Siemens Transformers
Power Transformers Nuremberg

HVDC Transformer Technology for Voltages ≥ 800 kV
Recent Projects and Future Trends

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Frank Trautmann

Transformer Factory Nuremberg, Germany
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Introduction

China Project Overview

1. Hami – C. China
   800 kV, 6400 MW, 2018

2. Xijaba – Shanghai
   800 kV, 6400 MW, 2011

3. Xiluodu – Hanzhou
   800 kV, 6400 MW, 2015

4. Xiluodu – Hunan
   800 kV, 6300 MW, 2013

5. Jinsha River II – East China
   800 kV, 6400 MW, 2016

6. Jingping – East China
   800 kV, 7200 MW, 2012

7. Jinsha River II – East China
   800 kV, 6400 MW, 2019

8. Jinsha River II – Fujian
   800 kV, 6400 MW, 2018

9. Nuozhadu – Guangdong
   800 kV, 5000 MW, 2015

10. Jinghong – Thailand
    3000 MW, 2013

11. Yunnan – Guangdong
    800 kV, 5000 MW, 2009

12. Humeng – Liaoning
    800 kV, 6400 MW, 2018

13. Humeng – Tianjiang
    800 kV, 6400 MW, 2016

14. Hulunbeir – Shenyang
    3000 MW, 2009

15. BtB NE-North (Gaoling)
    1500 MW, 2007

16. Humeng – Jinan
    (Shandong)
    800 kV, 6300 MW, 2015

17. North Shaanxi – Shandong
    3000 MW, 2011

18. BtB Shandong – East
    1200 MW, 2011

19. BtB North – Central
    1000 MW, 2012

20. Goupitan – Guangdong
    3000 MW, 2016

21. Ningxia – Tianjing
    3000 MW, 2010

22. NW – Sichuan
    3000 MW, 2010

23. Irkutsk (Russia) – Beijing
    800 kV, 6400 MW, 2015
HVDC (High Voltage Direct Current) Transmission is more efficient for Long Distances (>600km) or Cable Links (>50km) than HVAC (HV Alternating Current)

HVDC is efficient for:
- Overhead lines (>1000MW, >600km)
- Cable Links (about 50km, for >80km or different frequencies the only technical solution)

Advantages of HVDC:
- Low Line Cost, but Converter Cost
- No capacitive charging currents - less losses and CO2 emissions
- Firewall function for grids
- Load flow regulation (HVDC Plus)
- Connection for different frequencies
- High Transmission Power density (usage of less land or space)
- Offshore connections for wind parks or oil rigs (substitution of CO2 emissions from diesel generators)
Introduction
HVDC at 800 kV for economical, long-distance electricity transfer

= HVDC ±800 kV

- Very high power capacity (5,000 MW and higher) of a single system
- 25% lower transmission cost compared to 500 kV HVDC
- Smaller footprint and lower overhead transmission line costs as only one bipole is needed
Introduction
800 kV DC Overhead Line Towers
Introduction

Clear economical advantage of an ±800 kV HVDC solution

Total transmission cost

(5,000 MW over 1,400 km; 30 year lifetime)

<table>
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<tr>
<th>Voltage</th>
<th>Total Transmission Cost Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC 765 kV</td>
<td>100%</td>
</tr>
<tr>
<td>DC ±500 kV</td>
<td>83%</td>
</tr>
<tr>
<td>DC ±800 kV</td>
<td>64%</td>
</tr>
</tbody>
</table>

Legend:
- Losses
- Line costs
- Station costs
System Design
Comparison of schematics of 500 kV and 800 kV HVDC systems

500kV HVDC
- single phase
- 3 winding transformers or
- 2 winding transformers

800kV HVDC
- single phase
- 2 winding transformer

+200 kV
+500 kV
+800 kV
+200 kV
-200 kV
-200 kV
System Design
Insulation Coordination - Insulation Levels

BIL / SIL: 1900 kV / 1600 kV
BIL / SIL: 1800 kV / 1600 kV
BIL / SIL: 1300 kV / 1050 kV
BIL / SIL: 1550 kV / 1300 kV
BIL / SIL: 950 kV / 750 kV
BIL / SIL: 1175 kV / 950 kV
BIL / SIL: 450 kV / 325 kV
Receiving Station
Yunnan - Guangdong
Transformer Design

Typical Winding Arrangements

Valve Winding inside

- Upper Yoke
- Valve Winding
- HV Winding
- Tap
- Core
- Return limb / window
- Lower Yoke

Insulating system is to design both for AC and DC

Insulating system is to design only for AC

Valve Winding outside

- Upper Yoke
- Tap
- HV Winding
- Valve Winding
- Core
- Return limb / window
- Lower Yoke

Insulating system is to design both for AC and DC

Insulating system is to design only for AC

Insulating system is to design only for AC

Insulating system is to design both for AC and DC
Dielectric Stress and Insulation Design

Dielectric Tests (Test Voltages) for AC Transformers

AC Voltage

Switching Impulse

Lightning Impulse (Full Wave)

Lightning Impulse (Chopped Wave)
Long Time AC / DC Voltage Test

- Applied DC voltage duration 2 h, positive polarity, PD-measurement
- Applied AC voltage duration 1 h, PD-measurement

Polarity Reversal (PR) Test according to the IEC standard

- Usual cycle:
  90min(-) → PR 90min(+) → PR → 45 min(-)
  → Applied DC voltage duration 90 min, negative polarity
  → First PR within 1min...2min
  90 min positive polarity
  → Second PR within 1min..2min
  45 min negative polarity
- PD-measurement
Equipotential Lines for AC and DC Electric Field

Equipotential Lines for an AC Field
Dominant for the field distribution:
- Electrostatic displacement field
  \[ D = \varepsilon_0 \cdot \varepsilon_r \cdot E \]

Equipotential Lines for a DC Field
Dominant for the field distribution:
- Stationary Flow Field
  \[ J = \kappa \cdot E \]

Permittivity
pressboard / oil \( \varepsilon_r \) ratio = 2

Conductivity
pressboard / oil \( \kappa \) ratio > 50
Dielectric Stress and Insulation Design

Parameter which influence the Oil Conductivity

Dielectric Stress and Insulation Design

Polarity Reversal (PR)

Change of the Field Strength during and after PR

Applied Voltage

![Graph showing voltage change over time](image)

Equipotential Lines

Electrical Field Distribution
Projects, Developments and Trends

Long time DC or DC polarity reversal test with PD measurement – Test setup

800kV HVDC Transformer
Projects, Developments and Trends
Active Part and Leads Assembly – 800kV HVDC Transformer
Projects, Developments and Trends

Barrier System for the 800 kV Bushing of the Valve-Winding
Projects, Developments and Trends
The World’s first 800 kV UHV DC in China Southern Power Grid

Commercial Operation:
- 2009 – Pole 1
- 2010 – Pole 2

Yunnan-Guangdong

Quelle: Prof, Retzmann
Projects, Developments and Trends

Sending Station Chuxiong
Projects, Developments and Trends

Converter Transformer at Suidong
Projects, Developments and Trends

UHV DC Transformers arriving
Projects, Developments and Trends

UHV DC Transformers arriving
Projects, Developments and Trends

UHV DC logistics – a crucial task
Projects, Developments and Trends

Yunnan-Guangdong – UHV DC Valve Halls

800 kV DC
2 x 400 kV DC
800 kV DC
Projects, Developments and Trends
Yunnan-Guangdong – UHV DC Valve Hall

800 kV DC
Yunnan-Guangdong – UHV DC Converter

400 kV DC
Yunnan-Guangdong – UHV DC Converter

Inauguration first pole on 28.12.2009

800 kV DC

Power Transmission Division
Yunnan-Guangdong – UHV DC Converter

800 kV DC
Projects, Developments and Trends

World's biggest and longest 800 kV UHV DC Transmission Project

State Grid Corporation of China

Quelle: Prof. Retzmann, Siemens
Projects, Developments and Trends
HVDC Transformers

3000 MW, 500KV
TSQ-GBJ

5000 MW, 800kV
Yunnan-Guangdong
250 MVA

6400 MW, 800kV
Xiangjiaba-Shanghai
321,1 MVA

7200 MW, 800kV
Study

2000
2008
2009
2010

in operation
in operation
in operation
Study
Projects, Developments and Trends
Jinping ± 800 kV UHV DC Transmission Project

- Jinping Plant I
- Jinping Plant II
- Leshan
- Xichang
- To Sichuan Power Grid
- Guandi
- Linping
- Wuhan
- Changsha
- Shanghai

2,237 km

* 6.4 GW initially

* 7,200 MW

+/- 800 kV DC

Planned for 2013

For Comparison: Germany

840 km

Source: “Brazil-India-China Summit Meeting on HVDC & Hybrid Systems – Planning and Engineering Issues”, July 2006, Rio de Janeiro, Brazil
# Projects, Developments and Trends

**HVDC Transformers – Technical Data**

<table>
<thead>
<tr>
<th></th>
<th>1. 800 kV</th>
<th>2. 800 kV</th>
<th>3. 800 kV</th>
<th>1. 1100 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Yunnan</td>
<td>Xiangjiaba</td>
<td>Study</td>
<td>Study</td>
</tr>
<tr>
<td></td>
<td>Guangdong</td>
<td>Shanghai</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated Power</td>
<td>5000 MW</td>
<td>6400 MW</td>
<td>7200 MW</td>
<td></td>
</tr>
<tr>
<td>Transformer</td>
<td>250 MVA</td>
<td>321 MVA</td>
<td>360 MVA</td>
<td></td>
</tr>
<tr>
<td>Vector Group</td>
<td>li0</td>
<td>li0</td>
<td>li0</td>
<td></td>
</tr>
<tr>
<td>Ratio</td>
<td>525 kV/√3</td>
<td>530 kV/√3</td>
<td>530 kV/√3</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>168.85 kV/√3</td>
<td>170.3 kV/√3</td>
<td>170.3 kV/√3</td>
<td></td>
</tr>
<tr>
<td>Weights</td>
<td>512 t</td>
<td>551.8 t</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>142 t</td>
<td>148.8 t</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Insulation level</td>
<td>909 kV</td>
<td>912 kV</td>
<td>912 kV</td>
<td></td>
</tr>
<tr>
<td>Line (HV)</td>
<td>LI 1550 kV</td>
<td>SI 1175 kV</td>
<td>AC 680 kV</td>
<td></td>
</tr>
<tr>
<td>Valve (LV)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AC (60min)</td>
<td>912</td>
<td>912</td>
<td>912</td>
<td></td>
</tr>
<tr>
<td>LI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SI Potential</td>
<td>1800 kV</td>
<td>1600 kV</td>
<td>1258 kV</td>
<td></td>
</tr>
<tr>
<td>DC (2h)</td>
<td>1254 kV</td>
<td>1258 kV</td>
<td>1258 kV</td>
<td></td>
</tr>
<tr>
<td>PR -/+/-(90/90/45) min</td>
<td>969 kV</td>
<td>970 kV</td>
<td>970 kV</td>
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Transforming know-how into solutions.

Siemens Transformers.

Thank you for your attention!
Information about the Presenter

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1991 Electrician
till 1997 Electrical Engineering (HV and High Current)
(Dipl.-Ing. TU Dresden and Virginia Tech)
1997-2002 Doctorate, Scientific Assistant (Dr.-Ing. TU Dresden)
Thermal Design of High Voltage Equipment

2002 ABB Switzerland AG
R&D, Design of Generator Circuit Breakers
11/2002-10/2007 SGB Regensburg (SGB/SMIT Group)
Director R&D, Director Engineering
2004-2006 Executive MBA
(Northwestern University Chicago, WHU Koblenz)
since 11/2007 Siemens AG, Power Transformers Nuremberg
Director Engineering and R&D
responsible for R&D, Electrical Design
Mechanical Design and Production Technology