Insulation Resistance Testing Simplified

An inside look at the reasons for testing, the types of testing available, and the proper test methods for each application

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In a perfect world, electrical insulation would allow no current to flow through it. Unfortunately, several factors can — and will — result in the deterioration and failure of electrical insulation over time. 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, as well as pose a danger to personnel.

To assess and monitor insulation integrity, several tests have been developed. These typically involve injecting a test voltage and then measuring the current. Given these two values, resistance can be calculated using Ohms law [R=E/I]. This "stress tests" the insulation in a similar way that applying high water pressure to plumbing systems tests for leaks.

A regular program of resistance testing can detect insulation deterioration so it can be addressed before it becomes a major problem (**Photo 1**). 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.

There are three commonly used methods for testing insulation resistance: spot reading test, time resistance test, and step voltage test. These three tests are used primarily to test insulation in motors, generators, cables, transformers, and other electrical apparatus. Additionally, there are two ratio test methods that are also helpful when testing rotating machinery, such as motors and pumps.

To perform these tests, it is best to have a megohmmeter with a timed test function and the ability to select from a range of test voltages. It is also helpful to have a thermometer or similar temperature measurement device on hand. 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, the local safety procedures of your organization, and the facility you are testing at. Insulation

Photo 1. A worker performs an insulation resistance test on a 50-hp 480V motor.

resistance testing involves the application of high DC voltages. Properly preparing the system under test and the instrument used to conduct the test are crucial to your safety and help 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 lockout/tagout (LOTO) procedures required 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,

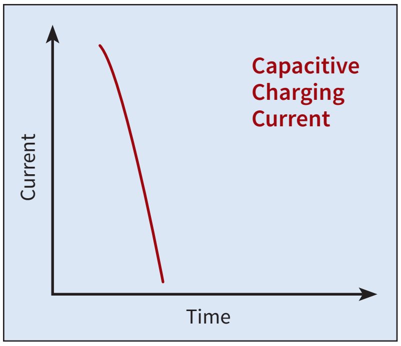

Fig 1. Typical capacitive charging current curve.

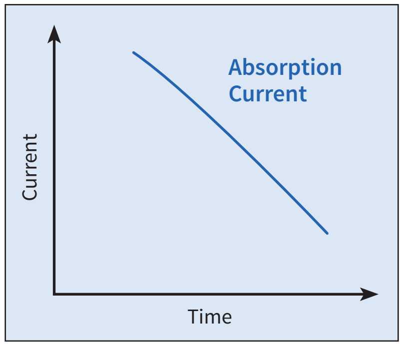

Fig 2. Typical absorption current curve.

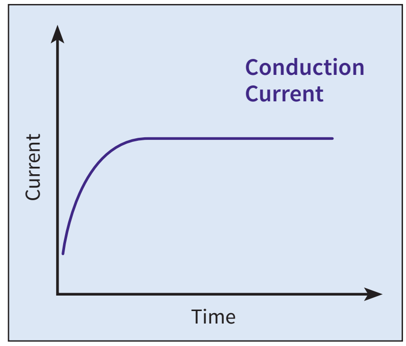

Fig 3. Typical conduction curve.

and either adjust the test voltage accordingly or exclude these components from the test.

3. Discharge capacitive buildup before conducting an insulation resistance test. Note that modern megohmmeters automatically discharge this buildup 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, safety glasses, and other protective equipment (where appropriate). 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 include a built-in feature to ensure a safe discharge after the test.

THE TESTING PROCESS

Three electrical current components involved in an insulation test need 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 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 example, 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 (**Fig. 1**). 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 under one second (although on very long cables or large motors this can last 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 (**Fig. 2**).

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 like capacitive charging current but at a much slower rate; the effect can last from several seconds up to a minute or more.

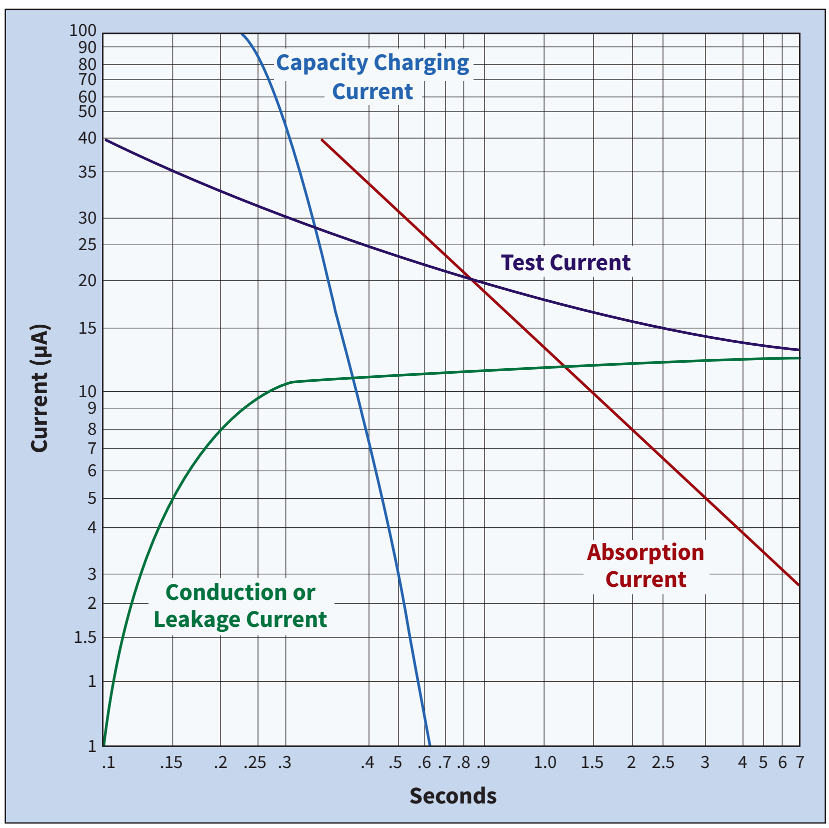

Fig 4. Composite graph of the three electrical current components of an insulation test.

What to Consider When Purchasing an Insulation Test Instrument

If you are considering purchasing a new megohmmeter, here are some points to consider.

Voltage requirements:

- Plan for the highest voltage you need.
- Consider multiple range instruments; it will give you more flexibility.
- Consider the voltage generation method (hand-crank, battery operated, AC/DC powered). For long test times, AC/DC-powered instruments are best.

Resistance measurement capability:

- Consider a meter that can measure into the Tera Ohm range.

Test current:

- IEEE recommends the availability of 1mA of test current and the ability to hold the test voltage throughout the total test time for valid test results.
- Short-circuit current should be two to three times the available test current to accommodate testing equipment with higher inductive properties in shorter time.

Safety conditions:

- Should function as a voltmeter when not performing an insulation test.
- Should automatically discharge the device under test.
- Should inhibit the test if live voltage detected.
- Test leads should be rated for the test voltage.
- Output should be fused.

Other features:

- Ability to do timed tests.
- Automatic calculation of PI and DAR ratios.
- Automatic display of discharge voltage.
- Display capacitance and leakage current values.
- Ability to automatically conduct step voltage testing.
- Back lighting.
- Ability to configure instrument, run tests, and generate reports from a PC.

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

Conduction current (aka leakage current)

Conduction current, also called leakage current, is the steady current present both through and over the insulation (**Fig. 3** on page 42). This is the critical measurement, since an increase in leakage current over time is likely an indication of deteriorating or damaged insulation.

For a typical test, the initial measurement primarily reflects capacitance charging current. After a period of time, absorption current is dominant. Beyond a period of time, often one minute to 10 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 like the one shown in **Fig. 4** on page 42.

Understanding how these individual currents contribute to the total insulation 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. If the 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, then 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 more than a few minutes), and 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 large drop in resistance. This is likely an indication that the insulation has begun to deteriorate at an accelerated rate (**Fig. 5** on page 46). To address this, you can schedule downtime for the

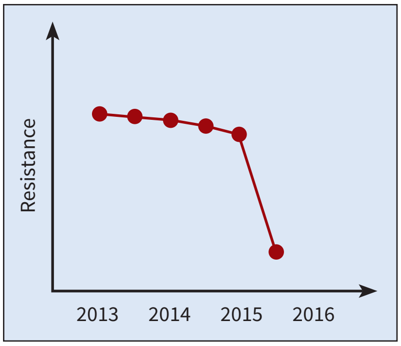

Fig 5. Typical example of insulation degradation over time.

Fig 6. Plot of good and bad insulation resistance shown from time resistance testing.

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 20°C (68°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

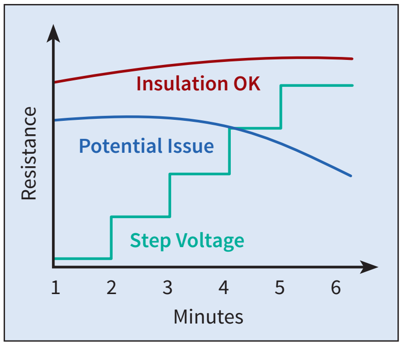

Fig 7. Plot of good and bad insulation resistance shown from step voltage testing.

measurement taken 10 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 test 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 has applicability when testing older insulation materials and/or materials that have a PI ratio of less than 2.

Plotting timed test results if readings are recorded all during the test is also beneficial. You should first see a curve that rises relatively rapidly, and then continues to gradually rise throughout the testing period (**Fig. 6**). If the curve is relatively flat or begins to turn down as the test progresses, then 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 process is repeated through several steps, with measurements taken after one minute at each step. 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 (**Fig. 7**). Insulation that is thoroughly dry, clean, and in good physical condition should provide roughly the same resistance measurements across the voltage range. If you observe a significant decrease in resistance at higher voltage, your insulation may be contaminated or deteriorating.

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

IN SUMMARY

Insulation resistance testing is easy to perform correctly once you understand the basic principles. Some devices have mostly resistive characteristics and can be tested quickly using the spot test method. Comparing the test results to previous tests will give you a trend that is valuable in determining the possible need for preventive maintenance. Remember that temperature plays an important role in obtaining the proper results.

Larger equipment, such as motors, pumps, and long cable runs, have inductive properties that need to be considered when testing insulation resistance. The timed test method (along with the ratio tests of DAR and PI) are best used to achieve an accurate indication of the health and quality of the insulation. Capacitive and absorption currents must be dissipated before you can get the actual leakage current measurement needed to calculate insulation resistance. Although these tests take longer to perform than the spot test method, they have the advantage of being independent of the temperature to provide accurate results.

Step voltage testing is like timed testing with the advantage of not over stressing sensitive equipment by gradually applying the test voltage. For your own safety, always remember when doing a timed test to allow the discharging to take place before you remove the test leads.

An understanding of these fundamental requirements will help ensure that you perform the test properly, complete the job with confidence, and stay safe in the process. **EC&M**