Power supply systems are changing fundamentally

Key trends in energy system:

- Capacity increases and change in generation mix
- Energy system increasingly distributed and driven by prosumer
- New competitors and business models emerging

Digital grid

- Grid control
- Grid applications
- Prosumer applications

Transmission
- HVDC
- HVAC

Distribution
- Primary distribution
- Secondary distribution

Prosumer
- Critical power
- Distributed energy systems
- Building & construction electrification
### Changes in global generation mix until 2030

#### Global generation capacity (TW)

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>2015e</th>
<th>2030e</th>
<th>3.0% CAGR 15-30e</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PV</strong></td>
<td>6.5</td>
<td>10.1</td>
<td><strong>13.8%</strong></td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td></td>
<td>7.1%</td>
<td></td>
</tr>
<tr>
<td><strong>Hydro</strong></td>
<td></td>
<td>2.1%</td>
<td></td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td></td>
<td>5.9%</td>
<td><strong>5.9%</strong></td>
</tr>
<tr>
<td><strong>Nuclear</strong></td>
<td></td>
<td>1.4%</td>
<td></td>
</tr>
<tr>
<td><strong>Gas</strong></td>
<td></td>
<td>2.4%</td>
<td></td>
</tr>
<tr>
<td><strong>Oil</strong></td>
<td></td>
<td>-0.2%</td>
<td></td>
</tr>
<tr>
<td><strong>Coal</strong></td>
<td></td>
<td>1.0%</td>
<td></td>
</tr>
</tbody>
</table>

- Further electrification and change in generation mix drive generation capacity increase by 3% p.a.
- 50% of capacity additions in distributed energy systems.
- PV with strongest increase in generation capacity.

1 Share of Renewables in %
Electric Highways = Energy System Backbone

Overhead line

Cable

Gas insulated line
Development of AC Transmission

Losses:
\[ P_v = 3(I^2R) \]

Currents:
\[ I = \frac{S}{\sqrt{3}U} \]

Higher Voltage = Lower Currents

**FACTS:**
Flexible AC Transmission Systems

1. 110 kV Lauchhammer – Riesa / Germany (1911)
2. 220 kV Brauweiler – Hoheneck / Germany (1929)
3. 287 kV Boulder Dam – Los Angeles / USA (1932)
4. 380 kV Harspranget – Halsberg / Sweden (1952)
5. 735 kV Montreal – Manicouagan / Canada (1965)
6. 1200 kV Eikibastuz – Kokchetav / USSR (1985)
7. 1200 kV China, Indien, Japan
HVDC offers significant savings for long-distance energy transport

Cost of 5 GW Overhead Link

- 1150 kV HVAC
- ± 800 kV HVDC

Investment [M€] vs Distance [km]

Break even distance: 500 - 1000 km
Technology for HVDC Transmission

HVDC Classic
- Line-commutated current-sourced Converter
- Thyristor with turn-on Capability only

HVDC PLUS
- Self-commutated voltage-sourced Converter (VSC)
- Semiconductor Switches with turn-on only and turn-off Capability, e.g. IGBTs

- Direct-light-triggered Thyristor (LTT)
- Up to 10000 MW
- MI Cable up to 600 kV
- OHL up to 800 kV

- XPLE Cable up to 320 kV DC
- Half bridge up to 1,56 kA
- Full bridge up to 2 kA
HVDC and FACTS have significant advantages when integrating renewables

- Use of bulk power energy highways with HVDC & FACTS
- Avoidance of loop flows and overloads
- Control of power flow
- System interconnections with HVDC (Firewall) e.g. Texas
- Use of integrated AC/DC systems with FACTS & HVDC
- Support of voltage recovery after system faults
- Reduction in Transmission losses (HVDC)
Germany: High wind generation in northern part, Load centres in South – HVDC as solution element

- Interconnected system: Today Loadflow follows Ohm’s Law – leads to power flow through neighbouring countries
- HVDC connections allow to control the loadflow direction and active/reactive power.
- Avoidance of neighbouring network utilizsation and loopflows
- Use of FACTS allows voltage recovery after incidents from rapidly changing loadflows coming from renewable infeeds

Planned North-South Corridors (Blue)

Actual Flow:
Part of the Power flows via other countries

Source: Bundesnetzagentur: Monitoringbericht 2015
Comprehensive power system studies for the HVDC PLUS transmission system project “Ultranet”

Challenge

- Realization of the first HVDC transmission link for the German transmission system based on the network development plan
- Hybrid AC/DC overhead line system
- Multi-terminal system enhancement in future
- First full-bridge MMC converter for HVDC transmission on DC +/- 420 kV voltage level

Solution

Pioneering project requiring full set of system studies for the “Engineering and design phase” comprising, including

- Investigation of AC/DC interaction in order to reach the targeted system performance
- Integrated view on the entire system
- Harmonic impedance
- Transient interaction (AC protection)
- EMT system study
- Resonance interaction study
- Network reduction for real-time digital simulation

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siemens.com/power-technologies
India develops an AC/DC Hybrid system and foresees to operate in 2027:
- 1200kV AC Lines (Red)
- 765kV AC Lines (Green)
- 800kV DC Bipolar (Purple)
(Source: Central Electricity Authority)

The HVDC corridors allow for a controlled power flow for long distances and across challenging geographies in North East.
Feasibility study of HVDC PLUS for Japanese transmission networks

Challenge

- Feasibility study of HVDC PLUS for future applications in the Japanese transmission grid
- Evaluation of replacement of existing LCC technology by VSC converters

Solution

- Workshop with customer delegation focused on basics of VSC technology and operation in the Japanese grid
- Preliminary basic design of MMC converters for selected application cases defined by the customer
- Performance of feasibility study for these application cases and comparison to existing LCC technology
- Model development in the software tools PSS®SINCAL and PSS®NETOMAC
- Demonstration of VSC operating diagram and fault ride through performance

Customer benefit

- Introduction of VSC converter technology for high voltage applications and future grid development
- Technical and economical comparison of existing LCC technology with new VSC based solutions for the grid
Comprehensive stability study for the Vietnamese transmission network

Challenge

- Identification and evaluation of problems related to the system stability
- Revision and completion of the database for power stability studies and possible solutions for enhanced system stability
- Requirement of training and technical transfer

Solution

- Data collection, PSS®E data base, measurements
- Generator stability, small signal stability, frequency stability, voltage stability, recommendations to improve stability
- Improvement of dispatch function (DSA)
- Improvement of protection
- New functions for the regional 3 dispatch centers
- New compensation equipment for 500/220 kV

Customer benefit

- Improvement of reliability and stability of the Vietnamese system
- Risk reduction of system brown outs and black outs
- Higher safety of operation

EVN NLDC
Vietnam
Calculation and planning for grid integration of EEA generation

Challenge

- Technical elaboration based on available on-site data sources
- Representation of elaborations to different divisions

Solution

- Integration of numerous distributed power generation systems into the service area of E.ON and checking on the grid compatibility
- Provision of alternatives for a technical and economical reasonable connection point

Customer benefit

- Fast handling in spite of heavy workload
Challenge

- Identification of poor damped system inter-area modes where MH participates in.
- Analysis of participation and impact of the new BP III HVDC link on inter-area modes of interest.

Solution

- Based on Small Signal Analysis results, the BPIII HVDC Power Oscillation damping Controllers (POD) were tuned to provide positive damping to targeted inter-area modes

Customer benefit

- Proper use of available BP III HVDC POD controllers to provide positive damping to reduce risk of stability issues critical inter-area oscillations modes associated to MH

Manitoba Hydro
Canada
Comparison of capabilities

- **Gas Insulated Power Transmission Lines** are successfully under operation since more than 40 years, more than 750 km GIL tubes installed worldwide.

- **Main advantages** of Power Transmission Lines (compared to power cable systems):
  - Very high power transmission with low losses
  - No ageing, >40 years of lifetime
  - No fire load
  - Very low electromagnetic fields
  - Low reactive power demand
  - Elbow

- **DC Power Transmission Lines („DC GIL“)** under development:
  - ±500 kV, up to 5000 A DC $\rightarrow$ up to 5 GW
  - All the main development tests are successfully passed
  - First directly buried test installation for long term investigations in 2016

- **Mobile Factory principle** for direct laying on ground
  - High increase of installation speed
  - Large reduction of costs for GIL
  - Cost efficient installation of large transmission lines