



The Investigation and Development of HVDC Submarine Cable

State Grid Corporation of China

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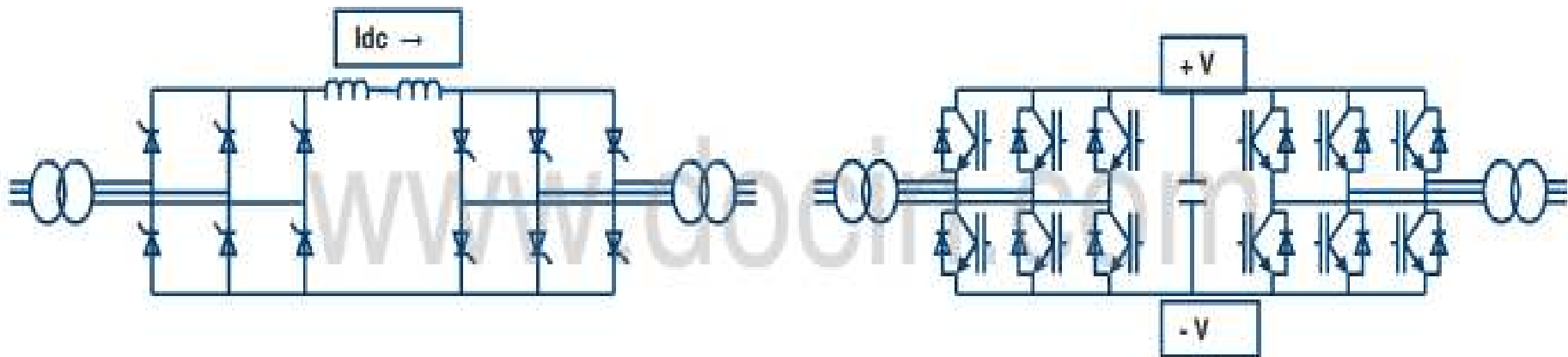
Contents

- 1 Overview of HVDC-VSC cable system**
- 2 The investigation on HVDC cable insulation materials**
- 3 The development of HVDC submarine cable**
- 4 The development of HVDC submarine cable accessories**
- 5 HVDC-VSC projects and application prospect**

1 Overview of HVDC-VSC cable system

1) The technology of HVDC-VSC transmission

- According to difference of converter valve, the HVDC transmission can be divided into two kinds.
- The traditional HVDC transmission is LCC (Line Commutated Converter) technology based on thyristor. The new-type HVDC transmission is VSC (Voltage Source Converter) technology using IGBT, IGCT etc., which is called as HVDC Light by ABB, named as HVDC Flexible in China.



LCC HVDC

VSC HVDC

1 Overview of HVDC-VSC cable system

2) Application scope

HVDC-VSC technology overcome the inherent defects of traditional HVDC technology, and extend the application scope of HVDC. Its main application scope include:

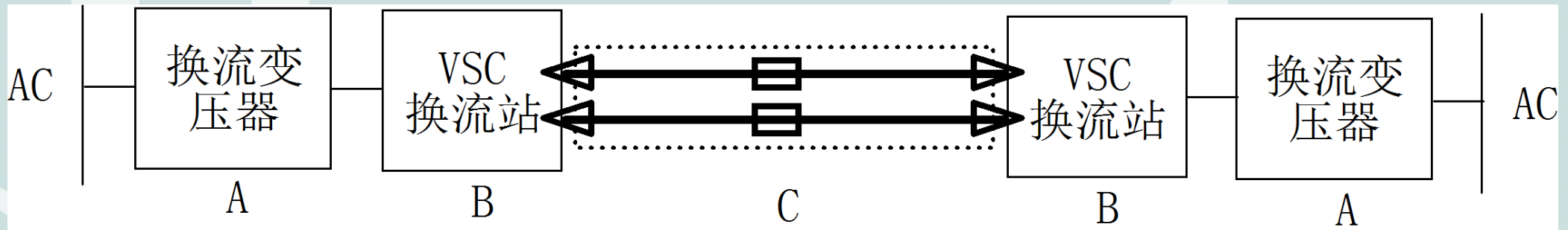
- Offshore wind power entry grid
- Constructing urban DC transmission and distribution grid
- Offshore platform power supply
- 跨国电网互联。



1 Overview of HVDC-VSC cable system

3) HVDC-VSC cable system

HVDC-VSC transmission system include converter transformer, converter valve and cable system, which is shown as follow.



Part C in figure represents the HVDC-VSC cable system, including cable, cable accessories (joint and termination).

In China, the technology of HVDC-VSC cable lag behind converter valve technology. At present, the converter valve with the voltage level of $\pm 800\text{kV}$ is developed, but the $\pm 800\text{kV}$ cable system is not yet developed.



1 Overview of HVDC-VSC cable system

4) The development status of HVDC-VSC cable system

The HVDC-VSC cable is mainly XLPE (crosslinked polyethylene) cable, and NKT corporation is leading the world in the HVDC-VSC XLPE cable, which develop the HVDC cable with highest voltage level of $\pm 640\text{kV}$. At present, there are about 30 HVDC-VSC projects in commission in the world, but the highest voltage is $\pm 320\text{kV}$.

With the development of HVDC-VSC transmission, the State Grid Corporation of China (SGCC) attach importance to the investigation of HVDC submarine cable, and set several technology projects to support the development of HVDC submarine cable system. Especially, SGCC set the special technology project to support the $\pm 500\text{kV}$ submarine cable system in 2016 in order to support the Global Energy Interconnection.

Contents

- 1 Overview of HVDC-VSC cable system
- 2 The investigation on HVDC cable insulation materials**
- 3 The development of HVDC submarine cable
- 4 The development of HVDC submarine cable accessories
- 5 HVDC-VSC projects and application prospect



2 The investigation on HVDC cable insulation materials

1) Introduction of HVDC-VSC cable insulation materials

- In world, the well-known corporations are developing the HVDC-VSC cable insulation materials, for example Borealis (Borouge), Dow, NUC in Japan, Hanwha in Korea etc..
- At present, the HVDC-VSC cable materials (including insulation and screen) are mainly from Borealis. The insulation material have the excellent electric and Scorching resistance performanc, it is the appropriate material for long submarine cable. Additionally, it yet owns the corresponding super-smooth screen material.
- In China, the HVDC-VSC cable insulation material is all from import. At present, the insulation materials with the voltage of $\pm 160\text{kV}$, $\pm 200\text{kV}$ and $\pm 320\text{kV}$ are from Borealis.



2 The investigation on HVDC cable insulation materials

2) The properties of HVDC cable insulation material

According to the investigation of HVDC cable insulation material, it should have the following properties:

- Suppressing the accumulation of space charge;
- The high DC breakdown electric field;
- The high electrical resistivity, which is insensitive with temperature and electric field;
- The uniform material properties;
- The excellent extruding performance, meaning the few scorched product.

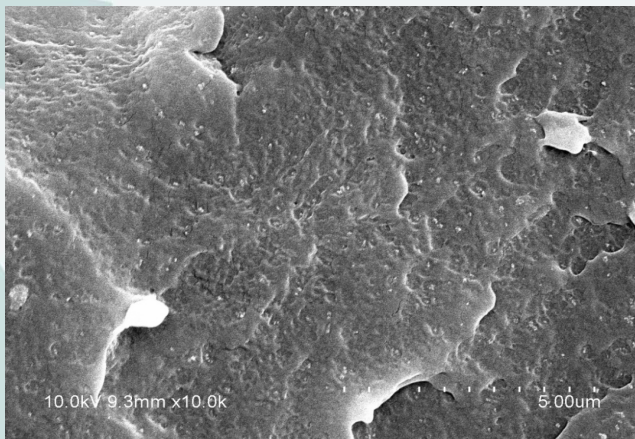
2 The investigation on HVDC cable insulation materials

3) The investigation of HVDC cable insulation materials in China

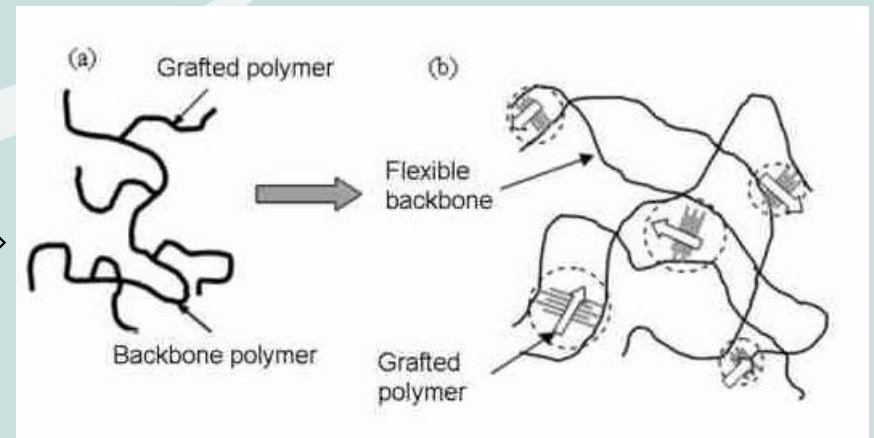
In China, some research institutes are engaged in the development of HVDC cable insulation materials. In order to suppress the accumulation of space charge, the LDPE resin is mainly modified by physical or chemical methods, which can be expressed as follows:

- Nano doping. Mixing the metallic oxide into LDPE, for example MgO, SiO₂ etc..
- Chemical grafting. Grafting the polar molecular group onto LDPE chain, for example maleic anhydride, sorbitol etc..

nano
doping →



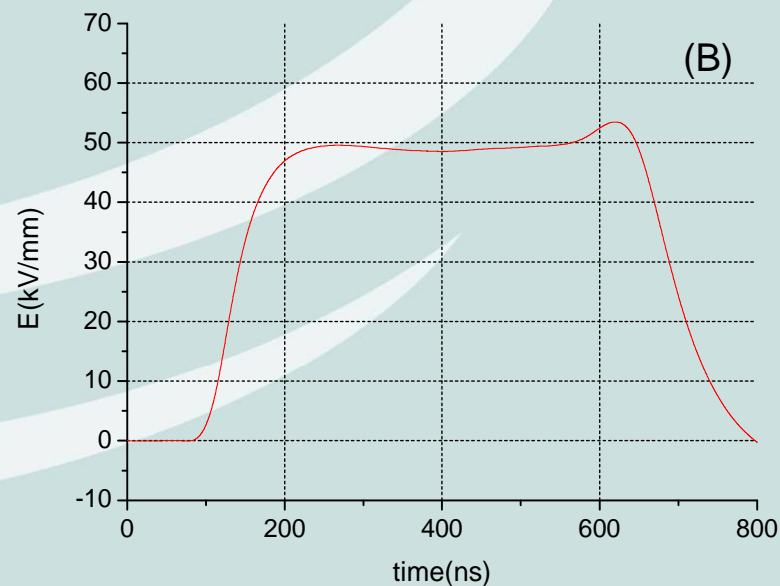
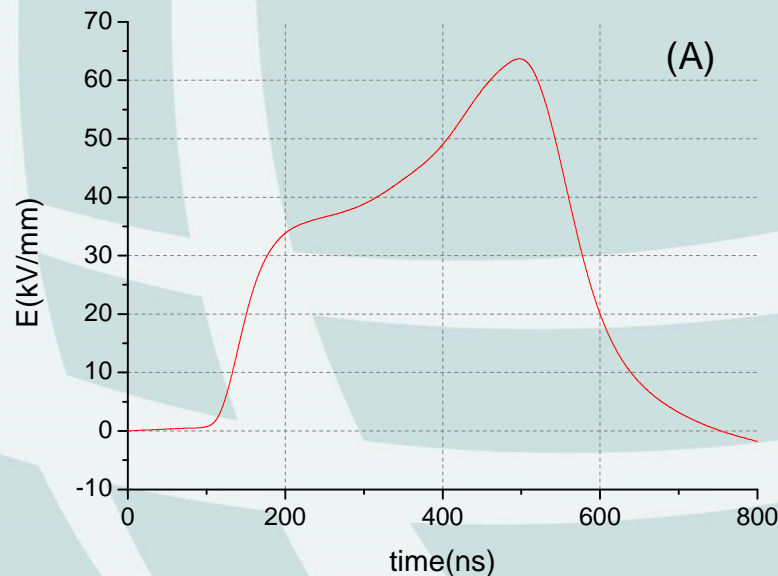
chemical
grafting →



2 The investigation on HVDC cable insulation materials

3) The investigation of HVDC cable insulation materials in China

The researchers study on the space charge distribution of LDPE under different conditions, for example temperature, electric field, time etc.. It indicates that the insulation material developed by China have the excellent space charge suppressing performance.



(A) electric field distribution of AC materials, (B) electric field distribution of DC materials (Test condition: 1 h, -50 kV/mm, 40°C)

2 The investigation on HVDC cable insulation materials

3) The investigation of HVDC cable insulation materials in China

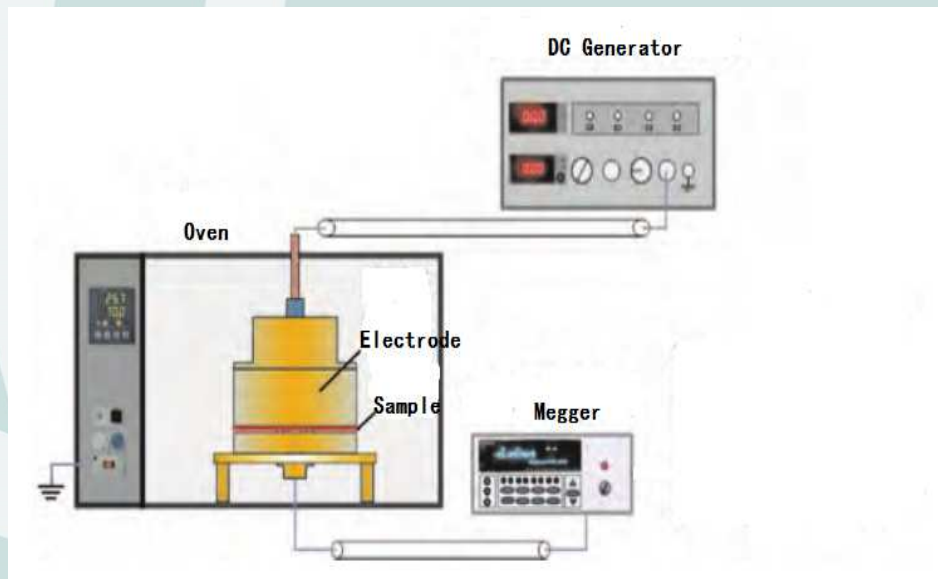
items		DC material	AC material
DC breakdown field - Weibull (kV/mm)	20°C	406	442
	50°C	253	235
	70°C	257	200
	90°C	259	190
KT,DC	E50/E20	0.62	0.53
	E70/E20	0.63	0.45
	E90/E20	0.64	0.43

It can be concluded that the breakdown electric field of DC material is higher than AC material. Additionally, the breakdown field at high temperature of DC material is also higher, i.e. its $K_{T,DC}$ coefficient is bigger.

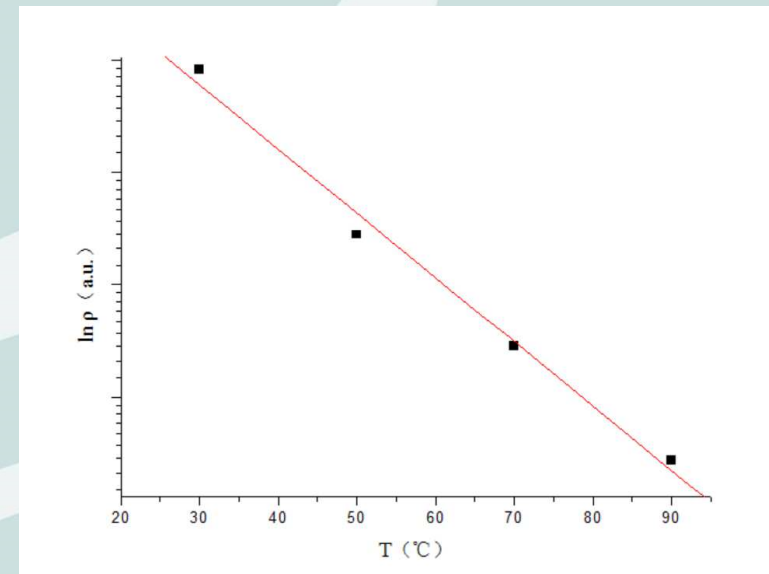
2 The investigation on HVDC cable insulation materials

3) The investigation of HVDC cable insulation materials in China

The relationship between resistivity and temperature is studied, it indicates that there is linear relation between logarithm of resistivity and temperature. Additionally, it is also found that the logarithm of resistivity is linear with the logarithm of field.



Volume resistivity test system



The relation of ρ - T

Further research shows that the smaller dependence of resistivity on temperature and electric field, the better performance of insulation material.



2 The investigation on HVDC cable insulation materials

4) Problems for development of HVDC cable insulation material in China

There are some problems for development of HVDC cable insulation material in China, they can be expressed as follows:

➤ The PE resin is not applicable to HVDC cable insulation. There are much impurities (including physical and chemical impurities) in PE resin, and its performance is not stable.

In order to solve the above problem, the petrochemical corporations in China are constructing the special production line for PE resin using in HV cable insulation.

➤ During the nano powder doping into LDPE, the nonuniform doping may lead to difference of material performance. Additionally, some impurities are inevitably introduced to the LDPE.

Contents

- 1 Overview of HVDC-VSC cable system
- 2 The investigation on HVDC cable insulation materials
- 3 The development of HVDC submarine cable**
- 4 The development of HVDC submarine cable accessories
- 5 HVDC-VSC projects and application prospect



3 The development of HVDC submarine cable

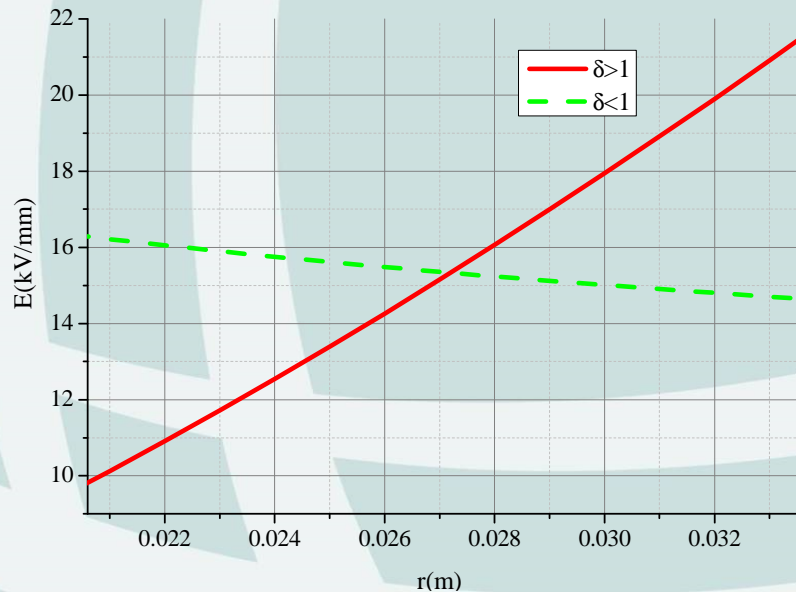
1) The status of HVDC submarine cable

- The HVDC-VSC submarine cable is mainly XLPE cable, NKT corporation have the leading technology for HVDC-VSC cable. At present, there are more than 30 HVDC-VSC projects in commission in world, and the highest voltage of operating cable is $\pm 320\text{kV}$.
- The main HVDC submarine corporations concentrate in Europe, including NKT, Prysmian, Nexans, but the latter two mainly produce MI cable. The XLPE cable with the highest voltage of $\pm 640\text{kV}$ developed by NKT have passed the type test and pre-qualification test, and the $\pm 600\text{kV}$ HVDC cable named P-Laser by Prysmian have passed test verification.
- In China, The $\pm 320\text{kV}$ and $\pm 200\text{kV}$ HVDC cables is in commission, and the $\pm 500\text{kV}$ HVDC-VSC submarine cable has passed the type test.

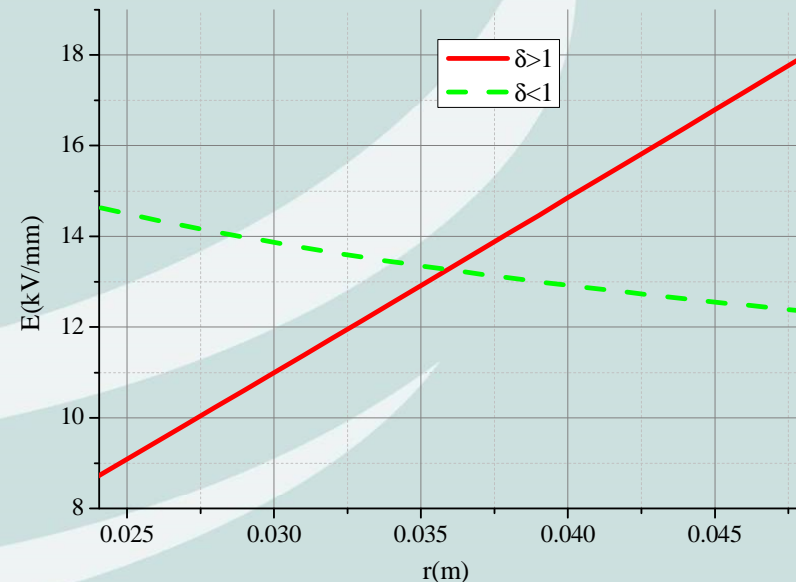
3 The development of HVDC submarine cable

2) The characteristic of electric field for HVDC submarine cable

Differently from AC electric field, DC electric field depends on the resistivity, which is related to T (temperature), E (electric field) and ΔT (difference in temperature).



The field distribution for $\pm 200\text{kV}$ cable



The field distribution for $\pm 320\text{kV}$ cable

The highest E appears at outer insulation in the case of high conductor temperature, and it make the design of HVDC cable accessory difficult.

3 The development of HVDC submarine cable

3) Design of HVDC-VSC submarine cable

The key point for HVDC-VSC submarine cable is thickness design of insulation, which is decided by DC breakdown field and impulse breakdown field. Both of the DC breakdown field and impulse breakdown field are investigated seldomly in China.

$$d_{dc} = U_{dc}/E_{dc}$$

$$d_{pu} = U_{pu}/E_{pu}$$



Additionally, the effect of space charge on insulation thickness should be further studied besides the Bader coefficient.

3 The development of HVDC submarine cable

4) The type test of HVDC-VSC submarine cable system

Some test institutions are qualified for $\pm 500\text{kV}$ submarine cable system type test in China, and ChangZhou Test Institution of SGCC is even qualified for $\pm 800\text{kV}$ test. The main submarine cable corporations have passed the $\pm 500\text{kV}$ type test.



The type test of $\pm 500\text{kV}$ submarine (ChangZhou Test Institution of SGCC)

Contents

- 1 Overview of HVDC-VSC cable system
- 2 The investigation on HVDC cable insulation materials
- 3 The development of HVDC submarine cable
- 4 The development of HVDC submarine cable accessories**
- 5 HVDC-VSC projects and application prospect



4 The development of HVDC submarine cable accessories

1) The key points of HVDC submarine cable accessories

- Comparing to HVDC cable, the electric field in accessories insulation is more complex. For the accessories, the double-layer insulation (cable insulation and accessories insulation) must be considered.
- The relationship between resistivity and temperature, electric field for the insulations of cable and stress-relief cone should be considered.
- The mechanism of space charge accumulation in the interface of double-layer insulation should be investigated.
- The insulating tube is easy to absorb dust under the DC electric field, and the creepage ratio should be designed according to the operating condition.

4 The development of HVDC submarine cable accessories

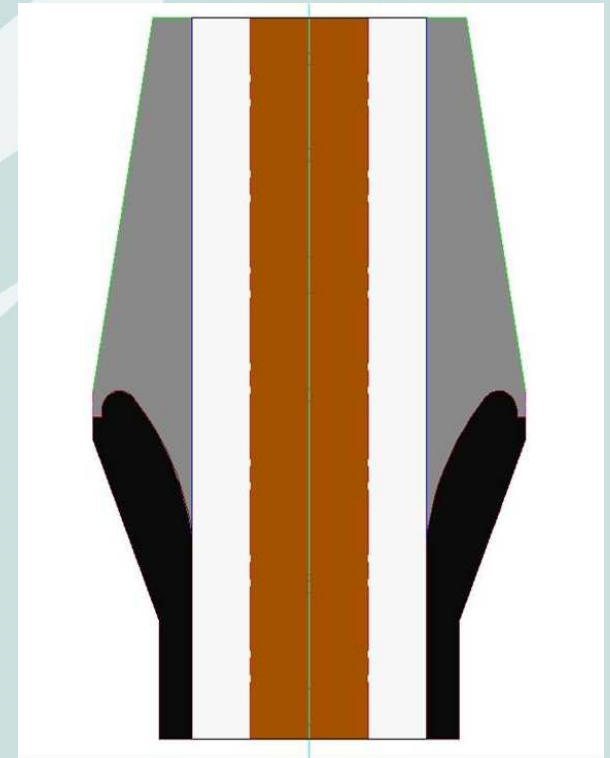
2) The design of HVDC submarine cable accessories

The stress-relief cone is the key part of HVDC submarine accessories. The investigation includes the insulation materials, structure design.

To control the electric field in the interface of cable/accessories, the resistivity of insulation material of the stress-relief cone should match with cable insulation.

To control the electric field in the stress-relief cone and at the interface, the cone curve between insulation and semi-conductor should be designed.

The $\pm 500\text{kV}$ cable accessories have been developed, and passed the type test in China.



Contents

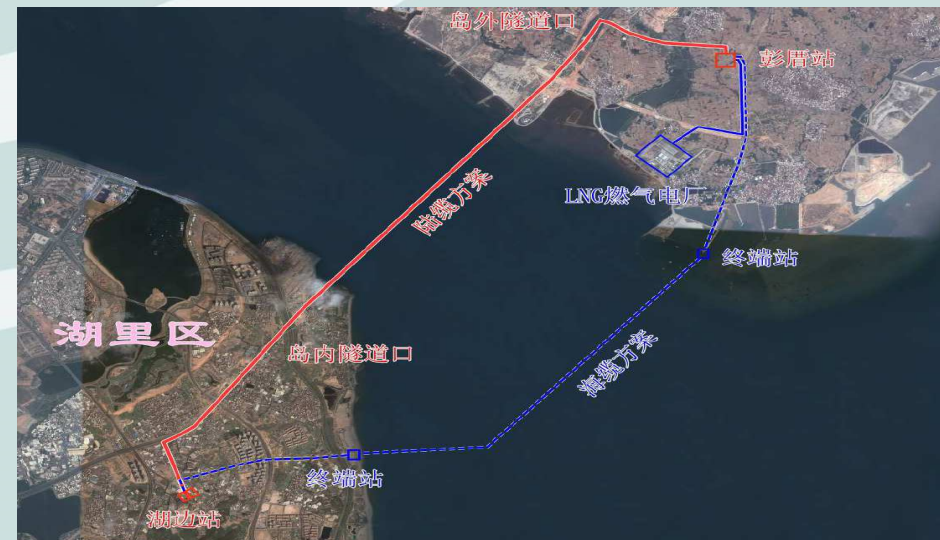
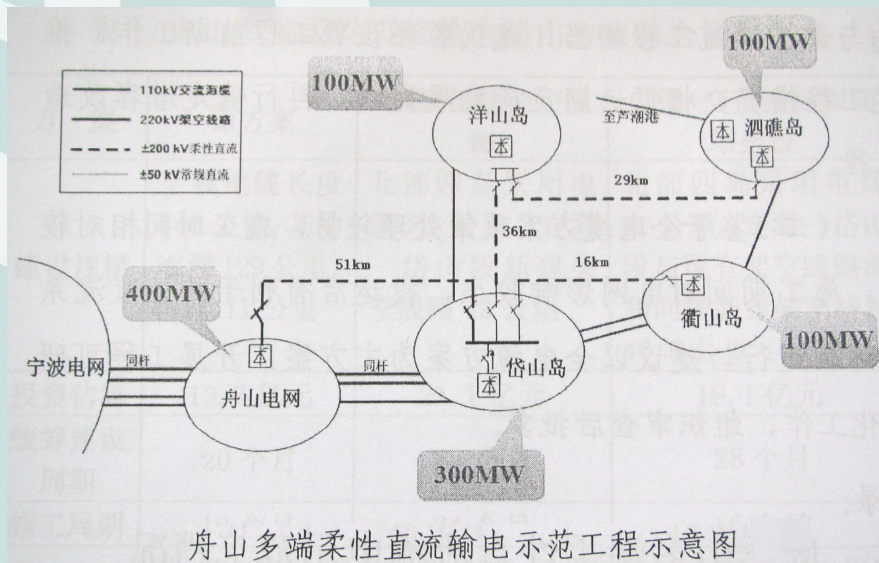
- 1 Overview of HVDC-VSC cable system**
- 2 The investigation on HVDC cable insulation materials**
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- 4 The development of HVDC submarine cable accessories**
- 5 HVDC-VSC projects and application prospect**

5 HVDC-VSC projects and application prospect

1) The typical HVDC-VSC projects in China

$\pm 200\text{kV}$ Zhoushan HVDC-VSC project. It is the first four terminal project in world, the whole capacity of converter stations is 900MW, and the line length is about 140km.

$\pm 320\text{kV}$ Xiamen HVDC-VSC project. The capacity is 1000MW, and it is in commission by the end of 2015. At present, it is the HVDC-VSC project with the highest voltage and the biggest capacity in China.





5 HVDC-VSC projects and application prospect

2) The application prospect of HVDC-VSC in China

➤ Renewable energy access network

SGCC is building the $\pm 535\text{kV}$ Zhangbei HVDC-VSC project, aim to use the wind energy and solar in Zhangjiakou, Hebei province. China is building the HVDC-VSC project for developing the offshore wind power in southeast coast, for example $\pm 400\text{kV}$ HVDC-VSC project with the line length of 100km in Rudong, Jiangsu province

➤ power supply of island

China owns more than 5000 islands, they need to connect to the mainland power grid for the reason of power increase and economic development

➤ power increase of city

HVDC-VSC transmission is the good way for solving the power increase and shortage of power transmission corridor

5 HVDC-VSC projects and application prospect

3) Strategy of Global Energy Interconnection Development and Cooperation Organization (GEIDCO)

“Memorandum of Cooperation on Power Interconnection in Northeast Asian” was signed by SGCC, Korea Electric Power Corporation, Softbank Corporation of Japan and Russian Power Grid Corporation on March 30, 2016, and the power interconnection in Northeast Asian has been discussed.

- The global energy interconnection contain domestic interconnection, intracontinental interconnection and intercontinental interconnection, and HVDC-VSC is the key technology in inerconnection.

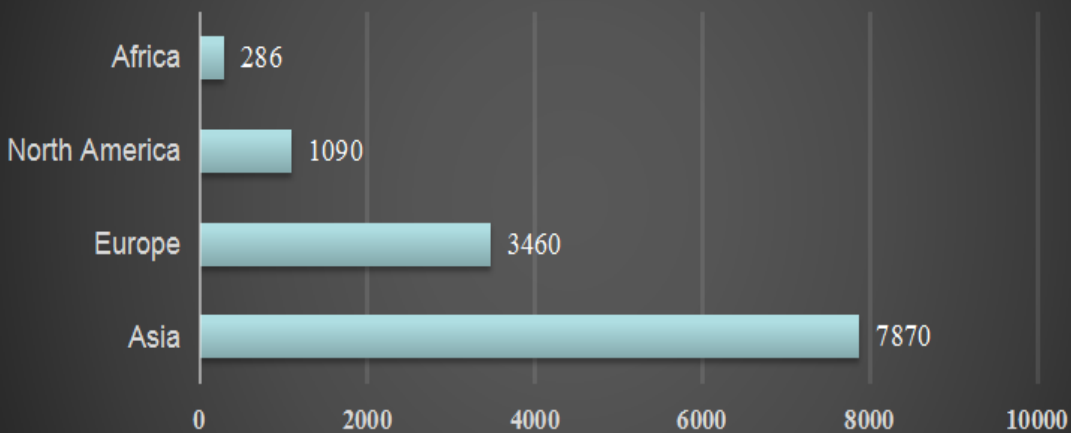


5 HVDC-VSC projects and application prospect

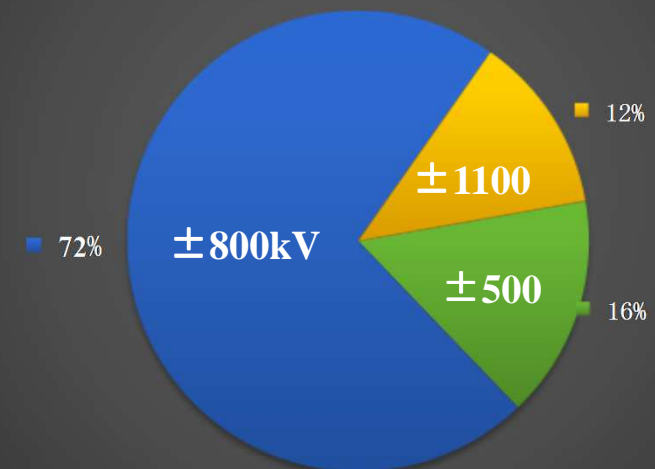
According to the plan of GEI from GEIDCO, the future HVDC projects with the voltage level of more than $\pm 500\text{kV}$ (including $\pm 500\text{kV}$, $\pm 800\text{kV}$, $\pm 1100\text{kV}$) is:

- Total projects: 32
(Asia 18, Europe 8, North America 2, Africa 4)
- Total length: 12700km
- Total capacity: over 253GW

Total length for submarine cable projects in different continent/km



The voltage levels for submarine cable projects /kV





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Thank you !