AC to DC Line Conversion

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HVDC Lines and Cables Course
June 12. 2017
Industry Needs

- Need more transmission capacity to meet load demand
- Less incentives to build new lines - deregulation
- Difficult to get new rights-of-way
Solutions

- Maximize the use of existing AC transmission Corridors

- Many options
  - Dynamic Ratings
  - FACTS Controllers
  - HTLS Conductors
  - AC to DC line conversion

- Each option provides different benefits at different costs
What does AC to DC Conversion mean / Implications

- Structures – No change
- Conductors – No change
- Insulators – Re-insulation is required
- Terminal substations – DC converter stations have to be built
- Repermiting for DC
Options for Power Increase

Voltage
- Increases in voltage level above peak of AC wave is possible
- Certain limiting factors need consideration
  - Corona
  - Insulation
  - NESC
  - Ground level E-fields

Current
- Thermal limits only
- No Skin effect in conductors
  - Loss Reduction: Approx. 2/3 of AC
- Voltage constrained AC lines can be taken to thermal limits
Configuration options

Single Circuit
- Outer phases used as a traditional Bipole – centre phase used as emergency metallic ground return
- Tripole configuration

Double Circuit
- One circuit converted – as above
- Three conventional Bipoles
- A single Bipole (3 bundles making up a single pole)
- Two Tripoles
DC Voltage Limiting Factors

- Conductor gradient
- Ground-level electric field
- Clearance for insulators at the structure
- NESC clearance to ground
- Live Working Clearances

A DC voltage of up to 1.55 times the AC I-g peak voltage can often be achieved.
DC Power also depends on Max DC Current

While AC Current is limited by:

1. Surge Impedance of Line
2. Voltage Drop limits
3. Steady State Stability limits
4. Thermal Limits

...DC Current is limited only by Thermal Limits
## Power Gain Summary Table

<table>
<thead>
<tr>
<th></th>
<th>Single Circuit - Bipole</th>
<th>Single Circuit - Tripole</th>
<th>Double Circuit – 3 Bipoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Voltage = 1.5 * Peak AC I-g voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC Current = AC Current</td>
<td>155%</td>
<td>213%</td>
<td>235%</td>
</tr>
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<td>DC Voltage = 1.5 * Peak AC I-g Voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC Current = 1.5 * AC Current</td>
<td>233%</td>
<td>320%</td>
<td>353%</td>
</tr>
</tbody>
</table>
Advantages of AC-DC Conversion

- Increased power flow
- Lower % losses
- Power flow controllability
- Limitation of short circuit currents
- Line investment costs
- Asynchronous connections
- ROW – cost and environmental

Challenges

- Acceptance
- Less institutional knowledge / utility experience in DC
- Terminal station costs / justification
Structures Reviewed: 138 kV

<table>
<thead>
<tr>
<th>ACSR</th>
<th>Diameter</th>
<th>Insulators</th>
</tr>
</thead>
<tbody>
<tr>
<td>795 kcmil</td>
<td>1.106&quot;</td>
<td>8</td>
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<tr>
<td>2,156 kcmil</td>
<td>1.735</td>
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</table>
Structures Reviewed: 230 kV

<table>
<thead>
<tr>
<th></th>
<th>ACSR:</th>
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<tbody>
<tr>
<td>a</td>
<td>954 kcmil</td>
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<tr>
<td>b</td>
<td>1,590 kcmil</td>
<td>1.502&quot;</td>
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<td>c</td>
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<tr>
<td>A</td>
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<td>C</td>
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Structures Reviewed 345 kV

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<tr>
<th>ACSR:</th>
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<tbody>
<tr>
<td>2 x 795 kcmil</td>
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<tr>
<th>ACSR:</th>
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<tbody>
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Structures Reviewed: 500 kV

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<th>ACSR:</th>
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<tr>
<td>Diameter</td>
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<tr>
<td>Insulators</td>
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</table>

<table>
<thead>
<tr>
<th>ACSR:</th>
<th>2 x 1,780 kcmil</th>
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</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>1.602&quot;</td>
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<tr>
<td>Insulators</td>
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</table>
Structures Reviewed: 765 kV

<table>
<thead>
<tr>
<th>ACSR</th>
<th>4 x 1,585 kcmil</th>
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</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>1.602&quot;</td>
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<tr>
<td>Insulators</td>
<td>32</td>
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Sustainable dc Voltage

Voltage constrained only by conductor gradient:

In this case the shield wire gradient limits voltage.

But if insulator and earth field limits are considered.....
Sustainable dc Voltage

Voltage constrained by insulation and/or earth gradient:

![Graph showing voltage constraints](https://via.placeholder.com/150)

- Voltage constrained by insulation
- Voltage constrained by earth field

Legend:
- Horizontal
- Vertical
- Delta
- Hybrid
- 2 Ckt dc
Post-Conversion DC/AC MW Ratio

Multiple bipoles

Two tripoles

DC at Max Continuous conductor rating, AC at 80% of maximum rating, pf = 0.95 (Voltage respects all constraints)
HVAC to DC Testing @ Lenox, MA

Eskom

- **Opportunity**
  - 275kV AC → ±400kV DC
  - Potential Power Flow Increase:
    - 1.5 → 1.7

- **Issues**
  - Fair Weather Noise
  - E-field on Ground
  - Insulation
  - Pole to Pole Spacing

- **Approach**
  - Testing @ Lenox, MA
    - E-Field
    - Noise: AN / RI
  - Insulation Under Consideration
Conclusions: AC/DC Line Conversion

- Conversion allows major increase in voltage at low or intermediate voltages.
- Conductor gradient usually limits $V_{dc}$ up to 500 kV, Earth field for 765 kV.
- Where insulation is limiting, there are work-arounds.
- Conversion can increase a circuit’s contribution to path flow by 2:1 or more… largest gains at lowest transmission voltages.
- Conversion may increase path flow more than an additional ac circuit of like rating.
- Reconductoring along conversion can double ampacity gain.
HVDC…Shaping the Future of TRANSMISSION
Together…Shaping the Future of Electricity