Content

- **SGCC and CET Overview**
- HVDC Flexible Technology
- Comparison of Conventional HVDC and Flexible HVDC
- Applications of Flexible HVDC
- Flexible HVDC in China
# Overview of SGCC

<table>
<thead>
<tr>
<th></th>
<th>Forbes Global 500</th>
<th>Annual Electricity Sales</th>
<th>Transmission Lines Total Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7th</td>
<td>3522.7 Billion kWh</td>
<td>771,000 km</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Geographic Coverage of China</th>
<th>Annual Revenues</th>
<th>Substation Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>88%</td>
<td>341.5 Billion USD</td>
<td>3,030,000 MVA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Population Coverage of Service</th>
<th>Total Asset</th>
<th>Number of Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.1 Billion</td>
<td>426.7 Billion USD</td>
<td>1.86 million</td>
</tr>
</tbody>
</table>

Service Coverage of China

- State Grid Dispatch Center

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Overview of CET

China Electric Power Equipment and Technology Co., Ltd. (CET)

◆ CET is the operation platform and executor for SGCC to carry out international EPC business.

◆ Relying on the advanced technical capabilities and operating experience of SGCC in fields such as UHV and smart grid, CET exploits its comprehensive advantages in capital, management and brand and implements strategic cooperation with domestic and foreign enterprises.

◆ CET actively participates in the international power engineering market, aspiring to become a world-class EPC contractor.
Integrated Solutions for HVDC Projects

- **100% SGCC own technology** and intellectual property right
- Full package solution for **Design, Engineering, Construction, Commission, Operation and Maintenance**
- Core technology for key HVDC equipments manufacturing
- Full range HVDC solutions from ±125kV to ±1100kV
- Leading-level know-how of HVDC system design
- Integrated project solution for different clients
- Outstanding performance of project operation
- Strong financing capability
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- SGCC and CET Overview
- **HVDC Flexible Technology**
- Comparison of Conventional HVDC and Flexible HVDC
- Applications of Flexible HVDC
- Flexible HVDC in China
The demand for secure, reliable and sustainable energy is increasing, human being wants technologies to deliver the energy with lower environmental impact, greater reliability and increased availability.

**HVDC technology is an old technology.** It had been developed in 1930s in Europe. It has been used primarily for bulk electrical transmission over long distances for interconnecting separate power grid, hydro power and thermal power excavation. Till now, there are more than 100 HVDC projects in operation all over the world and about 1/3 of them are in China. Once installed, HVDC transmission systems often form the backbone of an electric power system, combining high reliability with a long, useful life.

**HVDC technology is also a new technology.** HVDC light is a kind of new technology and developed by Europe at the end of 20th century. It had been used to transmit power by overhead line and ground and submarine cables for offshore links to wind farms and oil and gas platforms.
HVDC Technology

What is HVDC Flexible

VSC-HVDC (Voltage Source Converter)

ABB: HVDC Light
Siemens: HVDC Plus

China: HVDC Flexible

VSC-HVDC in combination with cables or overhead lines makes transmission systems technically and economically viable over long distance.

In 1997, the first VSC-HVDC project (Hallsjon, 3MW, 2 × 10kV) was in operation by ABB.
Technical Features

◆ Integrating renewable energy, hydro, wind and solar into the grid system
◆ Provision of electricity into well populated city centers
◆ Enabling remote load connections such as island, offshore platform
◆ Overcoming limits in the new right-of-way by land and sea
◆ Environment friendly (noise, radio intervention, magnetic field)
◆ Compact design and short construction period
◆ Stabilizing the transmission grid (STATCOM)
HVDC Technology

DC Control & Protection

Converter Unit
- Converter Valve
- Interface Transformer
- Cooling System
- Others

AC Yard
- Start-up Resistor
- Bridge-arm Reactor
- AC Arrester/Switch
- Others

DC Yard
- Smoothing Reactor
- DC Arrester/Switch
- DC Bushing
- Others

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HVDC Technology

VSC-HVDC Converter

One-storey layout

Compact and flexible station layout

Valve hall

AC yard

DC yard

Two-storey layout
HVDC Technology

Weakness of HVDC flexible

- Expensive Underwater Cable or Underground Cable
- Complex Underwater cable laying
- High loss
- Mass Impregnated HVDC Cable
## Project Performance

<table>
<thead>
<tr>
<th>Project</th>
<th>Year</th>
<th>Power MW</th>
<th>Voltage kV</th>
<th>Voltage at Ends</th>
<th>Current A</th>
<th>Length km</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hellsjon</td>
<td>1997</td>
<td>3</td>
<td>±10</td>
<td>10/10</td>
<td>150</td>
<td>10</td>
<td>Test</td>
</tr>
<tr>
<td>Gotland</td>
<td>1999</td>
<td>54</td>
<td>±80</td>
<td>80/80</td>
<td>350</td>
<td>2×70</td>
<td>Wind Farm/Cable</td>
</tr>
<tr>
<td>Directlink</td>
<td>2000</td>
<td>180</td>
<td>±80</td>
<td>132/110</td>
<td>342</td>
<td>6×59</td>
<td>Interconnection</td>
</tr>
<tr>
<td>Tjaerebog</td>
<td>2000</td>
<td>7.2</td>
<td>±9</td>
<td>10.5/10.5</td>
<td>358</td>
<td>2×4.3</td>
<td>Wind Farm Demonstration</td>
</tr>
<tr>
<td>Eagle Pass</td>
<td>2000</td>
<td>36</td>
<td>±15.9</td>
<td>132/132</td>
<td>1100</td>
<td>0(B-B)</td>
<td>Interconnection/Cable</td>
</tr>
<tr>
<td>Cross Sound</td>
<td>2001</td>
<td>330</td>
<td>±150</td>
<td>345/138</td>
<td>1175</td>
<td>2×40</td>
<td>Interconnection/Cable</td>
</tr>
<tr>
<td>Cahle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murray Link</td>
<td>2002</td>
<td>200</td>
<td>±150</td>
<td>132/220</td>
<td>1400</td>
<td>2×180</td>
<td>Interconnection/Cable</td>
</tr>
<tr>
<td>TrollA</td>
<td>2005</td>
<td>2×42</td>
<td>±60</td>
<td>56/132</td>
<td>400</td>
<td>4×70</td>
<td>Subsea Cable</td>
</tr>
<tr>
<td>Estlink</td>
<td>2006</td>
<td>350</td>
<td>±150</td>
<td>400/330</td>
<td>1230</td>
<td>2×72</td>
<td>Interconnection/Cable</td>
</tr>
</tbody>
</table>
## Project Performance

<table>
<thead>
<tr>
<th>Project</th>
<th>Year</th>
<th>Power MW</th>
<th>Voltage ±kV</th>
<th>Voltage at Ends</th>
<th>Current A</th>
<th>Length km</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valhall</td>
<td>2010</td>
<td>78</td>
<td>±150</td>
<td>300/11</td>
<td>-</td>
<td>292</td>
<td>Subsea Cable</td>
</tr>
<tr>
<td>Nord E.ON 1</td>
<td>2009</td>
<td>400</td>
<td>±150</td>
<td>170/380</td>
<td>-</td>
<td>203</td>
<td>Wind Farm</td>
</tr>
<tr>
<td>Trans Bay Cable</td>
<td>2010</td>
<td>400</td>
<td>±200</td>
<td>400</td>
<td>-</td>
<td>88</td>
<td>City Center</td>
</tr>
<tr>
<td>Nanhui</td>
<td>2011</td>
<td>18</td>
<td>±30</td>
<td>35</td>
<td>300</td>
<td>10</td>
<td>Wind Farm</td>
</tr>
<tr>
<td>East West Interconnector</td>
<td>2012</td>
<td>500</td>
<td>±200</td>
<td>-</td>
<td>1250</td>
<td>-</td>
<td>Interconnection</td>
</tr>
<tr>
<td>DolWin1</td>
<td>2013</td>
<td>800</td>
<td>±320</td>
<td>150/380</td>
<td>1250</td>
<td>75/90</td>
<td>Wind Farm</td>
</tr>
<tr>
<td>Skagerrak HVDC</td>
<td>2014</td>
<td>700</td>
<td>±500</td>
<td>400</td>
<td>1400</td>
<td>140/104</td>
<td>Interconnection</td>
</tr>
<tr>
<td>Zhoushan</td>
<td>2014</td>
<td>1000</td>
<td>±200</td>
<td>220</td>
<td>1000/500</td>
<td>148</td>
<td>Subsea Cable</td>
</tr>
</tbody>
</table>

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+/-500kV Long Quan Converter Station
Conventional Converter Station

AC Line
交流输电线

AC switchyard
交流场

Converter Transformer
换流变

Valve Hall
阀厅

DC line
直流输电线

Shunt Capacitor
并联电容器

AC Fliter
滤波器

DC Switchyard
直流场

Approximately 80 x 180 meters
HVDC Flexible Converter Station

Daishan Converter Station
Comparison of Conventional HVDC and Flexible HVDC

Current source Converter
Conventional HVDC

Voltage Source Converter
Flexible HVDC

<table>
<thead>
<tr>
<th>Constant Voltage</th>
<th>Constant Current</th>
<th>Constant Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thyristor</td>
<td>CSC</td>
<td>VSC</td>
</tr>
<tr>
<td>Constant Voltage</td>
<td>Constant Current</td>
<td>Constant Voltage</td>
</tr>
<tr>
<td>IGBT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Comparison of Conventional HVDC and Flexible HVDC

Current source Converter Conventional HVDC

A

Converter Transformer

Rectifier

Rectifier

DC

AC

B

Converter Transformer

Inverter

Inverter

HVDC Transmission Line

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Comparison of Conventional HVDC and Flexible HVDC

Voltage Source Converter Flexible HVDC

Voltage Source Converter (VSC) connected to the HVDC transmission line.
## Comparison of Conventional HVDC and Flexible HVDC

<table>
<thead>
<tr>
<th>Description</th>
<th>HVDC Flexible</th>
<th>HVDC Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi Conductor</td>
<td>Fully controlled, IGBT</td>
<td>Half controlled, thyristor</td>
</tr>
<tr>
<td>Power control</td>
<td>Independent control of active and reactive power</td>
<td>Active power control</td>
</tr>
<tr>
<td>Powering weak or passive system</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dynamic voltage support</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Filtering and Var compensation</td>
<td>Little or even no need</td>
<td>Yes</td>
</tr>
<tr>
<td>Multi-terminal</td>
<td>Easy</td>
<td>Difficult</td>
</tr>
<tr>
<td>Footprint</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Communication</td>
<td>No communication</td>
<td>Yes</td>
</tr>
<tr>
<td>Loss</td>
<td>1%(C/S)</td>
<td>0.75%(C/S)</td>
</tr>
<tr>
<td>Type of Conductor</td>
<td>Cable</td>
<td>Conductor</td>
</tr>
</tbody>
</table>

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Applications of Flexible HVDC

Isolate load supply

Island, cities or industry in remote locations

- Can operate into very weak or even passive network
- Increase availability of electric power supply
- Reduce carbon emission associated with local power generation
- Small footprint and light weight due to compact converter structure

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Applications of Flexible HVDC

Offshore wind power grid integration

Key source of large-scale renewable energy supply

- An effective solution for offshore wind integration farms
- No transmission distance limit compared to AC solutions
- Reactive power control and voltage support
- Compact design

Atlantic wind connection (AWC)

<table>
<thead>
<tr>
<th>Expected date of Commissioning</th>
<th>Long-term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated capacity</td>
<td>7000MW in total</td>
</tr>
<tr>
<td>Cable length</td>
<td>483km-subsea cable</td>
</tr>
<tr>
<td>Type</td>
<td>VSC-HVDC</td>
</tr>
</tbody>
</table>
Applications of Flexible HVDC

City Center infeed

- Eliminate the difficulties to secure new right-of-way
- No visual or environment impact using cable
- No contribution to system short-circuit levels

### Dalian city in-feed

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commissioning year</td>
<td>2013</td>
</tr>
<tr>
<td>Rated capacity</td>
<td>1000 MW</td>
</tr>
<tr>
<td>Rated DC voltage</td>
<td>±320 kV</td>
</tr>
<tr>
<td>Cable length</td>
<td>43 km subsea cable</td>
</tr>
<tr>
<td>Type</td>
<td>VSC-HVDC</td>
</tr>
</tbody>
</table>
Applications of Flexible HVDC

Multi-terminal scheme

- No change of DC voltage polarity during power reversal
- Increase reliability and security of all grids involved

<table>
<thead>
<tr>
<th>Zhoushan multi-terminal scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Commissioning</strong></td>
</tr>
<tr>
<td><strong>Rated capacity</strong></td>
</tr>
<tr>
<td><strong>Rated DC voltage</strong></td>
</tr>
<tr>
<td><strong>Cable length</strong></td>
</tr>
<tr>
<td><strong>Type</strong></td>
</tr>
</tbody>
</table>
Applications of Flexible HVDC

- Power can flow in both directions
- Networks stability
- Underground and underwater cable transmission over distance in the range of 50-100kM
- Black-start capability

+-200MW East-West Interconnector (500MW)
Content

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➢ Flexible HVDC in China
2/3 coal resources, wind power, solar power located in the North and North-West of China

4/5 of hydropower located in the South-West of China

Over 2/3 of the power demand concentrates in the East and Central of China

The imbalance allocation of generation resources and consumption centers needs strong and smart grid.
Flexible HVDC in China

China's grid in the future

- **By 2015**
  - North China-central china-east china with 1000kV AC synchronous interconnection
  - West China-Northeast-CSG with DC asynchronous networking
  - Cross regional power transmission: 260GW
  - UHV power transmission: 150GW
  - Wind power access to grid: 100GW

- **By 2020**
  - More than 20 UHV lines
  - Cross regional power transmission: 420GW
  - UHV power transmission: 330GW
  - Wind power access to grid: 200GW
Flexible HVDC in China

M2000 VSC-HVDC converter

- Up to 1000MW/±320kV, using 300V/1500A IGBT
- Easily scalable with modular design
- Superior inflammability conforming to UL94
- Excellent seismic performance (0.2g typical)
- KEMA certification
- Easy assembly and maintenance

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Flexible HVDC in China

- **Interface transformer**
  - Voltage: 220/330kV
  - Capacity: 350MVA
  - Single-phase oil-immersed type

- **Bridge arm reactor**
  - Inductance: 104mH
  - Dry-type air-core

- **Valve cooling system**
  - Cooling capacity: 4320kW
  - Flow rate: 369m³/h
  - Ambient temperature: -21.1°C to 38.1°C

---

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Flexible HVDC in China

**Power System Power Electronics Lab**

- Type tests for HVDC valves
  - LCC-HVDC valve up to \( \pm 1100 \text{kV} / 6250 \text{A} \)
  - VSC-HVDC valve up to \( \pm 500 \text{kV} / 2000 \text{A} \)
- Type tests for the whole family of FACTS valve, incl. SVC, TCSC, SCR, etc.
- Accredited by China National Accreditation Board for Conformity Assessment (CNAS)

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**AC voltage test facilities**
- 600kV/5A

**DC voltage test facilities**
- \( \pm 2400 \text{kV} / 300 \text{mA} \)

**Synthetic operational test facilities**
- 80kV/7500A

**IGBT valve test facilities**
- 20kV/2000A
Flexible HVDC in China

Laboratory of DC Grid Technology & Simulation

- System analysis and design verification
- Verification of Control & Protection system, MMC-Valve and VBC configuration
- Simulate up to 6000 SM’s (up to ±500kV VSC-HVDC Scheme)
- Suitable for the simulation of up to 20-terminal VSC-HVDC system
- Scalable to simulate and verify a AC system with more than 300 buses
## Flexible HVDC in China

### Conventional HVDC Project of SGCC in operation

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>In operation</th>
<th>In Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>± 400kV</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>± 500kV</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>± 660kV</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>± 800kV</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>BTB</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
# Flexible HVDC in China

## Flexible HVDC Projects in China

<table>
<thead>
<tr>
<th>No.</th>
<th>Project name</th>
<th>Voltage</th>
<th>Capacity</th>
<th>Distance</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nanhui wind farm integration</td>
<td>±30kV</td>
<td>18MW</td>
<td>8.4km (land cable)</td>
<td>2011</td>
</tr>
<tr>
<td>2</td>
<td>Zhoushan five-terminal interconnection</td>
<td>±200kV</td>
<td>1000MW</td>
<td>141 (incl. 129km subsea cable)</td>
<td>2014</td>
</tr>
<tr>
<td>3</td>
<td>Xiamen Island power supply</td>
<td>±320kV</td>
<td>1000MW</td>
<td>10.7km (subsea cable)</td>
<td>2015(under construction)</td>
</tr>
<tr>
<td>4</td>
<td>Yu-E HVDC Interconnection</td>
<td>±400kV</td>
<td>4x1250MW</td>
<td>BtB</td>
<td>2017(planning)</td>
</tr>
</tbody>
</table>
Typical Projects (Domestic)

Nanhui Demostration Project

- Links Nanhui wind farm to the Shanghai main grid
- C-EPRI undertook system design, equipment supply and project implementation, excluding civil works.

**Main data**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Commissioning year</td>
<td>2011</td>
</tr>
<tr>
<td>Rated capacity</td>
<td>18MW</td>
</tr>
<tr>
<td>Rated DC voltage</td>
<td>±30kV</td>
</tr>
<tr>
<td>Cable length</td>
<td>8.4km land XLPE cable</td>
</tr>
<tr>
<td>Type</td>
<td>VSC-HVDC</td>
</tr>
</tbody>
</table>
## Typical Projects (Domestic)

### Zhoushan ±200kV Flexible HVDC Project (Completed)

<table>
<thead>
<tr>
<th>Transmission Capacity</th>
<th>500+400+300+2x100 MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned Construction Period</td>
<td>March 2013-June 2014</td>
</tr>
<tr>
<td>Total Length</td>
<td>140.4 km</td>
</tr>
</tbody>
</table>
Zhoushan ±200kV Flexible HVDC Project (Completed)

- Total electric power capacity: 1,000 MW
- The first Five-Terminal flexible HVDC transmission project in the world.
- Construction Period: 15 months, from March, to June, 2014
- Self-developed multi-terminal flexible HVDC technology by SGCC
- All equipment and material from Chinese manufacturers
- Hybrid DC and AC grid
Xiamen Multi-terminal HVDC Project

- Rated at ±320kV/1200MW
- Upon completion, the reliability of electric power supply will be improved in Xiamen; furthermore, this project would have a significant influence on the development of VSC HVDC in China.

<table>
<thead>
<tr>
<th>Commissioning year</th>
<th>Sep, 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated capacity</td>
<td>1000MW</td>
</tr>
<tr>
<td>Rated DC voltage</td>
<td>±320kV</td>
</tr>
<tr>
<td>Type</td>
<td>VSC-HVDC</td>
</tr>
</tbody>
</table>
### Technical Specification for Converter Station

<table>
<thead>
<tr>
<th>DC current</th>
<th>1600A</th>
<th>Converter Valve</th>
<th>Bipole, 500MW for each pole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Converter Transformer</td>
<td>(3+3)X176.7MVA</td>
<td>AC Substation</td>
<td>220kV/ 2 Transmission line</td>
</tr>
<tr>
<td>Connection Model</td>
<td>One pole, metal return 10kV</td>
<td>Construction Period</td>
<td>16 months</td>
</tr>
</tbody>
</table>

### Technical Specification for Transmission Line

<table>
<thead>
<tr>
<th>Transmission Line</th>
<th>2.1km overhead line+6.2km Cable+2.0km overhead line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable Type</td>
<td>XLPE Copper Condutor</td>
</tr>
<tr>
<td>Cable Size</td>
<td>1800m2(pole)+1600m2(return) (2X10.7kM+1X10.7kM)</td>
</tr>
</tbody>
</table>
Bird View of Converter Station