CHAUVIN® ARNOUX
CHAUVIN ARNOUX GROUP

50 to 5000 VDC Megohmmeters

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Insulation Resistance Testing Guide

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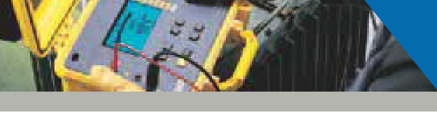


Electrical insulation testing

All electrical installations and equipment comply with insulation resistance specifications so they can operate safely. Whether it involves the connection cables, the sectioning and protection equipment, or the motors and generators, the electrical conductors are insulated using materials with high electrical resistance in order to limit, as much as possible, the flow of current outside the conductors.

The quality of these insulating materials changes over time due to the stresses affecting the equipment. These changes reduce the electrical resistivity of the insulating materials, thus increasing leakage currents that lead to incidents which may be serious in terms of both safety (people and property) and the costs of production stoppages.

In addition to the measurements carried out on new and reconditioned equipment during commissioning, regular insulation testing on installations and equipment helps to avoid such incidents through preventive maintenance. These tests detect aging and premature deterioration of the insulating properties before they reach a level likely to cause the incidents described above.

At this stage, it is a good idea to clarify the difference between two types of measurements which are often confused: dielectric testing and insulation resistance measurement.

Dielectric strength testing, also called "breakdown testing", measures an insulation's ability to withstand a medium-duration voltage surge without sparkover occurring. In reality, this voltage surge may be due to lightning or the induction caused by a fault on a power transmission line. The main purpose of this test is to ensure that the construction rules concerning leakage paths and clearances have been followed. This test is often performed by applying an AC voltage but can also be done with a DC voltage. This type of measurement requires a **hipot tester**. The result obtained is a voltage value usually expressed in kilovolts (kV). Dielectric testing may be destructive in the event of a fault, depending on the test levels and the available energy in the instrument. For this reason, it is reserved for type tests on new or reconditioned equipment.

Insulation resistance measurement, however, is non-destructive under normal test conditions. Carried out by applying a DC voltage with a smaller amplitude than for dielectric testing, it yields a result expressed in kΩ, MΩ, GΩ or TΩ. This resistance indicates the quality of the insulation between two conductors. Because it is non-destructive, it is particularly useful for monitoring insulation aging during the operating life of electrical equipment or installations. This measurement is performed using an insulation tester, also called a **megohmmeter**.

Insulation and causes of insulation failure

Because measuring insulation with a megohmmeter is part of a wider preventive maintenance policy, it is important to understand the different possible causes of insulation performance deterioration so that you can take steps to correct it.

It is possible to divide these causes of insulation failure into five groups, while keeping in mind, if no corrective measures are implemented, these different causes are superimposed, leading to insulation breakdown and equipment failure.

Electrical stresses:

Mainly linked to overvoltages and undervoltages.

Mechanical stresses:

Frequent start-up and shutdown sequences can cause mechanical stresses. Also, balancing problems on rotating machinery and any direct stress to the cables and the installations in general.

Chemical stresses:

The proximity of chemicals, oils, corrosive vapors and dust, in general, affects the insulation performance of the materials.

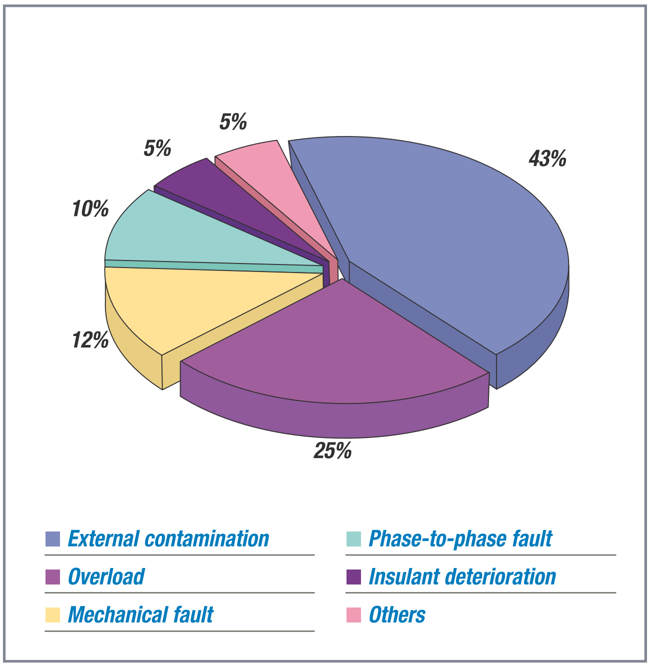
Stresses linked to temperature variations:

When combined with the mechanical stresses caused by the start-up and shutdown sequences, expansion and contraction stresses affect the properties of the insulating materials. Operation at extreme temperatures also leads to aging of the materials.

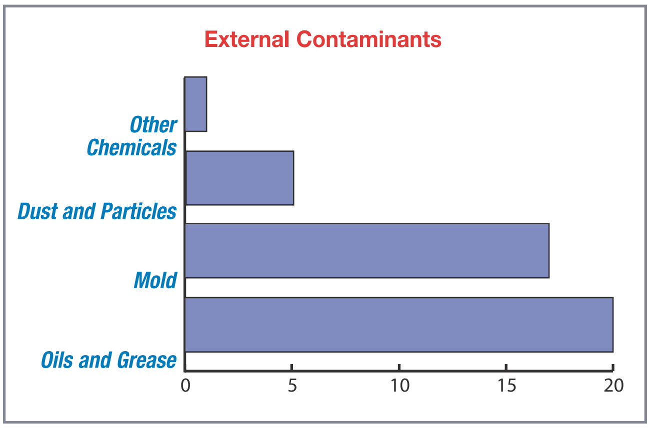
Environmental contamination:

The build-up of mold and particulate deposits in warm, moist environments also contributes to the deterioration of installations' insulation properties.

The chart below shows the relative frequency of the various causes of an electric motor failure.



Reference: AEMC® Instruments



Reference: AEMC® Instruments

In addition to sudden insulation faults due to exceptional events such as flooding, factors liable to reduce insulation performance are combined when the installation is started up, sometimes amplifying one another. In the long term, without monitoring, this will eventually lead to situations which may be critical in terms of both people's safety and operational considerations. Regular testing of the insulation on an installation or machine is therefore a useful way of monitoring this type of deterioration so you can act before total failure occurs.

Principle of insulation testing and influencing factors

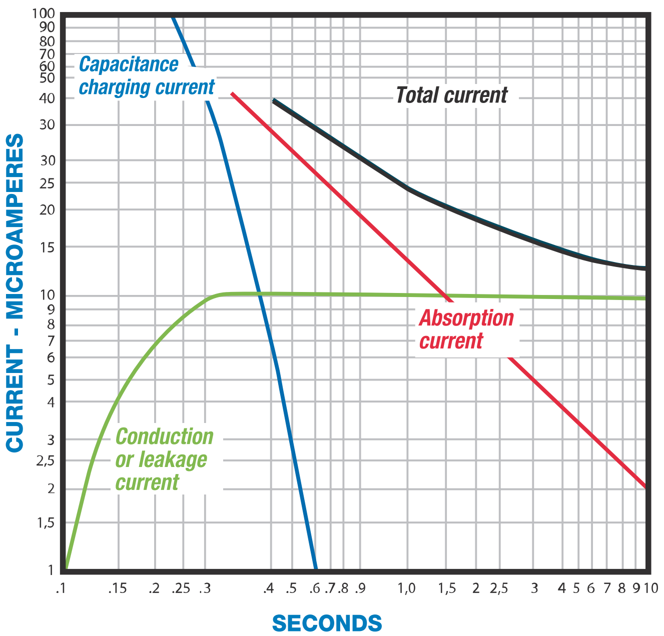
Insulation resistance measurement is based on Ohm's Law. By injecting a known DC voltage lower than the voltage for dielectric testing and then measuring the current flowing, it is very simple to determine the value of the resistance. In principle, the value of the insulation resistance is very high but not infinite, so by measuring the low current flowing, the megohmmeter indicates the insulation resistance value, providing a result in kΩ, MΩ, GΩ and also TΩ (on some models). This resistance characterizes the quality of the insulation between two conductors and gives a good indication of the risks of leakage currents flowing.

A number of factors affect the value of the insulation resistance and therefore the value of the current flowing when a constant voltage is applied to the circuit being tested. These factors, such as temperature or humidity for example, may significantly affect the measurement result. First let's analyze the nature of the currents flowing during an insulation measurement, using the hypothesis that these factors do not influence the measurement.

The total current flowing in the insulating material is the sum of three components:

- **Capacitance:** The capacitance charging current necessary to charge the capacitance of the insulation being tested. This is a transient current which starts relatively high and falls exponentially towards a value close to zero once the circuit being tested is charged electrically. After a few seconds or tenths of seconds, this current becomes negligible compared with the current to be measured.
- **Absorption:** The absorption current, corresponding to the additional energy necessary for the molecules of the insulating material to reorient themselves under the effect of the electrical field applied. This current falls much more slowly than the capacitance charging current, sometimes requiring several minutes to reach a value close to zero.
- **Leakage current:** The leakage current or conduction current. This current characterizes the quality of the insulation and is stable over time.

The graph below shows these three currents as a function of time. The time scale is indicative and may vary depending on the insulation tested.
Very large motors or very long cables may take 30 to 40 minutes before the capacitive and absorption currents are minimized enough to provide proper test results.



Reference: AEMC® Instruments

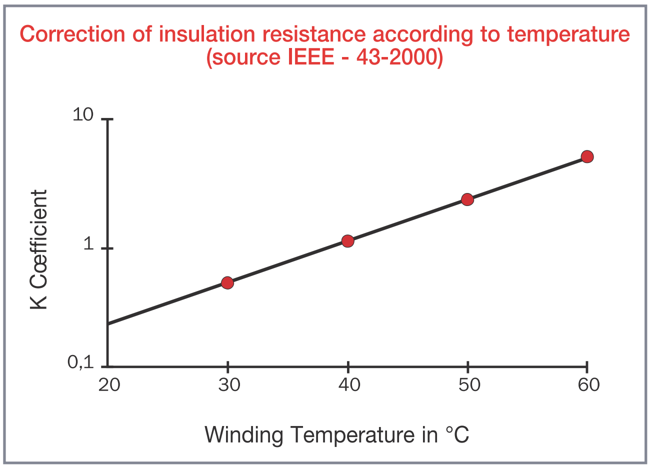
With the circuit supplied at a constant voltage, the total current flowing in the insulant being tested varies over time. This implies a significant resulting variation of the insulation resistance.

Before examining the various measurement methods in detail, it would be useful to look again at the factors that influence the insulation resistance measurement.

Influence of temperature:

The temperature causes the insulation resistance value to vary quasi-exponentially. In the context of a preventive maintenance program, the measurements should be carried out in similar temperature conditions or, if this is not possible, should be corrected so that they are expressed in relationship to the reference temperature. For example, as a rough guideline, a 10 °C increase in temperature halves the insulation resistance, while a 10 °C reduction doubles the insulation resistance value.

The level of humidity influences the insulation according to the degree of contamination of the insulating surfaces. Care must always be taken not to measure the insulation resistance if the temperature is lower than the dew point.



Reference: AEMC® Instruments

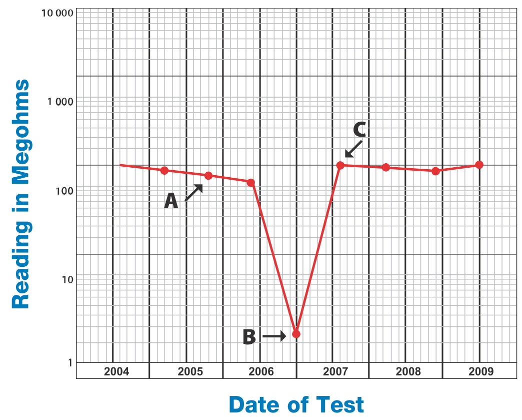
Testing methods and interpretation of the results

Short-time or spot-reading measurement

This is the simplest method. It involves applying the test voltage for a short time (30 or 60 seconds) and noting the insulation resistance reading at that moment. As indicated previously, this direct measurement of the insulation resistance is significantly affected by the temperature and humidity, so the measurement should be standardized at a reference temperature and the level of humidity should be noted for comparison with the previous measurements. With this method, it is possible to analyze insulation quality by comparing the current measured value with several previous test results. This trend, over time, is more representative of the evolution of the insulation characteristics on the installation or equipment being tested than a single test.

If the measurement conditions remain identical (same test voltage, same measurement time, etc.), it is possible to obtain a clear assessment of the insulation by monitoring and interpreting any changes in these periodic measurements. After noting the absolute value, the variation over time should be analyzed. Thus, a measurement showing a relatively low insulation value which is nevertheless stable over time is, in theory, less of a concern than a significant decrease in the insulation value over time, even if the insulation is higher than the recommended minimum. In general, any sudden fall in the insulation resistance is evidence of a problem requiring investigation.

The graph below shows an example of the insulation resistance readings on an electric motor.



*At **A**, the insulation resistance decreases due to aging and dust accumulation.*

*The sharp fall at **B** indicates there was an insulation fault.*

*At **C**, the fault has been repaired (rewinding of the motor) so the insulation resistance has returned to a higher value and has remained stable over time, indicating a good conition.*

Reference: AEMC® Instruments

Testing methods based on the influence of the test voltage application time (PI & DAR)

These methods involve measuring successive insulation resistance values at specified times. They have the advantage of not being particularly influenced by temperature, so they can be applied, without correcting the results, as long as the test equipment is not subject to significant temperature variations during the test.

They are ideal for preventive maintenance on rotating machines and for monitoring insulation.

If the insulation material is in good condition, the leakage or conduction current is low and the initial measurement is strongly influenced by the capacitance charging and dielectric absorption currents. The insulation resistance measurement will rise during the time when the test voltage is applied because these disturbance currents decrease. The stabilization time necessary for measurements on insulation in good condition depends on the type of insulation material.

If the insulation material is in poor condition (damaged, dirty and wet), the leakage current is constant and very high, often exceeding the capacitance charging and dielectric absorption currents. In such cases, the insulation resistance measurement will very quickly become constant and stabilize at a high voltage.

By examining the variations of the insulation value according to the test voltage application time, it is possible to assess the quality of the insulation. This method allows conclusions to be drawn even if there is no insulation measurement log, but it is nevertheless advisable to record the periodic measurements carried out in the context of a preventive maintenance program.

Polarization Index (PI)

For this method, two readings are taken at 1 minute and 10 minutes, respectively. The ratio (without dimensions) of the 10-minute insulation resistance over the 1-minute value is called the Polarization Index (PI) and can be used to assess the quality of the insulation.

The measurement method using the polarization index is ideal for testing solid insulating circuits. Because of this, it is not recommended for use on equipment such as oil-immersed transformers as it will give low results even if the insulation is in good condition.

The IEEE 43-2000 recommendation on "Recommended Practice for Testing Insulation Resistance of Rotating Machinery" defines the minimum value of the Polarization Index (PI) for AC and DC rotating machinery in temperature classes B, F and H as 2.0. More generally a PI greater than 4 is a sign of excellent insulation, while an index under 2 indicates a potential problem.

PI = R10-minute insulation / R1-minute insulation

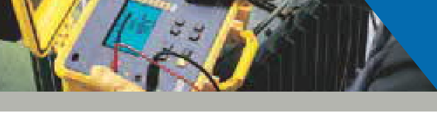
The results are interpreted as follows:

PI Value	Insulation condition
< 2	Problem
2 to 4	Good
> 4	Excellent

Dielectric Absorption Ratio (DAR)

For installations or equipment containing insulation materials in which the absorption current decreases quickly, insulation measurements after 30 seconds and 60 seconds may be sufficient to qualify the insulation. The DAR is defined as follows:

DAR = R60-second insulation / R30-second insulation



The results are interpreted as follows:

DAR value	Insulation condition
< 1.25	Insufficient
< 1.6	OK
> 1.6	Excellent

Method based on the influence of test voltage variation (Step voltage test)

The presence of contaminants (dust, dirt, etc.) or moisture on the surface of the insulation is usually clearly revealed by time-dependent resistance measurements (PI, DAR, etc.). However, aging of the insulation or mechanical damage may sometimes be missed by this type of test, carried out with a low voltage in relation to the dielectric voltage of the insulating material tested. A significant increase in the test voltage applied may, on the contrary, cause these weak points to fail, leading to a considerable reduction in the insulation value measured.

To be effective, the ratio between voltage steps should be 1 to 5, and each step must last the same time (typically 1 to 10 minutes), while remaining below the classic dielectric test voltage (2 Un + 1000 V). The results from this method are totally independent of the type of insulation and the temperature because the method is not based on the intrinsic value of the insulants measured, but on the effective reduction of the value read after an identical time with two different test voltages.

A reduction of 25% or more between the first-step and second-step insulation resistance values is a sign of insulant deterioration usually linked to the presence of contaminants.

Dielectric Discharge (DD) Test method

The dielectric discharge (DD) test, also known as the re-absorption current test, is performed by measuring the current during dielectric discharge of the equipment being tested.

As all three components of the current (capacitance charging current, polarization current and leakage current) are present during a standard insulation test, the determination of the polarization or absorption current may be affected by the presence of the leakage current. Instead of trying to measure the polarization current during the insulation test, the dielectric discharge (DD) test measures the depolarization current and the capacitance discharging current after the insulation test.

The measurement principle is as follows: the equipment to be tested is first charged for long enough to reach a stable state (capacitance charging and polarization are completed and the only current flowing is the leakage current). The equipment is then discharged through a resistor inside the megohmmeter and the current that flows is measured. This current is made up of the capacitance charging current and the re-absorption current, which combine to give the total dielectric discharge current. This current is measured after a standard time of 1 minute. The current depends on the overall capacitance and the final test voltage. The value DD is calculated using the formula:

DD = Current after 1 minute / (Test voltage x Capacitance)

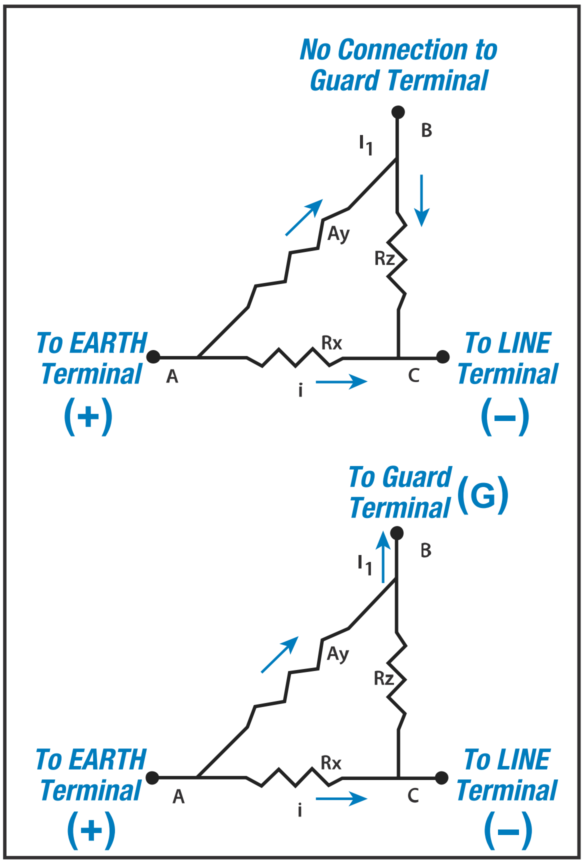
The DD test can identify excess discharge currents occurring when one of the layers of multi-layer insulation is damaged or contaminated, a defect that may be missed by spot tests or PI and DAR tests. The discharge current will be higher for a given voltage and capacitance if one of the insulation layers is damaged. The time constant of this individual layer will no longer match that of the other layers, leading to a higher current value than for undamaged insulation. Homogeneous insulation will have a DD value close to zero, while acceptable multi-layer insulation will have a DD value of up to 2. The table below indicates the sanctions according to the DD value obtained.

DD	Condition
> 7	Bad
4 to 7	Poor
2 to 4	Questionable
< 2	OK

Caution: This measurement method is temperature dependent, so every attempt should be made to perform the test at a standard temperature or at least to note the temperature alongside the test result.

High insulation testing: Using the guard terminal

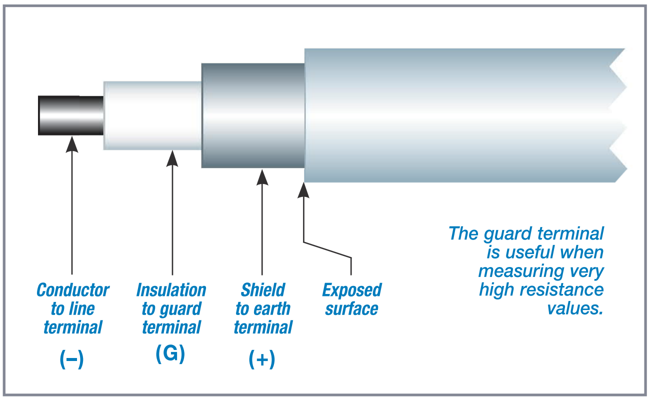
When measuring high insulation resistance values (more than 1 GΩ), the accuracy of the measurements may be affected by leakage currents flowing on the surface of the insulating material via the humidity and surface contaminants, whose resistance value is no longer very high and is therefore negligible compared with the resistance of the insulation that you are trying to assess. In order to eliminate this surface leakage current, which reduces the accuracy of insulation measurements, some megohmmeters include a third terminal called the guard terminal. This guard terminal shunts the measurement circuit and re-injects the surface current at one of the test points, bypassing the measurement circuit (see diagram below).



Reference: AEMC® Instruments

The first circuit, without a guard terminal, simultaneously measures the leakage current i and the unwanted surface current I1, so the insulation resistance measurement is incorrect.

The second circuit, however, only measures the leakage current i. The connection to the guard terminal drains the surface current I1, so the insulation resistance measurement is correct.



Reference: AEMC® Instruments

The guard terminal must be connected to a surface that allows surface currents to flow, which is not the case of insulants such as cable or transformer insulation materials. Thorough knowledge of the possible paths taken by the test current when flowing through the element tested is crucial for choosing where to position the connection to the guard terminal.

Selecting the test voltage

Cable/Equipment operating voltage	DC test voltage
24 to 50 V	50 to 100 VDC
50 to 100 V	100 to 250 VDC
100 to 240 V	250 to 500 VDC
440 to 550 V	500 to 1000 VDC
2400 V	1000 to 2500 VDC
4100 V	1000 to 5000 VDC
5000 to 12,000 V	2500 to 5000 VDC
> 12,000 V	5000 to 10,000 VDC

The table above shows the recommended test voltages according to the operating voltages of installations and equipment (taken from the IEEE 43-2000 Guide).

In addition, these values are defined for electrical appliances in a wide variety of local and international standards (IEC 60204, IEC 60439, IEC 60598, etc.).

In France, for example, the NFC15-100 standard stipulates the test voltage values and the minimum insulation resistance for electrical installations (500 VDC and 0.5 MΩ for a rated voltage of 50 to 500 V).

However, you are strongly advised to contact the cable/equipment manufacturer to find out about their own recommendations on the test voltage to be applied.

Testing safety

Before the test:

A The test must be carried out on a disconnected, NONCURRENT-CARRYING installation to ensure that the test voltage will not be applied to other equipment connected electrically to the circuit to be tested.

B Make sure that the circuit is discharged. It can be discharged by short-circuiting the equipment's terminals and/or connecting them to earth for the specified time (see discharge time).

C Special protection is necessary if the equipment to be tested is in a flammable or explosive environment, as sparks may occur while the insulation is discharging (before and after the test), as well as during the test if the insulation is faulty.

D Because of the presence of DC voltages which may be high, it is advisable to restrict access for other personnel and to wear individual protective equipment (i.e. protective gloves) for electrical applications.

E Only use connection cables suitable for the test to be performed and make sure that they are in good condition. In the best-case scenario, unsuitable cables will cause measurement errors, but even more importantly, they may be dangerous.

After the test:

By the end of the test, the insulation has accumulated a considerable amount of energy which needs to be discharged before any other operations can be attempted. One simple safety rule is to allow equipment to discharge for FIVE times the charging time (time of last test). The equipment can be discharged by short-circuiting the poles and/or connecting them to the earth. All the megohmmeters manufactured by Chauvin Arnoux are equipped with internal discharge circuits which ensure safe, automatic discharging.

Frequently asked questions

My measurement result is x megohms. Is that OK?

There is no single reply to this question. The equipment manufacturer or the applicable standards can answer it definitively. For LV installations, 1MΩ can be considered the minimum value. For installations or equipment operating at higher voltages, a good rule of thumb gives a minimum value of 1 MΩ per kV, while the IEEE guidelines concerning rotating machinery recommend a minimum insulation resistance of (n+1) MΩ, where n is the operating voltage in kV.

Which measurement leads should be used to connect the megohmmeter to the installation to be tested?

The leads used on the megohmmeters must have suitable specifications for the measurements carried out, in terms of the voltages used or the quality of the insulating materials. If unsuitable measurement leads are used, it may cause measurement errors or even prove dangerous.

What precautions should be taken for high insulation measurements?

In addition to the safety rules indicated above, specific precautions should be taken when measuring high insulation values.

- Use the guard terminal (see the paragraph explaining this).
- Use clean, dry leads.
- Set up the leads at a distance from one another and without contact with any objects or with the floor to limit the possibility of leakage currents within the measurement line itself.
- Do not touch or move the leads during measurement to avoid capacitive effects leading to disturbances.
- Wait for the necessary stabilization time for spot measurements.

Why do two consecutive measurements not always give the same result?

The application of a high voltage causes an electrical field which polarizes the insulating materials. It is important to understand that, after the test, the insulating materials will require what may be a considerable time to return to the state they were in before the test. This time may be significantly longer in some cases than the discharge times indicated previously.

I can't shut down the installation, so how can I check the insulation?

If it is not possible to switch off the power supply to the installation or equipment to be tested, a megohmmeter can obviously not be used. In some cases, it is possible to carry out a live test using a leakage-current measurement clamp, but this method is much less accurate.