Overhead or Underground
A Comparison

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Vancouver, Canada
Presentation Outline

• Professional Background
• Professional Experience
• Video
• Advantages of Underground Cables
• Disadvantages
• Photographs OH Lines and UG Cables
Professional Background

• Engineer-in-Training 1960
• NESCA climbing poles, underground cables
• Part-time Bachelors Degree UNSW 1966
• Masters Degree UBC 1969
• Thesis topic: Series Comp. of OH Trans. Lines
• PhD UNSW UG Cable Diagnostics
• BCHydro Research 1977, Corona Loss, RI and TVI Studies of Transmission Lines, UG Cables
• Consulting Engineer 1994
Litigation Experience

- KEPCO Korea
- HYLSA Mexico
- PG&E San Francisco, 230 kV, Tri-Valley Project, Pleasanton, San Ramon
- US Department of Justice, NY, Cross Sound, 150 kV Subsea HVDC Light.
- Singapore Power, PowerGrid, 230 kV XLPE cable.
Professional Experience

• Seminars UBC and Worldwide since 1990
• Published over 40 papers on OH and UG cables
• IEEE, Insulated Conductors Committee (ICC)
• Chairman of Transnational Committee
• Chairman of Task Group A2D, Cable Shields
• Chairman of Task Group B15D, Accessories
• Co-chair of Task Group C27D, Joint ROW
Professional Experience continued

• Registered Professional Engineer in the Province of British Columbia, Canada
• Listed as a consultant for Alberta and BC Civil Trial Lawyers Associations
• The World Bank
• ASTM
Underground Cable Historical Perspective

<table>
<thead>
<tr>
<th>Year</th>
<th>Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>600</td>
</tr>
<tr>
<td>1975</td>
<td>500</td>
</tr>
<tr>
<td>1950</td>
<td>400</td>
</tr>
<tr>
<td>1925</td>
<td>300</td>
</tr>
<tr>
<td>1900</td>
<td>200</td>
</tr>
</tbody>
</table>

- **Type**: Paper, Polymer
Basic Power System Diagram

- Steam Turbine
- Generator
- 13.8 kV
- Transmission Network: 230 kV
- Sub. Transf.
- Distribution Network: 15/25 kV
- Dist. Transf.
- 110/220 V
Underground Power Cable Systems

- New York City – no overhead since 1890’s
- Singapore - 100% underground
- The Netherlands – Distribution 100%
- Belgium ban on OH Lines since 1992
- Denmark replaced six 132 kV OH lines with two new 400 kV UG cables in 1997 and 1999
- December 1999 storms in France caused many blackouts-new policy 25% HV lines are UG
Underground Power Cable Systems Continued

• Connecticut Underground Power Line Legislation Approved
• “Overhead Lines Need a Quick Burial” in Atlanta Journal Constitution
• Two major developments cancelled in Atlanta one for $150M and the other $100M
Advantages of UG Cables

Environmental

- Minimal visual impact
- Low EMF
- No corona discharge, RI and TVI
- No bush fire problems
- Minimal lightning problems
- High level of personnel and public safety, no fallen lines (France 2000, 19 contact deaths with OH lines, 0 with UG cables)
- Good working conditions
Furthermore, it has to be noted that household appliances and industrial machinery generate magnetic fields in their vicinity which may sometimes be much higher than those produced near overhead lines and cables. Indeed, magnetic fields of a tenth of a millitesla and more have been measured, for instance up against hair dryers and vacuum cleaners, and fields of even higher magnitude have been found near welding equipment and arc furnaces.
LOAD CURRENT = 700 AMPS

MAGNETIC FIELD (mG)

DISTANCE FROM CIRCUIT (FL)

OVERHEAD LINE
UNDERGROUND (SCOF OR XLPE)
UNDERGROUND (PIPE TYPE)
Advantages of UG Cables
Power Grid Security

• Not affected by ice, snow, rain, wind, dust, smoke or fog
• Not affected by Ice storms, Tornadoes, Hurricanes
• Nothing to be stolen
Advantages of UG Cables
Power Grid Security Continued

• French storms in 1999, 8% of OH lines out of service, 90% of substations back in service after 4 days
• 6 months to complete repairs to the lines
• Total cost of damage Euro1.3 Billion
• No estimate for economic losses
• Interruption lasted 15 million customer-days
Advantages of UG Cables

Power Grid Security Continued

• Quebec ice storms in the winter of 1998
• Hydro-Quebec hundreds of kilometres of EHV and HV lines collapsed
• Thousands of towers
• Blackout initiated by OH line at First Hydro in Ohio
Advantages of UG Cables

Economy

- Low maintenance costs
- Land use minimized
- Value of land and buildings unaffected
Advantages of UG Cables Operation

• High reliability and availability
• Few faults, bumps on power system
• Major blackouts in NE
• Diagnostics available to locate problems
Table 5: Benefits from undergrounding of electricity lines

<table>
<thead>
<tr>
<th>Benefit type</th>
<th>Utilities</th>
<th>Customers</th>
<th>Local residents</th>
<th>Wider community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced electricity price (from construction of missing electricity links)</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced transmission losses</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower maintenance costs</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved electricity service</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced storm damage</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced accidents (inc. wildlife electrocutions)</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Improved views/property values</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Health &amp; Environment (e.g. noise, EMFs, vegetation management)</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

Source Study Ref. [16]
Disadvantages

- Cost, must consider life time costs not just initial
- Cost differential decreasing with time
- Cost of losses (30-60% less than OH), maintenance and repair
- Undergrounding 25% of the existing EHV and HV lines in Italy and the UK will increase the price of electricity by 3-5%
- Undergrounding all of the lines in Italy would increase the cost of electricity by 16%
Disadvantages

• Outage time, locate fault and repair (OH one day, UG 7-10 days)
• Fault location instantaneous, can have longer repair time
• Continuous trench required (sensitive areas, directional boring)
• Soil thermal conditions modified
Disadvantages
Continued

• Presence of vaults and manholes
• Distance limitation 100 km for ac cables
• HVDC Light 600 km - planned
• Murray Link 177 km – longest in the World 2002
Increasingly cables are being seen as the lowest cost solution for reliable delivery of power. This recognition is seen in the increasing use of cables within utilities. Within Europe the total amount of underground cable used has risen from 15-20% in 1960 to 40% in 1994. In Japan at 275 kV there was 11.5 % in 1980 and in 2001 there was 28%.

<table>
<thead>
<tr>
<th>Region</th>
<th>Europe</th>
<th>North America</th>
<th>Asia / Pacific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of UG Cables to OH</td>
<td>40</td>
<td>17</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1 Amount of Underground Energy Cable installed at 1994
Table 2 Public Concerns for cables and overhead lines (CIGRE1996 21/22-01):
0 no importance, 1 low importance, 2 high importance, 3 compulsory

<table>
<thead>
<tr>
<th>Concern</th>
<th>Rating for Overhead</th>
<th>Rating for Cables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>2.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>2.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Land Depreciation</td>
<td>2.2</td>
<td>1</td>
</tr>
<tr>
<td>Electric Field Effects</td>
<td>2.1</td>
<td>0</td>
</tr>
<tr>
<td>Ground Occupation</td>
<td>1.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Security of Supply</td>
<td>1.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>
It is interesting to note that, despite the fact that public opinion often asks for replacing overhead power lines with underground cables, about 60% of the countries have declared they are facing protests against cables and in about 40% of the countries these protests are followed by legal actions.
Table 3 Cost ratio of UG cables to OH lines

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Based on Installation Cost</th>
<th>Based on Lifetime Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.2-1.5</td>
<td>1</td>
</tr>
<tr>
<td>66</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>132</td>
<td>5.7</td>
<td>2.6</td>
</tr>
<tr>
<td>225</td>
<td>5-10</td>
<td>N/A</td>
</tr>
<tr>
<td>400</td>
<td>5-10</td>
<td>N/A</td>
</tr>
</tbody>
</table>