Electrical Equipment - Course PI 30.2

INSULATION

OBJECTIVES

On completion of this module the student will be able to:

1. *Explain, in writing, the term "leakage current" and indicate the normal* range of its magnitude.
2. Briefly state, in writing, four factors which affect insulation resistance.
3. Briefly state, in writing, five insulation materials and one application of each.
4. Explain, briefly, in writing the term "insulation failure".
5. Briefly state, in writing, seven causes of insulation failure.
6. In two or three sentences, explain why the fault current must be interrupted quickly.
7. In a few sentences, state why the insulation is temperature rated and *and how this temperature rating is established for a given application.*
8. Briefly, explain, in writing, the term "puncture" as related to electrical insulation.
9. Briefly, state in writing, two results of insulation failure.
10. In writing, list six points which must be considered in the selection of an insulation.
11. In writing, list nine points which must be considered when testing an insulation.

1. Introduction

This lesson examines:

(a) What is insulation; examples of various insulations in use.
(b) Why insulation is used.
(c) Requirements, causes of failure and their effects and hazards.
(d) Testing of insulation.

2. Insulation

Insulation is used in electrical equipment and systems to electrically separate one live conductor from the other, as in multi-conductor cable; or, a live conductor from another conducting surface, such as a grounded motor, bushing and its support structure, etc.

3. Insulation Resistance and Leakage Current

A good electrical insulator must have high resistance to current flow. However, all materials will allow some current flow through them. In insulating materials, this current is in the order of microamperes (10^{-6}A) or nanoamperes (10^{-9}A). It is referred to as **leakage current.** In a good insulation material, the leakage current is so small, (microampres) that for all practical purposes, it is considered zero.

The leakage current value is very low due to very high insulation resistance; typically, in millions of ohms.

The value of insulation resistance depends on:

(a) insulation material,
(b) insulation thickness.
(c) temperature.
(d) humidity.

Some typical insulation materials used in NGD are given in Table 1, along with their applications.

Insulation Material	Application
Air	Variable capacitors, bare overhead lines
Asbestos	Heaters, heater cords
Bakelite	Switches, breakers
Cotton	Cables, transformers, motors
Epoxy	Small transformers, bus work
Fibreglass Tape	Generators, switch sticks
Glass	Pole top insulators
Magnesium Oxide	Cables
Mica	Capacitors, generators, appliances
Nylon	Control room panel wiring
Paper	Transformers
Plastic	Cables, air circuit breakers
Polyvinylchloride (PVC)	Cables
Porcelain	HV bushings
Rubber	Test leads, safety mats and gloves
Teflon	Transformers, circuit breakers, capacitors
Mineral Oil	Transformers, circuit breakers, capacitors
Askarel Oil	Transformers, capacitors (Its use is banned in the new equipment)

Table 1

Insulation Materials Types and Their Use in NGD

4. Insulation Failure

An insulation is considered "failed" if it does not prevent current flow, other than the normal leakage current between the two live conductors or a conductor and a conductive surface. Most insulators will become conductors if some conditions, as follows, are not met.

4.1 Causes of Insulation Failure

The following are major causes of insulation failure.

4.1.1 Aging

Aging of insulation occurs due to many causes. Some of the important ones are listed below.

(a) Environment
(b) Radiation
(c) Corona
(d) Drying
(e) Excessive Heat

When an insulation ages, it becomes brittle, dry and develops cracks. Its resistance drops to a point such that it can not effectively perform as an insulator.

4.1.2 Chemical Changes

Chemical changes occurring in the insulation cause permanent damage to the insulation. Electrical properties of the new chemical product formed are normally poorer than the original.

Chemical changes in an insulation are caused by the operational environment, for example: heat, radiation, contaminants.

4.1.3 Thermal Stress

Thermal stress occurs when a material is overheated. It causes carbonization and/or melting. Overheating of insulation can be caused by the following.

(a) Fire.
(b) Fault current, which can be very large. Fault current causes large I^2R heat production, which overheats the insulation. (This is why fault conditions must be quickly interrupted).

4.1.3 Thermal Stress (continued)

(c) Extended overload. Overload current is the current which is a few percent more than the normal current. This increased current applied for an extended period of time, will overheat the insulation. This is why insulation is "temperature rated". Table 2 shows the various classes of insulation and their temperature ratings. For any application the expected operating temperature must be known. To this, a safety factor is added in order to arrive at the type of insulation needed.

As a general rule, for every 10°C increase in the operating temperature of an insulation, its life is reduced by half.

Class	Max Working Temperature °C	Examples of Materials
O(Y)	90	Cotton, silk, paper - not impregnated nor immersed in a liquid dielectric shellack.
A	105	Cotton, silk, paper - impregnated or immersed in liquid dielectric (oil).
E	120	Organic materials impregnated with asphalts, polyesters.
B	130	Mica, asbestos, fibreglass with polyester varnishes, bitumen, varnish.
F	155	Mica, fibreglass, asbestos with epoxy resin varnishes.
H	180	Inorganic insulations, silicones.
C	Over 180 (Navy 200)	Inorganics like mica, ceramics, glass, porcelain, polytetraflourethylene (teflon).

Table 2

Insulation Classes and Temperature Ratings of Various Materials Used for Electrical Insulation

4.1 Causes of Insulation Failure (continued)

4.1.4 Electrical Stress

(a) When a voltage is applied across any insulation it causes an electrical field to appear within the insulation. The intensity of the electrical field is usually specified as kV per centimeter (kV/cm) and is a measure of electrical stress of the insulation. **There is a certain electrical stress at which the insulation will be punctured.** The electrical stress to puncture new insulation is higher than that for old insulation. An increase in the electrical stress also causes the leakage current in the insulation to increase, which eventually leads to insulation failure. Every insulation must be used within its rated operating voltage. The voltage rating of the insulation must be at least equal to the line r.m.s. voltage.

Electrical stress of insulation not only depends on the magnitude of the applied voltage, but also on the shape of the electrode. Shape of the electrode influences the electric field distribution. In high voltage applications, electrodes and insulation are designed not to have sharp edges. Sharp edges create, local, high electric field intensities. Such electrical stress can be high enough to cause puncture through the insulation or cause corona.

(b) In dry air, the electrical stress to puncture (also called the dielectric strength) equals 30kV/cm. When the electric field intensity reaches 30kV/cm, the air becomes ionized, and a conductive path can be established. The conductive path can be from one conductor to the other, or from one conductor to a grounded surface, such as a transformer tank. This phenomenon is known as corona effect.

In air, corona can be observed, when the conductors in a high voltage switchyard are energized. A hissing sound can be heard, and at night, a blue or purple glow can be seen.

Corona can also occur in air pockets,which may be present in insulation, due to manufacturing defects. Corona cannot be eliminated. It can only be minimized. Some commonly used methods to minimize corona are:

- increasing the distance between the conductors.
- better manufacturing techniques to eliminate air pockets.
- improved design; for example, elimination of sharp edges, use of several conductors (bundled conductor) per phase, as done with 500kV transmission lines.

When corona occurs in air, O_2 and N_2 molecules break down to form O_3 (ozone), NO and NO_2. If moisture is present, these oxides of nitrogen combine with water to form nitric acid. In turn, this nitric acid attacks the insulation or the insulation bonding agents. This process can also occur, in tiny air pockets, within a solid insulator.

Figures 1 and 2 show porcelain insulators used in high voltage applications. Their design provides for the following:

- As many as required can be connected in a string form to provide the proper operating voltage.

- Rounded edges are designed to reduce electrical stress.

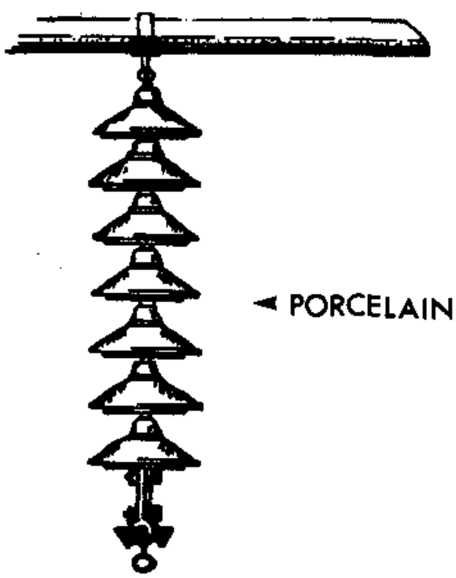

Figure 1: Typical String of Porcelain Strain Insulators

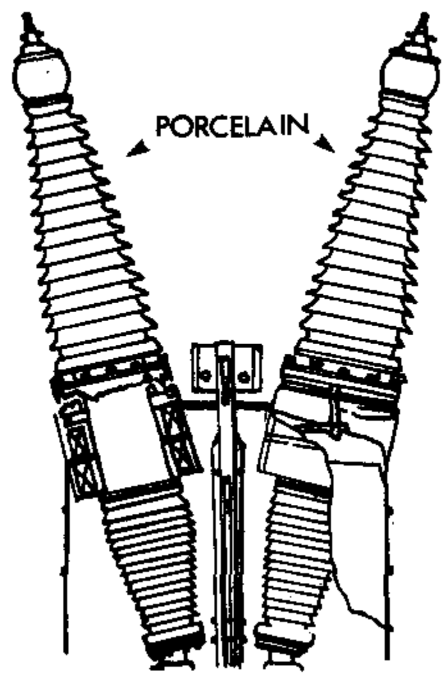

Figure 2: Two Typical Porcelain Brushing Insulators

4.1.5 External Contamination

Dirt and dust collecting on the surface of insulation can provide a layer through which current can flow. Current flowing through this layer of contamination eventually chars the insulation under it and creates a permanent carbonized path. This phenomenon is known as "tracking". Organic materials are greatly affected by tracking, while inorganics, such as porcelain are more resistive to tracking. Tracking will eventually lead to insulation failure.

4.1.6 Internal Contamination

If moisture or dirt gets in between the conductor surface and the insulation, or if moisture is absorbed by the insulation, failure of the insulation will occur.

Some examples of insulations that can be damaged by moisture are: paper, wood, cotton, transformer oil and magnesium oxide.

4.1.7 Mechanical Stress

This is a straining force exerted on an electrical insulator. Mechanical stress deforms, cracks, or cuts an insulating material. Also, at the point of stress, electrical resistance of the insulation decreases and puncture results. Mechanical stress can be due to the following:

(a) Improper installation. Insulation installed on sharp edges can damage the insulation at the point of contact.

(b) Fault current produces high heat which reduces the mechanical strength of the insulation.

(c) Vibration. If equipment is not properly levelled or securely installed, vibration will cause the insulation to chafe through. Some insulations, such as epoxy resins, shrink due to aging. This causes loosening of the insulation and may result in vibration and eventual damage.

4.2 Results of Insulation Failure

One, of two phenomenon may occur, due to insulation failure.

(a) PUNCTURE through or tracking across the surface of an insulating material.
(b) FLASHOVER in air and gases.

In either case, high fault currents may flow.

4.3 Hazards of Insulation Failure

Insulation failure creates two concerns.

4.3.1 Hazard to personnel; it could be potentially lethal.

4.3.2 Hazard to equipment.

5. Checklist for Insulation Selection

5.1 Voltage rating: Insulation must be rated for the nominal line voltage of the circuit, in which it is used.

5.2 Temperature rating: Insulation must be able to withstand the temperature it is to be exposed to.

5.3 Waterproof: If the insulation is to be exposed to moisture, it must be waterproof.

5.4 Mechanical properties: Insulation must be able to lend itself to bending or shaping, if required, without changing its insulating characteristic.

5.5 Resistant to tracking: Insulation must have adequate surface area and have a hard, smooth,glossy finish. (For example, rubber has a low resistance to tracking; whereas, glass or porcelain has a high resistance to tracking).

5.6 Cost: Should be cost effective for the application.

6. Testing of Insulation

Insulation testing is done with an instrument called a "megger". This instrument is calibrated in ohms, KΩ, or MΩ. A megger is capable of measuring very large resistances, tens or hundreds of meg-ohms. (These are typical values for insulation resistance. Since insulations have low leakage currents, the megger must apply a high voltage across the insulating material, in order to achieve a reasonable accurate measurement.Insulation testers come in various voltage ratings. Typical values are: 100 V, 250 V, 500 V, 1000 V and 5000 V.

6.1 Points to Consider

6.1.1 The voltage output of the insulation tester must not be higher than the maximum voltage rating of the insulation, or damage to the insulation may occur.

6.1.2 Sufficient time must be allowed for the insulation test instrument reading to stabilize. This can be 3 to 5 minutes, depending on the size of the equipment, dryness, etc.

6.1.3 Insulation testing must be done in accordance with the work protection code.

6.1.4 It is useful to compare the insulation resistances of previous tests or comparable installations. Any large variations indicate a poor insulation health condition.

6.1.5 Temperature at the time of test will affect the reading.

6.1.6 Humid test conditions will result in lower insulation resistance measurements than would normally be expected.

6.1.7 New insulation will have a higher resistance reading than old insulation, of the same type. This should be considered when interpretating the test data.

6.1.8 On completion of the test, the insulation must be discharged, in order to ensure personnel safety.

6.1.9 For personnel safety, no one must come in contact with the conductor during a megger test. The conductor and the protective outer sheath could be at a high potential if the insulation is faulty.

Assignment

1. What is the purpose of insulation in electrical equipment? (Section 2).

2. Explain what is meant by "leakage current". What is the normal range of magnitude for this current in an insulation of good quality? List four factors which affect the insulation resistance. (Section 3).

3. List any five insulation materials and one application of each. (Section 3, Table 1).

4. What is meant by "insulation failure"? (Section 4).

5. List seven causes of insulation failure. (Section 4.1).

6. Why must a fault current be interrupted quickly? (Section 4.1.3).

7. Why must insulation be temperature rated? (Section 4.1.3).

8. Explain the process of "puncture" when considering an electrical insulating material? (Section 4.1.4).

9. What are the two results of insulation failure? (Section 4.2).

10. List five points which must be considered when selecting an insulation material? (Section 4).

11. List nine precautions that must be observed when testing the insulation resistance of an insulating material. (Section 5).

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Notes