High Technology Solutions
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Cadick Corporation

TECHNICAL BULLETIN — 012a
Principles of Insulation Testing

Introduction

Probably 80% of all testing performed in electrical power systems is related to the verification of insulation quality. This Cadick Corporation Technical Bulletin briefly describes the fundamental concepts of insulation testing including – insulation behavior, types of tests, and some test procedures. For more detailed information, refer to the bibliography at the end of the paper.

AC or DC?

Most electrical equipment in utility, industrial, and commercial power systems uses either 50 or 60 Hz alternating current. Because of this,, the use of an alternating current source to test insulation would appear to be the logical choice. However, as will be described a little later, insulation systems are extremely capacitive. For this and other reasons, DC has found a large niche in the technology.

Before we can really evaluate the value of one system as opposed to the other (e.g. AC vs DC), let us examine how each type of voltage affects insulation.

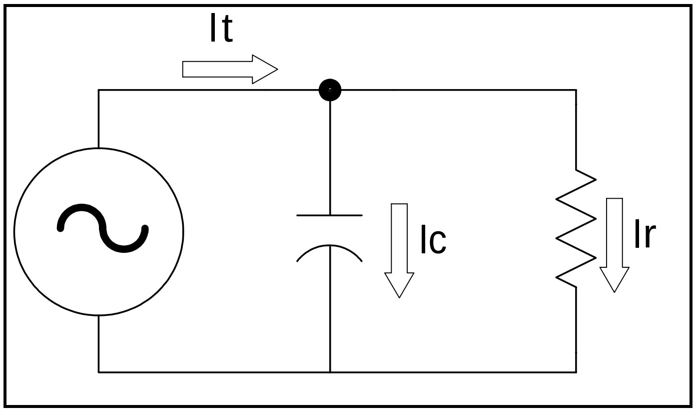

Figure 1 – Insulation with an AC voltage applied

Insulation Current Flow (AC)[1]

Insulation may be simply modeled as a capacitor in parallel with a resistor as shown in Figure 1. The current flow that results will comprise two components: the capacitive current (I_c) and the resistive current (I_r). Figure 2 shows the time domain graph of the two currents. For ***good*** insulation:

- Ic ≥ 100 x Ir
- Ic leads Ir by close to 90°

For ***marginal*** insulation:

- Ic ≥ 50 x Ir
- Ic leads Ir by ≤ 80°

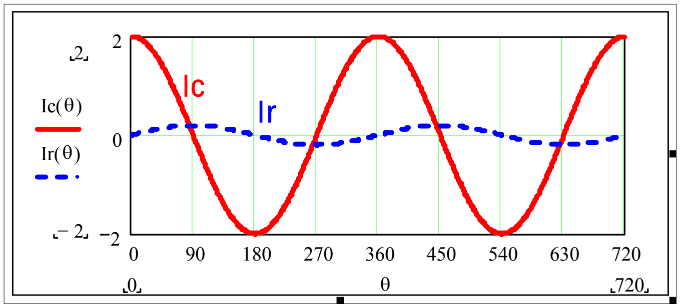

Figure 2 – Insulation current with AC voltage applied

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[1] Note that the currents discussed in this paper are the insulation currents NOT load currents.

Insulation Current Flow (DC)

When DC current is involved, insulation may be modeled in a slightly different way. Consider Figure 3. When switch S1 is closed, the DC supply is connected to the insulation system. In the DC model an extra capacitor has been added (dashed lines). The current that flows through this new capacitor is called the dielectric absorption current (Ida) and will be explained later. Figure 4 show the time relationship for these three currents. The following paragraphs explain each of the three currents.

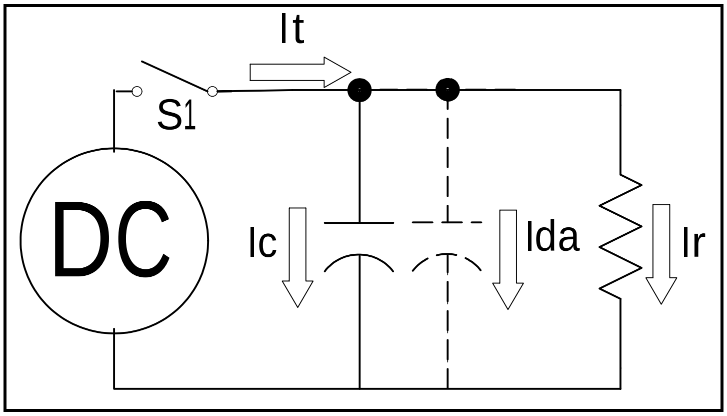

Figure 3 – Insulation with DC voltage applied

Capacitive Current (Ic)

The capacitive current charge the capacitance in the system. It normally stops flowing a few seconds (at most) after the DC voltage is applied. The short burst of capacitive current flow may put a rather substantial stress on any test equipment that is applied to very large insulation systems such as cables or large rotating machine.

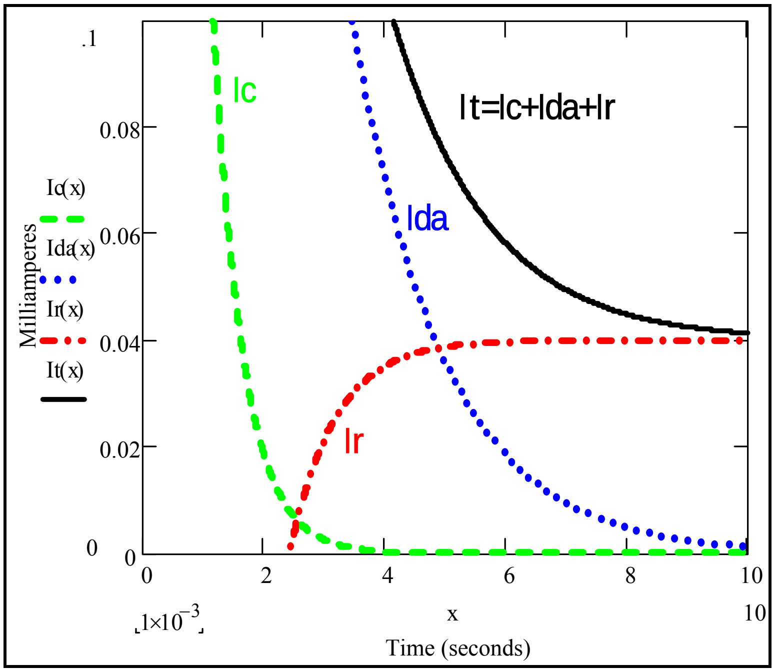

Figure 4 – DC current flow in good insulation

Dielectric Absorption Current (Ida)

The applied insulation voltage puts a stress on the molecules of the insulation. The positive side of the molecules are attracted to the negative conductor and the negative side of the molecules are attracted to the positive conductor.

The result is an energy that is supplied to realign the molecules much like force will realign a network of rubber bands.

Like Ic, Ida usually dies off fairly quickly as the molecules realign to their maximum extent.

Resistive (Leakage) Current (Ir)

This is the electron current flow that actually passes through the insulation. In good insulation the resistive current flow will be relatively small and constant. In bad insulation the leakage current may be fairly large and it may actually increase with time.

Testing Insulation Quality with AC (See Appendix for Test Voltages)

Limitations

Testing with AC has two significant problems

1. Since a large percentage of insulation current in both good and marginal insulation is capacitive, good insulation will have close to the same amount of AC current flow as marginal insulation. It is, therefore, not possible to evaluate the quality of insulation by simply measuring the magnitude of current flow. (For an exception to this see the Power Factor Testing discussion below). Of course we note that if the insulation is extremely bad or if it fails the current drawn will be high enough to clearly identify the problem.

2. The high amount of current flow drawn by the insulation requires a large test instrument to supply it. This causes AC test sets to be heavier and mor difficult to transport than equivalent capability DC test sets.

In spite of these limitations many manufacturers specify that AC be used to test their equipment, and AC testing has a large following. At least four basic approaches are used for testing insulation with AC.

AC High Potential Testing (Also called an Over-potential Test)

In this test a high voltage AC is applied to the insulation. Usually two or more times the rated insulation current will be used. The concept here is somewhat equivalent to overloading the dam with too much water. If the insulation is good, it will not fail during the test. Note that failure during an AC high potential test is usually very rapid and the insulation is completely destroyed. Because of this, the AC Over-potential test isclassed as a go-no go type of test.

Power Factor Testing

This approach evaluates the ratio of the resistive current to the total current – $\frac{I_r}{I_t}$ (power factor) or the ratio of the resistive current to the capacitive current – $\frac{I_r}{I_c}$ (dissipation factor) . Since the resistive current is very small, their ratio should be very small. (Note that ideally the ratio would be zero since ideally Ir = 0). To perform this test the test equipment must have relatively sophisticated circuitry that is able to distinguish among the three different current types (resistive, capacitive, and total).

Bad insulation will have a relatively high power or dissipation factor. Tables and references are available to compare the measured values against other insulation of the same type.

0.1 Hertz Test Set

This type of test set uses a very low frequency test signal. Because capacitors act like very high impedances to very low frequencies, the insulation system draws relatively low current and much of it will be the resistive or leakage current. Proponents of the 0.1 Hertz test set identify at least two significant advantages over other types:

1. Since the insulation draws relatively low current the 0.1 Hertz test set is much smaller than its 60 Hz counterparts.

2. The 0.1 Hertz signal tends to be less destructive than improperly applied DC test voltages. For this reason many test personnel have moved away from DC over-potential testing (described later) in favor of the 0.1 Hz test.

Capacitive Canceling (Resonant) System

This method is normally applied on very high voltage systems of 230 kV and higher. The test set adjusts its own internal inductance to effectively cancel the insulation capacitance. This leaves only the resistive (leakage) current to be read.

The last three test systems (Power Factor, 0.1 Hertz, and Capacitive Cancelling) are relatively specialized systems and may require special training for test personnel. Also, sometimes the results are more complex to analyze. Because of these factors DC test equipment still remains the odds-on favorite for the majority of insulation testing applications.

Testing Insulation Quality with DC (See Appendix for Test Voltages)

Limitations

The principle concerns to be observed when testing with DC is the possibility of damaging otherwise good insulation. Some studies have indicated that DC testing at very high voltages may cause insulation damage for one of two reasons:

1. Sudden application or removal of the voltage (creating a very large $\frac{dV}{dt}$) causes an abnormal amount of stress. Whenever possible the test voltages should be gradually applied and removed.

2. If a large over-voltage (on the order of 2 or more times normal) is applied to some insulation systems, the small air voids in the insulation will become charged. If the insulation is then suddenly re-connected to the power system, it may fail due to the addition of the system voltage to the still charged voids. Even if the insulation does not immediately fail, it will be stressed and may lose life.

   To avoid this problem insulation should always be drained of DC test voltage for 1 to 5 times the length of time that the test voltage was applied before it is re-energized.

Effects of Humidity and Temperature

Temperature will change the measured insulation resistance. When the temperature goes up the resistance of insulation will go down and vice versa. Tables of correction factors are available from industry publications to correct for temperature variations (See Appendix). If no table is available the field rule of thumb may be used that the insulation resistance will double of each 10°C drop in temperature and will halve for each 10°C rise in temperature.

Humidity will not generally have much effect on insulation resistance unless the temperature is very close to the dew point and condensation forms on or in the insulation. Despite this, good practice calls for making measurements when insulation is clean and dry whenever possible.

Insulation Quality Tests

There are three commonly used methods to evaluate the quality of insulation using DC voltage – the so-called *spot check*, *the polarization index test*, and *the step voltage test*.

Spot Check

Table 1 – The insulation resistance Spot Check

Step #	Description	Comments
1	Apply the DC Voltage	Usually applied with a megohmmeter or high potential test set
2	Wait one minute for the Ic and Ida to decay	If using a high voltage test set, monitor current closely for indications of insulation failure
3	At one (1) minute read the meter current (Ir) or the insulation resistance in megOhms	Compare to previous values or industry standards such as International Electrical Testing Association (NETA)

Since Ic and Ida disappear in time, a true insulation resistance value, called a spot check, can be read by applying the DC and then simply waiting long enough for only Ir to remain. Unfortunately the time required for the decay may be several minutes or more for very large insulation systems. To simplify the wait, and since comparison is the main purpose of such a test, general industry practice has established the waiting time as one (1) minute. Table 1 summarizes the method.

Table 2 – The Polarization Index Test

Step #	Description	Comments
1	Apply the DC Voltage	Usually applied with a megohmmeter or high potential test set
2	Wait one minute for the Ic and Ida to decay. Read and record the insulation resistance (R_1)	If using a high voltage test set, monitor current closely for indications of insulation failure
3	Wait nine (9) additional minutes (10 minutes total) and read the insulation resistance again. (R_{10})	If using a high voltage test set, monitor current closely for indications of insulation failure
4	Calculate the polarization index (P.I.)	$P.I. = \frac{R_{10}}{R_1}$

Polarization Index

To avoid the uncertainties introduced by temperature correction, and to provide an even more diagnostic result, the polarization index may be calculated for an insulation system. Table 2 lists the steps for performing the polarization index test. Table 3 shows how to evaluate the results of the polarization index test.

Table 3 -- Evaluation of the polarization index test

Value P.I. $\left(\frac{R_{10}}{R_1}\right)$	**Insulation Evaluation**
<1	Dangerous
<1.5	Poor
<2	Fair
3 to 4	Good
> 4	Excellent
If P.I. is 5 or greater, insulation may be dry and brittle.	

Step Voltage Test

Electrical resistance is a physical characteristic of a material and, therefore, should not be changed by the voltage level that is used to measure it.

At higher voltages, however, cracks and other such insulation faults will be stressed more. This means that ionization may occur, causing an increased, disproportionate current flow. In other words, bad insulation will tend to display a lower resistance when a higher voltage is applied.

The step voltage test is accomplished by performing a spot check test at two or more voltages. Usually the voltages are separated by at least 500 Volts and the last step should be five (5) times the lowest voltage. For example the first spot check is performed at 500 Volts with additional one minute checks at 1000, 1500, 2000, and 2500 Volts.[2]

If $R_{HV} < 0.60 \times R_{LV} \pm 15\%$, the insulation should be investigated for possible failure.

Summary

The effective electrical maintenance program must include periodic evaluation of the insulation quality. Technical Bulletin only scratches the surface of the subject. For more information you can consult these resources:

AVO, International:	http://www.avointl.com
Doble Engineering:	http://www.doble.com
AEMC:	http://www.aemc.com

If you have any questions or comments about this technical bulletin, please contact us at info@cadickcorp.com.

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[2] Although a megohmmeter is a low energy device, avoid applying more than 3 to 4 times the insulation rated voltage.

Appendix – Test Values and Temperature Tables

The following three tables are taken from the International Testing Association's standard NETA MTS-2001.For more detail you should obtain a copy of this standard directly from NETA (http://www.netaworld.org).

Table 4 – Temperature correction factors (NETA Table 10-4)

Temperature		Multiplier	
°C	**°F**	**Apparatus Containing Immersed Oil Insulations**	**Apparatus Containing Solid Insulations**
0	32	0.25	0.40
5	41	0.36	0.45
10	50	0.50	0.50
15	59	0.75	0.75
20	68	1.00	1.00
25	77	1.40	1.30
30	86	1.98	1.60
35	95	2.80	2.05
40	104	3.95	2.50
45	113	5.60	3.25
50	122	7.85	4.00
55	131	11.20	5.20
60	140	15.85	6.40
65	149	22.40	8.70
70	158	31.75	10.00
75	167	44.70	13.00
80	176	63.50	16.00

Table 5 – Minimum test values for electrical apparatus (NETA Table 10-1). To be used for Megohmmeter type tests

Maximum Rating of Equipment in Volts	Minimum Test Voltage, dc	Recommended Minimum Insulation Resistance in MegOhms
250	500	25
600	1,000	100
5,000	2,500	1,000
8,000	2,500	2,000
15,000	2,500	5,000
25,000	5,000	20,000
35,000	15,000	100,000
46,000	15,000	100,000
69,000	15,000	100,000

Table 6 – Maximum withstand voltage for testing electrical apparatus (NETA Table 10-2) For High-Potential Testing

Type of Switchgear	**Rated Maximum Voltage (kV) (rms)**	**Maximum Test Voltage (kV)**	
		ac	**dc**
Low-Voltage Power Circuit Breaker Switchgear	.254/.508/.635	1.6	2.3
Metal-Clad Switchgear	4.76	14	20
	8.25	27	37
	15.0	27	37
	27.0	45	Consult Manufacturer
	38.0	60	Consult Manufacturer
Station Type Cubicle Switchgear	15.5	37	Consult Manufacturer
	38.0	60	Consult Manufacturer
	72.5	120	Consult Manufacturer
Metal Enclosed Interrupter Switchgear	4.76	14	20
	8.25	19	27
	15.0	27	37
	15.5	37	52
	25.8	45	Consult Manufacturer