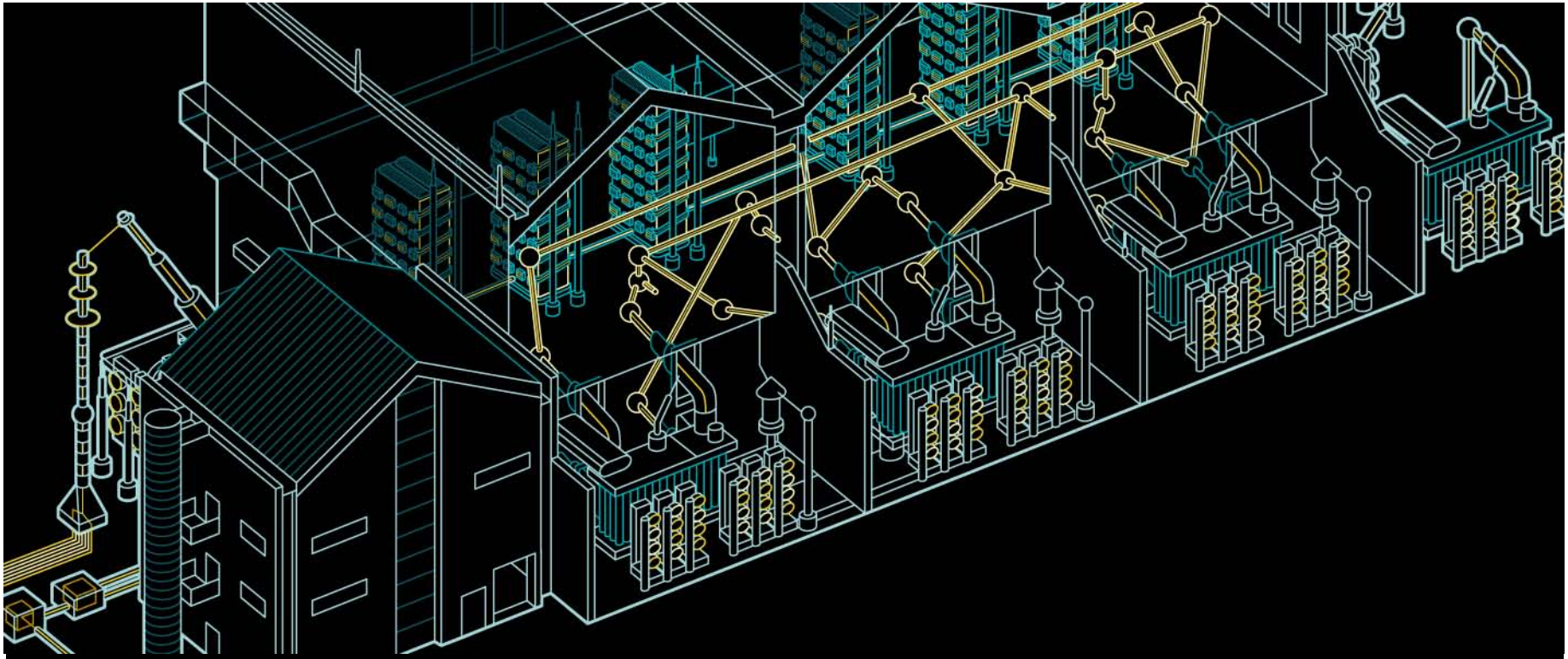


Workshop “Transporting tens of Gigawatt of Green Power to the Market”, Potsdam, May 12, 2011 – Jochen Kreusel

High Voltage Direct Current (HVDC) Power Transmission

Alternatives for power transmission
Alternating current (AC)

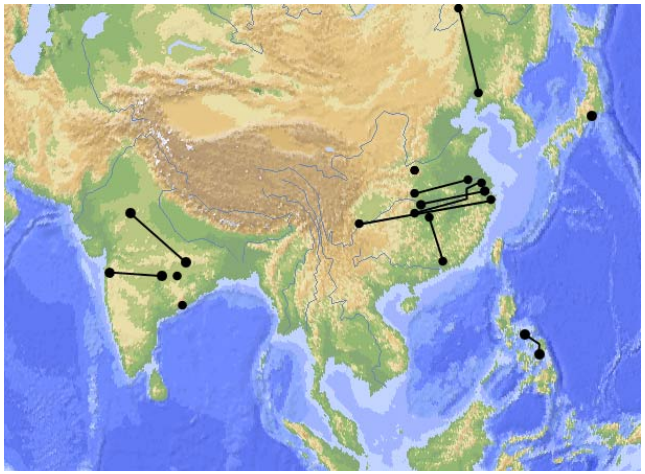
UCTE
transmission grid

- Advantages
  - Voltage transformation
  - Current intrerruption
  - Easy conversion into mechanical energy and vice versa
  - Frequency as system-wide control signal
  - Meshed networks
- Limitations
  - Long distance transmission
  - Difficult to use cables, already at ≈ 100 km high reactive power consumption

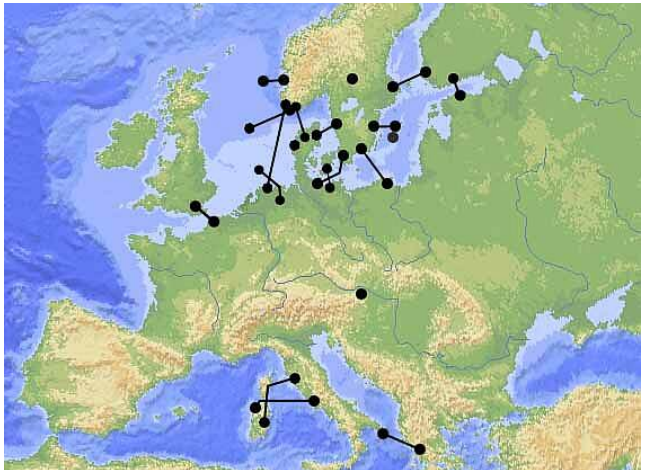
Up to now the solution of choice for Europe.

Alternatives for power transmission
High voltage direct current (HVDC)

HVDC projects by ABB in Asia



HVDC projects by ABB in Europe



- Advantages
  - Low losses (direct current)
  - Small footprint
  - No limitations in length
  - Cables can be used over long distances as there is no reactive power consumption
- Disadvantages
  - Base costs for converter stations ⇒ economically interesting only at longer distances (offshore: from ≈ 80 km, onshore beyond some 100 km)
  - Point-to-point connection (multi-terminal possible with VSC HVDC)

Proven solution for long distance transmission and sub-sea cables.

HVDC technologies

600 MW, 200 x 120 x 22 m

- HVDC Classic (CSC) 300 – 6’400 MW (2’000 MW)
  - Current source converters
  - Line-commutated thyristor valves
  - Typical layout: valve building and outdoor installation of filters and switchyards
  - Overhead lines or mass-impregnated cables
  - Minimum short circuit capacity > 2x converter rating
  - Bulk power long distance transmission, coupling of asynchronous power systems

550 MW, 120 x 50 x 11 m

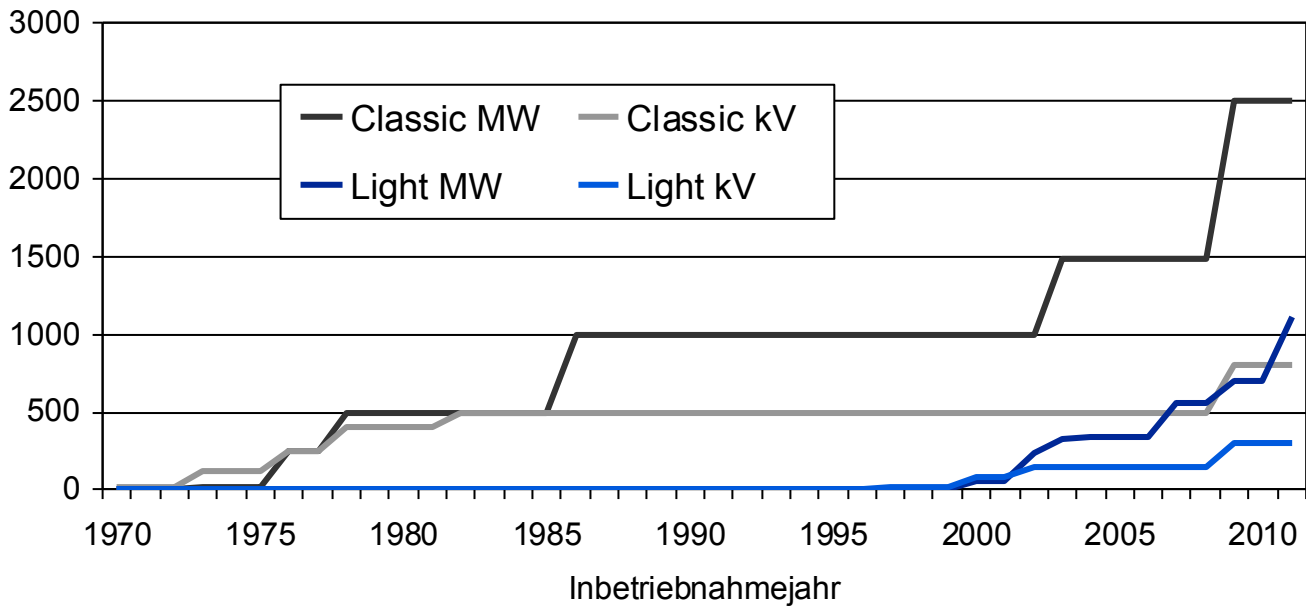
- HVDC Light® (VSC) 50 – 1’100 MW (2’400 MW)
  - Voltage source converters
  - Self-commutated IGBT valves
  - Typical layout. complete installation (except transformers) indoor
  - Extruded cables or overhead lines
  - No minimum short circuit capacity, black start
  - Multiple areas of application

CSC: current source converter
VSC: voltage source converter

Comparison of HVDC technologies

	HVDC CSC (Classic)	HVDC VSC (Light)
Converter technology	Thyristor valve, grid commutation	Transistor valve (IGBT), self commutation
Relative size	4	1
Cable technology	▪ Oil paper ▪ Field joints (5 days) ▪ Sea cable installation special ship (3 available)	▪ Extruded ▪ Prefabricated land joints (1 day) ▪ Sea cable installation from barge (> 200 available)
Typical delivery time	36 months	24 months
Static reactive support	yes	yes
Dynamic reactive support	no	yes
Independent control of active and reactive power	no	yes
Scheduled maintenance	typically < 1 %	typically < 0,5 %
Losses typical system	2,5 – 4,5 %	4 – 6 %
Multiterminal operation	Complex, limited to 3 terminals	Simple, no limitations

Development of HVDC technologies



- HVDC Light® systems in operation since 1997
- Rapid development since mid of the 90ies due to requirements of emerging markets (HVDC Classic) and in Europe/USA (HVDC Light®)

High voltage direct current transmission
Areas of application

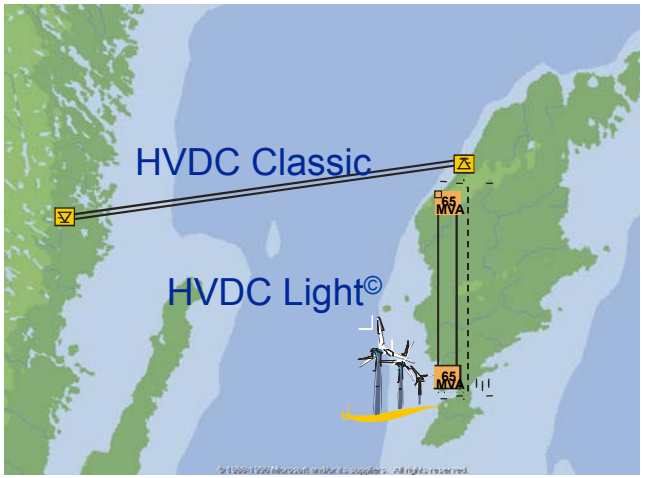
- HVDC Classic (CSC)
  - Point to point transmission of bulk power over very long distances
  - Sea cables (> 100 km)
  - Connection of strong, asynchronous grids with high power
- HVDC Light® (VSC)
  - Point to point transmission of small up to medium power over long distances
  - Connection of several (few) feed-in points, e.g. to support an existing AC grid
  - Suitable to be connected to weak grids or to supply passive loads (e.g. offshore platforms)

CSC: current source converter
VSC: voltage source converter

Applicability always depending on specific situation, difficult/impossible to come to general conclusions!

Examples of projects

Gotland – HVDC Light®



- Capacity: 50 MW
- Length: 70 km
- In operation since 1999
- Requirements
  - additional wind power, 90 MW
  - minimized environmental impact
- Advantages
  - voltage control for wind turbines
  - increased transmission capacity of parallel AC line
  - loss reduction on whole island due to improved voltage control

1953: first HVDC world-wide
1999: first HVDC Light®

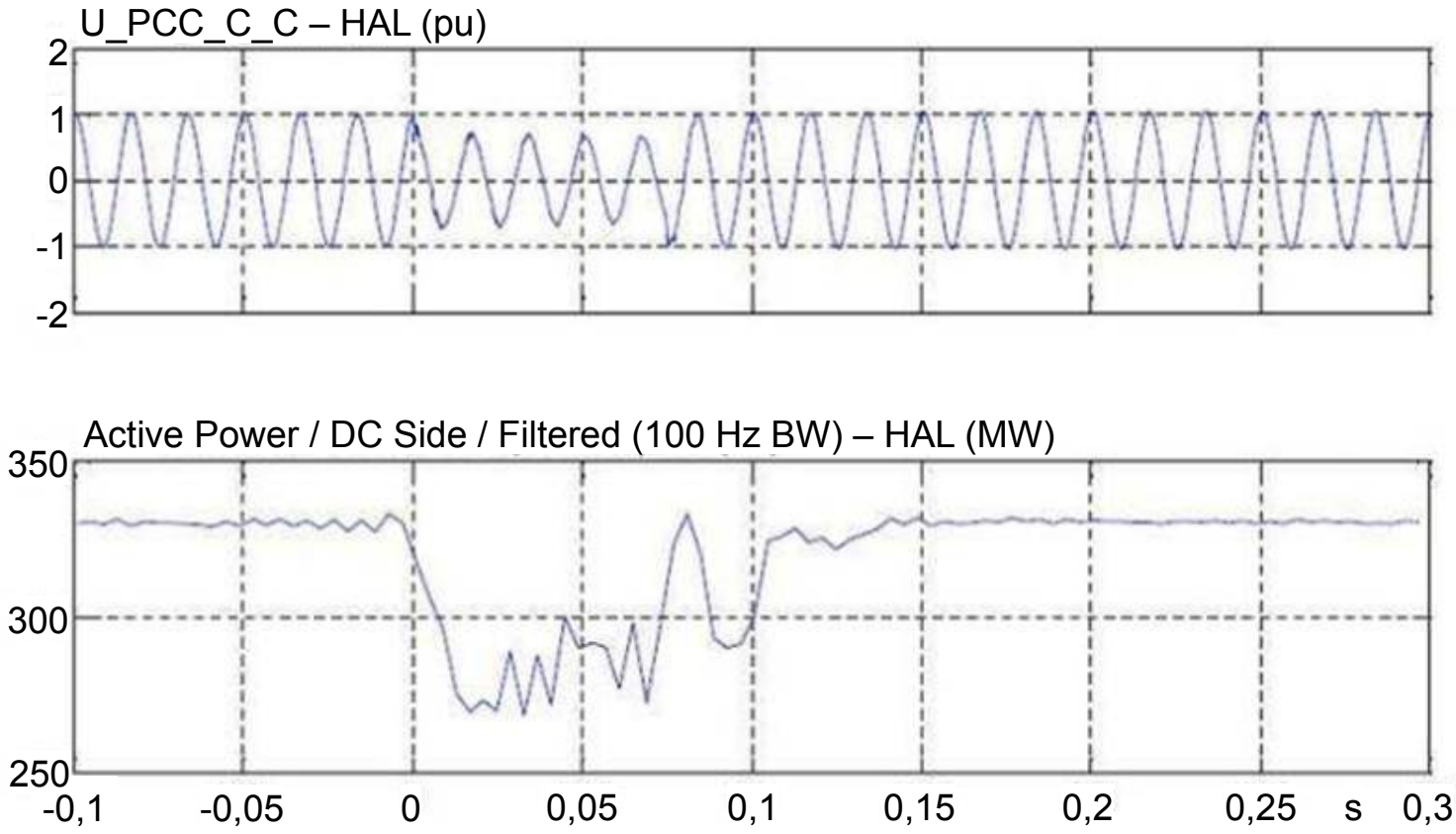
Murraylink – HVDC Light®
The longest land cable in the world

- Capacity: 220 MW
- Length: 160 km
- In operation since 2002
- Connecting the grids of Victoria and Southern Australia
- Experiences
  - more than 400 cable joints (150 kV)
  - in operation since more than four years
  - no failures
  - availability above 98,5 % (including planned maintenance!)

Cross Sound – HVDC Light®
The first large VSC project

- Capacity: 330 MW
- Length 40 km
- In operation since 2003
- Requirements
  - improvement of security of supply in Connecticut/Long Island
  - interconnection of two electricity markets
- Advantages
  - no grid enforcements required
  - improved security of supply because of continuous voltage and reactive power control
  - low space requirements

Cross Sound – HVDC Light®
Stabilizing the system instead of being sensitive



Cross Sound Cable – Dynamic Response to Network Faults
March 17, 2005 – Cross arm fault on 353 Line (345 kV)

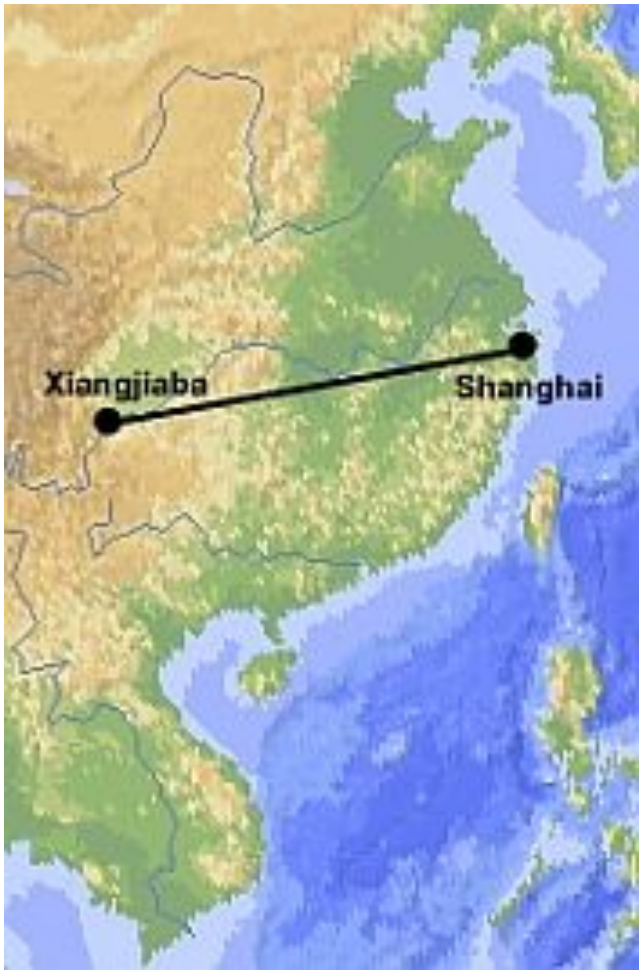
NorNed HVDC cable, Norway–The Netherlands
The longest cable in the world

Customer:
TenneT (NL) and
Statnett (N)

In operation: 2008

- Requirement
  - Connection of two power markets
  - Optimal use of differences in production and consumption
- ABB response
  - Turnkey 700 MW system with new ± 450 kV converter system
  - Longest cable in the world: 580 km
- Customer benefit
  - Very low losses (system losses: 3.7 %)
  - Avoiding about 1.7 mio t CO_2 emissions per year
  - Support of wind power development in The Netherlands

Xiangjiaba–Shanghai ± 800 kV UHVDC, China
The biggest transmission system in the world



Customer: SGCC

In operation:
2010-2011

- Requirement
  - Utilization of renewable energy (hydro power) 2’000 km apart from load centers
- ABB solution
  - Most powerful and longest transmission system in the world
  - ± 800 kV UHVDC, 6’400 MW
- Customer benefit
  - High efficiency - 93 %
  - Compact footprint - 40 % less space requirement compared to conventional solution
  - Reliability:
    outage probability < 0.5 %

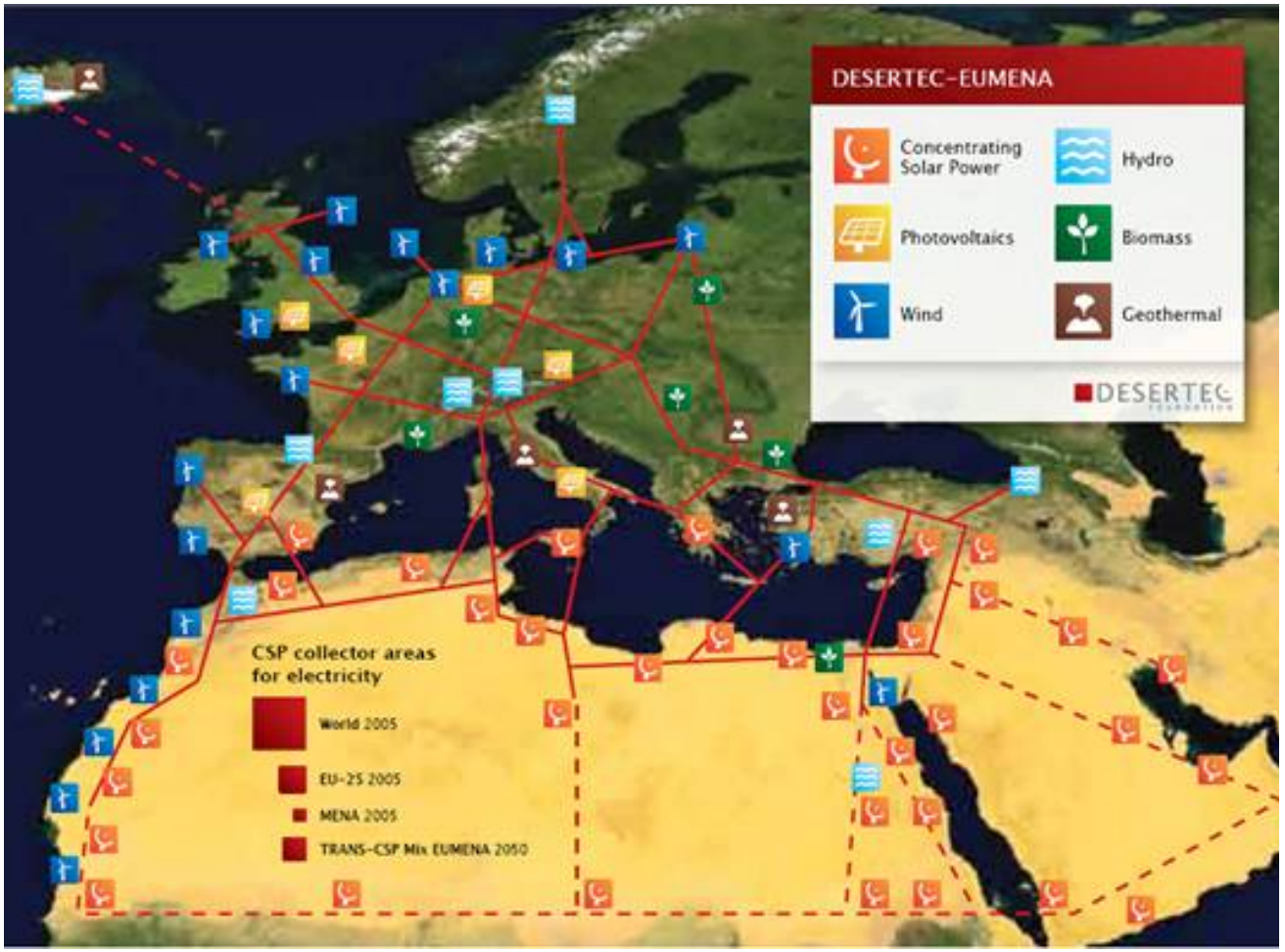
BorWin 1 – HVDC Light®, Germany
The world‘s first HVDC offshore wind farm connection

Customer:
transpower

Ready for operation:
October 2009

- Capacity: 400 MW (phase 1)
- Length: 128 km sea cable,
  75 km land cable
- Ready for operation: October 2009
- Requirements
  - Turnkey project execution
  - Integration into transmission grid according to grid code
  - Short delivery time
- Advantages
  - Modular extension concept
  - About two years delivery time

The future?
A scenario for Europe



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for a better world™