How do you know you need an Electrical Insulation System?

By: Brandy LaBanca

Abstract: This paper presents the basic understanding of how and when an Electrical Insulation System (EIS) is needed, and outlines the essential aspects of EIS testing. EIS evaluates the thermal life of the electrical insulation portion of the system, and it evaluates a combination of two or more materials with at least one conductive part in a single test object.

This paper will illustrate a wide range of tests for motors, generators, transformers, stators and encapsulated coils which in turn could be low voltage, medium voltage or high voltage; this factors on the application of your system. Electrical Insulation Systems testing can provide valuable information regarding performance expectations and material interactions, and is a more efficient way to achieve a thermal rating than testing the actual end-product; thus saving you time and money.

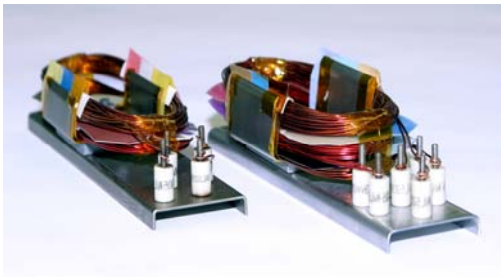
Brief History of Electrical Insulation Systems

Between the 1890 and the 1950's all Electrical Insulation System testing was performed on units straight out of production. As you learn about Electrical Insulation Systems testing, you will find this is both costly and time consuming.

The Naval Research Report; Reliability Prediction Study on Electrical Insulation Navy Summary Report Document[1]

In 1952, a program was initiated at the Naval Research Laboratory to do a major study on the aging properties of electrical insulating materials in what we call today Electrical Insulation Systems. This program was started because equipment in Navy vessels needed to be reduced by weight and bulk. At the same time it helped to maintain and improve the reliability of the motors. Evaluation techniques for comparing the expected lives of new insulation systems were developed for the program.

The researchers developed general purpose models that included magnet wire, varnish (if used), and the insulating materials used in the slot and oval of a general purpose model. A picture below illustrates just two of the models that represent Electrical Insulation Systems.



Standard Channel Piece Tall Channel Piece

While the test program started in the 1950's and completed in the 1960's, it was not until July of 1977 that the document addressed above was issued by the Naval Research Laboratory in Washington DC. This document provided most of the thermal aging data needed for establishing the Standards for today.

Some may wonder "How do I know I need an Electrical Insulation System?" Before we answer that question there are a few things you need to be aware of:

1. Electrical Insulation System testing rates a group of electrical insulating materials as a single system.
2. No individual materials (EIM) are rated by Electrical Insulating System testing.
3. The performance of an Electrical Insulating System is not directly related to the rating of the electrical insulating materials selected to be in the Electrical Insulation System. (You may have a lower or higher rated material in your electrical insulation system than the class rating you're asking for, example: 130 class material can be used in a 155 class system)

4. Only electrical properties are evaluated. Anything in the Electrical Insulation System that is directly related to the energized part of the motor is tested. There are things in the Electrical Insulation System that are for construction purpose only.
5. Electrical Insulation Systems testing can evaluate interactions between electrical insulating materials, but this does not tell which one of the materials may be the cause of early failures.
6. Electrical Insulation Systems testing addresses one very simple and direct question:
7. What is the maximum thermal class application rating for this system (Group of electrical insulating material)?

1. EIS testing rates a group as a single set.

Electrical Insulation System testing rates a group as a single set. Before describing the specific aspects of the maximum thermal class application rating for a system, a basic definition of an EIS is needed.

EIS (Electrical Insulation System)[2] - this is a product manufactured from one or more electrical insulating materials. It is employed in a particular electrical apparatus together with electrically conductive parts at different voltages.

The specimens are tested as a single entity. When a specimen passes a specific test cycle the cause of the retained electrical insulation is due to total insulation capability of the group. It is impossible to assign a level of retained insulation to any one or any portion of the group, because of this simple fact the group of materials are evaluated as a system.

The system is a unique set of materials and the results of the testing relate only to the specific group under test.

The specimens are tested electrically, there are no physical tests conducted during a standard EIS test.

Table 1

Turn-to-Turn at 120 volts ELECTRICAL TEST	A test voltage (electrical stress) is applied by energizing one strand of a bifilar (bifilar is two separate coils wound together) winding at 120 volts and grounding the other strand in the same winding. This applies a 120 V differential throughout the entire length of the winding. Discussion: It is essential to understand that the value of 120 volts must not be confused with the line voltage in the United States which happens to be between 110-120 VAC. This test voltage refers to a differential between the turns within a winding.

Coil-to-Coil Or Winding-to-Winding At 600 Volts ELECTRICAL TEST	A test voltage (electrical stress) is applied by energizing the top coil, or winding, and grounding the bottom coil, or winding. This applies 600 volt differential across the wire insulation and ground insulation between the windings. 600 volts is used because of the 600 volt classification used by the E/E industry world-wide.
Coil-to-Coil or Winding-to-Ground At 600 Volts ELECTRICAL TEST	A test voltage (electrical stress) is applied by energizing all windings and grounding the metal frame. 600 volts is used because of the volt classification used by E/E industry world-wide.
PHYSICAL TEST	There are no physical tests or evaluation conducted.

Electrical stresses for EIS testing covered by IEEE 275[3]/429[4] (soon to be IEEE 1776[5]) and IEEE 259[6] will follow the same test pattern, only the test voltage will be different from the values listed above.

Table 2
Test Summary of exposures for EIS testing for the GPM specimens IEEE 117[7]

Thermal exposure at three or more elevated temperatures; the length of time used for each aging cycle is dependent on the temperature.	The thermal exposure is intended to cause the decomposition of the molecular structure of the EIM's causing a loss of electrical insulation. The calculation used to establish the thermal rating, the Arrhenius plot, is based on the assumption that a single factor is the dominate cause of the loss of property. For EIS testing, the single factor is thermal.
Physical vibration one (1) hour after each thermal exposure cycle.	The vibration exposure is intended to simulate some minimum level of physical stress all electrical devices will experience during operation. The common vibration period is for one hour at 60 Hz with 1.5 g of force at the peak of vibration motion.
Cold Shock at zero degrees for indoor application at -20 degrees for outdoor applications.	The cold shock exposure is intended to simulate thermal conditions when a device is not in operation. The common cold shock exposure is a minimum of two hours.

Condensation with visible condensation on the windings.	The condensation exposure is intended to simulate outdoor conditions. The common exposure time is 48 hours. Condensation is achieved by holding the water in the bottom of the chamber approximately 5 degrees above ambient and the test specimens held approximately 5 degrees below ambient. The specimens are held at the lower temperature by means of a water cooled holding shelf inside the chamber.

The electrical stresses identified above are used to determine if the EIM are able to retain a pre-defined level of voltage withstand. That is, the specimen is defined to be good if the applied voltage cannot produce a predefined current flow. The

specimen is considered to have failed if the applied voltage does produce a current above the predefined level.

Stresses for EIS testing covered by IEEE 275 and IEEE 259 will follow the same test pattern; the magnitude of the specific test may vary from the value listed above.

2. No individual material [EIM] is rated by EIS testing.

Since each EIS is tested as a group and since no individual material can be assigned a proportion of the total insulation resistance, NO INDIVIDUAL MATERIAL CAN BE RATED BY EIS TESTING.

Even when the test is turn-to-turn for an unvarnished specimen, the evaluation is testing the interaction between the conductor and the insulation and the retained insulation of the coating on the conductor. If the coating on the conductor loses adhesion due to oxidations, the specimen will reflect some level of reduced life.

Because of this aspect in the testing, the selection of the categories of EIMs to include in the test specimen is extremely important because of the basic idea covered in Question #1 above. The entire purpose of this test program is to evaluate the life of a group of materials. If a test specimen is constructed with coated conductor(s), ground insulation materials and an insulation varnish, the varnish cannot be removed from the package because the test data is related to the full set of materials and there is no information about the possible performance of the set with any material excluded.

3 The performance of an EIS is not directly related to the ratings of the EIMs selected to be in the EIS.

Since material ratings are based on different criteria than EIS rating, the rating of an EIM cannot be directly used to protect the performance of the EIS. If a system is varnished; the varnish may retard the oxygen migration to another material in the group. This may result in extended life of the material which had a lower rating when evaluated as a single material.

Likewise, one material may produce a ‘by-product” due to decomposition which is harmful to the other materials in the set. This by-product could reduce the life of the group.

Material testing cannot indicate the possible effects of interactions of the materials. Only EIS testing can evaluate that feature.

4. Only electrical properties are evaluated.

As presented in Table 1, only electrical properties are evaluated. The mechanical properties of a final unit may need to be evaluated. The evaluation of the physical properties is related to design and application. EIS testing is not intended to evaluate design properties. This testing is conducted with final unit testing.

EIS testing is not intended to replace end unit evaluation. EIS testing is intended to help manufactures select (a) a system of materials that have the thermal capabilities to perform; (b) eliminate the need to build a functional unit prior to testing; (c) reduce cost by eliminating systems that have a compatibility problem.

When an end unit is used as the test specimen, the electrical and design properties do come directly under test. However, the physical stresses of an operating unit may be simulated by the conditions of EIS testing. If the intent of a test program is to simulate the full stresses of a final unit, both electrical and physical, the test program must be modified to properly represent the actual environment.

5. EIS testing can evaluate interactions between EIM's.

The two types of test program, EIM and EIS, are designed to evaluate different situations. EIM testing is designed to preset conditions to allow for comparisons between materials of the same type. When the user knows the requirements, the EIM test results can be used to select the appropriate EIM. When EIS test data is used, the user has important insight into the expected life of the electrical side of the device.

6. EIS testing addresses one very simple and direct question.

The most important question is:
WHAT IS THE MAXIMUM THERMAL CLASS APPLICATION RATING FOR THIS SYSTEM (GROUP OF EIM's)?

As explained above, since only electrical properties are evaluated, the EIS testing can only provide the rating of the electrical performance of the group.

What is the value of EIS testing if the results are limited?

The value is that the user of the data has the technical information of select materials and to move directly to the more important part of the design work; designing a product to sell. The reduced time to reach the design stage of manufacturing is the benefit of EIS testing.

Long term thermal aging is not considered to be a significant cause of unit failure at operating temperatures at or below the 105 class. This means that the technical data is of significant value for units operating at or above the 130 class. Using the internationally accepted classifications, this offers six (6) classes for which this type of testing is needed:

- 130 degrees
- 155 degrees
- 180 degrees
- 200 degrees
- 220 degrees
- 240 degrees

As stated above, EIS testing evaluates the performance of a group, or set, of materials as a single entity. No individual material is rates as a result of the EIS testing of the group. The rating of the EIS is not a direct reflection of the rating of the rating of any individual EIMs. These statements can be illustrated by taking a look into one of the earliest EIS Programs developed by a supplier to the E/E industry.

To help understand the actual ratings of EIS compared to the EIM ratings; there was a study designed and tested during the 1960's. The EIM selection and the target class for each EIS in this study were made based on a pattern change of materials. This study provided us with percentages that are still used today.

1. 100% of the systems get a rating.
2. 60% made the actual rating that was requested
3. 29% made a rating lower than what was requested
4. 1% made one rating higher than requested

We here at ELTEK redid this study 30 years later and found the same exact findings.

Here is a list of System Testing available

IEEE 117: Standard Test Procedure for Evaluation of Systems of Insulating Materials for Random Wound AC Electric Machinery up to 600 V.

IEEE 259: Standard Test Procedure for Evaluation of Systems of Insulation for Specialty Transformers.

IEEE 275/429 (Soon to be IEEE 1776): Standard Test Procedure for Recommended Practice for Thermal Evaluation of Unsealed or Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Pre-Insulated Stator Coils for Machines Rated 15000 V and below.

IEC 61857[8]: Electrical Insulation Systems / Part 1: General Requirements – low voltage.

IEC 61857[9]: Electrical Insulation Systems / Part 21: Specific requirements for general purpose model wire-wound applications. [Part 23 for Tall-Channel designs was merged into part 21].

IEC 61857[10]: Electrical Insulation Systems / Part 22: Electrical Insulation Systems – specific requirements for encapsulated coil models – Wire-wound electrical insulation systems (EIS).

IEC 61858[11]: Thermal evaluation of modifications to an established wire-wound EIS.

UL 144[12]6: Standard for Systems of Insulating Materials – General.

DEFINITIONS

Electrical Insulating Material also [EIM] Ground Insulation [GI]
A material which separates an energized conductor from a ground and acts to prevent the conductor from discharging electrical energy to ground.

Electrical Insulation System [EIS]
A combination of two or more EIM and conductor(s) used in a single electrical devise or in an isolated portion of an electrical device.
Discussion: One of the main purposes of EIS testing is to evaluate interactions between the EIM's when in direct contact with each other. The interaction is at a chemical or molecular level and cannot be evaluated with a material-type of test.

Temperature Index [TI]:
A number which permits comparison of the temperature/time characteristics of an electrical insulating material, or a simple combination of materials, based on the temperature in degrees Celsius [Celsius], which is obtained by extrapolating the Arrhenius plot of life versus temperatures to a specified time, usually 20,000 hours.
Discussion: there is a significant difference between RTI and TI. The main difference is the selection of the value used

for doing the calculation and hence establishing the rating. For RTI the new or candidate material or EIS is always compared to the performance of a known or established material or EIS. This is the reason for the word “relative” in the description. For a TI value, a fixed time frame is used.

Thermal Class:
A grouping of thermal index values into brackets.
Discussion: Thermal classes are defined in several documents, but the International Publications used for this reference is IEC 60085[13]. The RTI and TI values for EIM’s and EIS’s are grouped according to the following pattern:

RTI/TI value in degree Celsius assigned	Thermal class Letter designation
105.0 to 129.9	
105……	A
130.0 to 154.9	
130……	B
155.0 to 179.9	
155……	F
180.0 to 199.9	
180……	H
200.0 to 219.9	
200……	N
220.0 to 239.9	
220……	R
>240.0	240

RTI:
Relative Thermal Index [RTI] is a long term thermal aging test using a control to compare the results. RTI applies to Plastics and Electrical Insulation Systems [EIS]. This overview pertains to Plastics only. Plastics include sheet, films, molding resins, etc.

[1] NAVAL RESEARCH LAB, “Reliability Prediction Studies on Electrical Insulation: Navy Summary Report”, 07-13-1977, 138 pages

[2] International Electrotechnical Commission, “IEC 60505, definition 3.1.1”, IEC 61857-1, ed. 3.0, 2008-09

[3] Electric Machinery Committee of the IEEE Power Engineering Society, USA, “IEEE recommended practice for thermal evaluation of insulation systems for alternating-current electric machinery employing form-wound pre-insulated stator coils for machines rated 6900 V and below”, IEEE 275-1992, 1992

[4] Electric Machinery Committee of the IEEE Power Engineering Society, USA, “IEEE recommended practice for thermal evaluation of sealed insulation systems for AC electric machinery employing form-wound pre-insulated stator coils for machines rated 6900 V and below”, IEEE 429-1992, 1992

[5] IEEE, “Draft Recommended Practice for Thermal Evaluation of Unsealed or Sealed Insulation Systems for AC Electric machinery Employing Form-Wound Pre-insulated Stator Coils for Machines Rated 15000 V and Below”, P1776/D12, 06-2008

[6] Transformers Committee of the IEEE Power Engineering Society, USA, “IEEE standard test procedure for evaluation of systems of insulation for dry-type specialty and general-purpose transformers”, 259-1999, 1999

[7] IEEE, “IEEE Standard Test Procedure for Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery”, IEEE 117-1974, 1974, Pages i-22

[8] International Electrotechnical Commission, “Electrical insulation systems - Procedures for thermal evaluation Part 1: General requirements - Low-voltage”, IEC 61857-1, 09-26-2008, Pages 1-32

[9] International Electrotechnical Commission, “Electrical insulation systems - Procedures for thermal evaluation Part 21: Specific requirements for general-purpose models - Wire-wound applications”, IEC 61857-21, 08-27-2004, Pages 1-29

[10] International Electrotechnical Commission, “Electrical insulation systems - Procedures for thermal evaluation - Part 22: Specific requirements for encapsulated-coil model - Wire-wound electrical insulation system (EIS)”, IEC 61857-22, 07-25-2008, Pages 1-25

[11] International Electrotechnical Commission, “Electrical insulation systems - Thermal evaluation of modifications to an established wire-wound EIS”, IEC 61858, 07-25-2008, Pages 1-37

[12] Underwriters Laboratories Inc. (UL), “UL Standard for Safety for Systems of Insulating Materials - General”, UL 1446 Sixth Edition, 02-08-2007, Pages 1-54

[13] International Electrotechnical Commission, “Electrical insulation - Thermal evaluation and designation”, IEC 60085, 11-07-2007, Pages 1-16