Contents

HVDC Technology
Cost Estimates & Schedule
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HVDC TECHNOLOGY
Technology: Why HVDC?

- Power flow is controllable
- Bypasses congested AC circuits w/o inadvertent flow
- Bipole DC performs similar to dbl-ckt AC line under contingencies
- Protects against cascading outages
- Power flow can be maintained at reduced levels during loss of one pole by switching to monopole with metallic return
- Can carry more power with reduced losses for a given size of conductor
- Lower cost per MW of delivered capacity ($/MW) for large systems
Technology: Voltage Source Converters

- VSC marketed as HVDC Light by ABB and as HVDC Plus by Siemens
- Insulated Gate Bipolar Transistor (IGBT) technology does not require strong AC sources for commutation
- Low Short Circuit ratio requirements
- Does not have minimum transfer requirements
- Minimal filtering is required at the terminals
- Smaller terminal footprint and easier to “harden” to improve reliability
- Present technology being used on underground and submarine lines but has limited use and experience on overhead lines
- Allows use of solid dielectric cable technology for submarine cables
Technology: Classic HVDC

- Extensive track record up to ±800 kV
- Converter terminals typically less expensive than VSC terminals but reactive compensation requirements drive up costs
- Thyristor valve technology requires strong AC sources for commutation
- Higher Short Circuit ratio requirements often resulting in need for synchronous condensers or other devices
- Minimum transfer requirements
- Filtering required at the terminals
- Large footprint required at terminals
Technology: Why Metallic Return?

- Improved operational reliability and flexibility
- Bipole operation does not require separate return path; monopole operation will require return path
- Sustained use of earth return during monopole operation often not permitted for environmental reasons (e.g. impact on other buried utilities)
- Planned events, such as planned maintenance, requiring sustained monopole operation may use metallic return
  - Metallic return configuration achieved by controlled switching procedures
  - Metallic return can include a separate return conductor or can be implemented by switching to the remaining unused pole if serviceable
- Unplanned events may use earth return for initial period (minutes) and then switch to metallic return (hours to weeks)
## Technology: Example Submarine Projects

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Cross Sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>New York – Conn.</td>
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<tr>
<td>Voltage</td>
<td>± 150 kV HVDC</td>
</tr>
<tr>
<td>Capacity</td>
<td>330 MW</td>
</tr>
<tr>
<td>Technology</td>
<td>ABB HVDC Light (VSC)</td>
</tr>
<tr>
<td>Sea Route</td>
<td>25 miles</td>
</tr>
<tr>
<td>Land Route</td>
<td>1 mile</td>
</tr>
<tr>
<td>Project Status</td>
<td>In commercial operation since 2002</td>
</tr>
</tbody>
</table>
Technology: Example Submarine Projects

- Project Name: Trans Bay
- Location: San Francisco Bay
- Voltage: ± 200 kV HVDC
- Capacity: 400 MW
- Technology: Siemens HVDC Plus (VSC)
- Sea Route: 53 miles
- Land Route: 1 mile
- Project Status: In commercial operation since 2010
Technology: Example Submarine Projects

- **Project Name:** BorWin1
- **Location:** North Sea
- **Voltage:** ± 150 kV HVDC
- **Capacity:** 400 MW
- **Technology:** ABB HVDC Light (VSC)
- **Sea Route:** 77 miles
- **Land Route:** 46 miles
- **Project Status:** In commercial operation since 2009
Technology: Example Submarine Projects

Project Name: DolWin1
Location: North Sea
Voltage: ± 320 kV HVDC
Capacity: 800 MW
Technology: ABB HVDC Light (VSC)
Sea Route: 46 miles
Land Route: 56 miles
Project Status: 2013 Completion
Technology: Example Submarine Projects

- **Project Name:** SylWin1
- **Location:** North Sea
- **Voltage:** ± 320 kV HVDC
- **Capacity:** 864 MW
- **Technology:** Siemens HVDC Plus (VSC)
- **Sea Route:** 99 miles
- **Land Route:** 28 miles
- **Project Status:** 2014 Completion
Technology: Example Submarine Projects

Project Name: MAPP
Location: Chesapeake Bay
Voltage: ± 320 kV HVDC
Capacity: 2000 MW
Technology: ABB HVDC Light (VSC)
Sea Route: 39 miles
Land Route: 44 miles
Project Status: 2015 Completion
Technology: Example Submarine Projects

Project Name: Atlantic Wind Connection
Location: Mid-Atlantic Coast
Voltage: ± 320 kV HVDC
Capacity: 7000 MW (total)
          2000 MW (max per project phase)
Technology: VSC
Sea Route: ~600 miles
Land Route: ~50 miles
Project Status: 2016-2020
              Staged Completion

[Map of Atlantic Wind Connection Project]
Technology: Submarine Cable Installation

Cable Laying

Cable Burial Plowing
COST ESTIMATES & SCHEDULE
Order of Magnitude Cost Estimates

- Cost estimates include:
  - HVDC converter stations
  - AC substations adjacent to each converter station
  - Synchronous condensers at southern terminal for HVDC Classic
  - Lattice tower structures and 2 conductors per pole on overhead option
  - 1 cable per pole on underground/submarine option
  - Metallic neutral cable

- Cost estimates do not include:
  - Upgrades to existing system not included in the report
  - Cost of remote interconnection
  - Cost of right-of-way/site
  - Owner’s costs
    - Development/permitting costs
    - CCN Process
    - Financing costs
    - Construction management
## Estimated Project Cost – Overhead Option

<table>
<thead>
<tr>
<th></th>
<th>VSC Technology</th>
<th>HVDC Classic</th>
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<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
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</tr>
<tr>
<td>Peak Delivered Power (MW)</td>
<td>1000</td>
<td>1000</td>
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<tr>
<td>Line Voltage</td>
<td>+/- 320 kV HVDC</td>
<td>+/- 400 kV HVDC</td>
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<tr>
<td>Miles of Bipole HVDC Overhead Lines</td>
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<td>220</td>
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<tr>
<td><strong>Line Rating</strong></td>
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<tr>
<td>Line Losses at Peak Line Loading</td>
<td>3.2%</td>
<td>2.0%</td>
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<tr>
<td>Terminal Losses at Peak Load (2 Terminals)</td>
<td>2.0%</td>
<td>1.5%</td>
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<tr>
<td>Total Peak Losses</td>
<td>5.2%</td>
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<tr>
<td>Conductor Rating (MW)</td>
<td>1,052</td>
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<td>Conductor Size Per Pole</td>
<td>(2) 1943 TWD</td>
<td>(2) 1943 TWD</td>
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<td><strong>Total Project Capital Costs</strong></td>
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<td>Bipole HVDC Overhead Lines ($M)</td>
<td>$264</td>
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<td>Two HVDC Converter Stations ($M)</td>
<td>$300</td>
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<td>AC Substations ($M)</td>
<td>$40</td>
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<td>Reactive Compensation [Synch. Cond.] ($M)</td>
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<td>System Impacts ($M)</td>
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<td>Total Capital Cost ($M)</td>
<td>$604</td>
<td>$626</td>
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- Capital Cost per MW of Delivered Capacity ($/MW) $604,000 $626,000

- Further cost optimization of converters would reduce project cost
### Estimated Project Cost – Submarine Option

<table>
<thead>
<tr>
<th>General</th>
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<tbody>
<tr>
<td>Peak Delivered Power (MW)</td>
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<tr>
<td>Line Voltage</td>
<td>+/- 320 kV HVDC</td>
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<td>Miles of Alignment</td>
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<td>Miles of Bipole HVDC Submarine Lines</td>
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<td>Miles of Bipole HVDC Underground Lines</td>
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<td>Line Losses at Peak Line Loading</td>
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<td>Terminal Losses at Peak Load (2 Terminals)</td>
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<td>Cable Rating (MW)</td>
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<td>Submarine Cable Size Per Pole</td>
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<td>Underground Cable Size Per Pole</td>
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<td>Bipole HVDC Submarine Lines ($M)</td>
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<td>Bipole HVDC Underground Lines ($M)</td>
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<td>AC Substations ($M)</td>
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<td>System Impacts ($M)</td>
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<tr>
<td>Total Capital Cost ($M)</td>
<td>$911</td>
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| Capital Cost per MW of Delivered Capacity ($/MW) | $911,000 |

- Further cost optimization of converters would reduce project cost
- Cable costs based on longest distance to Northern Terminal
# High Level Schedule – Overhead Option

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High Level Schedule – Submarine Option

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</tbody>
</table>

- **Project Definition**
- **Preliminary Design and Studies**
- **Preliminary Project Approvals**
- **EIS Activities**
- **CCN Activities**
- **Land Rights**
- **Detailed Design**
- **Equipment & Material Procurement**
- **Construction Procurement**
- **Construction**

**Construction Procurement**

**Land Rights**

**Detailed Design**

**Equipment & Material Procurement**

**CCN Activities**

**Preliminary Project Approvals**

**Preliminary Design and Studies**

**Project Definition**
CONCLUSIONS & NEXT STEPS
Conclusions

• Both Submarine and Overhead Options:
  • Provide fully controllable 1,000 MW capability, and ability to manage congested AC circuits
  • Protects against cascading outages
  • Can carry more power with reduced losses for a given size of conductor
  • Lower cost per MW of delivered capacity ($/MW) for large systems

• Submarine Option:
  ➢ Most reliable alternative to ERCOT for coastal region
  ➢ HVDC/VSC is the preferred choice for submarine transfer of 1000 MW

• Grid connected HVDC options at Loma Alta, Pawnee, and Corpus Christi area (White Point, Las Brisas or Barney Davis) appear to be viable
Next Steps

• Recommend ERCOT to perform UPLAN-based economic assessment
  • Identify production cost savings following incorporation HVDC line vs. AC solutions
• Review Power System Studies to determine optimal capacity and performance requirements
  • AC power flow analysis
  • Reactive power requirements of existing system
  • Assess most viable technology (HVDC or HVDC light) for Pawnee project
  • Dynamic and SSTI Analysis
• Perform field/route constraints review and update preliminary route and permitting requirements
• Update cost estimates
Building a world of difference.

Together

BLACK & VEATCH