Qualifications of AMS: Cable Testing and Condition Monitoring

Figure 1. AMS Headquarters

AMS has served the nuclear power industry for 45 years in instrumentation and control (I&C) system testing, diagnostics and prognostics, cable and connector testing, cable aging management, electromagnetic capability (EMC) measurements, EMI/RFI troubleshooting, wireless technology deployment, predictive maintenance of equipment and processes, and automated test equipment development.

Since the early 1990s, AMS has been an industry leader in the field of cable testing, providing equipment and services for troubleshooting and condition monitoring of electrical cable systems in nuclear power plants and other industrial facilities**. Using our cable testing technologies, AMS has served every operating nuclear power plant in the U.S. as well as many overseas.** The experience gained through our work with the commercial nuclear power industry over the last three decades, as well as our research and development (R&D) in the area of cable testing, provides a mature technology base that can be leveraged for the immediate benefit of a variety of industries around the world.

Cable faults in industrial facilities can manifest themselves in many ways, such as a faulty indication of a sensor, display unit spikes, intermittent performance issues, and spurious actuations of systems that can cause costly downtime of critical equipment. AMS has extensive experience troubleshooting these issues and provides routine and emergent services to help mitigate and solve cable circuit problems. AMS' laboratories are equipped with expert personnel and state-of-the-art facilities for cable fault finding and aging assessments including a host of cable condition monitoring test equipment, a polymer material testing laboratory, environmental chambers, aging ovens, and a variety of cable raceways (Figure 2).

Figure 2. AMS Aging Ovens and Cable Raceways

1. CHAR CABLE CONDITION MONITORING SYSTEM AND FDR CAPABILITY

A foundational technology behind much of AMS's work in cable testing is the CHAR Cable Condition Monitoring System. The CHAR System (pronounced "care" and derived from *CHAR*acterization) is an integrated package composed of both hardware and software that provides a non-destructive evaluation of a cable circuit. All testing is performed using a platform that automatically switches between different test techniques within the single piece of equipment and compiles the collected data into a database designed to facilitate analysis, diagnostics, and trending. The suite of electrical tests integrated in the CHAR System provides a comprehensive approach for locating and diagnosing cable circuit problems. The measurements made by the CHAR System are listed below:

- Circuit Impedance including Inductance, Capacitance, and Resistance (LCR)
- Insulation Resistance (IR)
- Time Domain Reflectometry (TDR)
- Frequency Domain Reflectometry (FDR)
- Reverse Time Domain Reflectometry (RTDR) to Confirm Shield Integrity in Coaxial and Triaxial Cable Circuits
- Current-Voltage (IV) Testing of NI Detectors
- Signal-to-Noise Ratio Testing of NI Circuits through "Waveform" Acquisition
- Waveform Measurements for Other EMI Troubleshooting Applications
- AC and DC Voltage Measurements
- DC Resistance
- Dynamic Time Domain Reflectometry (DTDR) which is a form of Real-Time TDR
- Intermittent Fault Detection Using "Live Cable" Software and DTDR

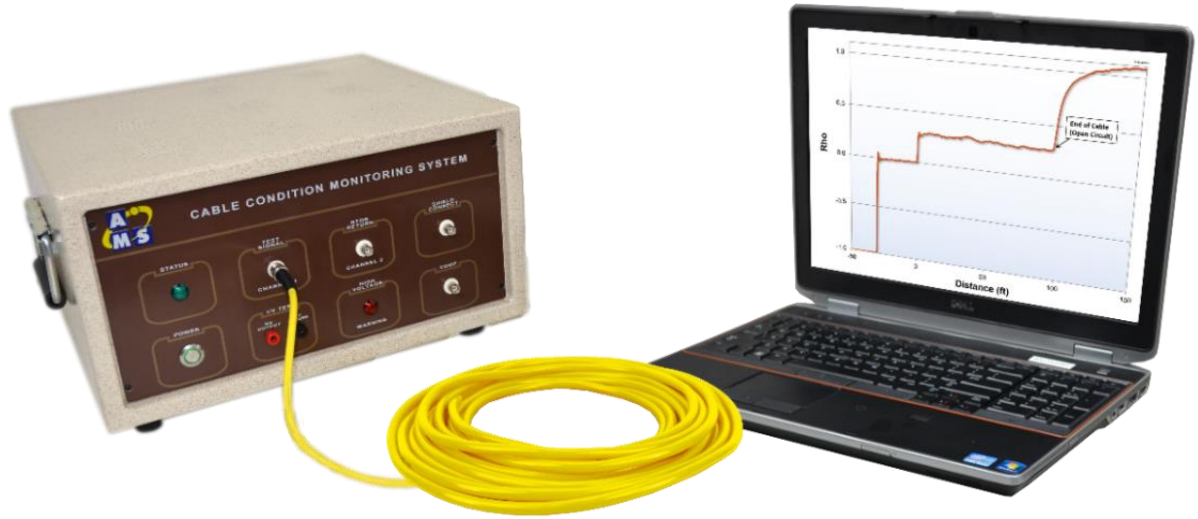

Figure 3. AMS CHAR Cable Condition Monitoring System

The Frequency Domain Reflectometry (FDR) technique, which can be integrated into the CHAR System or provided as a separate standalone system, has been adapted by AMS to enhance cable fault finding, troubleshooting, and aging management of industrial cables. Like TDR, the FDR technique is a non-destructive in-situ electrical test that uses the principle of transmission line theory to locate and quantify impedance changes in a cable circuit. These impedance changes can result from connections, faults in the conductors, degradation in the cable polymer material, etc. Compared with other traditional methods, the FDR test method provides improved measurement sensitivity to cable insulation material degradation that results from environmental stressors such as heat, moisture, and radiation.

To perform an FDR test (Figure 4), one end of a cable is connected to a signal source which sends a sequence of sine waves of constant amplitude and varying frequency through the cable. The waves travel the length of the cable and a portion of them are reflected back from the locations where the impedance is different from the rest of the cable. The reflected signal is separated, measured, and then correlated with the outgoing or incident signal. This correlation is established for each individual frequency within the measured spectrum. The frequency domain data is then converted to the time domain using an inverse Fast Fourier Transform (FFT). Once in the time domain, the distance-to-fault is calculated using the velocity of propagation (Vp) for the cable under test. The FDR test can be adjusted to specific frequency ranges to compensate for bandwidth attenuation from losses that result from the distributed impedance along the length of the cable.

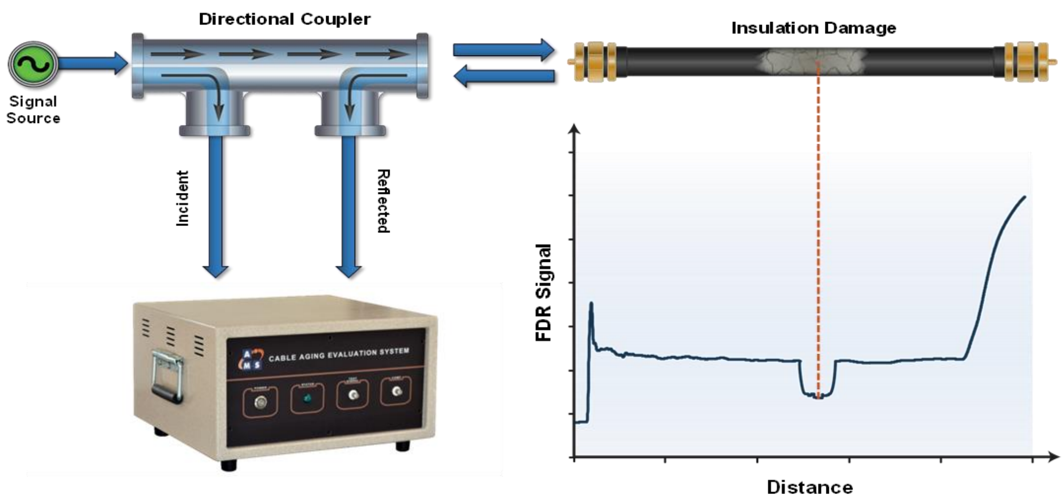

Figure 4. Overview of the FDR Technique

2. CABLE MATERIALS TESTING LABORATORY

In addition to field testing capabilities, AMS' Materials Testing Laboratory, shown in **Figure 5**, offers specialized testing services for evaluating the insulation materials of cables as well as other components and materials used in aging infrastructure and industrial facilities. **AMS has supported cable laboratory testing services for multiple countries, including for the oil and gas industry in the Middle East.** Through years of experience conducting these evaluations, the AMS engineers working in this laboratory have developed the expertise necessary to offer materials testing services to support a wide range of industries and to ensure that aging facilities continue to operate safely and reliably. Capabilities include: condition and aging assessments for industrial materials and components, lifetime and remaining useful life predictions, failure analysis, root cause analysis, environmental stress testing, elemental and chemical analysis, and condition based quality assurance testing of materials to support environmental qualification programs.

Figure 5. AMS Cable and Materials Testing Laboratory

3. INNOVATION, R&D, AND NATIONAL/INTERNATIONAL ACTIVITIES

Innovation is a key component of AMS' long-term strategy for providing cable testing technologies to industrial facilities. For example, in recent years, AMS has performed approximately $10M USD in R&D projects specifically focused on enhancing cable testing and condition monitoring technologies. This continuous improvement has helped AMS to become a leading provider of testing to the U.S. nuclear power industry.

In addition to our ongoing R&D, AMS participates in the development of national and international standards related to cable testing and condition monitoring as well as actively publishing papers and journal articles in this area. A description of these standards as well a sample list of applicable AMS publications are provided below.

Example Participation in National and International Guidance and Standards

1. The International Electrotechnical Commission (IEC) released a series of cable related standards under the IEC SC 45A Technical Working Group on "Instrumentation and Control Important to Safety – Management of Ageing of Electrical Cabling Systems". AMS participated in these standards as a committee chairman or member. These include:
   a. IEC standard 62465 which provides strategies, technical requirements, and recommended practices for the management of normal aging of cabling systems that are important to safety in nuclear power plants.
   b. IEC standard 62582 which contains requirements for application of several electrical, mechanical, and thermo-chemical methods for condition monitoring in electrical equipment important to safety of nuclear power plants.
2. AMS is currently serving as a member of the Insulated Conductors Committee, a working group within the Power and Energy Society of the Institute of Electrical and Electronics Engineers (IEEE). The working group is tasked with developing a standard which provides a comprehensive list of cable condition monitoring techniques for testing nuclear power plant cables. The standard entitled "Recommended Practice for Applicability of Methods for the Evaluation of Low Voltage and Medium Voltage Installed Cable Systems in Nuclear Facilities" will provide test methods for many of the available cable test techniques to support nuclear industry cable aging management programs.
3. AMS President and CEO Dr. H.M. Hashemian served as the Chairman of an International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP) titled "Condition Monitoring and Management of Low Voltage Cables in Nuclear Power Plants." The goal of this CRP was to provide nuclear power plants with information and guidelines on how to monitor the performance of insulation and jacket materials of existing cables and establish a program of cable degradation monitoring and aging management. The results of the project were published in 2017 in the publication, "Benchmark Analysis for Condition Monitoring Test Techniques of Aged Low Voltage Cables in Nuclear Power Plants," IAEA Publication TECDOC-1825, Vienna, Austria (October 2017).

Example AMS Publications - Cable Testing and Condition Monitoring

1. Toll, T., Ward, P., Ferree, C., Sexton, C. and Harmon, G., "Application of Cable Condition Monitoring Technologies to Assess Age-Related Degradation of Industrial Cables Installed in Harsh Environments," Nuclear Technology, Vol. 207, Issue 12 (December 2021). DOI: 10.1080/00295450.2020.1855289.
2. "On-Line Condition Monitoring and Aging Management System for Nuclear Power Plant Cables," Presented at the 39th IEEE Electrical Insulation Conference (EIC) (2021).
3. "A Cable Condition Monitoring Strategy for Safe and Reliable Plant Operation," Presented at the 38th IEEE Electrical Insulation Conference (EIC) (2020).
4. "Development and Implementation of An In-Situ Cable Condition Monitoring Method for Nuclear Power Plants," Presented at the 38th IEEE Electrical Insulation Conference (2020).
5. Hashemian, H.M., Sexton, C.D., "Cable Aging Management of Medium Voltage Cables." Nuclear Plant Journal, Vol. 37 No. 2, pp. 40-43 (March-April 2019).
6. "A Cable Condition Monitoring Strategy for Safe and Reliable Plant Operation," American Nuclear Society 11th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human–Machine Interface Technologies (NPIC & HMIT), Orlando, FL (2019).
7. "A Holistic Approach to Testing Cables, Connectors, Shielding, and End Devices in Nuclear Power Plants," American Nuclear Society 11th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human–Machine Interface Technologies (NPIC & HMIT), Orlando, FL (2019).
8. "Identification and Repair of Intermittent Cable Faults in Nuclear Power Plants," Proceedings of the American Nuclear Society (ANS) 10th International Topical Meeting on Nuclear Plant Instrumentation, Control & Human-Machine Interface Technologies (NPIC & HMIT), San Francisco, CA (June 11-15, 2017).
9. "Implementation of New Cable Condition-Monitoring Technology at Oyster Creek Nuclear Generating Station," Nuclear Technology, Vol. 200, No. 2, pp. 93-105 (November 2017).
10. "In-Situ Cable Condition Monitoring," Nuclear Engineering International (March 2017).
11. "Methods for Testing Nuclear Power Plant Cables," IEEE Instrumentation & Measurement Magazine, pp. 31–36 (October 2013).