Technical Guidelines for First HVDC Grids

European HVDC Grid Study Group

contact: frank.schettler@siemens.com (convenor)
gerhard.imgrund@vde.com (secretary)

Information from the German National Committee of CENELEC
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Integrated AC and HVDC Grid Systems Require Efficient Coordination

So far, HVDC links have been designed individually according to the specific requirements of TSOs. The solutions of individual manufacturers differ significantly and cannot be combined easily today.

HVDC Grid Systems will be built in steps, starting with a small number of interconnected stations with the possibility of future system expansion and interconnection. They will involve different TSOs and different HVDC manufacturers.

This requires efficient coordination of:
- design,
- operation,
- control and
- regulation
between the connected AC and DC systems.
Harmonised Technical Regulations Require Cooperation

Transmission System Operators

Applications
- Functions
- Performance
- Grid Code

Functional Specifications and Standards

Technology
- Capabilities
- Parameters
- Economics

Manufacturers
The European HVDC Grid Study Group

- Founded in September 2010
- Report submitted to CLC TC8X in September 2012

- Objectives
  - describing basic principles of HVDC grids with the focus on near term applications
  - developing functional specifications of the main equipment and HVDC Grid Controllers
  - developing proposals to CENELEC for starting work on guidelines and standardization
## Contributors and Connections

### Contributors

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<th>Company</th>
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<tr>
<td>50Hertz Transmission</td>
<td>DE</td>
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### Involved on Informative Level

- CIGRÉ SC B4
- CENELEC TC8x
- ENTSO-E
- Friends of the Supergrid
Scope of Work

Typical Applications and Performance Requirements
- Principles of DC Load Flow
- Short Circuit Currents and Earthing
- Principles of Fault Detection and Fault Clearing

Functional Specifications
- AC/DC Converter
- DC Circuit Breaker

New Work Item Proposals for CENELEC TC 8X

Converter Technologies
- Reference Technologies
  - LCC
  - 2Level VSC
  - 3Level VSC
- SCOPE FOCUS
  - VSC
  - MMC
    - Half Bridge Type
    - Full Bridge Type

HVDC Circuit Topologies and Earthing
- SCOPE FOCUS
  - Radial Network
  - solidly grounded (Bipolar, Monopoles)
  - isolated (Symmetrical Monopoles)

LCC: Line Commutated Converter
VSC: Voltage Sourced Converter
MMC: Modular Multilevel Converter

Source: CIGRE Session 2012, Paris
Typical Applications

Planning Criteria

Reliability of HVDC Grid Systems

- to be considered together with HVAC as part of the same transmission grid applying analogue rules to the reliability and security-of-supply aspects of existing HVAC transmission systems, such as the n-1 criterion to be fulfilled for the combined HVDC/HVAC systems

This could require (among others):

- HVDC Grid System resources to include extra capacity margin (temporary or permanent)
- Fast system reconfiguration, considering:
  - HVDC circuit topology (monopole or bipolar connection)
  - Topology of protection zones
  - Definition of the maximum fault clearing time
  - Energisation and de-energisation AC and DC systems

Losses

- Selection of DC transmission voltage (optimization operation costs and investment costs)
- Evaluation could be based on typical operational power profiles
- Standards similar to IEC for AC systems recommended

Future System Expansion

- Balance between early investment and benefits for the future
- An open market for equipment based on the same regulatory rules
- Standardisation of the principles of equipment function, system operation, control and communication will make expansion easier

Source: CIGRE Session 2012, Paris
Principles of DC Load Flow

HVDC Grid Control Concepts
- Three concepts benchmarked
  - Voltage-power droop together with dead band
  - Voltage-current droop
  - Voltage-power droop

Benchmarking Criteria
- Fulfil P or Udc reference points
- Continue stable operation after a large disturbance
- Keep the DC voltage within acceptable limits
- Schedule optimal power flow (DC voltage as high as possible)
- Handle fluctuating loads and generation
- Flexible to combinations of Uac/f, P/Q and Udc control
- Handle restrictions and limitations in the DC and AC networks
- Prevention of overload of any DC grid component
- Autonomous control during temporary loss of communication
- Be robust against non-ideal conditions (e.g. tolerances)
- Interoperability

Benchmark Model
Results for a Load Rejection Case

Source: CIGRE Session 2012, Paris
Calculation of Short Circuit Currents
Discharging of lines (overhead lines or cables)

Phase-to-Earth Fault Currents
 due to Line Discharge

Point-to-Point Cable (example)

Contribution of Converters
Principle Behaviour of Converters
 in Case of DC side Short Circuits

VSC Half Bridge Type converters together with DC Circuit Breakers can result in similar behaviour as VSC Full Bridge type in solidly grounded DC circuits

Source: CIGRE Session 2012, Paris
Principles of Fault Detection and Clearing

Fault Isolation Concepts & Tolerable Outage Times

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<th>Fault isolation time</th>
<th>Breaking device type needed</th>
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<tr>
<td>&lt; few ms</td>
<td>Fast dynamic isolation is needed.</td>
</tr>
<tr>
<td>&lt; 100 ms</td>
<td>Mechanical DC breakers are needed.</td>
</tr>
<tr>
<td>&lt; few sec</td>
<td>Conventional AC breakers are needed. The term High Speed Switches is often used.</td>
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Points of Common Connection

- The converter pole has a single point of common connection (PCC) to the HVDC Grid System as it has to the AC system.

DC Protection Zones

Coordinated by the HVDC Grid System
- DC Line Voltage Unbalance Protection
- DC Line Overvoltage Protection
- DC Undervoltage Protection

Coordinated by the Converter Design
- DC Overcurrent Protection
- DC Current Differential Protection
- Busbar Current Differential Protection
- Asymmetry Protection
- Converter / Valve Reactor Overcurrent Protection
- AC Secondary / Limb Current Differential Protection
- AC Secondary Undervoltage Protection
- Pre-Insertion Resistor Over Dissipation Protection

Source: CIGRE Session 2012, Paris
Functional Specifications

**Practical Approach:**
- Take Structure of Existing Functional Specifications of Converter Stations
- Extract all items that are relevant for HVDC Grids
- Add more items as needed

**Draft Functional Specifications provided:**
- **AC/DC Converter Stations**
  - DC System Characteristics
  - Operational Modes
  - Testing and Commissioning
- **HVDC breaker**
  - System Requirements
  - System Functions
  - Interfaces and Overall Architecture
  - Service Requirements
  - Technical System Requirements

Some items need further elaboration as proposed with **New Work Items**
New Work Items

- Continue work on Functional Specifications for future Multi-Vendor Systems, such as:
  - AC/DC Converters including their controls
  - HVDC Grid Controllers
  - HVDC Breakers

- Focus on technologies and network topologies that are most relevant for first HVDC Grids, such as:
  - Modular Multilevel Converters
  - radial systems
  - expansion of existing HVDC systems

- Elaborate New Work Items identified and summarise the results in a Technical Report supplementing the Functional Specifications
Next Steps

- Report and New Work Items presented to CENELEC TC8x (Meeting 22 November 2012 in Brussels)

- CLC TC 8x has decided to start a new Working Group for HVDC Grids (WG 6) and to circulate report as "Document for Comments (DC)" giving the National Committees of CENELEC the opportunity to provide comments within next two months.

- CLC TC 8x WG 6 is expected to start in spring 2013

- A first meeting has taken place with ENTSO-E drafting team (7 November 2012). The collaboration is intended to be continued.
Possible HVDC Grid Projects – Kriegers Flak

- Kriegers Flak DK
  - Capacity 600 MW
  - Expected to be commissioned in ~ 2018
- Baltic 2
  - Capacity 288 MW
  - Expected to be commissioned in 2013
- Baltic 1
  - Capacity 48 MW
  - Was commissioned in May 2011

Source: ENERGINET.DK
German Grid Development Plan

Scenario for B 2022

- Based on the pilot study of the BMU (Ministry of Environment)
- Fulfills all requirements for the target year 2022
- The outlook for the year 2032 confirms the measures
- The result of the grid development plan

Optimization in existing routes
- New AC construction in existing routes: 2,800 km
- AC enhancements and AC power circuit systems on existing routes: 1,300 km
- DC power circuit systems: 300 km

Grid expansion in new routes
- Route construction: 1,700 km
- 4 DC corridors
  - Transmission capacity: 10 GW
  - Route length: 2,100 km

Estimated investment: € 20 billion

"Vision"

Internationally agreed operating principles, Functional Specifications and Grid Codes prepare the ground for a broad development of combined HVAC/HVDC Grid applications and corresponding projects.

The experiences gained from HVDC Grid projects are the basis for developing standards for design principles and components in future steps of the standardisation process.