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Abstract 3 Oral

Recent North American Performance Experience of HV and EHV Extruded Cable Systems

Riley & Hampton

Underground Transmission Systems are viewed by some utilities as “New Technologies” and by others as “Established Technologies”. Independent of which perspective is considered utilities and specification preparation bodies are very interested in understanding the true meaning of industry wide performance surveys conducted to date. The most recent document considered by utilities is CIGRE TB 379 from WGB1.10, issued in 2009. Unfortunately, some issues limit the usefulness of this document in the North American context.

The work reported here sought to provide users with a current assessment of the risk associated with HV & EHC cable systems, by expanding on the information in the CIGRE document by surveying both manufacturers and utilities and focusing on cable systems installed since 2000, including components that failed in service and excluding third party damage. The authors simultaneously collected data on failures, installed lengths, and then identified components that failed, considering both HV (69 – 150 kV) and EHV (230 – 400 kV) cable systems. The disbursement of component failures was then obtained and the most likely failure rate and most likely failure range were estimated.

Finally, a perspective on a partial “bathtub curve” for HV & EHV cable systems was developed. This work found that North American HV & EHV Service Performance data for modern extruded systems differ from the CIGRE data. This could be due to differing data sets, larger North American participation, reduced confirmation bias, and/or increased data verification.

Topic 7 HV & EHC AC Cable Systems
Abstract 10 Poster

**Evolution of MV Extruded Cable Designs Used in the US from 1996 to 2014**

Shu & Hampton

Developments in cable designs have always been of great interest to utilities and manufacturers alike. However, when there are many potential design choices available, it can be difficult to determine underlying trends and developments. In 2003, Joe Dudas, with support from utility bodies (AEIC & NRECA), performed several surveys to establish the industry trends in medium voltage (MV) extruded cable usage. The results of these surveys proved to be very useful to utilities and manufacturers in understanding current trends in the use of different insulation types, cable designs, and installation practices of particular use is the fact that the 2003 survey was the last of a series starting back in 1992. However, due to the development of new cable standards and designs and the evolution of replacement / maintenance strategies, these survey results are likely no longer accurate. The authors estimate that there are approximately 9 different generations of designs currently installed on utility systems.

In 2016, the authors undertook a utility survey on cable, materials, and accessories to all interested parties. This study covered the experiences of >50 different utilities. The analyses within the 2016 study enabled the authors to follow the methodologies of the previous studies of Dudas et al, to provide perspectives on present day cable and accessory usage in the US, including:

- metal used for the conductor,
- conductor shield type (conventional or supersmooth),
- conductor size,
- insulation type (WTRXLPE or EPR),
- insulation wall thickness,
- metallic shield design, and
- accessory types (premoulded, heat shrink, or cold shrink)
- etc

As this work follows very closely the methodology used by Joe Dudas and his colleagues, in some cases it is possible to extend the trends developed by these earlier studies.

This study also collected information on the important factors considered by utilities when selecting a cable for use within the distribution system.

**Topic 2 Cables & Accessories – design and modeling**
Abstract 19 Oral

Asset Management of MV Cables using Data Driven Health Indices for Water Treeing

Hampton, Perkel & Williams

The underground distribution system makes up approximately 18% - 24% of the distribution infrastructure (EEI) in the US. This system is comprised of terminations / elbows, cable, and joints, which all contribute to the reported SAIDI and SAIFI data. Most of the reported failures are associated with the accessories, which can easily (relative to the whole system) be addressed through replacement and diagnosis because they are discrete devices. However, the larger concern are the cables that; which as distributed devices, are more difficult and costly to address. This is especially concerning as cable from earlier generations still make up a large portion of the utility system.

Since the earliest days of extruded insulations and the discovery of water trees in PE (HMWPE, XLPE, WTRXLPE) and EPR insulations, many utilities and laboratories have performed a large number of water tree inspections on extruded power cables returned from the field. These examinations include both those which have failed and, very often, cohort lengths that have not failed. These studies have been conducted in an effort to shed light on the processes that initiate and determine the rate of water tree growth.

Generally, these studies have been single or small group investigations and little consideration has been given to consolidating the knowledge embedded in these analyses. Over the last few years, the authors have created a knowledge base from the many examinations (>450 investigations, 40 utilities, >5000 trees) nd used this repository to develop a factbase (initial measured data and data developed more recently) to support the coming asset management challenges around the ageing cables within the distribution infrastructure. This is particularly useful for utilities

- Who are proactively replacing cables and wish to confirm that the cables being extracted are nearing end of life
- Who extract samples upon failure and wish to understand the velocity of degradation and the asset health

Health Indices are well suited to these tasks as they are commonly used to condense and summarise many quantitative and semi qualitative factors.

This paper will focus on how the factbase has been used in a diagnostic mode to:

1. Provide context to the outcomes of in-service diagnostic tests: tree initiation, relative degrees of treeing etc
2. Guide the selection of the appropriate diagnostic features to be included in assessments: usefulness of a single feature, how many features are required to describe treeing etc
3. Develop a structure to estimate the health of the cable (dielectric and neutral system) by addressing both water tree data and cable system meta data?
4. Support the appropriate framing of the outcomes: how does treeing relate to the chronological age; is it ageing slower or faster, how best to represent the results in context within a single utility and the industry?

Topic 11 Asset Management of cable systems all along their life cycle
Implementation of Ageing Laws and Cable Models to Estimate Service Life for MV Cable Designs using Laboratory Endurance Tests

Shu, Perkel & Hampton

Feedback from utility cable engineers consistently shows that the anticipated longevity of the cable system is the number one priority when deciding on which cable design to employ at their utility. Longevity is ranked significantly more highly than first cost or temperature rating etc. This finding can be understood when recognising that failures adversely impact SAIDI / SAIFI data and represent considerable Operations and Maintenance Costs. Thus anticipated life is a key factor in determining the total, rather than first, cost of a cable system.

Initial service performance of extruded cable systems is well documented and has led to many improvements in design, manufacturing, materials, specification and testing. The benefits of these developments are easily recognised through the non-reoccurrence of early poor performance, with useful service lives extending past 20 years. However, it is much more difficult to determine the anticipated life of a cable design and thus the benefits of a particular design element (jacket or WTRXLPE or supersmoothe semicon etc). In principle, such lives could be determined from utility records. However, the volume and fidelity of records are not sufficient, in most cases, to support such analyses. Thus, the only recourse to garner these estimates is to return to laboratory test data and to model the impact of design elements on the life in service.

A multi-disciplinary team of experts drawn from utilities, manufacturers and academia examined the options and recognised that the most appropriate starting point was the Accelerated Cable Life Test (ACLT). The principle benefit was that the outcome of these tests were described in terms of time to a specified endurance for voltage / temperature / environmental acceleration; most usually mean life (B50). However, for practical cable designs these data are not directly usable as they are developed for short length cores tested at elevated temperatures and voltages. Thus, the modeling activity needs to deconvolve these accelerating factors, which are used to make the tests to implement in practical timescales.

This paper will describe:

- Details of the basic test procedure (ACLT)
- Basic results of ACLT tests
- Modelling methodology to scale data on cores to cables in service using Life Expansion and Reduction Factors
- Life Expansion Factors
  - Lower voltages in service compared to test voltages
  - Lower temperatures in service compared to temperatures used in the tests
  - Use of jackets in service cables compared to jacketless cables used in tests
Lower load factors in service
- Absence of water introduced into the conductor interstices
  - Life Reduction Factors
    - Longer lengths installed in service compared to the short lengths employed in lab tests
    - Higher volume of insulation used in service cables due to the larger conductor sizes compared to the relatively small conductors used in tests
    - Lower critical risk levels (B1 or B5) for cable failures considered by utilities compared to the mean lives (B50) considered by tests
  - Illustrate the outcome of the model with selected case studies
    - With and without jackets
    - 50, 100 & 1000 m service lengths
    - Operation at conductor temperatures of 50, 70, 90 °C
    - etc

Topic 1 Materials, New Materials and Ageing Assessment in AC and DC
Abstract 32 Poster

**Operating Extruded Distribution Cable Systems at Elevating Temperatures**

Smalley, Shu, Richardson, Hawig, Hartlein, Hampton

ICEA, UL, and AEIC cable standards and specifications for EPR and TRXLPE insulated cables allow for operating cable conductors at highly elevated temperatures. The associated industry cable and accessory test program requirements, however, do not adequately evaluate the performance the system components at these elevated temperatures. Therefore, the consequences of operating an extruded cable system at highly elevated temperatures are not fully understood by operators of these systems.

This paper will describe the work undertaken to review and summarize current industry requirements for evaluating the performance of cable systems operating at and above the generally accepted normal operating conductor temperature of 90 Deg. C. During this process, gaps between industry evaluation requirements and actual operating conditions that could impact operation at elevated temperatures were identified. Furthermore, guidance was developed so that users could determine the appropriate level of testing required for the accessories, cables, connectors; should users wish to operate at elevated temperatures. The guidance is based upon the performance of current technologies and the levels of risk that can be accepted by users. The paper will provide the risk / component / test matrix.

Topic 6 LV & MV AC Cable Systems
Abstract 33 Poster

**Modeling and Testing of Temporary Protective Ground Cable Systems for High Fault Current Applications**

Poda, Perkel, Lancaster & Hampton

Temporary protective grounds are cable systems (cables, connectors and special terminating clamps) that are used to provide adequate protection to line workers while working on the de-energized electrical power systems that can accidentally become energized. In usual applications a single cable system TPG is used. However, there is a growing number of high fault current substations where the capacity of a single TPG is not sufficient, yet the critical safety application of a TPG cable system is required.

Consequently installing more than one TPG for high fault current applications is a widely accepted practice in the electric utility industry. The extreme electro-mechanical forces present under high fault current conditions can cause failures of TPG assemblies below their cumulative single rating. Unlike thermal energy, the electro-mechanical forces on individual TPGs do not reduce in the same proportion as the current. The laboratory tests were performed on three parallel TPG sets with different spacing distances at 80 kA in a similar method to ASTM F855 requirements. The results strongly indicate that the spacing between the parallel TPGs should be installed as close as possible to each other to reduce the likelihood of failure due to electro-mechanical forces during the high fault current conditions.

This poster will provide details of the testing to verify the critical design parameters and the circuit modeling of the TPG cable systems in a multi parallel arrangement. The value of the modeling, whereby the experience can be extended to many different cases will be shown with selected case studies.

**Topic 12 Industrial and Special Cables**
Abstract 67 Oral

Methods and experience of Very Low Frequency (VLF) diagnostic testing to support asset management of critical MV circuits

Perkel, Hernandez, Hampton, Drapeau

Utilities find that the small footprint and ready availability of VLF voltage sources are very beneficial when undertaking testing in the field. The possibility of augmenting the withstand capability with diagnostics such as dielectric loss and partial discharge further increases the usefulness.

Although guidance on use and interpretation is provided in IEEE 400.2 for either withstand or dielectric loss operations, this is focused primarily single diagnostics on conventional land distribution cable systems. The needs for the use of coupled diagnostics on critical cable systems, where the risk profile is quite different to conventional distribution circuits, is not currently addressed in normal references. In this context critical cable systems may be considered as those associated with

- subsea / river crossings,
- power plants and
- life safety systems

These applications are, as noted previously, quite different from those of the standard analogues and require a number of extensions to the standard diagnostic testing paradigm

This paper will discuss these issues and use a number of case studies to consider the important differences and describe the solutions employed. These include:

- Decision protocols – provision of interim outcomes to support implementation or cessation of subsequent tests
- Diagnostic features – the circuit value supports a more in depth analysis
- Management of the data obtained – trending and contextualizing in the Big Data paradigm is very important
- Maximising the diagnostic power from coupled techniques
- Test sequencing – management of test resources and risk profile
- Test voltage levels and granularity – management of risk profile and optimal information content

Topic 4 Diagnostic Monitoring, Remaining Life Estimation