Implementation of Long AC HV and EHV Cable Systems

WG B1.47

Presented by

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• Convener: Ken Barber (AU)
• Secretary: Gert Aanhaanen (NL)
This working group was formed 3 years after the Jicable and WETS workshop in 2011 where issues regarding experience with long AC cable links was actively discussed.

A CIGRE Task force was established and at a meeting in June 2013, the definition and scope prepared. This was then discussed at the SC B1 the meeting in Brazil in late 2013.

The formation of a Working Group was agreed, terms of reference approved by the CIGRE technical committee and the first WG meeting held in Japan in May 2014.

In the two years following a further 8 meetings were held around the world and the final draft document submitted to SC B1 at the Paris meeting in 2016.
### CIGRE WORKING GROUP WG 1.47

#### MEMBERSHIP of WG

<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
<th>Name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>K. Barber, Convenor</td>
<td>AU</td>
<td>G. Aanhaanen, Secretary</td>
<td>NL</td>
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<tr>
<td>S. Lauria</td>
<td>IT</td>
<td>F. Waite</td>
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<tr>
<td>S. Kobayashi</td>
<td>JP</td>
<td>H. Suyama</td>
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<tr>
<td>V. Werle</td>
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<td>H. Orton</td>
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<tr>
<td>J. Kim</td>
<td>KR</td>
<td>C. Akerwall</td>
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<tr>
<td>F. Renaudin</td>
<td>NO</td>
<td>J. Domingo</td>
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<tr>
<td>F. Lesur</td>
<td>FR</td>
<td>M. Boedec</td>
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<td>N. Rahman</td>
<td>AU</td>
<td>U. Gudmundsdottir</td>
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<td>P. Morgen</td>
<td>IE</td>
<td>Y. Wang</td>
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<td>P. Bracher</td>
<td>CH</td>
<td>D. Lindsay</td>
<td>US</td>
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<td>S. Dambone Sessa</td>
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<td>S.K. Ghosh</td>
<td>IN</td>
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<tr>
<td>M. Soga</td>
<td>JP</td>
<td>T. Yamamoto</td>
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</table>
The final draft was approved in late 2016 and the Technical Brochure published in April 2017. This Tutorial will focus on the contents of the brochure and will highlight some of the achievements and service experience with long length High Voltage AC electrical links by insulated power cables. It is interesting to note that when we first started looking for examples of long length AC cable systems in 2013 we found very few in the earlier CIGRE publications. However, when you study this Technical Brochure you will see that we have identified more than 80 examples of current of planned long length AC links.
Progress with the of long length AC cable links

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of years in the period</th>
<th>Number of Projects</th>
<th>Links length</th>
<th>Cables Length</th>
<th>Average project /year</th>
<th>Average cable km/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967-1997</td>
<td>30 years</td>
<td>13</td>
<td>398 km</td>
<td>458 km</td>
<td>0,43</td>
<td>15 km/year</td>
</tr>
<tr>
<td>1997-2007</td>
<td>10 years</td>
<td>12</td>
<td>538 km</td>
<td>682 km</td>
<td>1,20</td>
<td>68 km/year</td>
</tr>
<tr>
<td>2007-2012</td>
<td>5 years</td>
<td>20</td>
<td>1122 km</td>
<td>1343 km</td>
<td>4,00</td>
<td>269 km/year</td>
</tr>
<tr>
<td>2012-2015</td>
<td>3 years</td>
<td>22</td>
<td>1349 km</td>
<td>1947 km</td>
<td>7,33</td>
<td>649 km/year</td>
</tr>
<tr>
<td>2015-2018+</td>
<td>-</td>
<td>14</td>
<td>703 km</td>
<td>1216 km</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>48 years</td>
<td>81</td>
<td>4111 km</td>
<td>5645 km</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Cable circuit km – 50 years from 1967 – 2017
Why is there now such a significant interest in Long Length AC transmission Power Transmission by insulated cables? Some of the reasons being:-

- Now possible with new cable designs and materials
- Now possible with new installation techniques
- Difficulties in obtaining approvals for OHL
- Quicker implementation time than using OHL
- Lower cost differential between Underground and OHL
- Connecting renewable energy sources to the grid
- Need to provide electric power to remotely located plants
- Need for greater reliability of supply due to weather conditions, particularly in remote areas.
- Need for lower losses and impacts on the environment
Key feature of Long HVAC cable systems

➢ At power frequencies cables behave as capacitors therefore they generate reactive power – hence some inductive reactance may be required in the system.

➢ Conversely overhead lines because of their spacing generate inductive reactance – hence some capacitive compensation may be required at substations.

➢ Under certain conditions AC Cables and AC Overhead lines might be quite compatible.
Definition :-

A long length of insulated cable

➢ One where the load due to the capacitive current needs to be taken into account in the system design.

➢ Typically this would be 40 km for voltages less than 220 kV and 20 km for voltages above 220 kV
Format of Technical Brochure

• Introduction - Terms of Reference – Executive Summary.

• Current State of Development
  ◦ Reasons for growth, Cable design trends, Cable types, New Installation trends, Associated equipment and Reliability of supply.

• Challenges for Implementation
  ◦ Effect on the grid, Protection systems, Voltage effect, Zero miss phenomenon, Switching, Harmonics, Mitigation of EMF, Life time expectancy, and Testing..

• System Design
  ◦ AC-DC comparison, Compensation, Sheath Bonding, Thermo-Mechanical forces, EMF, Maintaining Circuit Ratings, Limiting induced voltages and Future systems.
Format – Cont.

• **Installation**
  - Selection of best cable, design, Routes & rights of Way, Route planning, Installation methods, Transport, Testing and Q.A.

• **Monitoring**
  - Introduction. Temperature, Strain, SVL’s, Sheath condition, P.D., TDR, and other systems.

• **Maintenance**
  - Land & Submarine, including Route & Fault location, Rapid repair options and procedures

• **Examples of World Wide Experience**

• **Statistics of Long HVAC cable projects**
1. CURRENT STATE of DEVELOPMENT

Reasons for Growth in demand

- Possible 50 years ago but now more practical with new cable designs, materials, accessories & installation methods
  - Improved overall performance
  - Cost of supply and installation significantly lower
  - Availability of Monitoring systems
- Transfer power from renewable energy sources to the grid
  - Demand for offshore wind farms
  - Limited space on Offshore platforms for other options
- Need to provide electric power to remotely located plants
  - New Mine sites, Desalination plants
  - Need for lower losses
- Difficulties in obtaining approvals for Overhead Lines (OHL)
  - Quicker implementation time than using OHL
  - Environmental issues
1. CURRENT STATE of DEVELOPMENT

Cable Types

- Fluid filled designs
  - SCFF
    - Paper
    - PPL
  - HPOF

- Solid dielectric
  - PE,
  - XLPE
  - New materials
1. CURRENT STATE of DEVELOPMENT

Summary of Modern HV AC Cable design

- Improvements made in the design of Fluid Filled cables
  - Manufacturing and installation costs higher than XLPE cable.
- Today’s 500kV XLPE cables have very low dielectric losses
  - Considerably lower than the older fluid filled cables
- The operating temperature of XLPE cable is significantly higher
  - Hence ratings much improved compared to original SCFF cable
- XLPE cables can be made and installed in long lengths
  - No concerns about changes in ground level and oil pumping
- Significant experience in manufacture of cables & accessories.
  - More than 100 cable plants worldwide making EHV AC cables
1. CURRENT STATE of DEVELOPMENT
CABLE DESIGN - Metallic Screen

TYPES

- Lead Alloy – Extruded
- APL – Aluminum Poly Laminate – “Moisture Barrier”
- CAS – Extruded - Corrugated Aluminum
- CAS – Welded - Corrugated Aluminum
- CCS – Welded - Corrugated Copper
- CSS – Welded - Corrugated Stainless Steel
- SAS – Welded – Plain – ”swaged & bonded” Aluminum
1. CURRENT STATE of DEVELOPMENT
CABLE DESIGN Outer sheath Protection

MATERIALS

- PVC
- MDPE
- HDPE
- Semi Cond PE

INSTALLATION

- Abrasion, scratching, bending and pulling

APPLICATION

- Buried or exposed

ENVIRONMENT

- Moisture, Sea water, chemicals, oils, petrol, corrosion
- Animals, Insects, Rodents, Worms
- Tropical, Vibration, Sunlight, Tidal forces, Seismic

SERVICE LIFE

- Wear, abrasion and damage
- Vandalism and theft
1. CURRENT STATE of DEVELOPMENT

New Installation Trends

➢ Today we can use HDD to cross under rivers, roads and rail.
  • In the past such crossing could only be done with overhead lines

➢ New cable laying techniques
  • Trenching, Conduits, Tunnels, Directional drilling
1. CURRENT STATE of DEVELOPMENT

Advances in associated equipment

➢ Joints & Terminations
  • *Premoulded*
    *i.e.*
    *prefabricated*

➢ Link Boxes
➢ Surge arrestors
➢ Reactive Compensation
➢ Harmonic filters
1. CURRENT STATE of DEVELOPMENT

Advances in reliability of supply

➢ Prequalification test
  • *Well established requirements*

➢ Site Testing
  • *New low frequency devices can test long lengths of AC cable*

➢ Monitoring
  • *Inclusion of Optical fibre in Cable*  
  > *30 years experience*
2. CHALLENGES for IMPLEMENTATION
Effect on the Grid & Matching Ratings

Introduction
- Most transmission grids consist of Overhead Lines
- Nowadays long lengths of Cable are being introduced
- One needs to consider the effects on the network

Effect on the Grid
- Voltage effect.
- Current Rating
- Matching ratings to that of the Overhead line
  - Load Cycle
  - Post fault condition
  - Dynamic ratings
2. CHALLENGES for IMPLEMENTATION
Protection, Voltage effect, Zero Miss,

- Protection Systems
  - Effect of Hybrid
  - Distance protection
  - Auto re-closure and lock-out system
  - Unchanged or no auto re-close

- Voltage rise, e.g. Ferranti Effect
  - Increased voltage at remote end
  - Cable & accessory selection

- Zero Miss Phenomenon
  - Depends on amount of reactive compensation
2. CHALLENGES for IMPLEMENTATION, Switching, Harmonics, EMF

- Switching off Capacitive currents
  - Charging current
  - Circuit breaker current limits
- Harmonic Resonance
  - Short circuit power – cable length
  - Harmonic filter requirements
- Mitigation of Magnetic fields
  - Benefits compared with Overhead Lines
  - See Chapter 3 for more details
2. CHALLENGES for IMPLEMENTATION
Life Expectancy & Testing

• Factors to be considered
  ◦ Cable design
  ◦ Route and installation
  ◦ Service Maintenance

• Testing
  ◦ Commission test essential for long lengths
  ◦ AC testing essential for Solid Dielectric cable
  ◦ Effect of frequency on charging current
  ◦ Capacity of mobile test
3. SYSTEM DESIGN
Comparison of an AC with a DC link

Benefits and limitations of both systems

➢ Costs
➢ Losses
➢ Power flow

<table>
<thead>
<tr>
<th></th>
<th>132 kV AC</th>
<th>220 kV AC</th>
<th>±150 kV DC</th>
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<tbody>
<tr>
<td>Losses (MW)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Compensation</td>
<td>0.5</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>DC Converter</td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

Cigré SCB1 – Implementation of long AC HV & EHV cable systems
3. SYSTEM DESIGN
Reactive compensation

Amount of Reactive compensation required:-

- Proportional to \( C \times V^2 \)
- Refer to TB556 “Power System Technical performance issues related to long AC links”

Location of Reactance

- Ends
- Mid point

\[
Q_{\text{cable}} = 2.\pi. f. C. V^2
\]
3. SYSTEM DESIGN

AC1 - 100km link with 132 kV AC cable

**Grid**

**Plant**

- 132 kV AC cable
- 100 km
- 55 Mvar

- 135 MVA
- \( \cos \varphi = 0.95 \)

**Voltage and Current**

- \( I_{\text{max}} = 0.95 \text{ pu} \)
- \( U_{\text{Plant}} = 0.98 \text{ pu} \)

**Losses (MW)**

- Cable System: 3.4
- Compensation: 0.2
- Total: 3.6

As reported at WETS 11
3. SYSTEM DESIGN

AC2 - 100km link with - 220 kV AC cable

Grid

220 kV AC cable

Plant

135 MVA

\( \cos \varphi = 0.95 \)

\( I_{\text{max}} = 0.90 \text{ pu} \)

\( U_{\text{Plant}} = 0.98 \text{ pu} \)

<table>
<thead>
<tr>
<th>Losses (MW)</th>
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<tbody>
<tr>
<td>Cable System</td>
</tr>
<tr>
<td>Compensation</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>2.8</td>
</tr>
<tr>
<td>0.3</td>
</tr>
<tr>
<td>3.1</td>
</tr>
</tbody>
</table>

As reported at WETS 11
3. SYSTEM DESIGN
Sheath Bonding

Standing Voltage vs. Circulating current

- Single Point
- Cross-bonding
- Combination
- Solid Bonding

With Cross–Bonding the metal sheath of the cable is interrupted at the cross-bonding points

Submarine cables typically SOLID BONDED
3. SYSTEM DESIGN
Cross bonding & Joint location

CAD drawings, Google overlay,
3. SYSTEM DESIGN
Installation Condition - Forces

• THREE METHODS

1. Rigid Constrained
   ▪ Buried or closely Clamped or cleated

2. Semi Flexible
   ▪ Fixed/clamped – with snaked sections

3. Flexible Constrained
   ▪ Ducted and Pipe installations

• THERMO MECHANICAL FORCES

1. Cable Thrust

2. Route alignment
3. SYSTEM DESIGN
Flexible installation

• Systems which allows to expand in length and laterally
  ◦ Initially installed in a sinusoidal formation
  ◦ Movements should be controlled
  ◦ Thrusts are low
  ◦ Special care
    – *in stiff bends*
    – *For short circuit forces, straps are needed between cleats*
3. SYSTEM DESIGN
EMF, Rating, Induced Voltages

EMF

- Mitigation, Ref TB 373

MAINTAINING CIRCUIT RATINGS

- Spacing
- Selected backfill
- Change in Conductor
  - *E.g. Size or Material*

LIMITING INDUCED VOLTAGES

- Adjacent cables
3. SYSTEM DESIGN
FUTURE SYSTEMS

Reduction in Frequency

➢ Lowering Frequency reduces $I_c = less$ compensation

➢ One project @ 16 Hz

New Insulation materials

➢ Non–Cross linked materials

➢ Nano composites
4. INSTALLATION

**Cable type**

SELECTING BEST CABLE TYPE

➢ Very much depends on method of installation and environment

MUST BE A COMPROMISE

➢ between lowest cost
➢ robust design
➢ ease of installation
➢ long service life
4. INSTALLATION
Methods and world wide examples

- ROUTES
  - Rights of way

- ROUTE PLANNING
  - Traffic management
  - Security

- INSTALLATION METHODS
  - Rigid Constrained
  - Semi Flexible
  - Flexible Constrained

- Open Trench – Direct buried
- Duct installation
4. INSTALLATION

Specific factors for long lengths

• Long lengths of cable is key factor
  ➢ Reducing number of joints and jointing cost
  ➢ Reducing transportation & installation costs

• Cable laying
  ➢ Trench excavated by conventional means
  ➢ Trench excavated by trenching machines with rock saws
  ➢ Direct ploughing
4. INSTALLATION
Boring & Tunnelling

Horizontal Direct Drilling (HDD)
• Long bores - guided drill heads.

Sleeve bore/micro tunneling (pipe jacketing)
• Typically under road/rail crossings

Tunnels
• TBM’s – Shared structures

• Directional drilling
• Micro tunnelling
4. INSTALLATION
Transportation – World wide Experience

SEA
➢ Drums on Flat racks
➢ Limited Bulk carrier shipping available

INLAND WATERWAYS
➢ Where practical

RAIL
➢ Gauge & Height issues
4. INSTALLATION
Transportation – World wide Experience

ROAD
- Maximum load per axle
- Maximum Width
- Minimum turning radius

SUBMARINE
- Cable barge
- Cable laying vessel
4. INSTALLATION
TESTING after INSTALLATION

Commissioning tests

1. Sheath tests
2. SVL verification
3. Phase identification
4. Insulation resistance
5. Capacitance
6. Conductor resistance
7. Zero Sequence Impedance
8. Positive & Negative Sequence Impedance
9. Cross Bonding verification
4. INSTALLATION

Onsite tests

**High Voltage AC Test**
Preferably using a 10 - 300Hz resonance test set with testing to IEC 60840 or 62067 as applicable

**PD testing**
As above

**FO testing**
OTDR
Apart from external damage there are 3 basic reasons for failure of any cable system

1. A latent defect not detected during final testing
2. A defect caused by damage during installation or incorrect fitting of accessories
3. A defect caused by inappropriate operation in service or changes in the environment.

To avoid the first two manufacturers and installers need to have in place appropriate Quality Management procedures. To protect from the latter good Monitoring systems are essential.
5. MONITORING
TEMPERATURE

DISTRIBUTED TEMPERATURE SENSING (DTS)

- Now well established (more than 25 years experience)
- New systems can be used over 100km
- For long length systems most appropriate if fibres included in the cable construction
5. MONITORING
STRAIN, SVL’s, SHEATH Condition

STRAIN
➢ Optical fibre in the cable can be used to detect physical actions on the cable.
➢ Also enables very accurate fault location.

SVL Inspection
➢ Systems being developed to remotely monitor SVL’s in link boxes

SHEATH CONDITION
➢ Systems are being developed to remotely monitor the condition of sheaths
5. MONITORING
Partial Discharge, TDR

Monitoring P.D.
P.D. of accessories
Commissioning or routine inspection?
TDR Measurement

Normally for fault location, but may be used to check condition

Other systems
6. MAINTENANCE
LAND CABLES

➢ VISUAL INSPECTIONS
➢ Terminations
➢ Outer Sheath Test
➢ Link boxes & SVL’s
➢ Route inspections
➢ FAULT location
➢ Procedures & methods
➢ GIS & CAD for route location
➢ TIMES to REPAIR
➢ Rapid response team
6. MAINTENANCE
SUBMARINE CABLES

Maintenance Guidelines
Origin and nature of cable failure
Fault detection and location
➢ Often difficult on long lengths
Repair execution & operations
➢ Locate, Cut, Repair, Lay
7. Practical Experience
Examples of World Wide Experience

AUSTRALIA
➢ 88 km on land @ 220 kV -135 MVA

CANADA
➢ 30 km Submarine double circuit @ 525 kV – 1200 MW

CHINA
➢ 30km Submarine @ 500 kV – 600 MW

DENMARK
➢ 84 km - 24 km Submarine + 60km Land @ 245kV -- 400 MVA
7. Practical Experience
Examples of World Wide Experience

ITALY
➢ 44 km – 38km Submarine + 6 km Land
   Double circuit @ 400 kV - 2000 MVA

JAPAN
➢ 40 km Land double circuit @ 500 kV – 900 MW/circuit
➢ 28 km Land double circuit @ 275 kV - 590 – 900 MW/circuit

GERMANY
➢ 80 km - 50km Submarine + 30km Land
   @ 155kV - 113MVA
NETHERLANDS
➢ 100 & 110 km Submarine @ 220 kV – 600 MW total

NORWAY
➢ 13 km Triple circuit @ 420 kV – 2700 MW total
➢ 23 km + 9 Km Submarine @ 420kV - 300 MVA
7. Practical Experience
Examples of World Wide Experience

SWEDEN

➢ 46 km - 43.5 km Submarine + 2.5 km Land @ 60kV for 60 MW
➢ 55km - Submarine @ 84 kV for 35 MW
➢ 55km - Submarine @ 110 kV for 80 MVA

U.K.

➢ 20 km – Land @ 400kV for 1600 MVA
8. STATISTICS
Review world experience

Outside: Country, number of projects
Inside: Continental repartition
8. STATISTICS

Review world experience

<table>
<thead>
<tr>
<th>Voltage Level</th>
<th>Number of System</th>
<th>Cable Length (per circuit)</th>
<th>Total cable length in system</th>
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</thead>
<tbody>
<tr>
<td>$U_0 \leq 170$ kV</td>
<td>36</td>
<td>2446 km</td>
<td>3222 km</td>
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<tr>
<td>$170 kV \leq U_0 \leq 380$ kV</td>
<td>34</td>
<td>1298 km</td>
<td>1860 km</td>
</tr>
<tr>
<td>$U_0 &gt; 380$ kV</td>
<td>11</td>
<td>367 km</td>
<td>563 km</td>
</tr>
<tr>
<td>TOTAL</td>
<td>81</td>
<td>4111 km</td>
<td>5645 km</td>
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</table>
8. STATISTICS

Review world experience

<table>
<thead>
<tr>
<th>Power Level</th>
<th>Number of System</th>
<th>Cable Length (per circuit)</th>
<th>Total cable length in system</th>
<th>Average length of cable / Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power &lt;100MVA</td>
<td>10</td>
<td>856 km</td>
<td>856 km</td>
<td>86 km</td>
</tr>
<tr>
<td>Power &lt;200MVA</td>
<td>17</td>
<td>1100 km</td>
<td>1401 km</td>
<td>82 km</td>
</tr>
<tr>
<td>Power &lt;300MVA</td>
<td>8</td>
<td>536 km</td>
<td>729 km</td>
<td>91 km</td>
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<tr>
<td>Power &lt;400MVA</td>
<td>4</td>
<td>136 km</td>
<td>224 km</td>
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<tr>
<td>Power &lt;500MVA</td>
<td>5</td>
<td>229 km</td>
<td>294 km</td>
<td>59 km</td>
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<td>Power &lt;600MVA</td>
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<td>89 km</td>
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<td>Power &lt;700MVA</td>
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<td>467 km</td>
<td>772 km</td>
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<tr>
<td>Power &lt;800MVA</td>
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<td>142 km</td>
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<tr>
<td>Power &lt;900MVA</td>
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<td>52 km</td>
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<td>87 km</td>
<td>171 km</td>
<td>57 km</td>
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<tr>
<td>Power &gt;2000MVA</td>
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<td>87 km</td>
<td>195 km</td>
<td>65 km</td>
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<tr>
<td>TOTAL</td>
<td>35</td>
<td>2492 km</td>
<td>2985 km</td>
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## 8. Statistics

### Long length AC links by Country

<table>
<thead>
<tr>
<th>No</th>
<th>Country</th>
<th>Number of Links</th>
<th>Circuit Length km</th>
<th>Cable length km</th>
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<tbody>
<tr>
<td>1</td>
<td>Australia</td>
<td>2</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>2</td>
<td>Belgium</td>
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*Projects commissioned since 1967 or planned to be in commission by 2019*
10. REFERENCES & APPENDIX’s

• References listed (63)
• Appendix A - Listing of 81 - Long HV AC Projects
• Appendix B - Long HVAC Line Load flow – model one-phase & coaxial propagation reduced.
• Appendix C - Example of a Long HVAC Line - Load Flow.
• Appendix D - Example of efficiency of a 400 kV UG Power Transmission Cable versus circuit length.
Implementation of Long AC HV and EHV Cable Systems

Thank You Very Much For Your Attention

Four extra summary slides if required

Ken Barber
KEY FACTORS
Reliability of Supply Key Criteria for Asset Managers

PERFORMANCE / FEATURES
• Low Overall Cost
• Longer length of cable
• Easy Installation
• Ease of fixing
• Low Life Cycle Assessment (LCA)

RELIABILITY
• Environment – Direct buried/in Tunnel etc.
• Long life in service
• Compatibility with system and accessories
• Overload capability
• Monitoring in service

• The cable design is a very important factor when considering AC or DC underground cable projects.
• A compromise has to be made between the lowest cost and a robust design, which will enable ease of installation with long service life.
• For the conductor we can select copper or aluminium, but depending on the rating the latter is sometimes considered not only because of the lower capital cost, but because it reduces cable weight, which means longer lengths.
Summary of Challenges for Implementation

- System design issues
  - Matching the power rating for hybrid circuits
  - Acceptance of cyclic ratings – thermal delay for cables
  - Protection system arrangements - Cable vs. OHL,
  - Lower power losses on the cable and no corona losses
  - Reliability - repair times for underground cable
  - Controlling EMF - easier for cable than OHL
  - Controlling future changes in route to ensure circuit rating
  - Amount of reactive compensation - location
  - Impact on other network components
  - Sheath bonding for long lengths - tolerances
  - Sheath voltage levels
  - Link box maintenance – inspection – monitoring
  - Thermal mechanical forces from long straight cable lengths
Summary of Challenges for Implementation (cont.)

- **Installation**
  - Right of way,
  - Remote areas transportation
  - Inductive coupling with OHL,
  - Commissioning – Testing

- **Monitoring**
  - Long distance Distributed Temperature Sensing
  - Control of route condition

- **Maintenance**
  - Fault location
  - Access to route information – GPS data
  - Methods to reduce repair times and outage in case of cable damage.
CONCLUSION

What is a good link?
Well designed
Well manufactured
Well installed
Well maintained
ANY QUESTIONS