Design and Application of Cables and Overhead Lines in Wind Power Plants

• The power generated in the current generation of wind power plants has exceeded the through-put power capacity of most distribution substations and feeder systems.

• The increased power capacity requires more extensive and higher capacity collection systems with fewer transformer and switch grounding locations, taller structures with greater lightning strike exposure, and higher grid connection voltages.
Overview

• Underground or Overhead?

• Underground MV Cable and Construction
  – Cable Properties
  – Installation Methods/Practices
  – Cable Design Parameters

• Overhead Conductor and Construction
  – Design Considerations
  – Overhead to Underground Transitions
Overview

A wind power plant collection system is similar to a utility distribution system but designed for a different purpose.

- A wind power plant (WPP) can be thought of as a “reverse” load
- Uses larger conductors and higher amperage rated components
- 34.5kV is most common voltage for WPPs used in North America and is the highest voltage class for the common URD components available.
# Underground or Overhead?

## Underground Considerations:

<table>
<thead>
<tr>
<th><strong>PROS</strong></th>
<th><strong>CONS</strong></th>
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<tbody>
<tr>
<td>Aesthetics - Typically, the landowners’ preference and often a requirement to secure land during project development</td>
<td>Generally limited to a maximum of 25-30 MW’s per circuit</td>
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<tr>
<td>Limited impact on crane travel during construction</td>
<td>Underground hazards/obstacles - drain tile, gas &amp; oil lines, ravines, wetlands</td>
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<tr>
<td>Losses tend to be less due to larger conductor sizes used for similar MW loading as compared to OH</td>
<td>Duration of outages is longer due to time in locating and repairing faults</td>
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<td>Trenching/plowing difficult in rocky regions.</td>
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## Underground or Overhead?

### Overhead Considerations:

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<tbody>
<tr>
<td>More MW’s able to be carried on a single circuit (generally up to 50-60 MWs)</td>
<td>Can impede crane travel during construction</td>
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<tr>
<td>Multiple circuits can be strung on a single structure</td>
<td>Aesthetic concerns with Landowners</td>
</tr>
<tr>
<td>Outage durations usually less since faults easily located and repaired</td>
<td>More frequent outages as compared to UG</td>
</tr>
<tr>
<td></td>
<td>Losses tend to be higher since generally more MW’s are placed on a circuit</td>
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</tbody>
</table>
Underground MV Cable & Construction
Cable Properties

Conductor Selection:
Copper or Aluminum

Aluminum is the most commonly used conductor in WPP construction due to economics (copper is more than 3X the cost of aluminum and even considering losses over a 20-year operating life, copper will rarely overcome this cost differential)
Underground MV Cable & Construction
Cable Properties

**Insulation:**
Contains the voltage between the conductor and the Concentric ‘Shield’

- Two predominant types, EPR and TR-XLPE
- Two predominant thicknesses, 100% and 133%
- Two predominant temperature ratings, MV-90 and MV-105
Underground MV Cable & Construction
Cable Properties

Insulation-
EPR (Ethylene Propylene Rubber)

• More flexible due to its ‘rubber’ properties
• Softer than XLPE (some users report that slightly more care is required during installation than TR-XLPE)
• Higher dielectric constant leading to higher losses (not a significant factor for basis of selection)
• Traditionally more expensive than TR-XLPE
Underground MV Cable & Construction
Cable Properties

Insulation-
TR-XLPE (Tree Retardant- Cross Linked Polyethylene)

- Most commonly used insulation in WPP construction
- Significantly cleaner and improved properties than the XLPE introduced in the mid 1960’s that is known infamously for failures
- Lower Dielectric Losses compared to EPR
- Traditionally lowest capital cost
Underground MV Cable & Construction

Cable Properties

**Insulation-**
Thickness (100% or 133%)

- 100% (345mils at 34.5kV) permitted when the line-to-ground faults are cleared within 1 minute; common for grounded systems.

- 133% (420mils at 34.5kV) used when line-to-ground faults are cleared within 1 hour; common for ungrounded systems.

- 100% insulation is most commonly used in wind power plants.
Underground MV Cable & Construction
Cable Properties

Insulation-
Temperature Rating (MV-90 and MV-105)

- MV-90: operation at 90degC normal conditions / 130degC under emergency overloads.
- MV-105: operation at 105degC normal conditions / 140degC under emergency overloads.

Operating at higher temperatures results in higher losses therefore MV-90 is most often selected for WPP applications (note, most terminations and connectors are only rated to 90degC)
Underground MV Cable & Construction Cable Properties

Jacket Material
Most common:
• PVC (polyvinyl chloride)
• LLDPE (linear low density polyethylene)

LLDPE exhibits better mechanical properties and is more resistant to moisture ingress than PVC
Underground MV Cable & Construction Installation Methods/Practices
Underground MV Cable & Construction Installation Methods/Practices

Typical Cable Installation Detail
Underground MV Cable & Construction Installation Methods/Practices

Direct Buried either Trenching or Plowing

Conduit/duct bank not practical for length of runs involved
Underground MV Cable & Construction Installation Methods/Practices

Trenching Methods- Multi-pass method where trench, cable laying, bedding performed separately
Underground MV Cable & Construction Installation Methods/Practices

Trenching Methods- Single-pass, all activities performed in a single process
Underground MV Cable & Construction Installation Methods/Practices

Difficult terrain can be overcome with proper bedding/burial
Underground MV Cable & Construction Installation Methods/Practices

“Plowing’ Issues

• Not practical in rocky areas
• Drain tile damage will not be noticed until the next rain!!
• Must ensure the plow “shoe” allows proper cable configuration per design (trefoil or flat)

Drain Tile ‘Strike’ (common in Farm fields, can be encountered as much as every 125’
Cable Splicing
- With long distances between turbines is unavoidable

• Most Failures on WPP experienced at splices and joints

• Poor installation practices and inexperienced crews lead to failures (Tenting is recommended and splicers should be qualified by splice kit supplier prior to performing work)
Underground MV Cable & Construction Installation Methods/Practices

Cable Splicing/Junctions - Types

Above Grade cable Joint
Above Grade Sectionalizing Cabinet
Direct Bury Splice
Underground MV Cable & Construction Cable Design Parameters

Ampacity Calculation Considerations:

- Soil Thermal Properties
- Cable Configuration (flat or trefoil)
- Number of Circuits
- Shield Bonding (multi-point, single-point, cross-bonding)
- Others (load factor, conduit, direct bury, heat sources, etc.)
Underground MV Cable & Construction
Cable Design Parameters

Soil Thermal Resistivity

- Cable ampacity is significantly influenced by soil thermal resistivity
- According to Annex B in the NEC, 90% of soil in U.S. has a Rho value of 90? If true, wind plants are located on the other 10%!

(90°C Conductor, 25°C earth, 36IN depth, 100%LF, SC Shield)

- Typical Rho Values seen for wind plants vary from 125-300
Soil Thermal Resistivity

- Soil thermal resistivity depends on the soil type and physical conditions
  - As the Moisture Content or Dry Density decreases, the thermal resistivity increases
  - High earth-cable interface temperatures can dry the soil resulting in an increase in thermal resistivity and thus conductor temperature
  - Limiting the earth interface temperature in the 50 to 65°C range may be necessary to prevent “Thermal Runaway”
Underground MV Cable & Construction Cable Design Parameters (Shield Resistance)

• When the shields of single-conductor cables are bonded and grounded at multiple points, cable ampacities may be significantly reduced by the resultant circulating current losses
• This effect is most apparent on spaced single-conductor cables with large conductor sizes and low resistance shields
• For smaller conductor sizes, the variation of ampacity with shield resistance is relatively small
Underground MV Cable & Construction
Cable Design Parameters

Cable Configuration:
(Trefoil vs. Flat)

- Small conductor sizes with short circuit (S/C) shields
  - As spacing increases the ampacity increases due to a reduction in mutual heating
- Large conductor sizes with S/C shields
  - As spacing increases the ampacity decreases due to an increase in shield circulating current losses

(90C Conductor, 25C earth, 36IN depth, 100%LF, SC Shield, Flat configuration at 7.5IN separation)
Underground MV Cable & Construction Cable Design Parameters

Shield Bonding Alternatives

- Single-Point Bonded Shields (Open-Circuit)
- Multi-Point Bonded Shields (Short-Circuit)
- Cross-Bonded Shields
Underground MV Cable & Construction
Cable Design Parameters

• Single Point Bonded Shields (Open-Circuit Shields)
  – Shield circulating current losses eliminated regardless of configuration
  – Cable circuit length may be limited by the voltage induced in shield

• Solidly Bonded & Grounded Shields (Short-Circuit Shields)
  – Simplest solution to the problem of induced shield voltages
  – Available ampacity can be significantly reduced on large single-conductor cables with low
    resistance shields due to circulating current losses

• Cross Bonded Shields
  – Prevention of induced shield voltages and reduction of shield losses
  – Can be economically justified on large conductors circuits and extremely heavy loads where
    all heat generation has to be minimized
  – Consists of sectionalizing the shields into minor sections and cross connecting them so that
    total induced voltage is essentially neutralized in three consecutive sections
Underground MV Cable & Construction
Cable Design Parameters

Shield Sizing Considerations

Must be sized to handle the available fault current, particular attention should be made to those conductors nearest the substation.
Overhead Conductor & Construction
-Transmission level conductor applied at Sub-Transmission Level Voltage
Overhead Conductor & Construction Design Considerations

*Conductor type and size*
Sized based on ampacity requirements but primary consideration is for losses.

*Structure type, strength, configuration, and insulator size*
Selected based on NESC and regional loading considerations (wind, ice, etc.) and minimizing cost while avoiding excessive outages due to mechanical failure and lightning strikes.
Overhead Conductor & Construction Design Considerations

• Aeolian Vibration and Galloping-
The wake effect of the wind turbine must be considered for OH construction in close proximity to the wind turbine tower. Turbines up to a ¼ mile away could pose problems.

• Unventilated or Ventilated Riser-The riser portion of the circuit (underground to overhead) may be the limiting factor for the underground circuit.

(90C Conductor, trefoil, 90 Rho, 25C earth, 36IN depth, 100%LF, SC Shield- Riser 40C air, full sun, no wind)
Design and Application of Cables & Overhead Lines in Wind Power Plants

• Questions?

Wayne Dilling, PE
Sr. Electrical Manager

Feeding time at a wind plant

IEEE PES
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