INSULATION RESISTANCE TESTING OF THE MEDIUM VOLTAGE SWITCHES

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***Abstract* – This paper refers, in general, to the problem of off-line diagnosis of automated switches, and in particular it refers to the testing procedures regarding the insulation resistance. The factors that have a negative influence upon the insulation resistance will be analyzed as well as the principles of the measurement of the insulation resistance. The testing procedures, which are defined in standards, are applied to the extinguishing chamber of a medium-voltage circuit breaker, IUP-M. Through the process software Tera-Link, the tester used for experimental determinations Metrel MI 3200 TeraOhm 10kV emphasis the insulation resistance parameters of the tested equipment. The Metrel MI 3200 TeraOhm 10kV equipment, from the Electrical Equipment lab of the Technical University in Cluj-Napoca, allows taking the following tests and determinations for the electrical equipments insulation: determining the insulation resistance through the "spot reading" method, determining the „*polarization index*" (PI), through the „*absorption test*" procedure, determining the „*dielectric absorption ratio*" (DAR), the possibility of taking the dielectric discharge test and the possibility of measuring the insulation resistance tests with step voltage method. It is very interesting to notice the facility of portable equipment of the MI 3200 tester, the fast completion of the testing operations and the ease in interpreting results with Tera-link software.**

Keywords: *insulation resistance, absorption test, polarized index.*

1. INTRODUCTION

Before making a decision regarding the insulation resistance tests that need to be taken for the electrical equipments, in order to detect the electrical defects, the motives that lead to the appearance of these defects need to be studied. It is important to know the insulation groups, the aging process of the insulation and typical faulting scenarios. Only afterwards the decision upon the tests that need to be taken can be made, also it can be decided whether the high voltage test can be useful [1].

The insulation system of the electrical equipment is made of ground insulation, the phase-to-phase insulation and turn-to-turn insulation. The weakest link in this insulation system is often the turn-to-turn insulation [2], if these exist in the structure of the electrical equipment. For an adequate testing of the insulation system different tests need to be taken. The ground insulation can be tested using a megohmmeter in order to determine the values of the insulation resistance, and by taking the polarization index test the elasticity of the insulation can be evaluated. Also a test with DC high-voltage has to be taken, in order to determine the resistance of the dielectric of the insulation up to a pre-established level. The phase-to-phase insulation can be tested using one of the above methods if the electrical equipment is disconnected [3]. In most predictive maintenance scenarios the complete disconnecting of the motor is not possible and the insulation between phases must be tested in the same way as the turn-to-turn insulation with a surge test. The factors that contribute to the deterioration of the insulation resistance are important to be known:

- *Contamination*: chemical deposit on the power lines, that causes the deterioration of the insulation;
- *Mechanical factors*: vibrations of the activating mechanisms, that wears out the insulation system;
- *Normal aging:* the deterioration in time of the insulation;
- *Early thermal aging:* caused by excessive temperatures that lead to the deterioration of the insulation;
- *Overvoltage spikes:* lightning, or caused by static convertors.

All of the above factors have to be considered when building up a testing program. Usually a normal thermo process of aging is considered and also is taken into account how the aging of the insulation is influenced by mechanical factors, premature aging and surges.

2. THE PRINCIPLES OF MEASURING THE INSULATION RESISTANCE

According to the law of Ohm,

$$I = U / R \qquad (1)$$

the current is not time dependent, but a simple measurement of the insulation resistance will demonstrate the dependency of the current versus time. The reasons of this dependency of the current are determined by different phenomena that occur after applying a voltage on the isolating material. An insulation material is presented in figure 1:

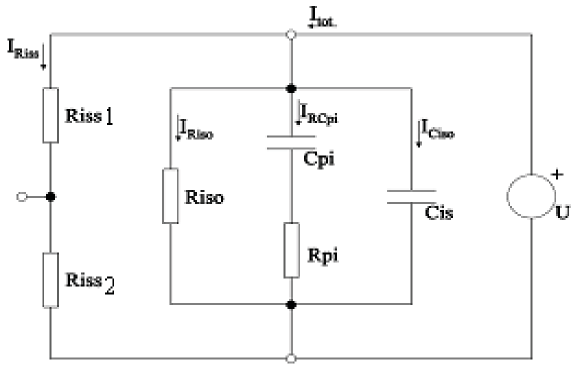

Figure 1: The insulation resistance and the capacitance model, individual and total currents.

where:
U is the applied test voltage;
R_{iss1} and R_{iss2}: the resistance of the leakage surface;
R_{iso}: insulation resistance;
C_{iso}: insulation capacitance;
R_{pi}: polarization resistance;
C_{pi}: capacitance of polarization.
The total current I_{tot} is composed by 4 components:
I_{Riss}: surface leakage current;
I_{Riso}: insulation current;
I_{Rcpi}: polarization absorption current;
I_{Ciso}: capacitance charging current
The surface leakage current I_{Riss} circulates at the surface of the insulation between the points where the voltage is applied, causing an error in the measurement of the insulation resistance and can be eliminated by using the guard terminal. Just as presented in figure 1 this current goes through the resistors R_{iss1} and R_{iss2} and does not depend on tine.

$$I_{Riss} = \frac{U}{R_{iss1} + R_{iss2}} \quad (2)$$

The insulation leakage current I_{Riso} circulates through the insulation, which encounters the resistance R_{iso} (figure 1) and does not depend on time:

$$I_{Riso} = \frac{U}{R_{iso}} \quad (3)$$

The polarization absorption current I_{Rcpi} is the charging current of the capacitor C_{pi}. Initially the capacitor is discharged and the initial value of the current is U / R_{pi}. The capacitor starts to charge and the current decreases. In the final stage the capacitor is fully loaded and the current is canceled. The polarization absorption current depends on time as shown in the following relation:

$$I_{RCpi} = \frac{U}{R_{pi}} \cdot e^{-\frac{t}{R_{pi} \cdot C_{pi}}} \quad (4)$$

The polarization absorption current measurement may be problematic because of the other currents which may chance the polarized current absorbed [1]. Often it is easier to measure the opposite process: the dielectric discharge. In this case the measurement begins with the loaded capacitor C_{pi}. The connection cables are short-circuited and the measurement is realized on depolarization current. The capacitive current I_{Ciso} loads the capacitor C_{iso} which represents the capacity between the metallic parts connected on measurements instruments inputs. These inputs are separated by the tested insulation. The current I_{Ciso} is limited only by the internal resistance of the instrument.

$$I_{Ciso} = \frac{U}{R_{int}} \cdot e^{-\frac{t}{R_{int} \cdot C_{iso}}} \quad (5)$$

where R_{int} represents the source internal resistance. Considering this we have the total current I_{tot}:

$$I_{tot} = I_{Riss} + I_{Riso} + I_{RCpi} + I_{Ciso} \quad (6)$$

Figure 2 presents the current diagram, based on the standard insulation model:

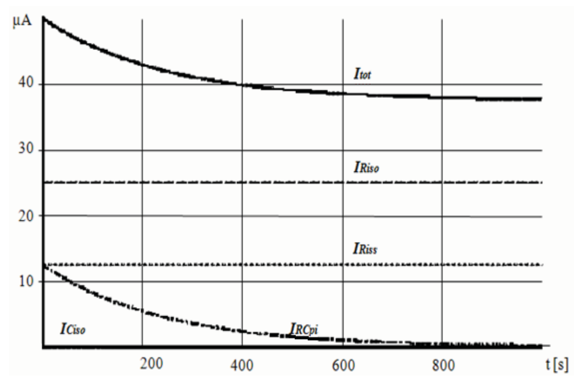

Figure 2: Current diagram of an ideal voltage source

In practice, the equipments that measure the insulation resistance don't include an ideal source of voltage and the available power is limited. This is why the time diagram of the total current is modified in comparison to the one in figure 2. At the beginning all the available power of the instrument is used to charge the capacitor C_{iso} for o short period of time. From this reason the voltage in the connection points decreases. These phenomena remodel the ideal curves of the current into real curves, as seen in figure 3:

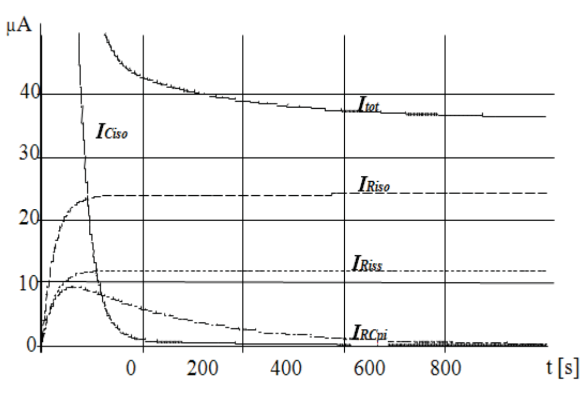

Figure 3: Current diagram of a real voltage source

3. PROCEDURES FOR TESTING THE INSULATION

For determining the insulation characteristics it was developed some different testing methods. In the following it is described the methods used by the authors [5] in order to test the extinguishing chamber of an automatic switch of medium voltage IUP-M.

The most simple and the most rapid method for determining the insulation resistance is the "spot-reading" method. Using this method it can be qualitative determined how good or how bad is the insulation. On this testing method, the measurement instrument is connected on the test object insulation. A test voltage is applied for a period of time. Usually the reading is made after one minute, as shown in Figure 4.

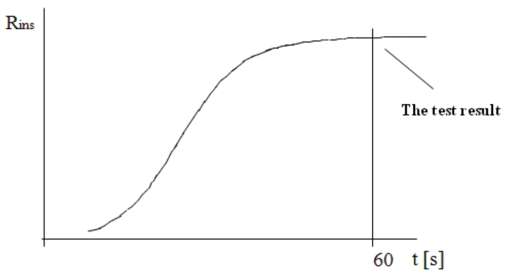

Figure 4: "Spot reading" testing method of time-resistance diagram

This testing method can be used when the insulation temperature is above the dew point. The insulation temperature is a very important value because the reading can be adjusted according to normal functioning temperature. The tested insulation normal functioning temperature is normally bigger than the ambient temperature and for the safety reasons its resistance must be adjusted according to normal functioning temperature.

In the figures 2 and 3 it is shown that an inadequate insulation leads to a decrease of the R_{iso} resistance and the I_{Riso} current. The absorbed current is low as compared to the leakage current, which has an approximately constant value, while the insulation resistance is low value.

A good insulation will cause a continuous growing of the resistance, on a period of time. This is determined by the absorption effect of duration much higher than the time required for the loading capacity of insulation. The results obtained by using this method are not dependent on temperature and provide conclusive information without comparing measurements with those made previously. The measurements achieved through this method do not provide data on insulation resistance, but only the ratio of two readings at different times. The influence of the temperature is the same in both measurements, so the temperature has no effect on the results.

This method is sometimes known as "the absorption test" and the result of this determination is "polarization index", (PI) defined as the ratio of resistance measured in two different times. The most common report is 10 minutes to 1 minute, at continuous measurement of insulation resistance, but it is not a rule.

$$PI = \frac{R_{tot}(10\,min)}{R_{tot}(1\,min)} \qquad (7)$$

A proper insulation presents a leakage current of a lower value and the total current decreases slowly. Therefore, the polarization index of a proper insulation has a high value and a damaged insulation has low polarization index, because current flow has a constant high value. The general the values of polarization index are presented in [1]. The polarization index measurement is very useful for testing older types of insulation, such as oil-soaked paper insulation, where the resistance measured at one minute with the previous method is relatively small. If insulation resistance measured at one minute is greater than 5000 MΩ, then the polarization index can not be taken into account.

The dielectric absorption ratio (DAR), is similar to the polarization index, the only difference being the time at which the results are read. The periods are shorter and the first result is obtained at 30 seconds and the second one at 1 minute.

$$DAR = \frac{R_{tot}(1\,min)}{R_{tot}(30\,sec)} \qquad (8)$$

When a test voltage is applied through the insulation, a series of currents will flow: I_{Riss} -surface leakage current, I_{Riso}- insulation current, I_{Rcpi}- polarization absorption current, I_{Ciso}- capacitance charging current.

It is difficult to determine the index of polarization, if I_{RCpi} current is low as compared to the other currents. It is indicated that instead of measuring the current polarization in the testing insulation to use dielectric discharge test. (Figure 5). The test device must be fully charged to ensure that the polarization process is completed. After the voltage is interrupted, the test equipment is downloaded and the current is measured; usually it is taken into account the current value after one minute. This current depends on the voltage test and the total capacity, which can be measured during unloading.

The dielectric discharge is calculated with the relation:

$$DD = \frac{I_{dis}(1\,min)}{U \cdot C_{iso}} \qquad (9)$$

where, I_{dis} (1 minute) is the discharge current measured at one minute after interruption of voltage, *U* is the voltage test and C_{iso} is the capacity of the tested object [1]. A large re-absorbability current proves that the insulation was damaged, usually from moisture. The typical values of dielectric discharge are presented in [1].

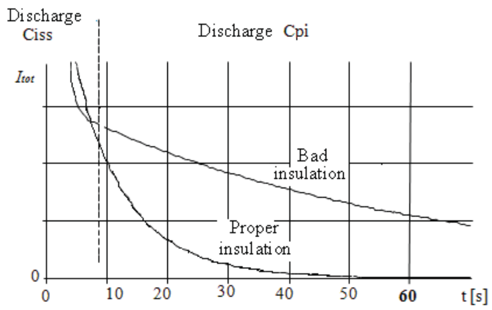

Figure 5: The time-current diagram of an insulation tested by DD method

The dielectric discharge test is useful for testing multilayer insulation. This test can identify excessive discharge currents that occur when a layer of a multilayer insulation is destroyed or damaged. This situation can not be identified by the "*spot test*" method or "polarization index" method.

Another method used is to measure the insulation resistance with high voltage. As Figures 2 and 3 show, the insulation resistance is not dependent on voltage. Basically, the insulation resistance depends on the voltage test. Testing the insulation with a voltage lower than nominal voltage, the measurement results are often influenced by moisture and dust, while the effects of aging or mechanical damage to insulation clean and dry, can not be determined at low voltage.

The influence of local defects is negligible in low voltage, but their influence increases rapidly when test voltage increases. This is indicated by the rapid decrease of insulation resistance.

The step voltage measurement is simple. The tested device is subjected to different voltage steps, beginning with the lowest power and increases in certain well-defined steps to the highest voltage. Figure 6 shows an example of testing in five steps with equal time periods. The recommended ratio for this type of testing is 1-5. At each step, test voltage must be applied the same period time, usually 60 seconds.

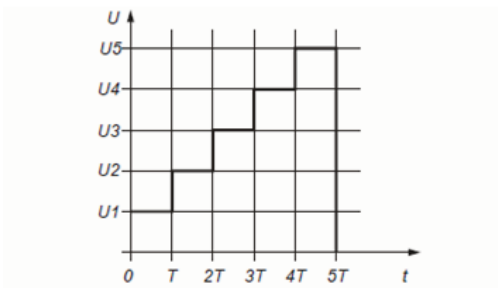

Figure 6: Step voltage method typical measurement method

Increased voltage test is one of basic tests used to diagnose the insulation resistance. The principle is very simple: increased voltage is applied to the test equipment for a certain period of time or until the failure of insulation (Fig. 8).

The measurement result shown in Fig. 7 represents a curve which emphasizes the resistance dependence according to the step voltage corresponding time.

The shape of the curve shows the quality of the insulation:

● the resistance of an damaged insulation will rapidly decreases;

● a good insulation will have an almost constant resistance on every voltage step.

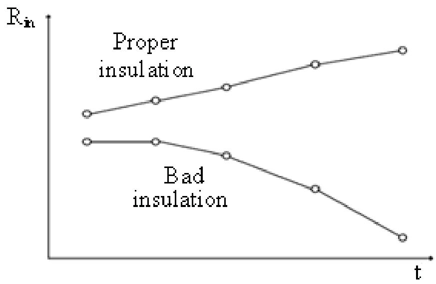

Figure 7: Typical results of the step voltage method

The degree of increase of voltage, the maximum voltage and maximum voltage application time is very important and depend on the test equipment. They are defined in standards. The insulation failure is indicated by the surge current over the preset limits.

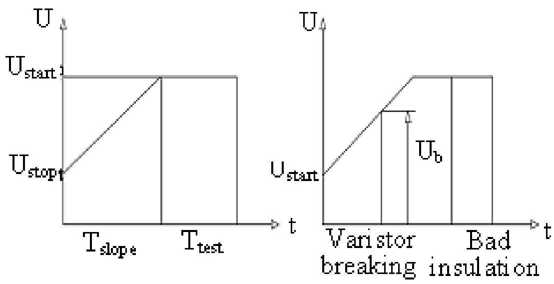

Figure 8: Increased voltage method measuring procedure

This procedure can be realized using two methods:

a) The first procedure is to maintain the voltage a predefined period of time. The device must withstand the stress test without insulation to fail. In this case, the slope of voltage increase should be small enough to prevent damage to insulation. The testing time for a predefined voltage is usually built for one minute and for 2 seconds up to 10 seconds for routine testing

b) The testing at the level of the breakdown voltage of a voltage suppressor. This test is similar to the above one except that the test voltage slowly increases until it damages the test object. For most voltage suppressors the nominal voltage is defined as being accordingly to the Volt-ammeters feature, for a threshold current of 1mA.

4. EXPERIMENTAL RESULTS

The authors conducted the experimental determinations of insulation resistance, on an extinguishing chamber which was the compound of a circuit breaker IUP-M (in = 630 A, A = 12 kV, Year: 1978), of the existing electrical equipment in the laboratory of the Technical University of Cluj.

As stated in the EP-116 normative [6], the measuring of the insulation resistance of parts or subassemblies, mobile and fixed, made of insulating materials, organic or combined, as part of the high voltage primary circuit (the main circuit), is made using a megohmmeter at 2500 V (at least). Minimum value (MΩ) guidance for operating equipment is presented in Table 1.

Insulation class	I	II
3,6-12 kV	1000 MΩ	300 MΩ
17-42 kV	3000 MΩ	1000 MΩ
67-123 kV	5000 MΩ	3000 MΩ
245-420 kV	10000 MΩ	5000 MΩ

Table 1: The insulation resistance minimal values

The manufacturer or user bulletins, regarding the parameters of the insulation, are available at PFI, if they don't exceed six months of the date of issue and there were no conditions for carrying out the commissioning tests. The measurement of the insulation resistance of the secondary circuits and/ or auxiliary low voltage is made using the 1000V mega-ohmmeter. The minimum values of the insulation resistance are:

- 5MΩ at the start-up;
- 1MΩ during the exploitation.

The testing of the insulation of primary voltage industrial frequency in open and closed positions of the switches are made according to the STAS 3686 / 3 and STAS 6669 at voltages indicated in Table 2. The insulation must withstand without flashover and / or penetrations of the insulation and tests must be made at the following moments:

- CI Commissioning instant
- RC at least once in 6 years in the stations and at least once in 3 years in the centrals.

This test must be done for up to 35 kV switches included.

For experimental determinations, the authors have used the MI 3200 TeraOhm 10kV equipment, a Metrel company product of Slovenia, which is a portable test instrument, powered by batteries or from the network and is used for testing the high voltage insulation resistance, up to 10 kV.

U_N [kV]	(3,8)	7,2	12	(17,5)
U_{ch}. [kV]	19	24	31	40
U_N [kV]	24	(30)	(36)	(42)
U_{ch} [kV]	50	58	67	76 k

Table 2: The correlation between nominal voltage and test voltage

The facilities offered by the MI 3200 -TeraOhm 10kV tester are:

- Measuring the insulation resistance up to 10 TΩ;
- Programmable testing voltage between 500V and 10 kV, with steps of 25 V;
- Programmable timer from 1 second up to 30 minutes;
- The tested equipment automatic discharge after ending the measurement;
- The capacity measurement;
- Measuring the insulation resistance according to voltage (step voltage);
- For the testing voltage, the usage of five discreet testing voltage values set as proportionally in the preset domain;
- Programmable timer of the voltage step from 1 minute up to 30 minutes;
- Polarisation index PI $\left(PI = R_{ins}\left(t_2\right) / R_{ins}\left(t_1\right)\right)$, the dielectric absorption ratio DAR $\left(DAR = R_{01min} / R_{15s}\right)$ and the dielectric discharge DD $\left(DD = I_{dis}\left(1\,min\right) / \left(C \cdot U\right)\right)$;

The instrument measures DD when the measured capacitance is in the range of 5nF to 50 µF.

- Continuously testing voltage up to 10 kV;
- Programmable testing ramp voltage from 500V up to 10 kV;
- High resolution ramp (approximately 25 V on each step);
- Programmable edge current up to 5mA;
- Measuring frequency and voltage up to 600V AC/DC;

The LCD type matrix displays the results, and all parameters set and the equipment allows storing the test results. The PC software professional TeraLink allows easy transfer of results and other parameters, bi- directional. The test bulletins can only be printed and it is impossible to save them and change test results.

In the tables below one presents the results of insulation resistance tests, spot testing and the testing voltage in steps.

Location	Function	Date, time
001	INSULATION RESISTANCE	11.Jun.2010, 14:16
Results		Parameters
R = 1.60TOhm, U = 2635 V, I = 1.63 nA, C = 0.0 nF, Rmax = 1.60 TOhm, Rmin = 1.60 TOhm		Un = 500 V, timer =01min00s

Table 3: Determining the insulation resistance for an IUP-M switch

Location	Function	Date, time
004	DIAGNOSTIC TEST	11.Jun.2010, 14:41
Results		Parameters
R = 2.40 TOhm, U = 2631 V, I = 1.09 nA, C = 0.0 nF, R(t1) = 1.25 TOhm, R(t2) = 1.82 TOhm, R(t3) = 2.40 TOhm, DAR = 1.45, PI = 1.31, DD = ____		Un = 2500 V, timer = 04min00s, time1 = 15 sec, time2 = 01 min, time3 = 04 min

Table 4: Determining the polarization index and the dielectric absorption ratio for an IUP-M switch

Location	Function	Date, time
005	STEP VOLTAGE	11.Jun.2010, 14:48
Results		Parameters
R = 66.2 GOhm, U = 2933 V, I = 42.5 nA, C = 0.0 nF, R(Un1) > 1.0 TOhm, R(Un2) = 1.95 TOhm, R(Un3) = ____, R(Un4) = ____, R(Un5) = ____, U1 = 1040 V, U2 = 2094 V, U3 = ____, U4 = ____, U5 = ____		Un = 5000 V, timer = 02min15s, U1 = 1000 V, U2 = 2000 V, U3 = 3000 V, U4 = 4000 V, U5 = 5000 V

Table 5: Determining the insulation resistance using the step voltage method for an IUP-M switch

5. CONCLUSIONS

The Metrel MI 3200 TeraOhm 10kV equipment, from the Electrical Equipment lab of the Technical University in Cluj-Napoca, allows taking the following tests and determinations for the electrical equipments insulation:

● determining the insulation resistance through the "spot reading" method;

● determining the „*polarization index*" (PI), through the „ *absorption test* " procedure;

● determining the „*dielectric absorption ratio*" (DAR);

● the possibility of taking the dielectric discharge test;

● the possibility of measuring the insulation resistance tests with step voltage method.

It is very interesting to notice the facility of portable equipment of the MI 3200 tester, the fast completion of the testing operations and the ease in interpreting results with Tera-link software.

Analyzing the measurements that were taken, presented in tables 3, 4 and 5, we notice:

● the insulation resistance determined through the spot reading method borders within the values imposed by the standards [7];

● the value 1,31 of the polarization index PI, cannot be considered because the insulation resistance exceeds 5000 MΩ, and the value 1,45 of the „*dielectric absorption ratio"* index shows that the insulations of the extinguishing chamber of the automated switch IUP-M is in good shape [8];

● regarding the test using step voltage [9], one can notice that starting with the voltage step of U_3=3000 V, it occurs the phenomenon of breakthrough of the dielectric between the poles of the automatic switch IUP-M.

References

[1] *** Metrel, *Guide for Modern Insulation Testing* Version 1.1, Code No. 20 750 784, Horjul, Slovenia, 2008;

[2] Schump, David E., *Predict Motor Failure with Insulation Testing*, Plant Engineering Magazine, September, 1996;

[3] Zotos, Peter A., Member IEEE, *Motor Failures Due to Steep Front Switching Surges: The Need for Surge Protection User's Experience,* " IEEE Transactions on Industrial Applications, Volume 30, Number 6, Nov/Dec 1994;

[5] *** Metrel, TeraOhm 10kV MI 3200 *User Manual* Version 2.2 Code No. 20 751 097;

[6] PE 116-94 Normativ de incercari si masuratori la echipamente si instalatii electrice;

[7] IEEE 43-2000: *Recommended Practice for Testing Insulation Resistance of Rotating.*