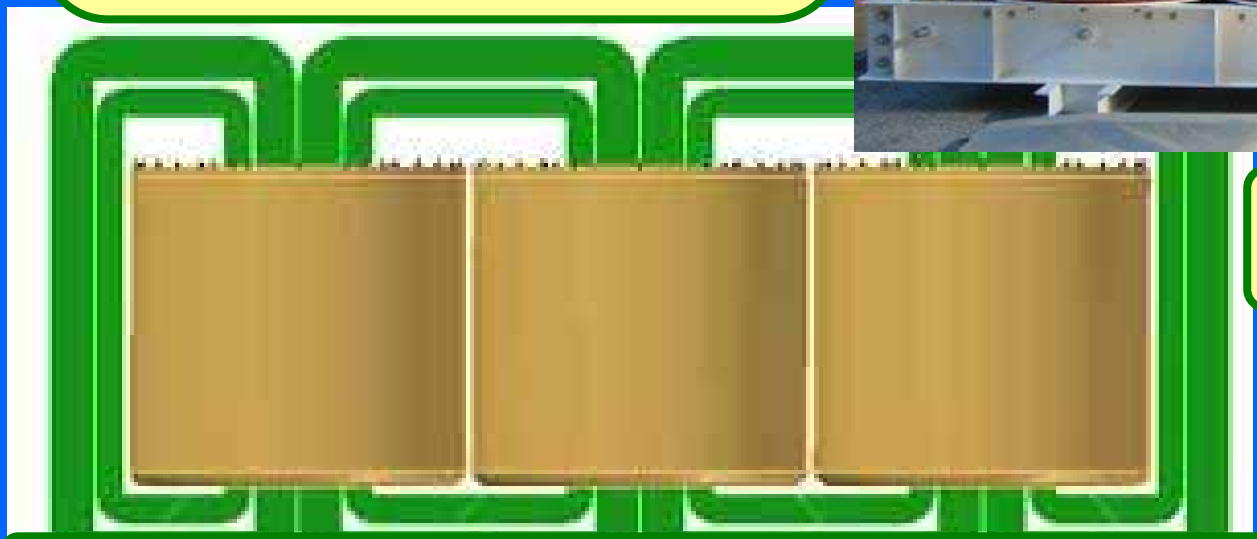


Energized: Aug., 2005 at Gaoxi substation;
Voltage: 110/10.5KV;
Operation time: more than 11000hours.

HTS Transformers 630kVA/10kV/0.4kV

- Rated: 630kVA/10.5kV/0.4kV;
- Iron core: ∅=310mm;
- Core area: Ac=697.43cm^2;
- Flux density: Bz=1.0643T;
- Turn Voltage: E=16.4957V/turn;
- Weight of Iron: G=2999.107kg;
- Load Loss: P_L=133W;
- Empty Load Loss: P_0=1309.56W.





The iron core was made of amorphous alloy.

Jointly developed at the Institute of Electrical Engineering, CAS, et al.

HTS Transformers 630kVA/10kV/0.4kV

The 630kVA/10.5kV/0.4kV HTS power transformer was installed at the headquarters of TBEA in Changji City, Xinjiang Autonomous Region, and was energized on November 21, 2005.

High Tc SMES 10.5kV/1MJ/0.5MVA

Parameters	Value
Inner diameter (mm)	400
Outer diameter (mm)	536
Height (mm)	590
Number of double pancakes	44
Number of tapes	82
Total length of used HTS tape (km)	16.4
Inductance (H)	6.4
Operating current (A)	548
Max. (*Br*) (T)	2.39
Max. (*B*) (T)	5.72
Operating temperature (K)	4.2
Stored energy (MJ)	1.0
Withstand voltage (V)	2000

Design and fabrication of the HTS magnet

High Tc SMES 10.5kV/1MJ/0.5MVA

Item	Value
Operation current	≥ 560A
Stored energy	≥1MJ
Dynamic response time	≤2ms
Energy conversion efficiency	≥90%
Voltage fluctuation	≤2%
Waveform distortion	≤2%
Power factor	≥0.95
Exercising rate of coil	≥0.7T/s
Magnetic shielding (5m from axis)	≤25Gauss

Main parameters of the SMES

The SMES has been demonstrated at Mentougou Substation, Beijing, 2008

A 220kV FCL – Saturated Core Type @Innopower

This FCL will be installed at Shigezhuang substation in Tianjin for live-grid testing and operation.

The FCL ready for testing

Rated voltage	220 kV
Rated current	0.8 kA
Max. expected fault current	55 kA
Max. limited current	30 kA
Impedance at power transmission	<2% voltage drop

Superconducting coil for FCL

Summary

- In the future, large scale of renewable energy must be transported from the north and west to the East, central region and south of China;
- Power-Packing with HVDC would be very promising for the future power transmission, and HTS would be a candidate for the large-scale energy transport, especially in DC busbar.
- In China, AC HTS cables have been demonstrated, and a 10 kV HTS substation has been built, a 360m/10kA DC cable would be operated for a aluminum electrolyzer soon;
- Significant progress had been made in power transmission by superconductors in China last few years, and HTS DC cable would be very helpful for green energy transport in China.

Thank you