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A REVIEW OF THE EXPERIENCE IN TESTING OF HIGH VOLTAGE GENERATORS

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Abstract

The convenience of testing the high voltage machine insulation is well known. Test methods used in our country for determining the state of degradation of the insulation are presented with results gathered during three years of experience. The data obtained from measurements on ten machines of different types are presented and analyzed according to international standards and practice. A standardized routine of nondestructive measurements is carried out in twenty machines under the management of our company.
Also some tests were made on machines that are already due to refurbishment. Destructive tests were performed on these machines to find out the real state of their insulations and to check the security margin given by testing worldwide practice.
Data from measurements before and after a small repair of the stator winding of one machine is presented. The level of partial discharges increased after the repair. It is shown that some techniques used for repairing a winding are not always a good practice.

Introduction

For a long time utility engineers have been interested in high voltage ac and dc testing of generators. Researchers have concluded that a single test is not enough for determining the condition of the stator winding insulation. Only the combined results of different testing methods are useful. One way of reducing the risk of an accident is to keep a maintenance schedule of nondestructive tests. In this way, generator operators expect to recognize damaging conditions at a very early stage. Also this maintenance schedule can help in delaying the decision of machine refurbishment reducing the financial cost of the operation.

Many methods have been developed for testing stator winding insulation with ac and dc high voltage. These methods are widely described in many publications and standards [1,2]. The dc high voltage tests are interesting because of the low volume of the needed equipment. Yet, the results of these tests are affected by moisture and surface contamination on post insulators at the machine output. The ac tests reproduce the in-service conditions of the windings but they require a larger equipment. Researchers have invested much time in developing adequate methods considering its limitations and the risk of puncture during the tests.
These tests are made individually on each phase of the generator or on the three phases at once. DC high voltage tests take between one and three days depending on the method used. AC high voltage tests take only some hours so the machine can quickly go back to service. Generally, the generator is taken off service the night before the tests. Only some covers are removed and the bars are disconnected as near as possible to the bushings. During the day the tests are made and after some hours the covers are replaced. The bars are connected and the machine is again in service by night. During longer planned outages it is possible to make dc-high-voltage tests. The stator winding is grounded the night before and the test takes one day per phase. This time can be reduced using other methods that do not consider the effect of residual currents caused by the charge of the dielectric.

DC high voltage tests

In this category of tests we perform polarization index, insulation resistance and the controlled overvoltage test or step voltage test. For these tests a very stable high voltage source up to 30 kV dc is used. The stability of its output voltage is 0.01% in 30 minutes. Generators with insulation class B and class F are tested, with polarization index ranging from 3 to 8 in normal conditions. Our common practice is to use the method recommended by EDF [1] for the step voltage test. This method considers the effect of residual absorption currents in the stator insulation. Consequently, it requires important calculation that must be done during the test. A computer program was developed to help technicians in the calculations and to make the right choice in as when to stop the test.
Another method proposed by IEEE [2] does not consider the residual absorption currents and so is simpler. However, differences between the results obtained by both methods are significant.

AC high voltage tests

The measurement of the capacitance and dissipation factor, is according to the method described in ASTM [3]. A self designed bridge based on an inductive voltage divider, is used. For the partial discharge test, a broadband capacitive coupler and a filter are used. The system bandwidth is 300 kHz and the measurement of the peak discharge is done with an oscilloscope. Also, new digital techniques to diagnose the insulation state, were developed [4] using a cheap digital oscilloscope working in the peak detect mode. A computer program was developed to transfer the data acquired to a PC and process data off line.

Generators operated by our company

Hydraulic power plants

There are three plants on the "Negro" river which halves the country. It is a flat land river with a nominal average flow rate of 550 m^3/s. Going downstream there are three plants which technical data is shown in table I.

Table I
Technical Data of Hydraulic Plants

		"Gabriel Terra"	"Baygorria"	"Constitucion"	"Ameghino"
number of generators		4	3	3	2
manufacturer		Alsthom-Jeumont	Siemens-Schuckertwerke AG	General Electric SA	CGE (Italy)
type		4 VG 40 MVA	SPFL 780/40-76	ATI-W68-111	-
power factor		0.95	0.95	0.9	0.8
class		F	B	B	B
power (MVA)		40	36	111	29
voltage (kV)		13.8	7	15	13.2
current (A)		1.673	2.970	4.276	1.600
frequency (Hz)		50	50	50	50
speed (rpm)		125	79	88	250
overspeed (rpm)		330	260	231	550
MD^2 (tm^2)		6.040	14.000	39.000	1.100
excitation	current (A)	719	629	780	620
	voltage (V)	244	378	270	220
rotor	Φ (mm)	7.480	9.240	10.846	4.100
	h (mm)	966	1.500	1.727	-

Our company also operates and maintain a hydraulic plant in Argentina, "Ameghino" which technical data is also shown in table I.
In two machines already due to refurbishment, destructive tests were done to verify the effectiveness of the security margins adopted when testing. In some phases the step voltage test was done raising the dc voltage up to 4 times the nominal voltage of the stator. The current measured reached reasonable levels and there was no puncture up to that level. In other phases ac voltage was applied up to twice the nominal voltage (30 kV, 50 Hz), between phases and earth. At this level, only arcs in the end of windings occured, but there was no puncture in any bar.

Although these machines were due to refurbishment as part of a renewal schedule of the whole plant they withstood the electrical stresses of the overvoltage in both tests. Clearly the security limits during tests (up to twice in dc and 0.8 the nominal voltage in ac) are adequate and represent a minimum risk to the insulation subjected to tests.

Thermal power plants

There are 3 thermal power plants in the country. All the machines are fossil fuel-fired. A new combined cycle plant of 400 MW is being designed to operate with natural gas, that come from Argentina. This plant is intended to increase the thermal backup of the country.
The most important is "Central Batlle" with four turbogenerators. The larger machines have 88 MW and 156 MW. In 1992 there was an explosion and fire. As a result one of the machines was seriously damaged and another was affected by dust and smoke. In 1995 the most affected machine was back to service. The mayor repairs involved mechanical areas. The stator winding was tested before the repair to have a reference of its condition, and only some large partial dischages were found in one phase. The tests were done by the same company that repaired the station. The repair consisted in repainting the conductor and semiconductor layers and applying an insulating varnish finish at the end of the windings. The painting begins at the output of the magnetic core.
Afterwards the tests were repeated. The level of partial discharges in the phase mentioned before had a small reduction but still was high. On the other hand, the level in the other two phases increased up to the same level of the first one. In table II the values of partial discharges and tg δ before and after the repair are shown. After analyzing the painting method it was found that one possible cause for the increase of PD and Δ tg δ, could be that not all the insulation varnish paint was removed, and isolated conducting layers appeared. The PD level was not possible to reduce in successive repainting. Although the level of PD was higher than before, the machine was put back to service but the warranty period was increased to three years, and periodic tests were arranged. In the last test (1996) the level of the PD was reduced, but it may be because the hydrogen pressure was higher than before.

Table II
Results Before and After Repair

	phase	before repair	after repair
PD (nC)	U	135	126
	V	54	180
	W	40	144
Δ tg δ	U	2.9	3
	V	2.6	4
	W	2.7	4

There is another power plant "La Tablada" with two generators. It was built in 1992. Recently, ac tests were done on one of the generators with very good results. The partial discharge level is about 5000 pC and Δ tg δ is about 0.2 in all phases. In this machine digital methods were used for the acquisition and processing of partial discharges.

During 1997, the testing schedule includes a large number of generators and HV large motors. A machine rewound in 1983 by local technicians, is also included by the first time. In table III the results of the tests performed during the last three years are shown.

Table III
Results of Tests

test	min	max	median
polarisation index	1.9	11.2	3.1
1 min insulation resistance at 40 °C (Mohm)	112	1.500	260
discharge current at 20 °C (A/kV.F)	.20	2.06	1.4
step voltage test	2.8	4.7	3.6
tg δ ($x10^{-3}$) at 0.2 U_n	26.2	46.2	32.0
Δ tg δ ($x10^{-3}$) ($0.6U_n$-$0.2U_n$)	.3	2.2	1.2
PD max (nC)	25	180	25

Conclusions

Our company will keep the test schedule and the maintenance program specified by manufacturers and our own experience. Plant operators are understanding the importance of regular testing of the machines and the results obtained so far are used to decide the renewal of old machines. Up till now our machines have been tested once every eighteen months in average. All the results obtained and techniques used are shared with other companies in the region. Our intention is to globalize the experience. The same standards and methods are used so as to compare results. It is important to have access to results of tests previous to contingencies or accidents. Many efforts on research have to be done to use all this experience to determine the expected life of machines and help to find the limit of reliable operation. Different test methods used in our country, were described. They follow international practice so that the results can be compared to the ones from similar machines.
Several cases have been described ranging from new machines to destructive testing in machines already due to refurbishment. The test voltage applied was raised up to more than twice the nominal voltage of the machine without a failure. We verified the security limits specified in the standards.
A case of a repair showed that some repair techniques used are ineffective.

References

1. Electricité de France, EDF Ref. PA/AAI/LL
2. IEEE std. 95-1977
3. ASTM std. 382-75
4. Jorge Fernández, Walter Mandl, Daniel Slomovitz, "Digital techniques for partial discharge measurements in utility generators", Maintenance and Refurbishment of Utility Turbogenerators, Hydrogenerators and Large Motors, CIGRE and EPRI, April 14-16 1997, Florence, Italy.