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Presentation to the:
EMERGING TECHNOLOGY ISSUES ADVISORY COMMITTEE
RICHMOND, VIRGINIA

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Engineer’s Question

- Why build underground when overhead looks so great?

Note: Until it’s in my backyard!
Let’s agree that a line is needed from Point A to Point B.

Then consider:
- Routing alternatives
- Design alternatives
Routing Alternatives

- Use existing ROWs
- Identify new ROWs
  - Public lands
  - Private lands
- Special considerations
  - Bodies of water (bridges)
  - Highways
  - Parks
  - Schools
Transmission Design Alternatives

- Voltage level
- Single versus double circuit
- Overhead versus Underground
- AC/DC
Basic Factors in Comparing Overhead versus Underground

- Overhead is less costly but much more visible
- Underground is “out of sight” but much more expensive
- Both line types produce EMF but exposures differ
- Sometimes there is no choice
  - Urban areas
  - Wetlands
  - Mountainous terrain
Key Considerations in Choosing the Underground Alternative

- Is it technologically feasible?
- Is the cost acceptable?
- What other costs will be incurred?
Elements of Technological Feasibility

- Effects on local system
- Effects on regional system
- Risks of implementation
  - Failure potential
  - Industry experience to date
Key Challenge – Transmission Line Capacitance

• Capacitance
  – Gives a gross measure of the electric field between two conductors.
  – Present whenever two (or more) conductors carrying varying currents at different voltages are close to one another.
  – Occurs in transmission lines and fixed capacitors (used to control voltage)

• Underground cables have much more capacitance than overhead lines
## Choice of Cable Type Affects Feasibility

<table>
<thead>
<tr>
<th></th>
<th>High Pressure Fluid Filled (HPFF)</th>
<th>Cross-Linked Polyethylene (XLPE)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design/Manufacturing</strong></td>
<td>• Proven Reliable – Over 30 years experience at these voltage levels</td>
<td>• Improving design/manufacturing techniques</td>
</tr>
<tr>
<td></td>
<td>• Fewer Manufacturers as Industry moves toward XLPE</td>
<td>• Direction the Industry heading</td>
</tr>
<tr>
<td><strong>Installation</strong></td>
<td>• Mature installation techniques</td>
<td>• Duct or direct burial</td>
</tr>
<tr>
<td></td>
<td>• Greater availability of experienced personnel</td>
<td>• Limited experience with splicing at higher voltages of 345 kV</td>
</tr>
<tr>
<td></td>
<td>• Continuous piping system between terminals</td>
<td>• Availability of skilled craftsmen</td>
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<tr>
<td></td>
<td></td>
<td>• Best practice – installation of partial discharge monitors for each splice</td>
</tr>
<tr>
<td><strong>Operation &amp; Maintenance</strong></td>
<td>• Higher capacitance – more reactive compensation required</td>
<td>• Lower capacitance</td>
</tr>
<tr>
<td></td>
<td>• Lower operating temperature, reduces current carrying capability</td>
<td>• Higher operating temperature – may eliminate 345 kV series reactor required for line out conditions</td>
</tr>
<tr>
<td></td>
<td>• More auxiliary equipment (cable fluid/pressurization system, piping cathodic protection)</td>
<td>• Cautiously optimistic about going forward reliability</td>
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<td></td>
<td></td>
<td>• Operating temperature can be continuously monitored by sensors</td>
</tr>
<tr>
<td><strong>Environmental Impact</strong></td>
<td>• Fluid filled</td>
<td>• Solid core</td>
</tr>
<tr>
<td></td>
<td>• Usually installed as 3-phases in one pipe, which cancels out the EMF</td>
<td>• Usually installed as a single-phase in each conduit creating the potential for EMF problems</td>
</tr>
</tbody>
</table>

Two Types of Underground Cables

Three-Phase High Pressure Fluid Filled, (HPFF)  
Single Phase Cross-Linked Polyethylene, (XLPE)

## Comparative Failure Rates

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>Actual (per 100 miles of cable per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPFF in steel pipe</td>
<td>0.5</td>
</tr>
<tr>
<td>XLPE in Duct – Optimistic</td>
<td>0.64</td>
</tr>
<tr>
<td>XLPE in Duct – Realistic</td>
<td>2.02</td>
</tr>
<tr>
<td>XLPE in Duct – Pessimistic</td>
<td>9.93</td>
</tr>
</tbody>
</table>

Analyses Used to Evaluate Feasibility

- Thermal & voltage
- Stability
- Short circuit
- Harmonic performance
- Transient
Harmonic Resonance – Plot 1

Effect of Load Variation on Harmonic Impedance of Phase II Base Case

Norwalk 345 kV Harmonic Impedance for Different Load Levels
Minimum Generator Dispatch, All Capacitors ON

Harmonic Impedance [Ohm]

Harmonic Number [n]

- Phase II-1 100% Load
- Phase II-1a 70% Load
- Phase II-1 50% Load

Source: KEMA Harmonic Impedance Study for Southwest CT Phase II Alternatives
Harmonic Resonance – Plot 2

Effect of Capacitor Allocation on Harmonic Impedance of Phase II Base Case

Norwalk 345 kV Harmonic Impedance with Capacitors On vs. Off
Light Generator Dispatch, Full Load

Source: KEMA Harmonic Impedance Study for Southwest CT Phase II Alternatives
Transient Network Analysis – Why?

• Transient switching events cause higher frequency currents.

• These currents are amplified by harmonic resonances.

• Temporary overvoltages (TOVs) occur with potential to damage equipment and cause outages.
Temporary Overvoltages (TOVs)

- Key Concerns
  - Maximum Level
  - Duration

- Must be measured for:
  - Various conditions
  - Various locations
Results for Connecticut – 2 Cycle TOVs

Source: Enerex
Results for Connecticut – 6 Cycle TOVs

Source: Enerex
Mitigation Possibilities

• STATCOMS
  – Operational complexity unacceptable

• Filtering
  – C-Type Filters appear promising
  – Little or no industry experience for this application
  – Risk unacceptable for TOVs anticipated
Thank you.

Questions?