Power Transmission and Distribution

HVDC and FACTS Technology for Global Market Requirements

IEEE-Meeting
May 12, 2004

SIEMENS
Developments of Power Markets

- Increasing Power Demand
- Environmental Constraints
- New Market Conditions
- Strong Competition

Advanced Solutions are required
- Use of Power Electronics
- New Technologies
Trends in Power Systems

Markets
- Dynamic Market Developments
- Involvement of Global Players
- Increasing Power Demand

Publics & Politics
- Growing Population
- Limitation of Resources
- Environmental Constraints

Technologies
- Improvements in Generation
- Increase of Transmission Efficiency
- Power System Interconnections
Development of Power Consumption

- Isolated Small Grids
- Higher Voltage Levels
- High Investments
- Long Distance Transmission
- Transmission Bottlenecks
- Demand for Clean Power & High Quality
- Least Cost Planning
- New Technologies
- Energy Imports

Power Consumption per Capita

Developing Countries  Emerging Countries  Industrialised Countries
The Global Tendency - Increase of Electric Power Demand

Installed Capacity:

Regionally in Gigawatt

<table>
<thead>
<tr>
<th>Region</th>
<th>1990</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Europe</td>
<td>21%</td>
<td>13%</td>
<td>19%</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>16%</td>
<td>27%</td>
<td>8%</td>
</tr>
<tr>
<td>Asia/Pacific</td>
<td>20%</td>
<td>7%</td>
<td>33%</td>
</tr>
<tr>
<td>Africa/Middle East</td>
<td>6%</td>
<td>34%</td>
<td>34%</td>
</tr>
<tr>
<td>North and South America</td>
<td>37%</td>
<td>34%</td>
<td>34%</td>
</tr>
</tbody>
</table>

For Energy Resources in Gigawatt

<table>
<thead>
<tr>
<th>Resource</th>
<th>1990</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>5%</td>
<td>22%</td>
<td>24%</td>
</tr>
<tr>
<td>Oil</td>
<td>10%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>14%</td>
<td>22%</td>
<td>35%</td>
</tr>
<tr>
<td>Oil</td>
<td>22%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Nuclear Power</td>
<td>17%</td>
<td>12%</td>
<td>15%</td>
</tr>
<tr>
<td>Miscellaneous Regeneratives</td>
<td>1%</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>Hydro Power</td>
<td>23%</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>Coal</td>
<td>22%</td>
<td>14%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Source: Siemens PG CS4 - 08/2002

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Potential of Hydropower - Worldwide

Total hydropower potential:
(billion kWh/year)
- Technically feasibly: 14230
- Economically exploitable: 7950
- Total utilized in 2000: 2660

Trends in Power Systems

Globalisation/Liberalisation

Deregulation - Privatisation: Opening of the markets, Independent Transmission Companies ITCs, Regional Transmission Organisations RTOs

Bottlenecks in Transmission

Problem of uncontrolled Loop-Flows Overloading & Excess of SCC Levels System Instabilities / Outages

Investments in Power Systems

System Enhancement & Interconnections:
- Higher Voltage Levels
- New Transmission Technologies
- Renewable Energies
Power Transmission - Connecting Generation to the Users

Power Transmission - It looks so simple - but it is much more than Lines

It needs ...

Intelligent Solutions
Transmission Systems - The VIPs of the Power Market

Regulated Markets:
- one Owner - the Utility

Deregulated Markets:
- Different Owners & Players

Transmission can be
- or

Distribution

Generation

for Cash-Flow & Return of Investments

Figure 3: Loop Flow of Power Transfer from Wisconsin to TVA


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Transmission Solutions

North System 50 Hz

Power Exchange – Asynchronous Networks

Clean & Low Cost Energy

Tariff

Central System 60 Hz

Avoidance of Loop Flows

Clean Energy

Short-Circuit Current Limiter

Submarine Cable Links

Bulk Power & Long Distance

Tariff

South System 60 Hz

Power Exchange

Industrial Energy supply

Symbols:
- △ TPSC/TCSC
- SVC
- FSC
- G GPFC ≤300MW
- HVDC ≥300MW
- HVDC plus 250/300 MW

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Power Electronics Solution Provider

Low Investment!
Transmission Efficiency!
Power Quality!
Long lifetime!
System Stability!
HVDC Converter Arrangement

6 pulse valve group

one 12 pulse per pole is the preferred solution for today’s HVDC technology
Configuration of HVDC Converters
<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>First Test Valve: 2 parallel 35 mm Thyristors @ 1650 V</td>
</tr>
<tr>
<td>1969</td>
<td>World's First Contract for an HVDC System with Thyristor Valves 2 parallel 35 mm thyristors @ 1650 V for 2000 A</td>
</tr>
<tr>
<td>1975</td>
<td>World's First Contract for Water cooled HVDC Thyristor Valves 2 parallel 52 mm thyristors @ 3500 V for 2000 A</td>
</tr>
<tr>
<td>1980</td>
<td>World's First Contract for HVDC System with 100 mm Thyristors no parallel thyristors @ 4200 V for 3600 A</td>
</tr>
<tr>
<td>1981</td>
<td>SVC Fortaleza TCR 4,2 kV, 75 mm</td>
</tr>
<tr>
<td>1985</td>
<td>SVC Brushy Hill TSC / TCR 5,6 kV, 100 mm</td>
</tr>
<tr>
<td>1994</td>
<td>First HVDC Contract Using 8 kV Thyristors 100 mm thyristors @ 8000 V</td>
</tr>
<tr>
<td>1997</td>
<td>First Thyristor Valve with Direct-Light-Triggering 100 mm thyristors with break over protection @ 8000 V for 2000 A</td>
</tr>
<tr>
<td>1998</td>
<td>SVC La Pila, first LTT valve for TSC and TCR</td>
</tr>
<tr>
<td>2001</td>
<td>First complete HVDC System using Direct-Light-Triggered Thyristor with integrated break over protection @ 8000 V</td>
</tr>
<tr>
<td>2001</td>
<td>First 500kV, 3000MW System using Direct-Light-Triggered Thyristors with integrated break over protection contracted</td>
</tr>
</tbody>
</table>
1967:
- The first Siemens HVDC thyristor valve was rated for 100kV d.c. bridge voltage and already included these modern features:
  - modular design
  - liquid cooling
  - air insulation
Typical LTT Module for HVDC Application
The LTT Thyristor Valve: Pacific Intertie, Celilo Converter Station

Bonneville Power Administration (BPA):
Replace all mercury arc valves rated 133kV, 2000A
with 36 roll-in LTT valves
500kV, 3000A Thyristor Valve Group including 5" LTT with integrated overvoltage protection for Guizhou-Guangdong (under assembly)

will look identical to

500kV, 1800A Thyristor Valve Group including 4" ETT in Tian-Guang as shown
Advanced Power Transmission Systems

FACTS

Power Quality in High Voltage Systems
**FACTS – Our Portfolio**

**FACTS** - Flexible AC Transmission Systems: *Support of Power Flow*

- **SVC** - Static Var Compensator (Standard for Parallel Compensation)
- **STATCOM** - Static Synchr. Compensator (Fast SVC, Flicker Compensation)
- **TCSC** - Thyristor Controlled Series Compensation
- **TPSC** - Thyristor Protected Series Compensation
- **GPFC** - Grid Power Flow Controller (FACTS-B2B)

**SVC/STATCOM**

**TCSC** - Thyristor Control

**GPFC** - simplified B2B

**TPSC** - Thyristor Protection
Advanced Power Electronic Components

Direct Light-Triggered Thyristor (LTT)
- 80 % Less Electronic Components
- Flame retardant Valves to UL standards
- High Reliability

Valve Group - Example Outdoor for FACTS

Module

Thyristor
The Transmission System:

Results of Dynamic System Tests:

a) No SVC Connected
b) Both SVC in Voltage Control Mode
c) Both SVC in Power Oscillation Damping Mode
From FSC to TPSC – the Development

Gap Protected

MOV Protected

Thyristor Protected

Sensitive to environmental influences, specific maintenance required

Long cooling-down time

Fast cooling-down time
TPSC Vincent/USA: 3 TPSC systems at 500 kV - fully proven in Practice

TPSC Technology:
- Outdoor Valves on a Platform
- LTT Thyristors, self-cooled
In Test Bay: 3 Gorges - Changzhou HVDC Project
283,7-MVA HVDC Transformer (Single Phase)
### HVDC Smoothing Reactors, Air Core Type

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Inductance</td>
<td>150 mH</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>500 kV dc</td>
</tr>
<tr>
<td>Rated Current</td>
<td>1800 A dc</td>
</tr>
<tr>
<td>Insulation Level</td>
<td>1425 kV LIWL to ground</td>
</tr>
<tr>
<td></td>
<td>1300 kV LIWL across coil</td>
</tr>
<tr>
<td>Total height</td>
<td>1313 cm</td>
</tr>
<tr>
<td>Air coil weight</td>
<td>37 ton</td>
</tr>
</tbody>
</table>
SCCL – Short-Circuit Current Limitation with FACTS

Impedance $X$

Zero Ohm for best Load Flow

Fast Increase of Coupling Impedance

$\rightarrow t$

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# FACTS & HVDC – Summary of Features

<table>
<thead>
<tr>
<th>Principle</th>
<th>Devices</th>
<th>Scheme</th>
<th>Impact on System Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Load Flow</td>
</tr>
<tr>
<td>Variation of the Line Impedance: Series Compensation</td>
<td>FSC (Fixed Series Compensation)</td>
<td><img src="image" alt="FSC Diagram" /></td>
<td>● ● ● ●</td>
</tr>
<tr>
<td></td>
<td>TPSC (Thyristor Protected Series Compensation)</td>
<td><img src="image" alt="TPSC Diagram" /></td>
<td>● ● ● ●</td>
</tr>
<tr>
<td></td>
<td>TCSC (Thyristor Controlled Series Compensation)</td>
<td><img src="image" alt="TCSC Diagram" /></td>
<td>● ● ● ●</td>
</tr>
<tr>
<td>Voltage Control: Shunt Compensation</td>
<td>SVC (Static Var Compensator)</td>
<td><img src="image" alt="SVC Diagram" /></td>
<td>○ ○ ○ ○</td>
</tr>
<tr>
<td></td>
<td>STATCOM (Static Synchronous Compensator)</td>
<td><img src="image" alt="STATCOM Diagram" /></td>
<td>○ ○ ○ ○</td>
</tr>
<tr>
<td>Load-Flow Control</td>
<td>HVDC (B2B, LDT)</td>
<td><img src="image" alt="HVDC Diagram" /></td>
<td>● ● ● ●</td>
</tr>
<tr>
<td></td>
<td>UPFC (Unified Power Flow Controller)</td>
<td><img src="image" alt="UPFC Diagram" /></td>
<td>● ● ● ●</td>
</tr>
</tbody>
</table>

**Influence:** *

* Based on Studies & practical Experience

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Siemens

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Lessons learned: HVDC and FACTS are essential for Transmission

Thank You for your Attention!