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Advancements in Wire Condition Monitoring Using Line Impedance Resonance Analysis (LIRA)

Paolo F. Fantoni
Wirescan AS
Norway

SUMMARY

Degradation of a cable system can result in loss of critical functions of the equipment energized by the system, or in loss of critical information relevant to the decision-making process and operator actions. In either situation, unanticipated or premature aging of a cable can lead to unavailability of equipment important to safety and compromise public health and safety.

While known to be difficult, advancements in detection systems and computerized data analysis techniques may allow ultimate use of electrical testing to predict future behavior and residual life of cables. The following describes the current results and development of a system (LIRA) and its progress in being able to determine the degree of cable degradation through electrical testing.

The LIRA (Line Resonance Analysis) Technology is a cable condition assessment, cable fault location and cable aging management system that works in frequency domain through advanced proprietary algorithms.

LIRA will detect and locate local degradations in the cable, which is specific to certain sections of the cable and caused by mechanical stress and damages, or by heat-induced oxidation and radiation. It will also detect global degradation in the cable, which is applicable for the entire cable, and caused by general aging, influenced by external and internal environmental conditions.

This paper presents the current technology at the base of this system, together with some interesting results on installed cables.

KEYWORDS

Condition monitoring, fault detection, transmission line, cable degradation

There is a continued interest worldwide in the safety aspects of electrical cable system degradation. Degradation of a cable system can result in loss of critical functions of the equipment energized by the system, or in loss of critical information relevant to the decision-making process and operator actions. In either situation, unanticipated or premature aging of a cable can lead to unavailability of equipment important to safety and compromise public health and safety.

Current techniques to evaluate aging properties of electric cables include electric properties tests. While known to be difficult, advancements in detection systems and computerized data analysis techniques may allow ultimate use of electrical testing to predict future behavior and residual life of cables. The following describes the current results and development of a system (LIRA) and its progress in being able to determine the degree of cable degradation through electrical testing. LIRA has gone through extensive tests since 2005 with low, medium and high voltage cables, both in laboratory tests and in-situ experiments and it has been used in service assignments since 2007.

The LIRA (Line Resonance Analysis) Technology is a cable condition assessment, cable fault location and cable aging management system that works in frequency domain through advanced algorithms. LIRA is based on the transmission line theory, and calculates and analyse the complex line impedance as a function of the applied signal for a wide frequency band. It detects and locate changes in the cable impedance and makes it possible to perform fault location and cable condition monitoring on I&C, low, medium and high voltage cables even in inaccessible challenging environments. The applied frequency band is a 5V signal, and is harmless to the cable.

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THE LIRA METHOD

The Line Resonance Analysis (LIRA) method has been developed by the Halden Reactor Project in the years 2003-2006 [4] and then further developed by Wirescan AS and it is based on transmission line theory [5-8]. A transmission line is the part of an electrical circuit providing a link between a generator and a load. The behavior of a transmission line depends on its length in relation to the wavelength of the electric signal traveling into it.

When the transmission line length is much lower than the wavelength (λ), as it happens when the cable is short and the signal frequency is low, the line has no influence on the circuit behavior and the circuit impedance, as seen from the generator side, is equal to the load impedance at any time. However, if the line length and/or the signal frequency are high enough, so that $Length \geq \lambda$, the line characteristics take an important role and the circuit impedance seen from the generator does not match the load, except for some very particular cases.

LIRA includes a proprietary algorithm to evaluate an accurate line impedance spectrum from high frequency measurements. Figure 1 shows the estimated impedance for an instrument cable 100m long, in the 0-10 MHz range.

Line impedance estimation is the basis for local and global degradation assessment. Tests performed with LIRA show that thermal degradation of the cable insulation and mechanical damage on the jacket and/or the insulation do have an impact on C and at a lesser degree on L. Direct measurement of C (and L) would not be effective because the required sensitivity has the same magnitude of the achievable accuracy, due to the environment noise normally present in installed cables (especially for unshielded twisted pair cables, see Figure 2. Some results were achieved with coaxial cables [4]). LIRA monitors C variations through its impact on the complex line impedance, taking advantage of the strong amplification factor on some properties of the phase and amplitude of the impedance figure, as shown in Figure 3.

Hot spot damage due to localized high temperature conditions and local mechanical damage to the insulation are detectable by LIRA through use of a proprietary algorithm starting from the line impedance spectrum .

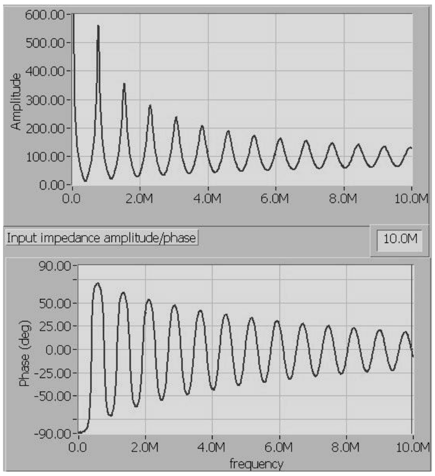

Figure 1 Cable input impedance spectrum, amplitude and phase.

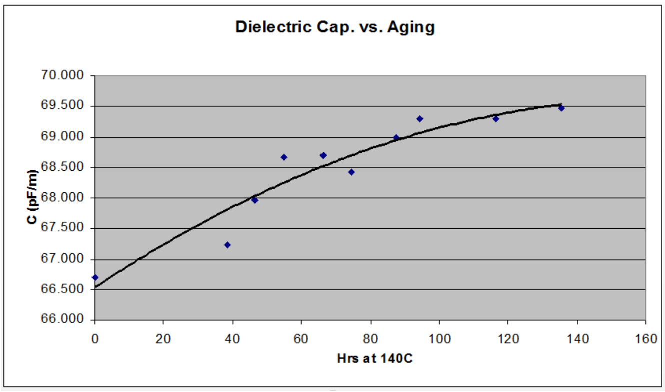

Figure 2 0-50 years thermal degradation on a LV cable showing 3 pF/m change in the all cable life

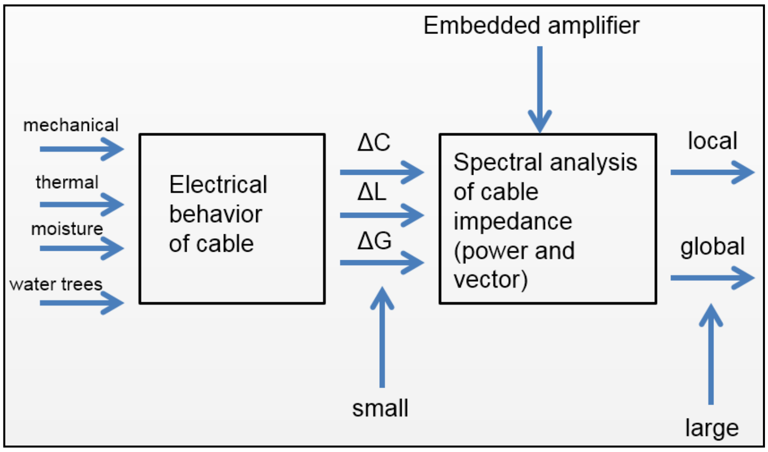

Figure 3 Spectral analysis of wire resonance effects in LIRA

LIRA is composed of several software and hardware modules, as depicted in Figure 4 and Figure 5, where the cable is connected to the LIRA RF measuring board.

- The LIRA RF generator controls the analog signal to be injected into the cable. It supplies a bandwidth configurable low voltage (5V) sweep signal to the system.
- The LIRA Analyzer, the system kernel, analyses the signals and provides the cable assessment.
- The LIRA Simulator contains a model of the chain *cable->modulator->digitizer* (any cable type and length can be modeled). The simulator can be used to extrapolate results of real experiments and perform *what-if* analysis.
- The LIRA Database, which allows to store measurements in a structured way, for later post-processing.

A measurement cycle in LIRA takes about 50 seconds and the analysis normally follows on-line immediately after. It is possible, however, to make measurement recordings for later offline processing and analysis. After the analysis, a report with results and findings is automatically produced.

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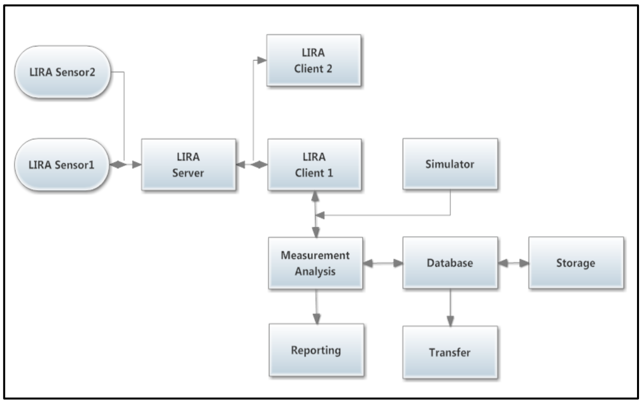

Figure 4 LIRA Functional Diagram

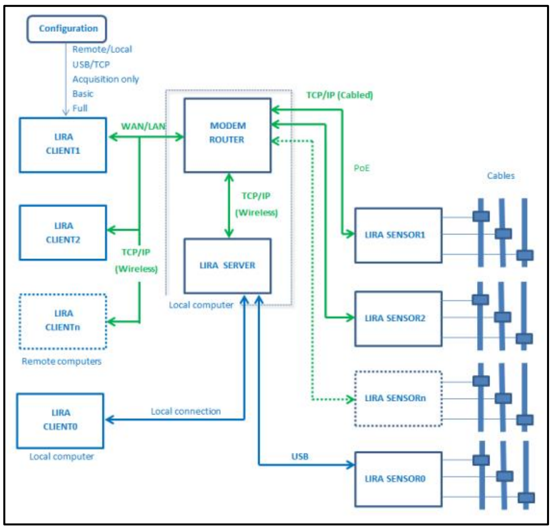

Figure 5 LIRA Client-Server Structure

RECENT ASSESSMENT OF MV AND HV CABLES

Some examples of LIRA measurements on Medium and High Voltage cables will be shown next. Figure 6 shows the LIRA cable signature for 2 measurements performed from both sides (red and yellow traces), on a 34 kV XLPE subsea cable, 15.6 km long. The clear spot at 12300 m (or 3350 m from the opposite side), is a consequence of a mechanical damage caused by an anchor.
Figure 7 is a photo of the cable termination of a 750 m, 420 kV PILC cable, with the connection probe to LIRA. This cable had a lead sheat deformation at 10m, as shown in Figure 8

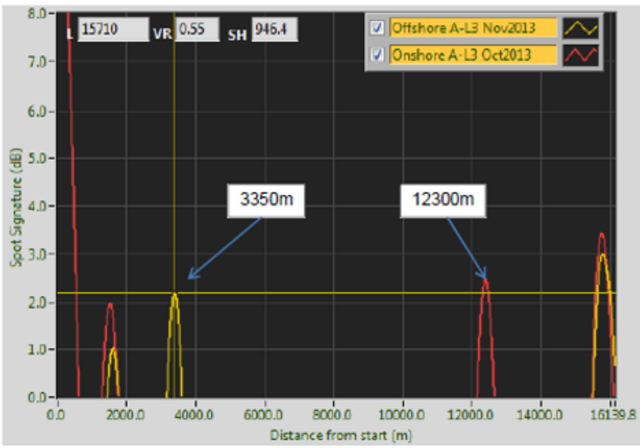

Figure 6 Anchoring damage on a 34 kV subsea cable with LIRA
(measured from both sides, 15.6 km length)

Figure 7 420 kV PILC cable with lead sheat damage

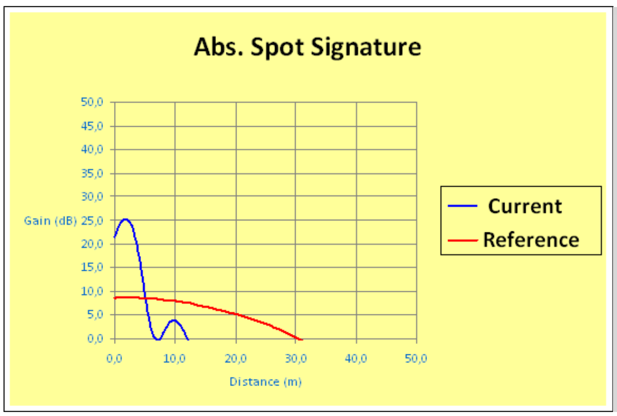

Figure 8 Lead sheat problem at 10 m, on a HV PILC cable with a clear failure at 2500 m

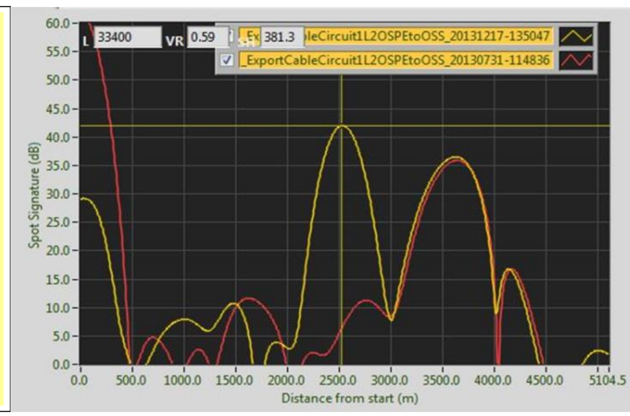

Figure 9 132 kv 3 phase cable, 34 km long,

Figure 9 shows the measurements of a 132 kV AC export cable, 34 km long. These measurements have been performed before (red trace) and after (yellow trace) a failure that occurred at the end of 2013. The failure was clearly identified and localized at 2500 m. After inspection, the failure position error was less than 0.3 %.

TERMINATION ASSESSMENT (BTS)

BTS is based on the Fourier transform of the cable impedance spectrum, at the maximum bandwidth allowed by the applied maximum frequency.

While the output of the Fourier analysis for the LIRA signature is a power spectrum, for the BTS analysis the complex output is preserved. The ratio between the difference of the imaginary and real component of the transformation function (also called the BTS signature function) has a significant diagnostic value and it is bounded between +sqrt(2) and –sqrt(2) (see Figure 10).

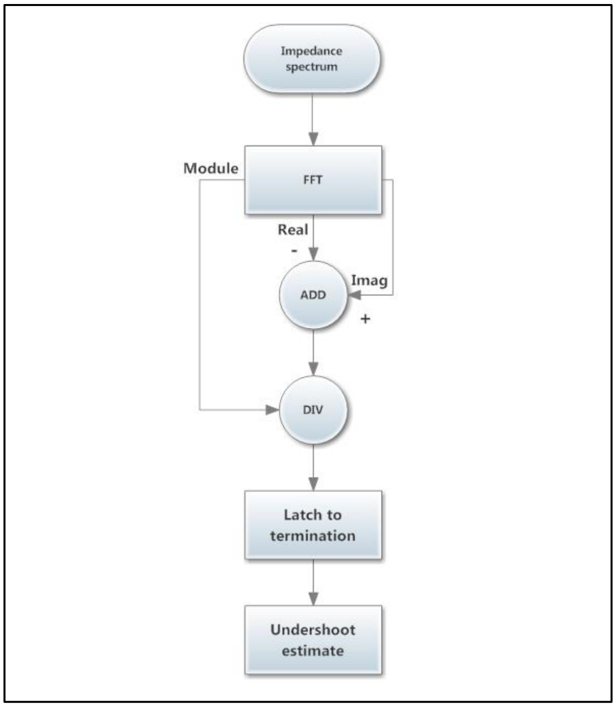

Figure 10 BTS estimation

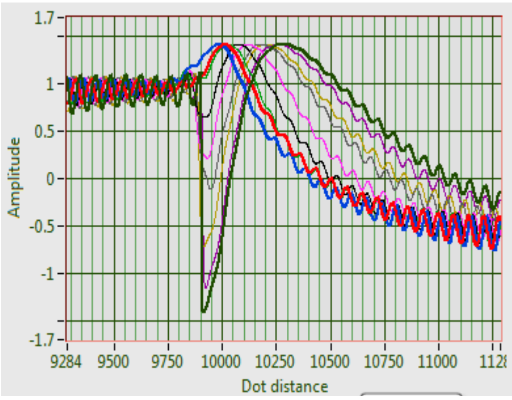

Figure 11 shows a real example of a resulting signature graph for a good termination. The peak at about 10000 dot units is the cable termination. Any change in the insulation properties at or near the termination (inside the shadow area), would cause an undershoot below the red line, with a corresponding BTS indication from 0 to 100. The maximum BTS value (100) corresponds to an undershoot of –sqrt(2).

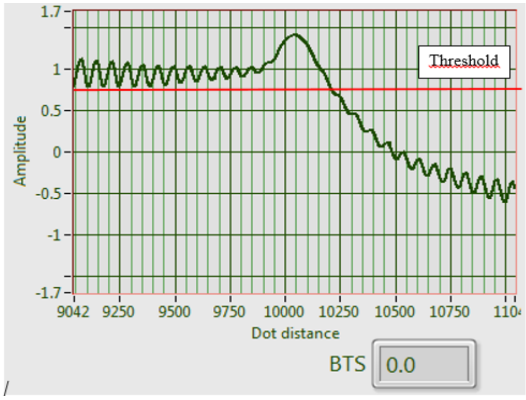

Figure 11 BTS signature for a normal termination condition

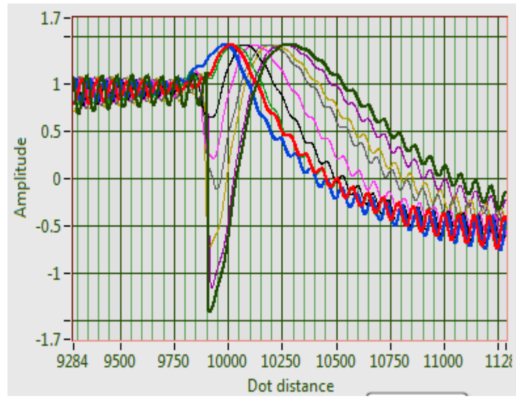

Figure 12 BTS Signatures for increasing termination damages

Figure 12 shows how the BTS signature changes when the termination condition degrades. Figure 13 shows the trend of the BTS indicator in these tests.

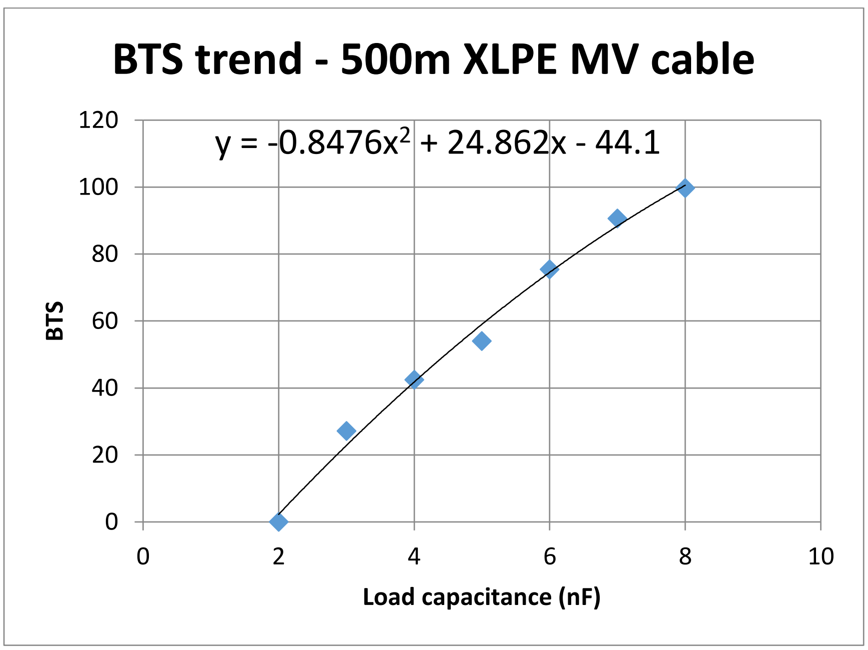

Figure 13 BTS indicator trend

CONCLUSIONS

LIRA is a frequency domain system for condition monitoring of electrical cables. This paper shows some laboratory and field cases where LIRA was used to successfully detect locations where the cable insulation was degraded because of thermal, electrical or mechanical stress.

The system is currently in use in several organizations for assessing the conditions of installed signal, medium voltage and high voltage cables.

pff@wirescan.no

BIBLIOGRAPHY

[1] P.F. Fantoni, 2004, "NPP Wire System Aging Assessment and Condition Monitoring: State-Of- the-Art Report" Halden Reactor Project (HWR-746).

[2] Environment Qualification of Low Voltage Instrumentation and Control Cables, US NRC RIS 2003-09, 2003.

[3] K.S. Chang-Liao, T.K. Chung, H.P.Chou, 2000, "Cable Aging Assessment by Electrical Capacitance Measuring Technique" Proc. NPIC&HMIT 2000, Washington D.C.

[4] P.F. Fantoni, 2005, "Wire System Aging Assessment and Condition Monitoring: The Line Resonance Analysis Method (LIRA)" Halden Reactor Project (HWR-788).

[5] P.F.Fantoni, G.J.Toman, 2006, "Wire System Aging Assessment and Condition Monitoring Using Line Resonance Analysis (LIRA)", Proc. NPIC&HMIT 2006, Albuquerque, NM.

[6] Line Impedance Resonance Analysis (LIRA) for Detection of Cable Damage and Degradation, EPRI, Rep# 1015209, 2007.

[7] G.J.Toman, P.F.Fantoni, 2008, "Cable Aging Assessment and Condition Monitoring Using Line Resonance Analysis (LIRA)", ICONE16, Orlando, Florida.

[8] P.F.Fantoni, 2009, "Cable Aging Assessment and Condition Monitoring Using Line Resonance Analysis (LIRA)", ICONE17, Brussels.

[9] P.F. Fantoni, J.I.Juvik, 2011, "Condition Monitoring of Electrical Cables Using Line Impedance Resonance Analysis (LIRA), JICABLE, Versailles, France

[10] Evaluation of Line Resonance Analysis (LIRA) for Assessing Transmission Cables. EPRI Rep# 3002003492, 2014

[11] Condition-Monitoring Techniques for Electric Cables used in Nuclear Power Plants, US NRC Regulatory Guide 1.218, 2011

[12] Assessing and Managing Cable Ageing in Nuclear Power Plants, IAEA, NP-T-3.6, 2011

[13] Wire System Ageing and Condition Monitoring (WASCO), NKS, NKS-R-2005-43, 2009