

9

Winding insulation and maintenance

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9.1 Insulating materials and their properties

The insulating materials form the heart of an electrical machine. During operation these materials may be subject to electrical, thermal and mechanical stresses and must be capable to endure the same and possess the following,

Electrical stresses

- high breakdown voltage
- good long time performance
- low partial discharges (minimum voids within insulation or on interface between insulation systems)
- very small leakage or creepage currents.

Thermal stresses

- high long time performance
- small deformation after temperature cycles
- least delamination within insulation material

Mechanical stresses

- high mechanical strength to sustain forces due to handling and mechanical forces under operation.
- least reduction of mechanical strength within specified operating temperature and voltage.

To achieve the above one may improvise the impregnation process to minimize voids within insulating materials. Also improvise hot iron press to minimize minute voids created inadvertently due to the process followed to wrap the insulating tapes in many layers on the coils.

Following are some insulating and binding materials that have traversed since time immemorial and may continue in times ahead,

- wood, gutta-percha, textile and mica as insulating materials.
- shellac or bitumen as binding material
- synthetic resins like polyester and epoxy resin.
- silicon rubber as high temperature material.

The common types of insulating materials in use for electric motors are E and B for small motors and F for medium sized and large ones. General industrial practice, however, is to limit the temperature to class B limits, even if class F insulation is used.

Insulation class A, previously in use, has been discontinued in view of its low working temperature. Motor frames have also been standardized with class E insulation only by IEC recommendations, as in Table 1.2, to harmonize the interchangeability of electric motors. This decision was taken because class E insulation offers a higher working temperature and a longer working life. These frames also ensure optimum utilization of active materials such as copper and steel in a particular frame size. The classification of insulating materials is based on their maximum continuous working temperature, established for 20 years of working life. The recommended temperature according to IEC 60034-1 is, however, less

than this, as shown in Table 9.1, to ensure an even longer life. Where the ambient temperature is likely to be high, of the order of 60°C or so during operation, such as close to a furnace, class F and H insulations are normally used, as they have higher working temperatures and thermal resistivity.

A brief description of the insulating materials in use for different classes of insulation is given below to provide an introduction to the types of materials being used in the preparation of a particular class of insulation. The actual ingredients may be an improvised version of these materials, in view of continuous researches and development in this field, to search out for still better and more suitable materials.

9.1.1 Insulation class A

This includes organic fibrous materials on a cellulose base such as paper, pressboard, cotton, cotton cloth and natural silk etc., impregnated with lacquers or immersed in an insulating liquid. The impregnation or immersion ensures that the oxygen content of the air does not affect the insulating properties or enhance the thermal ageing of the insulating material. Typical materials in this class are varnished cloth and oil-impregnated paper.

9.1.2 Insulation class E

This includes wire enamels on a base of polyvinyl formal, polyurethane or epoxy resins as well as moulding powder plastics on phenol-formaldehyde and similar binders, with cellulose fillers, laminated plastics on paper and cotton cloth base, triacetate cellulose films, films and fibres of polyethylene terephthalate.

9.1.3 Insulation class B

This includes inorganic materials such as mica, glass fibre and asbestos etc., impregnated or glued together with varnishes or compositions comprising ordinary organic substances for heat resistance such as oil-modified synthetic resins, bitumen, shellac and Bakelite.

Table 9.1 Maximum/permissible working temperatures for different insulating materials

Class of insulation	Maximum attainable temperature as in IEC 60085 °C	Permissible operating temperature as in IEC 60034-1 by the resistance method ^a	
		Up to 5000 kW °C	Above 5000 kW °C
A ^b	105	100	100
E ^b	120	115	110
B	130	120	120
F	155	145	145
H	180	165	165

^a Using the thermometer method this temperature will be less by 10°C.

^b These insulations are generally not used, for large motors, due to their low operating temperature.

9.1.4 Insulation class F

This includes inorganic materials such as glass fibre or polyester and mica impregnated or glued together with epoxy, polyesterimide (polyamide or polyimide), polyurethane or other resins having superior thermal stability.

9.1.5 Insulation class H

This comprises composite materials on mica, glass fibre and asbestos bases, impregnated or glued together with silicone resins or silicone elastomer. These materials must not contain any organic fibrous materials such as paper or cloth backing, which is covered under class B and even F insulation systems.

9.2 Ageing of insulation

With time, the insulation becomes brittle and shrinks, leading to cracks. The insulation at the point of cracks weakens gradually as surrounding pollutants find their way through these cracks. The weakening of insulation with time is called 'ageing'.

The life of the insulation will also be affected by an excessive operating temperature. It is halved for every 11°C rise in temperature over its rated value and occurs when a machine is occasionally over-loaded. Sometimes the size of the machine may be only marginal when it was initially chosen and with the passage of time, it may be required to perform duties that are too arduous. Every time the machine over-heats, the insulation deteriorates, and this is called thermal ageing of insulation. Figure 9.1 illustrates an approximate reduction in life expectancy with a rise in operating temperature.

9.3 Practices of insulation systems

• Insulation of steel laminations

- (i) For smaller ratings: by steam bluing the steel surfaces on both sides.

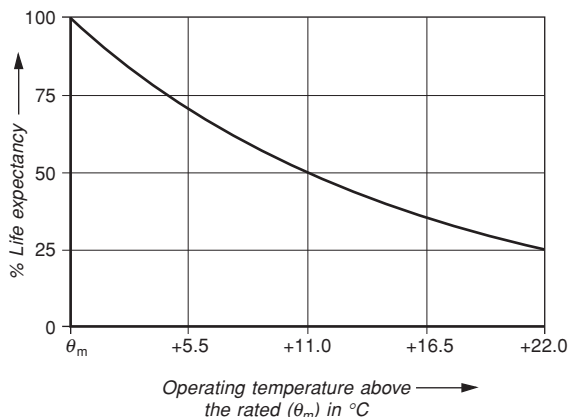


Figure 9.1 Reduction in life expectancy of a motor with a rise in operating temperature

- (ii) For larger ratings: by phenol or synthetic resin insulation on one or both sides. Although insulation on one side is common, by ensuring that the laminations are always punched and stacked in one direction only to avoid contact between the punching burrs, insulation on both sides is always preferred.

• Insulation of the windings

Different manufacturers adopt to different practices of insulating the coil or the windings. Practices generally used may be one of the following.

9.3.1 LV motors

Wound stator

- By simple impregnation in a recommended insulating varnish, normally synthetic or epoxy, followed by baking (curing), in a temperature-controlled oven, at a specified temperature for a specific period.
- For powerhouse insulation treatment the stator may be dipped in varnish for a minimum two to three times, each dipping being followed by backing. Sometimes one immersion of the entire stator and two additional immersions of the overhangs followed by backing may also be sufficient.

Formed wound machines

For large motors, the practice is to wind the stator with formed coils (Figure 9.2). The coils are pre-formed and cured before insertion into the stator slots. They are insulated with resin-rich glass and mica paper tapes. The

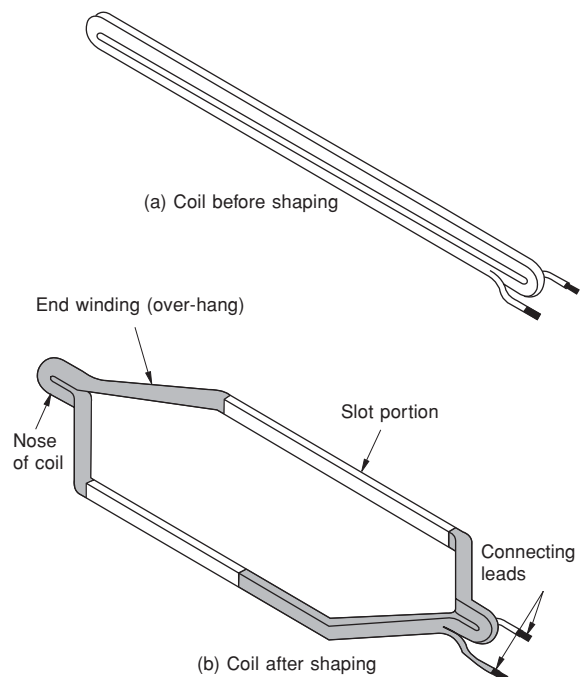


Figure 9.2 View of a formed coil

process of impregnation is therefore termed 'resin-rich' insulation. The completed formed wound stator is then heated to remove trapped moisture and finally impregnated in varnish class F or H as required. It may be simple dipping, roll impregnation (rotating in impregnating varnish for $\frac{1}{2}$ –1 hr) or vacuum pressure impregnation (VPI). While VPI is the preferred method being more reliable, as noted below, other methods also providing satisfactory results and being economical are practised by many manufacturers up to 1000 kW or so. The stator is then cured in an oven as described above. The process of insulation and curing conforms to powerhouse insulation requirements. This practice facilitates easy removal of an individual coil at site in case of a damage and replacement with a spare coil. The user can stock spare coils for such eventualities.

9.3.2 MV motors

To wind MV motors two methods are adopted:

1 Resin rich system

The stator is wound with pre-formed coils on similar lines as noted above. After thorough testing on each coil for the polarization index and dissipation factor ($\tan \delta$), as discussed in Sections 9.5 and 9.6, and the impulse voltage withstand test, as discussed in Section 11.4.9, the individual coils are completely cured and toughened before inserting them into the slots. The rest of the process is as noted earlier.

2 Vacuum pressure impregnation (VPI)

For MV motors, the recommended practice is to have the stator vacuum pressure impregnated (VPI) in insulating resins as a standard procedure, not only to meet the requirements of 'powerhouse insulation' but to also develop a more simplified insulating process, to cure and toughen the stator windings and to meet the severities of all operating conditions a motor may have to encounter. As described later, this is termed a resin-poor insulating process because the insulating tapes now have a low resin content as they are later to be impregnated in resin. Performance and field data of this insulating system have revealed excellent results, surpassing those of the normal impregnating process and even the process of resin-rich formed coils. As an economy measure, the general practice of leading manufacturers is to adopt a resin-rich formed coil system for frame sizes smaller than 630 and resin-poor VPI, simple dipping or roll impregnation for frame sizes 630 and higher. But it is always recommended to adopt a resin-poor system for all MV motor windings, irrespective of frame sizes. In a pressure-vacuum impregnation system, since the whole stator iron bulk and the stator windings form a solid mass, removal of one coil and its replacement is impossible, unlike in the previous case. But in view of the excellent properties of a post vacuum impregnated insulating system, the chances of any part of the stator winding developing an operational defect are remote. In all probability no such localized damage would arise over the life span of the motor. The windings may fail on account of a failure

of the protective system to clear a fault or isolate the machine on a fault, but if the motor fails, the whole stator is scrap and a totally new stator has to be requisitioned.

Bracing of the coil ends (overhangs)

The coil ends must be rigidly supported and adequately braced with binding rings or tapes to prevent their movement and also absorb shocks and vibrations during excessive over-loads, starting inrush currents (I_{st}), and voltage surges.

9.4 Procedure for vacuum pressure impregnation (with particular reference to MV motors)

In a resin rich coil system each individual coil is pre-formed, insulated and cured, and is made rigid before it is inserted into the slots. The dielectric qualities of the coil insulation are monitored closely during the process of coil formation to ensure the required quality. For procedure and acceptance norms see Section 11.4.9.

In the post-impregnated system, although the coils are formed as above, they are inserted into the slots when they are still in a flexible state. They are now easy to handle and cause no damage to their own insulation or the insulation of the slots while being inserted into the slots. The process up to the winding stage of the stator is thus faster and economical. The stator is then vacuum dried to remove trapped moisture, followed by immersion in a resin bath. It is kept immersed under vacuum so that resin can fill the voids. The bath is then pressurized to compress the resin so that it penetrates deeply into the slots, crevices and voids. Figure 9.3 illustrates the lowering of a stator's pre-formed windings into a resin impregnating tank. The stator is then cured in an oven under controlled conditions. The overall vacuum impregnating system may be expensive in view of the equipment required to dip the bulk of the stator into the impregnating resin and to create a very high vacuum, but the excellent properties of post-vacuum impregnation may compensate this initial cost.

Note

For MV motor windings, ordinary dipping and baking, as for LV motors, is not recommended in view of the very high stresses to which the windings may be subject to during switching or while clearing a fault, or in the event of a system disturbance. See also Section 17.5. An ordinary cured motor winding may not be able to withstand these conditions.

Repairing technique

Generally, no electrical fault would cause damage to the windings except in the event of failure of the protective system. Mechanical surface damage is, however, possible during transportation or installation or due to penetration of foreign matter into the windings. It is possible to repair such damage at site without affecting the performance or quality of the winding insulation. The

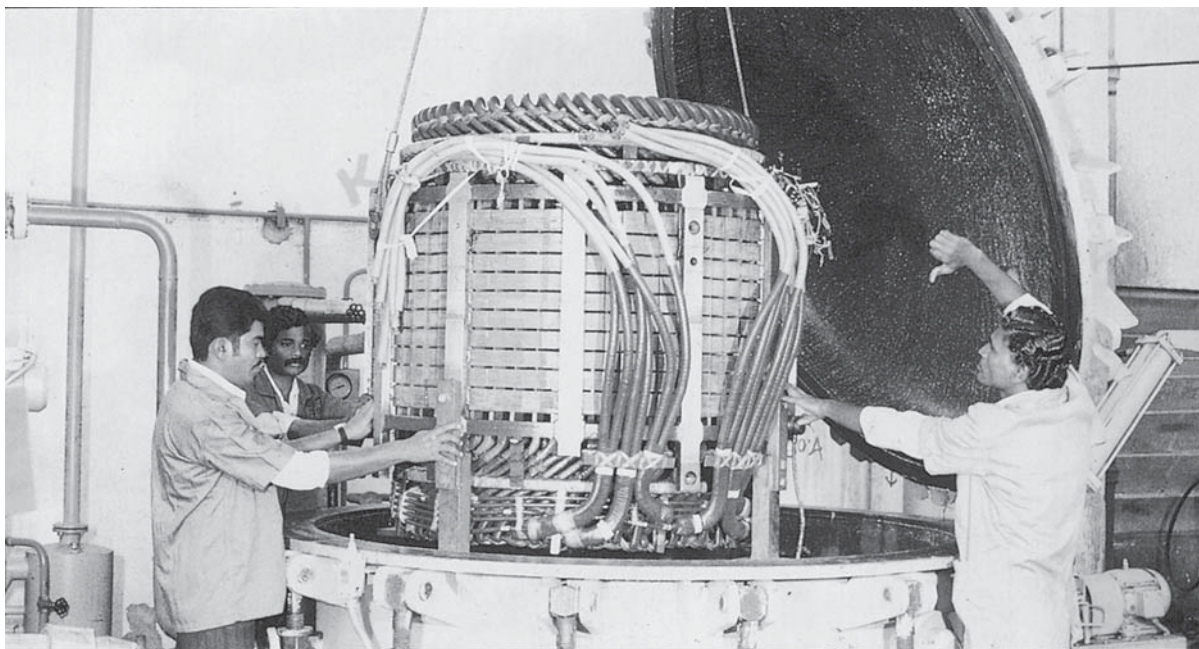


Figure 9.3(a) A stator core during vacuum pressure impregnation (resin-poor insulation) (Courtesy: NGEF Ltd)

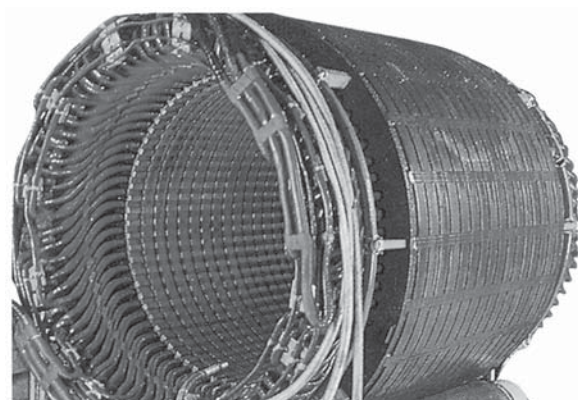


Figure 9.3(b) Stator core after vacuum pressure impregnation (VPI)

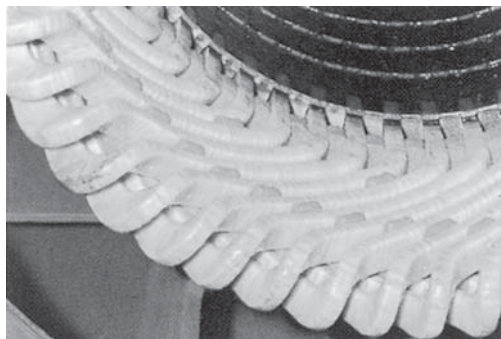


Figure 9.3(c) Exploded view of a VPI stator core

excellent electrical, mechanical and thermal properties of the end turn windings localize such damage. Repair is possible by slicing and cleaning the damaged part, and applying to it the pre-impregnated insulating tapes and other resins. It is recommended to request the manufacturer to carry out such repairs.

Note

For motors that are insulated other than by vacuum impregnation, it is recommended to rewind a damaged stator with class F insulation, even if the original insulation was E or B. This is to achieve a better life of the repaired motor, on the one hand, and facilitate an easy rewinding of the machine, on the other, as class F is a thinner insulation which is easy to rewind at site.

9.5 Maintenance of insulation

9.5.1 Against insulation failure

The properties of an insulating material are greatly affected by moisture, temperature, repeat over-voltages, and chemical vapour. Care must be taken to avoid these harmful effects to achieve prolonged life of the machine.

Whenever a motor is installed in a humid atmosphere and is switched on after a long shutdown, insulation resistance must be checked before energizing the motor. As a precaution, insulation resistance must be checked before a restart after a long shutdown, even in temperate conditions. If the insulation level is found to be below the recommended level as shown in Equation (9.1) it must be made up as noted below.

9.5.2 Making-up of the insulation level

This can be done by homogeneously warming and drying the windings in the following way:

- 1 A crude method can be to set up two lamps at both ends of the stator housing after removing the end shields. This can be done in smaller motors, say, up to '355' frame sizes.
- 2 By circulating roughly 50–60% of the rated current under a locked rotor condition, at a reduced voltage. To facilitate easy escape of the moisture to the atmosphere, the bearing covers may be removed.
- 3 At important installations, built-in heaters are recommended which can be switched ON when the motor is not in use. The rating of these heaters, known as space heaters, is such that a continuous 'ON' heater will not have any harmful effects on the motor windings, nor will they increase the winding temperature beyond the safe limits. The rule of thumb is to set the space heater rating so that it is able to raise the inside temperature of the motor by 8–10°C higher than the ambient. Its main function is to prevent the moisture condensation on the windings by maintaining a higher temperature inside the motor housing.

In certain cases, where the motor is too large and is stored for a long period before it is installed and electrically connected (the space heaters are also OFF during this period). Even these heaters may not be sufficient to absorb moisture which might have condensed deep in the slots, unless, of course, the heaters are kept ON for a considerably long period. In such cases, it is advisable to heat the motor by methods 1 and 2 in addition to using the built-in heaters, until the insulation level of the windings reaches the required level. Once the motor has been installed, these space heaters, when provided in the windings, are switched ON automatically as soon as the motor is idle, and thus eliminate deep moisture condensation.

9.5.3 Making-up of the insulation level in large machines (1000 kW and above)

IEEE 43 places special emphasis on determining the insulation condition of such machines before energizing and even before conducting a high-voltage test. This can be determined by the insulation test as noted below.

Insulation resistance test

Insulation resistance of the windings is a measure to assess the condition of insulation and its suitability for conducting a high-voltage test or for energizing the machine. A low reading may suggest damage to the insulation, faulty drying or impregnation or absorption of moisture. The insulation resistance may be measured according to the procedure laid down in IEEE 43 between the open windings and between windings and the frame by employing a direct-reading ohm meter (meggar). The ohm meter may be hand-operated or power-driven or equipped with its own d.c. source. A minimum of 500 V d.c. is the recommended test voltage for an insulation resistance test for all voltage ratings, as noted later. The

recommended minimum insulation resistance of the machine is obtained by the following empirical formula:

$$R_m = kV + 1 \quad (9.1)$$

where

R_m = recommended minimum insulation resistance in MΩ (meg-ohms) of the entire machine windings, at 40°C or 1 MΩ per 1000 V plus 1 MΩ, and
 kV = rated machine voltage in kV

The winding insulation resistance to be used for comparison with the recommended minimum value (R_m) is the observed insulation resistance obtained by applying a d.c. voltage to the entire windings for one minute, corrected to 40°C. In practice, motors with VPI have insulation resistance readings as high as ten to a hundred times the minimum recommended value R_m .

At site, when commissioning a new or an existing motor after a long shutdown, it must have a minimum insulation level according to Equation (9.1). An 11 kV motor, for instance, must have a minimum insulation of 12 MΩ. In normal practice, it is observed that when first measured the resistance reading may show more than the minimum value and may mislead the operator, while the winding condition may not be adequate for a high-voltage test or an actual operation. One must therefore ensure that the winding condition is actually suitable before the machine is put into operation. For this purpose, the polarization index (PI), which is determined from the insulation test data only as noted below, is a useful pointer. It must be evaluated at site while conducting the insulation test and then compared with the manufacturer's reference data for the machine to assess the condition of insulation at site and its suitability for operation. This is usually a site test, but to establish a reference record of the machine, it is also carried out at the works on the completed machine and test records furnished to the user.

Polarization index

This is the ratio of 10 minute to 1 minute value of insulation resistance readings. It will not be less than 1.5 for class A, 1.75 for class E and 2 for class B insulations for the windings to be regarded as suitable for a high-voltage test or actual operation. This index is based on the phenomenon that the insulation resistance of a winding rises with the duration of application of the test voltage. The rise is rapid when the voltage is first applied and then it almost stabilizes with time, as noted in Figure 9.4. For instance, after 30 seconds of the applied voltage this resistance may be too small, of the order of only a fraction of the final value. As a rough guide, the insulation resistance of a dry and normal winding may also continue to rise in the first few minutes after application of the test voltage before it stabilizes. Normally it may take 10–15 minutes to reach a steady state. If the windings are wet or dirty the steady condition may be achieved within one or two minutes of application of test voltage.

These test results are then compared with similar test data obtained from the manufacturer on similar windings carried out during manufacture. If the manufacturer's original test results are available, the results obtained at

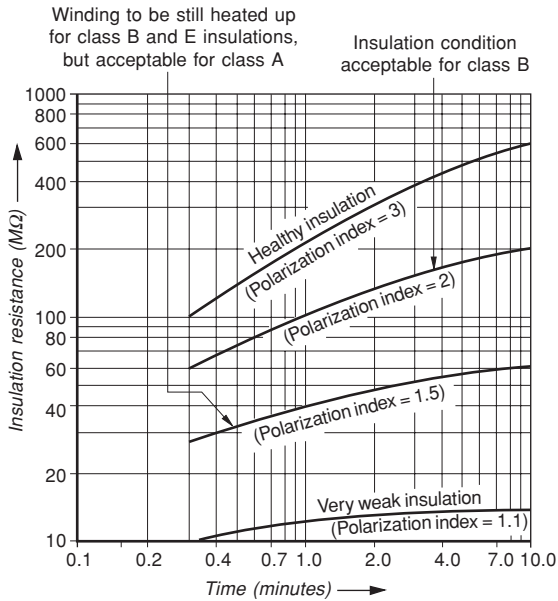


Figure 9.4 Variation of insulation resistance with time for class B insulation

site can be quickly compared and the condition of the insulation assessed easily and accurately. If the test facility to obtain test results at 1 minute and 10 minutes is not available, the results may also be obtained for 15 seconds and 60 seconds and a graph plotted as shown in Figure 9.5(a) to determine the polarization index.

From these insulation tests several test data for 1 minute and 10 minutes can be obtained during the process of heating over a few hours and a graph plotted for time versus insulation resistance. This graph is of great assistance in determining the state of the windings before energizing. Heating or cleaning-up of the windings should continue until the polarization index matches the reference value

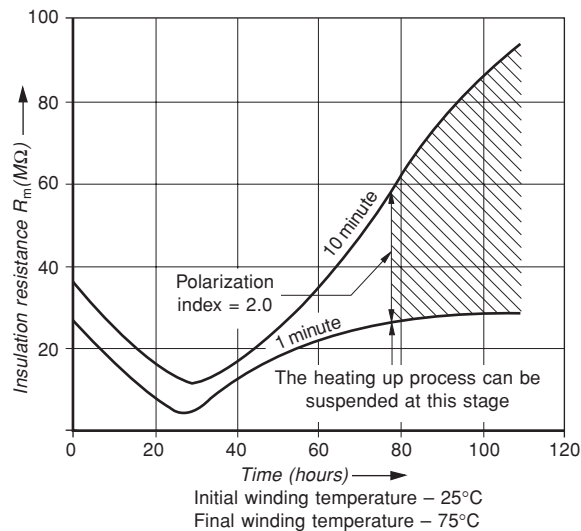


Figure 9.5(a) Typical values of 1- and 10-minute insulation resistances during the drying process of a class B insulated winding of a large machine

or reaches a minimum of 1.3 for all classes of winding insulation. Only then can the windings be considered suitable for a high voltage-test or actual operation.

Important aspects while measuring R_m at site

- 1 It will generally be seen that the insulation resistance will first fall to a very low level before rising, the reason being that when heating begins, moisture in the windings is redistributed in the stator windings. It may even reach the dry parts of the machine and indicate a very low value. After some time the insulation resistance will reach its minimum and stabilize at this level, before it begins to rise again and reach its maximum. See also the curves of Figure 9.5(a).
- 2 The insulation resistance thus measured at different intervals during the process of heating up will represent the insulation resistance of the windings at that temperature. Before plotting the curves, these test values must be corrected to one reference temperature, say, 40°C, to maintain coherence in the test results.
- 3 To correct the value of insulation resistance at 40°C the following equation may be used:

$$R_{40} = K_{t40} \cdot R_t \quad (9.2)$$

where

R_{40} = insulation resistance in MΩ corrected to 40°C.

R_t = test insulation resistance in MΩ at t °C and

K_{t40} = temperature coefficient of insulation resistance at t °C.

- 4 The temperature coefficient curve is given in Figure 9.5(b). This is plotted on the assumption that the insulation resistance doubles for each 18°C reduction in temperature (above the dew point).
- 5 The test voltage should be d.c. and restricted to the rated voltage of the windings, subject to a maximum of 5000 V d.c. for a 6.6 or 11 kV motor. Application of a higher voltage, particularly to a winding which is weak or wet, may cause a rupture of the insulation. It is therefore recommended to carry out this test only with a 500 V d.c. meggar. Accordingly, it is the practice to conduct this test at the works also on a normal machine, at 500 V d.c. only to provide consistency of reference.
- 6 The insulation resistance of the windings, R_m , can be calculated by

$$R_m = \frac{\text{Test voltage in volts}}{\text{Leakage current in } \mu\text{A}} \text{ M}\Omega \quad (9.3)$$

Depending upon the condition of the winding insulation, an increase in the test voltage may significantly raise the leakage current and decrease the insulation resistance, R_m . However, for machines in very good condition, the same insulation resistance will be obtained for any test voltage up to the rated voltage. The insulation resistance may hence be obtained with a low voltage initially and if the condition of the windings permits, may be raised, but always less than the rated and in no case more than 5 kV, irrespective of the rated voltage.

- 7 Before conducting the insulation test one should ensure

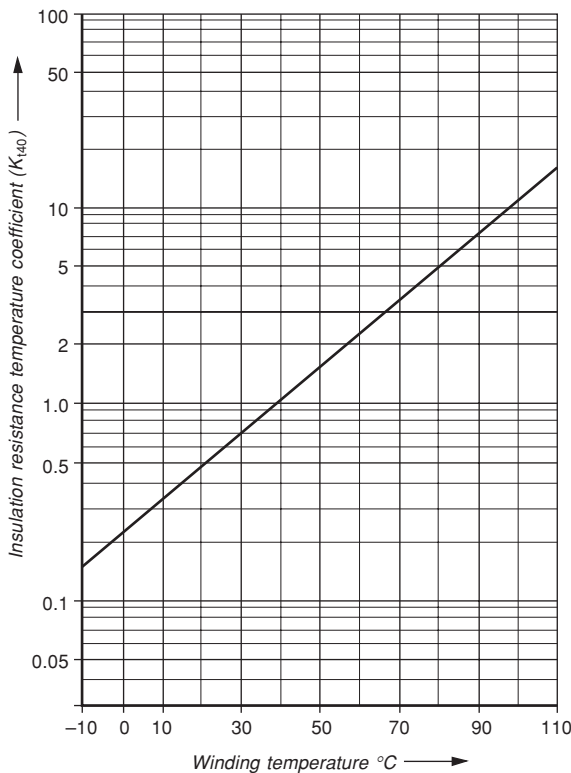


Figure 9.5(b) Approximate temperature coefficient of insulation resistance of rotating machines

that there is no self-induced e.m.f. in the windings. It is recommended that the windings be totally discharged by grounding them through the frame of the machine before conducting the test.

8 Winding connections for insulation resistance test

- It is recommended to test each phase to ground separately with the other phases also grounded. This is because the insulation resistance of a complete winding to ground does not provide a check of the insulation condition between the windings.
- It is observed that the insulation resistance of one phase with the other two phases grounded is approximately twice that of the entire winding. Therefore, when the three phases are tested separately, the observed value of the resistance of each phase is divided by two to obtain the actual insulation resistance.

9.6 Monitoring the quality of insulation of MV formed coils and resin-poor windings during manufacturing

9.6.1 Theory of dielectric loss factor or dissipation factor ($\tan \delta$)

Irrespective of the class of an insulation system and its quality, it will have some leakage current through its

dielectric circuit on application of a high voltage. For all practical purposes, therefore, we can consider an insulation system as an imperfect capacitor.

During the process of insulation, impregnation of an individual coil (resin-rich)* or the whole winding (resin-poor),† some voids in the insulation coating will always exist. They cannot be eliminated, however good the process of insulation coating or impregnation be adopted. While the ideal requirement will be a completely void-free insulation coating/impregnation, in practice this cannot be achieved. These voids cause internal discharges (corona effect)‡, or leakage current within the windings and leads to erosion in soft materials, or microscopic cracks in hard ones. All this may also lead to an eventual failure of the insulation. The level of such discharges/leakage currents should therefore be restricted as much as possible, so that they cause the least harm to the insulation of the windings, during the machine's long years of operation. For an illustration of the leakage current circuit, see Figures 9.6 and 9.7.

By measuring the capacitive and leakage currents, the phase angle (loss angle) δ between them can be determined. The tangent of this angle, $\tan \delta$, will give an indication of the condition of insulation:

In a capacitor, $\delta = 90 - \phi$ and

$$\tan \delta = \frac{\text{Capacitor loss}}{\text{Reactive output of the capacitor}} = \frac{i_r}{i_c} \quad (9.4)$$

(Figure 9.7)

A low $\tan \delta$ will mean a high degree of resin cure. Most insulation systems are composites of many materials. In practice, they almost always contain small voids. Consider

*Resin-rich

This is an insulating process for winding of MV motors with formed coils, and employs class F insulating materials. The winding coils are built individually, outside the slots and are pre-impregnated and cured before they are inserted into the stator or rotor slots. This system of coil making, however, possesses a poor heat transfer capability, from coil to iron core and provides a poor bonding of the coil with the slot. This may cause differential movement inside the slot during a run, due to thermal effects, and a peeling of the insulation, in addition to vibration and noise.

†Resin-poor

This is when the stator or the wound rotor is first wound with resin-poor formed coils, and then vacuum impregnated, as a whole mass and cured.

‡Corona effect

This is a discharge that occurs due to ionization of the air in the immediate vicinity of a conductor. It normally takes place on round conductors or at curvatures, rough spots, protruding nuts and bolts, and occurs due to humidity at locations where there is a large electrostatic flux, such as between two parallel running and current-carrying conductors. The higher the potential between the conductors, the more severe this phenomenon will be. It is a purple glow around the conductor, and is normally associated with a hissing noise and causes losses. We can sometimes see this phenomenon on an HV power pole and more so on a humid day. To minimize this effect, it is essential to keep the conductor surface clean, avoid sharp bends and curvatures and also jagged nut and bolt heads. Where unavoidable, such surfaces may be covered (insulated) with a non-conducting tape or tube.

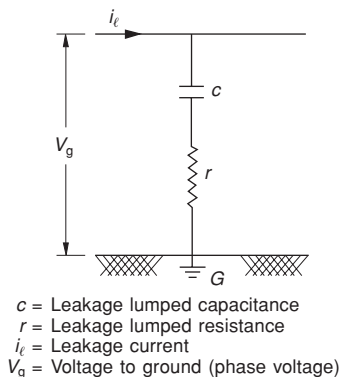


Figure 9.6 Representation of leakage current in an MV insulation system

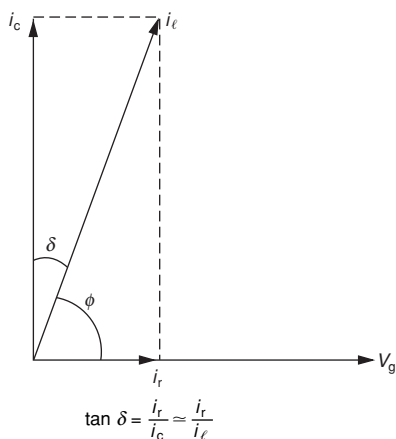


Figure 9.7 Phasor representation of the leakage current

a coil side with a single void. The voltage distribution across the insulation will be non-uniform, due to different permittivities of air and insulation. When a low voltage is applied, a proportion of this will appear across the void and the remaining voltage across the insulation (dielectric). When the applied voltage is increased, the air of the void at a certain value of the applied voltage will break down, causing an internal discharge. The void is now short-circuited and the full voltage will appear across the insulation (dielectric). The $\tan \delta$ – voltage curve at this point, where ionization begins, shows a rapid change (Figure 9.8). In practice, an insulation system, whether of a coil, winding or a slot, will always contain many small voids, often located at different depths of the dielectric. The higher the number of voids, the steeper will be the $\tan \delta$ – V curve beyond a certain voltage level (Figure 9.8). The value of $\tan \delta$ at low voltage and the rate of change of $\tan \delta$, i.e. $\Delta \tan \delta$, with an increase in the applied test voltage, gives an indication of the condition of the dielectric at higher test voltages, and also suggests the presence of moisture. Hence, $\Delta \tan \delta$ is a measure of voids in the insulation system and indicates the quality of curing. It is also a good method of monitoring the quality of insulation of MV formed coils during the course of manufacture. This is also useful in analysing the ageing condition of

an insulation. The methods and norms of acceptance limits are dealt with in IEC 60894. For acceptance norms see Table 11.5.

9.6.2 Wet test of resin-poor windings

MG-1-20.48 recommends this test for large MV motors that are resin-poor. In this test the whole stator is submerged in water, if possible, and a 10-minute absorption test is carried out. If this is not possible, then the windings are sprayed with water thoroughly, from all sides for 30 minutes (Figure 9.9). The water is mixed with a wetting agent to reduce its surface tension. During the last 10 minutes of the test the insulation resistance is measured at 500 V d.c., which should not be less than as indicated in Equation (9.1). If it is acceptable, the windings are then subjected to an a.c. high-voltage test at 1.15 times the rated voltage for 1 minute while the windings are still being sprayed. After the high-voltage test, the 1 minute insulation resistance reading using a 500 V d.c. source is obtained. This should not be less than as specified in Equation (9.1). This value will then form the reference data for the site tests.

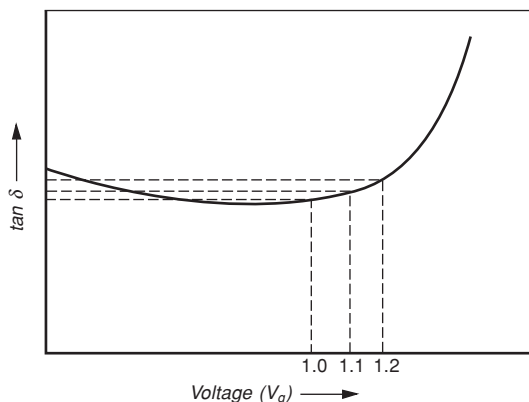


Figure 9.8 Variation in $\tan \delta$ with the applied voltage

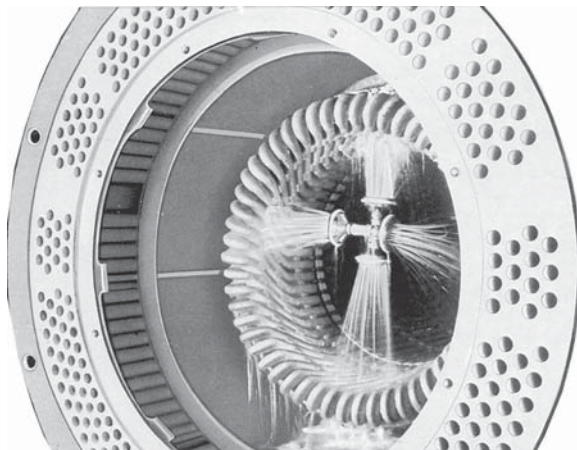


Figure 9.9 A NEMA spray test being carried out on a stator winding (Courtesy: BHEL)

Relevant Standards

IEC	Title	IS	BS
60034-1/2004	Rotating electrical machines. Rating and performance.	4722/2001, 325/2002	BS EN 60034-1/1998 –
60034-15/1995	Rotating electrical machines. Impulse voltage withstand levels with form wound stator coils.	–	– –
60034-18-1/1992	Rotating electrical machines – functional evaluation of insulating systems	–	– –
60071-1/1993	Insulation coordination phase to earth – Principles and rules. Insulation coordination phase to phase – Principles and rules.	2165-1/2001, 2165-2/2001	BS EN 60071-1/1997 –
60085/2004	Thermal evaluation and classification of electrical insulation.	1271/2001	BS 2757/1994 –
60894/1987	Specification for the insulation of bars and coils of high voltage machines, including test methods.	–	– –
60439-2/2000	Low voltage switchgear and controlgear assemblies Particular requirements for busbar trunking systems	8623-2/1993	BS EN 60439-2/1993 281/1990
62114/2001	Electrical insulation systems – thermal classification	–	– –

Relevant US Standards ANSI/NEMA and IEEE

ANSI/IEEE-1/2000	General principles for temperature limits in the rating of electric equipment and for the evaluation of electrical installation.
ANSI/IEEE-101/1987	Guide for the statistical analysis of Thermal Life Test data.
ANSI/IEEE-1313.1/1996	Insulation coordination – Definitions, principles and rules.
IEE-43/2000	Recommended practice for testing insulation resistance of rotating machinery.
NEMA/MG-1/2003	Motor and generators ratings, construction, testing and performance.

Notes

- 1 In the table of relevant Standards while the latest editions of the Standards are provided, it is possible that revised editions have become available or some of them are even withdrawn. With the advances in technology and/or its application, the upgrading of Standards is a continuous process by different Standards organizations. It is therefore advisable that for more authentic references, one may consult the relevant organizations for the latest version of a Standard.
- 2 Some of the BS or IS Standards mentioned against IEC may not be identical.
- 3 The year noted against each Standard may also refer to the year it was last reaffirmed and not necessarily the year of publication.

List of formulae used

Making-up of insulation level in large machines:

Insulation resistance

$$R_m = kV + 1 \quad (9.1)$$

R_m = recommended minimum insulation resistance in $M\Omega$ of the entire machine windings, at 40°C
 kV = rated machine voltage in kV.

$$R_{40} = K_{t40} \cdot R_t \quad (9.2)$$

R_{40} = insulation resistance in $M\Omega$ corrected to 40°C
 R_t = test insulation resistance in $M\Omega$ at t °C and
 K_{t40} = temperature coefficient of insulation resistance at t °C

$$R_m = \frac{\text{Test voltage in volts}}{\text{Leakage current in } \mu A} M\Omega \quad (9.3)$$

Dielectric loss factor or dissipation factor

$$\tan \delta = \frac{\text{Capacitor loss}}{\text{Reactive output of the capacitor}} = \frac{i_r}{i_c} \quad (9.4)$$

Further Reading

1. Ansaldo Componenti SPA, Italy. *Progress and development trends in the large induction motor stator winding insulation.*
2. Hogg, W.K., Miller, R., Rabach, G. and Ryder D.M. 'The relationship of partial discharge amplitude distribution with electric damage at different levels of voltage and frequency', *IEEE Symposium on Electrical Insulation, USA*, June 1984.
3. Lee-Neville., and Simons J.S., *Handbook of Epoxy Resins*, McGraw-Hill, New York (1967).
4. Meyer, H., 'Post impregnated micalastic insulation for large motors and generators,' *Siemens Review*, **XLV** April, No. 4 (1978).
5. Moses, G.L., *Electrical Insulation*, McGraw-Hill, New York (1951).
6. Moses, G.L., 'Alternating and direct voltage endurance studies on mica insulation for electric machinery,' *AIEE Transactions*, **70**, 763–769 (1951).
7. Renganian, S., Agrawal, M.D. and Nema R.S., 'Behaviour of high voltage machine insulation system in the presence of thermal and electrical stresses,' *IEEE Trans. on EI.*, E.I., 20, No.1, Feb. (1985).
8. Rhudy, R.G. *et al.*, 'Impulse voltage strength of AC rotating machines,' *IEEE Trans.*, **100**, No. 8 (1981).
9. Simons, J.S., 'Diagnosis of H.V. machine insulation,' *IEEE Proceedings*, **127**, May (1980).
10. *Testing the insulation systems of stator coils for rotating electrical machines*,
 - (i) Electricity Supply Industry Standard, U.K., ESI 44-5 Issue 3, Sept. (1982),
 - (ii) OCMA Standard Elec.-1, U.K.