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The Effect of Insulance Management on the Fitness-For-Service of Generators, Transformers, Motors and Switch Gears

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Abstract : *A Review of the Effect of Insulance Management on the Fitness-for-service of Generators, Transformers, Motors and Switch Gears is reported. Methods, standards, specifications for assessment of the insulance have been reviewed. Factors impacting on the insulance value have also been noted. And it is considered worthwhile for the proper management of the insulance of electrical assets as this automatically translate to high integrity of fitness-for-service.*

Key words*: Insulance Management, fitness-for-service, Generators, Transformers*

Introduction

The image quality of an uncoated fibre bundle is influenced by light leakage between neighbouring fibres. The point-spread function due to light leakage between neighbouring fibres is used to calculate the static and dynamic frequency response of an un-insulated fibre bundle. The static and dynamic frequency response is also measured for a bundle of uncoated fibres. The possibility of optically insulating smaller diameter fibres by depositing a thin coating of low refractive-index plastic material is well known. A process for drawing glass fibres with a core of high refractive-index glass and a 1–2-μ thick coating of low refractive index glass has been developed. This method is also used for depositing a second metal coating on fibres and drawing “multiple fibres.”[1] Also Base materials for heat-resistant cable insulants have been developed from blends of ethylene vinyl acetate (EVA) copolymer containing 28% VA and ethylene propylene diene (EPDM) rubber. Different electrical, mechanical, and thermal properties of these blends have been studied extensively. Aging under different conditions has also been studied. The chemical and mechanical stability of these compositions has been assessed at the actual temperature range of application. Dielectric properties have been determined against varying temperature. These blends may be used as insulating materials having a temperature rating around 90–130°C, which is above the temperature rating (85–90°C) of heat-resistant insulation based on EPDM. [2] In similar vein, measurements have been obtained for the thermal resistance of sheep-wool insulation and wool–hemp mixtures, both in the form of bonded insulation batts, using a calibrated guarded hot-box. The density was 9.6–25.9 kg m^{-3} for the wool and 9.9–18.1 kg m^{-3} for the wool–hemp mixtures. The measurements were made at a mean sample temperature of 13.3°C using a calibrated guarded hot-box. The estimated uncertainly in the resistance measurements was of the order of ±7%. The thermal conductivity of the samples, derived from the thermal resistance measurements on the basis of the measured thickness, was well correlated with the density, although the variation with density was larger than that obtained in previous studies. The conductivity of the wool–hemp samples was not significantly different from that of the wool samples at the same density. Moisture uptake produced an increase of less than 5% in the conductivity of the bonded wool insulation for an increase in absorbed moisture content of 20%. The thermal resistance was 1.6% lower on average for samples oriented in the horizontal plane rather than the vertical plane, but this difference is not significant..[3] In another dimension, wall was constructed of two leaves or skins (two walls), with a cavity between them. The leaves are given strength by being joined together with metal ties. Cavity-walls were invented to improve insulation and damp-proofing. Certain types of cavity-wall are used for conservatories etc., where it is possible to introduce hot air into the gap. [4] Extensive work has been done on insulants at ambient temperature: standards, reference materials, and national and international inter-laboratory measurements (ISO/TC 163 round robin test). The situation is more complex at high temperatures, and in an attempt to clarify this complexity, taking into account the new International Organization for Standardization (ISO) draft proposal on guarded hot plate apparatus, a simple model describing heat transfer through fibrous insulants, and introducing the notion of optical thickness or opacity was considered. The study proposes a quantitative criterion to minimize the radioactive transfer, in order to obtain measurement results independent of the experimental conditions (the thickness of the specimen and emissivities of the limiting surfaces). This criterion shows the importance of optical parameters and should, from a practical point of view, help in choosing the reference materials used for checking and in making inter-laboratory comparisons of guarded hot plate apparatuses. [5]

Insulation products have developed significantly with technological advances, with the development criteria remaining largely centred around performance. Legislation has acted as the catalyst for development, from the basic requirements under Building Regulations AD Part L, to compliance with government carbon reduction targets, driven through advanced programmes such as the Code for Sustainable Homes and BREEAM. It might be argued that legislation is driving technology. Consequently, technology has contrived to produce a range of products that are perceived to 'just work', presenting little apparent difference between them. But if specifiers can better understand how heat transfer principles influence insulation performance, and how insulation operates at its core level, there is the opportunity to insulate our buildings to a maximum and appropriate level with the confidence that specified performance can be sustained throughout the lifetime of the building. The installed performance of an insulation product is greatly reliant upon not only the adherence of contractors to manufacturers and general best practice workmanship requirements, but also the suitability of the insulant specified to its installed location.[6] Also, ultra-light and strong three-dimensional (3D) silicon carbide (SiC) structures have been generated by the carbon-thermal reduction of SiO with a graphene foam (GF). The resulting SiC foams have an average height of 2 mm and density ranging between 9 and 17 mg cm^{-3}. They are the lightest reported SiC structures. They consist of hollow struts made from ultrathin SiC flakes and long 1D SiC nano-wires growing from the trusses, edges, and defect sites between layers. AFM results revealed an average flake thickness of 2–3 nm and lateral size of 2 μm. In-situ compression tests in the scanning electron microscope (SEM) show that, compared with most of the existing lightweight foams, the present 3D SiC exhibited superior compression strengths and significant recovery after compression strains of about 70%. [7] Furthermore, a newly fabricated equipment to study the thermal properties of nonwoven textile fabrics treated with aerogel at subzero temperatures was considered. Thermal conductivity was calculated by using the empirical relation Fourier's law, The relationship between the thermal conductivity and thermal resistance of the samples were studied at various environmental temperatures (which was set in the climate temperature system between +25°C to -25°C). The newly fabricated equipment was found to be suitable for measuring at subzero temperatures..[8]

Natural insulation materials such as hemp, sheep's wool and flax are becoming widely recognised for their sustainability. A growing concern for the environment, alongside a need to reduce the energy consumption of built stock, has resulted in a flourishing market for these materials. For many years cellular, oil-based insulation materials have been the most common choice in construction projects. As a growing awareness of the effects of these materials on the environment is being recognised, many architects are making moves to specify natural materials wherever possible. Natural insulation materials often require a greater thickness of insulation in comparison with standard materials in order to achieve the same U-values. This has commonly been stated as a barrier to their use. A greater understanding of their additional benefits is beginning to reduce these perceived obstacles.

Increasingly, thermal performance is not the only consideration when choosing insulation. Many natural materials also have the added benefits of being breathable, improving internal air quality and reducing condensation levels. As airtight levels improve through requirements in building regulations and the increased use of Passivhaus standards, toxicity and air quality are of greater concern. The three main types of natural material products are sheep's wool, cellulose and hemp. Sheep's wool has been around for a while but its increased availability and use has caused costs to come down. Due to the hygroscopic nature of wool, the insulation is able to absorb, store and release moisture, naturally controlling condensation levels within the building and improving internal air quality. Cellulose insulation, made from recycled newspaper, is an obvious sustainable choice. It is most commonly used in roof and wall cavities, where it can be pumped and sprayed in. Hemp has seen a revival as an insulation material. A versatile and fast-growing agricultural crop, it can be used by farmers as part of a crop rotation to condition soil and is becoming more commonly grown in the UK. Acting as a carbon sink, hemp locks in up to 2 tonnes of CO2 per tonne of fibre, making it a particularly sustainable choice. It is available in a variety of different insulation forms. Semi-rigid batts are good for vertical installations as they do not slump, ensuring thermal properties remain constant throughout the wall. Hemcrete, used at Pat Borer and David Lea's building for the Wales Institute for Sustainable Education at the Centre for Alternative Technology, provides a solid-wall solution, with the advantage of increased thermal mass. [9]

The Insulation Resistance Test measures the integrity of the generator's winding insulation, and therefore the likelihood of developing a ground. A test voltage is applied to the generator and the current flow required to maintain that voltage is measured over a period of time (typically one minute). In simplest terms, the less current flow, the higher the resistance value, and the better the insulation. An IR test should be performed immediately following any type of event that is suspected of over-stressing an insulation system, prior to the generator being placed back into service. This is the first test that should be performed. The results will indicate the ability of the insulation system to withstand any more searching and/or strenuous testing. The IR test also measures the effect of contamination from water, oil, carbon, and other such undesirables. If a separate high voltage proof test is performed, an IR test should be performed both before and after the proof test. This in order to assure that the proof test itself has not compromised the insulation. The Insulation Resistance test must be performed by a well trained and experienced technician. Incorrect procedures can materially affect the results. The test should be performed to IEEE Standard 43-2000 (R2006), using a late model Megger brand machine such as Model MIT1025, or comparable. It is best practice to test at the main and neutral leads of the stator, as close to the windings as possible. Stator slot RTD's should be disconnected from the terminal board and grounded. Surge capacitors should be disconnected. The water or oil should be drained and completely evacuated from liquid inner-cooled windings, typically by vacuum-processing. Stator windings should be tested one phase at a time, with the other two phases grounded. In this manner, the windings are stressed both phase-to-ground and phase-to-phase. [10]

In evaluating the insulation resistance of machines such as motors and generators, frequently asked question is: What is the minimum acceptable megohm value for this winding? Fortunately there is a standard that identifies minimum values for insulation resistance of rotating machines. That standard is IEEE Recommended Practice for

Testing Insulation Resistance of Rotating Machinery, IEEE Standard 43-2000. The primary reasons for insulation resistance test are to determine if a machine can be placed back into service or if high potential winding tests such as high potential or surge comparison can prudently be performed. Another important reason for the insulation resistance test is to establish a baseline value for the winding insulation condition of an installed machine. If the winding insulation resistance value is below the acceptable minimum, the machine should not be energized and high potential tests should not be performed until the insulation resistance value meets or exceeds the prescribed minimum. Good winding ground insulation behaves like a capacitor, becoming charged when voltage is applied across it. According to IEEE 43, the insulation resistance value should be taken after applying and maintaining constant test voltage on the winding for one minute. That allows some of the capacitive effect to stabilize,

making the readings more consistent. A common error in performing an insulation resistance test is to take the reading after just a few seconds. The result is inconsistency in the readings, especially with larger machines whose windings take a relatively long time to reach stability. The most common instrument used for the test for motors and generators is the battery powered 500 or 1000 volt dc megohmmeter. The recommended test voltage to apply with the megohmmeter increases with machine voltage rating as illustrated in Table 1 below..[11]

Table 1 - insulation resistance test voltages versus machine rated voltages

Winding Rated Voltage (AC or DC)	Insulation Resistance Test Voltage (DC)
< 1000	500
1000 - 2500	500 - 1000
2501 - 5000	1000 - 2500
5001 - 12000	2500 - 5000
> 12000	5000 - 10000

Source: [11]

Winding temperature affects the megohm value test result. As temperature increases, insulation resistance decreases. The cause is not winding degradation with temperature, but is a physical property of the insulation. The insulation resistance reading must, therefore, be corrected for temperature. The temperature correction per IEEE 43 should be to 40 °C, and the correction factor for temperature is such that the minimum insulation resistance value is doubled for every 10 °C decrease in winding temperature. Windings that are very hot, for example over 100 °C due to the motor or generator having just been shut down, may result in relatively low megohm values. Allow the winding to cool to 60 °C or lower and then perform a temperature corrected IR test. [11] Expressed as a formula, the temperature correction factor is:

$$Kt = (0.5)\ (40-T)/10 \quad (1)$$

Kt Factor to multiply T by to obtain insulation resistance corrected to 40 °C

T = Temperature in °C at which insulation resistance was measured.

Humidity can affect insulation resistance readings; however, there are no formulas or "rules of thumb" for the effect of humidity with respect to rotating electrical machine windings. Nonetheless, it is a good practice to record the humidity reading as well as winding temperature and insulation resistance for each insulation resistance test. [11] In addition to temperature and humidity, other factors that can affect megohmmeter readings are the instruments and the method of application of the test. The implied accuracy of an instrument may change when the megohm scale is changed. By implied we mean the number of significant digits. For example, a reading of 190 megohms on the 1000-megohm scale of a meter may be indicated more accurately as 185 megohms on the 200-megohm scale. The 1000-volt scale has two-place accuracy in this case when reading up to 200 megohms, and three-place accuracy [11]

A regular program of testing insulation resistance is strongly recommended to prevent electrical shocks, assure safety of personnel and to reduce or eliminate down time. It helps

to detect deterioration of insulation in order to schedule repair work such as: vacuum cleaning, steam cleaning, drying and rewinding. It is also helpful when evaluating the quality of the repairs before the equipment is put back into operation. Some of the more common causes of insulation failure include: excessive heat or cold, moisture, dirt, corrosive

vapours, oil, vibration, aging and nicked wiring. There are numerous maintenance tests for assessing insulation quality. The three tests discussed here are used primarily to test motor, generator and transformer insulation.

(1) Dew point temperature is the temperature at which the moisture vapour in the air condenses as a liquid.

Time-Resistance Testing Method is fairly independent of temperature and often can give you conclusive information without records of past tests. It is based on the absorption effect of good insulation compared to that of moist or contaminated insulation. Simply take successive readings at specific times and note the differences in readings . Tests by this method are sometimes referred to as absorption tests. Good insulation shows a continual increase in resistance over a period of time (in the order of 5 to 10 minutes). This is caused by the absorption; good insulation shows this charge effect over a time period much longer that the time required to charge the capacitance of the insulation. If the insulation contains moisture or contaminants, the absorption effect is masked by a high leakage current which stays at a fairly constant value –

keeping the resistance reading low (R = E/I). The time-resistance testing is of value because it is independent of equipment size. The increase in resistance for clean and dry insulation occurs in the same manner whether a motor is large or small. You can compare several motors and establish standards for new ones, regardless of their horsepower ratings. When the insulation is in good shape, the 60-second reading is higher than the 30-second reading. A further advantage of this two reading test is that it gives you a clearer picture, even when a "spot reading" says the insulation looks ok. Time-resistance tests on large rotating electrical machinery – especially with high operating voltage – require high insulation resistance ranges and a very constant test voltage. A heavy-duty megohmmeter serves this need. Similarly, such an instrument is better adapted for cables, bushings, transformers, and switchgear in the heavier-duty sizes. Test Methods – Time-Resistant Tests Dielectric Absorption Ratio (DAR)

- The ratio of 60 seconds/30 seconds: less than 1 = failed; 1.0 to 1.25 = OK; 1.4 to 1.6 = excellent Note that this is not a commonly used test

$$\text{Polarization Index (PI)} = (\text{10-minute reading})/(\text{1-minute reading}) \quad (2)$$

The IEEE Std 43-2000 lists the following minimum values for the polarization index for AC and DC rotating machines: Class A: 1.5 Class B: 2.0 Class C: 2.0

There are two schools of thought regarding the voltage to test insulation at. The first applies to new equipment or cable and can use AC or DC test voltages. When AC voltage is used, the rule of thumb is 2 x nameplate voltage + 1000. When DC voltage is used (most common on megohmmeters manufactured today) the rule of thumb is simply 2 x nameplate voltage except when higher voltages are used. See Table 2 below for suggested values. [12]

TABLE 2; Equipment Cable Ranking versus DC Test Voltage

Equipment/Cable Ranking (V)	DC Test Voltage (V_{DC})
24 to 50	50 to 100
50 to 100	100 to 250
100 to 240	250 to 500
440 to 550	500 to 1000
2400	1000 t0 2500
4100	1000 to 5000

Source: [12]

Advantages of DC Testing : i) Lighter size and weight of test equipment; ii) Non-destructive iii) Historical data can be compiled.

Transformers are tested at or above the rated voltage to be certain there are no excessive leakage paths to ground or between windings. These are conducted with the transformer completely disconnected from the line and load. However, the case ground should not be removed. [12]

Table 3: NFPA 70B Guide on Insulation Resistance Testing for Different Types of Equipment.

Nominal Equipment Voltage (Vac)	Min Test Voltage (Vdc)	Min Insulation Resistance (MΩ)
250	500	25
600	1000	100
1000	1000	100
2500	1000	500
5000	2500	1000
8000	2500	2000
15000	2500	5000
25000	5000	20000
34000 and a bove	15000	100000

Source: [13]

The insulation resistance (IR) test (also commonly known as a Megger) is a spot insulation test which uses an applied DC voltage (typically either 250Vdc, 500Vdc or 1,000Vdc for low voltage equipment <600V and 2,500Vdc and 5,000Vdc for high voltage equipment) to measure insulation resistance in either kΩ, MΩ or GΩ. The measured resistance is intended to indicate the condition of the insulation or dielectric between two conductive parts, where the higher the resistance, the better the condition of the insulation. Ideally, the insulation resistance would be infinite, but as no insulators are perfect, leakage currents through the dielectric will ensure that a finite (though high) resistance value is measured. Because IR testers are portable, the IR test is often used in the field as the final check of equipment insulation and also to confirm the reliability of the circuit and that there are no leakage currents from unintended faults in the wiring (e.g. a shorted connection would be obvious from the test results). One of the advantages of the IR test is its non-destructive nature. DC voltages do not cause harmful and/or cumulative effects on insulation materials and provided the voltage is below the breakdown voltage of the insulation, does not deteriorate the insulation. IR test voltages are all well within the safe test voltage for most (if not all) insulation materials. [13]

In the ANSI/NEC world, the standard ANSI/NETA ATS-2009 provides test procedures and acceptance levels for most types of electrical equipment. Table 3 above provides representative acceptance values for IR test measurements, which should be used in the absence of any other guidance (from the manufacturer or other standards):The Megger company were the original manufacturers of IR test equipment over 100 years ago and have become synonymous with insulation resistance testing. Most modern IR testers are digital, portable / handheld units and some have multi-functional capabilities (e.g. built-in continuity testing). [13]

Whether working on motors, generators, cables, or switch gear, the Fluke Insulation Resistance Testers provide noise-free, reliable results. With advanced performance, the insulation tester line is designed to be safe, simple to use and gimmick-free and therefore provides a perfect solution for troubleshooting, commissioning, and preventative maintenance applications. **[14]**

The measurement of insulation resistance is a common routine test performed on all types of electrical wires and cables. As a product test, this test is often used as a customer acceptance test, with minimum insulation resistance per unit length often specified by the customer. The results obtained from IR Test are not intended to be useful in finding localized defects in the insulation as in a true HIPOT TEST, but rather give information on the quality of the bulk material used as the insulation. Even when not required by the end customer, many wire and cable manufacturers use the insulation resistance test to track their insulation manufacturing processes, and spot developing problems before process variables drift outside of allowed limits as shown in Table 4 below. [15]

Table 4: Insulation Resistance (IR) Values

Max Voltage Rating of Equipment	Mega Size	Min Insulation Resistance (IR) Value (MΩ)
250 Volts	500 Volts	25
600	1000 Volts	100
5KV	2500 Volts	1000
8KV	2500 Volts	2000
15 KV	2500 Volts	5000
25 KV	5000 Volts	20000
35 KV	15000 Volts	100000
46 KV	15000	100000
69 KV	15000	100000

Source: [15]

Application of the One Meg ohm Rule for IR Value for Equipment implies that based upon equipment rating: < 1K V = 1 MΩ minimum; >1KV = 1 MΩ /1KV as per IE Rules-1956. At a pressure of 1000 V applied between each live conductor and earth for a period of one minute the insulation resistance of HV installations shall be at least 1 Mega ohm or as specified by the applied Bureau of Indian Standards. Medium and Low Voltage Installations- At a pressure of 500 V between each live conductor and earth for a period of one minute, the insulation resistance of medium and low voltage installations shall be at least 1 Mega ohm or as specified by the Bureau of Indian Standards] from time to time. As per CBIP specifications the acceptable values are 2 Mega ohms per KV. Insulation resistance tests for Transformers are made to determine insulation resistance from individual windings to ground or between individual windings. Insulation resistance tests are commonly measured directly in megohms or may be calculated from measurements of applied voltage and leakage current. The recommended practice in measuring insulation resistance is to always ground the tank (and the core). Short circuit each winding of the transformer at the bushing terminals. Resistance measurements are then made between each winding and all other windings grounded. That is Insulation resistance testing be done: HV – Earth and HV – LV. [16] Guide to calculation of IR value for Transformers (Table 5), Temperatures correction factors (Table 6), IR for Transformer coils (Table 7) and IR values of Transformers (Table 8) as recommended by [16] are as indicated below.

Table 5: Insulation Resistance for Transformer

Transformer Type	Formula for Insulation Resistance (IR) Value (MΩ)
1 Phase	C*E/ √(KVA)
3 Phase (Star)	C*E(P – n)/ √ (KVA)
3 Phase (Delta)	C*E(P – P)/ √ (KVA)

Source: [16]

Table 6: Temperature Correction Factor (Base 20^{O}C)

°C	°F	Correction factor
0	32	0.25
5	41	0.36
10	50	0.50
15	59	0.720
20	68	1.00
30	86	1.28
40	104	3.95
50	122	7.85

Source: [16]

Table 7: Insulation Resistance of Transformer Coil (T/C)

Transformer Coil Voltage	Megger Size	Min IR Value for Liquid filled T/C , MΩ	Min IR Value for Dry Type T/C, MΩ
0 – 600 V	1 KV	100	500
600 V to 5 KV	2.5 KV	1000	5000
5 KV to 15 KV	5 KV	5000	25000
15 KV to 69 KV	5 KV	10000	50000

Source: [16]

Table 8: Insulation Resistance (IR) of Transformers

Voltage	Test Voltage DC LV Side, V	Test Voltage DC HV Side, KV	Min IR Value, MΩ
415 V	500	2.5	100
UP to 6.6 KV	500	2.5	200
6.6 KV to 11 KV	500	2.5	400
11 KV to 33 KV	1000	5	500
33 KV to 66KV	1000	5	600
66 KV to 132 KV	1000	5	600
132 KV to 220 KV	1000	5	650

Source: [16]

In another development, the mechanical performance of two commercial papers used as solid insulation in power transformers, namely standard Kraft and a thermally upgraded Kraft paper, were studied during accelerated aging in Luminol oil at 170 °C. The results show a relationship between the degree of polymerization and the mechanical properties measured by tensile testing. A linear relationship was found between the mechanical properties of paper, the tensile index (Tidx), and the concentration of methanol present in the oil. The methanol chemical marker has been proven to be an accurate assessment tool for the aging of cellulosic paper. The results show a promising tool for correlating the methanol concentration in oil, as an indirect indicator, with the mechanical performance of the paper. This approach can be used to monitor the real state of the cellulose chains in the power transformer insulation paper. Cellulosic paper and oil insulation in a transformer degrade at higher operating temperatures. Degradation is accelerated in the presence of oxygen and moisture. Power transformers being expensive items need to be carefully monitored throughout their operation. Well established time-based maintenance and conservative replacement planning is not feasible in a current market driven electricity industry. Condition based maintenance and online monitoring are now gaining importance. Currently there are varieties of chemical and electrical diagnostic techniques available for insulation condition monitoring of power transformers. Among these techniques polarisation/depolarisation current measurement, return voltage measurement and frequency domain dielectric spectroscopy at low frequencies are the most widely used. [18]

The energy crisis has raised demands for a substantial increase in the insulation of roofing systems, and calculations in this paper confirm that the financially most favourable insulation has a thermal resistance much higher than that of presently used systems. Objections have been raised to the increase in the thermal resistance of roofs on the basis that this will result in a substantial increase of the temperature range to which membranes are subjected, with resultant increase of membrane cracking from temperature movement. A number of calculations were made to check on the justification of such concerns. The outcome of the research based on a number of simplifying assumptions show that increasing the thermal resistance of insulation, over presently prevailing standards, does not significantly enlarge the thermal range to which roofing membranes are presently subjected. This applies both to changes in the ambient temperature and to solar radiation. Insulation thickness should therefore be based on considerations of economy and energy conservation, but there are still unresolved problems of decreasing impact resistance and lateral stability. [19]

Materials and method

Materials

Equipment necessary for conducting insulation resistance tests are: Megohmmeter with a timed test function, Temperature indicator, and Humidity meter (not necessary if equipment temperature is above the dew point).

Method

The battery powered 500 or 1000 volt dc megohmmeter is used for the test for motors, generators and transformers. One lead is applied to the winding leads (typically all tied to the instrument lead) and the other instrument lead to the frame (ground) of the machine. The meter actually applies a voltage, measures the current, and then displays the value of voltage divided by current, i.e., resistance in megohms. The megohmmeter voltage should be applied and held for one minute, and the reading at one minute is recorded as the insulation resistance value for the test. The recommended test voltage to apply with the megohmmeter increases with machine voltage rating. The Test Currents in Insulation which may be referred to as the Total current in the body of the insulation is the sum of three components, namely, Capacitance Charging Current, Absorption Current and Leakage or Conduction

Current. Insulation Resistance Readings are time dependent, that is at the start, capacitance is what you see first; at or about one minute, absorption; and at 10 minutes, reading is mainly leakage current. These changing readings are best seen with analog bargraphs on digital instruments or needle movement on analogue instruments and these readings are noted and recorded accordingly. Variation of these tests could be conducted under Spot reading or Step voltage modes. Winding temperature to be noted so that correction of readings to a base temperature of 20^0C can be done.

Summary of literature review

The Insulation Resistance Test measures the integrity of the generator's winding insulation, and therefore the likelihood of developing a ground. . A test voltage is applied to the generator and the current flow required to maintain that voltage is measured over a period of time (typically one minute). In simplest terms, the less current flow, the higher the resistance value, and the better the insulation. The IR test also measures the effect of contamination from water, oil, carbon, and other such undesirables. The test should be performed to IEEE Standard 43-2000 (R2006), using a late model Megger brand machine such as Model MIT1025, or comparable. Winding temperature affects the megohm value test result. As temperature increases, insulation resistance decreases. The cause is not winding degradation with temperature, but is a physical property of the insulation. The insulation resistance reading must, therefore, be corrected for temperature. Expressed as a formula the temperature correction factor is:

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Kt Factor to multiply T by to obtain insulation resistance corrected to 40 °C

T = Temperature in °C at which insulation resistance was measured.

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to detect deterioration of insulation in order to schedule repair work such as: vacuum cleaning, steam cleaning, drying and rewinding. It is also helpful when evaluating the quality of the repairs before the equipment is put back into operation. Some of the more common causes of insulation failure include: excessive heat or cold, moisture, dirt, corrosive

vapours, oil, vibration, aging and nicked wiring. Time-Resistance Testing Method is fairly independent of temperature and often can give you conclusive information without records of past tests. It is based on the absorption effect of good insulation compared to that of moist or contaminated insulation. Test Methods – Time-Resistant Tests Dielectric Absorption Ratio (DAR)

- The ratio of 60 seconds/30 seconds: less than 1 = failed; 1.0 to 1.25 = OK; 1.4 to 1.6 = excellent Note that this is not a commonly used test

$$\text{Polarization Index (PI)} = (\text{10-minute reading})/(\text{1-minute reading}) \quad (2)$$

Discussions

The insulation resistance test measures the integrity of the generator's winding insulation and therefore the likelihood of developing a ground. This test is so important in reality, as the results of the test are very informative in the prescription of treatment that will enhance the integrity of the generator, transformer or switch gear. Generators, transformers and switch gears are all capital intensive assets and one of the frequent modes of failure has been short circuit of the windings hence all the necessary steps that will be taken to preserve the life of these assets will be worth it. Also insulation resistance has been found to be temperature dependent, that is, there exist an inverse relationship between insulation resistance and temperature. Hence the derived formula for the temperature correction factor as expressed in equation 1 is timely and useful. Also, Humidity can affect insulation resistance readings and in most transformers and switchgears, moisture content has generally been managed by the absorptive quality of silica gel or its equivalent. Time resistant tests Dielectric Absorption Ratio (DAR). So the ratio of 60 seconds/30seconds is very informative, adequate and sufficient in evaluation of failed, okay or excellent status of insulance.

Conclusion

From the foregoing, therefore, managing the Insulance of generators, transformers and switchgears (with temperature and humidity correction in view) helps to protect and enhance the integrity of these assets for optimal service delivery. It is therefore important to put in place a proactive Risk-Based –Inspection schedule and Risk Centred Maintenance that will maintain fitness-for-service status quo of the assets.

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