

Electric Insulation

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Abstract—

When a dielectric is subjected to an alternating field, a time-varying polarization of the atoms and molecules in the dielectric is produced. The alternation of both the permanent and induced polarization in the dielectric results in power dissipation within the dielectric of which the power factor is a measure. This dielectric power loss is proportional to the product of the dielectric constant and the square of the electric field in the dielectric. Although it may be a loss that is small relative to other losses in most ambient-temperature applications, and even though it generally decreases at low temperatures, it is a relatively important loss for dielectrics to be used at cryogenic temperatures.

Index Terms—dielectric, polarization, insulation resistance, electric insulation

INTRODUCTION

Electrical insulation starts to age as soon as it's made. And, aging deteriorates its performance. Harsh installation environments, especially those with temperature extremes and/or chemical contamination, cause further deterioration. As a result, personnel safety and power reliability can suffer. Obviously, it's important to identify this deterioration as quickly as possible to take the necessary corrective measures.

1) Insulation resistance testing

Basically, we're applying a voltage (specifically a highly regulated, stabilized DC voltage) across a dielectric, measuring the amount of current flowing through that dielectric, and then calculating (using Ohm's Law) a resistance measurement. The resistance measurement is in mega ohms.

Current flow through a dielectric may seem somewhat contradictory, but, no electrical insulation is perfect. So, some current will flow.

2) The purpose of insulation resistance

A quality control measure at the time a piece of electrical equipment is produced;

An installation requirement to help ensure specifications are met and to verify proper hookup;

A periodic preventive maintenance task; and

A troubleshooting tool.

3) To perform an insulation resistance test

Generally, we connect two leads (positive and negative) across an insulation barrier. A third lead, which connects to a guard terminal, may or may not be available with our tester. If it is, we may or may not have to use it. This guard terminal acts as a shunt to remove the connected element from the measurement. In other words, it allows us to be selective in evaluating certain specific components in a large piece of electrical equipment.

During this interval, the resistance reading should drop or remain relatively steady. Larger insulation systems will show a steady decrease; smaller systems will remain steady because the capacitive and absorption currents drop to zero faster than on larger systems. After 1 min, should read and record the resistance value.

Electrical insulation materials exhibit capacitance and will charge during the test. This can be somewhat frustrating to a novice. However, it becomes a useful tool to a seasoned technician.

4) Affects insulation resistance readings

Insulation resistance is temperature-sensitive. When temperature increases, insulation resistance decreases, and vice versa. A common rule of thumb is insulation resistance changes by a factor of two for each 10 Degree C change.

Also, "acceptable" values of insulation resistance depend upon the equipment. Historically, many field electricians use the somewhat arbitrary standard of 1 mega ohm per kV. The international Electrical Testing Association (NETA) specification Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems provides much more realistic and useful values.

The dielectric constant, also known as the relative permittivity or specific inductive capacity, is a measure of the ability of the dielectric to become polarized, taken as the ratio of the charge required to bring the system to the same voltage level relative to the charge required if the dielectric were vacuum. It is thus a pure number, but is in fact not a constant, and may vary with temperature, frequency, and electric-field intensity.

Properties

All insulators may be classified as either solid or fluid.

1) Solid insulation

>flexible and rigid type

2) Fluid insulation

>Liquids, gases, and vacuum .

The dielectric strength of fresh, thoroughly purified (filtered, degassed, dehumidified) oil is several times higher than that of aged, contaminated oil, except under nano- or picoseconds pulses.

Some of the reasons for this difference are as follows:

(1) under the influence of an electric field, solid impurity particles or water may form a chain and initiate breakdown

- (2) solid impurities can be generated in oil as the result of accidental or intentional arcs, or oxidation of metals;
- (3) water may be absorbed from the atmosphere in non-hermetically sealed devices.

Effect of temperature on space charge trapping

Space charge distribution and high field conduction in cross-linked polyethylene (XLPE) plate sample at various electric fields for a broad temperature range from 30 to 90 °C. The temperature effect on charge trapping and transport mechanism is based on estimation of threshold characteristic and apparent mobility. It is shown that the threshold field for space charge accumulation apparently decreased with the temperature, probably associated with acceleration of charge injection and ionic dissociation. The apparent mobility of charges showed an exponential dependence on temperature, which indicates enhancement of charge de-trapping and transfer rate at higher temperature. The field dependence of the space charge decreases with the temperature, results in more space charge accumulate at room temperature than at high temperature at certain high field. This behaviour indicates that the space charge formation rate increases slower than the charge de-trapping rate as the temperature increases. Besides, negative charge is always dominant in the sample at the measuring field and temperature range. This is probably due to stronger electron injection at XLPE-aluminium interface or more negative ion formed by dissociation of chemical species.

Space charge behaviour in oil

Space charge behaviour is important in the oil-immersed-paper insulation in converter transformers for HVDC transmission. The space charge property in samples with two layers of oil-immersed, paper and oil. Based on pulsed electro acoustic (PEA) technique, a waveform recovery method was proposed to get rid of the effects of interface and anisotropy on PEA result, and the space charge distributions in the two-layer samples under different voltage and oil thicknesses were measured. It is found that the charges with the same polarity as oil side electrode were accumulated at the interface and gradually increased with the increase of applied voltage. However, the positive charge charges always appeared in the oil under positive and negative voltages. Moreover, the charges in samples increased with the increase of applied voltage, while the amount of interface charges decreased with the increase of oil thickness. Due to the existence of interfacial charges, the electrical field in oil-immersed-paper was distorted with its maximum close to the interface. It is indicated that due to the different mobility properties of charges in paper and oil and the interface trap state, the interface between paper and oil plays an important role in charge formation and decay.

Measurement of insulation resistance

The measurement of insulation resistance is a common routine test performed on all types of electrical wires and cables. As a production 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.

Selection of IR Testers (Megger):

Insulation testers with test voltage of 500, 1000, 2500 and 5000 V are available. The recommended ratings of the insulation testers are given below:

Voltage Level	IR Tester
650V	500V DC
1.1KV	1KV DC
3.3KV	2.5KV DC
66Kv and Above	5KV DC

Test Voltage for Meggering:

Equipment / Cable Rating	DC Test Voltage
24V To 50V	50V To 100V
50V To 100V	100V To 250V
100V To 240V	250V To 500V
440V To 550V	500V To 1000V
2400V	1000V To 2500V
4100V	1000V To 5000V

When AC Voltage is used, The Rule of Thumb is:

Test Voltage (A.C) = (2X Name Plate Voltage) +1000.

When DC Voltage is used (Most used in All Megger)

Test Voltage (D.C) = (2X Name Plate Voltage).

Measurement Range of Megger:

Test voltage	Measurement Range
250V DC	0MΩ to 250GΩ
500V DC	0MΩ to 500GΩ
1KV DC	0MΩ to 1TΩ
2.5KV DC	0MΩ to 2.5TΩ

5KV DC	0MΩ to 5TΩ
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The insulation resistance of the cables depends on:

- The dimension of the cables (diameter of conductor, insulation thickness, cable length)
- The type and composition of the insulating material
- The quality of the insulating material and,
- The temperature

$$R = K * \log (d/D) M \Omega * Km$$

Where

R: Insulation resistance [$M\Omega \times Km$]

K: Specific resistivity of the insulation [$M\Omega \times Km$]

$$K = 3,66 * 10^{-12}$$

ρ : Specific resistivity of the insulation [$\Omega \times cm$]

D: Diameter of the insulated core [mm]

d: Diameter of the conductor (including the eventual semi-conductive layer) [mm]

Dielectric strength

The loss of the dielectric properties by a sample of a gaseous, liquid, or solid insulator as a result of application to the sample of an electric field greater than a certain critical magnitude is called dielectric breakdown. The critical magnitude of electric field at which the breakdown of a material takes place is called the dielectric strength of the material (or breakdown voltage). The dielectric strength of a material depends on the specimen thickness (as a rule, thin films have greater dielectric strength than that of thicker samples of a material), the electrode shape**, the rate of the applied voltage increase, the shape of the voltage vs. time curve, and the medium surrounding the sample, e.g., air or other gas (or a liquid — for solid materials only).

Adoption of ultrahigh voltage

The adoption of ultrahigh-voltage ac and dc power transmission, it is desirable to develop a new kind of oil-paper insulation system, with higher dielectric strength and smaller volume compared with conventional insulation systems, in order to reduce the volume and mass of high-voltage power transformers and improve their long-term operational reliability. Methods of improving the dielectric properties of the oil-paper insulation have therefore been widely investigated. The most influential factors affecting the performance of oil-paper insulation systems are the low dielectric strength of transformer oil and its degradation caused by water and other contaminants. The dielectric strength of oil-paper insulation may be increased by filtering the oil in order to remove water and other contaminants. However, further increase in the dielectric strength of the oil is required in order to achieve reduction of transformer volume and mass.

The dielectric stress in the insulation

The dielectric stress in the insulation of power transformers during test and operation may become complex. Due to oscillations in the active part and due to reflections after switching operations in the power system, the relevant transient stresses during the lifetime of a transformer significantly differ from the standard lightning impulse

voltage. For an efficient insulation design, it is important to know not only the dielectric strength under standard lightning and AC voltage, but also to know the dielectric strength during "non-standard" impulse voltages. With the breakdown model measurements with 1.2/50 μs standard lightning impulses were performed. In future investigations, the model will be used, to compare the strength of the model under oscillating stresses with the standard lightning impulse stress.

The transformer is a very essential apparatus in an electric power system and its reliability is of utmost importance as a transformer failure results in a very costly and difficult to predict interruption of energy delivery.

In turn, transformer's performance depends heavily on its insulation system; therefore the insulation is perhaps the most critical transformer part.

Particle and moisture effect on dielectric strength

The effect of particles and moisture on the 60 Hertz breakdown strength of transformer oil was investigated. Different sizes and concentrations of iron, copper and cellulose particles were used. The breakdown voltage was determined according to ASTM D1816 using VDE electrodes with an 80 mil (2 mm) gap. The breakdown strength of oil decreased approximately 25 percent when the moisture content was increased from 5 ppm to 20 ppm. A further reduction in the breakdown strength of oil occurred when iron, copper or cellulose particles were added to the oil. The transformer oil showed very low values of 60 Hertz breakdown strength as the result of the combined effects of moisture and particles' type, size and concentration.

Effect of water content on PAO coolant

Many variables can affect the dielectric strength of coolants and insulating fluids including particulates, water content, temperature, viscosity, and pressure. The present paper evaluates the effects of dissolved water content, adjusted in a controlled manner, on the dielectric strength and the variability of breakdown voltages in synthetic polyalphaolefin (PAO) MIL-PRF-87252 coolants obtained from three different suppliers. Additionally, the effect on dielectric strength of using nitrogen gas versus air for the removal of water is evaluated. The results indicate that the dielectric strength of the fluids decreases by up to 80% over a range of 0 to 70 ppm water content. The variability in breakdown voltage generally increases with increasing water content for all of the samples tested. These results indicate the notable effects of water at concentrations below the MIL-PRF-87252 specified acceptable limit of 50 ppm. The effect on the dielectric strength of using two different sparging gases for the removal of water, dry air or dry nitrogen, was irrelevant when compared at similar water contents.

Material	Dielectric constant	Dielectric Strength (kV/mm)
Vacuum	1.00000	-

Air (dry)	1.00059	3
Polystyrene	2.6	24
Paper	3.6	16
Water	80	-

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Dielectric breakdown model (DBM) is a Macroscopic mathematical model combining diffusion limited aggregation model with electric field.

ELECTRIC INSULATION CHARACTERISTICS

The electrical characteristics of PVC such as electrical insulating properties or dielectric constant are excellent.

Materials	Value (Ω -cm)
PE	$10^{16} \sim 10^{20}$
PP	$10^{16} \sim 10^{20}$
PS	$10^{17} \sim 10^{19}$
Tetrafluoroethylene	$10^{15} \sim 10^{19}$
PVC	$10^{14} \sim 10^{16}$
Methacrylate	$10^{14} \sim 10^{15}$
PU	$10^{13} \sim 10^{15}$
Nylon	$10^{13} \sim 10^{14}$
Polyester	$10^{12} \sim 10^{14}$
Neoprene	$10^{11} \sim 10^{13}$
Epoxy resin	$10^8 \sim 10^{14}$

Source: "Plastics almanac" by Kogyo Chosakai Publishing Co. Ltd., p.422, 1976

To express electrical insulating properties, volume resistivity or dielectric strength is widely used as an index. The volume resistivity is expressed in terms of electrical resistance calculated per unit volume of the test piece. The dielectric strength is expressed in terms of the magnitude of voltage withstood without destruction of the test piece when a specified amount of voltage is applied for a specified period of time. In both cases, a higher value means better electrical characteristics.

The volume resistivity of PVC products is slightly lower than those of olefin resin products, but since higher fire resistant properties are required for electrical components, PVC is used widely in a variety of applications such as electric cables for residential buildings, vehicles, household electrical appliances, cable coverings, insulating tapes, switch boxes, wire coverings, and protecting tubes for power and telecommunications cables.

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