



CHAPTER 1

Introduction

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1.0 INTRODUCTION

1.1 Background

Almost all electric power utilities distribute a portion of the electric energy they sell via underground cable systems. Collectively, these systems form a vast interconnected and valuable infrastructure. Estimates indicate that underground cables represent 15% to 20% of installed distribution system capacity. These systems consist of many millions of feet of cable and hundreds of thousands of accessories installed under city streets, suburban developments, and in some cases, in the countryside. Utilities have a long history of using underground systems with some of these cable systems installed as early as the 1920s. Very large amounts of cable were installed in the 1970s and 1980s due to the introduction of economical, polymer-based insulation compounds and the decreasing acceptance of overhead distribution lines in residential areas. Today, the size of that infrastructure continues to increase rapidly as the majority of newly installed electric distribution lines are placed underground.

Cable systems are designed to have a long life with high reliability even though these concepts are not well defined. These goals were achieved via a variety of different technologies since the early 1900's. Regardless of the technology used, the useful life of a cable system is finite. These systems age and ultimately reach the end of their reliable service lives. Estimates set the anticipated lifespan of underground cable systems installed in the United States to be in the range of 30 to 40 years. Today, a large portion of this cable system infrastructure is reaching the end of that anticipated life, and there is evidence that some of this infrastructure is reaching the end of its reliable service life. This is a result of natural aging phenomena and that the technology used in some early cable systems was decidedly inferior as compared to current technologies. Increasing failure rates on these older systems are now adversely affecting system reliability and it is readily apparent that action is necessary to manage the consequences of this trend. Furthermore, complete replacement of old or failing cable systems is not an option. Many billions of dollars and new manufacturing facilities would be required. Electric utilities, cable, and cable accessory manufacturers are simply not in a position to make this kind of investment.

On the other hand, complete replacement of these systems may not be required because cable systems do not age uniformly. Cable researchers have determined that many cable system failures result from isolated degraded cable lengths/accessories or defects within specific circuit segments. Thus, the key to managing this process is to find these "bad actors" and to proactively replace them before their repeated failures degrade overall system reliability. Various cable system diagnostic testing technologies have been developed to detect cable system (cable and accessory) defects or deterioration. The results of diagnostic tests identify potential weak spots within cable systems and then again, after repair, verify that the repair work performed did resolve the problem(s) detected.

Appropriate maintenance and repair practices enable system aging to be controlled and help manage end of life replacements. Diagnostics to determine the health of the cable system are critical to this management program.

A number of cable diagnostic techniques are now available. Each claims to provide a reliable method for establishing the condition of a cable system. Furthermore, there are a number of different modes of application. No one technology or methodology has definitively demonstrated an ability to precisely and reliably assess the full condition of the wide variety of cable systems currently in service. To address this issue, NEETRAC created the Cable Diagnostic Focused Initiative (*CDFI*) – *Phase I* and *Phase II*. The intent of the *CDFI* was to provide cable diagnostic technology assessment and development via a series of tasks developed by NEETRAC with input from the Initiative participants. The primary objective was to clarify the concerns and define the benefits of cable system diagnostic testing.

Effectively implementing cable system diagnostics involves the careful consideration of a number of issues. This includes the type of system (network, loop or radial), the load characteristics (residential, commercial, high density, government, healthcare, etc.), the system dielectric (XLPE, EPR, Paper, mixed), and system construction (types of accessories, installation technique (conduit or direct buried), etc.).

While the need to establish the condition of underground cable systems is apparent to some, diagnostic tools have not been deployed extensively by electric utilities. Figure 1 shows the results of a 2014 study on the use of cable system diagnostics on MV cable systems in North America.

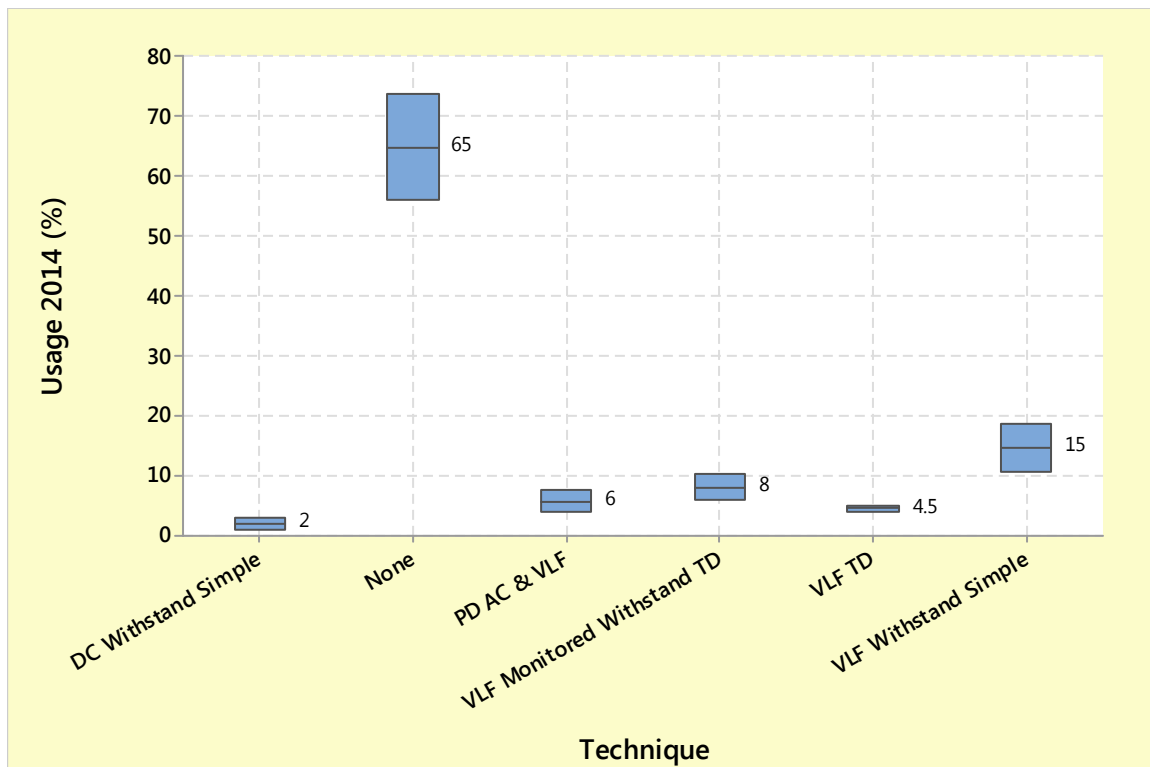


Figure 1: Results of a 2014 Study on the Use of Diagnostics on MV Cable Systems in North America

(PD AC: Online and Offline Partial Discharge in frequency range 20 to 300 Hz including DAC & VLF, TD = Tan δ , VLF = Very Low Frequency AC, Monitored = Withstand while monitoring a diagnostic property, typically Tan δ , Simple = Voltage Application Only without Monitoring)

As shown in Figure 1 between 56% and 74% of utilities do not employ diagnostics. The usage of diagnostics by utilities has grown since the start of the project in 2004. The reasons for the apparently low use of diagnostics are diverse. The studies of usage conducted in 2006 and 2014 clearly show that the reasons for not undertaking testing have changed. A large part of this is due to the development and better understanding of the knowledge gained over the course of the *CDFI*.

It is difficult to determine definitively the typical utility concerns about the use of diagnostics. However some insights can be garnered from the discussions that accompanied the studies carried out on the use of diagnostic methods at utilities (2006, 2011 and 2014) and tests have been carried out with >24 different sets of utility personnel. The concerns from the experience detailed above appear in Table 1. These concerns may not be present in each utility but they present a fair reflection of the overall views encountered in the two broad timeframes. They also serve to show how the thinking and acceptance of diagnostics have changed over time - from hard technical issues in 2006 towards implementation/integration concerns in 2014.

Table 1: Utility Concerns on the Use of Diagnostics in 2006 and 2014 – assessed from Utility Discussions	
Concerns affecting the Use of Diagnostics in 2006	Concerns affecting the Use of Diagnostics in 2014
Assessments of diagnostic techniques were conducted either in the laboratory or on a limited scale if carried out in the field or by the diagnostic providers. Thus, there were insufficient independently verified facts either to frame the debate or to make informed judgements.	The wish of managers/engineers for diagnostics to provide a precise/deterministic outcome. Diagnostics applied to aging systems are by their nature probabilistic and this uncertainty is often difficult to accept by utility decision makers.
Concerns that the available diagnostic techniques did not provide information that correlated with service performance of cable systems.	The perceived high total cost (field crew + engineering resource + test equipment or service cost) of diagnostic testing coupled with the difficulty of placing a value on the resulting improved reliability thereby making it difficult to make the “value case”.
A belief that diagnostic tests were inherently damaging to aged cable systems. Such that the act of testing reduced the reliability of the cable system.	Concerns with the addition of seemingly complicated/nontraditional activities to an already constrained operation and maintenance arena.
The competing claims of providers of significant superiority of a single diagnostic technology in all situations.	Perception that diagnostic techniques are not useful because of past bad experience.
The belief that the information provided by diagnostic techniques was inaccurate in the deterministic context used at that time.	A variety of embodiments of a particular diagnostic technology, making it unclear to select one that will provide the best value for the application.

The initiation of *Phase I* and *Phase II* of the *CDFI* highlights the importance to the electric utility industry of understanding how best to deploy diagnostics on cable systems. Both phases were co-funded by the United States Department of Energy (DoE) and a wide variety of electric utilities and companies that provide products and services to electric utilities. *Phase I* began in late 2004 and ended in late 2010. *Phase II* began in mid-2010 and ended in mid-2015.

This report reiterates and expands the important information learned from *Phase I* and provides significant additional insights from *Phase II*. While it serves as the final report for *Phase II*, it can also be considered a comprehensive diagnostic handbook that is based on all work performed under the Cable Diagnostic Focused Initiative.

This report is a very large document (>700 pages) containing a wide variety of information, some of it quite detailed, on cable system diagnostic testing. While the report is available as one large .pdf file, note that each chapter is designed as a standalone document that focuses on a specific aspect of diagnostic testing. Each of these individual documents contains this introduction along with the table of contents for the entire report, allowing the user to select the chapters that are most relevant to their needs while maintaining a quick, convenient reference to the overall diagnostic handbook.

1.2 CDFI Phases

As mentioned above, the *CDFI* was conducted in two phases. A brief review of the topics covered in each phase appears below.

1.2.1 Phase I

Phase I of the Cable Diagnostic Focused Initiative provided a broad overview of how diagnostic testing technologies can be deployed to help understand the condition of underground cable systems. The information gained from condition assessment can be used as an asset management tool to improve reliability, avoid future failures, and optimize cable replacement or restoration programs.

Large amounts of field and lab data were extensively analyzed to characterize and categorize cable systems to better understand which systems needed attention and which systems could be left in service without fear of significant failures in the near future. This analysis revealed the difficulty of cable system condition assessment and emphasized the stochastic nature of cable characterization data. While much was learned from *Phase I*, the need to gather additional data and continue the analysis became readily apparent. This led to the initiation of *Phase II* of the Cable Diagnostic Focused Initiative.

1.2.2 Phase II

CDFI Phase II commenced in August 2010 with 31 participants. The project scope included all diagnostic testing technologies that may be practically deployed in the field to assess the condition

of cable systems. To keep the scope manageable and relevant to the broadest possible utility industry stakeholders, the project primarily focused on,

- Aged, shielded medium voltage cable systems;
- Newly installed high voltage cable systems.

Phase II of the Cable Diagnostic Focused Initiative built on selected work performed in *Phase I* including,

- Working with participants to perform tests and analyze data on cable systems in the field.
- Understanding the capabilities of commercially available diagnostic test equipment.
- Collating diagnostic test and outcome data from tests performed by NEETRAC and tests conducted by *CDFI* participants.
- Disseminating information learned during the execution of the project in the form of papers, presentations, and through working with the project participants.

New areas of work in *Phase II* include,

- Undertaking and analyzing the results of repeat diagnostic testing;
- Simplifying the interpretation of test results through the development and deployment of health index methodologies using Principle Component Analysis;
- Understanding the capabilities and limitations of Damped AC tests;
- Extending VLF Tan δ testing to the assessment of three phase circuits;
- Collating results and developing a comprehensive suite of decision rules for Monitored Withstand testing;
- Disseminating knowledge via Excel tools and assessment brochures (Monitored Withstand and VLF Tan δ);
- Supporting national and international standardization activities within AEIC, CIGRE, ICEA, and IEEE;
- Undertaking and understanding the issues associated with the testing of HV cable systems;
- Undertaking and analyzing the results of Time Domain Reflectometry (TDR) testing to locate joints and perform a qualitative assessment of the condition of the cable system neutral;
- Estimating degradation and life lines for corroded cable neutrals;
- Understanding and disseminating information on the fundamental issues associated with Partial Discharge testing;
- Resolving long standing concerns associated with the effect of frequency on VLF Simple Withstand tests;
- Exploring simultaneous combined diagnostic tests (Tan δ and partial discharge);
- Supporting *CDFI* participants in the implementation and analysis of cable system diagnostic programs (AEP, Ameren, APC, Con Ed, Duke, GPC, PG&E, SNOUD);
- Developing a framework to quantify the value/benefit of diagnostic tests;
- Disseminating information/understanding of diagnostic testing (AEP, Ameren, Borealis, Dow, EPRI, GPC, PG&E, and Southwire).

1.3 Participation

The *CDFI* brought together utilities, equipment manufacturers, cable diagnostic providers, and other interested parties for the purpose of assessing and enhancing technologies used to diagnose the condition of underground cable systems. The resulting consortium worked for a total of ten years in an effort administered, coordinated, and largely conducted by NEETRAC. The project sponsoring companies appear below.

Ameren	Hydro Quebec
American Electric Power	NRECA
BC Hydro	Oncor ¹
<i>Borealis</i> ²	Pacific Gas & Electric
Centerpoint Energy	Pacificorp
Consolidated Edison Company of New York	PEPCO ¹
<i>Eaton's Cooper Power Systems</i>	<i>Prysmian Cables and Systems</i>
<i>Dow</i> ²	Public Service Electric & Gas
Duke Energy	South Carolina Electric & Gas
EPRI ²	Southern California Edison
Exelon	Southern Company
First Energy	<i>Southwire</i>
Florida Power & Light ¹	<i>TE Connectivity</i>
<i>GRESKO</i> ¹	

Note:

Companies in italic font are manufacturers/distributors; others are electric utilities.

¹ participated in *Phase I* only

² participated in *Phase II* only

In addition to cost sharing with the Department of Energy, many of these companies also supported the project by providing test data, technical advice, and by making their utility systems available for testing.

Cable system diagnostic providers (equipment or service) also participated in the project by providing in-kind cost sharing in the form of technical advice, test data, test equipment, and/or testing services. The list of participating diagnostic providers appears below.

Cablewise/Utilx	HV Technologies
HDW Electronics (Megger)	IMCORP ¹
High Voltage, Inc.	Kinectrics ²
Hipotronics ²	Techimp SPA ²
HV Diagnostics	

Note:

¹ participated in *Phase I* only

² participated in *Phase II* only

From this collaboration, significant progress was made towards understanding how to effectively deploy diagnostics to evaluate underground cable systems.

1.4 Cable System Diagnostics

Cable system diagnostic technologies usually fall into one of two categories. The first category involves techniques to assess the global or “bulk” condition of a cable system. Though a variety of techniques may be employed, the general approach is to measure electrical losses within a given cable system.

The second category involves techniques to assess localized defects within a cable system. Again, various techniques are used to accomplish this goal, including a withstand test to “blow out” the weak location or the measurement of localized electrical discharges within the system.

Cable system diagnostic tests usually achieve one of the following:

- a) They verify that a new circuit installation, or repaired circuit, is suitable to be placed into service. Thus, the test provides some assurance that the circuit does not contain significant workmanship problems and was not subjected to severe mechanical damage during a repair or installation process that would adversely affect the cable system design life.
- b) They assess the health of a cable system and thereby determine the likelihood that an aged cable system will experience failures in the near future. In this case, the test could be part of an overall cable system asset management program or a means of minimizing failures on highly critical or problematic circuits.

While these appear to be straightforward goals, it can be difficult to establish exactly how to employ diagnostic technologies effectively. This is due to one or more of the following:

- a) The diagnostic testing technologies are in different stages of maturity (i.e. equipment, usability, and/or interpretation).
- b) Cable circuits are often very complex with branches or multiple cable and accessory types, each with their own aging characteristics.
- c) Multiple diagnostic techniques are sometimes needed to detect different problems.
- d) Some diagnostic technologies have not been universally accepted.
- e) Independently developed information on the subject is not widely available in a single document.

Cable system diagnostic testing should be considered a process (either continuous or scheduled), not a single event. Ideally, circuits must be studied to match the appropriate technology to the specific components in the circuit as well as any known circuit conditions (e.g. failure history, cause of failures). In many applications, it is best to begin with an easy-to-apply technology, which provides general information that can then be used to select a more focused technology. In many cases, it is desirable to apply diagnostic technologies periodically over the life of the cable circuit to establish, over time, how a circuit is performing.

The basic cable diagnostic testing technologies used to assess cable circuit conditions appear below and are discussed in more detail in the subsequent chapters.

- a) Mainstream techniques (routinely deployed at utilities today)
 - i. Time- Domain Reflectometry (TDR)
 - ii. Tan δ at Very Low Frequencies (VLF)
 - iii. Simple Withstand Tests at Elevated Very Low Frequencies (VLF)
 - iv. Simple Withstand Tests at Elevated Resonant ac
 - v. Monitored Withstand Tests at Elevated Very Low Frequencies (VLF) with simultaneous monitoring of Tan δ
 - vi. Monitored Withstand Tests at Elevated Resonant ac with simultaneous monitoring of PD,
 - vii. Partial Discharge (PD) at elevated Resonant ac Voltages
 - viii. Partial Discharge (PD) at elevated Very Low Frequencies (VLF) Voltages

- b) Niche techniques (not routinely deployed but where equipment maybe/has been commercially available)
 - i. Partial Discharge (PD) at elevated Damped ac (DAC) Voltages
 - ii. Combined Diagnostic Tests at Very Low Frequencies (VLF) using sequential PD and Tan δ
 - iii. Dielectric Spectroscopy
 - iv. DC Leakage Current
 - v. Polarization and Depolarization Current
 - vi. Recovery Voltage

Different diagnostic testing technologies assess different cable system characteristics. In many cases, using more than one technology can help establish a reasonably complete picture of the cable system condition. This is a particularly complex problem for hybrid cable circuits that contain more than one type of cable insulation and/or one or more types of cable joints or cable terminations. Whether a cable circuit is simple or complex, diagnostic tests must be employed carefully to assure meaningful results.

Setting realistic expectations is one of the most important considerations when using cable diagnostic testing technologies. Diagnostic test results are meaningful and useful, but not precise or perfect. When diagnostic test results described in this report indicated no immediate action was required, the failure rate over the next three to five years for circuits with that designation was indeed quite low, but not zero. Conversely, when the diagnostic test results indicated that a circuit required action, they did not necessarily experience failures within a three to five year time horizon. Rather, the action required designation simply means that there is a notably higher risk (3 to 10 times) of failure in service than a circuit categorized as not needing immediate attention.

There is no question that when applied properly, diagnostic testing can provide information to help lower cable system failure rates. And the improved reliability using diagnostics can be more strategically achieved than would occur without diagnostic testing. In this respect, cable diagnostic testing is much like a medical examination in which the resulting information induces a patient to take corrective actions that extends their life. However, the information is rarely able to predict the patient's exact life expectancy. Carrying that analogy one step further, applying a technique that looks for a symptom that is not present in the patient will provide no useful information for that patient.

1.5 CDFI Findings

The collaboration between the NEETRAC team and the *CDFI* participants led to many interesting discoveries. First and foremost, it is apparent that diagnostic testing is generally very useful, even if imperfect. To maximize effectiveness, test programs must be carefully planned and results thoroughly studied. In addition, it often takes time to see the benefits in the form of reduced failure rates. However, with care and diligence, a cable diagnostic test program can help utilities improve system reliability.

To continue the medical analogy above, note that most diagnostic tests are invasive to the cable system. Thus, they carry risks and benefits that must be carefully weighed before use. It is obvious from the medical analogy that there can be situations where some techniques do not bring sufficient value to warrant the potential risks to the system. Therefore, the risks, benefits, and accuracy of diagnostic tests must be weighed carefully before commencing on the journey.

The work has highlighted a number of general findings that follow:

1. The interpretation of diagnostic data is probabilistic - not deterministic, i.e. diagnostic results indicate what is most likely to happen to a circuit; they do not predict precise outcomes for the circuit.
2. There is no one “right” approach to cable system diagnostic testing – each situation may be different, even within a single utility or area.
3. Effective diagnosis is a process which follows the acronym SAGE – Selection, Action, Generation, Evaluation. It is not appropriate to preselect a particular technique but rather choose one (or more) techniques that match the symptoms/characteristics of the cable circuit.
4. Multiple diagnostics may be needed to obtain sufficient information to understand the condition of the cable circuit under study.
5. Diagnostic test users have to accept that there are finite (non-zero) risks of failure associated with any diagnostic test, including those described as “online” diagnostics.
6. The benefits from diagnostic testing (knowledge/improved reliability) are not instantaneous; they take time to develop. Thus, it is important to stick with a program while continually evaluating the outcomes.
7. “Trending” and “Knowledge Building” are important benefits from diagnostics. However, it is difficult to garner these benefits if the test program parameters (voltages/times/decision criteria) change. It is important to be consistent with testing protocols.
8. Diagnostic testing does not in itself deliver the improvements in reliability; the actions taken based on the diagnostic indications yield increased reliability. That is, testing merely identifies the problems it does not fix them.
9. Most utilities do not currently undertake underground cable diagnostic testing.
10. The most widely utilized voltage source for diagnostic testing in the field is Very Low Frequency (VLF).

At the diagnostic technique level, the details and terminology appear in the individual chapters and the glossary, however the key takeaways are:

Time-Domain Reflectometry (TDR)

- This test should be utilized on all but the most complicated/long circuits to obtain at a minimum the length of the cable system.
- It provides useful information on the number of joints in a cable circuit
- It can be difficult to interpret when multiple joints are present
- It does not provide quantitative data on the condition of the cable neutral.

VLF Tan δ

- With input from the *CDFI*, test protocols are well defined and, with input from the *CDFI*, exist in an approved industry standard.
- Assessment tools are available for interpreting the data into “No Action Required”, “Further Study”, and “Action Required” classes for all insulation types.
- A Health Index can be determined from: (1) Tan δ voltage dependence during the test (2) Tan δ variability over time during the test, and (3) Tan δ magnitude.
- Age lines (the description of how a diagnostic classification changes with age of the cable system from all “No Action Required” when new to increasingly “Action Required”) and Outcome lines (the probabilistic description of what is likely to happen in service for each diagnostic class as the cable system continues to age) can be determined for VLF Tan δ assessment classes.

Simple Withstand

- The benefits of VLF versus dc test voltages both on test and after test have been determined on hybrid cable systems.
- This is the most straightforward diagnostic test to interpret and perform.
- Voltages and times must be carefully chosen. Increasing voltage to reduce the test time does not yield the same performance either on test or in service after the test as the lower voltage and longer test time protocols.
- Outcome lines (the probabilistic description of what is likely to happen in service for each diagnostic class as the cable system continues to age) could be developed for VLF Withstand testing using the protocol described in IEEE Std. 400.2-2013.

Monitored Withstand

- With input from the *CDFI*, test protocols are now defined and are published as approved industry standards.
- NEETRAC developed assessment tools that can be used to make decisions in real time while the test is being performed, significantly increasing test program efficiency. The tools can also be used to make final assessments after the successful completion of the test.
- The health indices were developed based on (1) the tan δ variability during the test, (2) the tan δ trend over time during the test, and (3) the tan δ magnitude.

Damped AC (DAC)

- This technique shows great promise for PD detection in the field by utilities; however, there are no users of this technique in the USA or Canada.

- The technology as currently implemented and described in standards does not meet the criteria for Simple or Monitored Withstand tests and cannot be used for effective withstand field tests.
- The dielectric loss calculation as currently implemented and described in standards, is based on the time constant of a decaying waveform therefore cannot be compared to dielectric loss ($\tan \delta$) measurements made using VLF test equipment.
- Equipment may include the capability of generating other waveforms such as VLF.

Partial Discharge

- There is limited agreement within the industry on the condition assessment if PD is present. There is only agreement that having PD on a cable system is “not desirable” and it is important to know where it is located. No industry standard is available for interpreting PD measurements in the field.
- Field testing cannot be quantitatively related to any tests that might be conducted in the factory.
- This is the most difficult diagnostic to employ in the field, as issues surrounding test setup and execution are diverse and complex.
- Outcome lines (the probabilistic description of what is likely to happen in service for each diagnostic class as the cable system continues to age) have been developed for Online and Resonant ac PD.
- This technique remains too complicated for most utilities to conduct and interpret on their own although recent automation efforts are improving usability.

Metallic Shield Assessment

- OhmCheck and TDR with impedance matching adapter/electronics are techniques that are most commonly used in the field.
- Corroded neutrals occur on jacketed as well as unjacketed cable systems.
- TDR can be difficult for utility personnel to interpret, as results are not quantitative.
- Age lines (the description of how a diagnostic classification changes with the age of the cable system) can be developed for OhmCheck.

1.6 How to Begin (SAGE)

Diagnostic techniques are generally used either to ensure the performance of newly installed equipment (commissioning tests) or to assess the state/health of older systems. Diagnostics do not operate in a vacuum. They are employed to increase the efficiency of reliability improvement programs. It is useful to use the acronym SAGE (Selection, Action, Generation, and Evaluation) to describe the four basic elements of an effective diagnostic program.

Figure 2 illustrates how the four SAGE elements function together over time to yield (if implemented properly) a reduction in the failure rate. It is important to note that this benefit is not realized immediately nor does it cease once the program has ended: there is a lag before the benefit is fully realized. Furthermore, failure rates do not begin to change until the actions directed by the diagnostic testing (Generation) are well underway. Selection, Generation, and Action are each defined stages in time while the Evaluation component is ongoing throughout the entire test program and beyond.

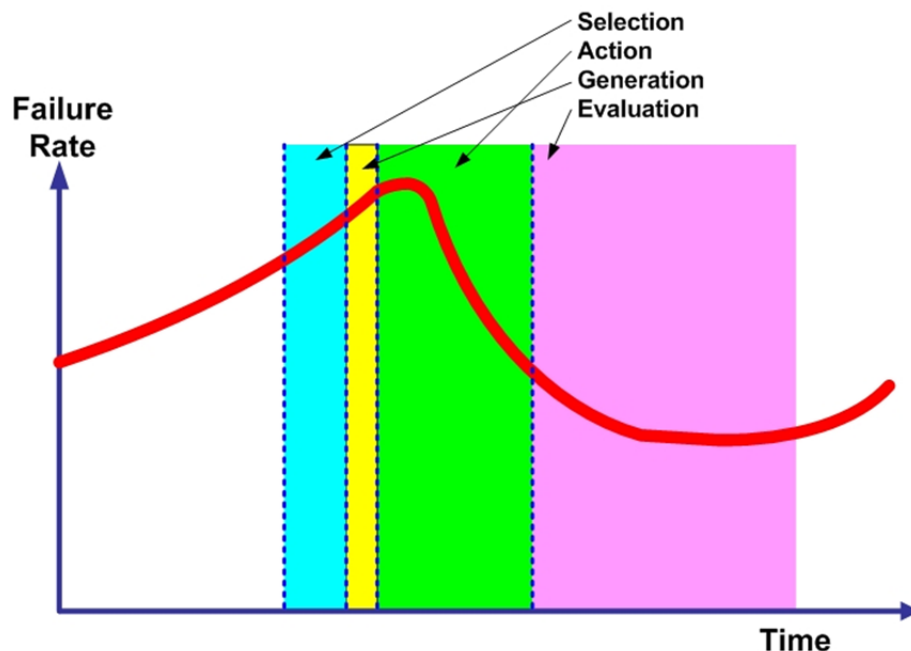


Figure 2: Effect of SAGE on the Failure Rate of a Target Population

Selection – Choose the cable systems for testing that will significantly improve reliability. Typically, this is based on age, failure rate, load sensitivity (hospitals, public buildings, industrial customers, etc.) or other engineering judgment.

Action – What actions are likely to be taken as the result of certain diagnostic outcomes or interpretations? The actions are in two groups (Act or Not Act) and may include replacement, defer action, rejuvenation, and/or repair. These actions are based on those most suitable for the system topology and most prevalent failure mechanisms (local or global degradation).

Generation – Using the prior information (Selection) diagnostic tests are chosen to generate data that support the preferred remediation (Action).

Evaluation – Are the methods employed for Selection, Action, and Generation giving the expected results: lower rates of failure and increased times between failures? Can the diagnostic elements be improved?

It is important to note that the failure rate in Figure 2 continues to increase during the Selection and Generation phases. Only after the actions are completed does the failure rate start to decrease. After some time, the failure rate will begin to increase again (Evaluation phase) and this would retrigger the whole SAGE process.

Chapter 4 provides much more information on how to get started with cable system diagnostic testing. Included in this chapter are some example cable system scenarios with a suggested suite of diagnostic tests.

1.7 Handbook Structure

The remaining chapters of this Handbook are structured as shown in Table 2.

Table 2: Diagnostic Handbook Overall Structure		
Part	Chapter	Title
--	1	Introduction
I Aging Mechanisms	2	Medium Voltage Cable System Issues
	3	High Voltage and Extra-High Voltage Cable System Issues
II Diagnostic Techniques	4	How to Get Started
	5	Time-Domain Reflectometry (TDR)
	6	Dissipation Factor (Tan δ)
	7	Medium Voltage Partial Discharge
	8	High Voltage and Extra-High Voltage Partial Discharge
	9	Simple Dielectric Withstand
	10	Monitored Withstand Techniques
	11	Metallic Shield Condition Assessment
	12	Other Diagnostic Techniques
	III Deploying Diagnostics	13
--	14	Glossary
	15	Brochures and Tools

Part I: Aging Mechanisms covers the basic defects and aging mechanisms that occur in cable systems either at birth or over time. Part II: Diagnostic Techniques focuses on the detailed work within *CDFI* on each diagnostic technique. Part III provides guidance and tools for deploying diagnostics in the field. **It is highly recommended that users who are new to cable system diagnostics begin with Chapter 4 prior to any other chapter in Parts II or III.**

Each of the diagnostic technique chapters (Chapters 5 through 12) are designed with similar structures with six primary sections in each chapter as outlined in Table 3.

Table 3: Part II Chapter Structure (X denotes any Chapter from Chapter 5 through Chapter 12)		
Section	Title	Description
X.1	Test Scope	Basic phenomena that is measured
X.2	How it Works	Fundamental measurement model
X.3	How it is Applied	How the technique is used along with its advantages, disadvantages, and open issues.
X.4	Success Criteria	Definition of assessment criteria and relevant documents
X.5	Estimated Accuracy	Accuracy calculations assuming all “Good” circuits should not fail and any “Not Good” circuit should fail.
X.6	<i>CDFI</i> Perspective	Details of the reasonable research effort including analysis and experimentation undertaken within <i>CDFI</i> . Includes explanation of the development/use of any Criteria/Tools.

A glossary is provided in Chapter 14 with key definitions from all chapters.