EDAIII: STATOR INSULATION DIAGNOSIS & PREDICTIVE MAINTENANCE

A. Tabernero* and B. Batlle*

***UNITRONICS, S.A. Spain**

DC STEP VOLTAGE TEST

Since publication of IEEE Std 62-1958, DC step voltage test has been well established in several European countries (France, Spain, Italy…) in order to gain insight into the insulation of the stator in medium and high size rotating machines. This test was usually performed in a manual mode connecting different instruments to a computer and was quite dependent on user ability.

From a R&D project started in Spain around 1993 between the companies Unitronics and Iberdrola (Spanish utility), a standard test system named EDAIII has been designed and developed for stator insulation's Diagnosis and Predictive Maintenance. This technique is based on the off-line DC Step Voltage test (guided today in IEEE 43-2000 & IEEE 95-2002) not only checking Insulation Resistance and Polarization Index, but integrating a number of extra parameters that can clearly define the status of a machine's insulation in order to have confidence in its service performance after each test.

Test description

The scope of this test is mainly to check the insulation in rotating machines above 1kV with form wound coils, where diagnostic criteria are clearly defined and demonstrated. It can also be used below that rating, but in this case there are no standards and the user would have to define diagnostic ranges from his experience and particular machines.

The dielectric in a rotating machine can be represented as in Figure 1. There, Cg is the geometric capacitance of the windings, Ri the insulation resistance and Rax/Cax stand for the equivalent circuit of the absorption behaviour inside the dielectric.

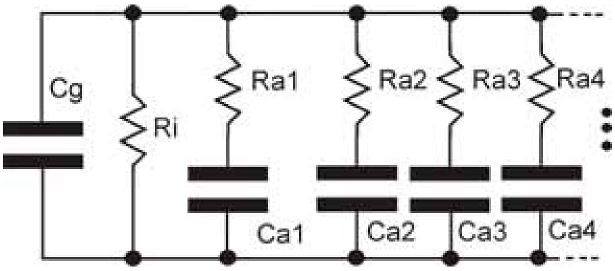

Figure 1 Equivalent diagram of a stator insulation.

The purpose of this test is to evaluate the main characteristics of the insulation based on this equivalent diagram.

The EDA test is a high voltage, direct current, off-line test, usually named Step Voltage Test. The test for each machine has become standarised in timing and the procedure is as follows:

- Environmental measurements (temperature and humidity).
- DC and AC (1KHz) insulation capacitance measurements.
- First DC Step. Usually 2.5kV or half the second step voltage value. Voltage and currents are measured during the 30 minutes charge period. After, there is a 2 minutes short circuit period and current is also measured.
- Second DC Step. Usually 5kV, depending on the machine rated voltage. As previously, voltage and current are monitored during the 30' charge and 2' discharge periods.

The way to perform each one of the steps is explained in Figure 2. The unit is basically composed of the following elements: DC power supply, the interruptors for load (S1) and discharge (S2), and the current meter (nA). The insulation under test is represented on the right hnd side. In each step, first S1 is closed and S2 open while the 30 minutes load period. After that, S1 opens and S2 closes to continue the 2 minutes discharge period.

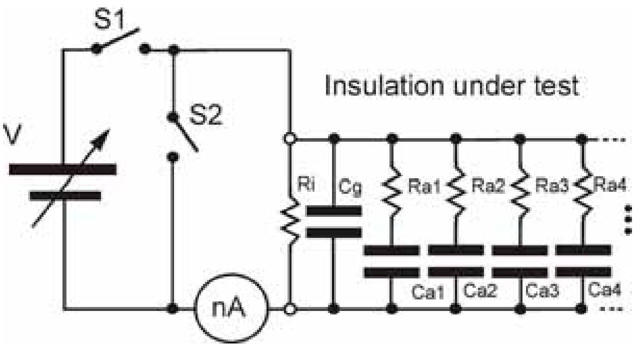

Figure 2 Diagram of the test circuit.

During the different periods, the current flowing through the insulation is monitored and evaluated. The change in the current (I_T) during the charge period is shown in Figure 3, where: $I_T = I_C + I_A + I_G + I_L$.

- I_C (capacitive current) is supplied to charge Cg. It is very high during a very short time period and disappears after a few miliseconds.
- I_A (absorption current) will depend on the Rax/Cax configuration. It is really important in order to learn about the internal state of the insulation.
- I_G (conductance current) represents the conduction through the solid (groundwall) insulation.
- I_L (leakage current) corresponds to the current flowing in surface paths.

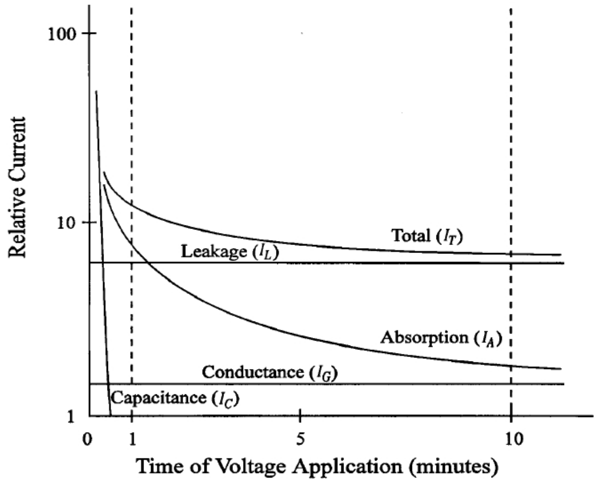

Figure 3 IEEE43-2000 plot for DC test currents.

During the discharge period (Figure 4), the system establishes a short-circuit, grounding the phases and we observe a re-absorption current that is exactly the same as the absorption one but in the opposite direction.

The machine condition is assessed from the change in those currents and the resulting parameters extracted from them.

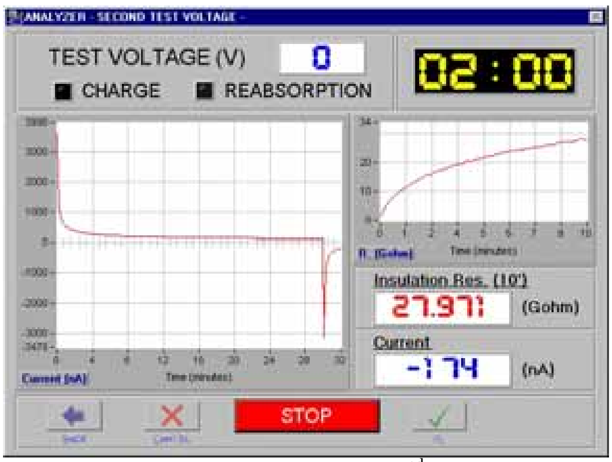

Figure 4 EDA measurement screen (2nd test voltage).

Why proceed this way?

- **Environmental measurements** allow comparison between different test made during machine's life. It is proved and accepted that currents are very dependent on temperature and also on humidity. Temperature tables are used to correct and normalize insulation resistance readings. Unfortunately, we cannot make the corrections on humidity as there are no rules, but at least this data is used to have an idea of the test validity.

- **DC & AC (1kHz) capacitance** measurement will help us to learn about pollution deposits on the insulation. It is based in the fact that the equivalent circuit of the insulation within a polluted machine changes as we can see in Figure 5. There, L1,L2… are the inductances across the complete winding with their corresponding extra contamination capacitances Cw1,Cw2… The contamination actually "enlarges" the plates of Cg and thus can be evaluated. When DC capacitance is measured, the inductances Lx behave like shortcircuits and the extra Cw contamination is added to Cg. When high frequency AC capacitance is measured, Lx becomes open circuit because of the high frequency and contamination is neglected. So the ratio between both capacitances gives a clear indication of the contamination on the solid insulation.

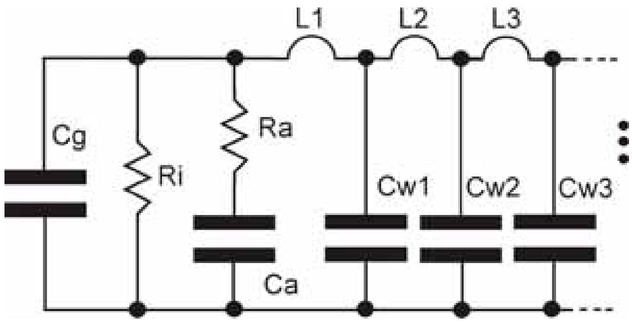

Figure 5 Equivalent diagram of a stator insulation including contamination effects.

- **Time standarising** provides a better comparison of the results between different machines or in the same machine but in different time, to perform trending analysis.
- **Two different test voltages** help to check the insulation linearity with voltage. If the insulation is in good condition, there should not be significant changes with voltage.

Parameters and their meaning

The different parameters extracted from the test and later used to diagnose the machine are as follows:

- **Insulation Resistance (IR)**. Is the ratio between test voltage and current flowing after 1minute applying the voltage step. It depends on the temperature and must be corrected (normalized) to a reference one. The value should be above a minimum depending on rated voltage and running hours of the machine.
- **Polarization Index (PI)**. Is the ratio between the flowing current after 1 minute and after 10 minutes.

It indicates the moisture and dirt level. The dependance on temperature is lower.

- **Capacitance Ratio (CRatio)**. This shows the difference between AC and DC capacitances as a percentage. Together with PI, it indicates the nature of the detected contamination, either moisture or simple contamination.

Figure 6 Example of contamination with oil detected with EDA system.

- **Absorption Index (AI)**. This is the ratio between the current during the dielectric absorption period after 30’’ and 60’’. This parameter together with PI and CRatio can indicate if detected problems are internal or external.
- **Time Constant (TC)**. Is the product of IR@2minutes and CAC (1kHz). It monitors insulation condition and ageing.
- **Reabsorption Current (Ir)**. This is the current 1 minute after the start of the reabsorption period, normalized in capacitance, voltage and temperature. It indicates the internal binder’s quality. High values when it’s thickness normalized also indicate internal lack of homogeneity within the insulation.
- **Leakage currents ratio (LCR)**. This ratio takes into account currents from second and first test voltages after the 30 minutes charge period. It searches for non-linearities leading to problems in endwindings.
- **Ratio I leakage / I reabsorption**. Can indicate transversal currents.

Scope

Most critical Machines from Iberdrola (Spanish Utility with long tradition in predictive maintenance) are tested with this system. Tests are also performed in key machines from other electric utilities (Endesa, Union Fenosa), Industries (Arcelor, Atlantic Copper, Repsol, Air Liquide) and workshops (ABB, Fejima, Tresa, GE…) and enters as a growing standard even in Europe and the rest of the world. Today, there are close to 100 systems operating worldwide.

Experience

Thanks to data taken from standards, empirical testing and utilities experience, the system has been completed with an expert diagnose software application. This can give the information about degradation for the tested machine (usually any kind of rotating machines above ~1kV) from the measured parameters.

System Implementation. EDAIII

The system implementation is shown in Figure 7. The unit is mains powered, has a serial port for computer connection and only two high voltage cables going to the tested machine. In addition, a warning lamp indicates when high voltage is applied for user safety.

Figure 7 EDAIII system implementation.

The software generates its own database with all the tests performed in every machine. Furthermore, all the steps are fully guided to allow any kind of user, skilled or not, to perform the test.

The unit complies with all European directives and it’s CE certified by an independent laboratory. Hardware and software have been improved thanks to several years of field-testing and in harsh industrial environments.

Diagnosis and Trending

The diagnosis can provide evidence humidity, contamination, aging, surface currents or degradation, and it also differentiates from internal to external.

Diagnosis procedure is made in three steps:

- First, the machine is tested for reversible problems: these are the problems that can be corrected with relative simple works. That means cleaning, drying, curing…
- After reversible problems are solved, the machine checks for irreversible problems. This is equivalent to knowing how aged the insulation is, and assesing its remaining life.

- The last step is to use the trending tools to have a look into the remaining life of the insulation of the machine.
- If this sequence is not followed, reversible problems can mask irreversible ones and lead to an ambigous diagnosis.

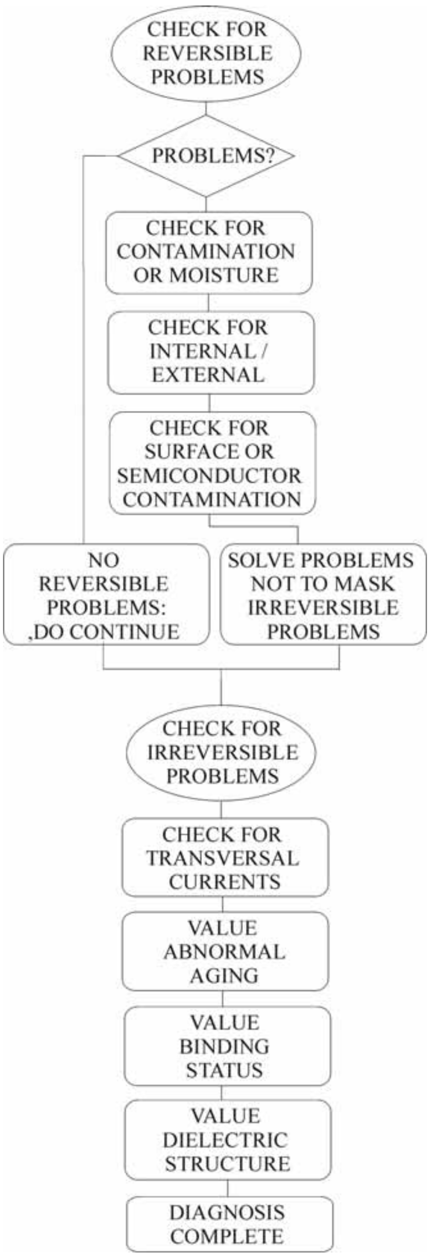

Figure 8 Diagnosis sequence.

Parameters to diagnose must be adapted. This means that some values have to be normalized regarding temperature or insulation width. Other parameters will depend on the running hours of the machine, so this data has to be taken into account.

Actually, the parameters used for diagnosis are those coming from the second test voltage (higher voltage), because they will give a better indication of the insulation problems as the insulation is more stressed and currents are measured with best resolution.

Diagnosis of the test results.

Users from EDA system might acquire experience in diagnosis in 4 different ways to become familiar with this kind of test. Each user chooses his own approach.

- **By themselves**. Personal experience testing with the EDA system in several machines and situations will give knowledge and allows users to establish diagnose criteria.
- **Software**. Additional software has been developed to help the system users to better diagnose the machines. Software indicates (figures 9 and 10) the diagnosis with a series of color indicators for each one of the potential degradation ways of the insulation.

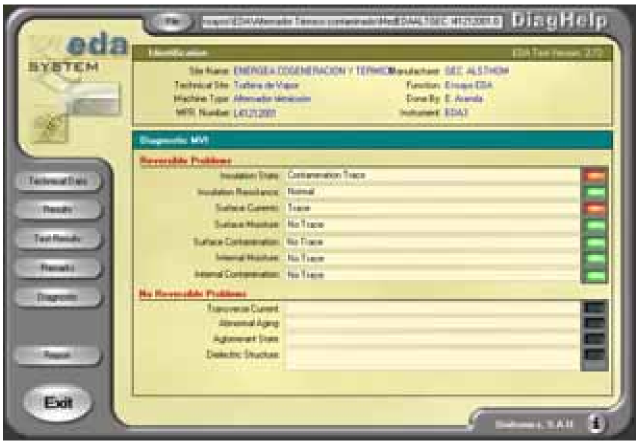

Figure 9 DiagHelp software shows contamination.

Figure 10 The same machine diagnosed after cleaning.

- **Training**. Long time experience allows Unitronics to perform expert training to learn through real cases to diagnose any machine. It is also a way to share the experience with other EDA users.

- **Trending**. The best approach in predictive maintenance of stator insulation is always to analyze the evolution of the different parameters in time. This will allow users to identify the degradation rate, the parameters evolution and act in consequence reducing test intervals, scheduling maintenance works (Figure 11) or determining a safe end of life of the machine.

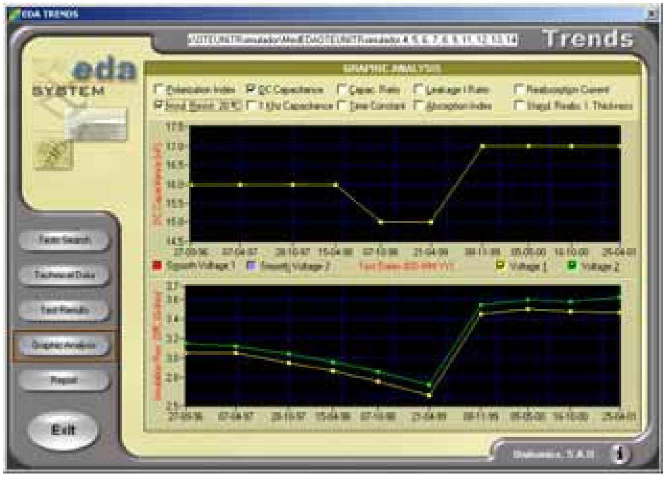

Figure 11 Trending EDATrends software.

References

1 Manés Fernández Cabanas, Manuel García Melero, "Técnicas para el mantenimiento y diagnóstico de máquinas eléctricas rotativas" ABB Service, S.A. Marcombo 1998, pp235-248.

2 Óscar Duque & Marcelo Pérez, "Motores de Inducción. Técnicas de Mantenimiento Predictivo". Abecedario Sept. 2005, pp248-150.

3 Emilio Sierra, "Mantenimiento del bobinado estatórico de MT basado en el estado. Método EDA" Magazine Mantenimiento, No.146, Julio-Agosto 2001.

4 Luis Odriozola Arteaga, "Evaluación del estado del aislamiento en bobinados de máquinas eléctricas rotativas" Anales de mecánica y electricidad, Enero-Febrero 2004, pp26-33.

5 Joan Puigmal Pairot, "Diagnóstico del estado del aislante en grandes máquinas eléctricas rotativas mediante el estudio de la capacidad del bobinado" Magazine Mantenimiento, No.81 Enero-Febrero 1995. pp31-36.

6 Salvador Carreras. "Mantenimiento predictivo en los devanados de las máquinas eléctricas rotativas de alta tension" Magazine Mantenimiento, No.119, Noviembre 1998, pp13-22.

7 IEEE Recommended Practice for Insulation Testing of AC Electric Machinery (2300V and Above) with High Direct Voltage, IEEE Std 95-2002.

8 IEEE Recommended practice for Testing Insulation Resistance of Rotating Machinery. IEEE Std 43-2000.