Nuclear Power Plant Cables

Maintenance Troubleshooting & Condition Monitoring

ECAD® System 2011 Cable Condition Monitoring System

ECAD® Plant Testing Services

CM Technologies Consultancy

CM Technologies Engineered Solutions

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PREFACE

Electric cables are one of the most important components in a nuclear plant. They provide the power needed to operate electrical equipment, and they transmit signals to and from the various controllers used to perform safety functions and accident mitigation. Despite their critical importance, cables typically receive little attention since they are considered passive, long-lived components that have been very reliable over the years when subjected to the environmental conditions they were designed and qualified for.

In the US, as well as facilities around the world, experience is showing that cables important to both operations and safety are failing prematurely (and without warning) in the absence of a thorough, periodic testing and inspection programs. From a production and safety perspective, proactive programs that trend critical cable performance to pre-empt failures offer great economic value to facility owners.

From a regulatory perspective, guidelines now on the books, and those forthcoming, mandate that each nuclear plant owner include a formal cable condition monitoring program into its maintenance and inspection protocols to demonstrate compliance with nuclear safety regulations. The US Nuclear Regulatory Commission is now recommending that major features of CM Technologies' automated test and diagnostic systems be utilized by US nuclear power plants, as proposed in Draft Regulatory Guide DG-1240, *Condition Monitoring Program for Electric Cables Used in Nuclear Power Plants*. See Appendix B. The detailed technical information presented in this document describes the test instrumentation and rigorous testing methodology embodied in our specialized products and services.

CM Technologies began to offer specialized equipment and services to the nuclear industry over 25 years ago. Indeed, we were the first company to do so. The company's name was selected because it represented then, as now, the common acronym for condition monitoring (CM); hence, ***CM*** *Technologies Corporation*. Over the years, CM has earned a worldwide reputation for manufacturing the most advanced automated electric cable testing system for the nuclear power industry. Today, our ECAD® testing systems are also used by military organizations, NASA, the US Department of Energy, Boeing and other industry sectors where failures of critical cables represents an important operational cost or safety risk.

Forward thinking owners and operators have realized that there is great economic and safety value in maintaining a cable condition monitoring program for the entire life of the plant; beginning at the design (to include provision for testability), and following through to construction, startup, operations, routine maintenance and troubleshooting unanticipated failures. For example, over 20 years ago, CM Technologies delivered the first of 5 of its ECAD® test systems to the USDOE Defense Waste Processing Facility to monitor cable integrity during construction. These systems continue to be relied up after 15 years of successful plant operations, and are set to continue in this proactive condition monitoring strategy all the way through to the end of the plant's schedule operational lifetime.

Today, CM Technologies continues to be a leader and innovator in its field. Our expert **Consultancy Group** assists plant owners in the most effective ways to improve plant operations and maintain compliance with regulatory requirements and commitments. Our field seasoned **ECAD® Services Group** is on 24/7 call to nuclear plant owners worldwide to assist in forensic investigations of forced outages, or to verify proper installation and maintenance of critical electrical systems during planned outages.

Finally, our **Engineered Solutions Group** works with customers to develop specialized testing equipment, procedures or interfaces to manage custom requirements. For example:

- In cooperation with the US Federal Aviation Authority (FAA), CM has developed and patented a special enhanced dielectric test (EDT®) to monitor critical systems in commercial aircraft for loss of insulation material;
- We qualified our unique time domain reflectometry instrument for space use, and it is now one of the special diagnostic instruments available to astronauts onboard the International Space Station, and
- More recently, we developed and deployed our Cable Mapping Services solution onboard the latest military aircraft to assist in the management of premature wiring failures in the flight control systems. With this latest tool, relatively inexperienced aircraft maintainers can pinpoint the location of cable and connection failures on a graphical map that points to the nearest connector or wiring harness identification by name and number.

We hope your review of the ECAD® testing systems and testing methodology described in this document will raise your awareness of the importance and benefits of establishing a cable condition monitoring program in your nuclear plants, and that you will provide CM Technologies an opportunity to support your efforts in this regard.

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Tables and Figures

Introduction

ECAD® electronic circuit and diagnostic systems have been in commercial production since 1986. The all-digital, completely integrated, rugged and highly portable (33 lbs) ECAD System 2011 (Figure 1) has matured considerably over the last 25 years, fitting easily into an airline overhead bin; a feat not possible in its original 120 lb rack-and-stack instrumentation package (Figure 2).

CM Technologies supplies its specialized ECAD systems and testing services to utilities throughout the world. In fact, over 80% of our clients own and operate nuclear power plants. Our non-utility customer base includes major aerospace, defense and energy sector clients: NASA, DOD, DOE, Boeing and Schlumberger to name a few. Accordingly, we are very familiar with the demands and expectations that nuclear utilities and other mission oriented, safety-critical, and highly regulated industries place upon their suppliers.

Figure 1. The ECAD System 2011

The ECAD® System 2011 is a PC-based, fully automated cable condition monitoring system designed to test, trend and troubleshoot many types of power, instrumentation, and control circuits. The test methodology embodied in the ECAD system, characterizes an entire circuit in a single-ended test, with all of the necessary measurement data quickly obtained from one central test location. For example, a motor circuit's feeder cables, connections and windings are tested from the switchgear room, thus eliminating the need to enter into equipment operating spaces.

Software and hardware embodied in the standard ECAD System 2011 will support efforts to develop and implement a cable condition monitoring program meeting the requirements generally outlined in the 10CFR50.65 *Maintenance Rule* and Regulatory Guide 1.211, and more specifically those means and methods described in Draft Regulatory Guide DR-1240. ECAD System 2011 software and measurement instruments are designed and manufactured by CM Technologies exclusively for use in our test systems, and are suitable for testing low and medium voltage power cables, control and instrumentation cables commonly used in nuclear power plants. ECAD system design and manufacturing controls have served our company and our customers well, ensuring data compatibility, reliability, repeatability and trendability across systems, plants, fleets, industries, and the span of time.

Figure 2.Early ECAD System at Beznau NPP, Switzerland, circa 1990

The standard ECAD test and measurement suite includes user selectable/programmable:

- Dielectric Loss-Dissipation Factor/Power Factor Test (tan δ test)
- Insulation Resistance/Polarization Index Test
- Time Domain Reflectometry (TDR) Test
- Waveform Acquisition (glitch-capture) for intermittent events
- Standard bulk electrical property measurements:
    - capacitance,
    - inductance,
    - impedance,
    - phase angle,
    - reactance,
    - AC & DC resistance,
    - AC & DC voltage, and
    - insulation resistance

Optional hardware and software is available to extend the standard measurement suite and technical capabilities of the system. These can be ordered as part of the initial purchase decision, or they may be added later as part of a future upgrade package, as the standard configuration ECAD System 2011 contains the necessary features and expansion ports to accommodate these future upgrades.

- Automated V/I Test for Nuclear Instrumentation
- Enhanced Insulation Resistance Test (up to 5kVDC)
- Direct Current High-Potential Test (up to 12kVDC)
- Step Voltage Test (up to 6kVDC)
- Line Resonance Analysis using CM Technologies' Enhanced Dielectric Test (EDT®)
- Cable Mapping Services
- Expanded internal coaxial switching for multiple conductor circuits
    - 15 points with an internal coaxial switch card
    - 128 points with our external, MIL-810F coaxial switching module

Finally, all data, including time domain reflectometry (TDR) waveforms, is acquired automatically and stored in a database resident on the ECAD Systems hard drive. This data is immediately available for analysis of possible sources of degradation such as moisture intrusion, heat-damaged insulation, resistive connections, opens, shorts, and faulty end devices. The TDR waveforms allow users to pinpoint the location of anomalous conditions, whether the problem is located in a penetration, cable insulation, connections, or at end device itself. Regardless of whether or not any problems, faults or defects are identified during the testing, the software allows users to trend the data, thus supporting the development of more proactive maintenance activities over time.

Organization of Technical Information

CM Technologies manufactures the state-of-the-art ECAD System 2011 at its facility in Pittsburgh, Pennsylvania. The general characteristics and a description of the measurements performed by the proposed system are outlined under "System Design". Detailed specifications for the hardware and software are presented in Appendix A, located at the end of this document

System Design

The ECAD System 2011 is a powerful collection of PC-based instrumentation that can be used for troubleshooting and condition monitoring.

The value of the ECAD System 2011 lies in its power and versatility to quickly establish a system baseline of critical circuit parameters that are automatically collected and digitally stored. Briefly, Table 1 lists these parameters in terms of bulk electrical properties and an expanded characterization of cable condition, including indicators of potential cable insulation degradation.

Table 1. Summary of Standard ECAD System 2011 Measurement Characteristics.

Circuit Parameter	Significance
Time Domain Reflectometry (TDR)	Required to locate damaged or degraded circuit components.
Capacitance	Useful in assessing the condition of cable insulation.
Inductance	Useful in assessing the condition of motor windings
Insulation Resistance	Useful in assessing the condition of cable insulation.
AC Resistance	Useful in assessing the condition of connections and conductors
DC Resistance	Useful in assessing the condition of connections and conductors
AC and DC voltage	Used to protect sensitive instruments and the operator from induced voltage on the circuit under test
Impedance and Phase Angle	Primary AC parameters from which all other data are derived
Quality and Dissipation Factors	Measurements of purity; used to determine how close a circuit is to being a perfect circuit
Dielectric Absorption Ratio, Polarization Ratio, and Polarization Index	Used to eliminate the temperature dependence of insulation resistance test data.

Time Domain Reflectometry (TDR)

Digital TDR provides unsurpassed resolution and accuracy.

With a 1 nsec rise time, the Time Domain Reflectometer (TDR) card used in the ECAD System 2011 provides excellent horizontal and vertical resolution compared to traditional instrumentation. This exceptional resolution and accuracy is achieved through a 100% digital design – CM Technologies' TDR card is the only commercially available TDR on-a-card in the world!

Automatic comparisons of TDR signatures are provided.

Device and cable testing is simplified with the ECAD System 2011 TDR. When a circuit is first tested, that signature is stored as a reference or baseline trace. During subsequent tests, the results are automatically compared to the baseline. This feature allows for the rapid support of maintenance decisions when troubleshooting a circuit fault, as shown in Figure 3.

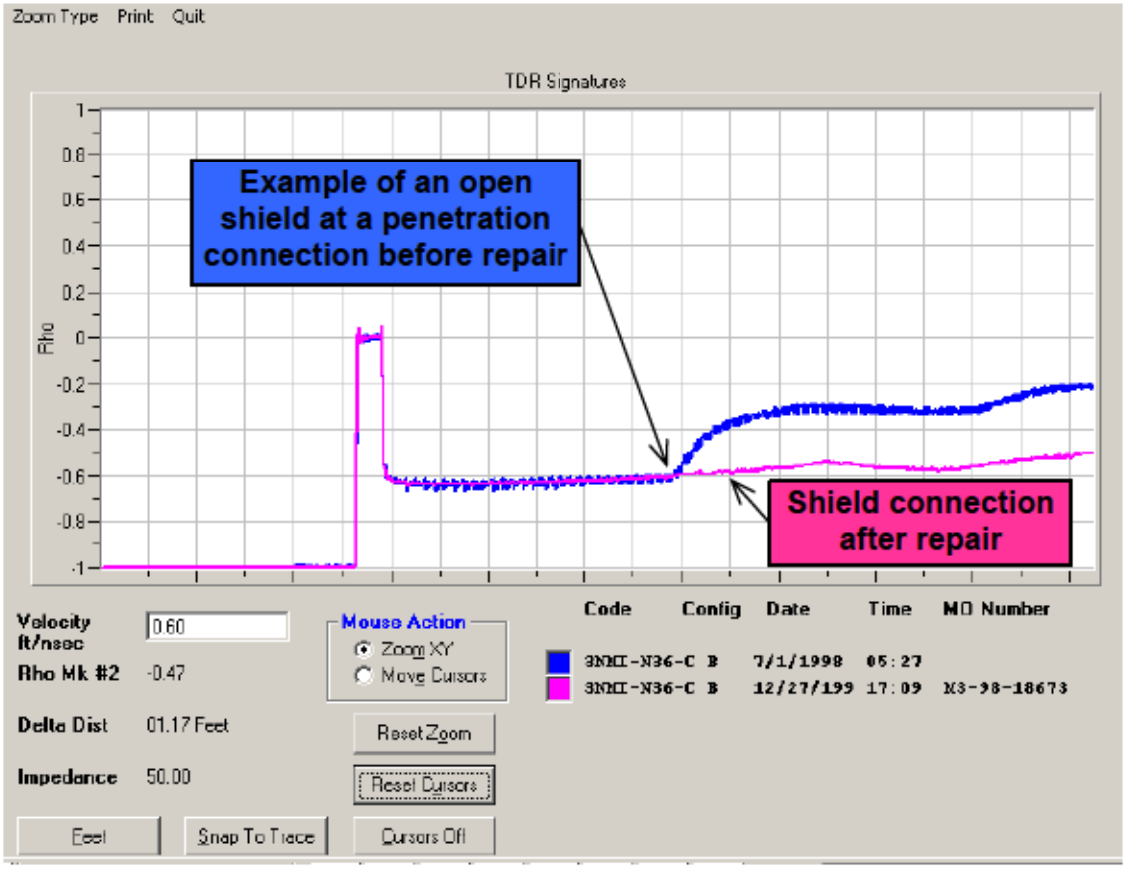

Figure 3. Example of TDR Results after Repairing a Shield Connection at the Penetration.

Software provides powerful tools for analyzing TDR signatures.

The ECAD System 2011 software contains many tools to make the analysis of TDR signatures easy. Examples of these analysis tools are shown in Figure 4.

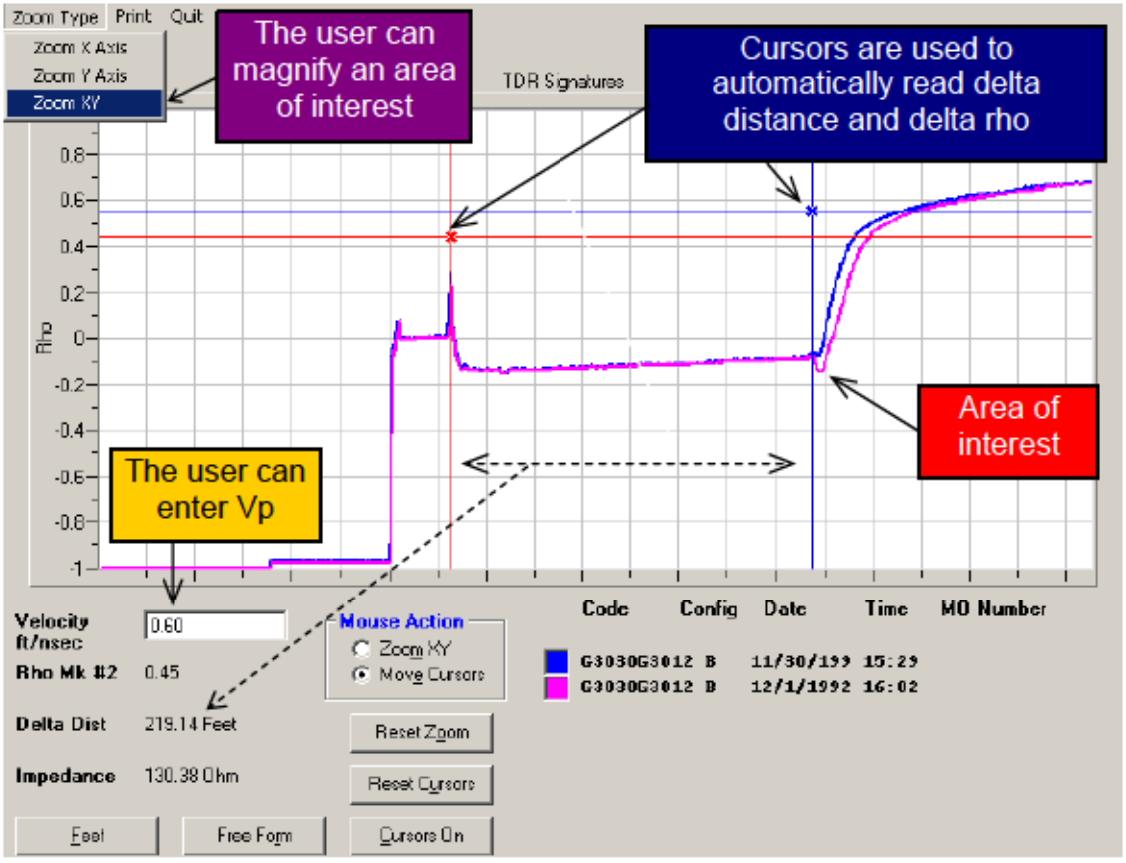

Figure 4. TDR Analysis Tools.

With the high resolution digital storage employed in the ECAD System 2011 TDR, detail is not lost when the signature is magnified. This allows the user to closely investigate suspect areas and conveniently compare current and historical data, as shown in Figure 5.

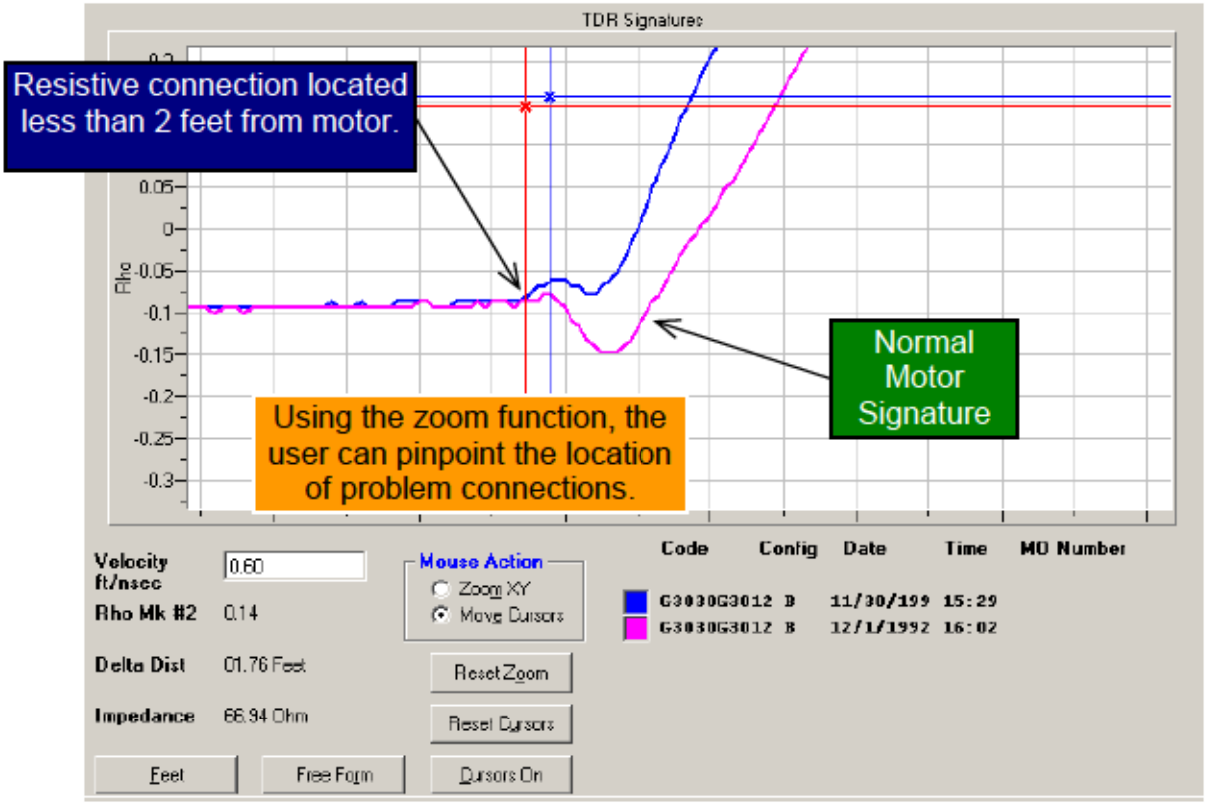

Figure 5. Example of Zoom Feature.

Impedance Measurements

Noise suppression filters solve a vital data acquisition problem in the field.

Impedance measurements represent the first and best indicators of circuit degradation. Accordingly, they form a valuable subset of the cable condition monitoring data. The PCI-3232 LCZ card, designed exclusively for the ECAD® System 2011, contains an impressive array of noise suppression filters to allow reliable and repeatable impedance measurements to be performed under the most "electrically hostile" conditions that may exist in the plant.

Historically, a major shortcoming of precision cable condition monitoring systems has been their use of commercial, laboratory-grade instruments to obtain precise impedance measurements. Problems have resulted because these instruments tend to be very sensitive to low levels of induced voltage/noise on the circuit under test; to the point where their inputs would be routinely saturated. This practical weakness can frequently prevent valid impedance measurements in the typically noisy environment of a nuclear power plan. The inherent filtering capability built into the ECAD® System 2011 avoids these difficulties and gives our system a great technical and practical advantage over other systems, especially when test and/or access time is limited during a scheduled outage or other events that might otherwise limit opportunities to acquire test data.

Floated or grounded impedance measurements

One of the more desirable characteristics of an impedance analyzer is its ability to make measurements on systems that are either floated or grounded. This characteristic is incorporated into the PCI-3232 LCZ card designed for the ECAD System 2011. Hence, whether the circuit under test is grounded or floated, the ECAD System 2011 will always obtain the measurement.

Insulation Resistance Measurement

The internal insulation resistance tester in the standard ECAD System 2011 supports insulation resistance (IR) measurements at selected voltages from 50 to 500 VDC. NOTE: Upon request, we can offer higher voltage insulation tests at 1,100VDC or 5kVDC in the form of external instrument options.

The ECAD System 2011 will consistently obtain a pre-programmed set of IR measurements over 1, 3 or 10 minutes.

The user can select the duration for insulation resistance test. Any polar insulating media will demonstrate a reduced IR until the molecules in the material align themselves with the imposed electric field. Over time, the instantaneous insulation resistance should increase and approach some final value, which makes a 'snapshot' insulation resistance measurement meaningless. By imposing an electric field on the insulation over a defined period of time, the quality of the insulation material can be determined.

IR ratios and Polarization Index (PI) values are automatically calculated for the selected test duration.

For the 10 minute IR test, the ECAD System 2011 calculates the IEEE Standard 62-1978 Polarization Index (PI). This is defined as:

$$\frac{\text{IR @ 10 min}}{\text{IR @ 1 min}}$$

If a 3 minute IR test is selected, the ECAD System 2011 calculates a Polarization Ratio variant, defined as:

$$\frac{\text{IR @ 180 sec}}{\text{IR @ 15 sec}}$$

For the 60 second test, the Dielectric Absorption Ratio is calculated:

$$\frac{\text{IR @ 60 sec}}{\text{IR @ 30 sec}}$$

A value larger than 1 for of any of the resulting test ratios is an indicator of good insulation quality.

The ECAD System 2011 software provides safeguards against 'meggering' something that should not be tested in this manner.

The ECAD System 2011 software uses the data obtained from the DC resistance measurement as an indicator of whether an insulation resistance (IR) test is allowed. If the measured value of DC resistance is greater than 500 kΩ, users will be permitted to specify and perform an insulation resistance test; otherwise, the test is automatically skipped. This feature prevents the operator from accidentally "meggering" a sensitive circuit.

IR data can be viewed graphically.

IR data collected from a circuit can viewed graphically versus time, as shown in Figure 6, or as a trend, shown in Figure 7.

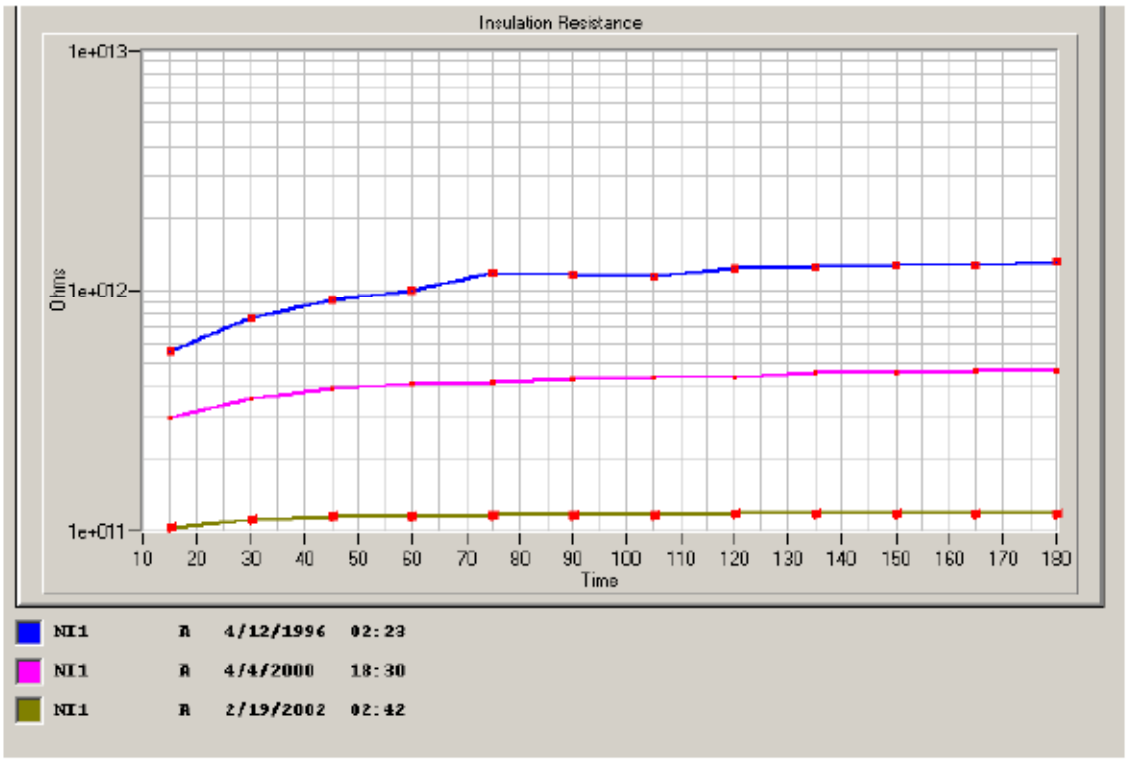

Figure 6. Insulation Resistance Data Viewed as a Function of Time.

Trend graphs are useful when the ECAD System 2011 is used as part of a condition monitoring or predictive maintenance program.

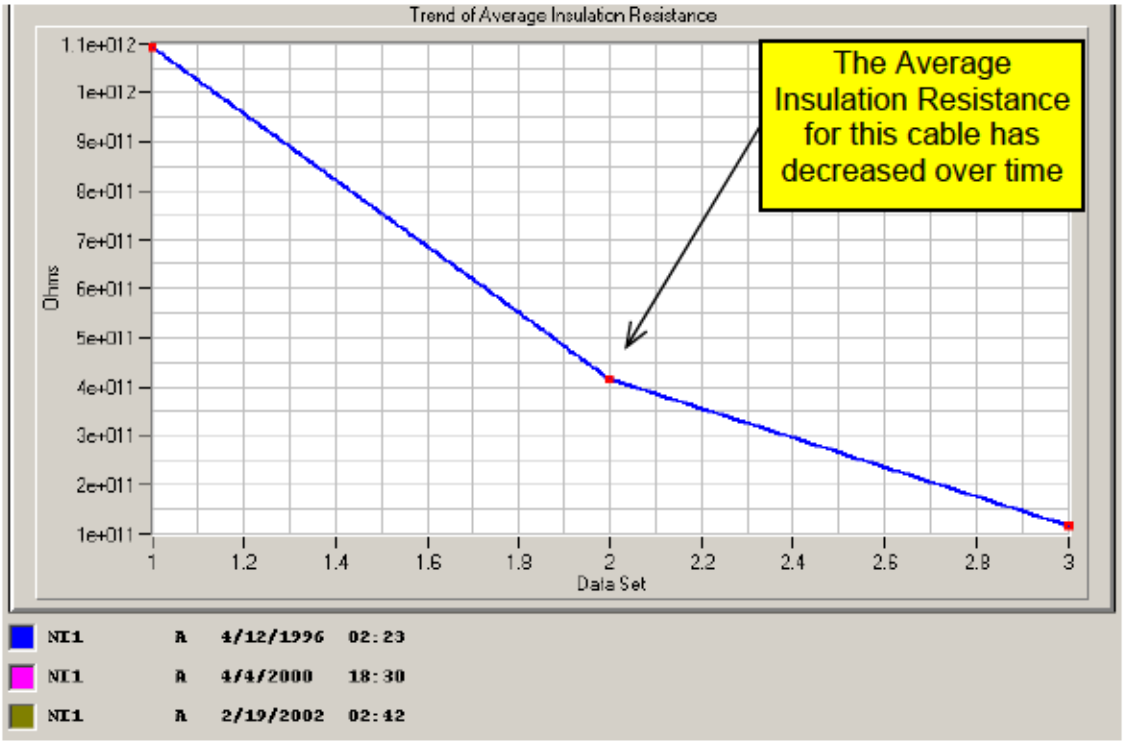

Figure 7. Trend Graph of Insulation Resistance.

DC Resistance Measurement

The ECAD System 2011 uses an internal Digital Multimeter (DMM) card to make DC resistance measurements, as well as, AC and DC voltage measurements

AC and DC voltage measurements provides protection for the operator and equipment

The first test performed during data acquisition sequence is a voltage measurement. This measurement is made to determine the amount of induced voltage, if any, on the circuit under test. If the induced voltage level is greater than an allowable threshold, the test sequence is halted and a message is displayed to the operator.

Physical Characteristics

The ECAD System 2011 weighs approximately 33 pounds and is about the size of a benchtop oscilloscope.

Overall dimensions for the ECAD System 2011 are 18 inches x 8 inches x 13 inches. At 33 lbs, the system is light enough to be hand-carried throughout the plant and small enough to pass through radiation check points, security barriers, labyrinth access passages and down stairwells and by a single technician. It actually passes as a carry-on and fits in the overhead compartment of commercial passenger aircraft (this feature has been demonstrated many times when deployed emergency service calls where freight delays are not an option!). The rugged design of the ECAD System 2011 has stood up to the demands of the military environment as well as careless baggage handlers around the world.

Services Included With Basic System

Initial Training

A three (3) day on-site training class will be provided. Students will gain a general understanding of the ECAD technology, the ECAD System 2011 hardware and software, and the application of the technology and system to the plant.

The class will include a review of circuit degradation, fundamental transmission line theory and its application to the characterization of plant circuits. Students will learn about the instrumentation and software comprising the ECAD System 2011, time domain reflectometry, AC and DC circuit theory as applied to cable condition monitoring and diagnosis, and the application of the system to typical plant circuits. Upon completion of the training, the student will be able to set up and operate the ECAD System 2011, perform testing, and interpret data for maintenance support.

Initial Hotline Support and Followon Services

The standard hotline support service provides no-cost access to our customer support staff on a 7-day, 24 hour basis. Questions can be phoned in during regular business hours, or transmitted electronically at any time. The hotline subscription is free for the first year.

As a matter of business policy, CM Technologies has always understood the need for customer Your program managers can rest assured that CM Technologies will continue to provide the same high-level of responsive customer support after the sale. We will also remain available to provide onsite assistance during peak outage periods or under emergency conditions. To assure timely response, we should utilize established contracting mechanisms for these purposes.

Furthermore, we can offer consulting assistance to help establish your formal cable condition monitoring program, as well as participate in the conduct of accelerated initial baseline testing of those systems and components so included. We can offer these services with complete confidence in data compatibility, as each ECAD System is designed to produce compatible, reliable, repeatable and trendable results regardless of whether it is owned or operated by our customers or by our own technicians and engineers.

Optional Equipment and Upgrades

Integrated UPS function 1-20 Minutes (P/N I02521000)

An internal, uninterruptible power supply (UPS) can be integrated into the ECAD controller. This option helps protect the system from transients associated with power interruptions, and allows the equipment to be moved between locations in an operating state without having to re-initialize the test instrumentation.

Rubber Keyboard - IP65 Protection (P/N I02520000)

The standard ECAD keyboard and optional IP65 rubber keyboard are shown in Figure 8. Both styles include an integrated pointing device (mouse).

The standard keyboard provides 84 keys and uses a trackball as the pointing device.

The optional IP65 keyboard provides 95 keys uses a hula-mouse as the integrated pointing device. The IP-65 rating prevents inadvertent damage or contamination by locking out water, coffee, dust and other undesirable tramp materials.

Figure 8. Keyboard Options - Standard (Left) and Optional IP65 (Right)

Hard Polymer Transit/Storage Case (P/N K02501000)

An optional, MIL-810F qualified hard-sided transit storage case, shown in Figure 9, provides an additional level of protection when shipping or storing the ECAD tester. The foam-lined case provides internal space for the ECAD tester, power cords, manuals and test lead. The case is configured with a collapsible handle and wheels for easy transport.

Figure 9. Optional Storage Case for the ECAD System 2011.

Soft Carrying Case for the ECAD (P/N K01502000)

A custom-fit, soft-sided carrying case is also available for the ECAD tester to keep it clean while carrying it around the plant or for temporary stoage. The soft case can accommodate the ECAD tester, test lead, power cord, and operating manual. The soft carrying case is shown in Figure 10.

Figure 10. Optional Soft Carrying Case for the ECAD Tester.

Automated V/I, 5kVDC Characterization Module (P/N HV-IR-MOD)

This option allows the user to configure the ECAD tester to perform general Step Voltage testing of circuits, and more specifically, automated voltage vs. current (V/I) measurements of nuclear instrumentation. The system is provided with a custom software package to control the testing using the ECAD System 2011.

The external meters provided with this accessory module can also be used to extend the test voltage range of the internal 500 VDC meghommeter up to 5 kVDC (i.e. IR tests from 501 VDC to 5,000 VDC are performed using the ECAD System 2011 software in conjunction with the external meters).

The modules external meters, shown in Figure 11, consists of the following major components:

- Keithley 6845 picoammeter,
- Stanford Research PS350 high voltage power supply (HVPS), and
- IEEE-488 GPIB controller
- Soft carrying for the meters and cables

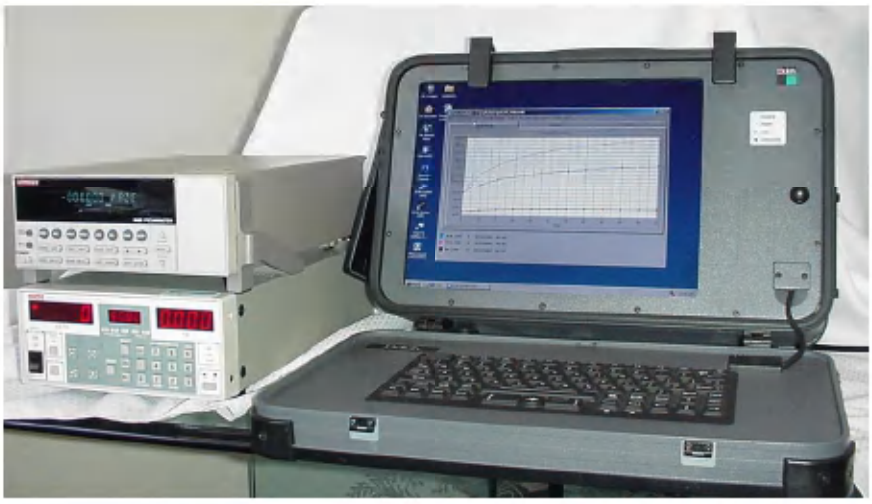

Figure 11. DC Characterization Module and the ECAD System 2011.

Step Voltage Testing

The step voltage test (SVT) is a diagnostic test that can be applied to low- and medium-voltage cable and all insulation and jacket material. The SVT is capable of detecting aging mechanisms such as thermally induced embrittlement and cracking, radiation-induced embrittlement and cracking, mechanical damage, water treeing, moisture intrusion, and surface contamination.

Automated V/I Testing for Nuclear Instrumentation

In general, a V/I test is performed by defining an automated test sequence. The HVPS is pre-programmed to apply a specified voltage, wait for a period of time (dwell time) and then record a current measurement. This process (i.e., voltage step, dwell time and current measurement) can be repeated up to 40 times for a device to obtain a well defined V/I curve. A further detailed description of the programming sequence and user interface is presented below.

A V/I test is preprogrammed via the user interface shown in Figure 12. The setup process is straightforward. First, the user provides the identification reference for the device under test (e.g., LPRM ID number, source range channel ID) – this reference is entered in the field labeled "Code" in Figure 12.

The user can then select from a list of pre-defined device types (e.g. source range, LPRM) or can select "Other". Pre-defined devices have the voltage steps and maximum voltage fields already completed.

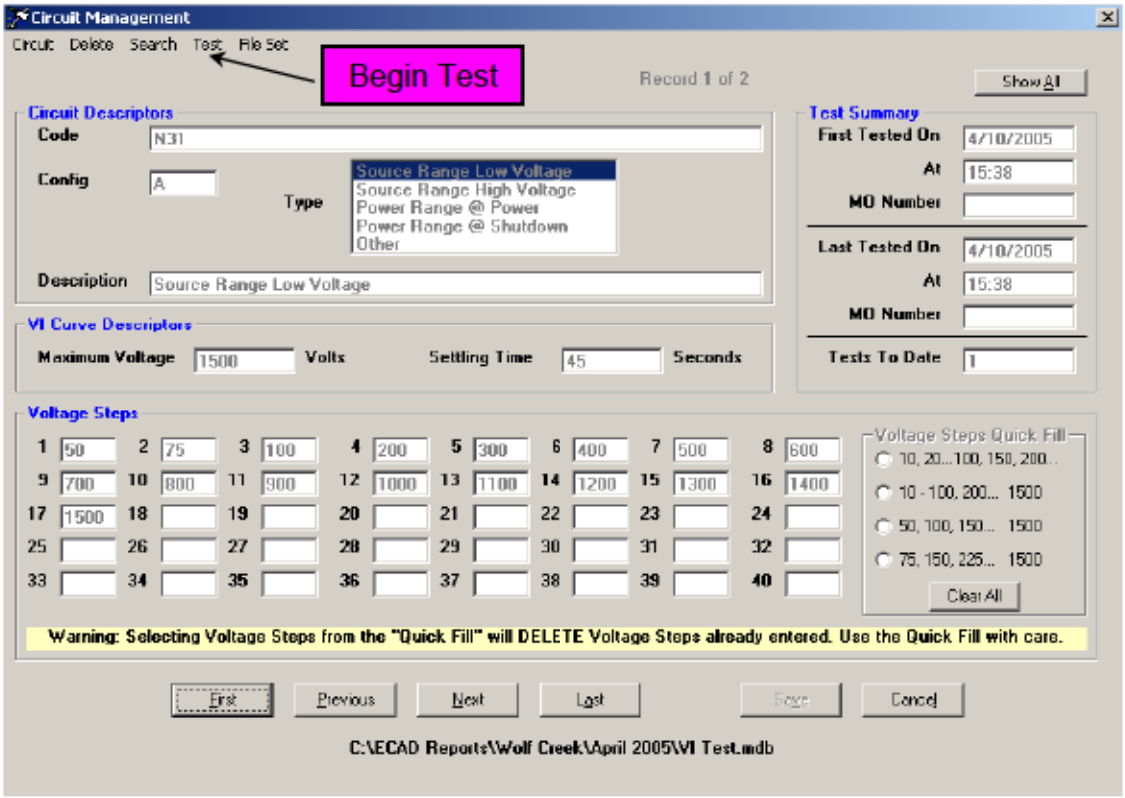

Figure 12. An Example of Defining a V/I Test on a Source Range Circuit.

The last step is to define the amount of time (in seconds) that will elapse (dwell) before the next current measurement is recorded.

After defining the test, the operator clicks on "Test" and the sequence begins. The software uses the computer clock to accurately measure the dwell time. Current measurements are automatically stored in the MS Access database.

Data analysis software is provided to allow comparisons of up to eight (8) sets of data. Figure 13 shows an example of comparing two data sets – the blue curve, acquired during the April 2005 refueling outage, and the pink curve, acquired during the October 2006 refueling outage.

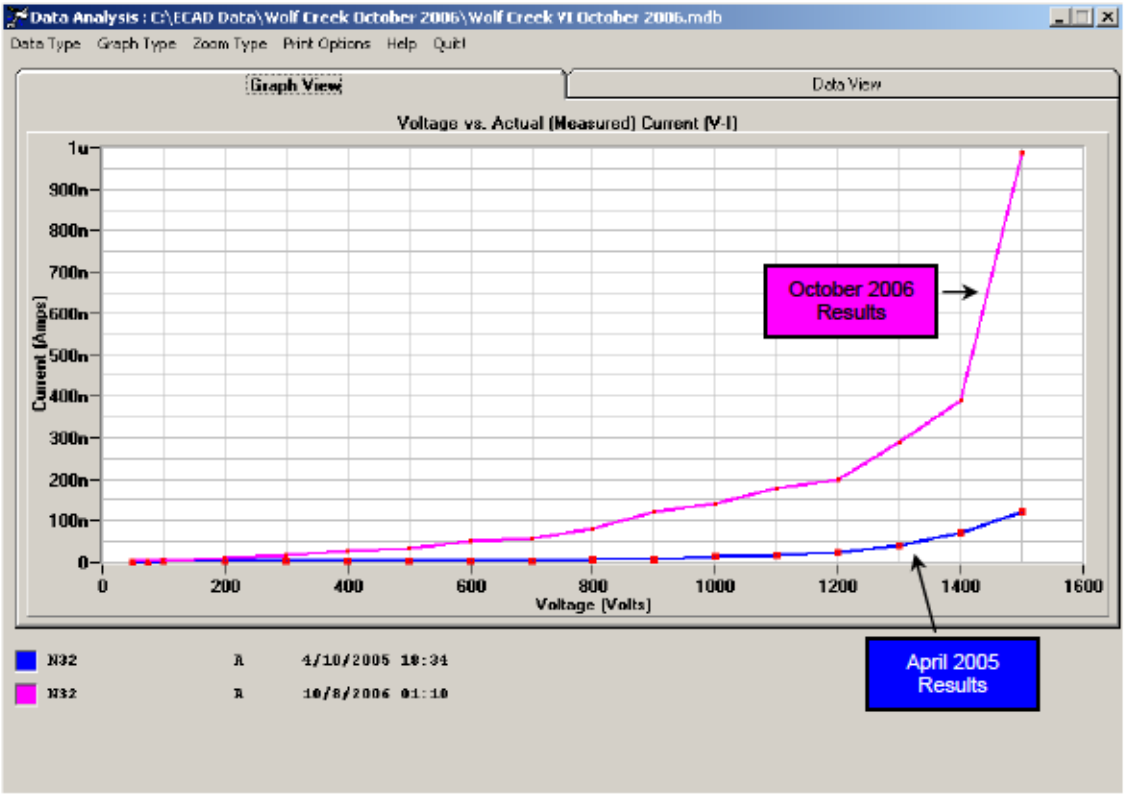

Figure 13. V-I Test Results Can Be Compared Graphically.

Automated Testing Module (P/N E01010000)

The standard ECAD System 2011 is configured as a 2-wire, single-ended test set; vis, wires are tested as conductor pairs from only one (1) end. This method is very precise and repeatable, and accommodates many of the circuits in found in a typical power plant.

However, some special circuits have a characteristic design that includes multiple conductors. And some control wiring and distribution systems are designed with multiple pin connectors or termination blocks to simplify construction. In these special cases, the standard ECAD system can be upgraded with an additional 15-point internal coaxial switch to allow automatic testing of multiple conductor circuits. This configuration is very useful where testing can be accelerated by connecting to CRDMs, RTDs, 3-phase circuits, and multi-conductor circuits using a single mating connector.

The hardware associated with the automated testing is shown in Figure 14.

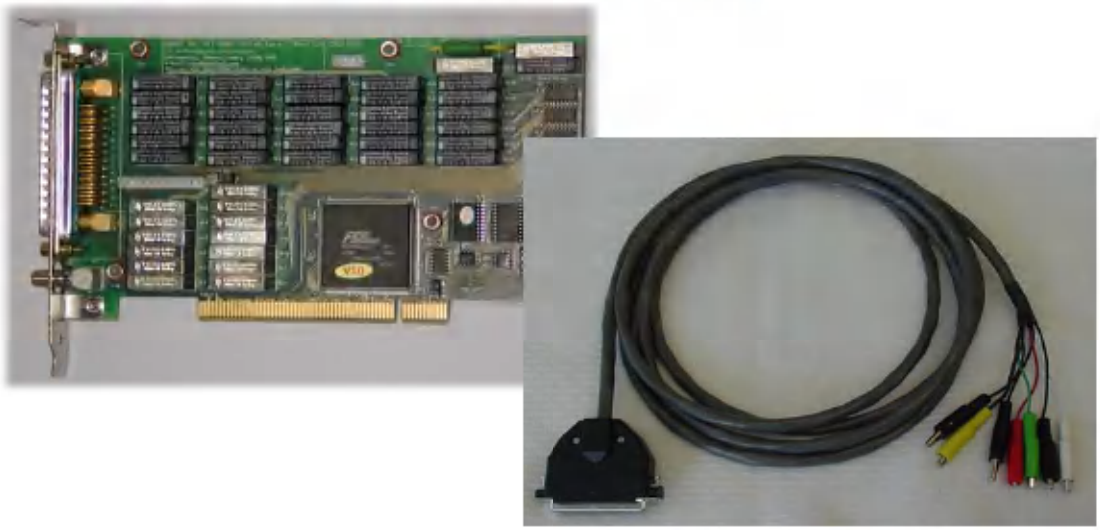

Figure 14. ECAD System 2011 Provides for Automated Testing.

The generic adapter cable shown in Figure 14 is used to connect the ECAD System to the circuit under the test. CM Technologies provides one (1) additional cable connector with this module to assist the Customer in fabrication of plant-specific adapter cables, if desired. Additional connectors may be ordered directly from CM Technologies or catalog electronics suppliers (e.g., Digi-Key Electronics or Newark Electronics).

Upon request, CM Technologies will provide a quotation to custom-manufacture adapter cables to suit the Customer's particular interface and technical requirements.

128-Point, External Coaxial Switching Module for Testing High-Density, Multiconductor Connectors (P/N A53002901)

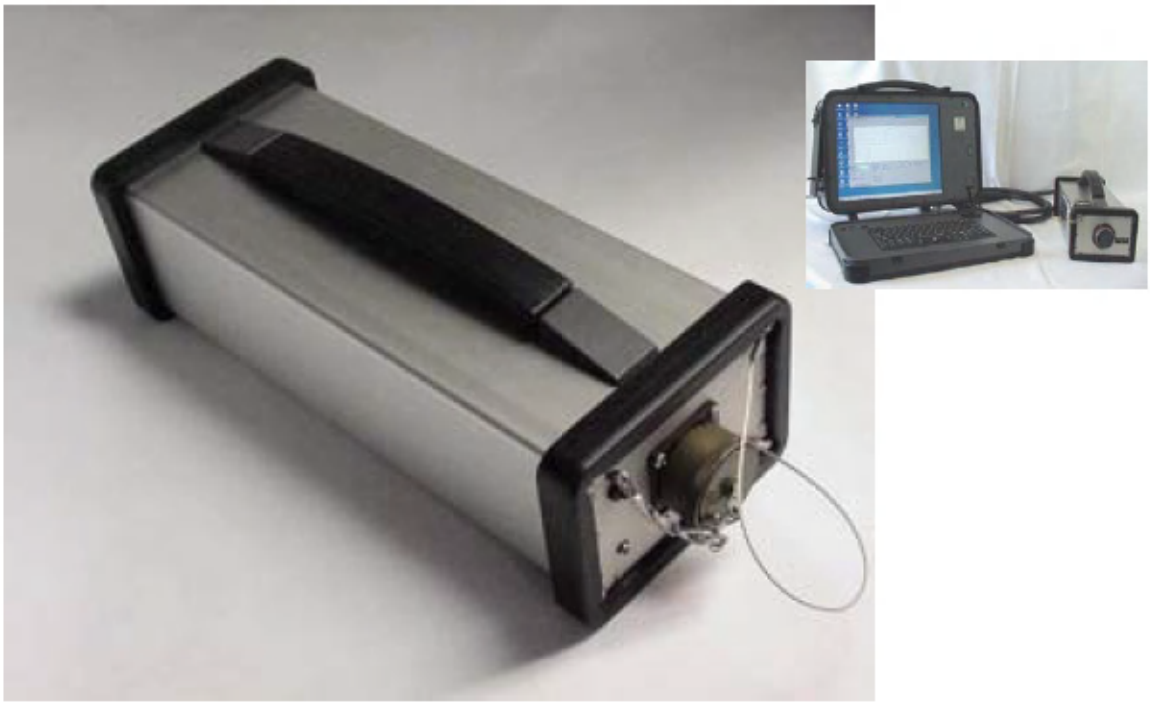

Figure 15. Special 128-Point, External Coaxial Switching Module for the ECAD System 2011

In some special circumstances, systems and components may contain many pairs of conductors group in high-density connectors or termination blocks. This configuration is very typical of military systems.

CM Technologies' 128-point high density coaxial switching module is an extremely rugged, lightweight, external accessory designed to speed up and simplify the automated testing of these circuits; total weight is less than 6.5 lbs (3kg). The assembly is MIL-810F and MIL-461E qualified against harsh environmental and electromagnetic (EMI) environments.

The switching module is compatible with all standard ECAD System 2011 testing modes, and will serve as a seamless extension of the ECAD system when testing requires inter-connection to complex plant termination points.

The generic 128-pin circular connector located on the output of the switching module can be readily adapted to any particular connector configuration specified by the customer. Upon request, CM Technologies will quote Customers for special designs and fabrication of custom adapter cables.

Appendix A: Product Specifications

Product Specification

ECAD System 2011

The ECAD® System 2011 is a portable, precision test system for evaluating the condition of power, instrumentation, and control circuits. The ECAD system is designed to perform a pre-defined sequence of laboratory-quality electrical tests on a **de-energized** circuit. These tests are AC voltage, DC voltage, resistance, impedance and phase angle, time domain reflectometry (TDR) and insulation resistance. All of the measurements are software controlled by the system controller. A manual control mode is also provided.

Table 1. Summary of Standard ECAD System 2011 Hardware Characteristics.

Host PC Controller Characteristics	♦ Industrial enclosure; MIL 810F/461E qualified ♦ 14.1-inch display – SXGA+ 1400x1050 LCD ♦ 84-Key Keyboard/Integrated Trackball ♦ USB, RS-232, GPIB, Ethernet ports
PCI-3102 Time Domain Reflectometer (TDR) Card	♦ Step pulse, 50 Ω characteristic impedance ♦ 10-bit vertical resolution ♦ Two (2) data record size options: ▪ High resolution (16k points) ▪ Low resolution mode (1k points); compatible with older ECAD data ♦ ISA form-factor
PCI-3432 DMM/IR Card	♦ Performs AC and DC voltage measurements ♦ Performs DC resistance measurements ♦ Performs insulation resistance tests ▪ Selectable test voltages in 1 volt steps ▪ Range: 50 VDC to 500 VDC ♦ PCI form-factor
PCI-3232 LCZ Card	♦ Measures impedance and phase angle directly ♦ Nine pre-set test frequencies: 100 Hz to 40 kHz ♦ Extended frequency range to 260 kHz ♦ Floated or grounded measurements ♦ PCI form-factor
PCI-3332 Coaxial Instrument Switch Card	♦ Provides connection between instrument cards and test lead ♦ PCI form-factor
Environmental Characteristics	♦ Operating temperature: -14°F to +113°F ♦ Non-operating temperature: -13°F to +158°F ♦ Operating shock: 15 G, 8 msec ♦ Non-operating shock: 40G, 8 msec
Physical Characteristics	♦ Dimensions: 19 in (W) x 13 in (H) x 8in (D) ♦ Weight: 33 lbs (15kg)

Table 2. Summary of ECAD System 2011 Software Characteristics.

ECAD Database Structure	All of the information describing the circuit under test and the measurement results are stored in a user accessible relational database. The database utilizes Microsoft Access format.
Example of Information Contained in the ECAD Database	♦ Name of the Circuit Under Test (Device Code) ♦ Circuit type (e.g., cable, motor circuit) ♦ Test location (e.g. control room) ♦ Cabinet number, terminal board ID and wire ID ♦ Source drawing number ♦ Comments ♦ Test date and time ♦ High and low resolution TDR signatures ♦ Impedance and phase angle (9 frequencies) ♦ IR readings (12 per test duration) ♦ Reference test flag allows users to select any test to serve as a reference point
System Self Test	The system self test verifies the proper communication between the ECAD controller and each instrument. A PASS/FAIL result is reported for each test. Upon successful completion of the communications test, the self test will initiate each instrument's internal self test and display the results.
Test Lead Calibration	The self test and test lead calibration verifies the test lead and clips are suitable for testing. The loop resistance of the shorted test lead is measured and compared to acceptance criteria. The insulation resistance of the test lead is also measured and compared to acceptance criteria. After verifying the key electrical characteristics of the test lead, a test lead calibration is performed with open and shorted test clips. The calibration measures the open and short circuit impedance of the test lead at each test frequency. These data are stored and subtracted from the impedance measurement to remove the contribution of the test lead from the total circuit impedance.
Thumbnail Displays during Data Acquisition	A group of the thumbnail graphs is visible during data acquisition to provide the user with an instant comparison to baseline results.
Graphical Analysis Tools	The ECAD System 2011 software also includes analysis tools allowing the user to compare up to eight (8) data sets. Cursors are provided for TDR signature analysis.
Importing and Exporting Databases	Databases can be imported and exported as formatted text files. Older, DOS formatted databases used in ECAD test systems manufactured prior to model year 2000 can be converted to the advanced Microsoft Access format currently utilized in the ECAD System 2011.

Appendix B: US NRC Draft Regulatory Guide DG-1240