Experience in Off-line insulation testing and diagnosis of high voltage rotating machines

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1. Introduction

The high voltage rotating machine (motors and generators) is a major component in a power system and its proper functioning is vital to system operations. During its entire operational time, the high voltage rotating machine has to withstand numerous stresses such as thermal, electrical and mechanical. This generally results in degradation of the rotating machines insulation system. Rotating machine failures are sometimes catastrophic and almost always include irreversible internal damage. Therefore, it is necessary to closely monitor their insulation condition.

This paper describes experience Central Electrical Laboratory (CEL) of Israel Electric Corporation has in off-line stator insulation testing of high voltage rotating machines. The implementation of a tool for the diagnosis of faults is based on analysis of test results.

Diagnosis of the condition of HV insulation is based of the following tests [1]:

- insulation resistance (R) and polarization index (PI) measurement;
- dielectric dissipation factor (DDF) and capacitance (C) measurement;
- partial discharge (PD) measurement and corona detection ;
- applied high voltage testing

The recorded results are used for estimation of the insulation condition of electrical machines and for operation and maintenance recommendations.

KEYWORDS
Rotating Machines, Dielectric Dissipation Factor, Partial Discharge, High Potential Test.

2. Types of tests

2.1. Insulation resistance (IR)

The insulation resistance of a machine winding depends on the type of insulating material and on the condition of that material. As a rule, insulation resistance is proportional to insulation thickness and inversely proportional to the surface area of the conductor.

Resistance values are affected by contamination, humidity, temperature, and other factors. Low values may point to moisture ingress, dirt or damaged insulation. In order to measure phase-to-phase insulation, the phases of the machine should be disconnected and each phase of the winding tested separately.

By periodic checking and recording of values, a good basis for judging condition of the insulation can be built. Even if readings are higher than minimum suggested safe values for that machine, a constantly downward trend should be treated as a warning of need of maintenance. Results close to suggested minimum values may be considered satisfactory, provided that these values are constant over a number of periodic checks. Care should still be taken with machines with insulation readings nearing their minimum.

2.2. Polarization index (PI)

The state of insulation between the conductor and ground can further be determined by the Polarization index test. This test gives the ratio of the insulation resistance at 10 minutes to the value at 1 minute. Should the ratio be 2 or higher, then this should be taken as a sign that service is required.

Moisture and contamination of the winding and sometimes also thermal aging are indicated by the PI test. Very low and very high values are cause for concern and indicate an insulation system that requires further investigation. Depending on what type of insulation has been used, Low PI values might point to the need for drying out or cleaning of the machine, whereas windings near the end of their useful lives may give very high values. In order to identify possible problem areas, PI values between phases should be compared.

2.3. Dielectric Dissipation Factor (DDF)

The dissipation factor test measures the insulation condition using alternating current techniques [2] by application of test voltages less than or equal to the rated voltage of the test object. The test is useful in determining overall machine integrity when used in conjunction with other inspection activities. In order to measure phase-to-phase insulation, the phases of the machine should be disconnected and each phase of the winding tested separately.

2.4. Capacitance

Surface contamination of the winding insulation, increased humidity and temperature are factors which may cause capacitance to ground values to increase with time. The accumulation of moisture, dirt and conductive contaminants on the stator insulation will also cause changes in winding insulation capacitance, resulting in higher capacitance values. Degradation of the layers of corona protection may also cause a decrease in capacitance. Testing is used to build up a basis for comparison and for constructing trends.

2.5. Partial discharge (PD)

Wherever internal de-lamination, surface or slot discharge in electrical winding insulation occurs, PD activity may take place resulting in significant deterioration of insulation over time. PD measurements are used for assessment of the condition of complete windings as well as of individual form wound coils and bars – particularly useful in machines rated above 3kV, where PD can also give an indication of deterioration of external slot or end arm surfaces.

2.6. DC high potential

The DC high potential test is a pass/fail test with respect to integrity of insulation but is also a trending test, which detects moisture and contamination issues and is conducted by applying a DC voltage to the winding relative to the frame. In order to measure phase-to-phase insulation, the phases of the machine should be disconnected, untested phases grounded and each phase of the winding tested separately. Examining the results of leakage current versus voltage will yield information on relative winding

condition.
The leakage current depends on ambient moisture and surface contamination; therefore, this test detects moisture or dirt on the windings. If a DC test is used, the test voltages should be those values recommended for AC testing multiplied by a factor of 1.7.

2.7. AC high potential
The AC high potential test is a pass/fail test used to evaluate the condition of insulation and it should be noted that each time the AC high potential test is performed; the potential consequence is a winding failure.
New and rewound machines should have an AC high potential test of twice-rated terminal voltage plus 1 kV applied to them. When the machine is repaired and the winding is not involved, a reduced AC over voltage test may be performed prior to the commencement of works and again after completion of works. In the case of failed windings, where insulation is replaced or a partial rewind is performed, a reduced voltage final test may be used.

3. Test methods and test results

3.1. Insulation resistance and polarization index measurement.
For Insulation resistance and polarization index measurement, CEL uses the Megger S1-5010 Insulation Tester. For rotating machines with a rated voltage of 3.3 kV, the applied test voltage is 2500 V. For rotating machines with rated voltages above 6.6 kV the applied test voltage is 5000V.
Resistance and PI tests are performed simultaneously in an automatic mode.

Example 1
Motor data: 6600V 1250 HP. The motor was put into operation in 2000.
During periodic testing, very low values of insulation resistance and high value of DDF were obtained. It should be noted that the motors are located near the sea and the heating elements of the motors worked properly. After heating the motors from an external source, the value of insulation resistance increased, but immediately after turning off the heating for a short time dropped to a low value. Based on this data, impregnation of insulation was recommended. The one motor was removed for repair. During inspection in a repair shop, it was discovered that there was in fact weak impregnation of the winding insulation. Impregnation was carried out and additional heating elements were installed on the motor. There was a significant improvement in insulation test values and the problem was solved. A similar repair was performed on the remaining motors of this type.

3.2. Dissipation factor and partial discharge measurement.
For DDF and PD measurements, CEL uses the Mobile Insulation Diagnosis & Analyzing System MIDAS 2881 (Haefely Test AG), and the partial discharge detector ICM system (Power Diagnostix System GmbH). A resonance reactor is used in parallel for compensation of high capacitance in large rotating machines.
The software allows the test engineer to simultaneously perform both measurement and record all necessary parameters.

Example 2
Motor data: 11500V 20000 HP. It has been periodically tested since 2000.
The picture below shows the trend of PD activity with time. It is clear to see the increase in PD activity (Fig.1).

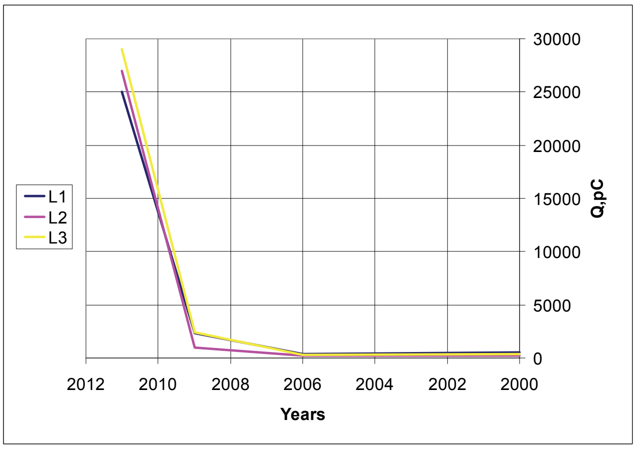

Fig. 1 PD activity trend with time

The picture below also shows the trend with time of DDF f (U) (Fig.2).

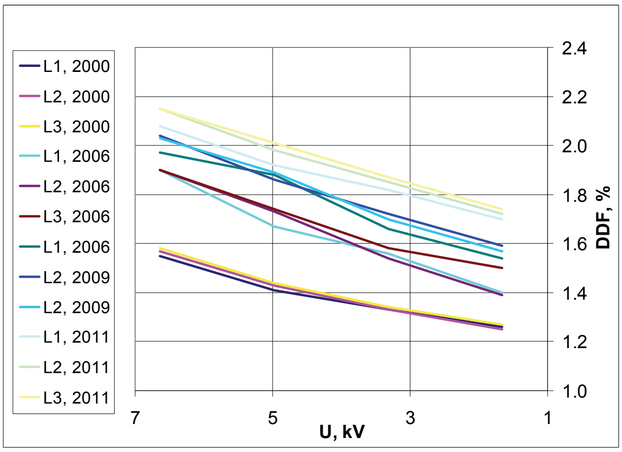

Fig. 2 DDF f (U) trend with time

There is a direct correlation between PD activity and DDF.
For PD localization, CEL uses the ultrasonic sensor UE 200 (UE system) and the UV detector Daycor (OFIL Ltd). This test was performed on open stator.

Example 3
Generator data: 22500 KVA, 11000 V
During periodic testing, high levels of partial discharge were recorded in one of the phases. An additional PD test was recommended with an ultrasonic sensor. During this test a strong discharge between winding and stator core was discovered. The reason for the problem was the destruction of the semiconductor layer (corona protection). Rewinding of the stator was recommended. At the pictures below shows PD pattern (Fig. 3).

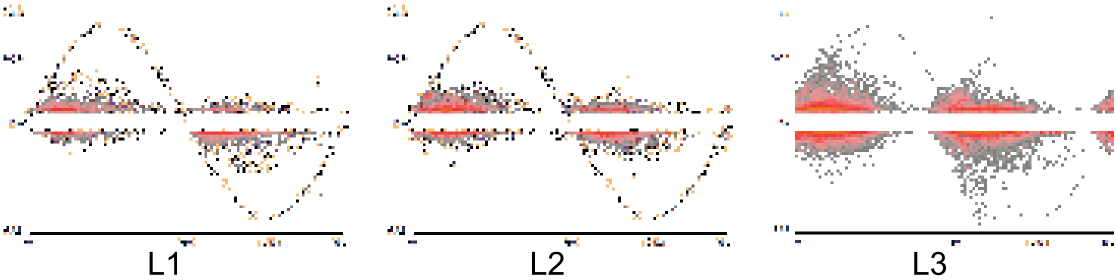

Fig. 3 PD pattern

The picture below, taken by a burrowscope, shows destruction of the corona protection layer of the stator coil (Fig. 4).

Fig. 4 Destruction of corona protection

Example 5
Generator data: 133750 KVA, 11500 V
In the course of periodic testing, Corona tests were carried out to locate corona discharge on generator windings at nominal voltage. During Corona testing, points of discharge were found. The generator was repaired by the manufacturer. Isolation was strengthened with resin impregnated glass tape. Corona discharge disappeared after repairing. The pictures below shows PD picked up with aid of a UV camera (Fig. 5).

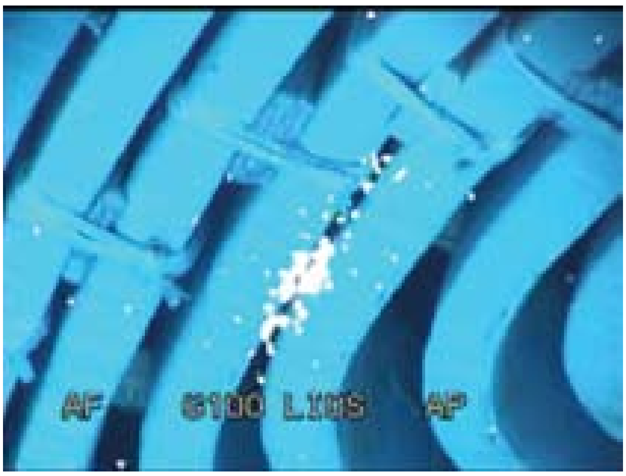

Fig. 5 Corona detection by UV camera

3.3. Applied high voltage testing

Mainly in CEL, all HV testing is performed at AC up to 50 KV, by using an HV compensation trans-reactor, which allows the use of a low consumption power supply. The test circuit includes: regulating transformer (1), trans-reactor (2), test object (3), voltmeter (4), ampere-meter (5) (Fig.6).

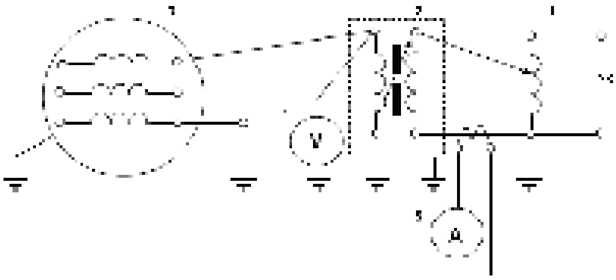

Fig.6 AC High potential test scheme

In the case of special requirements from the client, it is possible to perform DC high voltage testing for leakage current measurement. For this propose CEL uses the DC Dielectric Test Set 70 kV (Biddle).

3.4. Special test

The Partial Discharge test, in a traditional sense, performed at the phase voltage, does not allow testing of the insulation between phases in full, as the applied voltage is 1.7 times less than the true voltage. By applying line voltage, phase to ground insulation is subjected to additional stress, because the applied voltage is 1.7 times larger than the true voltage and that increases the risk of insulation breakdown.

Therefore, our laboratory has developed and implemented a three-phase scheme for measuring partial discharge, which approximates the testing conditions to be as close as possible to real working conditions. This KIT includes a three phase regulating transformer and 3 HV trans-reactors with an adjustable core gap, to regulate the inductance. This scheme allows the application of three phase voltage to the rotating machine with compensation for the capacity of the test object. This scheme also allows the testing of 3-Phases simultaneously, thus shortening the overall testing time.

The test circuit includes: regulating transformer (1), trans-reactor (2), test object (3) (Fig.7).

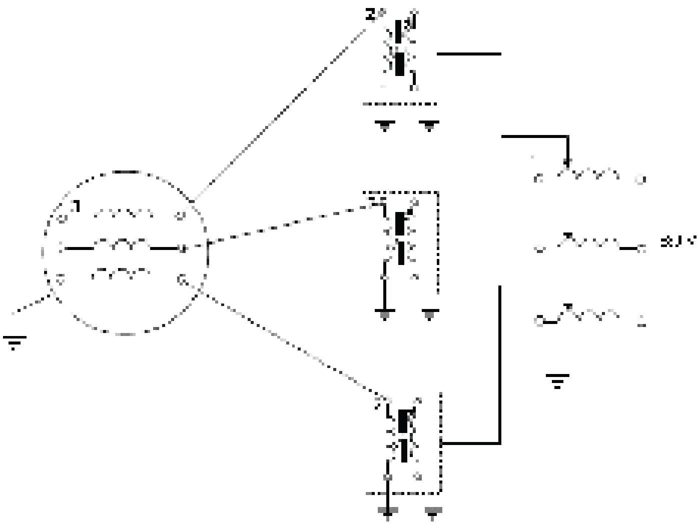

Fig. 7 Three-phase scheme for PD measurement

4. Conclusion

4.1. Comprehensive testing of insulation condition yields more information, so as to be better informed and make the right decision.
4.2. Timely periodic checks can identify problems and prevent the breakdown of the insulation.
4.3. The use of additional diagnostic tools, such as US sensor and UV camera, reduces repair costs and costs of unplanned outages related to equipment failure.

BIBLIOGRAPHY

[1] IEEE Std 1415-2006 IEEE Guide to Induction Machinery Maintenance Testing and Failure Analysis.

[2] IEEE Std 286-2000 (R2006). IEEE Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.

Anatoly Shkolnik was born in Ukraine on 1950. He received his M. Sc. degree in electronic engineering (dielectrics and semiconductors) from the Kiev Polytechnic University (Ukraine) in 1973 and Ph.D. in electrical engineering (electrical stations, electrical machines) from Electric Power Research Institute (Moscow, Russia) in 1990. He has experience in production, repair, testing and diagnosis of the HV equipment. Now he is senior specialist of the Central Electrical Laboratory in the Israel Electric; regular member of CIGRE SC D1- “Materials and Emerging Test Techniques”

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