US DOE Grid Tech

Applications for High-Voltage Direct Current Transmission Technologies

Panel Session :

State of HVDC Technologies

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Arlington, VA

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Agenda

- HVDC Technologies
- World View
- Key Projects
- Development Work

HVDC Transmission

Back to Back

- Asynchronous interconnection of adjacent networks
- DC Circuit is short - within the same building/station
- 2 Converters in 1 Station

Point to Point

- Long Distance Transmission by Overhead Line or Insulated Submarine or Underground Cable or a combination of these
- DC Circuit Distance according to application
- Two Converter Stations

Multi-terminal

- 3 or more HVDC Converter Stations on a common DC conductor
- Limited installations worldwide (2 systems in service)
- VSC technology makes this easier, increasing interest

DC Grid

- Many converters in a network with meshed, radial, circuit and AC interconnections

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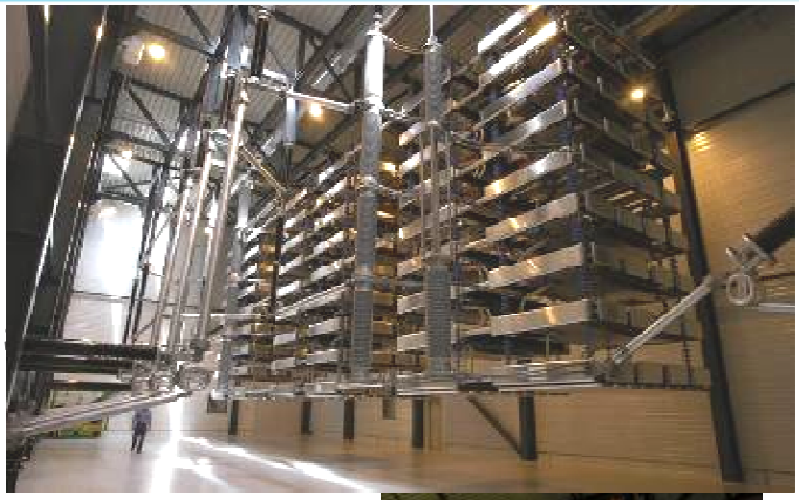
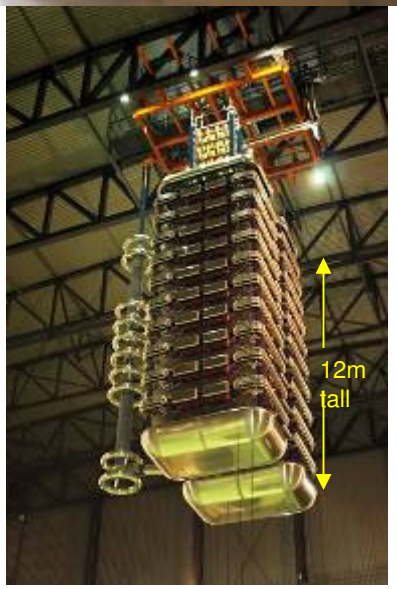
HVDC Using Thyristors



Classic HVDC

- In use since 1980's
- Over 100 schemes in operation
- Uses 4", 5" and now 6" thyri
- Ratings
  - Commonly 500 kVdc / 3000 MW
  - Recently 660 kVdc / 4800 MW and 800 kV / 6400
- Water cooled
- Most economical solution for :
  - Long distance / bulk power transmission
  - Large capacity cable / water crossings
- Commonly referred to as
  - Line commutated converter (LCC) HVDC
  - Conventional HVDC



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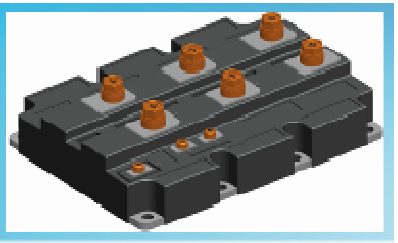
HVDC Using Transistors



Voltage Source Converters (VSC)

- Recently introduced
- Uses IGBT, IGCT or similar device
- Ratings
  - 320 kVdc / 1000 MW
  - Increased ratings being developed
- Water cooled
- Reduced overall site footprint than LCC
- Easier construction than LCC
- More Versatile Function than LCC
  - Simultaneous control of MW and MVars
  - Faster response to events
  - Can "black start" a network

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World View of HVDC - Major Markets

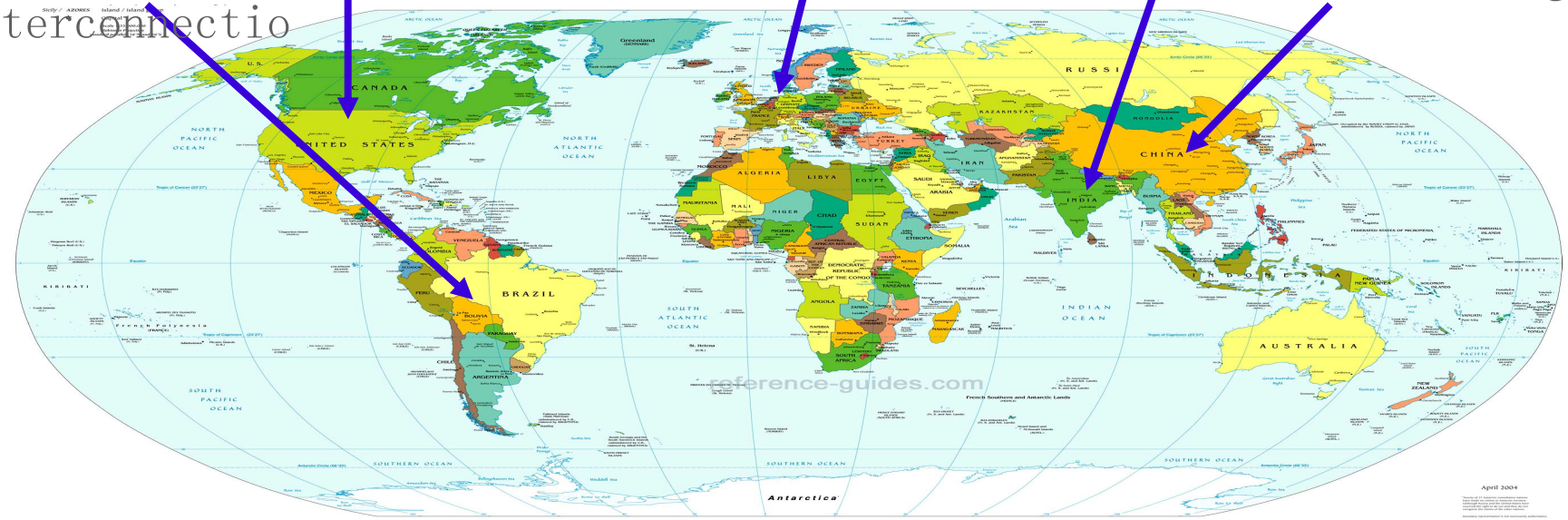
N America : Asynchronous Interconnections, Water Crossings, Bulk Renewable Power Transfer

South America : Bulk Power over Long Distances and Asynchronous Interconnections

Europe : Water Crossings, severely restricted ROW Permits

India : Bulk Power over Long Distances and Asynchronous Interconnections

China : Bulk Power over Long



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Brazil :
Rio Madeira – Bipole 2

Purpose:

- Interconnect Rio Madeira Hydro-plants (Santo Antonio and Jirau) in NW Brazil to major load centers in South / Southeast Brazil

Project:

- 3150 MW / 600 kV Bipole HVDC
- 2375 km World's Longest HVDC Link

Contract Value

- 300 MEuro ($ 480 MUSD)

Date:

- Contract Signed September 2009

End Customer:

- ANEEL – Agencia Nacional de Energia Eletrica

Consortium : Consórcio Madeira Transmissão

- Furnas (Alstom)
- CHESF
- CTEEP

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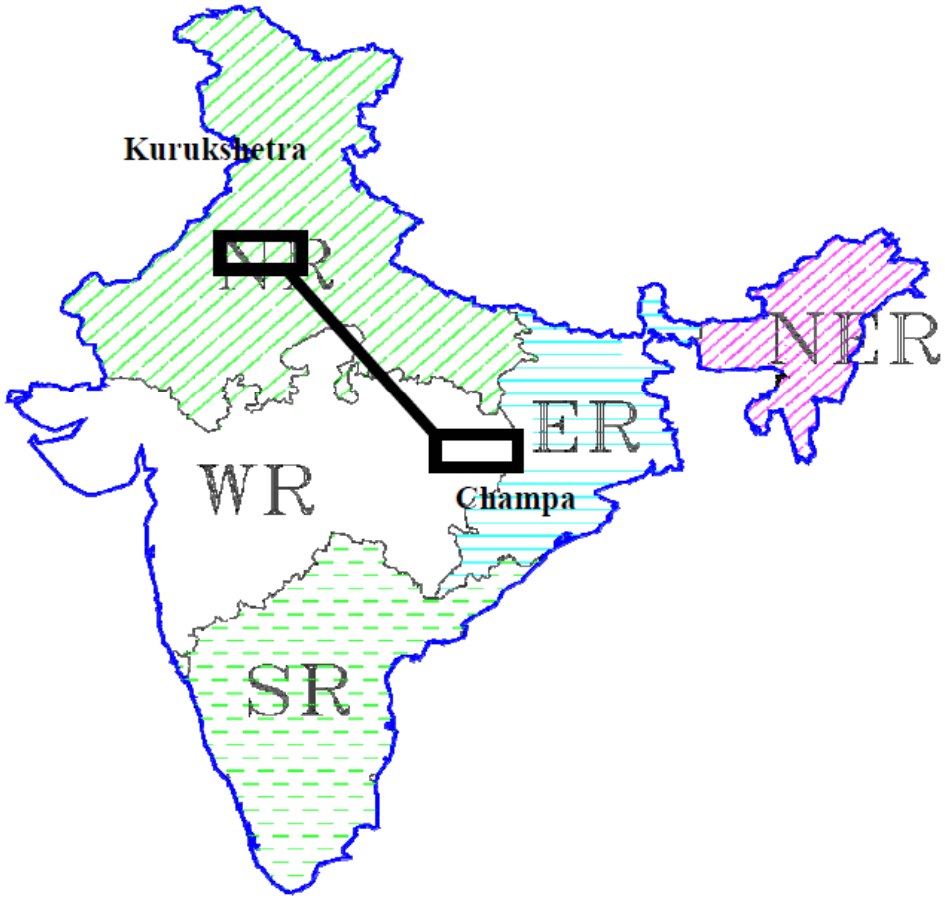
India :
Champa-Kurukshetra ±800kV HVDC Project



- **POWERGRID of India Project funded by ADB**
- **+/-800kV 3000MW Bipole with Dedicated Metallic Return Conductor.**
- **Between Champa "pooling" station and Kurukshetra**
- **Provision to include upgrade to 6000MW at a later date (additional 3000MW bipole utilising existing conductors).**
- **37 Month Contract**

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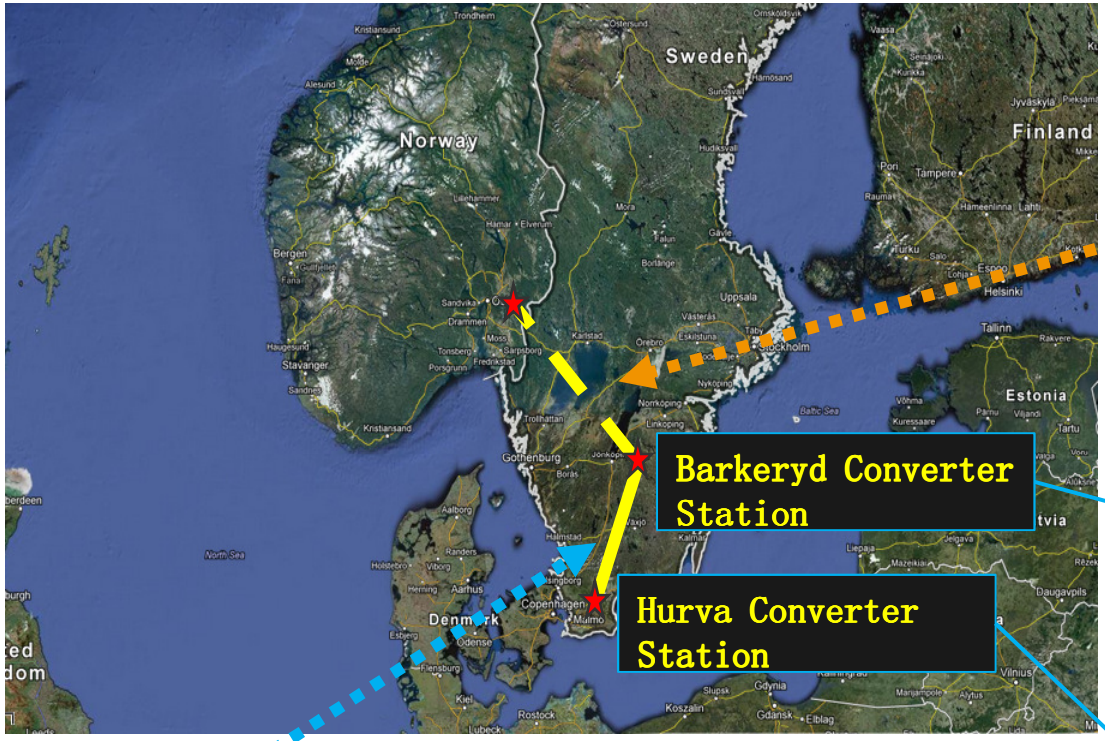
SouthWest Link : Sweden/Norway – World First VSC Multi-Terminal HVDC



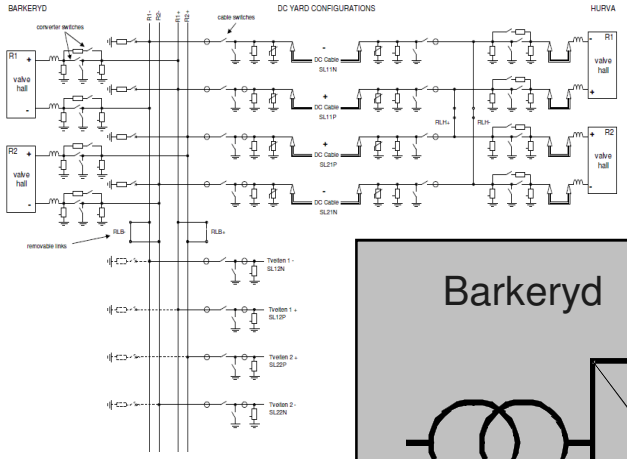
Phase 2:

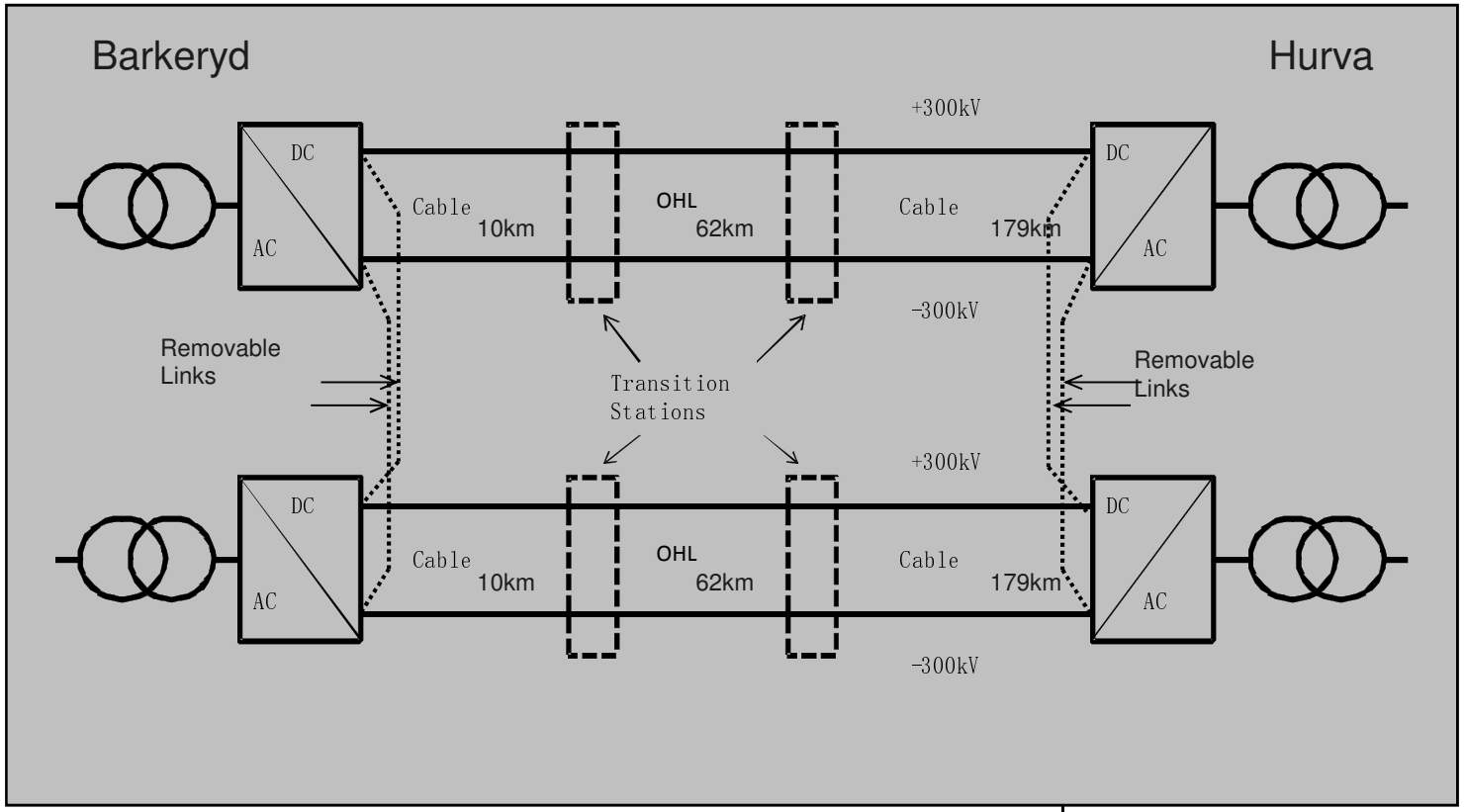
- Extension to 3-Terminal
- 2 x VSC Converters in Norway
- Connection of Barkeryd Converters to Norway

Phase 1:

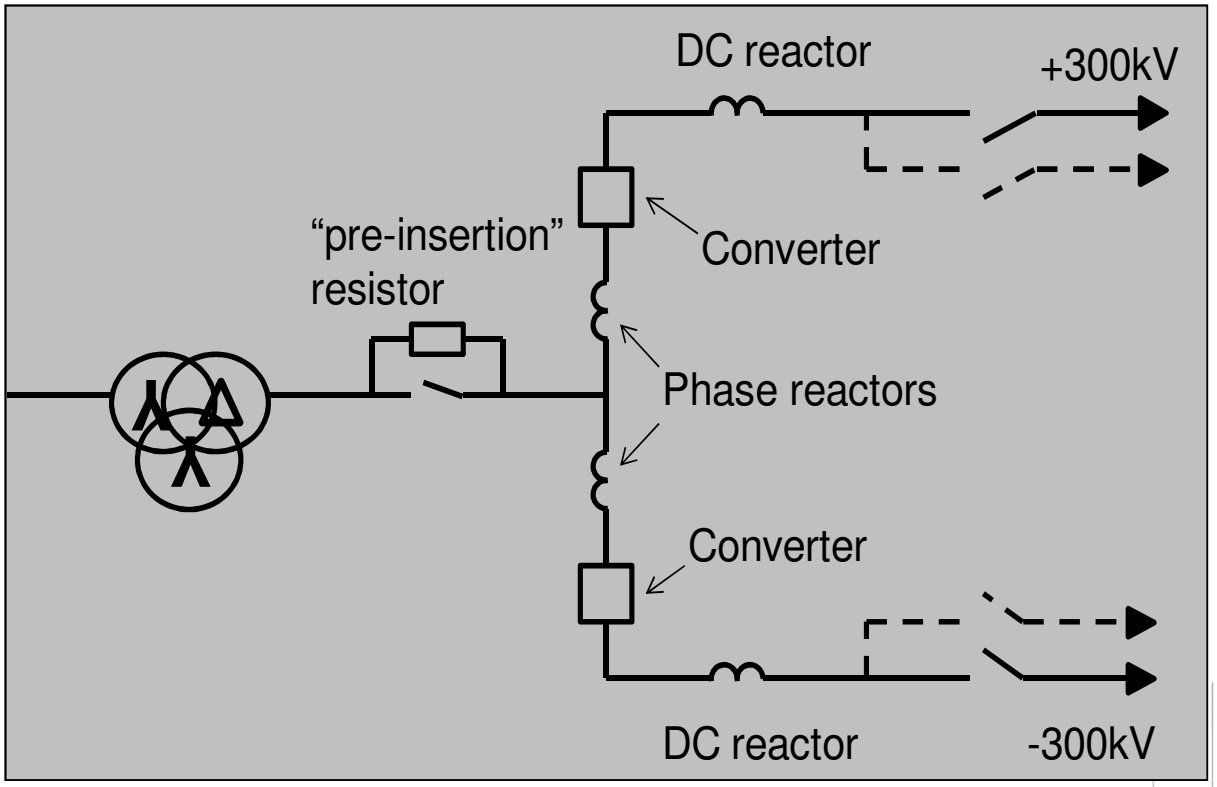
- South West Link
- 4 x VSC Converters
- 2 x 720MW links, +/- 300kV DC, OHL & Cables

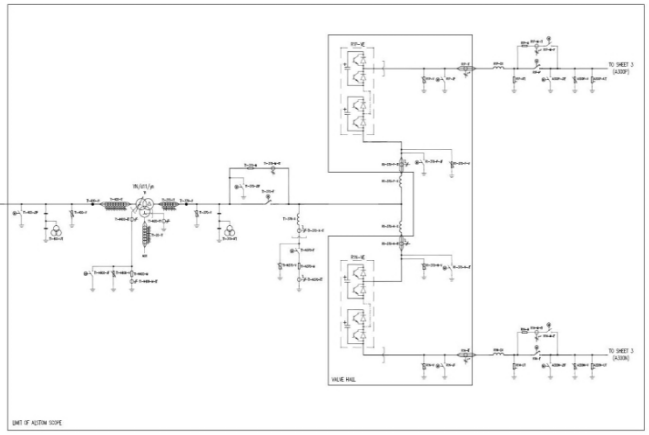
Multi-terminal Functionality



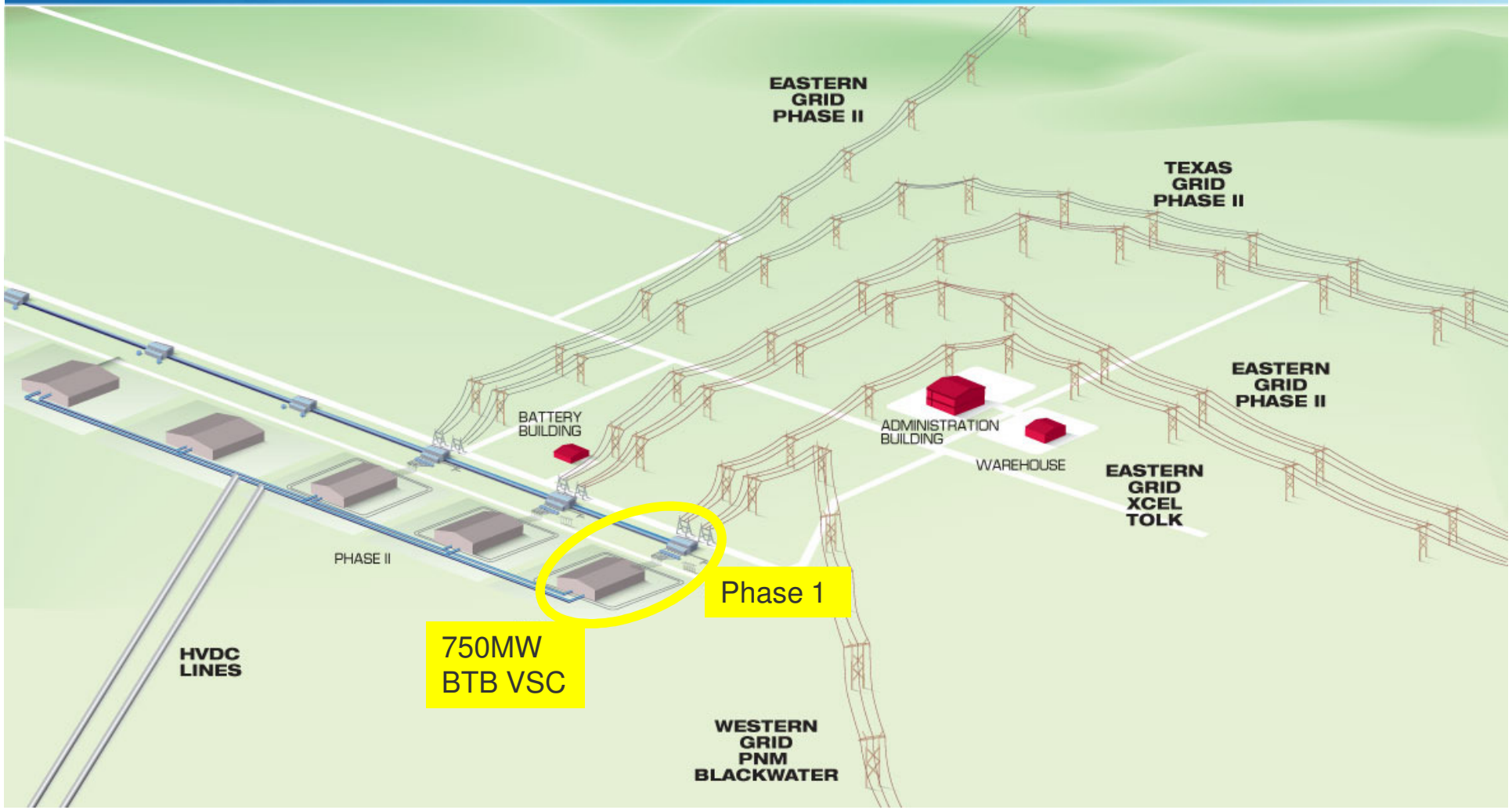


Single Line Diagram – Barkeryd

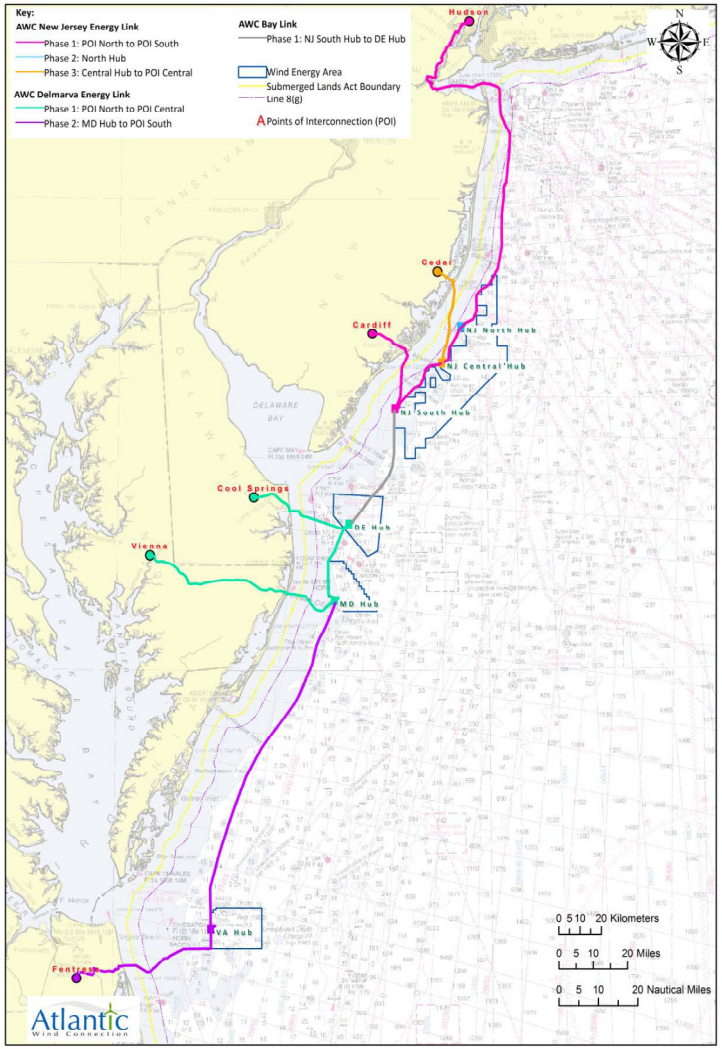




Tres Amigas SuperStation



Atlantic Wind Connection



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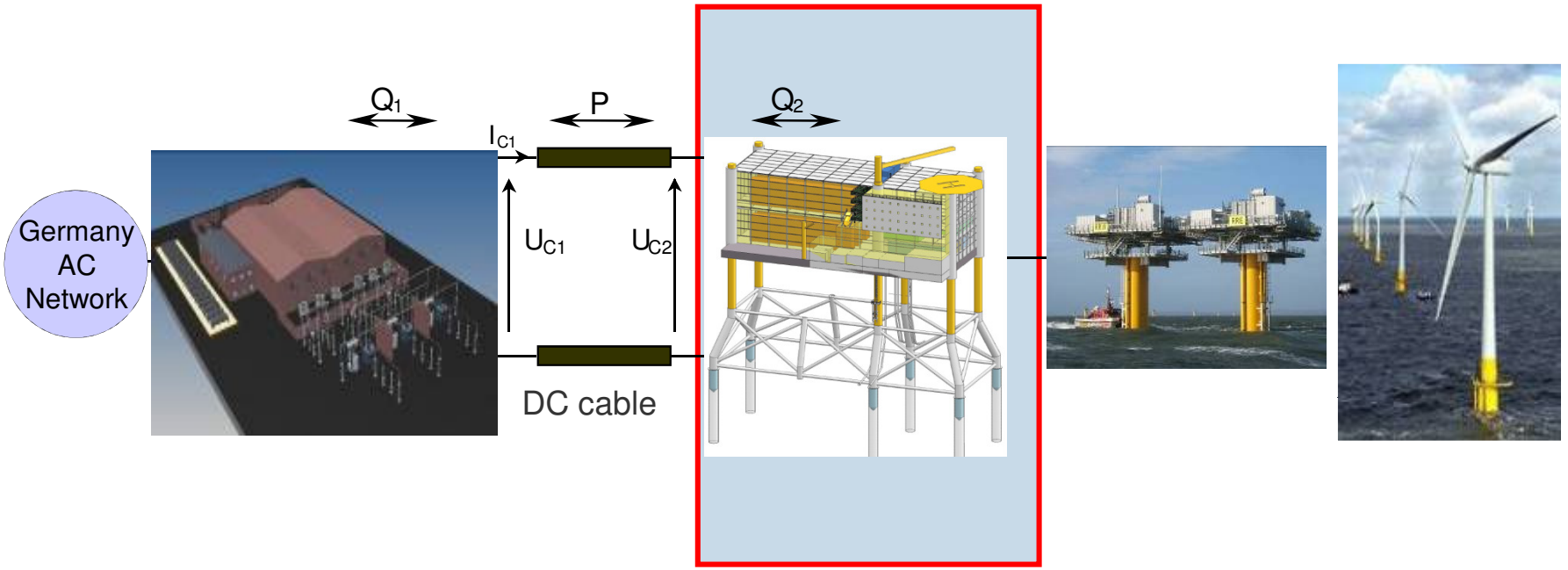
HVDC Connections - Off-shore Wind Farms



On-shore HVDC station | **HVDC platform** | **HVAC platform** | **Off-shore wind farm**

Dolwin 3 Project: 900 MW VSC HVDC Link

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Off-shore Germany

- 10 Ongoing Offshore HVDC Projects
- 400 - 900 MW

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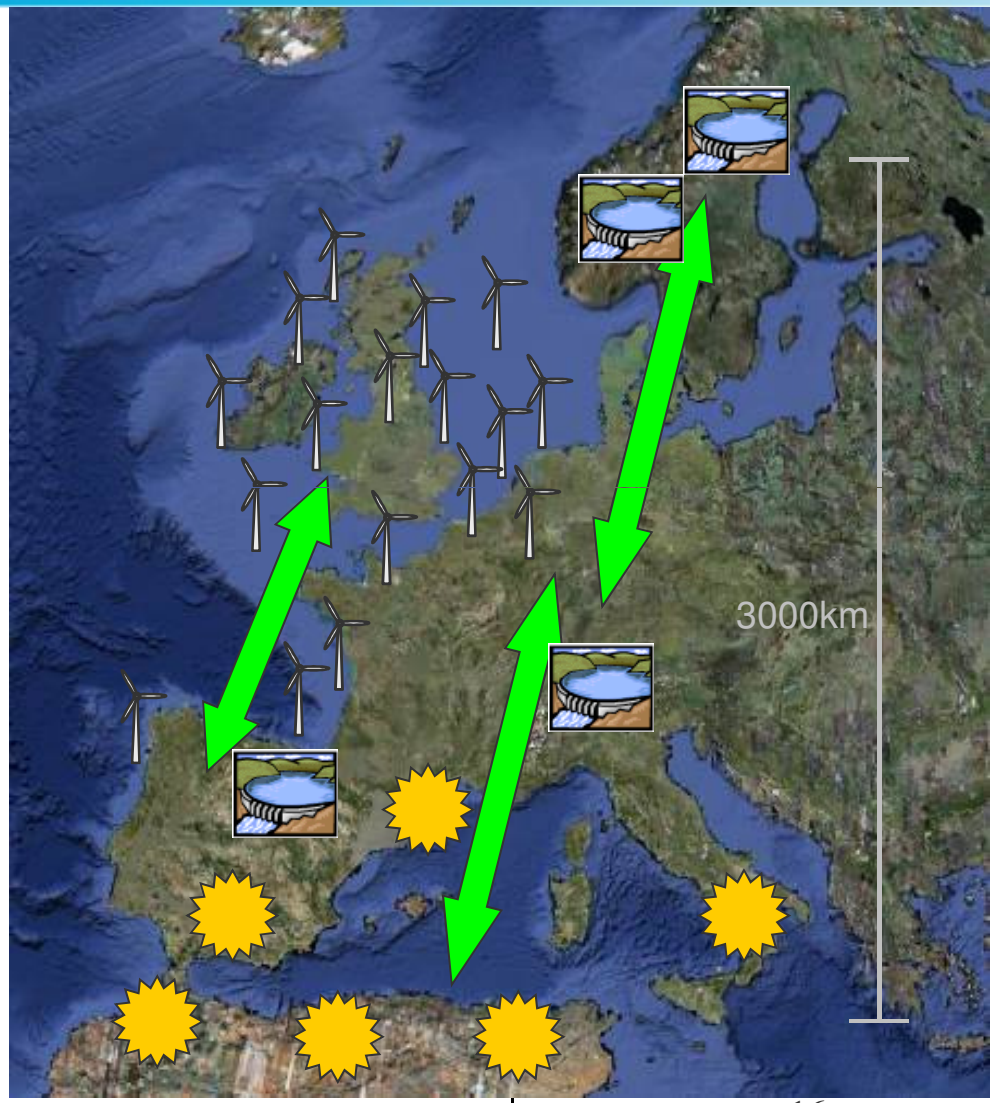
Overlay DC Grid Gives Access to Renewable Sources within Europe

- Interconnection of remote renewable energy sources
- Overcoming “bottlenecks” in the existing AC grids
- Low loss (HVDC) transmission systems
- Controllable power flows over a wide area
- Avoidance of synchronisation over a wide area
- Less environmental impact than AC reinforcement

Markets also in North America, China and India



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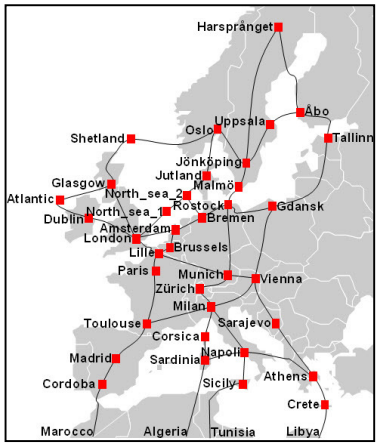
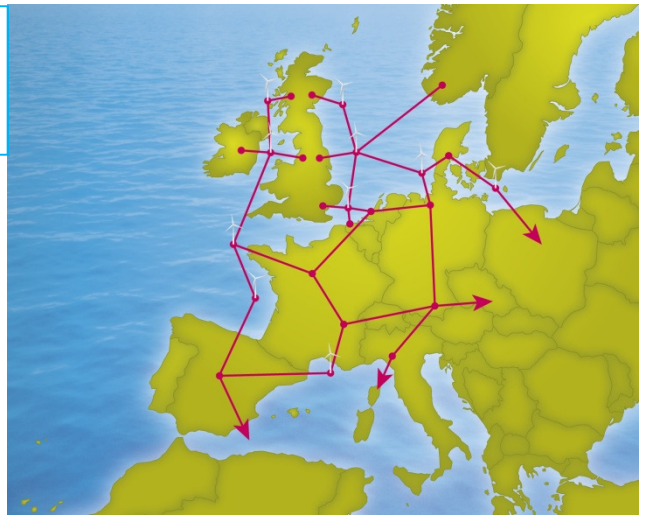
A Sample of European Initiatives

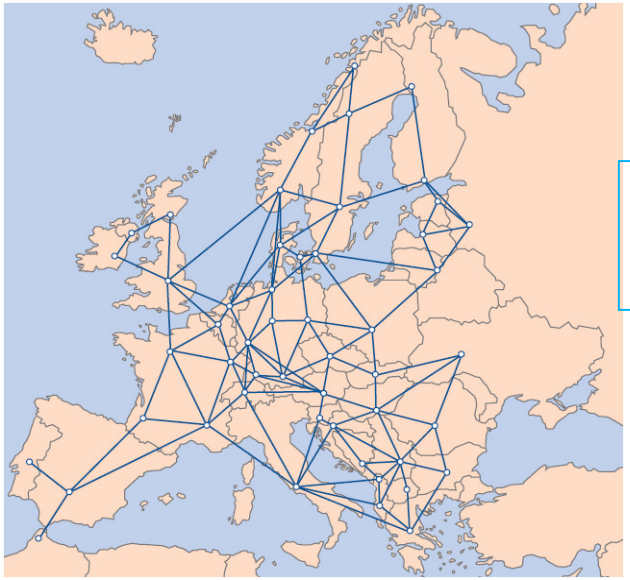


G. Asplund, B. Jacobson, B. Berggren, K. Lindén ”Continental Overlay HVDC-Grid”, Cigré conference, B4-109, Paris, 2010

Desertec Foundation

Friends Of The SuperGrid





OffshoreGrid Europe

“Offshore Electricity Grid Infrastructure in Europe; Techno-Economic assessment”
3E (coordinator), dena, EWEA, ForWind, IEO,NTUA, Senergy, SINTEF
Final Report, October 2011

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DC Grid Recommendations Activities

- Cigré B4-52 “Feasibility of HVDC Grids” now published
- Cigré has started five further DC grid working groups;
  - B4-56: Guidelines for the preparation of “connection agreements” or “Grid Codes” for HVDC grids
  - B4-57: Guide for the development of models for HVDC converters in a HVDC grid
  - B4-58: Devices for load flow control and methodologies for direct voltage control in a meshed HVDC Grid
  - B4-59: Protection of Multi-terminal HVDC Grids
  - B4-60: Designing HVDC Grids for Optimal Reliability and Availability performance
- Other bodies, such as CENELEC, and FOSG, also actively producing recommendations

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Development

- DC Grid control philosophy being refined
- Optimised protection strategies are being developed
- Modular DC Breakers suitable for application in different HVDC schemes
  - fast acting and reliable mechanical switch is critical component
  - 3000A / 2.5ms achieved
  - 170 kV / 7500A next milestone
  - Part of European “Twenties” Project sponsored by RTE France
- Dynamic Breaking Resistor circuits under development for Windfarm application
- New Markets associated with DC Grids being addressed
- Current flow control being developed
- DC-DC converter design optimisation on-going
- Half-Bridge, Full-Bridge, and other configurations being developed

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HVDC