

# Insulation Resistance Testing: How Many Megohms Does it Take to Start a Motor?



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All of us in the electrical service industry test the winding ground insulation resistance of machines such as motors and generators. A frequent question is: What is the minimum acceptable megohm value for this winding? Fortunately there is a standard that identifies minimum values for insulation resistance of rotating machines. That standard is *IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery*, IEEE Standard 43-2000.

Before going into the topic of minimum insulation resistance, let's go through a brief refresher on the insulation resistance test. The primary reasons for an insulation resistance test are to determine if a machine can be placed back into service or if high potential winding tests such as high potential or surge comparison can prudently be performed. Another important reason for the insulation resistance test is to establish a baseline value for the winding insulation condition of an installed machine. If the winding insulation resistance value is below the acceptable minimum, the machine should not be energized and high potential tests should not be performed until the insulation resistance value meets or exceeds the prescribed minimum.

Good winding ground insulation behaves like a capacitor, becoming charged when voltage is applied across it. According to IEEE 43, the insulation resistance value should be taken after applying and maintaining constant test voltage on the winding for one minute. That allows some of the capacitive effect to stabilize, making the readings more consistent. A common error in performing an insulation resistance test is to take the reading after just a few seconds. The result is inconsistency in the readings, especially with larger machines whose windings take a relatively long time to reach stability.

The most common instrument used for the test for motors and generators is the battery powered 500 or 1000 volt dc megohmmeter. One lead is applied to the winding leads (typically all tied to the instrument lead) and the other instrument lead to the frame (ground) of the machine. The meter actually applies a voltage, measures the current, and then displays the value of voltage divided by current, i.e., resistance in megohms. As previously mentioned, the megohmmeter voltage should be applied and held for one minute, and the reading at one minute is recorded as the insulation resistance value for the test. The recommended test voltage to apply with the megohmmeter increases with machine voltage rating as illustrated in Figure 1.

Winding rated voltage ac or dc	Insulation resistance test voltage dc
< 1000	500
1000 - 2500	500 - 1000
2501 - 5000	1000 - 2500
5001 - 12000	2500 - 5000
>12000	5000 - 10000

Figure 1 — Insulation resistance test voltages versus machine rated voltages.

Winding temperature affects the megohm value test result. As temperature increases, insulation resistance decreases. The cause is not winding degradation with temperature but is a physical property of the insulation. The insulation resistance reading must, therefore, be corrected for temperature. The temperature correction per IEEE 43 should be to 40 °C, and the correction factor for temperature is such that the minimum insulation resistance value is doubled for every 10 °C decrease in winding temperature. Figure 2 can be used to graphically convert temperatures to 40 °C. Note: Windings that are very hot, for example over 100 °C due to the motor or generator having just been shut down, may result in relatively low megohm values. Allow the winding to cool to 60 °C or lower and then perform a temperature corrected IR test.

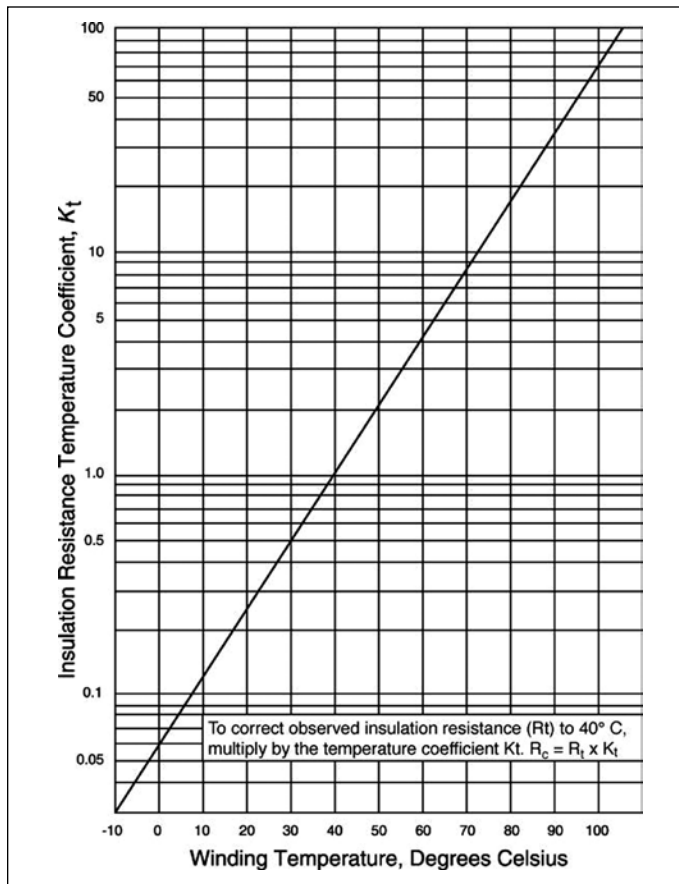


Figure 2 — Insulation resistance versus temperature.

Expressed as a formula the temperature correction factor is:

$$K_t = (0.5)^{(40-T)/10}$$

$K_t$  Factor to multiply  $T$  by to obtain insulation resistance corrected to 40 °C

$T$  Temperature in °C at which insulation resistance was measured

Here is an example for a winding being tested that has its insulation temperature at 35 °C:

$$K_t = (0.5)^{(40-35)/10} = (0.5)^{5/10} = (0.5)^{1/2} = 0.707$$

If the measured insulation resistance was 100 megohms at 35 °C, the corrected megohms would be:

$$100 \times 0.707 = 70.7 \text{ or about } 71 \text{ megohms at } 40 \text{ °C.}$$

Humidity can affect insulation resistance readings; however, there are no formulas or "rules of thumb" for the effect of humidity with respect to rotating electrical machine windings. Nonetheless, it is a good practice to record the humidity reading as well as winding temperature and insulation resistance for each insulation resistance test. Knowing

these parameters, insulation resistance readings can be evaluated for the possible effect of humidity, recognizing that at higher humidity the insulation resistance reading may be lower for a specific temperature.

Having considered how to perform the insulation-resistance test, we will now address interpretation of the results. For many years the IEEE 43 standard used the rule of "kV + 1" (1 kV = 1000 volts) to determine the minimum megohms for rotating electrical machinery. After nearly three decades of being reaffirmed, from 1974 to 2000, the standard was significantly revised for the 2000 edition. IEEE 43 now states that "for most dc armature and ac windings built after about 1970 (form-wound coils)" the minimum insulation resistance is 100 megohms. The standard also states that "for most machines with random wound stator coils and form-wound coils rated below one kV" the minimum insulation resistance is five megohms. Capturing the remaining windings, IEEE 43 states that "for most windings made before about 1970, all field windings, and others not described" above, the minimum insulation resistance is kV+1. For a 460 volt winding the minimum, using the former "kV+1" rule, would be  $0.46 + 1 = 1.46$  megohms, whereas the minimum is now five megohms.

Note that all of these minimum values are based on a winding temperature of 40 °C. The winding rated voltage can be either ac or dc, and the standard calls for using the line-to-line voltage for three phase windings, line-to-ground voltage for single phase windings, and (nameplate) rated voltage for dc machines or field windings. If the insulation resistance is below the minimum levels as described above, the machine should not be energized or high potential tested. Corrective measures, such as cleaning and baking, should be taken to increase the insulation resistance value to an acceptable level.

We will use some examples to demonstrate the application of the minimum insulation resistance rules. Our first example is a form-wound stator winding rated 4160 volts, with an insulation resistance test result of 80 megohms at 20 °C. Recalling that every 10 °C decrease results in a halving of the minimum insulation resistance value, the 20 °C difference means we halve the insulation resistance value twice ( $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$ ), that is, it is reduced by a factor of 4. The result is that the corrected insulation resistance value is 20 megohms ( $80 \div 4$ ) at 40 °C, a value much less than the minimum insulation resistance of 100. The insulation resistance of this winding is not acceptable, and corrective measures should be taken.

The second example is a random wound direct current motor armature rated 500 volts dc with an insulation resistance of 46 megohms at 30 °C. Correcting the megohm value from 30 °C to 40 °C, a 10 °C increase, the result is 23 megohms ( $46 \div 2$ ). The 23 megohm value exceeds the five megohm minimum value; therefore the armature could be energized or high potential tested if desired. However, the motor should not be energized until the fields are also tested to determine if their insulation resistance value is satisfactory.

The field windings of the random wound armature ma-

chine will be used for our third example. The field voltage rating is 150/300 volts and the insulation resistance value at 25 °C is 28 megohms. The 15 °C (40 °C – 25 °C) difference dictates that we use the Kt correction factor formula given above. For the sake of brevity we will omit displaying the math and use the resulting factor of 0.354. The corrected value is 9.9 megohms (28 x 0.354), and the minimum insulation resistance per the standard is 1.3 megohms (kV + 1). Notice that we used the higher voltage rating of the winding to determine the minimum acceptable megohm value. Since the 9.9 megohm result is greater than the 1.3 megohm minimum, the fields can be energized or high potential tested if desired. Also, since both fields and armature insulation resistance values are satisfactory, the motor can be energized and placed back in operation.

Another potentially useful assessment is to apply the insulation resistance test at the lower recommended test voltage, discharge the winding, and repeat the insulation resistance test at the higher recommended test voltage. For example, apply 1000 volts to a winding rated 4160 volts and obtain the insulation resistance, discharge the winding and repeat the insulation resistance test at 2500 volts. The winding can be discharged after the IR test by connecting the winding leads together and to ground, e.g., the frame of the electrical machine. If the insulation resistance values are about the same at both voltages, and exceed the minimum insulation resistance recommendations, the winding ground insulation is probably in satisfactory condition. Conversely, if the insulation resistance value decreases with applied voltage there is a weakness in the insulation system that should be corrected.

In addition to temperature and humidity, other factors that can affect megohmmeter readings are the instruments and the method of application of the test. The implied accuracy of an instrument may change when the megohm scale is changed. By implied we mean the number of significant digits. For example, a reading of 190 megohms on the 1000-megohm scale of a meter may be indicated more accurately as 185 megohms on the 200-megohm scale. The 1000-volt scale has two-place accuracy in this case when reading up to 200 megohms, and three-place accuracy on the 200-megohm scale.

Another factor is the charging current decay and change in reading as voltage is reapplied. Winding insulation forms a capacitor with the winding and ground conductors and the current across it becomes lower with time. Applying the megohmmeter and maintaining the voltage causes the capacitive current to decrease, thus increasing the megohm value (recall that megohms are equal to volts divided by microamperes). If the megohm reading at one minute is obtained from one lead of a winding and the megohmmeter is reapplied to another lead of that winding, the second megohm test value will be higher than the first. The reason is that some of the winding capacitance has been charged by the first test, thus the second test begins at a megohm value greater than that of an uncharged winding. This case applies when the leads of the winding being tested are interconnected internally, that is, there is continuity among all the leads. When there are separate windings, such as with a six-lead wye-delta motor with separate circuits of leads 1-4, 2-5 and 3-6, each circuit should be tested individually.

A final note of caution: Make certain that the machine to be tested has been ventilated prior to the insulation resistance test, particularly if a winding fault is suspected. Gases from the fault (or from a volatile substance such as a solvent) may be ignited by the insulation resistance test if an arc occurs during the test. ⚡

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