

A Review of Polarization Index and IEEE Standard 43-2000

An ALL-TEST *Pro*, LLC White Paper by
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INTRODUCTION

The standard that all of us have lived by for insulation resistance testing was re-issued in May, 2000. The “IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery,” had been updated because “during the 1970’s, several changes were made to the types of insulation used in rotating machines. The insulation resistance characteristics of these newer insulation systems are different from the older systems, and therefore required [a] substantial revision to the standard for measuring insulation resistance.” The revised standard drastically changed a number of traditional testing programs for insulation resistance that had been in place for over 50 years, including Polarization Index (PI), insulation to ground tests and AC vs DC testing of insulation systems. This article will discuss each of the changes referencing directly to IEEE Std 43-2000.

The purpose of insulation resistance (IR) reading is to evaluate the condition of the insulation between conductors and ground. This is done by applying a direct voltage between the conductors (windings) and the casing of the electric motor (machine) and measuring current leakage across the insulation system. The readings are applied to Ohm’s law ($R = V/I$) and an resistance is provided. In the case of an insulation system, the current may be measured in milli- or micro-Ohms, with the lower the current reading, the higher the insulation resistance reading. These IR readings change over time because of dielectric absorption. Basically, the insulation system consists of polarized atoms that line up (polarize) with the applied DC voltage. As they polarize, the insulation resistance will increase.

POLARIZATION INDEX

Prior to 1974, a system was developed to evaluate the polarization of the insulation system. It was found that many insulation systems would polarize over ten minutes to many hours, so by looking at the insulation resistance between the one minute reading and the ten minute reading would produce a ratio. This ratio could be trended or compared to a simple table that would provide an indication of the condition of the winding. Two methods of approaching this Polarization Index (PI) would be to provide the direct ratio or plotting the readings in steady increments over time. In the past, a PI of under 2.0:1.0 would indicate a problem with the insulation system, usually the insulation would be carbonized (burned) or would have absorbed contamination. A poor reading would indicate that additional testing was necessary.

With the release of IEEE Std 43-2000, new limitations on the use and evaluation of PI were issued. No longer is the test easy and straight-forward as many changes have occurred with the insulation systems themselves. For instance, most new insulation systems start with test results in the Gig-Ohm and Terra-Ohm (Billions and Trillions of Ohms) range. The result is leakage current between the windings below the micro-Ohm range, requiring tremendous accuracy in the instrument and test methods, including how to position the conductors, etc. The readings must also be taken at the machine, itself. Readings taken from the motor control center (MCC) or disconnect may have high leakage currents in the cables due to the cable surface area, causing errors. The testing at this point is so critical that the standard states: "If the 1 minute insulation resistance is above 5000 Meg-Ohms, the calculated PI may not be meaningful. In such cases, the PI may be disregarded as a measure of winding condition."

There are additional concerns with PI testing outlined within IEEE Std 43-2000, including temperature limitations, dew-point limitations, trending tests, surface conditions, types of windings to be tested, and more. For instance, the tests must be performed above the dew point and corrected for temperature to 40 degrees C. This is a change from the past where it was assumed that PI was not a temperature dependent test. The main change has to do with the polarization of new insulation systems based upon temperature for, unlike conductors where the resistance increases with temperature, insulation resistance is inversely proportional to temperature so insulation resistance DECREASES with temperature. Therefore, a PI performed on an insulation system that is hot (ie: the machine was just turned off) compared to cold (ie: in storage) may be dramatically different. The only true way to trend the PI is to perform each test with the winding at approximately the same temperature, over the dew point. This may be very difficult in a production environment, where extended inactivity of the machinery will have adverse effects on corporate profitability (ie: 10 min for test + 5 min for setup + any additional time for cooling, etc. and calculations = minimum 15 minutes per machine). PI can also only be used on form-wound or random-wound machines. Open winding machines, transformers, and certain insulation materials will not provide appropriate ratios and will fail a one-time test. In most cases, now, PI is used for the "estimation of the suitability of a machine for the application of appropriate over-voltage tests..."

INSULATION RESISTANCE

Insulation resistance readings have been used to troubleshoot and evaluate the condition of electric motors since the test method was first introduced, often with disastrous results. There are very clear limitations on the ability of insulation resistance tests to evaluate the condition of an electric motor for operation. For one thing, the fault has to have a direct path between the windings and casing of the machine. Air, mica or any other non-conducting material between the winding and ground will provide a high insulation resistance. Faults on the end-turns of motor windings will also not provide a clear path to ground & most winding faults start out as internal winding shorts and may graduate to insulation faults, but not always.

Excerpt from IEEE Std 43-2000:

“Insulation resistance test data is useful in evaluating the presence of some insulation problems such as contamination, absorbed moisture or severe cracking; however, some limitations are as follows:

- a) IR of a winding is not directly related to its dielectric strength. Unless the defect is concentrated, it is impossible to specify the value of insulation resistance at which the insulation system of a winding will fail.
- b) Windings having an extremely large end arm surface area, large or slow speed machines, or machines with commutators [ie: DC] may have insulation values that are less than the recommended value.
- c) A single IR measurement at one particular voltage does not indicate whether foreign matter is concentrated or distributed throughout the winding.
- d) Direct voltage measurements, such as IR and PI tests, may not detect internal insulation voids caused by improper impregnation, thermal deterioration or thermal cycling in form wound stator coils...”

The recommended safe minimum values for rotating machinery are:

- a) For insulation systems before 1974 = 1 Meg-Ohm + 1 Meg-Ohm / kV rating of the machine.
- b) For insulation systems after 1974, random wound and under 1,000 Volts = 5 Meg-Ohms or greater.
- c) For armatures, form-wound equipment and machinery = 100 Meg-Ohms or greater

DC VS AC VOLTAGE TESTING OF INSULATION

DC voltage testing is normally done by applying the DC source directly across the insulation system between the windings and stator frame of the machine. “Because the resistivity values of the dirt, oil, and water that often contaminates the end-winding areas of rotating machinery are quite low, direct-voltage testing of a contaminated winding normally results in a high surface leakage current and subsequent low resistance reading. This property makes DC voltage testing a viable method for determining the extent of contamination to an insulation system. In addition, if the insulation system utilizes a cotton-backed tape with mica as the primary electrical insulation, a DC voltage test might reveal whether or not the cotton has absorbed moisture and has a lower resistivity. Note that most windings manufactured after 1970 do not have these hygroscopic tapes, and a DC voltage test will not normally detect problems internal to the insulation system, such as thermal deterioration.” (IEEE 43-2000 p. 19)

“Since the primary electrical insulation used in the design of form-wound stator windings is mica, and mica has virtually infinite resistivity (thus a good insulator), only one layer of mica tape would prohibit any direct current. Therefore, if a void exists within the insulation system due to improper impregnation, thermal deterioration, or thermal

cycling, a DC voltage test would be unable to detect it. If however, there exists a severe crack through the entire insulation system, it is possible that an electrical track would be established between the copper conductors and ground, and would appear as a low resistance.

When a(n) alternating voltage is connected between the terminals of the test specimen [machine]... the capacitance of the test specimen dominates the current. Capacitance is determined by [the following] equation

$$C = \epsilon A / D$$

Where C is capacitance; ϵ is dielectric permittivity of the material; A is the cross-sectional area; and, d is the thickness of the material.”

Since the dielectric permittivity of an insulation system is greatly effected by the presence of voids and/or water, an alternating voltage test is more sensitive than direct voltage tests with regard to detection of internal insulation problems associated with all types of insulation systems. Because of the different test capabilities, both a DC and an AC test should be conducted to more completely assess the condition of an insulation system.” (IEEE Std 43-2000, p. 19).

With this in mind, an impedance based test (impedance includes resistance, inductance, capacitance and frequency) compared to other test results such as resistance and inductance, could be used as the AC test. A standard IR test could be used to accomplish the DC test. If you compare the inductance across three phases of a three phase machine and compare it to the impedance, changes to capacitance in one or more phases would cause a negative effect on the impedance, causing the value to fall towards inductance. The DC test would identify continuity to ground, while a comparison of impedance to inductance would indicate additional winding problems.

CONCLUSION

The new IEEE Std 43-2000 addresses some new issues regarding modern insulation systems. In particular, it identifies the complexities of performing PI and IR tests and their limitations. It does, however, provide an acceptable alternative: combined AC and DC testing, such as those tests associated with the ALL-TEST instruments, in particular the ALL-TEST IV PRO 2000. The ALL-TEST provides a DC IR test that meets the IEEE Std 43-2000 requirement coupled with AC inductance and impedance readings that can be immediately compared. Total test time from the MCC or disconnect is 3 to 5 minutes and the AC tests are not temperature dependant. Time savings on the testing exceeds 10 minutes per machine being tested and provides a complete set of data for comparing the insulation to ground, insulation condition and evaluates the inter-turn insulation for winding shorts. This evaluation system can be used in place of, or in conjunction with, PI tests for insulation systems under 5000 Meg-Ohms or alone in systems where the insulation system value is above 5000 Meg-Ohms.

ABOUT THE AUTHOR

Dr. Howard W. Penrose, Ph.D. has over 15 years in the electric motor and electric motor repair industry. Starting as an electric motor repair journeyman in the US Navy to field service and evaluation of small through large rotating equipment of all types, as the Chief Engineer of a large Midwestern motor repair shop. Dr. Penrose has been directly involved in rewinding, training and troubleshooting AC, DC, wound rotor, synchronous, machine tool, and specialty equipment. His further studies involve electric motor and industrial reliability, test methods, energy efficiency and maintenance impact on production. Dr. Penrose is a past Chair of the Chicago Section of IEEE, a past Chair of Dielectrics and Electrical Insulation Society of IEEE Chicago, a Professional Member of the Electrical Manufacturing Coil and Winding Association, a US Department of Energy Certified MotorMaster Professional, a Vibration Analyst, Infrared Analyst and Motor Circuit Analyst.

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