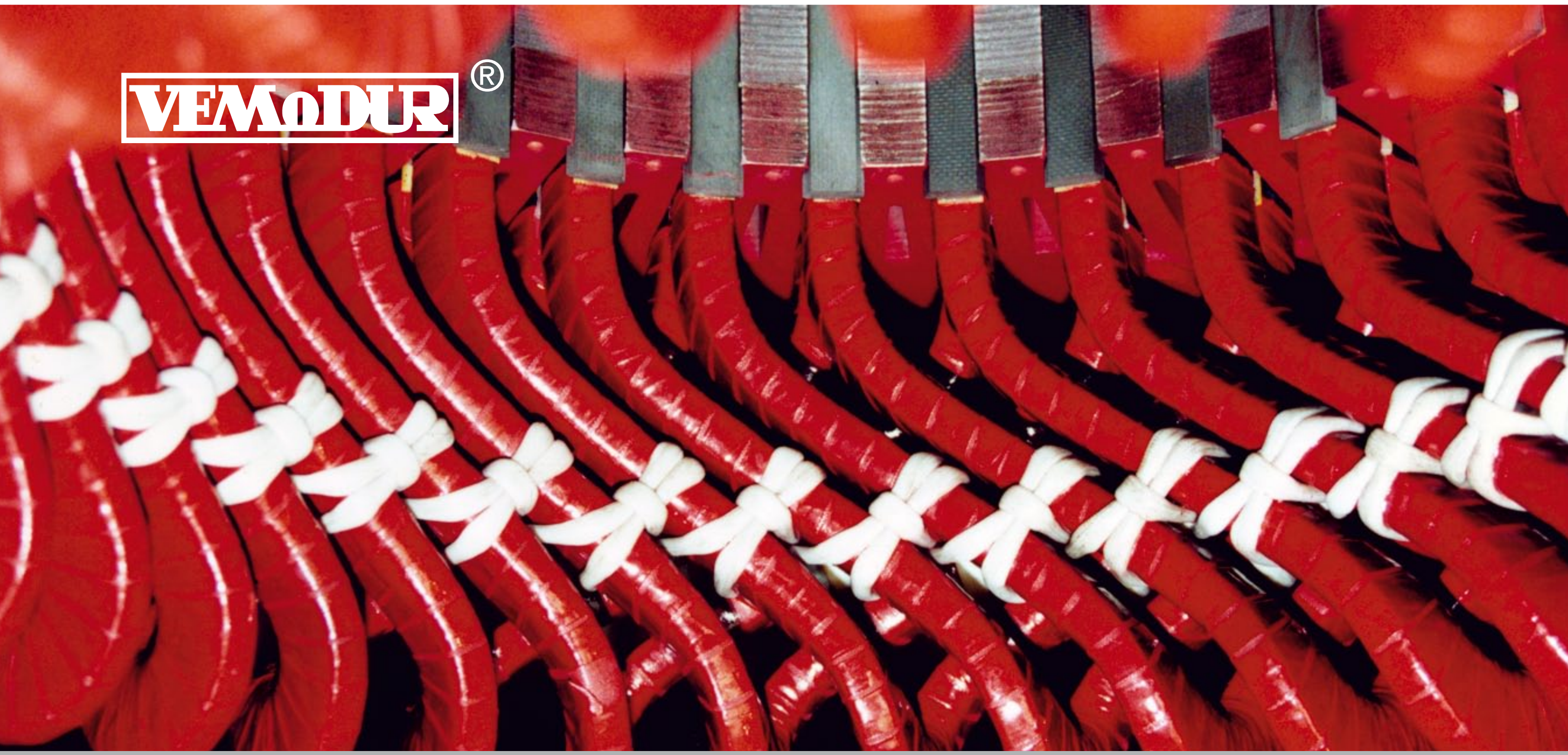
Thermal endurance of the insulation system VEMoDUR®-VPI-155

based on IEC and DIN EN standards



VEM

VEMoDUR®-VPI-155

Thermal endurance of the insulation system

Activities in the technical committee TC2/SC2J “Classification of insulation systems of electrical machines”

TECHNISCHE UNIVERSITÄT DRESDEN

VEM Sachsenwerk GmbH

HOCHSCHULE ZITTAU/GÖRLITZ
University of Applied Sciences

IEC 34-18-01 : 1992	IEC 34-18-21 : 1992	IEC 34-18-22: 1996	IEC 34-18-31: 1992	IEC 34-18-33: 1995
Functional evaluation of insulation systems for rotating electrical machines	**Rotating electrical machines**	**Rotating electrical machines**	**Rotating electrical machines**	**Rotating electrical machines**
Part 1: General guidelines	*Part 18:* Functional evaluation of insulation systems *Section 21:* Test procedures for wire-wound windings – Thermal evaluation and classification	*Part 18:* Functional evaluation of insulation systems *Section 22:* Test procedures for wire-wound windings – Classification of changes and insulation component substitutions	*Part 18:* Functional evaluation of insulation systems *Section 31:* Test procedures for form-wound windings – Thermal evaluation and classification of insulation systems used in machines up to and including 50 MVA and 15 kV	*Part 18:* Functional evaluation of insulation systems - *Section 33:* Test procedures for form-wound windings – Multifactor functional evaluation Endurance under combined thermal and electrical stresses of insulation systems used in machines up to and including 50 MVA and 15 kV

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The drawing (left) symbolically shows the involvement of VEM in the technical discussions held in the early 90‘s in the field of functional evaluation of insulation systems of electrical machines and their transformation into technical standards. In a close, long-lasting cooperation with our Saxon partner universities and a sustained personal collaboration on the competent IEC working groups - in this time in the technical committee TC2/SC2J „classification of insulation systems“ - VEM has been particularly involved in enabling the publishing of an comprehensive series of standards for the first time. Based on our own very successful work in the field of basics and standards in the 70‘s and 80‘s, it was possible to prepare and enforce essential principles of functional evaluation of insulation systems for industrial use (also see the enclosed article „Historical overview“).

On behalf of IEC/TC2, the entire series of standards IEC 60034-18 is currently being revised by a working group (MT10) especially established for this purpose. The revision has reached an advanced stage, that means, some standards are already completed, for others, the technical discussion is about to finish and furthermore, two parts (18-41 and 18-42), which are dealing with the qualification of insulation systems for converter operation, have been added to the series of standards. The thermal evaluation of small changes to the insulation system is no longer discussed in part 18-22. For this problem, reference is made to the existing standard IEC 61858 which contains similar testing procedures applicable for individual insulating materials. The main focus of the review in particular is the adjustment to the current level of knowledge, e.g. the consideration of new material, technologies, testing procedures and their utilisation, the consideration of testing experiences with this series of standards, the consideration of new normative rules and harmonisation requirements, an improved statistic analysis of test results, as well as an adaptation of length with regards to contents and coordination of the individual parts. According to the stage of work, the table on the left is updated as follows:

IEC 60034-18-1 Ed.2: 2010	IEC 60034-18-21 Ed.2: 2011	IEC 60034-18-31 Ed.2: 2011	IEC 60034-18-32: Ed.1: 2010	IEC 60034-18-33: Ed.2: 2010	IEC 60034-18-34: Ed.1: 2011
Rotating electrical machines	**Rotating electrical machines**	**Rotating electrical machines**	**Rotating electrical machines**	**Rotating electrical machines**	**Rotating electrical machines**
Part 18 1: Functional evaluation of insulation systems General guide-lines	*Part 18-21:* Functional evaluation of insulation systems Test procedures for wire-wound windings Thermal evaluation and classification	*Part 18-31:* Functional evaluation of insulation systems Test procedures for form-wound windings Thermal evaluation and classification	*Part 18-32:* Functional evaluation of insulation systems Test procedures for form-wound windings Evaluation by electrical endurance	*Part 18-33:* Functional evaluation of insulation systems Test procedures for form-wound windings Multifactor evaluation by endurance under simultaneous thermal and electrical stresses	*Part 18-34:* Functional evaluation of insulation systems Test procedures for form-wound windings Evaluation of thermomechanical endurance of insulation systems

Note on the table: the standards IEC 60034-18-41 and IEC 60034-18-42 are missing because converter operation is not dealt with here

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VEMoDUR®-VPI-155

Thermal endurance of the insulation system

The following report deals with the functional thermal evaluation on a high-voltage insulation system by VEM Sachsenwerk GmbH. The experimental tests have been carried out in the high-voltage laboratory of the University of Applied Sciences Zittau/Görlitz (FC), department of Electronics. 1)

1. Introducing the insulation system to be tested

All insulation systems of VEM Sachsenwerk GmbH are carrying the trade name VEMoDUR® based on the existing long-term operating experience. For the insulation of high-voltage machines, for which the VPI (Vacuum-Pressure-Impregnation) technology with small amounts of bonding agents, accelerator containing mica-paper-glass-silk-tissue-bands and epoxy impregnating resin has established both nationally and internationally, the insulation system VEMoDUR®-VPI-155 is used by VEM Sachsenwerk GmbH since 1984. This insulation system is primarily used for electrical high-voltage machines up to 13.8 kV. The material components are obtained from leading manufacturers of insulating material in western Europe. Because of the high thermal endurance of the individual components and the extensive operational experience, these electrical machines can be classified with thermal class F (allowed permanent temperature 155°C). For quantified data on life expectancy, for the determination of thermal overload capacity and mainly for the comparison to advanced, new insulation systems („candidate insulation systems"), the check-out of the entire insulation system is necessary.

2. Task

A thermal functional evaluation according to IEC 60034-18-1 and IEC 60034-18-31 (DIN EN 60034-18-1 and DIN EN 60034-18-31) shall be carried out on an insulation system VEMoDUR®-VPI-155 with the rated voltage UN 6.6 kV.

According to these standards, the functional tests are carried out on representative models in cycles. An ageing-subcycle is followed by a diagnostic-subcycle, in which the status of the insulation condition is tested. As a result of a functional test like this, a thermal classification can be done.

The diagnostic test voltage for the main insulation has been set to $2 \cdot U_N$, as recommended. This results in a comparatively effectively short test lifetime, that means testing time and testing costs are saved. On the other side, lower absolute time to failures compared to operation in service are reached, because the highest steady state line-to-ground voltage e.g. in the 6 kV network is only $7.2\ \text{kV}/\sqrt{3} = 4{,}2\ \text{kV}$.

With the check-out, it has to be proven that not only, as argued in the past, must the components be suitable for allowed permanent temperatures of 155°C, but also that the entire system in connection with the technology used for its manufacture complies with the requirements of thermal class F and therefore can be used as a reference-insulation system for new insulation systems in the future at the same time.

When testing, the main and turn insulation of real stator coils must be evaluated separately.

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1) *In charge of the test and author of the report:*
Prof. Dr.-Ing. Wolfgang Golbig [Project Manager for the development of the insulation system VEMoDUR®-VPI-155 and Professor of high-voltage technology at the University of Applied Sciences in Zittau/Görlitz (FH)], Dipl.-Ing. (FH) Günther Wieland [Researcher at the University of Applied Sciences in Zittau/Görlitz (FH)]

3. Test Objects

Test objects are high-voltage form-wound coils for a rated voltage of $U_N = 6.6$ kV. The design of the insulation was carried out according to the rules on desing and manufacture of such machines.

Main components of the insulation system:
- Winding wire insulated with mica paper - PETP-film band, bakingable
- Slot-part and end-winding insulation with low content of bonding agents, mica paper-silk-glass-tissue-band, containing an accelerator
- Slot-part or end-winding corona protection with low-resistance or semi-conductive corona protection band
- Impregnation with epoxy impregnating resin according to plant customary VPI technology

Main dimensions of the test objects:
- Length in laminated core: 250 mm
- Step size: approx. 190 mm
- External dimensions slot-part: 12.5 mm x 22 mm
- Number of turns : 2 x 14

For testing the turn insulation, some coils are disconnected in the end-winding in order to enable voltage stress between adjacent coils.

The test objects are slot-models with angular, stainless sheets in the slot-part. The slot-models are designed in way that a large support surface is available to the floor (Figure 1).

This:
simplifies the mounting of the test coils during the diagnostic vibration loading and ensures a heat transfer between cooling surface and test coil during the condensation process.

Figure 1: Test object for the determination of long-term heat resistance

4. Test Facilities

The tests have been carried out in the „test laboratory for the thermal evaluation of insulation systems“ at the University of Applied Sciences Zittau/Görlitz (FH).
Besides appropriate equipment for the creation of ac-voltage and impulse voltage, laboratory heating oven with corresponding dimensions with temperature consistency as required by the standard, as well as systems for moisture exposure with cooling surfaces on the bottom which ensure constant condensation for 48 hours, are available (Figure 2).

Figure 2: Test facilities for the thermal evaluation of insulation systems

5. Test Procedure

5.1. Preliminary test

Before starting the ageing test, preliminary electrical tests have been carried our at the test objects. The following withstand voltages have been used:

- For the main insulation, ac-voltage 16 kV / 1min and 14,2 kV / 10 min
- For the turn insulation lightning impulse voltage 7 kV / 3 pulses/wave 1,2 / 50 µs

5.2. Thermal ageing subcycle

According to the expected thermal class, ageing temperatures and subcycle lengths have been chosen as follows:

Ageing temperature: T_A	°C	180	200	220
Time for a thermal ageing subcycle t_z:	Days	28	10	3
	Hours	672	240	72

5.3. Diagnostic Subcycle

For the diagnostic subcycle, the following test parameters have taken effect in the stated order after the thermal ageing subcylce and after cooling down the test objects to room temperature:

- Vibrational loading: 1 hour with 1.5 g
- Moisture exposure: 48 h condensation
- Electrical test: turn insulation: 7 kV/3 pulses/wave 1.2/50 µs; main insulation 13.2 kV/10 min/50 Hz

5.4. Evaluation

For each failed test object, the total number of hours of the thermal ageing

$$t_A = \sum_{n=1}^{n-1} t_z + \frac{t_z}{2}$$

has been recorded. From the statistical distribution function of these times to failures, the average times to failure (63% quantiles of the Weibull-function) with the corresponding 90% confidence limits have been determined and recorded in the lifetime diagram (test lifetime).

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6. Results

For the insulation system VEMoDUR®-VPI-155, a test lifetime > 10^4 h results at the class temperature 155°C (Figure 3). This value must be rated as very high considering relatively high diagnostic test voltage (see section 2). Orientating tests on single coils with reduced test voltage produced significantly higher times to failure.
During the visual evaluation of the failed main insulations it was detected that the breakdown points are in the area of the ends corona protection at the end of the test lifetime. This circumstance probably results from the high thermal test stress and the limited thermal stability of the semi-conductive ends corona protection band with carrier made of polyester silk tissue and SiC coating normally used. For future tests, an end-winding corona protection especially touched up for the test should be used as normatively possible.
The test life of the turn insulation is higher than the main insulation. From this, it can be reasoned that the turn insulation is able to sustain very high pulse voltage stresses (e.g. during switching operations), even after thermal ageing.

A halving interval of 15 K results from the rise of the life curve (Figure 3). By knowing this value, a life estimation is possible for the S10 operation according to IEC 60034-1 (DIN EN 60034-1) for motors. During this type of duty, the maximum stress may reach the 1.2-fold of the rated output in duty type S1.
The tested insulation system VEMoDUR®-VPI-155 is available as a reference system for future functional evaluations.

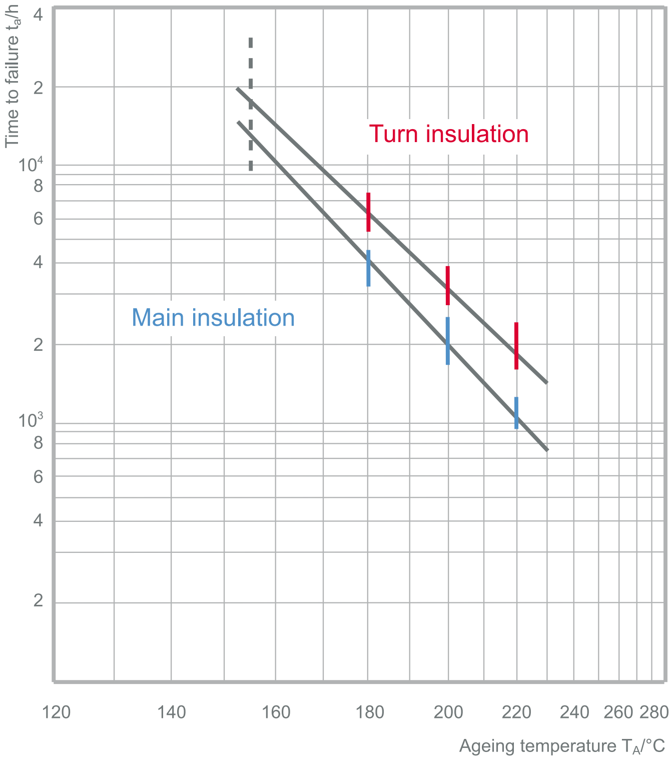
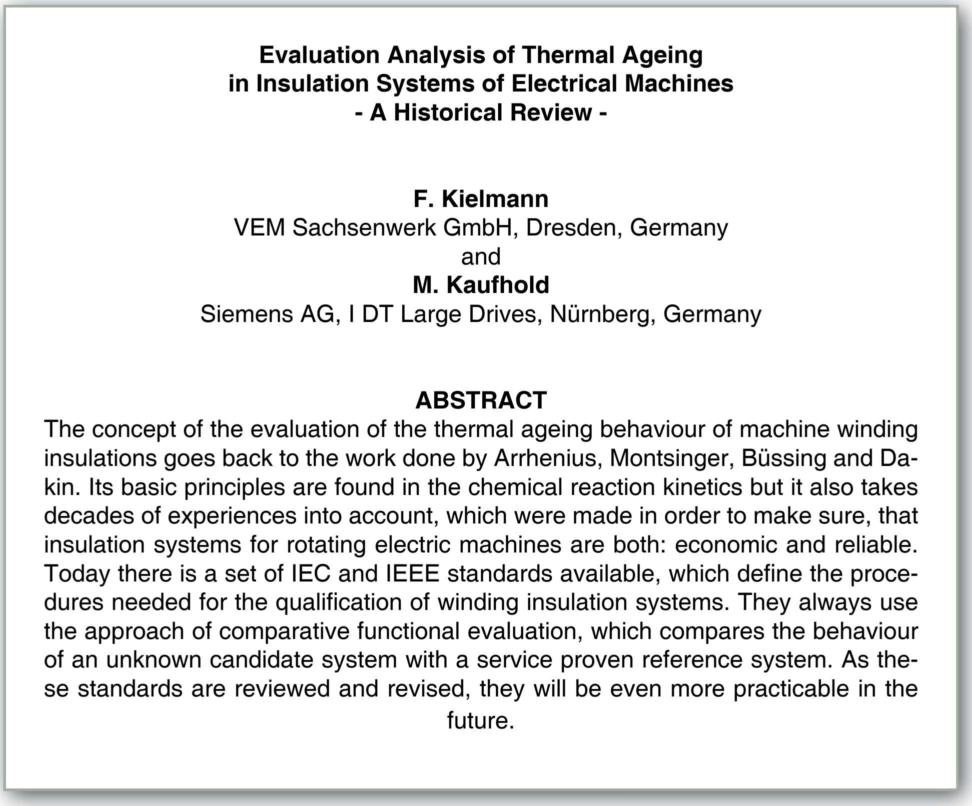


Figure 3: Life time diagram of the main and turn insulation VEMoDUR®-VPI-155

Annex

Instead of a list of references, a current publication of the author about the historical development of thermal evaluation of insulating materials/insulation systems of electrical machines is reproduced. This publications has originated in the course of the work in IEC/TC2/MT10 and the strategic cooperation with the company Siemens AG, and has been published as an article in IEEE .
The author Dr.-Ing. F. Kielmann is a member and the co-author Dr.-Ing. M. Kaufhold is the convener of the mentioned working group.

Complete reference:
Kielmann, F.; Kaufhold, M.: Evaluation Analysis of Thermal Ageing in Insulation Systems of Electrical Machines – A Historic Review, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 17, Issue 5, pp. 1373-1377, October 2010



Evaluation Analysis of Thermal Ageing
in Insulation Systems of Electrical Machines
- A Historical Review -

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ABSTRACT

The concept of the evaluation of the thermal ageing behaviour of machine winding insulations goes back to the work done by Arrhenius, Montsinger, Büssing and Dakin. Its basic principles are found in the chemical reaction kinetics but it also takes decades of experiences into account, which were made in order to make sure, that insulation systems for rotating electric machines are both: economic and reliable. Today there is a set of IEC and IEEE standards available, which define the procedures needed for the qualification of winding insulation systems. They always use the approach of comparative functional evaluation, which compares the behaviour of an unknown candidate system with a service proven reference system. As these standards are reviewed and revised, they will be even more practicable in the future.

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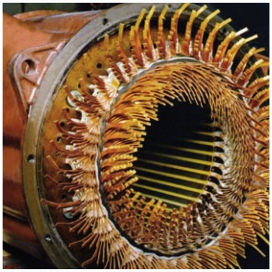

1. Introduction

When 120 years ago, Svante Arrhenius developed his Arrhenius Equation which is used to describe the relationship between the speed of a chemical reaction and temperature, he was probably not aware that in doing so he would trigger an ongoing discussion on the issue of how to evaluate thermal aging of insulation systems for electrical machines. Although the dynamo-electric principle had already been invented at the time, the first asynchronous machine was just being put into operation and so the initial focus of his analytical research was on a general scientific interest in the subject.

To date, there is hardly any article written about the thermal ageing of insulation systems that does not include either a direct or indirect reference to the Arrhenius equation. This alone shows the fundamental significance of this essential work in describing chemical reaction kinetics. It first became obvious that there was a need to do further research on aging mechanisms in the insulation system decades after the first electrical machine was commissioned.
Operational experience, which was the most important, and at the time, the only option available for assessing functional reliability, no longer sufficed.
The questions that remained revolved around how dependent the life-cycle was on the material composition of the insulation system, the operational demands and environmental effects on a machine, as well as the application of principles that had been recognized in the meantime. For a long time attempts had been made to apply empirical approaches to find answers on ageing and other technical questions similar in nature, such as for example, those relating to endurance curve.

Those recognized pioneers of the time were Montsinger (1930) [1], Büssing (1942) [2] and Dakin (1948) [3]. Their in-depth research on the mechanism of thermal ageing of insulation systems using organic insulation materials made it possible to make the first conclusions that could be used technically. The well-known Montsinger's 8 degree rule, which was empirically derived from the behaviour of the oil impregnated paper insulation in transformers, is one of these technical conclusions. It can be attributed to the Arrhenius equation; however it is so enticingly simple in the statement that often its validity is used without accounting for temperature limits and without taking the temperature dependency of the location parameter of the endurance curve into consideration. Even today assumptions are often made about the thermal ageing speed of machine insulations using a so-called 10 degree rule.

In his extensive research, Büssing focused exclusively on the insulation systems of electric machines and in the process attempted to clarify how a thermal endurance curve attained at high temperatures can be extrapolated for lower temperatures. And by doing so he was the first to extensively analyze an important principle of today's thermal functional testing. However, his research was based on the incorrect assumption that tests conducted on individual insulation material could be transferred to the machine as a whole. Based on what is known today, this represents a seriously inaccurate assumption prevalent even into the 1970s and 1980s, and it resulted in the thermal classification of individual insulation materials defined in standards.
Of mention in this regard is the basic standard IEC 85 (1957) [4], which was based on operational experience and contained lists with insulation material organized in classes by temperature limits (heat classes) and provided information on their use. However, in the years that followed, numerous new, synthetic insulation materials could not be included in the classification data found in the IEC 85 charts due to a lack of operational experience and new manufacturing procedures [5].

Moreover, it soon became obvious that it is not possible to analyze the insulation strength based purely on the temperature limits of individual insulation materials. Negative as well as positive material interdependencies can occur if a variety of ageing factors affect the insulation materials at the same time. Classic examples are the thermal upgrading of fleece materials using appropriate impregnating agents and in some circumstances the chemical incompatibility between wire enamel and impregnating agent.

2. Evaluating insulation materials

The association of insulation materials with heat classes was not removed until the publication of the revised version of IEC 85 (1984) [6]. Classification of insulation systems is only permissible from sufficient operational experience or from appropriate functional evaluations, compared to a reference insulation system that is tried and tested during operation.

The definition of the so-called temperature index (TI) combined with information about a thermal endurance profile (TEP) or rather a halving interval (HIC) in accordance with IEC 216 (3rd edition, 1987) has gained significance on an international level for the thermal evaluation of individual insulation material since 1984. [7] Based on the definidefinition, the TI is a figure that equates to the temperature in centigrade, which is derived through extrapolation of a thermal endurance curve up to a specified period of time, typically 20,000 h.

This figure provides information about how thermal ageing leads to the irreversible reduction of a very specific material property, which will presumably define the functional characteristics for application at a later stage. For the insulation systems of electric machines, this property is generally the "breakdown voltage of a sample arrangement".

This method has been the state of technology for some time now, and is only illustrated here again, because the extrapolation of the endurance curve is performed in situations where the Arrhenius equation applies and – is often graphically evaluated – in the so-called Arrhenius diagram.

The chemical reaction kinetics according to Arrhenius has become an indispensable theoretical principle used to describe the purely thermal aging of individual insulation materials, and, as will be shown later, also of complete insulation systems. The endurance principle derived from it is generally shown in the following form:

$$t_a = \alpha \cdot e^{n/T}$$

where t_a: time to failure, α: location parameter, n: endurance index

The time to failure - temperature characteristic equates to a straight line in the Arrhenius diagram, in which the time to failure is plotted logarithmically on the ordinate and the inverse of absolute temperature 1/T is plotted on the X-coordinate. Of course, the restrictions to the validity, especially for the linearity, must be continuously questioned.

Depending on the selected material property, ambient conditions, property limits and time limit of the extrapolation, an individual insulation material may have a wide range of characteristic temperature indices.

The information on the increase of the endurance curve (halving interval HIC or endurance index) can be of great benefit to a preselection of the insulation materials used in the composition of insulation systems. The current six-part edition of IEC 60216 [7] provides extensive and globally recognized recommendations and guidelines on the thermal evaluation of insulation materials. It gives detailed descriptions of aging procedures, evaluation methods, selection criteria, calculation methods, aging test equipment and the presentation of test results.

3. Evaluating insulation systems

The 1984 publication of the groundbreaking revised version of IEC 85 mentioned above led to an international discussion on wide scale new functional tests for insulation systems of all operational equipment. What was especially important was to take into account the variety of possible ageing factors (thermal, electrical, mechanical and ambient conditions) model type and size, manufacturing method, physical and/or chemical interactions among the components. These kinds of functional tests have been conducted since the mid 1970s in the United States – mentioned as an example are the tests according to IEEE 117 [8]. In addition there is IEEE 1776-2008 [23] which replaces IEEE 275 and 429. These already include important general recommendations for the evaluation process and basic design of the test models (e.g. "motorette").

In 1992, SC2J/TC2 prepared new guideines as a part of the IEC standards that can be used for the functional evaluation of the long-term behaviour of insulation systems of electrical machines. Among them were testing methods for the main winding types (random-wound and form-wound) or for the typical ageing factors (dominant thermal, dominant electrical and the combinations thermal-electrical and thermal-mechanical). For the thermal evaluation of complete insulation systems, which is the focus of the rest of this article, the following standards were prepared from the testing experience available up until then, in addition to considering also IEC 505 (1975) [9], IEC 610 (1978) [10] and IEC 611 (1978) [11].

- Functional Evaluation of Insulation Systems for Rotating Electrical Machines – part 1: General guidelines (IEC 60034-18-1)
- Functional Evaluation of Insulation Systems – section 21: Test procedures for wire-wound windings – thermal evaluation and classification (IEC 60034-18-21)
- Functional Evaluation of Insulation Systems – Section 31: Test procedures for form-wound windings – thermal evaluation and classification of insulation systems used in machines up to and including 50 MVA and 15kV (IEC 60034-18-31)

All of these functional tests have two principles in common:

1. A new insulation system (candidate system) is always tested and evaluated in comparison with a reference system, for which sufficient operation experience is available.
2. The functional tests are conducted in cycles on machines, parts thereof or representative models. An ageing sub-cycle is followed by a diagnostics sub-cycle, during which the state of the insulation is tested.

The application of testing standards for purely thermal ageing was always a matter of debate in the early stages because the assumption of dominant thermal aging during machine operation was merely supported by general operational experience and was not verified experimentally. However, subsequent experimental results presented in technical publications provided the justification for this kind of assumption.

Thus, for example, it was established that the thermal endurance coefficient of the time to failure - temperature characteristic during ageing in the motorette test is dependent on the mechanical and climatic stress factors in the diagnostic sub-cycle [12]. All that was impacted was the location parameter, which results in a stress-dependent parallel shift of the characteristic line. What was also established was that during a reversing test with complete low voltage asynchronous motors conducted at the same time as the motorette test simultaneously under thermal, mechanical and electrical stress, the endurance index also remained unchanged. Therefore it was quite clear that the same ageing process, i.e. dominant thermal aging, was at hand.

So, this statement does apply with regard to small low-voltage standard motors, however it must be reevaluated with regard to larger machines, which must also be thermally evaluated and classified, by incorporating operational experiences. The "classification", or the association of a specific heat class with an insulation system, is a distinctive feature of the thermal evaluation. Supported by the principles formulated by Arrhenius, the thermal endurance curve can also be extrapolated for insulation systems up to the class temperatures listed in IEC 60085 and 60505.

The essential difference, however, is that the extrapolation of the endurance curve of the reference system is not conducted up to a predefined time limit – say 20,000 hours – but instead up to a class temperature, from which the test endurance curve can be derived.

Whether or not the reference system is suitable for a particular application must always be deduced in advance based on operational experience and must be documented. What must also be considered is that there can be very different requirements for sufficiently long operational endurance within one heat class [13]. Attempts to predict the absolute endurance of the insulation system in service of a machine by performing a functional evaluation on a bench-scale can only lead to approximate solutions, even if the ageing mechanism is known, because typically not all the operational stresses that affect the machine can be accounted for [14, 15].
Additional standards in the 60034-18-series allow for the consideration of other or combined stress factors: Part 18-32 for electrical, Part 18-33 for thermo-electrical and Part 18-34 for thermo-mechanical ageing. Using a combined stress within the functional testing may bring up additional information relevant for the qualification of a candidate system or for general evaluation of its suitability.
While the result of a functional thermal test (at elevated temperatures according to Part 18-31) could support the qualification of a specific candidate, the result of a thermo-mechanical functional test of the same candidate (with thermal cycles between class and room temperature) may lead to the opposite conclusion, if it reveals delaminations [14, 16].
In another example, attempts were made to determine the endurance of small low-voltage standard motors by conducting a so-called "motorette-supported continuous reversing test". The two testing methods "motorette test procedure" and "motor test procedure" in accordance with IEC 60034-18-21 were combined ([12], [17]). The endurance index from the motorette test is transferred to the reversing test, which can only be conducted at one ageing temperature and thus with relatively little effort.

In these tests, the effects of the switching surges during the reversing test on the ageing of the insulation system also became known. Without any protective circuits, electrical ageing can also occur very easily ([17], [18]). This fact alone illustrates that these kinds of solutions to the problem may be a bit fuzzy.

4. Outlook

As part of the revision of the entire standard series IEC 60034-18 currently being carried out in MT10/TC2, those parts of the standard that relate to the thermal functional evaluation are also being reviewed with regard to compatibility with the latest state of knowledge.

The revision process is already well advanced and at this point it is already obvious that the essential principles listed above will remain valid. The individual partial standards will be tightened in terms of content and the statistical evaluation of the test results.

The thermal evaluation of small changes to the insulation sys-

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tem will no longer be treated as in the past in Part 18-22. Reference is made to IEC 61858, which relates to these problems.

The standard series has in the meantime been supple-mented with Parts 18-41 and Part 18-42, which deal with the subject of qualifying insulation systems for converter operation. The principles of functional evaluation are also consistently applied here, i.e. a new insulation system is suitable for converter operation if the diagnostic data acquired for the candidate system are, based on the comparison test, at least as good as those of a tried and tested reference system.
While in this article the discussion is primarily about the thermal evaluation of insulation systems, a closer look is given to particular issues resulting from the additional electrical stress in converter operation (as compared to sine wave operation) of low-voltage machines with random-wound windings or form-wound windings. The pulse-type electrical stress affects the failure rate and the failure mechanism of low voltage insulation systems [19, 20] as a consequence of the partial discharges in the insulation.
The ageing of the insulation system in sine wave operation is dominantly thermal. However, the ageing of low and high voltage machine insulation systems powered by converters is dominantly controlled by electrical ageing caused by high converter stress amplitudes and high pulse frequency [21].

The temperature only plays a minor role, because it merely influences the conditions under which the partial discharges exist [19]. The decrease in the partial discharge inception voltage, is only less than about 10% in real machines in operation and at class temperatures of 155 °C [22].

IEC 60034-18-41 required freedom from partial discharges as a qualification criterion for low-voltage insulation systems. The freedom from partial discharges must be demonstrated in a first step for test objects in accordance with Part 18-21 (low voltage machines) or Part 18-31 (high voltage machines) during and after thermal aging at a selected ageing temperature with a pulse voltage at a defined level.
During the second step, the freedom from partial discharges must be confirmed in a type test conducted on complete windings or machines (low voltage machines only).

The freedom from partial discharges is a necessary but not a sufficient safeguard for the successful operation of a new low-voltage insulation system for converter operation. This safeguard is, based on the principles for functional evaluation, not available until all diagnostic data have been compared with a tried and tested reference system.

The IEC standards of the series 60034-18-xy are currently under the maintenance cycle. The international team MT10 is reviewing these documents in order to improve their practicability.

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Evaluation and qualification of electrical insulation systems

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