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Insulation Resistance Testing Demystified

Part 1 of a 2 Part Article

Insulation Resistance Testing Demystified

By John Olobri, Director of Sales and Marketing, AEMC® Instruments

This article will attempt to explain the reasons for insulation testing, the types of testing available and the proper methods of testing. We will cover the basics and then we will look at some of the advanced testing options and methods.

In a perfect world, electrical insulation would allow no current to flow through it. Unfortunately, a number of factors can, and will, over time result in the deterioration and ultimate failure of electrical insulation. Excessive heat or cold, moisture, dirt, corrosive vapors, oil, vibration, aging, and damaged wiring can all compromise an insulation system. Faulty insulation can result in equipment underperformance and downtime, and pose a serious danger to personnel.

To assess and monitor insulation integrity, several tests have been developed. These typically involve applying a test voltage which causes a current to flow allowing the resistance to be measured. This "stress tests" the insulation, in a similar way that applying high water pressure to plumbing to test for leaks.

A regular program of resistance testing can detect insulation deterioration so it can be addressed before it becomes a major problem. Insulation resistance testing helps ensure personnel safety and optimal operation of equipment. It also helps evaluate the quality and level of repairs that may be required before equipment is put back into operation.

This article will present three commonly used methods for testing insulation resistance: the Spot Reading test, the Time Resistance test, and the Step Voltage test. These three tests are used primarily to test insulation in motors, generators, cables, transformer and other electrical apparatus.

To perform these tests, you will need a megohmmeter with a timed test function and the ability to select from a range of test voltages.

It will also be helpful to have a thermometer or similar temperature measurement device. And if the equipment temperature is below the dew point, a humidity measuring instrument will be necessary, especially when performing a spot test.

Safety

Before performing any insulation resistance test, be sure to observe the following safety measures, as well as any additional guidelines specified in the documentation that comes with your test instrument. Insulation resistance testing involves the application of high DC voltages. Properly preparing the system Continued on page 8

under test and the instrument used to conduct the test, is crucial to your safety and helps prevent damage to your wiring and machinery.

1. Take the equipment under test out of service. Shut down the apparatus, open all switches, and de-energize the unit. Disconnect from all other equipment and circuits, including neutral and protective ground connections. Be sure to follow any applicable lock-out/tag-out procedures during this step.
2. Perform a thorough inspection of the system. In general, the more equipment included in a test, the lower the resistance reading. Therefore it is critical to inspect the system and understand exactly what you're including in the test. Make note of any equipment that might be damaged by high test voltages, and either adjust the test voltage accordingly or exclude these components from the test.
3. Discharge capacitive build up before conducting an insulation resistance test. Note that modern megohmmeters automatically discharge this build-up when not running a test if the leads are connected to the device.
4. Check current leakage at switches and other connections.

When performing the test, restrict personnel access to the test site. Also, be sure to use personal protective gear such as gloves where appropriate.

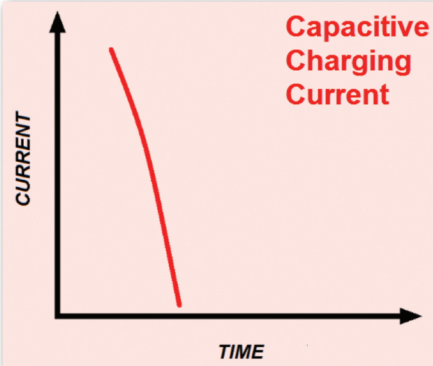
And after the test is complete, make sure the system under test is fully discharged. A minimum discharge time of four to five times the duration of the applied test voltage is recommended. As previously stated, some insulation resistance test instruments feature a built-in feature to ensure a safe discharge after the test.

There are three electrical current components involved in an insulation test that needs to be understood when conducting a test.

To properly interpret test results, it's important to understand that the total current flowing through the insulation consists of these three components: capacitance charging current, absorption current, and conduction or leakage current.

Capacitance Charging Current

When two conductors are in close proximity separated by an insulator – for exam-



ple, a length of common two-wire electrical cord — they can act as a capacitor.

When test voltage is first applied, this capacitive charging effect results in current flowing through the conductors until the voltage across the insulation reaches the test voltage. Consequently the initial resistance measurement will be relatively low and then quickly rise as the device becomes fully charged.

This effect is usually brief; often lasting less than a second (although on very long cables or large motors this can last much longer, up to 30 minutes or more). Capacitive charging current is not an indicator of insulation quality; but it needs to be accounted for to ensure your measurements are meaningful and relevant.

Absorption Current

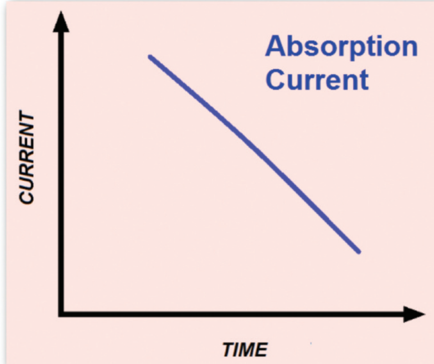
Absorption current, also called polarization absorption current, is caused by the insulating material becoming polarized by the electricity flowing through the conductor. As the polarization level increases, the absorption current decreases.

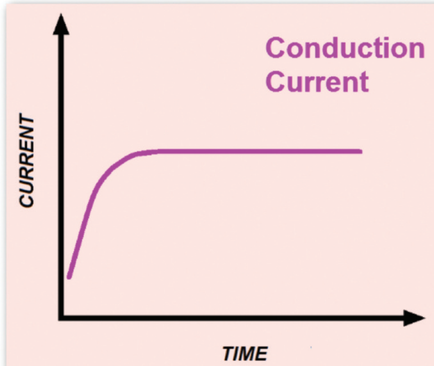
This gradual change reflects the storage of potential energy in and along the insulation. As a result, resistance is initially lower and then rises. This produces a measurement profile similar to capacitive charging current, but at a much slower rate; the effect can last from several seconds up to a minute or more.

The length of time it takes for absorption current to fall can be affected by moisture or other contaminants in the insulation material. Therefore absorption current is an important indicator of insulation integrity.

Conduction Current

Conduction current, also called leakage current, is the steady current present





both through and over the insulation.

This is a critical measurement, since an increase in conduction current over time is likely an indication of deteriorating or damaged insulation.

To summarize: for a typical test, the initial measurement primarily reflects capacitance charging current. After a period of time, absorption current is dominant. And beyond a period of time, often one to ten minutes, the measurement is mainly determined by conduction current which is the primary value used to calculate the quality of insulation resistance.

Combining these three components produces a total insulation current profile similar to the illustration shown below:

Understanding how these individual currents contribute to the total insulator current can help you correctly interpret the results you receive when performing a test.

Environmental Factors

It's also important to be mindful of how environmental factors can affect resistance. For example, oil or soot on the equipment's surface can lower insulation resistance. And if the Continued on page 12

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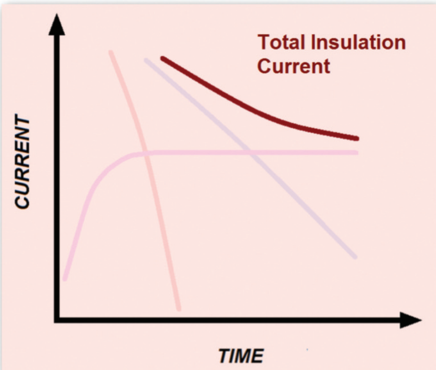
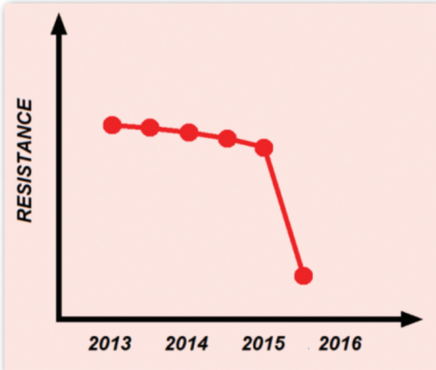
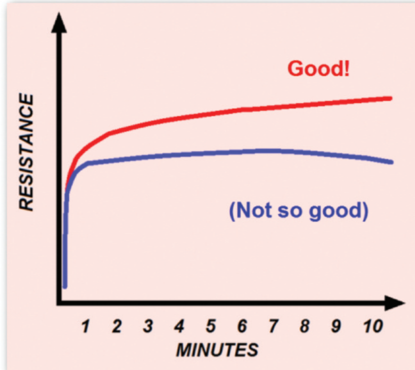






equipment's surface temperature is at or below the dew point of the ambient air, a film of moisture forms. This can significantly lower the equipment's resistance value.

Temperature is also a critical consideration. Insulation resistance can vary with temperature, with different materials exhibiting different rates of change. Ideally, all resistance testing should be done at the same temperature. If this is not possible, temperature should be carefully recorded so correction factors can be applied to the resistance measurements.

Spot Reading Test

This is a basic, relatively straightforward test method: simply connect the megohmmeter leads to the device to be tested, apply test voltage for a fixed period of time (typically not more than a few minutes), then take a resistance reading. Spot testing is suitable for a system with small or negligible capacitive effect, for example a short wiring run.

A single Spot Reading test is of limited value; but the results become meaningful when a series of tests, all featuring the same test voltage and duration, are performed periodically (typically yearly) and the results compared. This comparison can help predict a potential insulation failure in time to take corrective action.

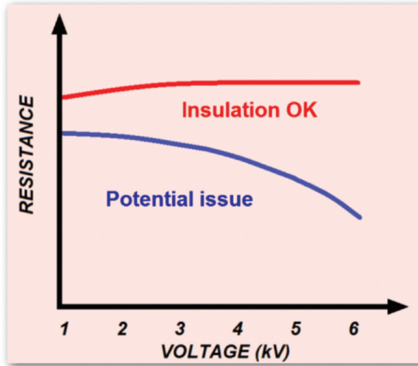
For example, suppose you perform a spot test every six months. By plotting the results on a graph, you observe a slow and gradual downward trend, as would be expected by the normal aging of the insulation. However, your latest measurement reveals a sudden drop in resistance. This is likely indication that the insulation has begun to deteriorate at an accelerated rate. To address this, you can schedule downtime for the system and take appropriate measures such as cleaning, upgrading, or replacing the insulation.

To ensure your results are valid, spot testing should ideally only be performed on systems with temperatures exceeding the dew point. If tests are performed at different temperatures, carefully record the temperature of each test and apply the appropriate correction to determine what the resistance would be if the test were performed at 20º C (68º F).

Time Resistance Test

Another insulation resistance measurement method is the Time Resistance test. Typically this test method is referred to as the dielectric absorption (DAR) or Polarization Index (PI) test depending on the length of test time. It involves noting and recording at least two readings during the test. For a DAR test it is typically the resistance measurement taken 30 seconds into the test and the measurement taken one minute into the test. For a PI test it is typically the resistance measurement taken one minute into the test and the measurement taken ten minutes into the test. The ratio is then calculated by dividing the second reading by the first reading to determine a ratio. The higher the ratio the better the insulation. In newer instruments these readings are automatically noted and the ratio automatically calculated and displayed. Although DAR is no longer commonly used with newer insulation systems; it still may have applicability when testing older insulation materials.

Plotting timed test results if readings are recorded all during the test is also very beneficial. You should see a curve



that rises relatively rapidly at first, and then continues to gradually rise throughout the testing period. If instead the curve is relatively flat or begins to turn down as the test progresses, moisture, dirt, or other factors may be compromising your insulation.

Time Resistance tests on large rotating electrical machinery, especially systems with high operating voltage, require high insulation resistance ranges and a very constant test voltage. Since this test provides meaningful results within the time duration, it is relatively independent of temperature. It is also independent of the size of the system under test.

Step Voltage Test

A third method is the Step Voltage test. This involves testing at multiple test voltages and comparing the results. The test begins at an initial test voltage. At a specified interval, typically one minute, a measurement is recorded, after which the test voltage is increased. This increase is usually five times the initial voltage. This process may be repeated through several steps, with measurements taken after one minute and the test voltage increased at a five to one ratio over the previous volt- Continued on page 14

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age. A common practice is to test at five voltage steps.

The Step Voltage test is designed to create electrical stresses on internal insulation cracks, identifying potential problems that may not be revealed by testing at lower voltages. Insulation that is thoroughly dry, clean, and in good physical condition should provide roughly the same resistance measurements across the voltage range. If instead you observe a significant decrease in resistance at higher voltage, your insulation may be contaminated or deteriorating.

Step Voltage testing is also often used as a way to dry wet cables or equipment. Gradual voltage steps, applied for increasingly longer durations, can facilitate drying through heating.

The three currents involved (capacitive, absorption and leakage) and their effect on the insulation resistance measured. The capacitive and absorption currents in the insulation are generally dissipated in a short period of time leaving the leakage current which is what we mostly want to measure to determine the quality of the insulation resistance. We also discussed the common test methods (spot, timed and step). Spot testing is effective when testing devices or cables that are resistive in nature where the capacitive and absorption currents dissipate very quickly. Not taking these two currents into account can lead to false low readings on larger equipment or long wire runs. It is also best when employing spot testing to compare the new measurement with historical data. Doing so will provide a better picture of the insulation resistance properties.

One of the most common uses of a spot test is to check the quality of electrical wiring on new installations. It is effective in finding breaks or damaged insulation.

For example, spot testing will be less effective on larger devices such as motors, pumps, valves and transformers, or long cable runs where there is capacitive and inductive properties to be considered. Timed testing should be considered with these devices. Additionally, the IEEE recommends test voltage ranges to consider for rotating machinery based on their normal operating voltage. Table 1 from IEEE-43-2000 shows these recommended test voltages.

Table 1 - Guidelines for DC voltages to be applied during insulation resistance test

Winding Rated Voltage (V)[a]	Insulation Resistance Test Direct Voltage (V)
<1000	500
1000-2500	500-1000
2501-5000	1000-2500
5001-12000	2500-5000
>12000	5000-10000

Dielectric Discharge (DD) Test Process

The Dielectric Discharge (DD) or "reabsorption current" test operates during the discharge of the dielectric.

As all three current components (charging, polarization and leakage currents) are present during a standard insulation test, the determination of polarization (absorption) current is potentially confused by the presence of the leakage current. Instead of measuring the polarization current during an insulation test, the DD test looks at the depolarization and capacitive discharge currents at the end of an insulation test.

The insulator must first be charged for a sufficient time to be "stable" (charging and polarization are complete and the only remaining component is leakage current). The insulator is then discharged and the current that flows is measured. This current constitutes the capacitive discharges and the "reabsorption currents", combining to give the total "dielectric discharge". The current is measured after a standard time of one minute, which should be greater than the primary time constant of the discharge. The result is not affected by surface leakage, which is effectively short-circuited. The current is dependent on the overall capacitance and the final test voltage. Dielectric discharge is measured as follows:

Dielectric Discharge = I(1 min) / V x C

Where I is the leakage current at the end of one minute, V is the voltage measured at the end of one minute and C is the capacitive measurement.

Test results using this equation are evaluated as follows

Bad if greater than	7
Poor	4 to 7
Questionable	2 to 4
OK if less than	2
Homogeneous	0

DD testing is generally employed to evaluate the properties of multi-layer insulation.

Utilizing the Guard Terminal

When measuring the resistance of the insulator it is also important to take into account the potential resistance path of the outer surface of the insulation. It will be part of the measurement result taken by the Megohmmeter. It can be a significant part of the measurement as well if the surface area is contaminated. In some cases the surface leakage current will be five to ten times greater than the leakage that flows through the insulation itself. It, in effect, is a parallel resistance to the resistance of the insulation. The larger the surface area along with the higher test voltages employed to test these devices, the more likely that this parallel surface path will affect the measurement. The solution is to employ the use of the guard terminal of the Megohmmeter to eliminate this unwanted leakage from the measurement process. Figures 2 and 3 show this effect and placement of the guard lead.

What to Consider When Selecting a Megohmmeter

Test Voltage

First and foremost consider the voltage levels you will need to test at on a normal basis. Plan for the highest voltage you need and consider at least one level higher for future use. Megohmmeters are generally categorized by test voltage indicating the highest test voltage they produce. Common offerings are 50V, 100V, 250V, 500V, 1kV, 5kV, 10kV and 15kV. There are specialized megohmmeters that offer higher voltages as well. A multiple range instrument will provide you with the most versatility.

Test Voltage Generation

The method of generating the test voltage is also important. The three methods are hand-crank, battery operated and AC/DC powered. Hand-crank units are ideal considerations for spot test applications that only require intermittent use as there are no batteries to replace after long periods of non-use. They are also good work horses to consider when working in areas recovering from a flood where no power or batteries are available. Battery operated units offer the convenience of portability but have a limitation on the test time. Devices with higher inductive and capacitive properties can take a long time to eliminate the capacitive charging current from the measurement. Continued on page 16

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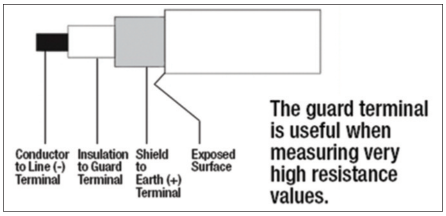

Figure 2 Effects of using the Guard terminal

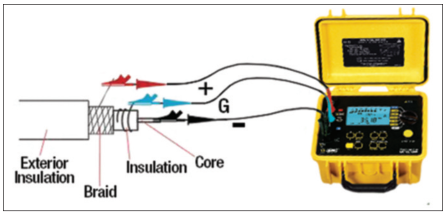

Figure 3 Guard lead placement

This time can be beyond the battery's charge capacity. AC/DC powered units that allow testing while the batteries are recharging could be your best choice. It provides the versatility of portability as well as the ability to generate the test voltages needed for long test times.

The IEEE recommends that a megohmmeter should have the ability to maintain test voltage throughout the test.

Resistance Measurement Range

Next consider the applications you will be using the instrument on and the expected insulation resistance you will need to measure. Choose a megohmmeter that can measure high enough. Many materials have insulation resistances in the Tera-Ohm (10^{12}) range. An instrument that cannot measure high enough will usually indicate some sort of over range condition. While this is at least an indication that the insulation resistance is high, it does not allow for comparative data to past measurements to determine if the insulation resistance is deteriorating or not.

Test Current

The instrument's short circuit current gives a good indication of the testing strength for testing large machinery and long cables. The higher the short circuit current, the shorter the time it will take to complete the capacitive charging. A good megohmmeter will have a short circuit current that is at least 2 to 3 times the test current.

The ability to program current limits provide a level of confidence that sensitive equipment will not be harmed by the test. This can take the form of limiting the current to a specific value, limiting the rate of change of current or allowing the maximum current which can sometimes show a visual sign of insulation failure in the form of a spark.

Safety Considerations

A good megohmmeter should also function as a volt meter when not performing an insulation test. This will give an indication of the charge on the device at the completion of the test and provide an indication if it is safe to remove the test leads. Megohmmeters should also provide the ability to automatically discharge the device under test at the completion of the test.

Insulation tests should be performed on de-energized devices. Look for megohmmeters that have a test prohibit feature preventing them from generating a test voltage if a voltage above a safe level (user programmable) is detected.

Test Leads

Test leads should be rated for the test voltage they will test at. Also consider the insulation material on the test leads themselves. Whereas PVC type insulation material is good, Silicone type insulation is much better in colder conditions and it will not be as stiff to work with.

Other Considerations

Back lighting may seem trivial but because insulation testing is conducted on de-energized devices and often in dark areas, backlighting can be of great benefit to the user.

Many megohmmeters available today come with software that provide the ability to configure the instrument thus saving a considerable amount of time on higher end instruments with a broad range of programmable options. Software also provides the ability to run tests and is a benefit where repetitive testing is required like found on production lines. Lastly but equally important is the ability to generate reports eliminating errors associated with transposing numbers or illegible documents. It also saves considerable time when comparing new data to historical data.

Megohmmeters offer a wide variety of capability and choices from the basic spot testing device to the more sophisticated instrument that lets you automate multiple test profiles and store and report data. Choosing the right one for your needs requires some thought to the applications you need to deal with on a regular basis. Picking an instrument that goes beyond your present needs can be beneficial and save you time and money in the long run. Knowing how to test properly is key to insuring good results with confidence. ❏

About the Author: *John Olobri holds degrees in both Electrical and Industrial Engineering and has worked in the design and marketing of instrumentation for over 37 years. He began his career designing Oscillographic chart recorders in the mid 1970s. Since then he has held positions of Service Manager, Product Marketing Manager and Sales Manager for several instrument manufacturers. For the past eighteen years, John has been the Director of Sales and Marketing for AEMC® Instruments where he has been actively involved in the areas of Insulation Resistance, Ground Resistance, Power Quality Testing and Data Logging. He also conducts accredited seminars on ground resistance testing in various cities around the country.*