500 kV AC Underground Transmission Evaluation

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Presentation Outline

• Overview of Study and Objectives
• Key Participants of Study
• Technical Aspects and Challenges
• World EHV cable experience
• Cost Comparisons
• CCI report Conclusions/Recommendations
• Next Steps
Study Objectives

• Examine the technical feasibility of placing a portion of the Heartland 500 kV circuits underground in order to mitigate siting issues

• Enhance knowledge of underground transmission given the considerable opposition to overhead transmission siting from landowners
Feasibility Study Focus Areas

- Losses
- Rating Capability
- Reliability Availability Maintainability
- Quantify Practicability
- Technical Feasibility Study
- Life Cycle Costing
- Capital Costs
- Risks

500 kV Underground Cables
Transmission Circuit Layout with Underground

10 km or 20 km

65 km
Single Line Representation – Scenario – B

GIS TERMINATION STATION A

GIS TERMINATION STATION B

STATION A

STATION B
Cable Capacity to Match Overhead Line

Circuit 1
Peak Load 1,500 MW

Circuit 2
Peak Load 1,500 MW

Group 2
Peak Load 750 MW

Group 1
Peak Load 750 MW

Group 1
Peak Load 750 MW

Group 2
Peak Load 750 MW
Transition Station Termination

Example of a 400 kV Transition Station
Study Participants

• Cable Consulting International (CCI) of the UK was contracted by the AESO to carry out the study

• Teshmont Consulting contracted by the AESO to study reactive power requirements, system losses, and reliability

• AltaLink and EPCOR provided certain inputs including such items as constructability, operating/maintenance issues, transport limitations, cost estimates for civil works, transition station layouts and costs, and general routing data
Technical Aspects of Study

• 500 kV AC underground cable required to carry 3,000 MVA on each circuit
• Nominal voltage – 500 kV; maximum 550 kV
• 1,550 kV BIL
• Need for reactors
• Burial options; trench or tunnel
• Cold temperature considerations
• Number of cables per phase
• Reliability/Availability
• Maintenance and operating considerations
• Maximum lengths
EHV (XLPE) Underground Cable Around the World

North America- 240 kV and 345 kV
Europe- 400 kV
Middle East - 400 kV
Japan- 500 kV
China- 500 kV
## Cumulative Quantities of Underground Cables installed in each Country

<table>
<thead>
<tr>
<th>Country</th>
<th>220-314 kV</th>
<th>315-500 kV</th>
<th>220-500 kV</th>
<th>%</th>
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<tbody>
<tr>
<td></td>
<td>cct km</td>
<td>cct km</td>
<td>cct km</td>
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<tr>
<td>Japan</td>
<td>1,440</td>
<td>123</td>
<td>1,563</td>
<td>22</td>
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<tr>
<td>USA</td>
<td>663</td>
<td>536</td>
<td>1,199</td>
<td>17</td>
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<td>France</td>
<td>903</td>
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<td>905</td>
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<tr>
<td>Singapore</td>
<td>651</td>
<td>111</td>
<td>762</td>
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<td>United Kingdom</td>
<td>496</td>
<td>166</td>
<td>662</td>
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<td>559</td>
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<td>2</td>
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<tr>
<td>Canada</td>
<td>153</td>
<td>16</td>
<td>169</td>
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<tr>
<td>Others</td>
<td>549</td>
<td>237</td>
<td>786</td>
<td>11</td>
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<tr>
<td><strong>Total cct km</strong></td>
<td><strong>5,576</strong></td>
<td><strong>1,591</strong></td>
<td><strong>7,167</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

| Polymeric   | 2,230      | 430        | 2,660      | [2007 data-CIGRE] |
| Non-polymeric | 3,346    | 1,161      | 4,507      |
| Polymeric to total % | 40 | 27 | 37 |
Shinkeiyo-Toyosu 500 kV Line

The first long underground 500 kV XLPE transmission line in the world

- Connecting Shin-Toyosu S/S and Shin-Keiyo S/S
- Transmission Capacity: 1,200 MW/cct
- Currently operated for 900 MW/cct
- Route Length: 40km x 2cct
- Number of Splices: 264
- Operation: November 2000
XLPE Cable and Cable Reel

**500kV XLPE Cu Cable**
- Conductor Size: 2,500mm²
- Insulation Thickness: 27mm
- Corrugated Aluminum Sheath
- PVC Jacket
- Cable Outer Diameter: 170mm
- Cable Weight: 35kg/m

**Cable Reel for long cable**
- Cable Length: 1,800m
- Flange Diameter: 4,250mm
- Drum Diameter: 2,750mm
- Outer Width: 8,300mm
- Total Weight: 9,500kg
Shinkeiyo - Toyosu 500 kV Line-Tunnel
Shinkeiyo - Toyosu 500 kV Line-Tunnel
Cable Reel- Viscas Plant-Tokyo
## 500 kV AC Land Circuits by Installation Type

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>Number of Faults</th>
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<td></td>
<td>Internal</td>
<td>Third Party</td>
<td>Other External Causes</td>
<td>Total</td>
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<tr>
<td>Direct Buried</td>
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<td>28</td>
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<td>2</td>
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<tr>
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<td>2</td>
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<tr>
<td>Bridges</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
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<tr>
<td>In-Air</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>All Installation Types</td>
<td>74</td>
<td>34</td>
<td>23</td>
<td>131</td>
<td></td>
</tr>
</tbody>
</table>
System Factors - Thermal Transfer Capabilities (3,000 MVA)

O/H – 3 x 1590 MCM ACSR
U/G – 2 x 2500 mm²

Effective Power Transfer MVA
With Reactors

Effective Power Transfer MVA
Without Reactors

Charging MVA

All O/H 3x1590 3499 MVA

All O/H 75 Charging MVA 3x1590
CCI Study Findings

- Proven service experience exists in 500 kV transmission systems for two types of cable
  - Self contained fluid-filled (SCFF)
  - Extruded cross linked polyethylene (XLPE)
CCI’s Key Conclusions

- Project total estimated costs (end-to-end) would increase 2 to 3 fold with the inclusion of 10 to 20 km underground transmission systems for the Study Project (Heartland Project)

- Installation estimated cost for 500 kV underground transmission systems are 7 to 10 times higher than 500 kV overhead transmission lines

- Given system capacity requirements, staging a cable installation appears feasible with the proviso reliability requirements can be met
Estimated Capital Costs

Unstaged and staged (Stage 1 and Stage 2)
4 Groups of cable, 20 km u/g, 45 km Overhead, staged installation
CCI’s Key Conclusions

• Lifecycle cost analysis (40 years) concludes that the all-overhead line solution remains the lower cost alternative

• 500 kV underground transmission system is technically complex and typically involves custom design for each application

• Given the limited world experience with 500 kV underground, reliability of 500 kV cable systems is difficult to assess
  - Additional analysis is required
  - May require redundancy
Lifecycle Cost Estimates

Unstaged and staged

10 km cable

NPV values – Losses shown in Red

20 km cable

OHL

$M

4 Groups 3 Groups 4 Groups 3 Groups

798 767 733 730 1072 997 928 909 412

4 Groups 3 Groups
CCI’s Key Conclusions

• Introduction of a 500 kV cable system does not result in added savings in system losses given the projected loading of the 500 kV lines will generally remain below 1,700 MW, as illustrated by the following graph
CCI’s Key Conclusions (continued)

Combined Overhead and Underground transmission
Compared to
100 % Overhead

- Losses Difference MW
- MW
- 55 km OH and 10 km UG (AIS)
- 45 km OH and 20 km UG (AIS)
- 100 % OH
CCI’s Key Conclusions (continued)

• 500 kV XLPE underground cable application is feasible for a 10 to 20 km application at Heartland

• Cable joint development for low temperature operation remains to be proven by manufacturers. Prequalification tests will need to be commissioned

• A fully tested and proven “off the shelf” 500 kV cable system does not exist for the Heartland application

• The Heartland 500 kV underground project is ranked as a world leading application by virtue of its rating (3,000 MVA) and its location specific requirements
Continued Work Activities

• AltaLink/EPCOR filed facility applications for the Heartland Project on September 27, 2010
  – Recommended alternative is an overhead solution, however the application includes information regarding 500 kV AC underground

• AltaLink continuing with investigative work on 500 kV underground cable, including supplier preliminary qualification as well as test lab prequalification
Questions and References

• Full report on 500 kV AC underground study available at www.aeso.ca

• Report was released on February 24, 2010