High voltage underground and subsea cable technology options for future transmission in Europe

Ernesto Zaccone, Chairman Europacable High Voltage Systems Group
Talk plan: underground & subsea cables

• **Scope**
  - XLPE AC power cables ; XLPE and Mass Impregnated (MI) DC power cables; the war of the currents: AC vs. DC power transmission
  - Brief history of underground & subsea cables

• **XLPE AC underground & subsea cables**
  - State of the art
  - Highlight on technical performances
  - Highlight on environmental issues
  - Technical outlook 2050

• **DC XLPE and MI underground & subsea cables**
  - State of the art
  - Highlight on technical performances
  - Highlight on environmental issues
  - Technical outlook 2050

• **Highlights on costs**

• **Open questions for the considered technologies**

• **Conclusions**
Scope: AC and DC cables

Extruded Cross Linked Polyethylene Insulation (XLPE)
- Gradual introduction since 1960’s replacing impregnated paper cables:
  - DC: 1996: ±80 kV / 2012: ±320 kV

Mass Impregnated Paper cables
- used since late 1880’s
- still used for DC applications up to ±600 kV for transmission of power up to 2200 MW

The War of the Currents AC vs. DC

AC transmission
- is suitable for relatively short distances
- allows to realise meshed networks

DC transmission
- allows to carry high power over long distances practically without limits
- still used in point-to-point connections only; introduction of meshed / multiterminal transmission networks will depend on availability of switchgear technology
- requires conversion back into AC

⇒Today, meshed AC networks secure electricity supply in Europe
⇒Tomorrow, high voltage DC overlay networks will increasingly complement them
Scope: Brief history of underground & subsea cables

Evolution of transmission power cables

- AC mass impregnated underground cable since 1890: highly reliable, but complex installation required
- Introduction of XLPE insulation enabled wide spread use of underground cable as of 1960’s
- Extra High Voltage XLPE cables up to 550kV are deployed in important circuits around the world since 1990

⇒ Gradual, but exponential increase of underground cable deployment around the world

Source of graphs CIGRE TB 338 -2007
State of the art: XLPE AC underground & subsea

XLPE AC cables are most commonly used
- > 25 years: high voltage (110 – 150 kV)
- > 20 years: extra high voltage (220 – 275 kV) - over 1.100 km installed in Europe alone
- > 15 years: extra high voltage (400 kV) – over 200 km installed in Europe alone
- Longest cable Tokyo: 40km double circuit 500 kV EHV XLPE cable laid in tunnel
- XLPE AC subsea cables commonly used for submarine connections

Core technology for “Concept of Partial Undergrounding”
- To complement overhead lines in sensitive areas to facilitate faster project realisation
- ENTSO-e / Europacable joint paper recognises availability of technology
- Decision on case-by-case basis
- Best practice:
  - NL: TenneT Randstadt Project
  - DK: EnergiNet policy approach
  - DE: EnLAG Projects
Highlights on technical performance: XLPE AC

Today’s state of the art

- Voltages up to 550 kV
- Maximum power 1.5 GVA per circuit
- Copper conductor 2500mm$^2$
- Joints every 700 – 1000 m (on land) directly buried into the ground or installed in underground joint bays
- 400kV cable systems carrying 5000 MVA usually comprise up to 12 cables
- Length of AC underground sections is limited up to around 20km. Beyond that, compensation may be required

⇒ **XLPE AC EHV underground and submarine cables are state of the art and allow for reliable electricity transmission**

1) Copper conductor (alternative Al)
2) Semiconductor
3) Extruded XLPE insulation
4) Semiconductor
5) Waterblocking
6) Metallic screen and water barrier (aluminium laminated foil)
7) Polyethylene outer sheath
Highlights on environmental issues: XLPE AC

Environmental impact
– Significant, but temporary, impact during installation
  • Heavy machinery required for trenching
  • 70 – 80% of soil can be refilled
  • Vegetation usually reinstalled within 18-24 months
– Limited impact during operation
  • No limitation to agriculture or farming
  • Limited heating of ground only under constant full load
  • Limited EMF well within EU limits (possibility of screening)

2050 Outlook
⇒ Environmental impact is expected to remain constant, potentially new drilling techniques may become available
Technical outlook 2050: XLPE AC underground & subsea

Technical outlook 2050: XLPE AC underground cables
- Further increase of reliability & rationalisation
- European voltage level is likely to stay in range of 380 – 420 kV
- Current rating for typical partial undergrounding solution (400kV, 2500mm² copper) is expected to increase above 1.8 kA; maximum power to exceed 1250 MW

Technical outlook 2050: XLPE AC subsea cables
- Similar technical evolution as for XLPE AC underground cables
- Possible depth to increase from 200 meters today to over 2.500 meters in the future
- Improvement in cable design, material selection leading to weight reduction & easier installation
State of the art: XLPE and MI DC cables

**XLPE DC underground cables**
- Mainly used with VSC Converters enabling power flow to reverse without polarity reversal
- Low power connections connect islands or feed offshore oil platforms
- Powerful connections are used for interconnectors & offshore wind generation

**Mass Impregnated Paper cables**
- Mainly used with LCC Converters but also with VSC
- MI Cables will still continue to be used for many years
- Europacable does not expect major development of this technology
State of the art: XLPE and MI DC cables

Core technology for long distance point-to-point high power transmission

- Significant worldwide increase of HVDC underground & subsea projects
- HVDC transmittable power continuously increasing
- Best practice:
  - France-Spain Interconnector (INELFE)
  - Denmark-Norway Interconnector (Skagerrak 4)
  - BorWin, SylWin, HelWin, DolWin, Germany
  - Western Link (UK)
Highlights on technical performance: XLPE DC

Today’s state of the art

– Up to now, XLPE DC cables are installed up to ± 200kV with a capacity of 500 MW
– Some projects have reached voltages of ± 320 kV with a capacity of 800 – 1000 MW
– System approach is mandatory to ensure that joints and terminations are suitable for cable installation
– HVDC XLPE underground cables are in principle the same as HVDC subsea cables
– Cable length is defined by logistical constraints
  • On land: up to 1000 meters, then connected by joints
  • Subsea: length up to 100 km typical (Spain – Mallorca: 242 km cable length)
– Subsea cable laying requires special installation vessel and precision laying tools

Voltage Source Converter Technology (VSC) since 1999

– Can also be applied for linking isolated networks
– Lower transmission losses; Able of “black start”
– Currently limited in power and voltage (up to 500 kV)
– “Converter of the future”
Highlights on environmental issues: HVDC Cables

Environmental impact - Land

- Principally similar to XLPE AC, though significantly smaller footprint
- Possible layout to fulfil the 5000 MW transmission:
  - 1) Overhead line at 600 kV - HVDC
  - 2) Overhead line at 800 kV - HVDC
  - 3) Mass impregnated cables & LCC technology: 3 bi-poles 500 kV - HVDC
  - 4) Extruded cables & VSC technology: 5 bi-poles at 320 kV - HVDC

Environmental impact - Subsea

- Shallow water (up to 500 meters)
  - always buried in seabed or covered as protection against fishing gear and anchors
  - Cables may be laid in a bundle configuration or individually
  - Distance between 2 laying operations will be twice sea depth
- Deep water (500 – 2000 meters)
  - Simply be laid on the seabed individually, distance between cables usually twice sea depths
  - Over time, cable will be covered with by the local environmental segments with no effect on operation

2050 Outlook

⇒ Space required may still be further improved due to possible improvements in bedding materials or insulation compounds
Technical outlook 2050: XLPE DC underground & subsea

Technical outlook: XLPE DC underground & subsea cables by 2050

- Voltage increase up to 550 kV
- Conductor size increase from 2500 to 3000 mm², resulting in capacity increase exceeding 2 GW
- Drop in losses per circuit (2500 mm² conductor rated at 1 GW per bipole from 42 (today) to 14 (by 2050)
- Reduction of losses per circuit at max. power
- For subsea cables, max. laying depth should reach more than 2.5 km
Highlights on costs

Respecting EU competition requirements, Europacable can only provide general considerations on costs

Need for full life cycle approach
- Costs related to permitting and planning
- Costs of equipment and installation
  - Cost of cable systems largely depending on raw material costs, actual manufacturing costs are marginal
  - Cost of installation: up to 60% depending on soil conditions
- Costs of operation
- Costs of possible end of life

Cost considerations for “Concept of Partial Undergrounding”
- Higher cable costs (EHV XLPE AC factor 3-10) only apply to undergrounded section
- Project cost will be in the order of 1.2 – 2.0
- Can be neutralised through faster realisation

Outlook
⇒ Only marginal scaling effects can be expected as biggest cost factor lies in installation
⇒ Increasingly, the “cost of delays” is emerging as a factor relevant to societal benefits which need to be considered
Open questions: AC & DC underground & subsea cables

Key challenges for future decades include

– New insulation materials, innovative cable materials and novel cable architectures for improved performances
– Advanced / automated installation techniques to reduce installation costs
– Multifunctional cable systems with communication capabilities
– Development and validation of environment and ageing models
– Improved commissioning thanks to fast qualification methods based on field applications
– Automated remote sensing systems for O&M for optimal use of capacity

Consequences

⇒ Already today, AC and DC underground and subsea cables are state of the art
⇒ Looking towards 2050, resolving the challenges indicated above will facilitate a wider deployment
Conclusions

Extra high voltage XLPE AC underground and subsea cables
- Need to upgrade & expand Europe’s meshed EHV AC networks
- Public acceptance needs to be obtained to realise transmission projects without further delay
- Ongoing need for more subsea interconnection & offshore wind connection
- Further increase in transmission capacity
- EHV XLPE AC underground cables will complement overhead lines in more and more sensitive areas
⇒ Partial undergrounding will be most pre-eminent evolutions of the Europe’s AC Networks up to 2050

Extra high voltage DC underground and subsea cables
- Europe’s objective to create fully integrated electricity market will require to build an HVDC overlay network with more high capacity DC interconnection – both on land and subsea
- Voltage levels of DC underground and subsea cables will increase considerably
- With switchgear equipment gaining market experience, meshed HVDC networks will become available
⇒ For subsea DC interconnectors, cables are without alternative
⇒ For land DC interconnectors, partial undergrounding (with distances >50 km) is an option already today
E-Highway2050
WP3 workshop April 15th, 2014 Brussels

Potential of other innovative cable transmission technologies
Ernesto Zaccone, Chairman Europacable High Voltage Systems Group
Talk plan: Other cable transmission technologies

• **Gas Insulated Lines (GIL)**
  – State of the art
  – Highlight on technical performances
  – Highlight on environmental issues
  – Open questions for the considered technology

• **High Temperature Superconductor Cables (HTS)**
  – State of the art
  – Highlight on technical performances
  – Highlight on environmental issues
  – Open questions for the considered technology

• **Conclusions**
Gas Insulated Lines (GIL)

State of the Art
- GIL is composed by a conductor in a tube enclosure filled with gas
- Longest installation in Tokyo: 3.3km, 2850 MW, 275 kV

Highlight on Technical Performance
- Typical transmittable power around 2500 MVA with natural cooling; may reach 3500 MVA with forced cooling
- GIL dimensions depend on application
- Reduced capacitance, no reactive compensation required
- Possibility to transmit very high power with 1 single line

Highlight on Environmental issues
- Possible limitations due to GIL insulation (pure SF6 gas or a mixture of N2 and SF6)
- Negligible magnetic fields
High Temperature Superconductor Cables (HTS)

State of the Art

- Warm dielectric cable (WD): superconducting part including coolant is insulated from dielectric
- Cold dielectric cable (CD): entire cable including dielectric is immersed in coolant
- HTS technology has recently seen major technical breakthroughs, allowing integration into grids (HTS joints now available up to 138 kV)
- Technical feasibility and viability have yet to be proven

Highlight on Technical Performance

- Ability to carry large power at medium and high voltage ratings
- Zero resistance due to environmentally friendly coolant (concern on meshed grids)
- High voltage (> 100kV) adapted for high energy system > 500 MVA
- High maintenance required because of system complexity

Highlight on environmental issues

- No specific concerns
High Temperature Superconductor Cables (HTS)

The following evolutions are expected:

- new superconducting materials working at higher temperatures
- new electric insulation materials for High Voltage superconducting applications
- further increase of HTS material performance
- cost decrease due to volume increase and manufacturing processes improvement
- Cooling system: decrease of cost and of moving parts combined with efficiency increase
- Validation of models on low temperature phenomena and components ageing
- Demonstration of combined use of HTS with storage and with Fault Current Limiters

Main achievements expected in terms of power capability by 2050 are:

- Increase of power capability in medium voltage systems up to 500 MVA;
- Increase of power capability for AC transmission higher than 4000 MVA (500 kV class or higher);
- Integration of HVDC HTS cable system into the grid and increase of power transmission capability up to the 500 kV class or higher, and 10 kA (or higher), i.e. 5 GW.
- YBCO : Yttrium Barium Copper Oxide
Conclusions

Gas Insulated Lines (GIL)

- Europacable considers GIL to be suitable for specific applications to carry very high power power for short lengths.
- GIL technology will only offer a very limited contribution to the eHighway2050 networks
- This said, they may be deployed in specific projects ensuring safe use

High Temperature Superconductor Cables (HTS)

- Europacable does expect that High Temperature Superconducting Cables will eventually become available for wider scale deployment notably in urban areas
Thank you for your attention!