CIGRE ROUND ROBIN POLLUTION TEST FOR POLYMERIC INSULATORS: RESULTS IN FOUR HIGH-VOLTAGE LABORATORIES

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Abstract: There are presently no standardized artificial pollution test methods available for the testing of polymeric insulators. At the same time, utilities and manufacturers often need to determine the insulation performance of polymeric insulators under polluted conditions due to their increased use in service. Analysis of service and field experience led to CIGRE recommendation for modified version of the Solid Layer test with two options, i.e. “worst” and “intermediate” hydrophobicity case. CIGRE Working Group C4.03.03 made a proposal for the Round Robin Test (RRT), i.e. very strict test program to be used by a number of HV laboratories in the world to check the reproducibility of the test. More than 10 laboratories all over the world are participating in the RRT and four of them have already finished testing. The developed procedures comprise three steps: preconditioning; application of the pollution layer; the flashover test by “up-and-down” test method. The results of the tests were consistent, i.e. reproducible.

1 INTRODUCTION

At present there are no standardized artificial pollution test methods available for the testing of polymeric insulators. At the same time, utilities and manufacturers often need to determine the insulation performance of polymeric insulators under polluted conditions due to their increased use in service.

According to [1], the practically used modified procedures for Solid Layer (IEC 60507) testing of polymeric insulators are similar for laboratories in China, Russia, South Africa and Sweden. This can be advantageous from the standardization point of view due to:

- Several laboratories (countries) already have positive experience of the similar type of procedure
- Applied procedure is valid to simulate the flashover mechanism or process in actual service conditions
- Applied procedure is considered as relevant and practically applicable
- Further, as stated in [1], the repeatability of the procedure (in the same laboratory) is good.

However, until now there were no information on reproducibility of the Solid Layer pollution test method (sometimes called Clean Fog test) when applied for polymer insulators and, especially, for silicone rubber insulators. The reproducibility means the ability to obtain the same result when the test is performed in different laboratories. The ideas for such test method were implemented in the recently published CIGRE Brochure [2], where it was stated the follows: *“From some published proposals and information a recommended modified version of the Clean-Fog Test is outlined below in which the various cases-- from “worst” through “intermediate” to “best”--can be determined by increasing the elapsed time between the insulator being polluted to it being tested.”*

These CIGRE ideas were recently transformed by CIGRE WG C4.03.03 into the practical program for the so-called Round Robin Test (RRT). Thirteen high-voltage laboratories from Europe, Asia, North and South America volunteered to participate in this program as well as two manufacturers, which provided test objects. The program will be finished in the beginning of 2012, however four laboratories have already completed the tests and these results are presented and discussed below.

2 TEST METHOD

2.1 General

It will be advantageous to use the existing Solid Layer pollution test method prescribed by IEC 60507 with slight modifications needed for the application of pollution for polymeric (composite) insulators. Thus, the developed procedure should include pre-conditioning (to obtain uniform and repeatable pollution layer) and two different elapsed times between the application of the pollution and the voltage test. At present silicone rubber insulators are normally tested (after pre-conditioning) in a nearly hydrophilic state. However, silicone rubber insulators in service have been found to retain hydrophobicity for most of the time even in relatively harsh coastal environments [3], [6]. Thus, to simulate that, another option was included in the test program (called “recovery” in

Figure 1). The schematic presentation of the modified procedure applicable for all types of insulators and adopted from [3] is presented in Figure 1.

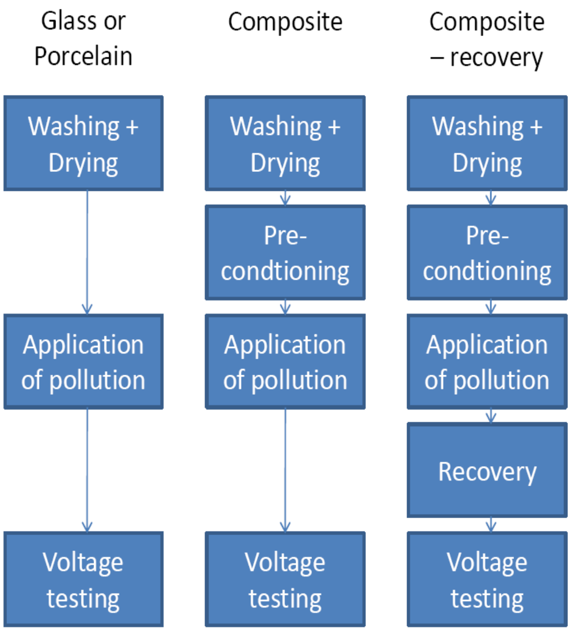

Figure 1: Principles of pollution testing of different types of insulators according to modified Solid Layer test method (adopted from [3]).

Detailed RRT test program developed by CIGRE WG C4.03.03 included the following. A suspension shall be prepared as specified in clause 13.2 of IEC 60507 using kaolin only (not Tonoko). The characteristics of the kaolin shall comply with clause 14 of IEC 60507. For pre-conditioning application of dry kaolin in powder form to the insulator housing should be performed first using a sponge, cotton wool or a brush, see example in Figure 2 adopted from another test at STRI. This kaolin layer should be applied as uniformly as possible, especially at places of the insulator, which are difficult to reach such as the transition from the trunk to the shed.

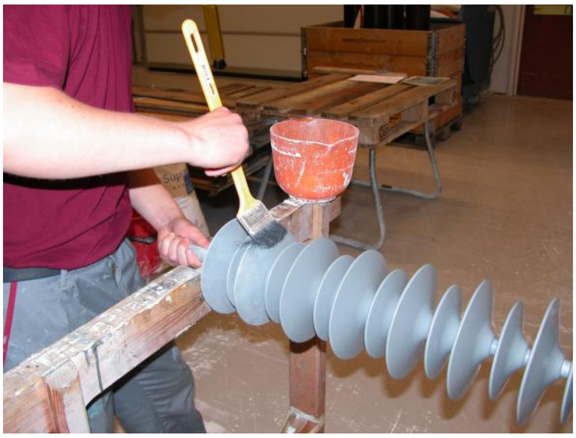

Figure 2: Example of pre-conditioning procedure at STRI, i.e. application of dry kaolin powder by a brush.

After the application of dry kaolin, most of the powder should be blown off by e.g. compressed air leaving a thin, uniform layer covering the insulator housing. The adequacy of this layer is then controlled both visually and by Wettability Class (WC) measurements according to IEC TS 62073 to ensure that the top of the surface of the polluted insulator is completely hydrophilic (WC=7) after pre-conditioning. This pre-conditioning procedure masks the hydrophobicity of the polymeric insulator sufficiently and the pollution suspension based on kaolin can be then applied using the method described in clause 15 of IEC 60507, see practical example from NGK HV laboratory in Figure 3.

Figure 3: Example of pollution of the insulator in RRT test performed at NGK (adopted from [4]).

It was required from the laboratories to measure the surface area for SDD/NSDD measurements on the supplied insulators by their own. Then the results were cross-checked with the manufacturer. This should provide additional information on the accuracy by which these parameters can be practically measured on real insulator being tested. The degree of pollution is expressed as usual by two standard parameters: Salt Deposit Density (SDD) and Non-soluble Deposit Density (NSDD). The SDD should be measured according to clause 16.2 of IEC 60507. This measurement should be performed as soon as the pollution layer has dried, i.e. before the insulator has regained its hydrophobicity. The NSDD is measured according to clause C.4.2 of IEC TS 60815-1.

The target value for SDD was 0,3 mg/cm^2. Using prescribed suspension, one should expect to get target NSDD about 0,1 mg/cm^2. No requirements for the possible deviation of pollution target parameters were given in RRT program, but they should be in accordance with indications in IEC 60507 (±20% on NSDD and ±15% on SDD). SDD/NSDD measurements shall be performed on insulators that are not tested and include both large and small sheds for measurement. The SDD/NSDD measurements should cover the whole circumference of the sheds and measurements should be performed at exact defined location on three insulators. It is also required to measure SDD/NSDD and to calculate average value on two insulators after testing to determine how much washing off has occurred. This could also give some indication on degree of encapsulation of salts. This is to be done on insulators with and without recovery (elapsed time between pollution and test).

The hydrophobic state of the insulator is varied by a predetermined elapsed time between the pollution procedure and the flashover test. The elapsed times for the different hydrophobic states are defined in the RRT program as follows:

- Worst case (without recovery). The test is performed as soon as the pollution layer is completely dry, but the elapsed time before the test is performed should not exceed 16-20 hours after finishing of the pollution application.
- Intermediate case (with partial recovery). The elapsed time is 64-68 hours after finishing of the pollution application.

Hydrophobicity measurements before the flashover voltage test should be done in accordance with IEC TS 62073. The wetting requirements are as described in clause 17 of IEC 60507. Wetting procedure is “Procedure B – Wetting after energization” according to clause 18.2 of IEC 60507.

Flashover test should be performed according to the “up-and-down” method. Minimum 8 valid points should be included in the calculation of the main output parameters, i.e. 50%-flashover voltage ($U_{50\%}$) and standard deviation (σ). The voltage step should be between 5% and 10% of the expected $U_{50\%}$.

The following parameters should be included in the test protocol:

- SDD
- NSDD
- $U_{50\%}$
- Standard deviation σ
- Wettability Class (WC) before the voltage test start
- Times to flashover
- Times to reach maximum leakage current in withstand tests
- Short-circuit current of the test transformer at minimum test voltage during the test

NGK and Chubu University provided results for CIGRE and published their own and some additional results separately in 2010 [4], [5].

3 TEST OBJECTS

Two manufacturers (Lapp Insulators and SEVES) supplied the test objects, which were silicone rubber insulators of 145 kV class (10 insulators per participating HV laboratory). They were split 50/50 between the participating laboratories. In this paper NGK, Chubu University and STRI were testing LAPP insulators, while CEPEL was testing SEVES (Sediver) insulators. Insulators with similar profiles (both alternating and having two small sheds between larger sheds) are shown in Figure 4 and their main geometrical parameters are in Table 1 (L=creepage distance, H=arcing distance; $D_2/D_1/D_0$=diameters of larger shed, smaller shed and trunk, respectively).

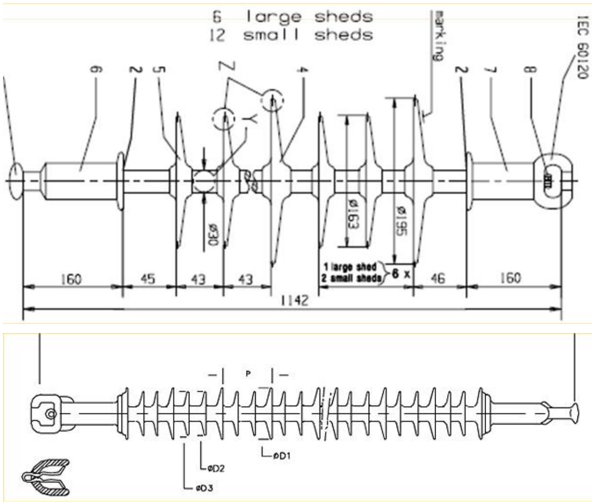

Figure 4: Profiles of tested insulators: top=LAPP; bottom=Sediver.

Table 1: Main geometrical parameters of tested insulators

Insulator	L, mm	H, mm	$D_2/D_1/D_0$, mm
LAPP	3160	870	195/163/30
Sediver	3092	850	175/95/37

4 TEST RESULTS

4.1 Preparation

In this section the comparative results of pollution in four different laboratories are summarized and presented in Table 2. These results should show if the processes for the insulators pre-conditioning and artificial pollution are reproducible.

The results are very consistent, i.e. reproducible. Average deviation from the target SDD value is 6% (is allowed up to 15% according to IEC 60507).

Average deviation from the target NSDD value is 11% (is allowed up to 20% according to IEC 60507). All laboratories were excellent in evaluation of an area for SDD measurements (maximum 2,5% deviation from exact figures provided by manufacturers).

Table 2: Comparative results for pollution

Parameter	Ref.	CEPEL	Chubu	NGK	STRI
SDD, mg/cm^2	0,300	0,330	0,317	0,296	0,323
Deviation, %	±15	+10	+6	-1	+7
NSDD, mg/cm^2	0,100	0,118	0,094	0,109	0,112
Deviation, %	±20	+18	-6	+9	+12

4.2 Test performance

In this section the comparative results of different parameters during the pollution test are summarized and presented in Table 3. These results show basically how reproducible is the physics of the recovery of hydrophobicity if wetting intensity is strictly controlled and the voltage source is stiff enough defined as voltage drop at I_{max} (ΔU) and short-circuit current at minimum test voltage (I_{SC}). The temperature during recovery before the test was also recorded (T_{rec}). The physical process of recovery is described by change of time-to-flashover (Δt_{toFO}), change of time-to-I_{max} (Δt_{toImax}) and change of maximum leakage current (ΔI_{max}).

Table 3: Comparative results during pollution test. ”-rec” means without recovery and “+rec” means with recovery (longer elapsed time)

Parameter	Ref.	CEPEL	Chubu	NGK	STRI
Wetting, kg/m^{3}h	0,045-0,055	0,049	0,054	0,050	0,047
ΔU, %	<10	N/A	<3	<5	<4
I_{SC}, A		10	5-14	7	11
T_{rec}, °C		29-33	13-22	25	31-32
Av. $t_{toFO\text{-}rec}$, min		57	53	37	34
Av. $t_{toFO+rec}$, min		62	80	59	59
Δt_{toFO}, %		+9	+51	+60	+73
Av. t_{toImax}, min.		N/A	74	67	44
Av. t_{toImax}, min.		N/A	100	74	71
Δt_{toImax}, %		N/A	+35	+11	+61
Av. $I_{max\text{-}rec}$		N/A	530	769	1400
Av. $I_{max+rec}$		N/A	61	653	795
ΔI_{max}, %		N/A	-88	-15	-43
WC_{-rec}		7	7	7	6
WC_{+rec}		6	6	7	6

The results are again very reproducible.

Wetting intensity and stiffness of voltage sources are excellent for all participating laboratories.

Recovery of hydrophobicity due to elapsed time between the pollution and voltage test means physically that Low Molecular Weight (LMW) components are penetrating the pollution layer and partly encapsulating salt particles, thus reducing the conductivity of the wetted pollution layer. The results in all laboratories confirm this process: both time-to-flashover and time-to-I_{max} are increased after recovery during only 2 days (about 40% in average), while maximum leakage current (I_{max}) significantly decreases (about 50% in average).

It is interesting and important to note that the recovery process took place only inside the pollution layer. Wettability class measured on the top of the pollution layer before/after the test was practically the same (there is only a slight visual difference between WC6 and WC7).

4.3 Test results

In this section the comparative output parameters of the RRT test (flashover voltage and standard deviation) are summarized and presented in Table 4 together with other details of voltage test parameters. These results show basically how reproducible is the whole test procedure. The test parameters in Table 4 are designated as voltage step (ΔU without/with recovery); number of valid points for $U_{50\%}$ calculation (N without/with recovery); change in flashover voltage after recovery ($\Delta U_{50\%}$) and standard deviation of flashover voltage (σ without/with recovery).

Table 4: Comparative output parameters of the test. ”-rec” means without recovery and “+rec” means with recovery (longer elapsed time)

Parameter	Ref.	CEPEL	Chubu	NGK	STRI
ΔU_{-rec}, %	<10	10	8	7	9
ΔU_{+rec}, %	<10	9	7	6	8
N_{-rec}	8	10	10	10	10
N_{+rec}	8	10	10	10	8
$U_{50\%\text{-}rec}$, kV		126	133	124	111
$U_{50\%+rec}$, kV		136	162*	134	125
$\Delta U_{50\%}$, %		+8	+22	+8	+13
σ_{-rec}, %	<10	4	3	6	4
σ_{+rec}, %	<10	4	5	2	7

*not exactly the same insulator, but partially short-circuited

The results are rather reproducible from physical point of view, in all cases after the short recovery period of two days the flashover voltage increased. The difference in kV of flashover voltage between different laboratories may be estimated as within

10% (one standard deviation). Application of shorter insulator sample (with re-calculation of ten results to a longer one) should be considered separately, when the results from other laboratories will be obtained and summarized.

4.4 After-test measurements

In this section the comparative results of measurements of SDD/NSDD before/after test and with/without recovery are presented in Table 5. They illustrate how much of pollution and what part of it is washed away during the test. These results show again how reproducible is the physics of the recovery of hydrophobicity and how the encapsulation of salts by LMW components influences the pollution parameters.

Table 5: Comparative SDD/NSDD parameters after the test. ”-rec” means without recovery and “+rec” means with recovery (longer elapsed time)

Parameter	CEPEL	Chubu	NGK	STRI
SDD_{-rec}, mg/cm^2	0,269	0,154	0,194	0,148
SDD_{+rec}, mg/cm^2	0,313	0,240	0,228	0,212
ΔSDD_{-rec} %	-18	-51	-35	-54
ΔSDD_{+rec} %	-5	-24	-23	-38
$NSDD_{-rec}$, mg/cm^2	N/A	0,072	0,085	0,091
$NSDD_{+rec}$, mg/cm^2	N/A	0,083	0,099	N/A
$\Delta NSDD_{-rec}$ %	N/A	-23	-21	-30
$\Delta NSDD_{+rec}$ %	N/A	-12	-9	N/A

The results are rather reproducible from physical point of view, in all cases after the short recovery period of two days the SDD/NSDD was washed slowly (giving less reduction in comparison to original values).

5 CONCLUSIONS

In this paper the first results of CIGRE Round Robin Test (RRT) for pollution test of polymeric insulators performed by four HV laboratories are presented and analyzed from reproducibility point of view. Comparative test parameters representing different phases of the test (pre-conditioning, pollution, voltage test performance, after-test measurements) are considered as rather reproducible and promising. More results (for 6 laboratories) are presented in [6] with the same conclusion.

It is confirmed that implementation in pollution test method a practical short recovery period of two days influences the physics of the interaction of LMW components and salts in the pollution layer and leads to the increase of flashover voltage.

Complete results of RRT for more than ten HV laboratories are expected to be published in 2012.

6 REFERENCES

[1] I. Gutman, X.D. Liang, B. Luo, Z.Y. Su, E. Solomonik, W.L. Vosloo: “Evaluation of OHL performance based on environmental stresses and pollution laboratory testing of composite insulators”, CIGRE-2008, C4-112

[2] CIGRÉ C4.303: “Polluted Insulators: Outdoor insulation in polluted conditions: Guidelines for selection and dimensioning, Part 1: General principles and the AC case,” CIGRÉ Technical Brochure 361, June 2008

[3] I. Gutman, A. Dernfalk: “Pollution tests for polymeric insulators made of hydrophobicity transfer materials”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 17, Issue 2, pp. 384-393, April 2010

[4] M. Maeda, K. Kondo, O. Fujii, S. Ito, Y. Suzuki: “Contamination flashover characteristics of polymer insulator under various kinds of test conditions”, 7th IWHV, 2010, paper HV-10-43

[5] R. Matsuoka, B.K. Gautam, K. Sakanishi, S. Kato, T. Ukai, Y. Hayashida, S. Tomida: “Results of Contamination Test of Silicone Rubber Polymer Insulators for the Round-Robin Test by CIGRE”, 15th Asian Conference on Electrical Discharge, Xi'an, China, November 7-10, 2010, paper A51

[6] I. Gutman: “Pollution Testing of Polymeric Insulators: Round Robin Test within CIGRE”, World Congress & Exhibition on Insulators, Arresters & Bushings, Seoul, Korea, 17-20 April 2011