

Electrical Safety Tester Verification

Ensuring Validity of Regulatory Tests

Verification of electrical safety testing equipment is a procedure that is often overlooked by manufacturers. Running test verification is crucial to ensuring that a safety device will properly detect product failures. While the task of setting up a test verification can seem daunting, it's a simple matter of having the necessary equipment and procedures in place so that the process is easy to follow.

WHY VERIFY

International safety testing agencies such as Underwriters Laboratories (UL), the Canadian Standards Association (CSA), the Association of German Electrical Engineers (VDE and TUV) and the International Electrotechnical Commission (IEC) set forth various standards to ensure that electrical devices meet set requirements for electrical safety. Performing electrical safety tests is done to ensure that an electronic product does not pose a shock hazard to the end user. An electrical safety test, however, is only as good as the tester being utilized on the product. Due to the nature of manufacturing environments, electrical safety testers can be damaged internally without showing physical signs of a problem. As a result, these damaged units can give incorrect readings with regards to insulation resistance, leakage current and withstand potential. Performing regular verifications on electrical safety testing equipment ensures proper operation and testing to NRTL standards.

According to the UL Mark Integrity Program document titled "Equipment Used for UL/C-UL/ULC Mark Follow-Up Services", all measurement and test equipment must go through regular inspection:

IMTE (Inspection, Measuring and Test Equipment) used to verify compliance with UL requirements shall be checked daily by the customer to ensure it is functioning properly. If this equipment is not used daily, then this function verification should be performed prior to use.[1]

The above excerpt outlines the importance of maintaining and verifying measurement equipment which includes electrical safety testers. This program is the driving force behind the requirement to run regular verifications on electrical safety testing equipment. This paper will outline the most common electrical safety tests, verification testing for each type of test and efficient means of verification for production line testing.

THE USUAL SUSPECTS: A BREIF REVIEW OF COMMON ELECTRICAL SAFETY TESTS

In order to ensure that an electrical product is safe for use, the product is passed through a rigorous gauntlet of testing. Among these tests are electrical safety test which are designed to test the electrical integrity of the product itself. These tests include the ground bond (or continuity) test, dielectric withstand or high potential (hipot) test, insulation resistance test and line leakage test. Each of these tests has unique parameters designed to pinpoint various potential problems with a device. For example, table 1 outlines common hipot test settings from various NRTL standards.

| Standard / Harmonized Standard | Testing Type | DIELECTRIC WITHSTAND | | |
|---|--------------|---|--------------|-----------|
| | | Test Voltage | Max I. | Test Time |
| IEC/UL 60601-1 3rd Edition Medical Electrical Equipment | Performance | 500 – 4000 VAC or 707 – 5656 VDC | No Breakdown | 60 s |
| | Production | 1000 – 3000 VAC | | 1 or 60 s |
| IEC 61730-2 UL 1703 Photovoltaic Modules & Panels | Performance | 1000 VAC + 2 x rated V or 2000 VAC + 4 x rated V | 50 uA | 60 s |
| | Production | 1000 VAC + 2 x rated V or (1000 VDC + 2 x rated V) X 120% | 50 uA | 1 or 60 s |
| IEC 60335-1 Household Electrical Appliances | Performance | 500 – 2400 VAC x rated V + 2400 VAC | No Breakdown | 60 s |
| | Production | 400 – 2500 VAC | 5-30 mA | 1 s |
| UL 60335-1 Household Electrical Appliances | Performance | 500V – 2400 VAC x rated V + 2400 VAC | No Breakdown | 60 s |
| | Production | 400 – 2500 VAC | 5-30 mA | 1 s |

Table 1 Common NRTL Hipot Parameters

Ground Bond Test

The Ground Bond or Ground Continuity test is used to analyze the integrity of the safety ground on an electrical device. The safety ground needs to be able to handle any fault current that could be imposed upon it due to a product or insulation failure. A low impedance path to ground will allow circuit protection devices such as fuses or circuit breakers to open when fault current flows through them. In order for this system of protection to effectively operate, there must be continuity between conductive components and the product’s ground pin or ground terminal.

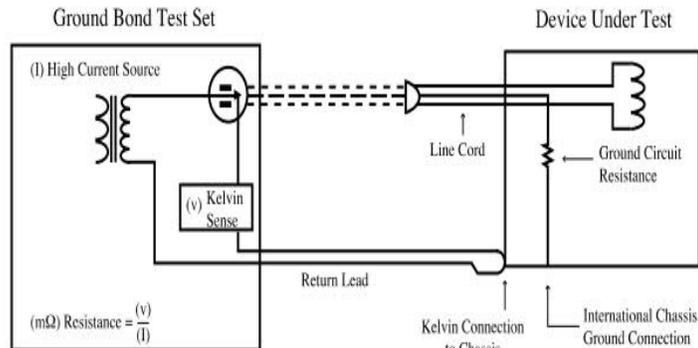


Figure 1: Circuit for a Ground Bond Test

Figure 1 shows a standard Ground Bond test circuit. The Ground Bond tester injects current onto the ground pin of a product and looks for a return path on the chassis or exposed dead metal. Simultaneously, the instrument must measure the voltage drop across the safety ground circuit to calculate the impedance of the circuit. Common ground bond test parameters are for a current of 10-30A with a maximum impedance of 100-200mΩ and a voltage drop not to exceed 6-12V.

Dielectric Withstand Test

The Dielectric Withstand Test, commonly referred to as the high potential or “Hipot” test is an electrical safety test designed to stress the insulation of a device beyond what it would encounter during normal use. The logic

behind running such a test is that if the device can handle the force of high potential for a short duration, it should be able to operate at rated voltage without posing a shock hazard to the user.

The Hipot test is a versatile electrical safety test. Not only is the test designed to find weak points in the insulation, it can also be used to measure excessively high leakage current, workmanship defects such as pinholes and scrapes, improper spacing with respect to a grounding point and degradation due to environmental conditions. Due to this versatility and the fact that this test can detect a number of insulation faults, this test is generally specified by NRTLs as 100% production line safety test. The method of running a Hipot test involves applying the high voltage across the current carrying conductors with a return point on a conductive chassis. The Hipot unit will measure the resulting leakage current flowing through the insulation. The potential used in a Hipot test varies from standard to standard but a common Hipot voltage formula is to take two times the rated voltage (V_r) of the product plus 1000V:

$$2 * V_r + 1000V = \text{Dielectric Withstand Testing Voltage}$$

A Hipot test circuit can generally be modeled as the device capacitance (C), insulation resistance (R_L) and small amounts of contact resistance (R_A). This model is shown in figure 2.

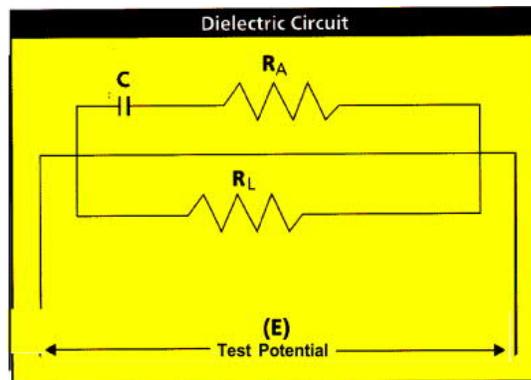


Figure 2: Dielectric Withstand Circuit Diagram

Insulation Resistance Test

While the Insulation Resistance or "IR" test is the least commonly specified electrical safety test, it can provide the user with some valuable quantitative data. Whereas a Hipot test provides a leakage current value, the insulation resistance test gives an actual resistance measurement of the insulation itself. The insulation Resistance test potential is generally specified by safety agencies at 500VDC or 1000VDC. Since the test potential is DC in nature, once the capacitive portion of the insulation has charged, the only leakage current flowing through the insulation is resistive and thus allows the user to measure an insulation resistance value.

An Insulation Resistance test is run in much the same way as a Hipot test. The high potential is applied to the current carrying conductors of a device and the return point of the circuit to the chassis. For example, an IR test run on a solar panel involves shorting the + and - terminal to high voltage and applying the return point to the metal frame. In this way, the insulation is stressed and the IR tester measures the leakage current on the exposed metal chassis. IR tests are usually specified as a test for repaired equipment or just after the Hipot test to ensure the Hipot test potential did not cause damage to the insulation.

Line Leakage Test

The Line Leakage test, like the Hipot test, measures current flowing through or on the surface of the insulation on a device. However, the Line Leakage test differs in that this measurement is performed while the product is running at rated voltage (or a high line condition of 110% rated voltage). The other major difference is how the leakage current is measured. For a Hipot test, the leakage current is measured through a current sensing resistor on the return side of the circuit (figure 3).

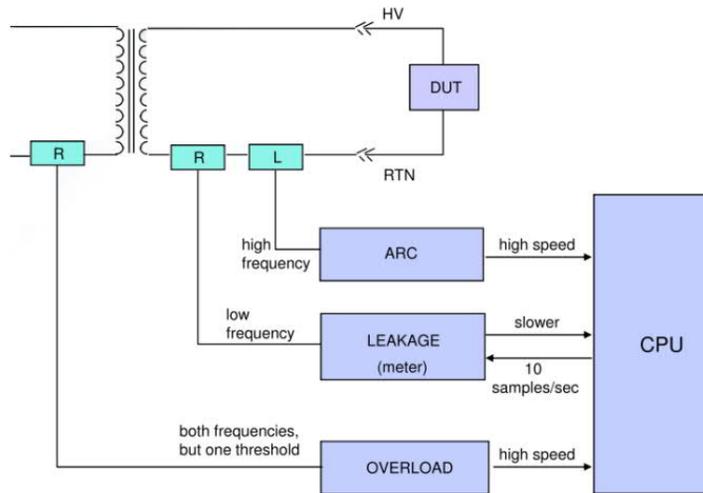


Figure 3: Hipot Detection Circuits

During a Line Leakage test, the leakage current is measured through what is known as a measuring device or “MD”. An example MD is shown in figure 4. The MD is designed to simulate the impedance of the human body.

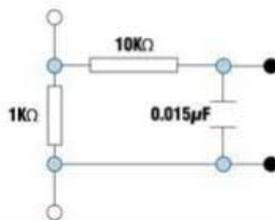


Figure 4: 60601-1 Measuring Device

Another aspect of the Line Leakage test that sets it apart from other electrical safety tests is the fact that it incorporates fault conditions. These fault conditions are designed to simulate “worst case” scenarios that could happen during the instrument’s operation. The three most common fault conditions are the opening of the neutral circuit, the reversal of line polarity and the opening of the ground circuit. A line leakage network is shown in figure 5.

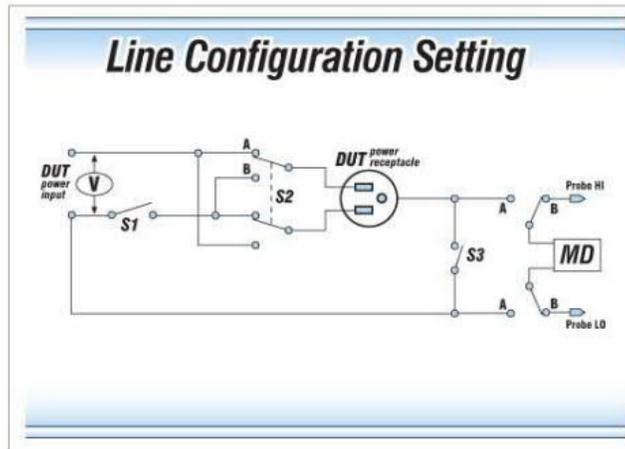


Figure 5: Line Leakage Configuration

Switch S1 represents simulation of the neutral fault condition, switch S2 represents the simulation of a polarity reversal and switch S3 represents the simulation of an open ground condition. The idea behind running tests under these various configurations is to measure exactly how much leakage current a human could be exposed to while the product is running and subjected to a series of fault scenarios. If the leakage current value is sufficiently low enough under all such fault conditions, the product should be able to operate normally throughout its lifecycle without posing a shock hazard.

Line leakage parameters vary greatly from standard to standard. However, some of the most commonly run line leakage tests are for compliance to the 60601-1 3rd medical device standard. For this standard, the line leakage test must be run at 110% line voltage, using the 60601-1 MD (figure 4) and running a product under the above mentioned fault conditions. Acceptable leakage current values range from 10uA all the way to 10mA.

THE IMPORTANCE OF TEST VERIFICATION

The Hipot, Ground Bond, IR and Line Leakage tests are either incorporated into multiple pieces of equipment or even an all in one tester. Due to the various functions of the unit(s), it is important to determine if the tester will fail properly when a regulated test value has been exceeded. In a high volume production line setting, it can be easy to miss a unit that should have failed if a test unit is not working properly. Performing verification on all unit functions ensures that a test unit is operating within specified parameters. According to UL procedures, if the test unit is taking measurements to make a determination on electrical safety, that test must be verified.

An example case that outlines this importance is a Hipot unit with a damaged measurement circuit. Most Hipot testers are not designed to handle an external voltage being input on to the return line of the Hipot instrument. There have been instances where an operator on a production line accidentally applies line voltage onto the return of the unit. Transient voltage suppressors on the return path of the instrument are installed to protect the other components in the Hipot instrument (figure 6).

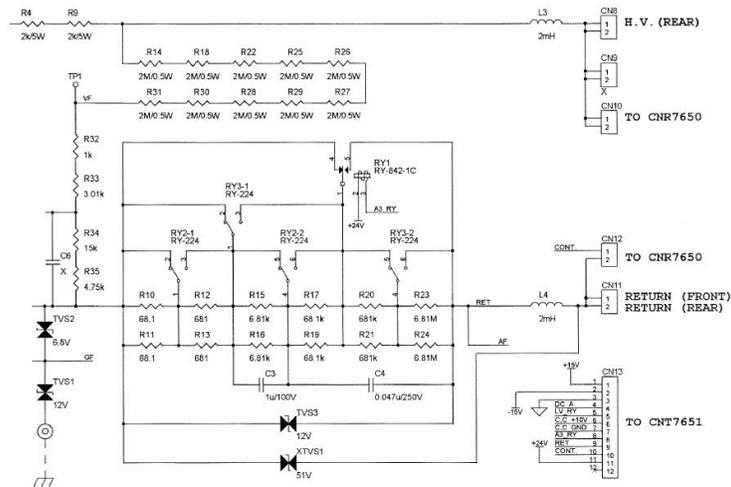


Figure 6: High Voltage and Return Path with TVS on Return

If external power is applied, the suppressor will conduct and dissipate this power. However, once the suppressor has been damaged it becomes a direct short and thus the measurement circuit is completely bypassed. When running the Hipot test, the Hipot instrument will register 0.0mA of leakage current and will pass the test. As far as the Hipot unit is concerned, zero leakage current implies infinite insulation value and the electrical device has passed the test. Running a simple verification on an instrument will immediately catch such an issue and warn the operator that there is a problem with the testing system.

The example given above outlines only one possible scenario. Other hazards include harsh environmental conditions such as heat and high humidity. Over time, these conditions can affect an instruments readings and accuracy. If the accuracy of a unit strays too far from the specified accuracy readings, it is possible to get false passes or failures on the device being tested. Running weekly or daily verifications on the full range of product tests ensures that potential issues with the measurement circuitry are immediately detected. Taking small steps to run verifications can avoid big problems and even product recalls down the road. Verification processes can create an initial time investment up front, but the damage that can be done by the alternative scenario greatly outweighs this allocation of time and resources.

EFFICIENT VERIFICATION PROCESSES ON ELECTRICAL SAFETY TESTING WORK STATIONS

Routine product safety tests are designed to identify faulty insulation, improper grounding, loose connections, defective parts, ground faults in the equipment, unguarded live parts and excessive leakage currents that could represent a potential shock hazard. Simply shorting or creating an open condition between test leads can prove to be an efficient method for ensuring the base failure detectors on an instrument are operating normally. However, such methods cannot catch all potential issues with a unit. Having simple resistive networks and relays can provide an easy means for an operator to check the functionality of the unit by dropping potential across these resistive networks and setting limits such that the verification tests fail. Additionally, building such a network with easily accessible ports and programmable control allow a verification to be run automatically with each verification process. Providing operators and technicians with a simple means of verification increases the chances that any problem with equipment measurement will be caught prior to product testing. Figure 7 shows a test box used specifically for verification:



Figure 7: Associated Research TVB-2 Test Verification Box

Using the example of the TVB-2 shown in Figure 7, a simple yet effective verification procedure can be setup to be run on a daily basis. This box consists of a series of resistors designed to draw a specific amount of leakage current or have a set resistance value. The following examples outline testing for verification on each type of electrical safety test. There are two posts for each type of safety test on the TVB-2 box: one post for a PASS and the other for a FAIL. This is achieved by connecting separate resistance values from each post back to the RETURN post on the box. Refer to table 2 for specific TVB-2 box values per test type:

| | ACW | DCW | IR | GC | GB |
|---------------------|---------------|-----------------|-------------|-------|--------------|
| PASS | 2MΩ | 2MΩ | 4MΩ | 500mΩ | 50mΩ |
| FAIL | 120kΩ | 120kΩ | 1MΩ | 2Ω | 200mΩ |
| Instrument Settings | 1240V 10mA | 2121V 5000uA | 500V 2MΩ | 1Ω | 30A 100mΩ |
| Ramp | 2s | 2s | N/A | N/A | N/A |

Table 2: TVB-2 Box Resistance Values and Test Settings

Dielectric Withstand Verification

The test voltage for a particular Hipot test is 1240VAC. Referring to Table 1, the fail circuit includes a 120kΩ resistor and the pass circuit utilizes a 2MΩ resistor. The Hipot instrument would then be set for two separate tests. The first test is a PASS test. The Hipot instrument is set at 1240VAC, 10mA high limit, 2sec ramp up, 1sec dwell time. The high voltage lead from the Hipot instrument connects to the PASS terminal on the ACW/DCW portion of the TVB-2 box and the return lead is connected to the RETURN terminal of the TVB-2 box. Using a simple Ohm's Law calculation, it can be determined that the leakage current should be around 620uA:

$$\text{Leakage Current (Ic)} = 1240\text{V}/2,000,000\Omega = 0.00062\text{A}$$

This should result in a test pass. The next test is a fail test with the Hipot instrument set to the same parameters as the pass test. The high voltage lead is then moved to the FAIL terminal on the ACW/DCW portion of the TVB-2 box. When the test is run, the leakage current should be around 10.3mA.

Leakage Current (I_c) = $1240V/120,000\Omega = 0.01033A$

To keep in specification with agency regulations, the test should fail within 0.5sec of the dwell cycle. If the test does not fail, the unit is not properly reading leakage current and should be repaired or calibrated.

Ground Bond Verification

The Ground Bond current for a test is 25A AC. Referring to Table 1, the fail circuit includes a 200m Ω resistor and the pass circuit utilizes a 50m Ω resistor. The Ground Bond instrument would then be set for two separate tests. The first test is a PASS test. The Ground Bond instrument is set at 25A AC, 100m Ω high limit, 6V potential drop, 1sec ramp up, 1sec dwell time. The high current lead from the ground bond unit is connected to the PASS terminal on the GB portion of the TVB-2 box and the return lead is connected to the RETURN terminal of the TVB-2 box. When the test is run, the resistance should be around 50m Ω which results in a test pass. The next test is a fail test with the ground bond unit set to the same parameters as the pass test. The high current lead is then moved to the FAIL terminal on the GB portion of the TVB-2 box. When the test is run, the resistance should be around 200m Ω which should result in an immediate test failure. To keep in specification with agency regulations, the test should fail within 0.5sec of the dwell cycle. If the test does not fail, the unit is not properly reading the resistance value and should be analyzed.

Insulation Resistance Verification

The IR test voltage for this test example is 500VDC. Referring to Table 1, the fail circuit includes a 4M Ω resistor and the pass circuit utilizes a 1M Ω resistor. The IR instrument would then be set for two separate tests. The first test is a PASS test. The IR instrument is set at 500VDC, 2M Ω low limit, 2sec ramp up, 1sec dwell time. The high voltage lead from the IR unit connects to the PASS terminal on the IR portion of the TVB-2 box and the return lead is connected to the RETURN terminal of the TVB-2 box. When the test is run, the resistance value should be around 1M Ω which results in a test pass. The next test is a fail test with the IR unit set to the same parameters as the pass test. The high voltage lead is then moved to the FAIL terminal on the IR portion of the TVB-2 box. When the test is run, the resistance value should be around 4M Ω and register an immediate fail. To keep in specification with agency regulations, the test should fail within 0.5sec of the dwell cycle. If the test does not fail, the unit is not properly reading leakage current and should be analyzed.

Line Leakage Verification

Line Leakage verification is not as well defined as verification for other test types. The TVB-2 box does not contain terminals to test for line leakage values. However, the same concept can be carried over to ensure that a Line Leakage instrument is operating within specified values. Since a product is operating at rated voltage while running a Line Leakage test, most Line Leakage instruments include a universal power receptacle (figure 8).



Figure 8: Universal Receptacle Box

As a result, a simple fixture can be made to mate with the receptacle box. A standard plug terminating in two separate resistor values is a simple means of creating a line leakage verification test fixture. Since the leakage meter reads between ground and neutral for normal polarity and ground and line under reverse polarity conditions, separate resistors can be wired between line to ground and neutral to ground. For example, for a line leakage verification, a plug is wired with a 2M Ω resistor between line and ground and a 200k Ω resistor between neutral and ground. The first line leakage test is set to run at 120VAC, 60Hz, 50uA high limit, reverse polarity, 5sec dwell. With a 2M Ω resistor from line to ground, the leakage current value should read about 60uA:

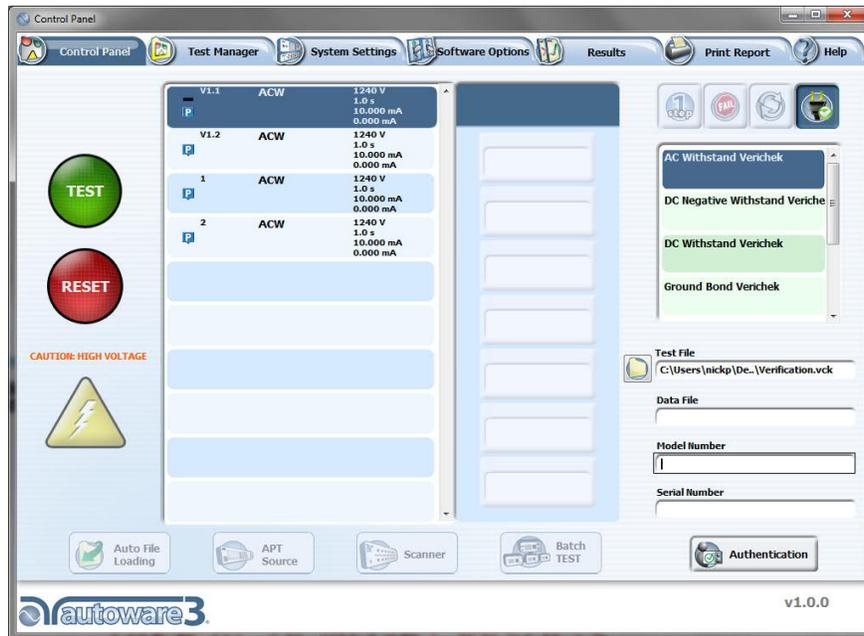
$$\text{Leakage Current (Ic)} = 120\text{V}/2,000,000 = 0.00006\text{A}$$

This leakage current should produce a failure on the test. The second test would check for a failure under normal polarity conditions. The second line leakage test is set to run at 120VAC, 60Hz, 550uA high limit, normal polarity, 5sec dwell. With a 200k Ω resistor wired from neutral to ground, the leakage current value should read about 600uA, thus producing a failure on the test.

While a Line Leakage instrument also contains various other relays, the main idea is to show that the leakage detectors on the instrument fail in the presence of excessive leakage. The two tests outlined above prove if a line leakage meter is properly reading leakage values.

Automated Testing Verification: Autaware 3 Software

Using the TVB-2 box provides an out of the box solution for running standard verification tests. However, in a production line setting, it is often advantageous to further streamline the process via automation. Associated Research Inc. has developed the Autaware 3 software to be used in tandem with the TVB-2 box to allow pre-built verification test files to be automatically downloaded as part of a test sequence. The Autaware 3 software features the VeriCHEK function which is designed to work with the TVB-2 box values. With the VeriCHEK files, customers to create custom verification test routines in order to verify the functionality of the electrical safety tester prior to executing tests. The VeriCHEK files include pre-configured Ground Continuity, Ground Bond, Insulation Resistance, and AC/DC Withstand verification routines. Users also have the ability to create a custom VeriCHEK test file. VeriCHEK files can be saved and stored independently from standard test files. The below image shows a screen shot of Autaware 3 with two VeriCHEK tests at the beginning of the test sequence.



In the above image, the VeriCHEK tests are represented by the “V” in front of the test number (V1.1 and V1.2). The VeriCHEK tests include all parameters as well as text prompts to give the user instructions for connecting the testing unit to the TVB-2 box. For more information regarding Autoware 3 and the TVB-2 box, please visit the Associated Research Inc. website: <http://www.asresearch.com/>

CONCLUSION

With the advent of microprocessor technology on electrical safety testing units, setting up instruments for test verification has become increasingly complex. Merging technology on units requires more in depth test verification than on old analog devices. Additionally, electrical safety testing instruments contain built in suppressors that are designed to protect unit circuitry. At the same time, damage to such suppressors can cause false readings on an instrument. Taking simple steps to run daily verifications can spare a great deal of trouble and effort down the road and can help avoid costly redesigns or product recalls. Using a resistor in series with the output of an electrical safety testing instrument will assist in validating measurements and ensuring that the failure detectors are functioning properly. Setting up a fixture with a series of resistors with calibrated resistor values takes the verification process one step further. Additionally, microprocessor controlled safety testing devices allow for programming and saving verification procedures. Such procedures can be setup to include working instructions and data acquisition. Verification methodology gives the operator a simple means of storing the verification test procedure as well as running validations on a daily basis. Performing regular verifications ensures that all equipment is working within NRTL specifications.

References: [1] Underwriters Laboratories, “UL Calibration Requirements: Equipment Used for UL/C-UL/ULC Mark Follow-Up Services,” Mark Integrity Program, oo-UM-C0025 Issue 4.0, 2012