Risk-based Techniques for LV/MV Cable Prioritization and Aging Management

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Elements of a Robust Cable and Connectors Aging Management Program
Determine Scope – Define which cable / connector components (MV, LV, Instrument, EQ and/or non-EQ, splices, etc.) are within the scope of the program at each plant.

Data Collection/Integration – Relevant data, whether from existing databases (e.g., cable, operating experience, corrective action) or other sources are collected and organized.

Risk Ranking – A risk assessment is performed to gain insights that best focus station resources in a way that mitigates the likelihood of failure and potential consequences of failure.

Inspection Planning – Develop risk prioritized inspection walkthrough scope and most appropriate tests based on environment, service conditions and materials of construction.
Risk Assessment Overview

- **Risk** = Consequence x Likelihood
  - Consequence of Failure
  - Likelihood of Degradation (based on aging mechanisms)

- **Cable Segment (definition): cable sections that:**
  - Share the same design and operational properties, including:
    - Material Design
    - Environment (temperature, radiation, water, etc.)
    - Service conditions (voltage, ampacity, etc.)

- **Risk can be assessed based on cable or cable segments**
  - Use of segments better allows plants to strategically manage risk through testing, trending and use of Operating Experience.
  - Facilitates establishing a sampling percentage which could allow for a smaller sample size, because it addresses factors such as lot homogeneity discussed in EPRI TR-017218-R1.
Consequence & Degradation Considerations

Risk of Failure = (Consequence due to Failure) x (Likelihood of Degradation)

- Consequence
  - Safety Impact
    - PRA Measures (CDF, etc.)
  - Economic Impact ($)
    - AP-913 Critical
    - Single Point Vulnerability
  - Regulatory Impact

- Likelihood of Degradation
  - Materials of construction
  - Service Conditions
  - Environment (ALEE, etc.)
  - Age
  - Inspection/Test Results

- Consequence Ranking

- Degradation Likelihood Ranking
## A Typical Risk Matrix

<table>
<thead>
<tr>
<th>Consequence Evaluation</th>
<th>FAILURE CATEGORY Cable/Circuit Failure Potential</th>
<th>CONSEQUENCE CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

- **Failure Potential**
  - Assessment *(Degradation Mechanism)*

- **Consequence Evaluation**
  - Potential
  - Failure

- **Consequence Categories**
  - None
  - Low
  - Medium
  - High
Treatment of Risk Categories

Risk Categories are Combined into Regions to:

Accommodate uncertainties in likelihood of failure

1. Sampling from a group of higher risk provides a stronger basis for conclusions from testing.

2. Ensure high consequence segments without identified damage mechanisms are considered.

3. Ensure segments with the high failure likelihood are considered even if the consequence category is low.

*Inclusion of samples from both the highest and non-highest prioritized groups validates and improves confidence in the risk prediction models (Type I & Type II errors).*
Two General Approaches to Risk Models

1. Subject matter expert (SME) approach.
2. Relative risk ranking (RR) approach – our recommendation.

Primary differences are:

- SME evaluation limited by experience of the experts.
- SME commonly treats both LOD and COF as “risk.”
- SME uses interpreted information in final conclusion whereas relative risk model uses an algorithm based on underlying information.
- RR approach emulates SME knowledge, but can be used more consistently by individuals with less experience.
- RR approach needs much less effort to accommodate new information (e.g., industry OE, trending of results).
A Simplified Example of a Subject Matter Expert Approach – Not Recommended

**Cable Insulation Material Risk Factor** - Likelihood

- XLPE: 10
- Butyl Rubber: 10
- Black EPR: 10
- Brown EPR: 10
- Pink EPR: 5
- All Others: 10

**Tech Spec / LCO Risk Factor** - Consequence

- LCO ≤ 3 days or PRA High Risk: 10
- LCO > 3 days and ≤ 14 days: 7
- LCO > 14 days and ≤ 30 days: 4
- LCO > 30 days: 1
- No LCO or compensatory actions: 0

Note: Overall risk is determined by taking the sum of “risk” elements that are actually two separate attributes of risk. This complicates segregation of the risk elements to establish the best means to manage overall risk.
Sentinel Locations

The sentinel locations in a group of cables may be thought of as a Peloton, which refers to a packed group of bicycle racers. A leader is established, but over time a new leader may emerge as conditions change.

Peloton

Therefore, cables and/or locations need to be evaluated on a uniform basis to ensure a valid risk ranking, identification of sentinel locations and to enable appropriate monitoring over time.
Risk Assessment Elements for Cable Aging Management

1. Scope Determination
2. Consequence of Failure Determination
3. Likelihood of Degradation Determination
4. Segment Risk Prioritization
   - Select Sentinel Segments and Determine Appropriate Inspection/Test Methods
   - Perform Inspection/Test
   - Evaluate Results
   - Adjust Sentinels
   - Adjust Testing & Test Interval

Lessons Learned / OE
Cable Risk Assessment Summary

CURRENT APPROACH:

• No common standard currently exists
• Risk is generally not determined consistent with other risk-informed approaches (e.g., RI-ISI) where consequence and likelihood threats are distinct factors
• Difficult to use as a decision-making tool.

PROGRAMATIC APPROACH:

• Establish a common framework, building on work performed for other EPRI-sponsored risk-informed applications and familiar processes.
• Designed to enable plants to apply risk insights as a decision-making tool.
An Improved Risk Approach Using IsoRisk Analysis
Inspection & Testing Phase

**Inspection / Walkdown** – Supplemental ‘performance’ field information (qualitative screening) is obtained and integrated in the cable aging management database. The information is used to improve the discrimination of adverse environments or identify physical characteristics with undesirable conditions (e.g., long unsupported spans, discoloration).

**Cable System Testing** – Tests are performed using a variety of quantitative techniques to characterize the condition of the cable for further disposition and trending of results. Acceptance criteria are established for use in evaluating results.

**Reporting** – Results are accessible through for review, disposition and inclusion in station health reports. GALL comparison and License Renewal commitment reports can also be developed.
Walk-Down Considerations

- **Observable defects:**
  - Charring
  - Crazing
  - Hardening
  - Softening
  - Weeping
  - Contamination
  - Deformation
  - Melting
  - Stress Point
  - Condition of tie wraps (leading indicator)
  - Cracking
  - Discoloration
  - Off-Gassing
  - Swelling

- **Adverse Environments:**
  - Chemicals
  - Mechanical
  - Heat
  - Moisture
  - Light
  - Radiation
Aging Trends of Insulation (FREPR & FRXLPE) and Jacket (Neoprene, CSPE) materials @ 110°C

Aging rate of Neoprene & Hypalon Jacket >>> FREPR & FRXLPE Insulation
Monitoring the condition of the jacket provides a leading indication of damage.
Ref: NRC Reg. Guide 1.218 – April, 2012
### Common Cable Insulating Materials

<table>
<thead>
<tr>
<th>Cable Manufacturer (Material - Trade Name)</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockbestos Firewall III (XLPE)</td>
<td>61</td>
</tr>
<tr>
<td>Brand – Rex (XLPE)</td>
<td>30</td>
</tr>
<tr>
<td>Raychem Flametrol (XLPE)</td>
<td>23</td>
</tr>
<tr>
<td>Anaconda Y Flame-Guard FR (EPR)</td>
<td>35</td>
</tr>
<tr>
<td>Okonite FMR (EPR)</td>
<td>26</td>
</tr>
<tr>
<td>Samuel Moore Dekoron Dekorad (EPDM)</td>
<td>19</td>
</tr>
<tr>
<td>BIW Bostrad 7E (EPR)</td>
<td>19</td>
</tr>
<tr>
<td>Kerite HTK (EPR like)</td>
<td>25</td>
</tr>
<tr>
<td>Rockbestos (Coax, SR)</td>
<td>24</td>
</tr>
<tr>
<td>Kerite FR (SR)</td>
<td>13</td>
</tr>
</tbody>
</table>

Ref: Electric Power Research Institute, EPRI TR-103841-R1. Low Voltage Environmentally-Qualified Cable License Renewal Industry Report, Revision 1.(1994)

The more extensive materials database knowledge you have, the better your ability to assess the likelihood of degradation associated with aging.


Condition Assessment

**Disposition** – An evaluation of walkdown / test results is performed to identify the capability of the cable system to perform as required. An engineering basis for “run/re-evaluate, replace/reroute” decisions are performed, including timing for performing these actions.

**Cause Analysis** – Involves forensic evaluations of significantly degraded or damaged cables and cause evaluation addressing programmatic elements in support of station corrective action program requirements. Conclusions integrated back into risk algorithm.

**Define Remediation** – Remediation activities are defined, which could range from expanding the inspection sample; to performing more frequent inspections; to replacement.
Asset Management Phase

Mitigation – Mitigation actions are identified based on the results of inspections, testing and risk insights. Actions target the prevention of similar degradation based on environmental and other factors that affect long term risk and reliability of each cable segment.

Monitoring – Prescribes the types, methods and frequency of measurements required to monitor changes in the condition of the cable and connector system.

Trending – Results of periodic inspections and tests are captured in a database for trending. Trending is an effective leading indicator.

Reinspection – Intervals are established from baseline results and adjusted based on trend analysis and shared test experiences.
Brief Case History
Software Tools
Visualization of Cable Information

A visual representation of cable database information (inspection & risk results, drawings, PDF or pictures) through a GIS interface can offer the following benefits.

– Visual review and analysis of data allows for multi-variant analysis and the recognition of patterns not possible with tabular information.
– Combinations of cable information (layers) can be selectively ‘turned on’ by user. Simply ‘clicking’ on a feature reveals a table of information relevant to the cables in that area.
– View assets associated with a specific cable or other information near cables (pipes, equipment, tanks, etc.) that may potentially contribute to degradation, such as from leakage.
– Data can help facilitate inspection planning.
– For underground cable, the risk associated with accidental contact during excavations (associated with fencing installation, buried pipe excavations, monitoring wells and other modifications) can be minimized.
Database Risk Plot
Cable Relative Risk Model Benefits

• Lessons learned from the EPRI buried pipe initiative (begun in 2008) have resulted in an approach to calculating relative risk that considers both design and environmental characteristics, but adjusts based on knowledge gained through inspection or monitoring. This self-improving process yields higher value sites for performing condition monitoring tests, ultimately assisting with the program objective to increase reliability and safety at the site.

• The risk model can be continually improved through user configurable changes to certain attribute scores, weights and scaling factors as more OE is shared and new conditions that suggest the early detection of issues are discovered (e.g., Dekoron EPDM derating to 60°C).

• Using a common industry approach will also allow utilities to aggregate information (voluntarily and anonymously) for future data mining to reveal patterns in the data, increasing the value to all sites.
Conclusions and Next Steps

• Risk-based techniques can be established for cables, consistent with what is done for other applications (e.g., buried piping, RI-ISI).
• These techniques would provide stations with improved risk insights as compared to practices generally in use at present.
• Next steps would be to transition to an industry standard approach for risk-informing cable efforts.
• Formation of an industry steering group with feedback from INPO, EPRI, NRC and others would help to establish a consensus approach for risk-informed prioritization.
• Guidelines for risk prioritization and sentinel monitoring for cables should be developed, as is being done for metal fatigue.
• Use of a standard approach should also seek to aggregate industry experience to further enhance prediction of cable reliability.
Questions?