MV Cable Fault Locating and Field Testing

March 20, 2018

Dave Cragle, Work Methods
Frank Dempsey, System Shops
Topics of Discussion

- Understanding where the Fault Is and Is Not.
- Understanding that Cable Fault Locating and Cable Testing are not the same thing.
- Fault locating methods based on fault type, system construction, and design.
- Effectiveness of Very Low Frequency (VLF) test methods.
- Cable Testing Methodology.
- Best practices for Fault Locating and Cable Testing.
- Test data value.
Medium Voltage Cable History

- 1960 - Bare Concentric Neutral (BCN) XLPE
- 1966 - Direct Burying Cable
- 1970 – Solid AL conductor (BCN)
- 1972 – Compact strand aluminum conductor
- 1980 - Covered neutral cable (Jacketed Cable)
- 1995 - Strand Filled Conductor
- 1995 – (CIC) Cable in Conduit
- 1995 – TRXLPE (Tree Retardant Insulation)
MV Shielded Power Cables

- Conductor
- Conductor or Strand Shield
- Insulation
- Insulation Shield
- Metallic Shield/Neutral
- Jacket
What Is The First Thing You Think About When There Is A Fault?
Fault Locating is Viewed as:

Fault Locating:

- “Where is the fault?”
- “Where is it not?”
- “How long will it take to find the fault?”
- “Can it be returned to service”
Where Is The Fault?

Bill, The #2 Circuit Breaker tripped again. How about finding the fault.
Where Is It Not?
How Long Will It Take To Find The Fault?
Can It Be Returned To Service?
Where is the Fault?
Where is the Fault?
Types of Cable Faults and Methods of Detection

- Very Low Impedance Fault (Bolted)-TDR, Sectionalize and Hi-Pot, or Arc Reflection With Acoustic Pickup
- High Impedance Fault (Insulated)-Hi-Pot-Burn, TDR, Arc Reflection With Acoustic Pickup
Fault Locating Methods Utilized

Fault Locating Methods:
- TDR (Time Domain Reflectometry)
- DC Hi-Pot
- Arc Reflection (Thumper)

Energization Sources:
- DC

Standards:
- IEEE 1234
Fault Locating

TDR Testing – Time Domain Reflectometer
Primary One-Line

Good spot to sectionalize based on:

- Safety (out of traffic)
- Accessibility and space
- # of branches in manhole
- Distance to end of line
DC Hi-Pot

Fault Locating/Proofing Network DC Test Voltages

15 kV System - For all cable types (XLP, EPR, PILC)

<table>
<thead>
<tr>
<th>Voltage Step</th>
<th>Time in Minutes</th>
<th>DC Test Voltage</th>
<th>Leakage Current (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>5 kV</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>10 kV</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>15 kV</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>20 kV</td>
<td>*</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>30 kV</td>
<td>*</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>40 kV</td>
<td>*</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>50 kV</td>
<td>*</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>56 kV</td>
<td>*</td>
</tr>
</tbody>
</table>

* See Network Engineer for approval to DC Hi-Pot above the following voltages
PPL’s Approach To Reduce Future Cable Faults
Cable Testing Is Viewed As:

Acceptance Testing (New or Repaired):
- “Can the cable system be safely energized?”
- “Is the cable system quality as expected?”

Proactive Testing:
- “What is the condition/health of the cable system?”
- “How should we prioritize the cable system if it needs to be replaced?”
Why Test Cables?
Condition of Cables?
Reliability “Bathtub” Curve

- Infant Mortality
- Stable
- Aging Failure

Unreliability vs. Time graph
Projected Vs. Actual Cable Failures
Cable Test Methods Utilized By PPL
Cable Test Methods Utilized

Cable Testing Methods:
- TDR (Time Domain Reflectometry)
- Tan Delta/Dissipation Factor
- Partial Discharge
- Withstand

Energization Sources:
- AC – Low Frequency (VLF-0.1 Hz)

Standards:
- IEEE 400, 400.2, 400.3
Cable Test Methods Utilized

- TDR (Time Domain Reflectometry)
- Tan Delta
- Partial Discharge
- Withstand
# Testing Matrix

<table>
<thead>
<tr>
<th>Voltage Class</th>
<th>References</th>
<th>ITS</th>
<th>ITS</th>
<th>ITS</th>
<th>ITS</th>
<th>ITS</th>
<th>ITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable - Overhead Bundle / Aerial Cable [A]</td>
<td>12kV</td>
<td>DDI L-311</td>
<td>X (2)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable - Temporary Bypass / Mobile Transformer</td>
<td>12kV</td>
<td></td>
<td>X (2)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable - Terminators</td>
<td>69kV-138kV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cable - Underground [A]</td>
<td>69kV-138kV</td>
<td>DDI L-311, L-313</td>
<td>X (2)</td>
<td>X</td>
<td>X</td>
<td>X (7)</td>
<td>X</td>
</tr>
<tr>
<td>Cable - Underground</td>
<td>12kV</td>
<td>DDI L-311</td>
<td>X (2)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tan Delta = IR / IC
Ratio between loss current and charging current
Power Factor = IR / IT
Neutral Degradation (Loss of Neutral)
  - Localized uneven electrical stress on cable insulation

Insulation Degradation
  - Water Trees
  - Electrical Trees

Additional Factors
  - Installation Defects—mainly at splices and terminations
  - Mechanical Stress – bending radius
  - Overload-thermal degradation
  - Manufacturing Defects
  - Lightning/Surges from switching
  - Water ingress into cable, joints, or terminations
Medium Voltage Cable Failures

Water and Electrical Trees:
- Progression of a cable failure
- Water tree through partial discharge failure
Medium Voltage Cable Failures
PPL Cable Test Methodology

TDR Testing – Time Domain Reflectometer

- Simple effective way to look down a shielded cable to determine the quality of the shield (drain/neutral).
- Pulse duration in the order of a few nanoseconds to a few microseconds.
- Detects changes of impedance such as, opens, shorts, splices, corrosion.
PPL Cable Test Methodology

TDR Testing – Time Domain Reflectometry

- Levels of degradation
  - L1 0-25%
  - L2 26-50%
  - L3 51-75%
  - L4 76-100%
PPL Cable Test Methodology

Tan Delta

- Very Low frequency test (0.1 HZ) sign wave that calculates the total losses in the insulation across the entire cable system.
- Effective for detecting water trees and degradation.
- Independent of cable length.
- Acceptable insulation has a very low Tan Delta and very little tip-up with increased voltage applied.
- Loss Factor and loss current increases as cable ages.
- Standard deviation at a voltage step: Stable is good, unstable is bad.
Tan Delta – (cont.)

- The IEEE Standard(400.2) for service aged cable:
  - < 4 tan delta (Good)
  - 4 - 50 tan delta (Further study)
  - >50 tan delta (Action required)

- Tip Up is the difference in Tan Delta from low to high test voltages

<table>
<thead>
<tr>
<th>Kilovolts</th>
<th>Tan Delta</th>
<th>Tip-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2.70</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
PPL Cable Test Methodology
Partial Discharge:

- Detects high frequency generated at the discharge site within the cable system and can pinpoint its location.

- These discharges do not completely bridge the insulation between the conductors of a cable and can be found:
  - Within the volume of an insulation
  - Along surface of an insulation
  - In a gas surrounding an electrode (Corona)
PPL Cable Test Methodology
PPL Cable Test Methodology

Withstand:

- Application of voltage above normal operating voltage for predetermined duration.
- Attempts to identify weakest locations in a cable. Only serious gross defects will fail the test, therefore; it is not considered a destructive test. Good cables will not fail.
- Simple or Monitored Tan Delta withstand
## Cable Test Data

<table>
<thead>
<tr>
<th>Date</th>
<th>Size</th>
<th>Oal ft</th>
<th>Neutral</th>
<th>Stranded</th>
<th>Splices</th>
<th>Tan-D</th>
<th>Tip-up</th>
<th>PD Found</th>
<th>PD Corrected</th>
<th>Action</th>
<th>Acceptance Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/27/2018</td>
<td>500Cu, 2/0 Cu</td>
<td>895</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 171 @ 350'</td>
<td>0.40</td>
<td>0.05</td>
<td>No</td>
<td></td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/27/2018</td>
<td>500Cu, 2/0 Cu</td>
<td>895</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 171 @ 350'</td>
<td>0.92</td>
<td>0.48</td>
<td>Yes</td>
<td>Yes</td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/27/2018</td>
<td>500Cu, 2/0 Cu</td>
<td>895</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 171 @ 350'</td>
<td>0.93</td>
<td>0.44</td>
<td>Yes</td>
<td>Yes</td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/26/2018</td>
<td>500Cu</td>
<td>1,150</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 209 @ 690'</td>
<td>0.38</td>
<td>0.03</td>
<td>Yes</td>
<td>Yes</td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/26/2018</td>
<td>500Cu</td>
<td>1,150</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 209 @ 690'</td>
<td>0.38</td>
<td>0.05</td>
<td>No</td>
<td></td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/26/2018</td>
<td>500Cu</td>
<td>1,150</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 209 @ 690'</td>
<td>0.39</td>
<td>0.04</td>
<td>No</td>
<td></td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/27/2018</td>
<td>2/0 Cu</td>
<td>160</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 171 @ 35'</td>
<td>0.70</td>
<td>0.09</td>
<td>No</td>
<td></td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/27/2018</td>
<td>2/0 Cu</td>
<td>160</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 171 @ 35'</td>
<td>0.64</td>
<td>0.06</td>
<td>No</td>
<td></td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
<tr>
<td>2/27/2018</td>
<td>2/0 Cu</td>
<td>160</td>
<td>Ok</td>
<td>Filled</td>
<td>Tee’s in MH 171 @ 35'</td>
<td>0.72</td>
<td>0.1</td>
<td>No</td>
<td></td>
<td>No Action Required</td>
<td>Yes</td>
</tr>
</tbody>
</table>
## 07-13 Cable Statistics Recommendations

<table>
<thead>
<tr>
<th></th>
<th>Count</th>
<th>Feet</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement Cable</td>
<td>1661</td>
<td>706,872</td>
<td>50.3%</td>
</tr>
<tr>
<td>No Action Cable</td>
<td>1392</td>
<td>623,554</td>
<td>42.2%</td>
</tr>
<tr>
<td>Cable Remediation</td>
<td>220</td>
<td>74,506</td>
<td>6.7%</td>
</tr>
<tr>
<td>Totals</td>
<td>3300</td>
<td>1,468,008</td>
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</tr>
</tbody>
</table>

## 07-13 Replacement Reasons

<table>
<thead>
<tr>
<th></th>
<th>Count</th>
<th>Feet</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Bad</td>
<td>925</td>
<td>432,913</td>
<td>61.1%</td>
</tr>
<tr>
<td>Tan Delta /Tip Up Bad</td>
<td>521</td>
<td>189,154</td>
<td>26.7%</td>
</tr>
<tr>
<td>Solid/Strand Filled</td>
<td>156</td>
<td>53,650</td>
<td>7.6%</td>
</tr>
<tr>
<td>Partial Discharge</td>
<td>72</td>
<td>31,446</td>
<td>4.5%</td>
</tr>
<tr>
<td>Mechanical Failure</td>
<td>14</td>
<td>1,613</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
What Are You Doing?

- Other
- VLF-WS
- VLF-PD
- TDR
- DC-HI Pot
- VLF-TD

(ppl logo)
### PPL Cable Test Requirements

**Table 1 – Test Requirements for Each Type of Cable**

<table>
<thead>
<tr>
<th>Type of Cable</th>
<th>Acceptance Test New/Replacement</th>
<th>Periodic or Condition-based Test by Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Cables, Rated 69 kV and Higher</td>
<td>TD, PD, Jacket Test, ACWS, TDR</td>
<td>TD, PD, Jacket Test, TDR</td>
</tr>
<tr>
<td></td>
<td>TD, PD, TDR</td>
<td>TD, PD, TDR</td>
</tr>
<tr>
<td></td>
<td>TD, PD, TDR</td>
<td>TD, PD, TDR</td>
</tr>
<tr>
<td></td>
<td>TD, PD, TDR</td>
<td>TD, PD, TDR</td>
</tr>
<tr>
<td></td>
<td>TD, PD, TDR</td>
<td>TD, PD, TDR</td>
</tr>
<tr>
<td></td>
<td>TD, PD, TDR</td>
<td>TD, PD, TDR</td>
</tr>
<tr>
<td></td>
<td>Hi-POT</td>
<td>TD, PD, TDR</td>
</tr>
<tr>
<td></td>
<td>Hi-POT</td>
<td>TD, PD, TDR</td>
</tr>
</tbody>
</table>

**Notes:**
- TD: Temperature Distribution
- PD: Partial Discharge
- ACWS: Alternating Current Water Seepage
- TDR: Time Domain Reflectometry
Cable Test - Benchmarking

Test Methods

- AC VLF: 56%
- AC: 22%
- DC: 11%
- None: 11%

AC VLF Test Details

- Withstand: 28%
- Tan Delta: 43%
- PD: 29%

Withstand – High Voltage AC Test
Tan Delta – VLF Diagnostic Test
PD – Partial Discharge

AC VLF – Very Low AC Frequency (1/10 Hz)
DC Hi-Pot – High Voltage Direct Current
AC – High Voltage Alternating Current
Fault Locating - Benchmarking

Fault Locating Methods

- DC Hi-Pot to narrow down faulted area, “Thumping” used if necessary.
- Fault locating is performed using past experience, judgement.
## Testing Method Evaluation

<table>
<thead>
<tr>
<th></th>
<th>VLF Withstand</th>
<th>Tan Delta</th>
<th>PD</th>
<th>DC Hi Pot</th>
<th>Discharge Testing</th>
<th>&quot;Thumping&quot;</th>
<th>TDR &quot;Radar&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance Testing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

- **VLF Withstand**: Voltage Level Frequency Withstand Test
- **Tan Delta**: Tangent Delta Test
- **PD**: Partial Discharge Test
- **DC Hi Pot**: Direct Current High Potential Test
- **Discharge Testing**: Test to measure discharge currents
- **"Thumping"**: A test sound similar to a thump
- **TDR "Radar"**: Time Domain Reflectometry, similar to radar
Understanding where the Fault Is and Is Not are both important.
Fault locating methods based on fault type, system construction, and design.
TDR is an effective Fault Locating method.
Reduce the amount of DC/Thumping – try to reduce the duration and voltage applied.
VLF Cable Test methodology does not destroy or degrade acceptable cable insulation systems.
Choice of Cable Test method often determined by age and type of cable and diagnosis.
Cable Testing strategy involving a combination of tests is most appropriate.
Data Repository for data analytics.
Questions?
More Information

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- Frank Dempsey, System Shops Manager
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Appendix
Definitions

- **Cable System** – Cable including splices and terminations
- **DC Hi-Pot** – High Voltage Direct Current
- **AC** – High Voltage Alternating Current
- **AC VLF** – Very Low AC Frequency (1/10 Hz)
- **Tan Delta** – VLF Diagnostic Test
- **Withstand** – High Voltage AC Test
- **PD** – Partial Discharge
- **TDR** – Time Domain Reflectometry
Fault Locating Methods:  
- TDR (Time Domain Reflectometry)  
- Surge Arc Reflection (Thumper and Scope)  
- Impulse Current (Thumper and Scope)  
- Bridge Method

Energization Sources:  
- Controlled Energy Thumper – DC Pulse

Standards:  
- IEEE 1234
## Cable Test Data

### 07-13 Development Stats

<table>
<thead>
<tr>
<th>Description</th>
<th>Count</th>
<th>Feet</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development Replacement Cable Total</td>
<td>1,661</td>
<td>706,872</td>
<td>50.33%</td>
</tr>
<tr>
<td>Development No Action Total</td>
<td>1,392</td>
<td>623,664</td>
<td>42.18%</td>
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<tr>
<td>Development Cable Cure Total</td>
<td>220</td>
<td>74,506</td>
<td>6.66%</td>
</tr>
<tr>
<td>Development Total Cable Test Recommendations</td>
<td>3,300</td>
<td>1,468,008</td>
<td></td>
</tr>
</tbody>
</table>

### 07-13 Other

<table>
<thead>
<tr>
<th>Description</th>
<th>Count</th>
<th>Feet</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>27</td>
<td>0.80%</td>
<td></td>
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</tbody>
</table>

### 07-13 Development Action Totals

<table>
<thead>
<tr>
<th>Description</th>
<th>Count</th>
<th>Feet</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Replacement - Neutral Bad, PD, Solid or Strand-filled, Mech. Failure</td>
<td>1,167</td>
<td>519,622</td>
<td>69%</td>
</tr>
<tr>
<td><strong>07-13 Recommended Replacement - Tan Delta Bad</strong></td>
<td>521</td>
<td>189,154</td>
<td>31%</td>
</tr>
</tbody>
</table>

### 07-13 Development Replacement Reasons

<table>
<thead>
<tr>
<th>Description</th>
<th>Count</th>
<th>Feet</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development Replacement - Neutral Bad</td>
<td>925</td>
<td>432,913</td>
<td>61.08%</td>
</tr>
<tr>
<td>Development Replacement - Tan Delta and/or Tip-up Bad</td>
<td>521</td>
<td>189,154</td>
<td>20.69%</td>
</tr>
<tr>
<td>Development Replacement - Solid or Strand-filled</td>
<td>158</td>
<td>53,880</td>
<td>7.67%</td>
</tr>
<tr>
<td>Development Replacement - Partial Discharge</td>
<td>72</td>
<td>31,446</td>
<td>4.44%</td>
</tr>
<tr>
<td>Development Replacement - Mechanical Failure</td>
<td>14</td>
<td>1,613</td>
<td>0.23%</td>
</tr>
</tbody>
</table>
Interpretation of $\tan(\delta)$ Measurement

1. Comparing the results of previous tests to determine, the
deterioration of the condition of insulation due to ageing effect.

2. Determining the condition of insulation from the value of $\tan\delta$,
directly.

- **If the insulation is perfect**
  The loss factor will be approximately same for all range of test voltages.

- **If the insulation is not sufficient**
  The value of tan delta increases in the higher range of test voltage.
PPL Cable Test Methodology
## Testing Method Evaluation

<table>
<thead>
<tr>
<th></th>
<th>VLF Withstand</th>
<th>Tan Delta</th>
<th>PD</th>
<th>DC Hi Pot</th>
<th>Discharge Testing “Thumping”</th>
<th>TDR &quot;Radar&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acceptance Testing</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td><strong>Maintenance Testing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fault Locating</strong></td>
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<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

### Pros
- **VLF Withstand**: Can be used for all cable types, Easy to use, can be integrated with Tan Delta and partial discharge, can grow defects faster than operating voltage.
- **Tan Delta**: Can be used for all cable types, identifies insulation aging, test voltage varying, aging changes more visible at lower frequencies, test can be trended.
- **PD**: Can be used for all cable types, can locate singular or multiple weak spots, test can be compared to previous test for trending.
- **DC Hi Pot**: Easy to use, long lengths can be tested, applicable for PILC cables.
- **Discharge Testing “Thumping”**: Easy to use, applicable for PILC cables.
- **TDR "Radar"**: Easy to use, detects and locates corroded neutral/shields, low voltage test, can locate faults, joints, and circuit length.

### Cons
- **VLF Withstand**: Frequency is different than operating frequency, Tests are interpreted, noise must be minimized, branched circuits may require multiple test locations.
- **Tan Delta**: Frequency is different than operating frequency, Tests are interpreted, noise must be minimized, branched circuits may require multiple test locations.
- **PD**: Pass or fail criteria not established, Duration of voltage application is not weak established, cable must be discharged before and after each test, can damage extruded materials, Requires higher test voltage than AC, voltage waveform is not the same as operating voltage.
- **DC Hi Pot**: Voltage level application is not well established, cable must be discharged before and after each test, can damage extruded materials, voids new cable warranties.
- **Discharge Testing “Thumping”**: Voltage level application is not well established, cable must be discharged before and after each test, can damage extruded materials, voids new cable warranties.
- **TDR "Radar"**: Cannot detect insulation defects, noise can cause interference, interpretation needed for results.

### PPL Recommendation
- **Utilize for testing cable repairs/Tee repairs. First method for faulting locating to localize trouble area**
- **Utilize for acceptance and maintenance testing, as proactive/condition assessment of cable system.**
- **Utilize for acceptance and maintenance testing, as proactive/condition assessment of cable system.**
- **Phase out/Discontinue use as primary testing methods. May be utilized as backup test if no other test methods are available.**
- **Utilize for fault locating, Third step, to be used if other methods are not conclusive.**
- **Utilize for acceptance, and maintenance testing for neutral to ground. Second step for fault locating.**
Projected Cable Failure

- Projected Failure Rate If Faults Are Repaired
## Testing Matrix

<table>
<thead>
<tr>
<th></th>
<th>Voltage Class</th>
<th>References</th>
<th>ITS</th>
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<td>Air Break</td>
<td>69-230kv</td>
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<tr>
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<td>69-230kv</td>
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<td>DDI S-107</td>
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<td>Cable - Terminators</td>
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<td>Cable - Underground [A]</td>
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<td>DDI L-311, L-313</td>
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