Latin American Workshop 2013

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Achievement and experience in service of long length HV DC electrical links by insulated power cables

Marco Marelli, Italy

Foz do Iguaçu – September 6th, 2013

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1. HVDC Systems
2. HVDC Cables
3. Service Experience and Ongoing Projects
4. Challenges for the Near and Far Future
5. Collective Efforts to Move Steps Forward

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1	HVDC Systems
2	HVDC Cables
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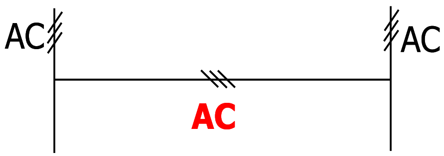
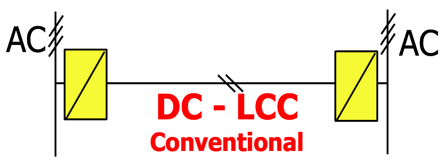
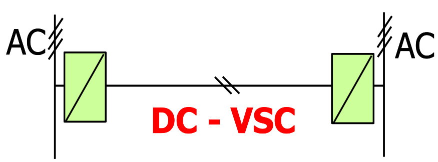
Characteristics of Cable Transmission Systems

Transmission Solution	Advantages	Drawbacks/Limitations
	Simple No maintenance High Availability	Heavy cable Length (50-150 km) Rigid connection/Power control Require reactive compensation
	Less no. of cables, lighter No limits in length Low cable and conv. Losses Power flow control Very high transmiss. power	Needs strong AC networks Cannot feed isolated loads Polarity reversal Large space occupied Special equipment (trafo, filters)
	Can feed isolated loads (oil platforms, wind parks, small islands, etc.), medium power Modularity, short deliv.time Small space and envir.impact No polarity reversal Standard equipment	Higher conversion losses Low experience Limited power

VSC characteristics have enabled new opportunities in HVDC transmission.

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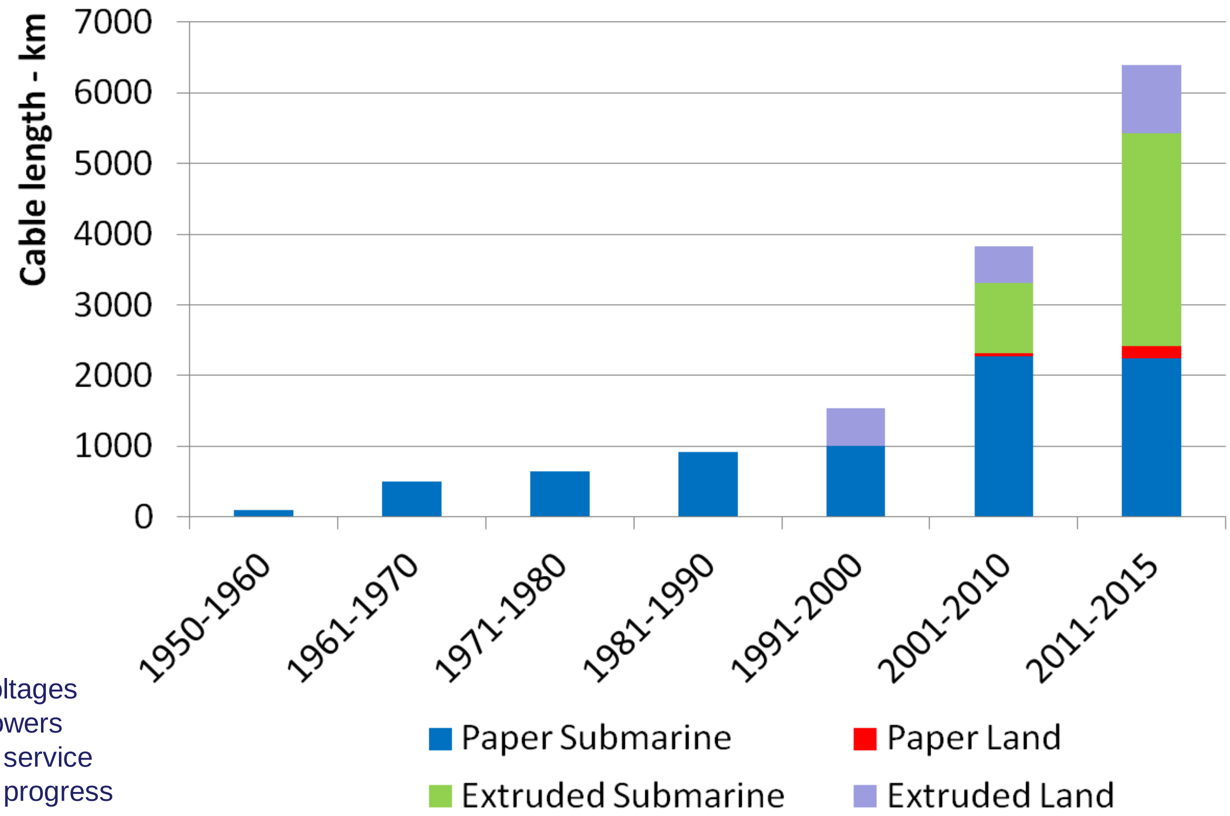
HVDC Cable Usage



All voltages
All powers
All in service
All in progress

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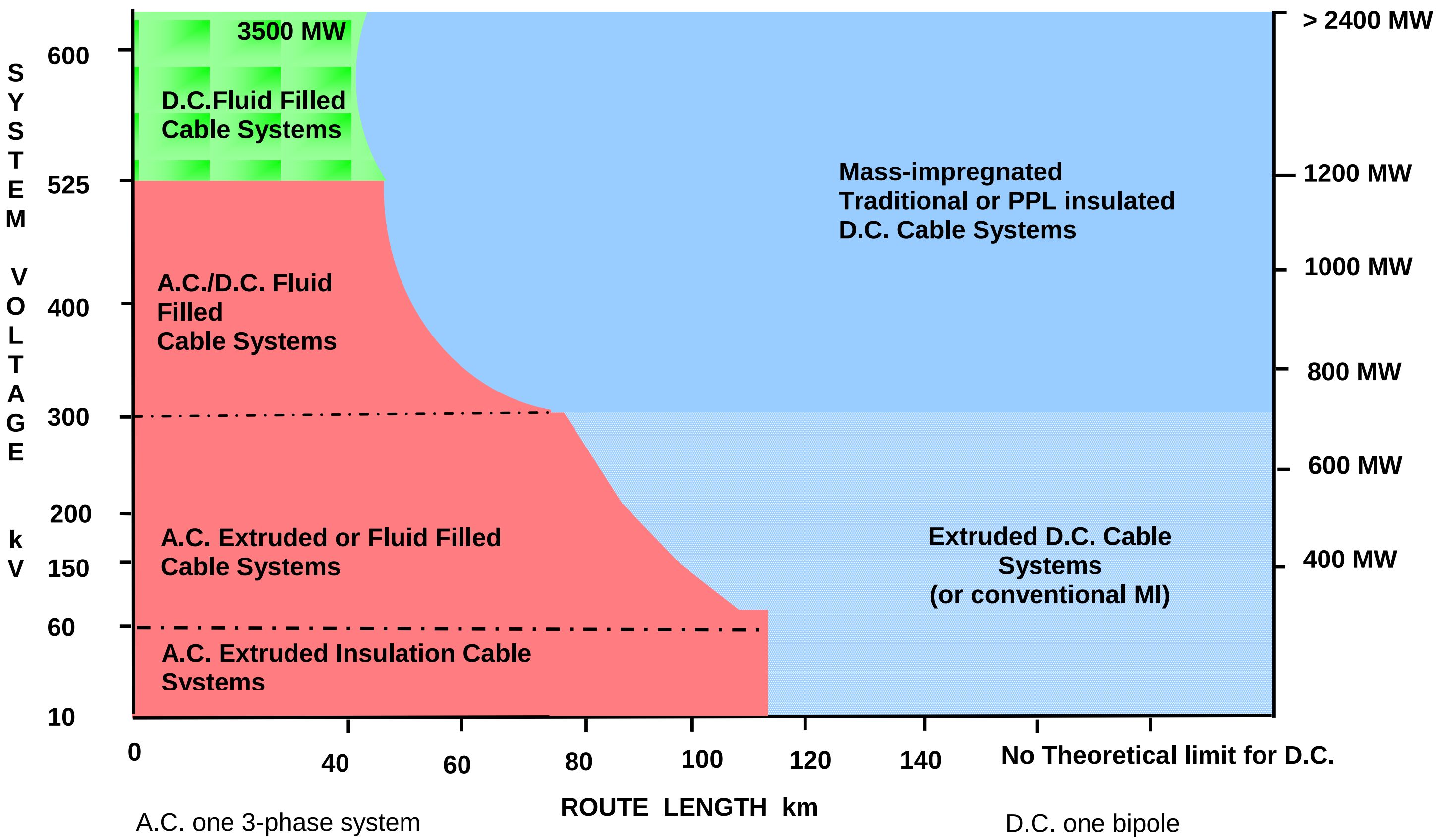
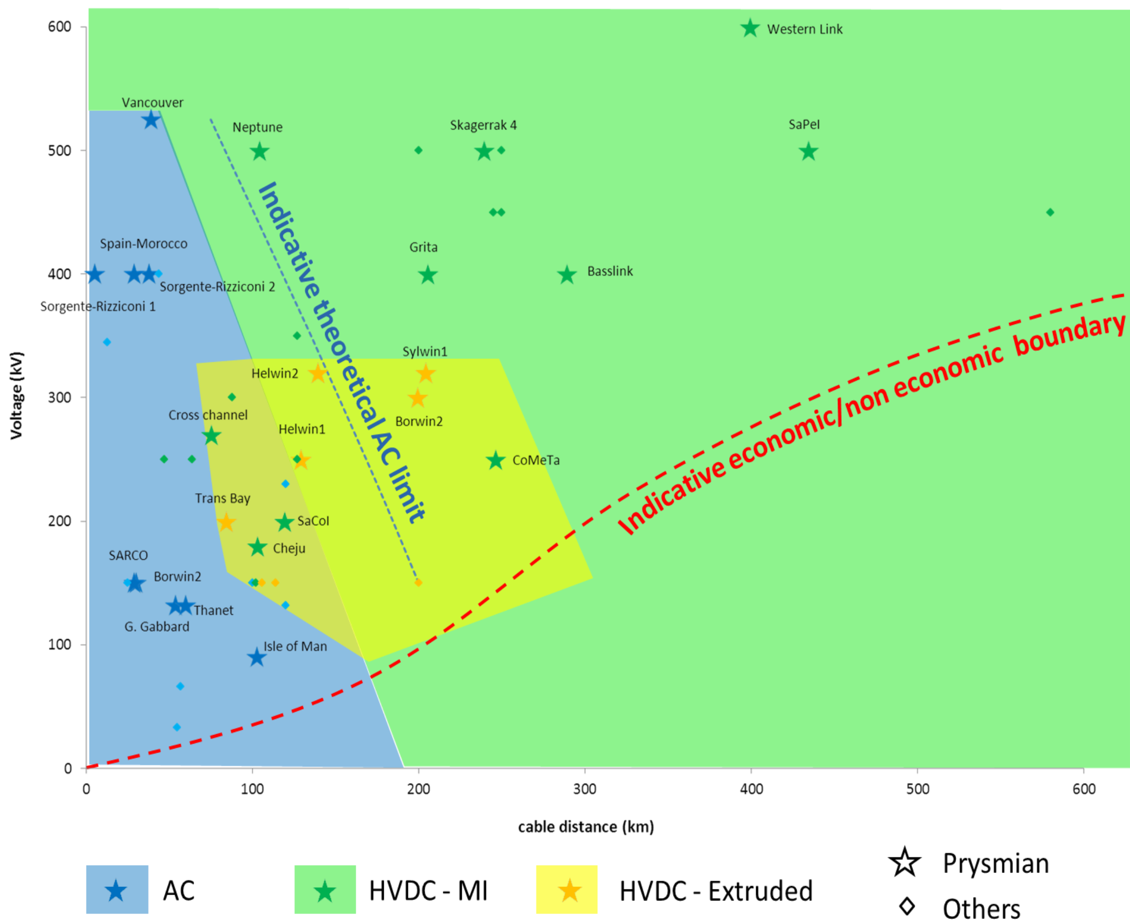
Power Transmission System Selection



Long Lengths in Submarine Cable Systems



1 HVDC Systems

2 **HVDC Cables**

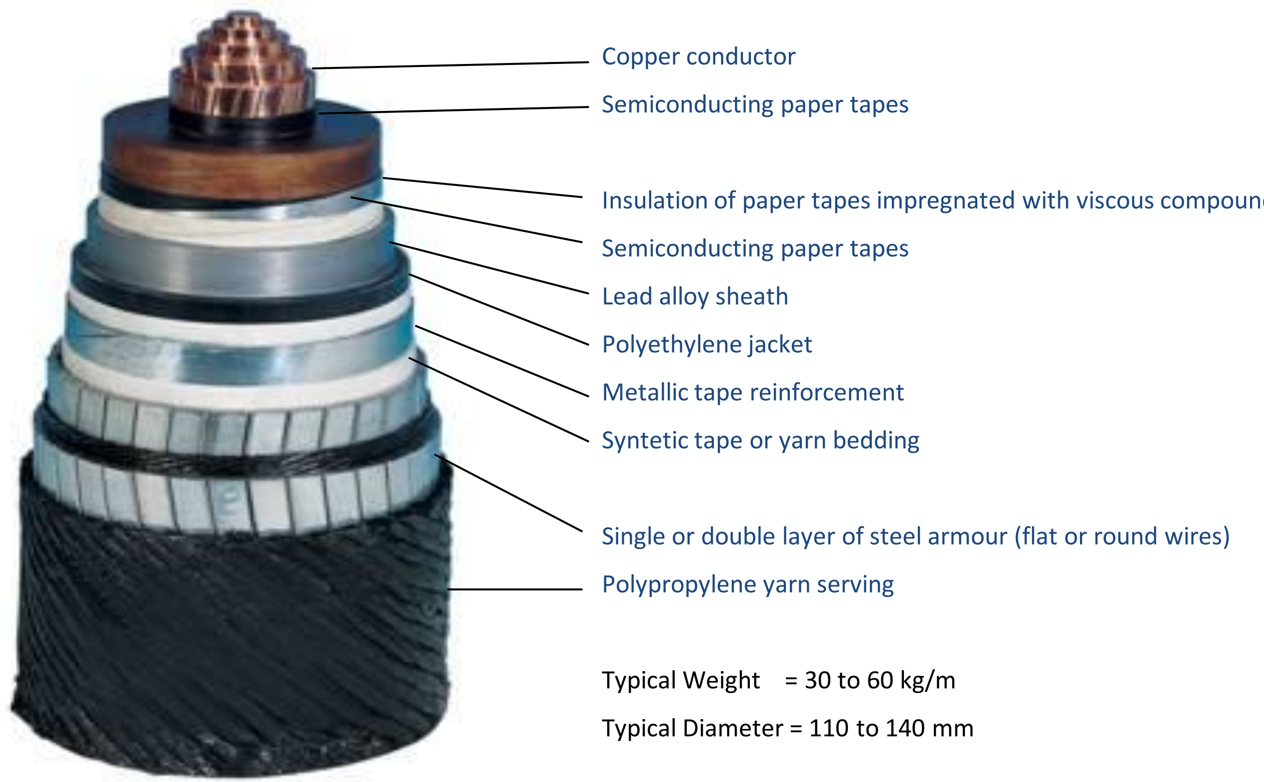
3 Service Experience and Ongoing Projects

4 Challenges for the Near and Far Future

5 Collective Efforts to Move Steps Forward

HVDC CABLE TECHNOLOGIES

Mass Impregnated Cables (MI) are still the most used; they are in service for more than 50 years and have been proven to be highly reliable. At present used for Voltages up to 500 kV DC (600 kV in progress). Conductor sizes typically up to 2500 mm^2.



Typical Weight = 30 to 60 kg/m

Typical Diameter = 110 to 140 mm

HVDC CABLE TECHNOLOGIES

Self Contained Fluid-Filled Cables (SCFF) are used for very high voltages (they are qualified for 600 kV DC) and for short connections, where there are no hydraulic limitations in order to feed the cable during thermal transients; at present used for Voltages up to 500 kV DC. Conductor sizes up to 3000 mm^2.

Typical Weight = 40 to 80 kg/m

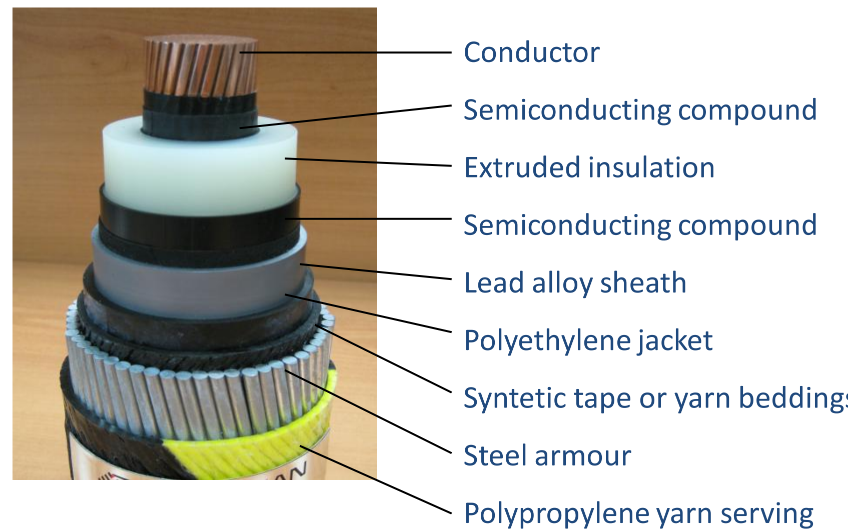
Typical Diameter = 110 to 160 mm

HVDC CABLE TECHNOLOGIES

Extruded Cables for HVDC applications are rapidly developing; at present they are used for relatively low voltages (in service at 200 kV, under construction up to 320 kV DC), mainly associated with Voltage Source Converters, that permit to reverse the power flow without reversing the polarity on the cable.

In fact, an Extruded Insulation can be subjected to an uneven distribution of the charges, that can migrate inside the insulation due to the effect of the electrical field.

It is therefore possible to have an accumulation of charges in localised areas inside the insulation (space charges) that, in particular during rapid polarity reversals, can give rise to localised high stress and bring to accelerated ageing of the insulation.



Typical Weight = 20 to 35 kg/m

Typical Diameter= 90 to 120 mm

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COMPARISON BETWEEN TECHNOLOGIES
STATE OF THE ART

	Maximum operating voltage	Maximum operating temperature	Transmissible power, per bipole (*)
MI – Paper	500 kV	55 ° C	1.6 GW
MI – PPL	600 kV	85 ° C	2.4 GW
Extruded	320 kV	70 ° C	1.2 GW

(*) submarine cables at 1.0 m burial depth, 15 °C temperature, 1.0 K.m/W TR, cables in bundle

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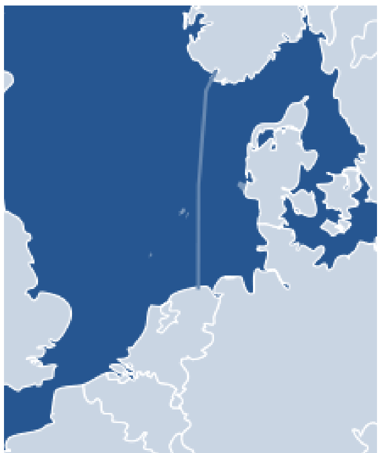
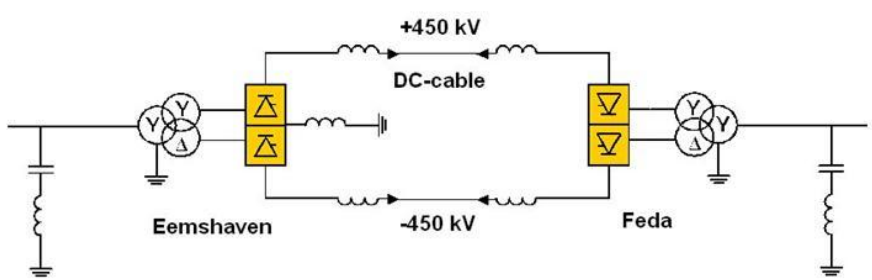
The NorNed HVDC link

The 580 kilometer-long NorNed link is the longest submarine high-voltage cable in the world



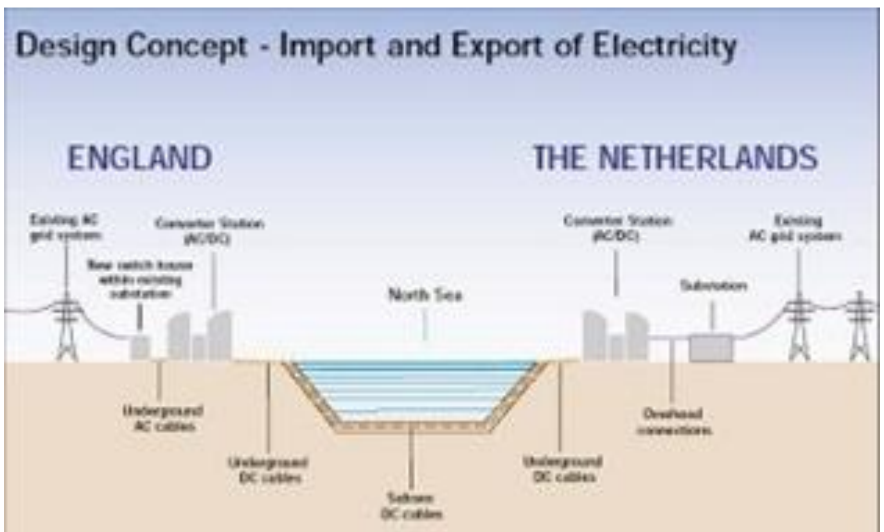
- Noway to Neatherlands
- Bipole
- Two different cable types
    - 1-core for deep waters
    - 2-core for shallow waters
- Taken in operation in 2008



BritNed

BritNed cable connects Nederlands and United Kingdom since 2011

- Voltage: ± 450 kV DC
- Cable capacity: 1000 MW
- Weight: 44 kg/metre (23.000 tonnes)
- Length sea cable: 250 km (two cables, bundled)
- Length land cable: 7 km (NL) and 2 km (GB), two cables, laid together
- Conductor: 1 x 1430mm² Cu (copper cable)



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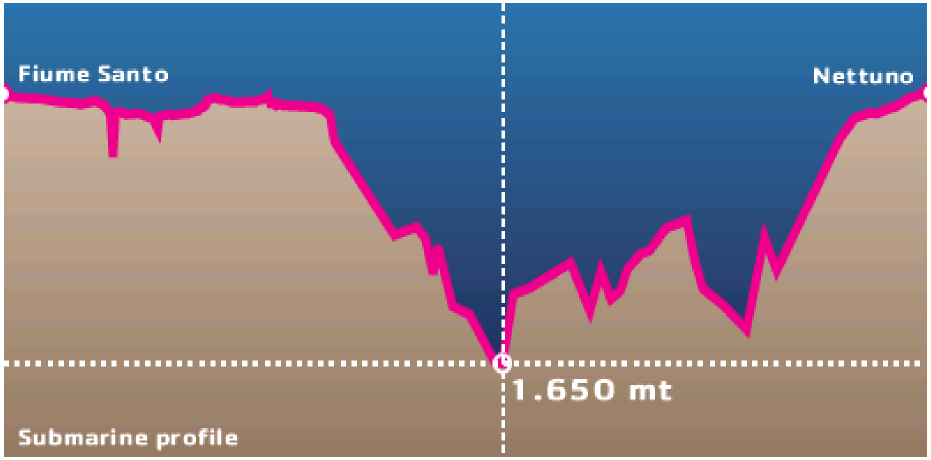
SA.PE.I (Sardinia-Peninsula Italiana)

PROJECT MAIN FEATURES

◆ RATED POWER	1000 MW (2x500MW)	
◆ RATED VOLTAGE	500 kV DC	
◆ ROUTE LENGTHS:	- Submarine	2x425 km
	- Land	2x15 km
◆ MAX WATER DEPTH	1650 m	
◆ CABLE TYPE AND SIZE	Paper, MI	
◆ IN SERVICE SINCE	Dec-2008 (Pole 1) / Oct-2010 (Pole 2)	



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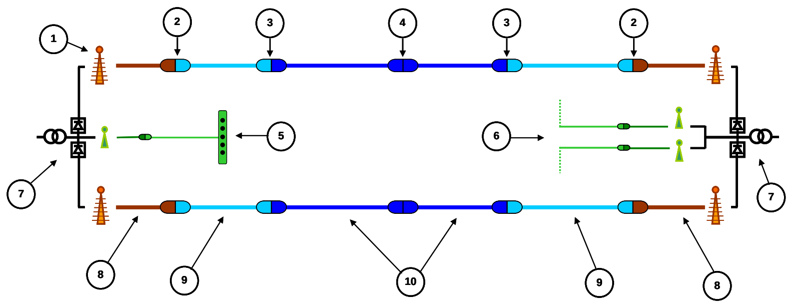
SA.PE.I (Sardinia-Peninsula Italiana)



1 – Outdoor termination
2 – Sea-land joint
3 – Medium water depth/high water dept joint
4 – High water depth joint
5 – Sea electrode (anode)
6 – Sea electrode (cathode)
7 – AC-DC converter station
8 – Land cable
9 – Low/medium water depth cable
10 – High water depth cable

Deep water cable

Rated voltage		(kV)	±500
Rated power per cable		(MW)	500
Rated current		(A)	1000
Insulation material		Mass Impregnated	
Deep water	Cross section	(mm^2)	1150
	Conductor material	Aluminium	
Medium-shallow water	Cross section	(mm^2)	1000
	Conductor material	Copper	
Land	Cross section	(mm^2)	1400
	Conductor material	Copper	

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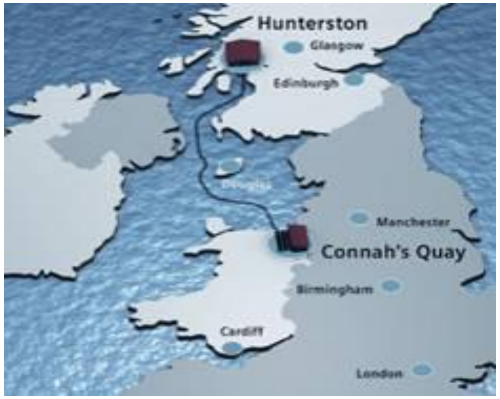
OTHER PROJECTS…

…are currently in progress, at voltages up to 600 kV

Skagerrak 4
4° link Norway-Denmark
500 kV DC (one pole)
137km sub, 105km land

HVDC Western Link
Scotand to England
600 kV DC - bipole
424 km route length



Mon.Ita
(Montenegro to Italy)
500 kV DC - bipole
2x 390km sub, 24km land

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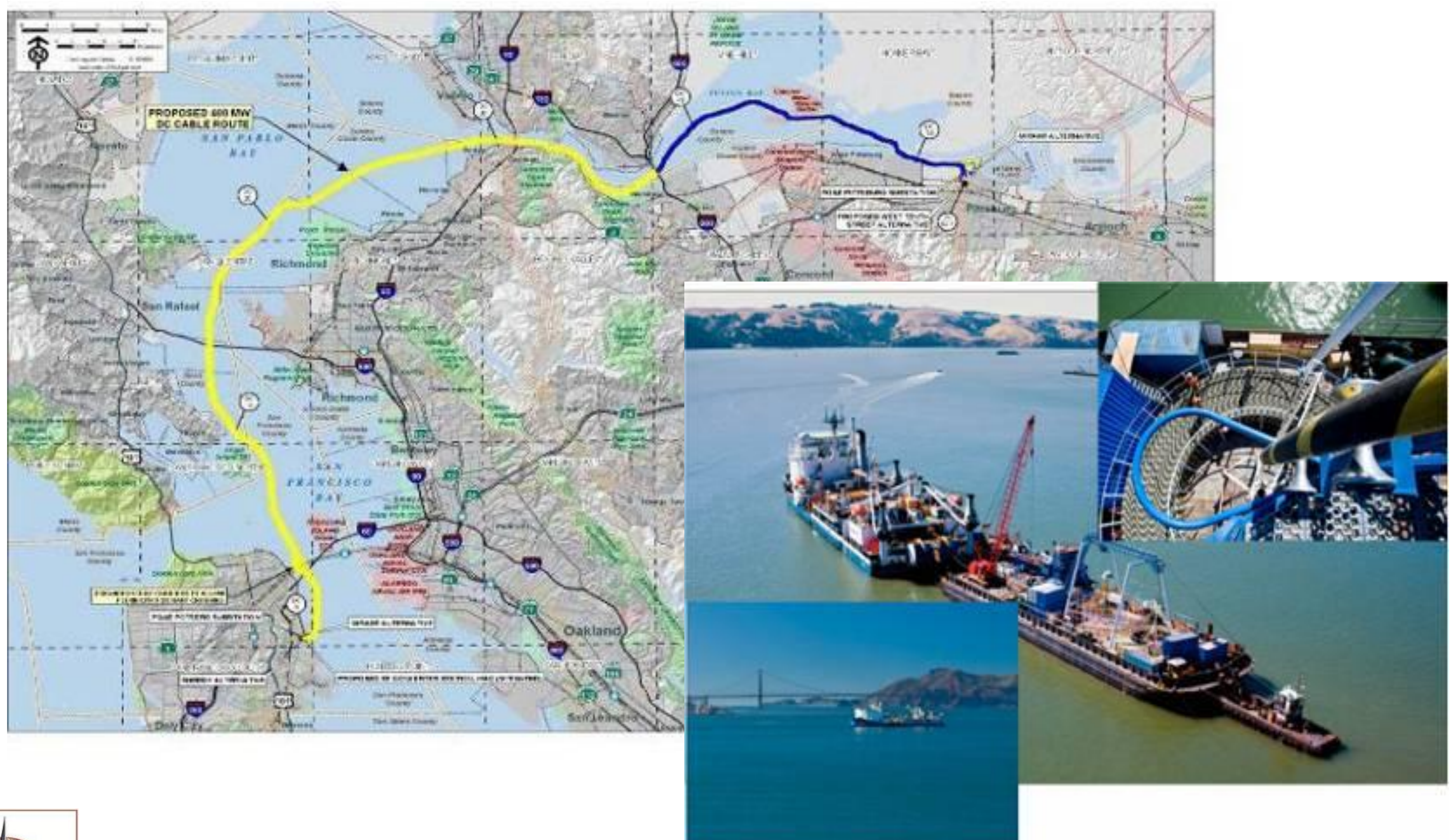
Trans Bay Cable Project

85 km, 200 kV, 400MW HVDC in the San Francisco bay



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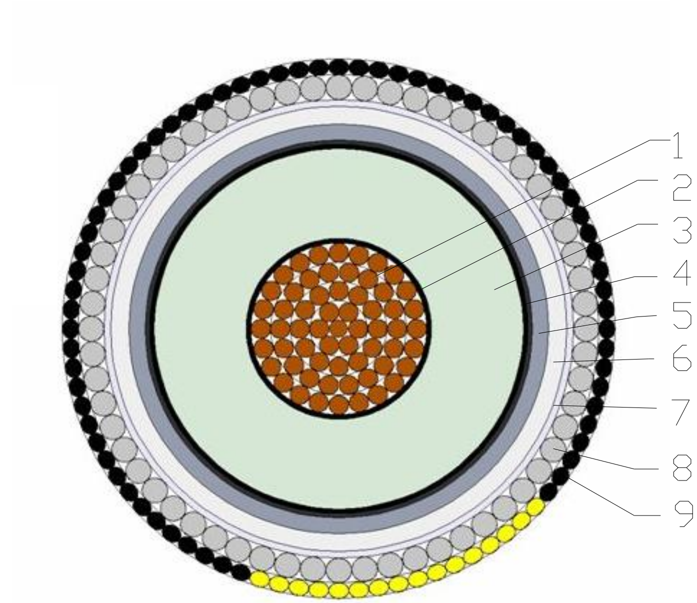
Trans Bay Cable Project

The first 200 kV HVDC extruded cable being installed and commissioned



1 – Stranded copper conductor, longitudinally sealed
2 – Semiconducting tape+extruded layer
3 – XLPE based special insulation compound
4 – Semicond. layer + Longitudinal water penetration barrier
5 - Lead alloy sheath
6 - Polyethylene sheath
7 - Polypropylene bedding
8 – Galvanised steel wires armour
9 – Polypropylene serving

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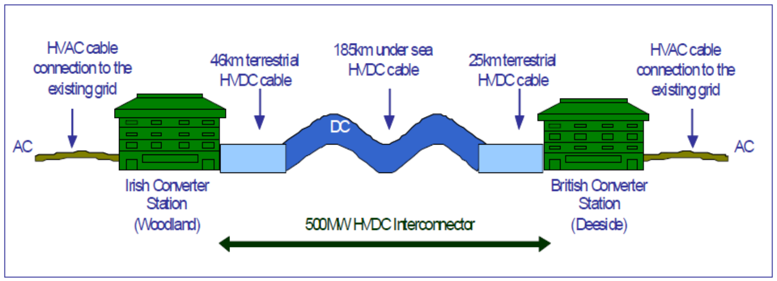
East West Interconnector



Main data	
Commissioning year:	2013
Power rating:	500 MW
DC Voltage:	±200 kV
Length of DC underground cable:	2 x 75 km
Length of DC submarine cable:	2 x 186 km
Application:	Interconnecting grids

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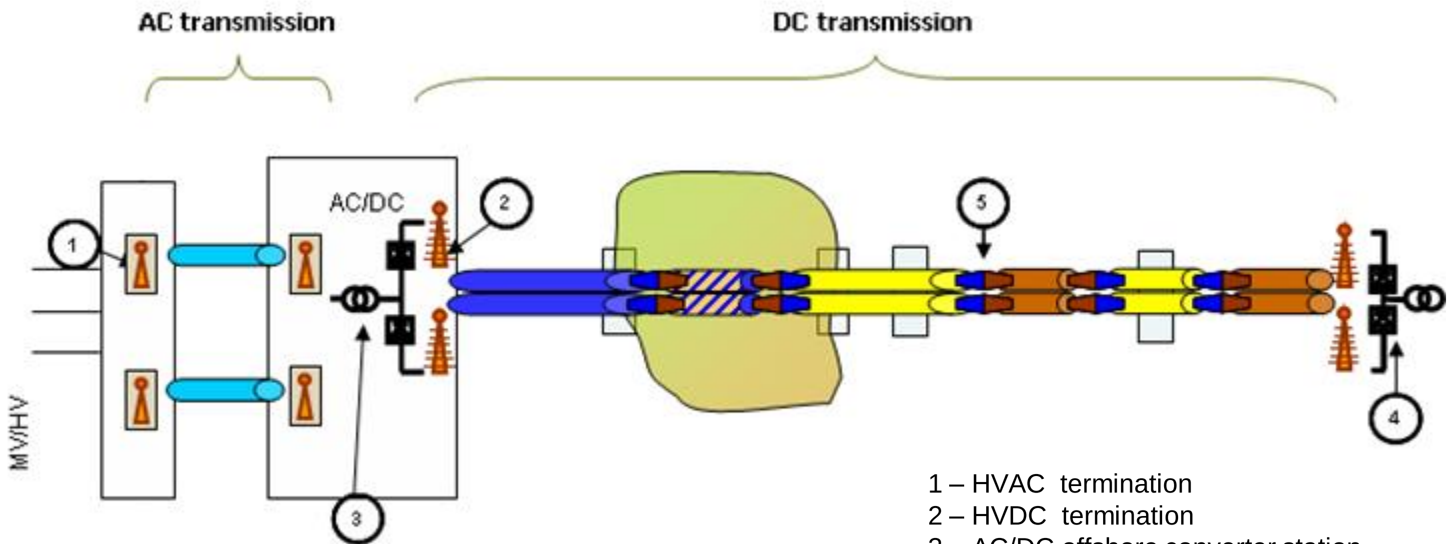
German North Sea Offshore Wind Farm Projects

HVDC submarine + land connections in the German North Sea:

- BorWin1 – 150 kV 400 MW
- BorWin2 – 300 kV 800 MW
- SylWin1 – 320 kV 864 MW
- HelWin1 – 250 kV 576 MW
- HelWin2 – 320 kV 690 MW
- Dolwin1 – 320kV 800 MW
- Dolwin2 – 320kV 900 MW
- Dolwin3 – 320kV 900 MW

Approx **2650 km HVDC cable** (782km submarine route length, 543 km land route length)

German North Sea Offshore Wind Farm Projects



1 – HVAC termination
2 – HVDC termination
3 – AC/DC offshore converter station
4 – DC/AC land converter station
5 – Sea/Land transition joint

TYPICAL SCHEME

- Different voltage levels (optimized for converters and cables)
- Different cable designs/sizes (different ambient conditions along routes)

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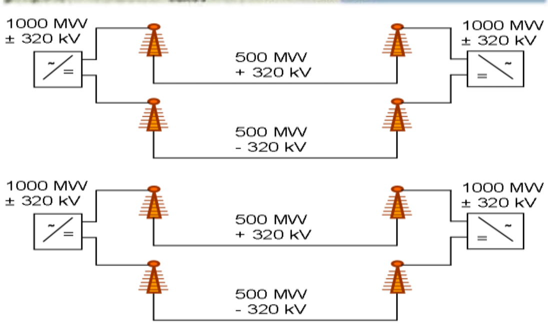
Interconnection Spain-France 320 kV DC « INELFE »



Rated voltage	(kV)	±320
Rated power per cable	(MW)	500
Cross section	(mm^2)	2500
Conductor material	Copper	
Insulation material	XLPE	
Metallic screen	Longitudinally welded aluminium sheath	

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OTHER PROJECTS…

…are currently in progress, mainly in Europe but also in North America and Asia

Hokkaido – Aomori
(Japan)
250 kV DC
45 km route length

NordBalt
(Sweden - Lithuania)
300 kV DC
450 km route length

South West Link
(Sweden, land connection)
300 kV DC
2x186 km cable route length

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HVDC Growth Drivers

http://www.friendsofthesupergrid.eu

- Merchant Transmission Lines
- Smart Grid / Super Grid
  - Interconnecting large / asynchronous regions
  - Controllable power
  - Reduction in spinning reserve
- Renewable Resources
  - Renewable locations distant from load centers
- Offshore Technologies
  - Wind Power
  - Drilling Platforms

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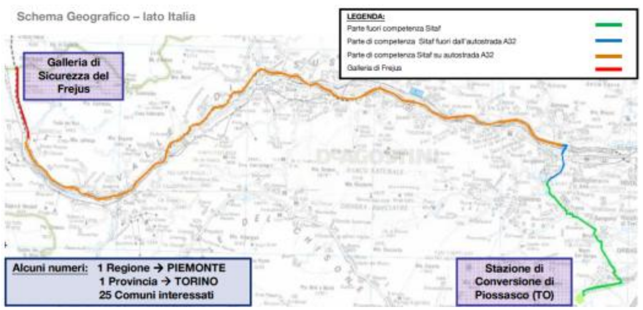
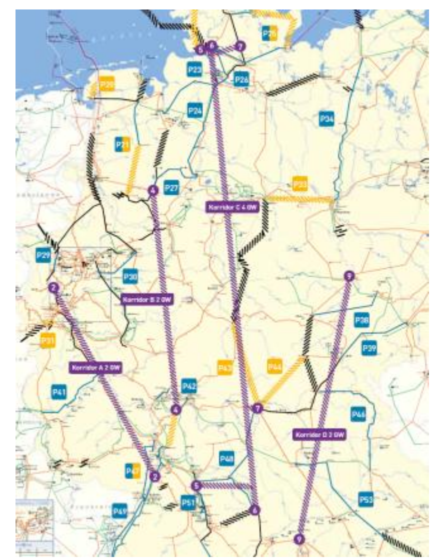
A Future HVDC Land Grid?

In addition to ongoing projects and studies for submarine connections, ther is a new interest for land HVDC long lines, including significant cable portions



Piemonte-Savoia
(Italy-France, land)
320 kV DC
200 km route length

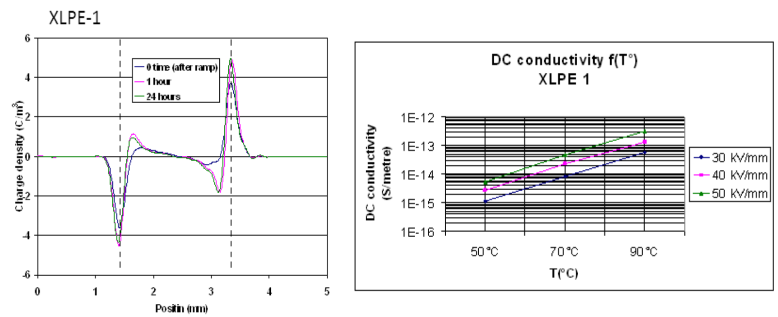
Germany
(north-south, partially underground)
4 x 4 GW HVDC



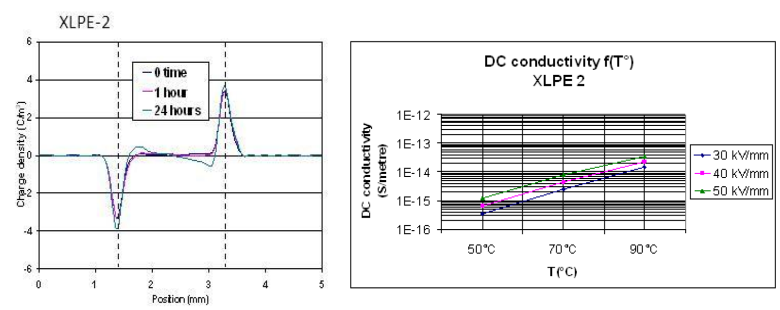
HVDC Cable System Development

Cable Technology

- Materials continue to be developed to improve key HVDC performance characteristics
- Increased voltage ratings can reduce losses or conductor costs
- Increased conductor sizes increases power transfer or losses
  - Cable size and weight and logistics requirements may offset benefits
- Accessories must match the changes in cable technology
  - System level testing is key aspect to ensure reliable operation



Maximum charge density: 2.0 C/m³
Maximum modified electric stress: +60%



Maximum charge density: 0.5 C/m³
Maximum modified electric stress: +20%

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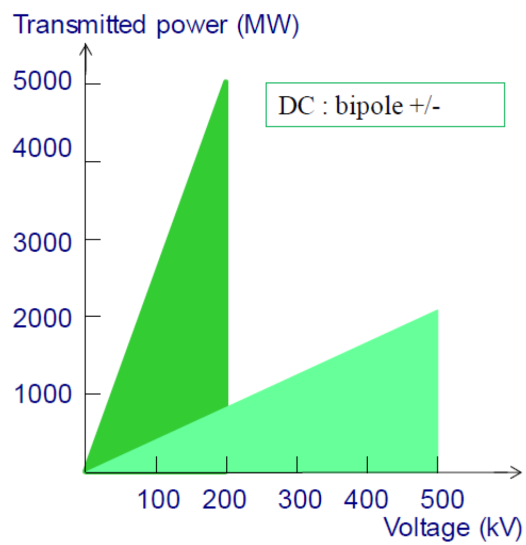
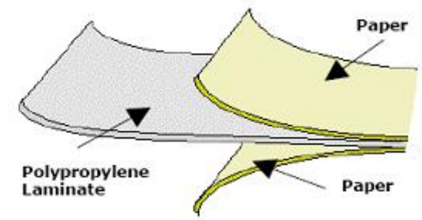
HVDC Cable System Development

Currently used materials are continuously improved. Additionally, newer development may improve near and far future perspectives.

Improved XLPE with special filler.
Applicable to VSC/LCC
Conductor temp. up to 90 deg.C.



Present maximum transmitted power vs voltage for HVDC resistive and superconducting HVDC cables systems



PPL insulation material for MI cables. Increased votage.
Conductor temp. up to 85 deg.C.

Challenges in Deep Water Applications

Deep water applications require maximum coordination between submarine cable and installation design in order to keep pulling forces during installation and recovery within acceptable limits for the cable and the installation ship

Deep water cable

Cable mechanical design requirements:

- Elongation within acceptable limits
- Minimize rotation under tensile loading.
- Minimize weight to lower cable tension during installation
- Acceptable breaking strength
- Flexible joints, with no or minimal diameter variation

Cable installation ship characteristics

- laying machine capable to withstand high pulling force
- dynamic positioning system
- rotating platform for the storage of cables

Most suitable vessels have a capstan able to withstand a braking force of 55 tons in dynamic conditions

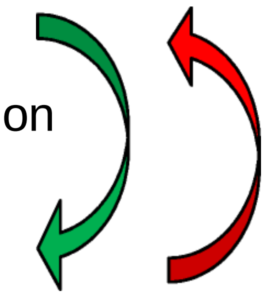
AC to DC?

DC cables

- Low insulation conductivity
- High partical and chemical cleanliness for insulation

AC cables

- High partical cleanliness for insulation



- DC *accessories* do not always allow continuous high AC stress
- AC *accessories* are not specifically designed for DC stress

Only if AC systems are specifically designed for both AC&DC they can be used for DC purposes

Only if DC systems are specifically designed for both AC&DC they can be for AC purposes

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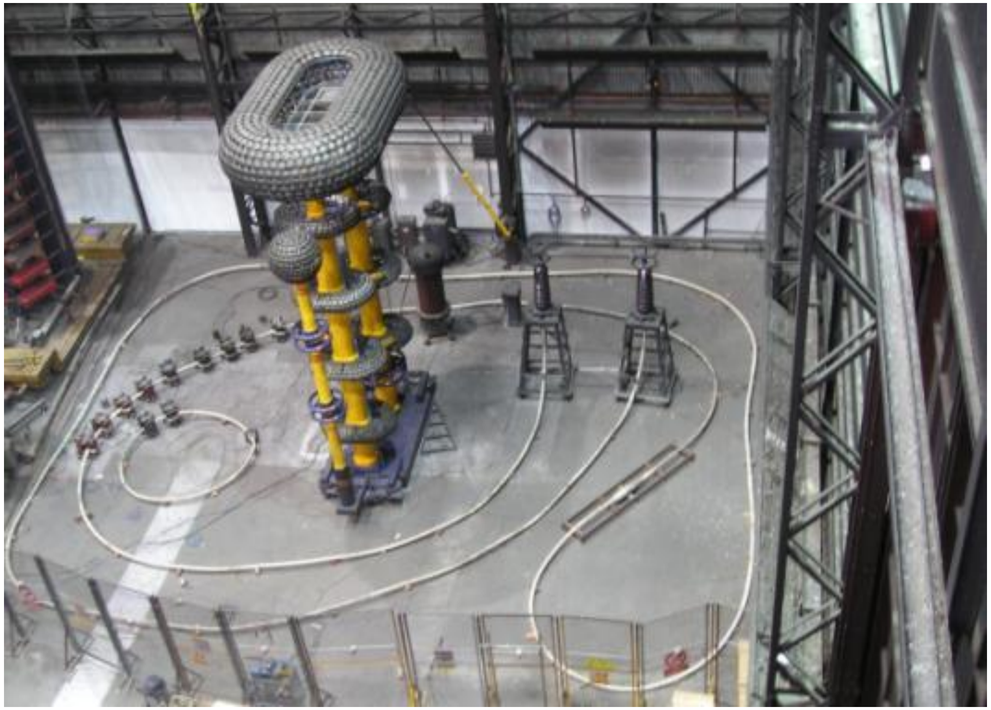
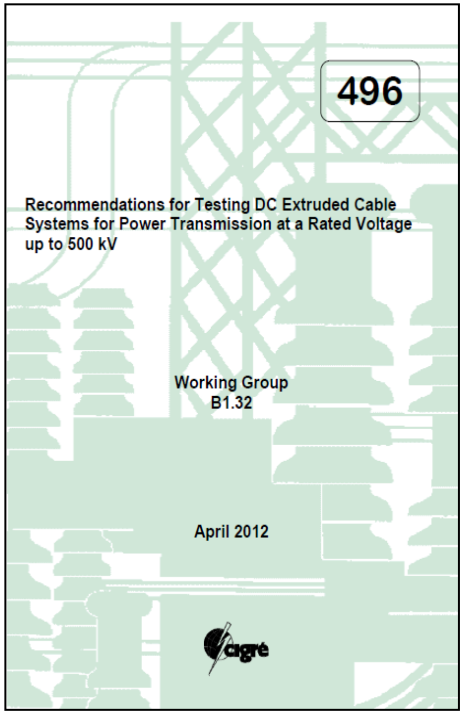
HVDC Testing and Qualification

Prequalification test recommendations are currently described in CIGRE technical brochures. The realization of technical innovation must be carefully tested to ensure a reliable and effective system.





Technical and Standardization Work

- **CIGRE Brochures Released in past 18 months...**
  - TB492 VSC Voltage Source Converter (VSC) HVDC for Power Transmission – Ecomonic Aspects and Comparison with other AC and DC Technologies
  - TB496 Recommendations for Testing DC Extruded Cable Systems for Power Transmission at a Rated Voltage up to 500kV
  - TB506 Gas Insulated System for HVDC: DC Stress at DC and AC Systems
  - TB518 Outdoor Insulation in Polluted Conditions: Guidelines for Selection and Dimensions – Part 2: The DC Case
  - TB520 Material Properties of Solid HVDC Insulation Systems

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Interest in HVDC from other International Bodies

HVDC: Economical aspects (1)

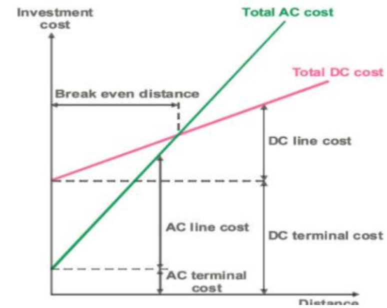
- Quantitative data on HVDC costs
  - based on publicly available data and on TSO questionnaire

System component	Voltage level	Power rating	Cost range		Unit
			min	max	
HVDC OHL, bipolar[(1)]	±150..±500 kV	350..3000 MW	300	700	kEUR/km
HVDC underground cable pair	±350 kV	1100 MW	1000	2500	kEUR/km
HVDC undersea cable pair	±350 kV	1100 MW	1000	2000	kEUR/km
HVDC VSC terminal, bipolar	±150..±350 kV	350..1000 MW	60	125	kEUR/MW
HVDC CSC terminal, bipolar	±350..±500 kV	1000..3000 MW	75	110	kEUR/MW

(1) cost ranges correspond to the base case, i.e. installation over flat land. For installations over hilly landscape +20% and +50% for installations over mountains or urban areas have to be factored in.

HVDC: Economical aspects (2)

- Qualitative comparison HVDC <-> HVAC



HVDC: Environmental impact (1)

- Quantitative data on HVDC land use
  - based on publicly available data and on TSO questionnaire

System component	Voltage level	Power rating	Land use		Unit
			min	max	
HVAC OHL, single circuit	400 kV	1500 MVA	40000	60000	m²/km
HVAC underground XLPE cable, single circuit	400 kV	1000 MVA	5000	15000	m²/km
Reactive power compensation unit for HVAC cable line	400 kV	1000 MVA	2000	3000	m²
HVDC OHL, bipolar	±150..±500 kV	350..3000 MW	20000	40000	m²/km
HVDC underground cable	±350 kV	1100 MW	5000	10000	m²/km
HVDC undersea cable	±350 kV	1100 MW	0		m²/km
HVDC VSC terminal, bipolar	±150..±350 kV	350..1000 MW	5000	10000	m²
HVDC CSC terminal, bipolar	±350..±500 kV	1000..3000 MW	30000	60000	m²

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Potential of HVDC in future power grids

- Increase of transmission capacity
  - Best suited for bulk-power transmission
  - No limitation in cable line length (no charging current)
  - No contribution to the short-circuit current (no upgrade of existent equipment necessary)
- Improvement of controllability
  - Easy and quick bi-directional control of active power flow
  - Easy and quick bi-directional control of reactive power balance (in case of VSC-HVDC)
  - HVDC lines stop fault spreading ("fire wall")
- Contribution to environmental protection
  - Enabling to go underground without limitation in line length
  - Less land use*
  - Lower visual profile of HVDC OHL*

*compared to an equivalent HVAC transmission system

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Institutions like EU ENTSO-E, DoE in US, Governments, etc.
Interest groups like Medgrid, FOSG, etc.

Seminars, conferences, workshops, …

- Lot of events focused on HVDC transmission
- Cigrè SC B1 has tutorials covering HVDC cables issues
- Cigrè SCs B1, B2, B4 coordinates their work

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Jicable 2011: large attention to HVDC

HVDC cables discussed in 4 Sessions

10 papers specifically dedicated to HVDC cables and systems

Long HVDC connections being presented (Spain-France, Western Link, German Offshore Wind connections, Sardinia-Italy, ...)

Closing Round Table on "State of the art and future prospects of HVDC links by power insulated cables"

Video still available at:

http://www.jicable.org/2011/Round_table.php

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HVDC Papers @ Jicable 2011

2011-A.2.1 - Specification for extruded HVDC land cable systems

2011-A.2.2 - Key parameters for extruded DC cable qualification

2011-A.2.3 - Development of pre-molded accessories for HVDC extruded cable system

2011-A.2.4 Development of a 270 kV XLPE cable system for HVDC applications

2011-A.2.5 - Development of high performance polymeric materials for HVDC cables

2011-A.2.6 - Evolution of electric field, space charge concentration and distribution in an extruded HVDC cable

2011-A.6.1 - Offshore wind parks grids connection projects in German North Sea

2011-A.6.2 - High capacity HVDC subsea link for the UK

2011-A.6.3 - Cables for deep water applications

2011-A.7.4 - On the optimum burial depth of submarine power cables

Jicable Workshops: WETS'11

HVDC cables were discussed in a workshop dedicated to Long Lengths

WETS'11 WORKSHOP
World Energy Transmission System

"Achievement and experience in service of long length (> 10 km), HV, EHV and UHV electrical links by AC and DC insulated power cables"

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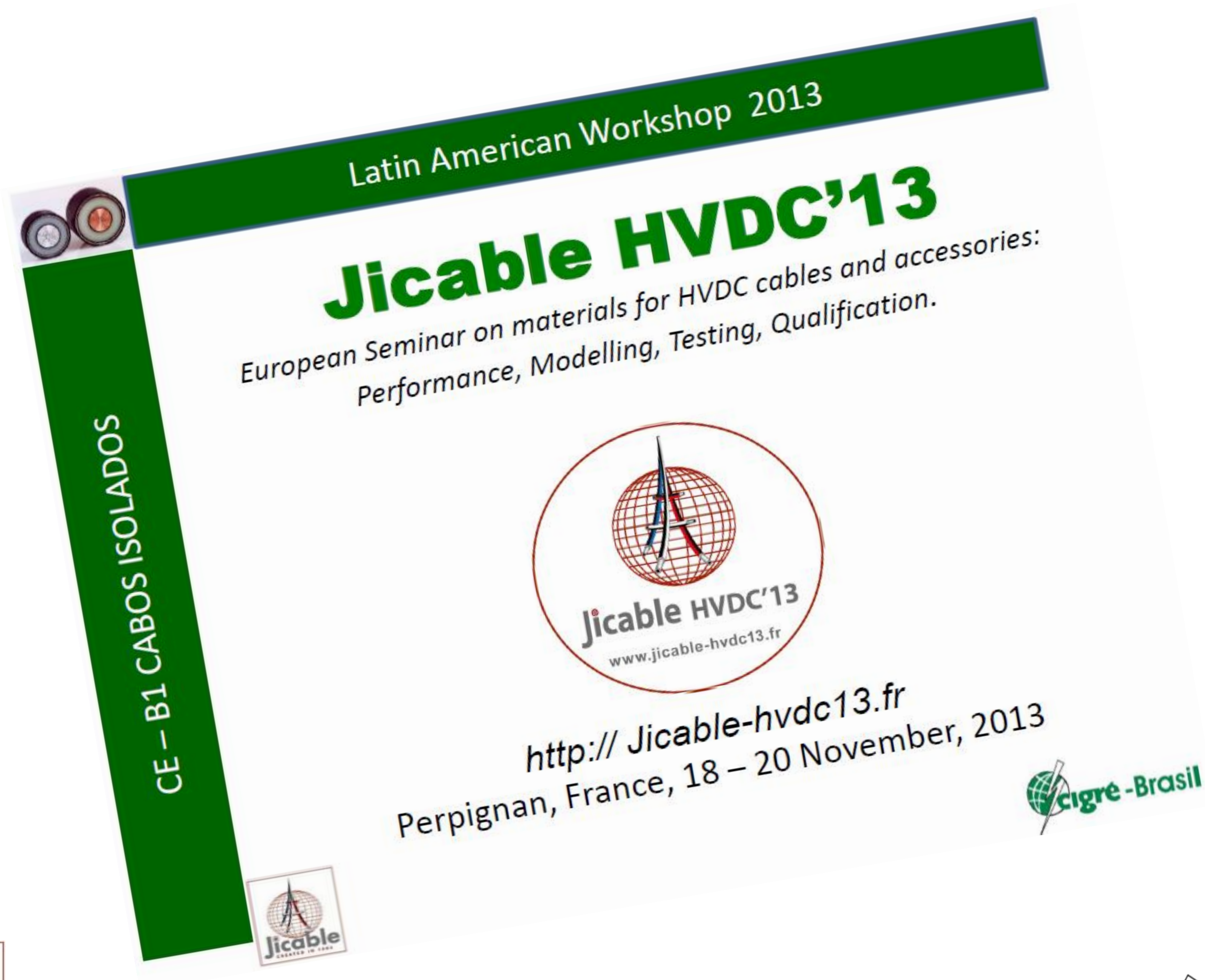
Next event…



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Achievement and experience in service of long length HV DC electrical links by insulated power cables

Thank you for your attention.

Questions?