CONSIDERATIONS FOR THE SELECTION OF MATERIALS FOR MEDIUM/HIGH VOLTAGE FORM WOUND STATOR COILS

Paul C. Gaberson
Curtiss-Wright

Dr. Nancy Frost
Gerome Technologies

Leah Simmons and Dr. Hugh Zhu
Doble Engineering Company

ABSTRACT

This paper will review the materials used in construction of stator coils. It will look at how the characteristics of these materials, whether desirable or undesirable, affect the coils performance. This paper will also review the tests that are available to evaluate specific characteristics.

INTRODUCTION

This paper will review the critical materials typically used in the construction of form wound stator coils for medium and high voltage machine applications and typical type tests for material selection. Coils of this type are commonly used in large motors (both induction and synchronous) and generators. Today the vast majority of these coils will be specified to have Class 155 (Class F) rated insulation systems although many will also be limited to Class 130 (Class B) operating temperatures. The need to reduce machine size in many applications is leading to higher power densities in large motors and generators causing an increased need for higher temperature capabilities, so Class 180 (Class H) rated systems are also popular. There are very few large medium/high voltage machines made today with Class 130 (Class B) rated insulation systems.

Figure 1 shows an exploded view of a typical form wound stator coil before insertion into the core structure. The major components are as follows:

1) Insulated copper wire
2) Dedicated turn insulation
3) Primary groundwall insulation
4) Glass armor tape
5) Semi- Conducting armor tape
6) Corona grading tape
7) Impregnating resin (not specifically shown)
8) Chemical resistant overcoat
Form wound coil insulation components [used with permission of Krempel Group]

**Figure 1**

In medium and high voltage designs all of these materials will typically be used. The dedicated turn insulation, the corona grading tape, and the chemically resistant overcoat may be omitted in some cases. The critical components that will be the focus of this paper are the copper wire insulation, the tapes which make up the turn and groundwall layers and the thermosetting resin that binds everything together providing structural support, moisture sealing, improved thermal transport and elimination of internal void spaces.

The materials that comprise the insulation system need to be evaluated to determine their ultimate capability and their condition at the time of application. The impact of manufacturing processes on material condition must also be considered. Finally, the results of possible interactions between the various materials used must be evaluated to make sure undesirable chemical interactions are not occurring. This all requires data collection, and this paper will discuss some of the many tests that can be performed and the implications of the resulting test data. While both resin rich and vacuum pressure impregnation (VPI) processes can be used to insulate a stator bar, this paper will focus on the VPI system, although the bar/coil testing section can be utilized for either manufacturing technique.

**THERMAL CLASSIFICATIONS**

The first thing to consider in all material selections is thermal capability. As noted in the introduction, virtually all insulation systems in use today for medium and high voltage applications will have Class 155 or higher thermal capability. The thermal rating of a complete insulation system is determined from an accelerated thermal aging test conducted in accordance with IEEE Std. 1776 [1]. In this test, prototypical coils from a candidate system and a service proven reference system are compared to establish the rating of the candidate based on the demonstrated capability of the reference. This method differs from the methods used to establish the temperature index of individual materials. Individual material evaluations are based on accelerated aging tests in which the change in a single parameter is determined as a function of time and temperature. The parameter used for the test will be chosen based on the intended application of the material evaluated. Because of this difference in definition, it is possible for the thermal index of some component materials in a given insulation system to have a rating lower than the complete system rating. Similarly, if all of the individual materials used for an insulation system are rated for a given temperature, it does not insure that the complete system will achieve the same rating.

The temperature rating of insulated copper conductors is well defined by industry standards so magnet wire specified per NEMA MW-1000 [2] will give good assurance that the temperature capability
(determined by testing per ASTM D2307 [3]) is adequate. The insulation system(s) used on magnet wire are well known and the thermal rating has been tested, and many have been verified experientially.

The tapes that make up the turn or groundwall layers of medium and high voltage machines will be composed of mica and a backing material (on one or both sides of the mica).

- The mica is unaffected by any reasonable operating temperature.
- The backing materials require careful consideration because many different materials are commonly used. For example;
  - Woven polyester fiber – typically not used above Class 155
  - Polyester film – discrete material for Class 155, limited experience for Class 180
  - Polyimide film – considered for use to at least Class 200
  - Glass – offers highest thermal capability

The impregnating resin should have the required thermal capability by itself and in combination with the magnet wire and the tapes. Resin manufacturers state a temperature rating for their materials. This rating will usually be based on a predetermined amount of weight loss over a given time period at the rated temperature. Specific test methods for thermal evaluation of impregnating resins will be discussed in the next section.

**MATERIAL EVALUATIONS**

**VPI Resin**

Basic resin testing can be broken into two general groups: capability for application and VPI storage tank maintenance parameters.

**Resin capability for application**

The following are some of the more popular tests used to identify the capability of the resin and verify adequacy for the intended application.

1) Weight loss of resin disks
2) Thermogravimetric analysis (TGA per ASTM D3850) [4]
3) Activation energy of decomposition reaction (per ASTM E1641) [5]
4) Thermal endurance (per ASTM D1877) [6]
5) Compatibility with wire insulation
   a. Bond strength change (per ASTM D2519) [7]
   b. Electrical property (per ASTM D2307) [3]
6) Glass Transition Temperature (per ASTM E1356 [8] or E1640 [9])
7) Thermal conductivity (per ASTM E1530) [10]
8) Dielectric withstand and breakdown (per ASTM D149) [11]
9) Dielectric constant and dissipation factor (per ASTM D150) [12]

A VPI resin is intended to hold the insulation system together and to fill the voids within the system. As such, the resin should have a thermal class that exceeds the operating range of the rotating equipment. The simplest method of testing a VPI resin involves weight loss studies, where discs of pure cured resin are aged in ovens and periodically weighed until the resin disc has lost the specified weight (typically 5-10% of original weight). The procedure for determining weight loss of resin disks is not defined by industry standards so it is difficult to make comparisons between different published results. Better accuracy is obtained by using thermogravimetric analysis (TGA) performed per ASTM D3850. In the TGA test the weight loss of a sample is measured as a function of temperature at a constant heating rate. This can be done in any desired atmosphere but should be done in the atmosphere appropriate for the application (typically atmospheric air). The resulting 5% weight loss temperature is a useful metric for making comparisons between different resins.
ASTM E1641 describes a method for determining the Arrhenius activation energy of the decomposition reaction using TGA results. Finally ASTM E1877 describes a method for calculating the thermal endurance of a material using the previously determined activation energy. These methods give an indication of the thermal capability of the VPI resin by itself but as noted previously, only a full test per IEEE Std. 1776 can assign a temperature class to the complete system.

The interaction of the VPI resin with the magnet wire is assessed through testing such as the helical coil bond strength (per ASTM D2519) and twisted pair electrical testing (per ASTM D2307). This testing takes samples of candidate magnet wire, with applied resin, and thermally ages the material in ovens at various temperatures. The time required for samples to exhibit reduced bond strength or dielectric strength to a predefined level is determined for each test temperature and plotted on a graph with log time on the ordinate and inverse of absolute temperature on the abscissa. The resulting Arrhenius curve can be used to define the thermal class of that magnet wire/resin combination by extrapolating the curve and determining the temperature at 20,000 hours. This information is readily available from the Underwriters Laboratory website of resin suppliers.

Figure 2 shows an example of a helical coil sample being tested for bond strength. The three point bend breaking strength is measured versus aging temperature. The twisted pair test sample is shown in Figure 3. In this case the ability of the sample to hold off 1000V from wire to wire is measured versus aging temperature. The specific testing requirements for both these tests are given in UL 1446[13].

The glass transition temperature (Tg) of the resin can also be measured via differential scanning calorimetry (DSC), shown in Figure 4, using ASTM E1356 or via dynamic mechanical analysis (DMA), shown in Figure 5, using ASTM E1640. The glass transition temperature defines the point where a polymer transitions from a hard, glassy material to a more flexible, rubbery material. This is often not a sharp transition, so Tg really identifies a temperature region more than an abrupt change (expect results determined by DSC and DMA to be slightly different). The appropriate value of Tg relative to machine operating temperature is an open question. It is generally agreed that Tg should be greater than or equal to the operating temperature of a machine to yield a mechanically stable structure. However, excessively hard inflexible resins are much more susceptible to cracking due to thermo-mechanical forces so flexibility is important. Also, silicone based resin systems, which are known to have extremely high stable temperature capability, are also known to have some of the lowest glass transition temperatures. Therefore, low Tg resins can be used but consideration should be given to support structures that may need to be enhanced.
The thermal conductivity of resin samples can be determined per ASTM E1530. Thermal conductivity is a valuable parameter to consider when making comparisons between different resins. However, it should be noted that although the impregnating resin is a primary contributor to the overall conductivity, testing should also be performed on the combined resin and groundwall tape system to determine the actual value that should be used in machine design.

Finally, all of the basic electrical properties of the resin by itself should be determined. Dielectric and breakdown strength per ASTM D149, along with dielectric constant and dissipation factor per ASTM D150, can often be obtained directly from the resin supplier. Again, these parameters need to be obtained for the combined resin/tape groundwall system when they are to be used for machine design considerations.

**Resin Tank Maintenance Parameters**

The second set of resin tests are used to check the condition of the base (neat) resin at the time of processing. All catalyzed resins degrade with age, so it is important to verify that the resin parameters are still within acceptable limits immediately before use. Typically these tests will include:

1) Resin gel time  
2) Viscosity  
3) Specific gravity  
4) Moisture content  
5) Shear thinning index (thixotropic resins only)  
6) Fourier Transform Infra-Red (FTIR) spectrometry scan

For most of these parameters the resin manufacturer will have recommended acceptance criteria and a recommended sampling schedule. Often resin samples are sent directly to the manufacturer for analysis on at least a monthly basis. A certain amount of resin turnover is needed in order to maintain a condition in a large processing facility, so early detection of stability problems is important. Keeping track of the resin condition, as recommended by the manufacturer, should minimize production disruptions. Table 1 shows some typical parameters for common VPI resins [14].

The gel time, viscosity, specific gravity, moisture content and shear thinning index are important from a processing standpoint. Variation from recommended limits for these parameters will yield poor impregnation and excessive or inadequate surface coating. The FTIR scan is useful for determining consistency of the resin chemistry. Comparison to past FTIR scans gives assurance that consistent results can be expected.
Table 1
VPI Resin Material Properties

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Viscosity (cps @ 25°C)</th>
<th>Gel Time (minutes)</th>
<th>Cure Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy A</td>
<td>350 – 650</td>
<td>8 – 15 @ 150°C</td>
<td>4 hr @ 180°C</td>
</tr>
<tr>
<td>Epoxy B</td>
<td>500 – 900</td>
<td>8 – 20 @ 171°C</td>
<td>6 hr @ 165°C</td>
</tr>
<tr>
<td>Polyester</td>
<td>600 – 900</td>
<td>15 – 20 @ 125°C</td>
<td>5 – 8 hr @ 150°C</td>
</tr>
<tr>
<td>Co-polymer</td>
<td>400 – 800</td>
<td>10 – 20 @ 125°C</td>
<td>5 – 8 hr @ 150°C</td>
</tr>
<tr>
<td>Polybutadiene</td>
<td>300 – 500</td>
<td>4 – 10 @ 125°C</td>
<td>5 hr @ 165°C</td>
</tr>
<tr>
<td>Silicone</td>
<td>1000</td>
<td>26 @ 200°C</td>
<td>16 hr @ 200°C</td>
</tr>
</tbody>
</table>

Chemical Compatibility

One of the fundamental concerns in the selection of an insulation system is the compatibility of the materials chosen for the application. Individual materials can have optimal properties, but if they don’t react correctly in the insulation system, those desired properties can be compromised. For example, if the binder in the mica tape is chemically incompatible with the VPI resin, it can result in a system with incomplete cure, leading to high dielectric losses and poor electrical performance. Interaction between the impregnating resin and the wire insulation has been discussed previously. Interaction between the resin and the tape systems will be considered later. This section will discuss another aspect of chemical compatibility, exposure to external contaminants.

Depending on the intended application of a machine there are numerous external contaminants that can come into contact with the insulation system. Strong acids or bases and highly abrasive materials are common in industry. To evaluate the insulation system it is common to check compatibility by exposing helical coil samples of wire and resin to the expected contaminants for a given period (often 168 hours or longer) and measuring the change in bond strength per ASTM D2519. This is a similar process to the resin/magnet wire insulation evaluation described earlier except the chemical compatibility evaluation is done at a constant temperature. In some specifications a change in bond strength from unexposed to exposed samples may not exceed 25% (higher or lower).

Manufacturing Process

The process used to manufacture the stator bars or coils is as critical as selection of the materials. Proper application of the mica tape to the bar or coil is important as wrinkles and incorrect lapping can lead to stator coil performance issues. An indicator of material incompatibility is elevated dielectric loss as determined by measurement of dissipation factor/power factor per IEEE Std. 286 [15], to be discussed in more detail in the electrical section along with several other tests.

One key parameter of manufacturing process is adequate impregnation of the mica tape and additionally sufficient retention of the VPI resin in the system during cure. A qualitative test of this is the “tap” test, where the bar/coil is gently tapped and the resulting ring of the bar is judged. A hollow sound is indicative of inadequate impregnation. A more quantitative measure is assessing the binder content in a cross section of the candidate system. This will be discussed more in the destructive testing section near the end of the paper.

TESTING INDIVIDUAL BARS OR COILS

In addition to assessing the base material parameters, the performance of the completed coil must be evaluated to ensure that not only the selected materials are optimum but that the processing of the materials and construction of the coil was adequate as well. This applies regardless of whether VPI or B-
staged processing is used. During this evaluation, there are several tests that assess the current condition of the groundwall insulation system. These tests can be used as a stand-alone evaluation of the groundwall insulation system and are often used as a means to evaluate the coils performance after it has been subjected to endurance tests.

The groundwall tape should be evaluated in combination with the impregnating resin as a combined groundwall sample. The tape itself will virtually always be composed of a mica paper layer with a backing layer on one or both sides of the mica to provide mechanical strength (mica paper has almost zero strength in tension). There are various backing materials used including glass tape, polyester film, polyester mat, and polyimide film. Sample coils should be made and tested to verify the compatibility of the resin/tape combination. After coil testing is complete, groundwall sections can be removed for diagnosis and testing.

**Dielectric Testing**

Typically testing is performed on candidate sample coils as a way of qualifying the insulation. The following tests are typically used:

1. Insulation resistance to ground (IEEE Std. 43 [16])
2. Power Factor/Dissipation Factor Tip-up (IEEE Std. 286 [15])
3. Partial Discharge (IEEE Std. 1434 [17])
4. Short term dielectric breakdown strength (per ASTM D149-93a [11])
5. Electrical withstand testing (IEEE Std. 4 [18])
6. Electrical impulse withstand (IEEE Std. 522 [19], IEC 60034-15 [20])

These tests will be described and material selection implications will be reviewed in the following sections. Tests in conjunction with other assessments will be reviewed in the Endurance testing section.

**Insulation Resistance**

As defined in IEEE Std. 43 – the insulation resistance (IR) is a simple direct current test to apply, so it is virtually always included. However, it is relatively insensitive to minor problems, e.g. voids within the groundwall insulation, so it will typically only identify gross structural deficiencies. This test is also used to determine the polarization index (PI) of an insulation system where the IR is typically measured once per minute over a 10 minute period. The ratio of the last and first IR measurement is taken to determine the PI. Comparison of PIs performed under similar conditions before and after endurance testing can be useful in determining the decomposition of the bonding material.

The surface resistivity may also be useful when evaluating the grading material and is evaluated per ASTM D257 [21]

**Power Factor/Dissipation Factor**

As defined in IEEE Std. 286, the intention of the test is to measure the power factor of the groundwall insulation system with respect to voltage. Power factor (PF) or dissipation factor (DF) is the lossy part of the insulation system, and is a fundamental characteristic of insulating materials. Tip-up is the difference between the DF measured at two voltages, typically 20% and 100% of rated line-to-ground voltage. The tip-up generally is a function of void content and as such assesses the processing, while the actual DF value is a measure of the material's degree of cure and contamination. So measuring DF and tip-up on a bar can be used as a quality assurance tool; where DF value shows that the insulation system is properly cured and tip-up shows that the bar/coil is processed correctly. Note that the DF value obtained from the test is an average value of the entire component. One extremely poor section will be masked by other good areas. Typical DF values for a coil are shown in Figure 6, while Figure 7 shows an example of the insulated bars used for testing. In Figure 6, the green line is an example of the desired DF measurement for a good insulation system, while the blue line shows that of a poor candidate system, which shows significantly increasing DF as a function of voltage.
Care should be taken when performing DF measurements on a coil or bar itself, as inaccuracies in the data from incorrect measurements techniques can be misleading. There are several techniques employed to ensure that the power losses from the slot portion are not overly affected by the voltage grading or semi-conductive material. This includes utilizing guard electrodes on the grading material; interrupting the semi-conductive material and/or extending the slot by use of foil wrapping. Each of these test methods cause inaccuracies, for instance extending the slot portion to include the resistive grading portion will increase the power factor and tip up. An interruption of the semi-conductive material may only be practical if this material is paint. It may be difficult to find and place the guard electrodes at the end of the semi-conductive material which may be overlapped by the resistive grading material. Doble Engineering utilizes the driven guard method defined in IEEE 286, to force the semi-conducting material to follow the potential of the dummy slots to minimize the problem of low power factor tip ups [22]. Note that the need to provide some form of guard electrode in DF testing makes it virtually impossible to eliminate the measurement errors when performing this test on a fully wound stator.

Some consideration should also be given to the impact of temperature on DF. The DF of all insulation systems increases with temperature, some much more significantly than others. If the dielectric losses in the groundwall layer are excessive at operating temperature a thermal runaway condition could result leading to rapid failure of the system.
Partial Discharge

The intention of the partial discharge (PD) test, when applied to an individual coil, is the identification of discharges caused by internal voids or problems with the external corona suppression layers. A PD coupler with a capacitance greater than 1 nF and a low frequency range <1MHz should be used to conduct PD testing on a single bar/coil, as defined in IEEE Std. 1434 and IEC 60034-27 [23]. A typical test frequency range is 100 kHz – 500 kHz. A PD test result from a coil is shown in Figure 8 [24]. Currently there are no generally accepted industry standards for PD magnitude so acceptance should be based on comparison to historical results. Internal voids in individual coils are not usually an indication of material condition; they are a result of poor manufacturing process control. PD testing can identify a single large defect in a coil/bar while dissipation factor testing indicates an overall insulation condition.

![Typical Phase Resolved PD Pattern](image)

**Typical Phase Resolved PD Pattern**

Figure 8

Short term dielectric breakdown

Destructive tests performed on full or reduced size sample coils per ASTM D149-93a should also be used to identify the short term A.C. dielectric breakdown strength of the full groundwall layer. Due to the high voltage levels required to achieve breakdown for good quality insulation systems, the coils generally must be submerged in oil for this test. It should be noted that this is a short term material property, meant to measure the dielectric insulation capability of the groundwall system.

Electrical AC Withstand Testing

Typically this is an AC test of up to 3 times the rated phase-to-phase voltage of the machine applied to a single bar/coil and is related to IEEE 4. The test is to check the integrity of the groundwall insulation in the slot portion. The voltage is gradually raised to the test voltage and is then maintained for 1 minute. This is a pass/fail test. If a bar/coil fails the AC withstand test, it generally indicates there are severe defects within the groundwall insulation. If a bar or coil fails this test, a dissection should be conducted to investigate the cause(s) of the failure.

Electrical Impulse Withstand

**Turn to Turn Insulation**

The voltage difference that turn insulation must withstand in multi-turn coils covers a broad range from less than 100 V in normal operation to as much as several thousand volts under transient conditions. An impulse voltage with a 100-200ns rise time and a peak magnitude of from 2 to 3.5 times the peak line-to-

© 2014 Doble Engineering Company – 81st International Conference of Doble Clients
All Rights Reserved
9-14
ground voltage of the machine is used per IEEE Std. 522 to simulate the transient pulses. A series of the impulse voltages are applied to a coil (minimum of five) and responses are recorded to evaluate the turn-to-turn insulation of the whole coil. An example of this waveform is shown in Figure 9; the amount of oscillations seen in the wave will vary with coil size and construction. Acceptance criteria for this test vary, most determine that a dampening or loss of oscillations in the waveform as a failure, typically seen with a complete insulation failure, while others will not accept an angular shift in the waveform that can be caused by deteriorations in the insulation system during testing.

Main Insulation
Although not specified in an IEEE standard, the test on what is considered the main stator insulation is defined in IEC 60034 Part 15. Shown in Figure 10, a full lightning impulse wave, having a wave shape of 1.2 x 50 μsec is applied between the coil terminals and ground. Again, comparisons of the waveforms generated during the test determine the acceptability of the coil.

Endurance Testing of Coils
There are several tests of insulation systems for long-term compatibility and performance. These tests use some form of accelerated aging and typically test electrical performance as an end-point. This section will discuss some of the multi-factor long-term tests that can be done on insulation systems.

Thermal endurance
Thermal class testing of the insulation system is measured following IEEE Std. 1776 for form wound coils. A sample of the formette used for this testing is shown in Figure 11[25] and was designed to simulate the slot section of a stator, complete with two coils per slot. This formette is built and subjected to thermal aging and then exposure to thermal shock, vibration, humidity (moisture) and finally electrical testing. The result is the thermal index of the system. While this test sounds straightforward and is based upon IEEE 117 [24], testing that is routinely used for random wound motors, the formette assembly is not trivial and this is a costly and time consuming assessment, requiring at least six formette assemblies and more than six months of testing and evaluation.
Voltage Endurance

Standard testing of coils for long-term voltage endurance is performed following IEEE Std. 1043 [25], which applies electrical stress to the insulated coils while plates clamped to the coil are heated to simulate machine operation temperature. This test has become an industry standard over the last several decades and is routinely used as a QC tool. Statistical analysis of test results is performed per IEEE Std. 930 [26] using Weibull statistical methods.

Thermo Mechanical Cycling

An additional test, particularly for long length stators that experience rapid load changes in service, is the thermo-mechanical endurance testing via IEEE Std. 1310 [27]. In stators with long core length, the stator bar experiences mismatching of the coefficient of thermal expansion between the core steel, insulation system and copper magnet wire. As a result, delamination can occur in the stator cross-section, which can lead to premature failure of the groundwall. This test is performed to evaluate the ability of the groundwall system to withstand this stress. Typical test temperature for Class 155 insulation is 40°C to 155°C. 500 thermal cycles are typically applied. Once IEEE Std. 1310 testing is completed, IEEE Std. 1043 voltage endurance testing can be performed to confirm suitability of the groundwall system. In addition, sample dissection can be performed to assess the insulation materials.

Mechanical Properties

The ability of an electrical insulation system to withstand the long-term mechanical forces experienced in service can be assessed by measuring the flexural properties using a four point bending test per ASTM D6272 [28]. These properties are important because over time the electromechanical forces acting on the windings can mechanically stress the electrical insulation, resulting in cracking and delamination of the insulation. It is up to the individual manufacturer to determine the level of mechanical endurance required for their machine design based on the specified duty and support structure design.
Destructive evaluation

Tests can be performed on groundwall material samples after completion of the testing of the sample coils, in order to gather further information as to the performance of the insulation system. The tests to consider are:

1) Resin content by burn-out (per ASTM D2584 [29])
2) Glass transition temperature (per ASTM E1640 using DMA)
3) Thermogravimetric analysis [TGA] (per ASTM D3850)
4) Thermal conductivity (per ASTM E1530)
5) Compressive strength (per ASTM D695 [30])

CONCLUSION

Material selection is a critical aspect of any stator bar insulation system. This paper discussed three key aspects of material selection: chemical compatibility, bar/coil manufacture and performance. It is through testing, aka data collection, that one can then move forward with a decision as to the selection of the critical insulation system materials. There are a significant number of parameters to evaluate and test stator bar insulation. It is important to assess not only the materials, but processing as well, as poor processing of great materials can still result in failure of the stator bar insulation. But it is equally important to Pareto, or prioritize critical performance parameters for your specific application. We hope that this paper has helped you understand some of the typical tests and considerations that are used to assess and select critical insulation materials for medium voltage form wound stator bars or coils.

ACKNOWLEDGEMENTS

This paper is a summary of the collective knowledge of countless insulation experts from the last several decades, many thanks to all for their contributions to the industry.

REFERENCES

[1] IEEE Std. 1776, IEEE 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 15,000V and below


BIOGRAPHY

Paul Gaberson is a Principal Engineer with Curtiss-Wright located in Cheswick, PA. He received the MSEE (Power) degree from Carnegie-Mellon University in 1981. He has over 35 years of experience in the design and manufacture of medium and high-voltage motors and generators. He is an active member of the IEEE Dielectrics and Electrical Insulation Society and the Industry Applications Society. His current activities involve the design of insulation systems for critical application electrical machines. He is a registered professional engineer in the commonwealth of Pennsylvania.

Dr. Nancy Frost is a Dielectrics Engineer working as Business Development Manager for Gerome Technologies, a fabricator based out of Menands (Albany), NY. She has worked in the electrical insulation industry since 1999, working with a variety of suppliers, manufacturers and service shops, after earning her Ph.D from Clarkson University, where she managed the High Voltage Laboratory. She has given over 40 presentations and multiple short courses in the area of insulation materials, aging phenomena and testing.

Nancy has been active in several professional societies since 1997, including the IEEE DEIS, Chair of the IEEE PES EMC Materials Subcommittee working on standards, as well as USA Technical Advisor for IEC TC 112 for NEMA IM6.

Leah Simmons is the High Voltage Test Engineer for Doble Engineering Company where she provides diagnostic and forensic testing and data analysis including writing reports and technical documents. She previously worked as an Electrical Systems Engineer for Entergy Nuclear, Inc. at Pilgrim Nuclear Power Station where she was responsible for providing technical information concerning system performance requirements and bases, compliance status and related industry operating experience. She has a B.S. in Electrical Engineering from Western New England University.

Hugh Zhu is a Principal Engineer with Doble Engineering Company. He received his Ph.D. studying partial discharge (PD) measurement of rotating machines and his post-doctor fellowship studying PD measurement of transformers in the UK. Hugh has 25- year experience on testing rotating machine insulation through working in the UK, Canada, and USA. He has been involved in field and lab testing, and condition assessment of hundreds of rotating machines worldwide. His expertise includes quality assurance testing on stator bars/coils, PD testing, condition assessment, and failure investigation of generator and motor insulation. His experience also includes PD testing on transformers, cables, and other HV apparatus. He has published over 40 technical papers that relate to his specialization.

Hugh chairs the Aging Factors Technical Committee of IEEE Dielectrics and Electrical Insulation Society. He is a member of the Technical Committees of IEEE, IEC and CIGRE to develop the standards of rotating machine insulation testing.