HV Submarine Cable Systems
Design, Testing and Installation

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Presentation Overview

• Applications
• Design
• Testing
• Installation
• Examples
Submarine Cable Applications

- Interconnections between grid systems
- Island connections
- Off-shore wind and wave power connections
Development of Submarine Cables

- **60-70s** MV 3-core XLPE & EPR
- **1980s** Large s/c core fluid filled up to 400kV
- **1990s** 3-core dry type XLPE designs up to 145kV
- **2000-** Long length XLPE 3-core & single core up to 400kV
## Submarine Power Cable Types

<table>
<thead>
<tr>
<th>Rated Voltage Uo</th>
<th>33 kV ac</th>
<th>150 kV ac</th>
<th>420 kV ac</th>
<th>320 kV dc</th>
<th>450 kV dc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation</td>
<td>XLPE, EPR</td>
<td>XLPE</td>
<td>Oil/paper or XLPE</td>
<td>Extruded</td>
<td>Mass Impregnated</td>
</tr>
<tr>
<td>Typical application</td>
<td>Supply of small islands, connection of offshore WTG</td>
<td>Supply to large islands, offshore platform export cables</td>
<td>Crossings of rivers, straits with large transmission capacity</td>
<td>Long distance connections of offshore platforms or wind parks</td>
<td>Interconnection of power grids over long distances</td>
</tr>
<tr>
<td>Max. length</td>
<td>20-30 km</td>
<td>70-150 km</td>
<td>&lt;50 km</td>
<td>&gt;500 km</td>
<td>&gt;500 km</td>
</tr>
<tr>
<td>Typical rating</td>
<td>30 MW</td>
<td>180 MW</td>
<td>700 MW / 3 cables</td>
<td>1000 MW / cable pair</td>
<td>600 MW / cable pair</td>
</tr>
</tbody>
</table>
HV Cable Construction

- Conductor
- Insulation
- Sheath
- Fibre Optic Cores
- Armour
- Outer Serving
<table>
<thead>
<tr>
<th>Single Core</th>
<th>Three Core</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>Lighter weight</td>
<td>Reduced magnetic field</td>
</tr>
<tr>
<td>Smaller Diameter</td>
<td>Lower sheath circulating currents and voltages</td>
</tr>
<tr>
<td>Longer lengths</td>
<td>Lower installation costs</td>
</tr>
<tr>
<td>Possibly fewer factory &amp; field joints</td>
<td>One trench on seabed</td>
</tr>
<tr>
<td>Higher current rating</td>
<td>Lower protection costs</td>
</tr>
<tr>
<td>Improved security, can add a 4th cable</td>
<td>Includes optional Fibre Optic Cable</td>
</tr>
<tr>
<td>Voltage rating up to 400 kV and greater</td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>Reduced repair costs and spares</td>
<td>Lower current rating</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Cons</strong></th>
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<tbody>
<tr>
<td>Higher magnetic field</td>
<td>Lower current rating</td>
</tr>
<tr>
<td>Greater installation costs</td>
<td>Heavier</td>
</tr>
<tr>
<td>Individual seabed trenching increases costs</td>
<td>Large diameter</td>
</tr>
<tr>
<td>Protection costs increased</td>
<td>Security of cable system decreased</td>
</tr>
<tr>
<td>Sheath current must be considered</td>
<td>All three phases have to be repaired after a fault</td>
</tr>
</tbody>
</table>
Electrical Design

- Voltage level ($U_0/U$)
- Rated transmitted power (kVA)
- Short circuit current (kA) & duration (s)
- Load factor
- Maximum losses allowed
Transmission Capacity Limits

Power* vs Cable Length

- Un=400 kV
- Un=230 kV
- Un=150 kV
- Un=132 kV

* With compensation, based on 3-core 1,000mm² conductor, 400kV is 1-core 1,200mm² (ref. Nexans)
Key Design Data

- Ambient temperature (seabed & land)
- Burial depth
- Particular burial/protection requirement at shore approach (deeper burial, directional drill pipe...)
- Axial spacing of cables
- Thermal resistivity of seabed & land
- Length of submarine cable
- Water depths
Connections to Floating Platforms

- Application specific
- Mechanical performance: movements and vibrations
- Hang-off arrangements on platform
- Corrosion protection and grounding conditions
Route Survey

- Hydrographic & geophysical survey
- Sea bed bathymetry
- Tide data Level, met ocean data
- Locate existing cables & obstacles
- Multi-beam echo sounder
- Side scan sonar
- Sub-bottom profiling
- Core Sampling

- Water depth profile
- Corridor width
- Risk of damage to cables
- Burial depth/protection requirement
- Shore landing point selection
- Environmental assessment
- Consents, Foreshore Licence
Shore Landing

- Near shore civil works
- Directional drill, pulling through pipes
- Mechanical protection of cables
- Space for Sea/land transition joint
- Parallel routing of cables
- Environmental considerations
  - Sand dune movements
  - Erosion concern
Accessories

- Factory Joints
- Repair Joints
- Terminations
- Transition Joints
Testing

- Prequalification / Development Tests
- Type Tests
- Routine Tests
- Sample Tests
- After-Installation Tests
CIGRE WG B1-27

• Test recommendations for long AC extruded submarine cables 150 - 500 kV (now also to cover 36 - 150kV)
• Addresses particular requirements of submarine cable systems:
  – Water tightness of conductor and under metallic sheath
  – Armouring
  – Mechanical forces during installation of cable and joints
  – Water tightness of rigid joints
  – Delivery lengths and weights
  – Routine tests of cable and joints – challenges in testing long lengths
CIGRE WG B1-27 Recommendations

- More stringent approach Partial Discharge measurement in factory joints
- Extended frequency range for ac tests: 10 – 500 Hz
- External water pressure test of rigid sea & repair joints
- Scheme for mechanical tests for repair joints
- Tests for visual inspection of submarine cables
- Range of approval for type tests modified: factory joints, mechanical testing etc
- Prequalification and Extended Qualification
- Factory joints still to be qualified
Cable Laying Vessels

In the old days...
Cable Laying Vessels

Now...
Cable Laying

Single Catenary

\[ y = a \cdot \cosh \frac{x}{a}, \quad a = \frac{H}{\cosh 1} \]

\[ R = a \cdot \cosh \frac{x}{a}, \quad h \]

\[ T \cdot \cos \theta = H \]

\[ T \cdot \sin \theta = W \]

\[ w \cdot (a + h) = w \cdot y = T \cdot a \]

\[ w = w \cdot a \]

\[ H = w \cdot a \]

\[ A(0,a) \]

\[ O(0,0) \]
Protection

Fishing

Anchoring

Dropped objects
Penetration of smaller anchors & fishing gear vs. soil hardness

Penetration depth (m) vs. soil hardness:
- 1 T anchor
- 500 kg anchor
- 400 kg anchor
- 200 kg anchor
- Otter trawl
- Beam trawl

Soil hardness:
- Hard
- Soft
Embedment by water jetting

Cable buried in hard to soft sediments to 0.5 – 3.0m

2.5 m
Protection

GROUT BAG / SAND BAG

MATTRESS

LANDFALL PROTECTION TROLL PROJECT

CONCRETE BOX PROTECTION
Cork Harbour Project

• One of the first 220kV XLPE submarine projects in the world
• Two circuits: Single core 1 x 1,600mm² copper, 570MVA rating
  – 3.5km length: Aghada-Raffeen 220kV
  – 4.5km length: Glanagow-Raffeen 220kV
• Continuous manufacturing lengths up to 4.5km
• Shallow water: 10 metres (1st crossing), 30 metres (2nd crossing)
• Crossing main shipping channel of major port
• Submarine cable embedment by water jetting
Cork Harbour 220kV: Feb 2010

Cable Laying Vessel

Cable shore landing
SEAI Wave Energy Test Site

2 x 15km 20kV subsea cables

2 x 7km 20kV subsea cables
Ireland – Wales East West Interconnector

186km Marine Route
45km Land Cable in Ireland
30km in Wales
Converter Stations at Woodland & Deeside
Thank you for your attention