Evaluation of Line Resonance Analysis for Detecting Defects in Distribution Circuits

1020611

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Evaluation of Line Impedence Resonance Analysis for Detecting Defects in Distribution Circuits

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Technical Update, December 2010

EPRI Project Manager
M. Olearczyk

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Cable and Splice Center for Excellence, Consolidated Edison Company of New York, Inc.

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Acknowledgments

The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

Consolidated Edison Company of New York, Inc.
Cable and Splice Center for Excellence
1610 Matthews Avenue
Bronx, New York 10462

Principal Investigator:
T. Faryna

This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Evaluation of Line Impedence Resonance Analysis for Detecting Defects in Distribution Circuits. EPRI, Palo Alto, CA: 2010. 1020611.

Abstract

This document describes an evaluation of the Line Impedence Resonance Analysis (LIRA) system conducted at Consolidated Edison Company of New York (Con Edison). The equipment test setup, test procedure, and test results from testing a de-energized distribution primary feeder are presented. Laboratory test results performed on cable samples in Con Edison's Cable and Splice Center for Excellence are also presented in this document.

The evaluation was first conducted in the High-Voltage Laboratory of Con Edison's Cable and Splice Center for Excellence (Cable Center). Three single-conductor 15 kV-rated ethylene propylene rubber cables and a three-conductor paper-insulated lead-covered cable were set up in the Cable Center's Manhole and Conduit System, emulating an in-service feeder. The cable properties were then measured using the LIRA set. Subsequently, measurement was carried out on an actual feeder in Con Edison's primary distribution system.

Due to the complexity of the typical feeder configuration in Con Edison's primary distribution system, no correlations between the test results and feeder conditions can be found. The conclusion is that LIRA is not effective in determining the condition of feeders that have a large number of cable joints, cable sections of different cable types, and feeder branches.

Keywords

EPR cable
Line impedance resonance analysis
PILC cable
XLP cable

Contents

List of Figures

1 Purpose

The purpose of this project is to evaluate the suitability of Line Impedence Resonance Analysis (LIRA) in assessing the condition of primary feeders in the distribution system of Consolidated Edison Company of New York (Con Edison).

2 Background

As an effort of the EPRI Cable Testing Network (ECTN) to provide information to the ECTN members on new technology in cable and accessories assessment, Con Edison's Cable and Splice Center for Excellence evaluated the LIRA system for its effectiveness in the condition assessment of primary distribution feeders. Tests were performed both in the Cable Center's high-voltage laboratory on lengths of cable samples removed from service and in the field on an in-service feeder.

3 The LIRA System

The LIRA (Line Impedence Resonance Analysis) technology is based on the transmission line theory, through the estimation and analysis of complex line impedance as a function of applied signal frequency. This technique is a nondestructive method that uses a low-voltage test signal (up to 5 V p-p). The test equipment consists of a LIRA hardware enclosure, a modulator box, and a laptop computer with LIRA software (see Figure 3-1).

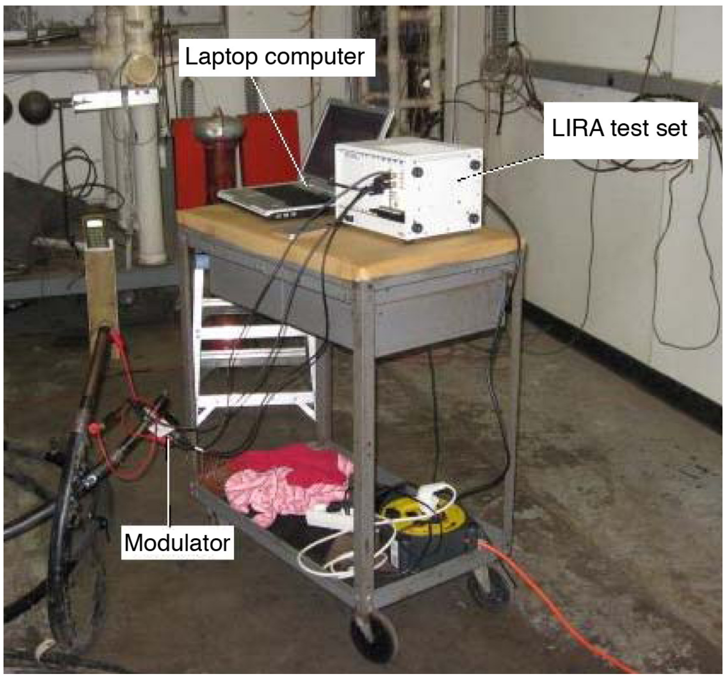


Figure 3-1
LIRA test set

4 Test Setup

Test Setup in the Lab

In the lab, the test samples are placed in concrete ducts (see Figure 4-1). The test equipment is attached to the test cable from one end of the duct.

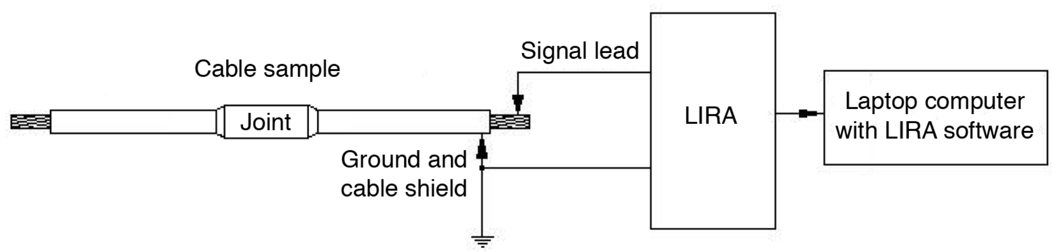


Figure 4-1
Lab test setup

Test Setup in the Field

Figure 4-2 shows the test set-up in the field. The field tests require access to high-voltage systems, and although the high-voltage system is de-energized at the time of the tests, compliance with Con Edison's safety procedures requires that the operator maintain a minimum distance of 2 feet (0.6 m) from the equipment. To achieve this, tests are conducted using wireless communication to control the test equipment.

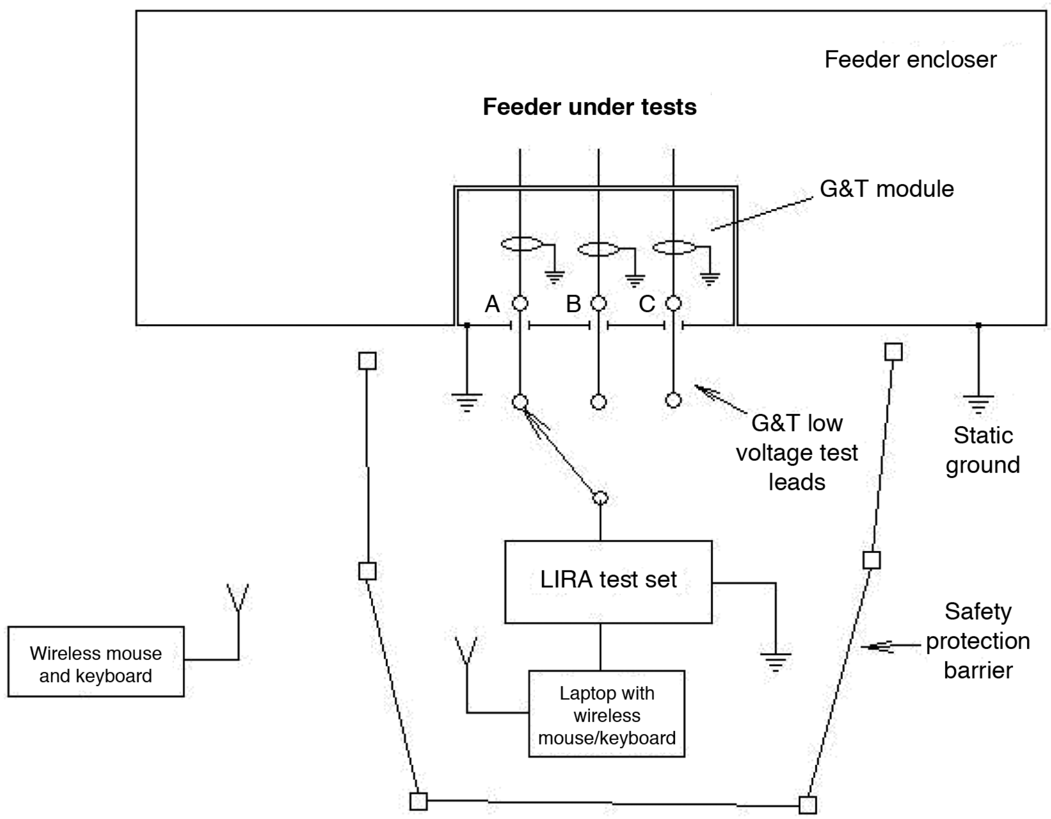


Figure 4-2
Field test set-up (Astor substation)

5 Test Samples

Cable Samples for Lab Tests

Three 34-meters (112 ft) long 2/0 AWG 27 kV EPR Insulated Concentric Neutral (Flat Strap), jacketed cables were used for the lab trial. Each cable had a cable joint in the middle, approximately 17 meters (56 ft) from each cable end.

Two lengths of 3-conductor PILC cables, 13 and 33 meters (43 and 108 ft), were also tested in the lab; however, the test results were inconsistent and have not been included in this report.

Primary Feeder for Field Tests

The feeder is one of the primary distribution feeders supplying the secondary network system in Manhattan (New York City). It consists of 81 sections of 15 kV-rated paper-insulated, lead-covered (PILC), crosslinked polyethylene (XLP), or etheylene propylene (EPR) cable and different conductor sizes. The lengths of the cable sections range from 8 to 413 meters (26 to 1356 ft). The feeder has eight branches off the main run. For testing, the longest stretch is 8552 meters (28,057 ft).

This feeder was chosen because it represents the typical configuration of the majority of feeders in Con Edison's primary distribution system.

6 Test Description

The LIRA instrument was connected to the de-energized feeder via a set of low-voltage test leads (see Figure 6-1). The LIRA instrument was connected to a laptop via a control cable. The laptop was remotely controlled by a wireless mouse and keyboard to provide electrical separation between the feeder and equipment operator. For safety purposes, the test equipment was also barricaded to separate personnel from the test equipment as indicted in Figure 4-2.

The LIRA test leads were connected to feeder cable via a Ground and Test (G&T) device (see Figure 6-1). G&T is an auxiliary device that provides a convenient means for grounding a feeder cable and connecting test equipment during maintenance work. With the G&T in the ground position, the LIRA equipment was connected to one of the three phases and ground via the low-voltage test leads. Once personnel were cleared and the LIRA operator confirmed that the LIRA equipment was working properly, the G&T was ungrounded, and data were collected via the LIRA equipment.

After the measurement was taken, the G&T was switched to the ground position, and the LIRA input lead was moved to the next phase of the feeder. The G&T was alternately ungrounded and re-grounded for each measurement as required. This process was repeated until all three phases were tested. Once testing was complete, the G&T was re-grounded, and the test leads were removed.

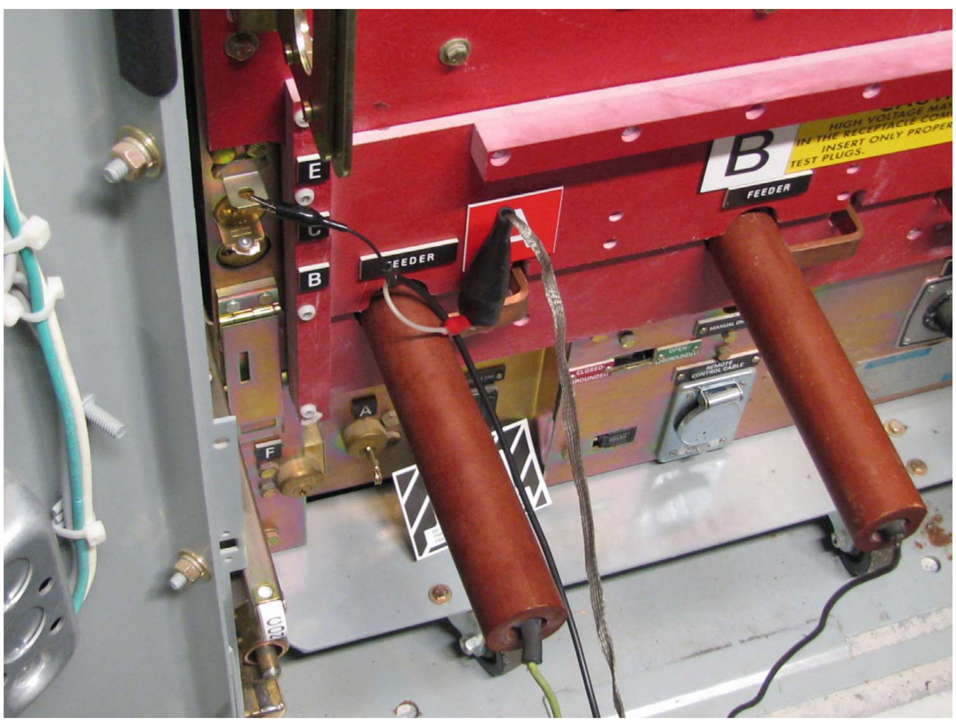
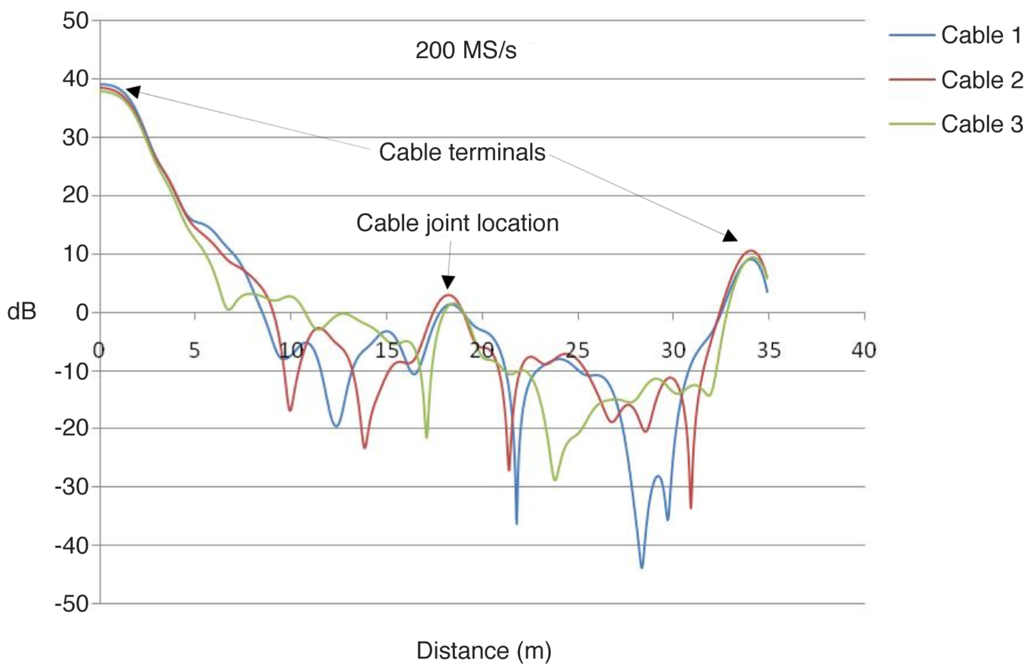


Figure 6-1
Ground and Test device and low-voltage test leads

7 Test Results

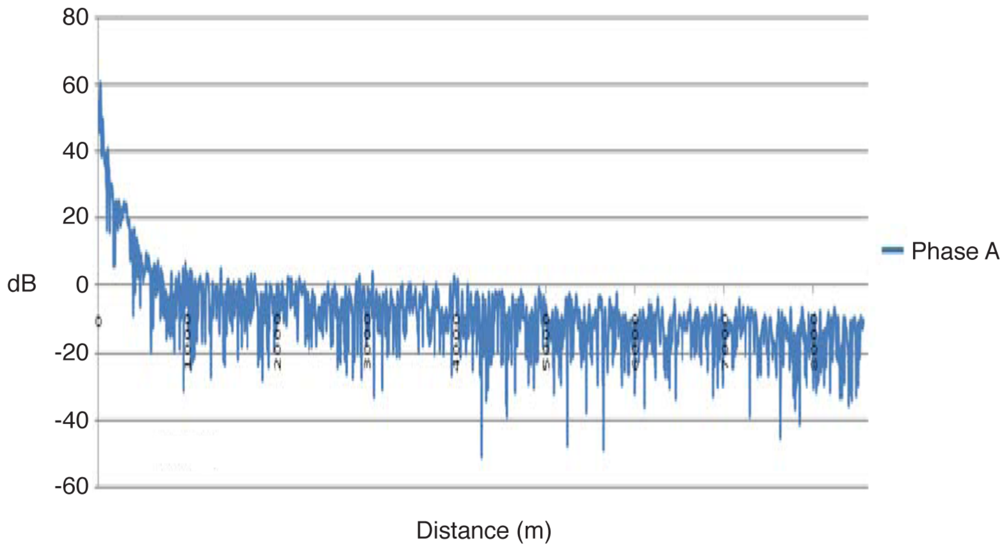
Figure 7-1 shows the laboratory test data on EPR cables. Figures 7-2 through 7-4 show the field test data.

After numerous preliminary feeder tests, it was found that the appropriate sampling rate was 50 MS/s (million samples per second) versus 200 MS/s for the lab test.



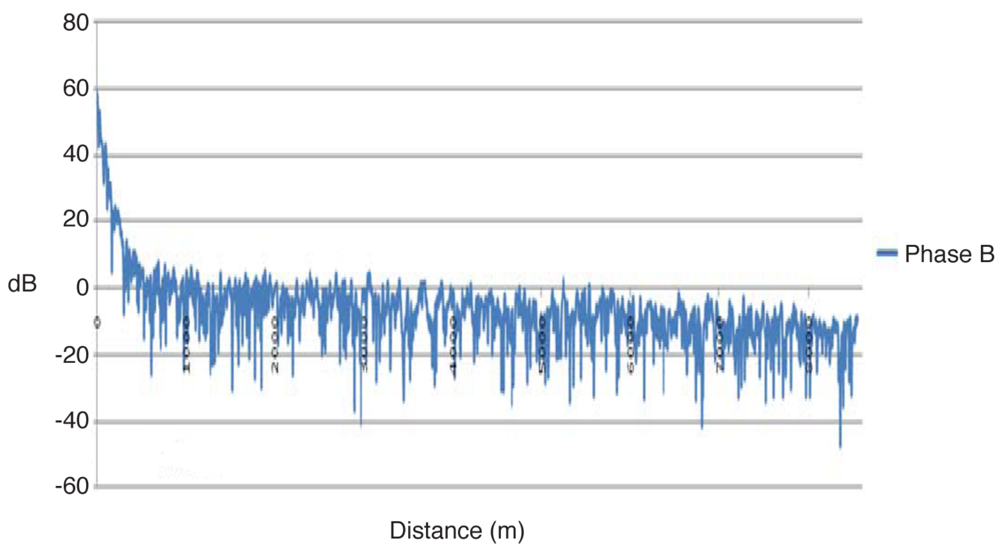
1 m = 3.28 ft

Figure 7-1
LIRA test result on EPR cables in the lab test



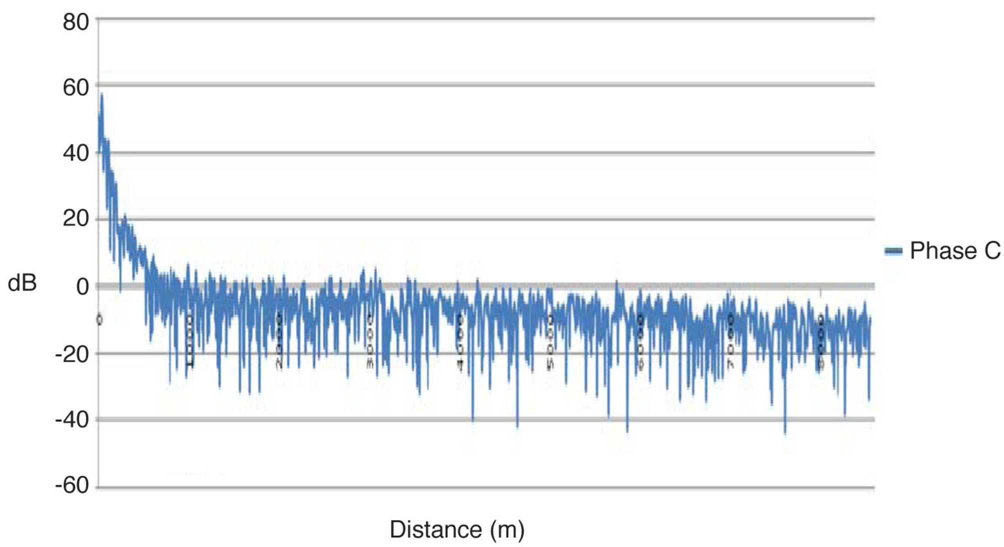
1 m = 3.28 ft

Figure 7-2
LIRA trace on Phase A of the feeder test in the field



1 m = 3.28 ft

Figure 7-3
LIRA trace on Phase B of the feeder test in the field



1 m = 3.28 ft

Figure 7-4
LIRA trace on Phase C of the feeder test in the field

8 Discussions and Conclusions

The LIRA system, in the lab trial, was able to detect the existence of cable joints in EPR cables. After the first round of tests, an artificial damage to the EPR cable insulation was introduced in the form of a round hole (approximately 3.2 mm [1/8 in.] in diameter) that penetrated the entire insulation wall including the conductor and insulation shields. The test results did not show significant changes in a LIRA trace to indicate a problem with the cable insulation. The traces before and after the introduction of the defect are basically the same (Figure 7-1).

Due to the complexity of the distribution feeder configurations in the field test (many cable sections of various cable types connected by different types of splices and multiple branches), it is extremely difficult to detect defects in the cable system. Given this complexity, and the fact that changes in impedance along the feeders are unknown, it is impossible to correlate the peaks shown on the charts with locations of the various components on the feeder (see Figures 7-2, 7-3, and 7-4).

It is concluded that the LIRA system is ineffective in determining the condition of feeders that consist of a large number of cable sections and multiple cable insulation types. It is not clear if the device can detect relatively small (a fraction of an inch), yet severe, cable insulation defects because of limited test resolution (0.5% of cable length according to instrument specification). In other words, a 30.5 m (100 ft) cable section with a defect smaller than 0.15 meteres (0.5 ft) might not be detected.

9 Bibliography

IEEE STD 510-1983, "Recommended Practice for Safety in High-Voltage and High-Power Testing"

DOJT – CSG0017, "Maintenance and Operation of High Voltage Test Equipment" (Con Edison internal document)

LIRA User Manual

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com