RAIN TESTS: A SPECIFICATION PROPOSAL

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Abstract: The paper analyses the main aspects involved with the insulator performance under rain and namely representativeness of present tests, criticality of the rain condition, reproducibility of the tests and finally applicability of the tests to the upper EHV and UHV range. In particular the characteristics of natural rain are reviewed and compared with the present standard requirements to assess the representativeness of the present tests. Then the influence of rain intensity and rain conductivity on the dielectric strength (taking also into account that insulators maybe not clean when rain occurs) is analyzed. In particular the condition of very heavy rain, as typical of some tropical environment is considered. The complexity of the rain tests and the rain tests poor reproducibility is discussed especially when insulators for the upper limit of EHV and UHV are considered. It is proposed as an alternative and/or complement to standard rain tests to set up Specifications for the selection of insulators under typical wet conditions similarly to what has been done for pollution (IEC 60815).

1 INTRODUCTION

According to field experience rain is one of the most critical conditions for the insulation performance especially for the highest level of EHV AC and DC and for UHV. In DC, apart the particular case of horizontal wall bushings, station insulators in vertical conditions were found critical under rain [1],[2],[3]. There are strong indications from service experience that the standardized test methods for evaluating the performance of external insulation may not be sufficient to qualify the insulators for all environmental conditions. For example:

- In Brazil there have been a number of instances where flashovers occurred on AC energized station insulators during tropical (heavy) rain, without the presence of any switching overvoltage [3]
- Collected service experience on HVDC systems indicates that the majority of flashovers on bushings and vertical insulators occurred during rain, as shown in Table 1, again at service voltage (without overvoltages) [1].

Table 1 DC field experience. Number of flashovers as a function of insulator mounting position and wetting conditions

Mounting position/ Insulator type	No. of flashovers	
	Fog	Rain
Wall bushings	1	39
Vertically mounted insulators	28	28

All the above insulators had passed the standard tests including SI wet tests

The common thinking is that the selection of the insulators on the basis of SI wet tests may be fully adequate to assure a satisfactory service experience under rain. The field experience seems to demonstrate that this assumption may be not valid for AC compact solutions, UHV and especially for DC.

Correct representation of rain conditions in laboratory, assuring the necessary test repeatability, is not an easy task , further complicated if reference to UHV insulation is to be made.

Considering all the above aspects, on request from IEC TC 36 a CIGRE working group have been proposed to evaluate experiences and methods to assess the insulator performance under non standardized environmental conditions and in particular:

- To collect and analyze field experience regarding the flashover performance of insulators during rain and pollution or a combination thereof.
- To perform an in-depth analysis of the available laboratory experience with artificial rain or heavy wetting tests with special emphasis on the following parameters: rain intensity, rain resistivity and insulator condition and type (clean, contaminated, type of material: hydrophobic, hydrophilic).
- To evaluate the representativeness of standardised rain test
- To evaluate the repeatability of rain tests
- To determine the feasibility of rain tests in the UHV range
- To provide guidelines for non-standard pollution tests, such as tests with contamination and rain and tests on service contaminated insulators.

The present paper intends to give a preliminary background for the new possible WG and some work development suggestions.

2 RAIN CHARACTERISTICS IN NATURE

The precipitation characteristics that have the greatest effect on the insulation behavior are the rain rate and the resistivity of rainwater, which are

site specific [4]. The rain intensity can vary remarkably depending on the area considered as shown in Figure 1 [5] [6]. Rain rates exceeding 5 mm/minute may be found for short time periods especially in tropical or semitropical environment. However as shown in Fig. 2 the duration of the rain period decreases and the return period increases as far as the rain intensity increases. Furthermore the differences between rain intensity in different sites attenuates when long duration events are considered.

Also the rain resistivity can vary remarkably as shown in Figure 3, depending on the site, with generally a low probability of occurrence for the events characterized by low resistivity waters.

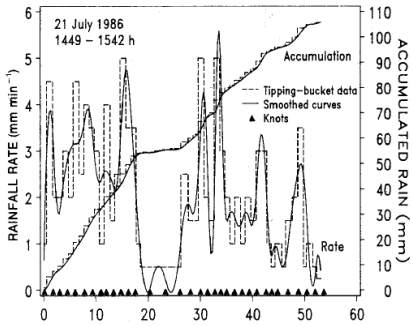

Figure 1: South eastern coastal plain USA. Analysis of rainfall on 21 july 1986. Experimental results: smooth continuous curves

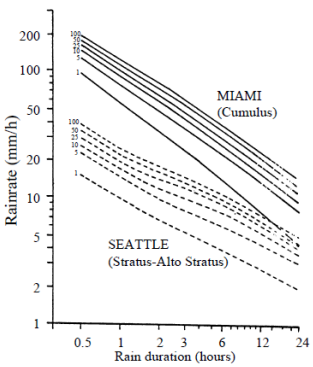

Figure 2: Rain intensity versus duration for various return periods [4]

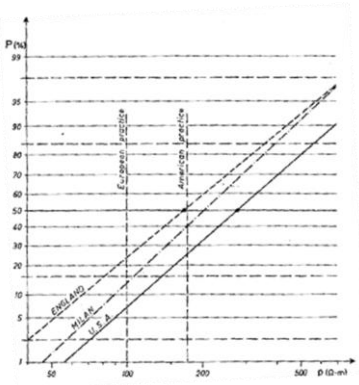

Figure 3: Cumulative frequency distribution of rain resistivities [4]

3 INSULATOR STRENGTH UNDER RAIN

As well known rain can affect remarkably the insulator strength of clean insulators, both under AC, DC and SI. As an example Fig. 4 and 5 report the influence of wetting under SI standard tests. The Figure confirm that the dielectric strength can be significantly influenced by rain, depending however on gap configuration, insulator types and materials.

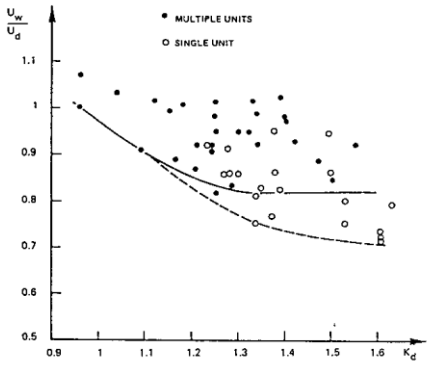

Figure 4: Post insulators. SI of positive polarity. Ratio of the flashover voltage under wet and dry condition as a function of the gap factor of the configuration and insulator geometry [7]

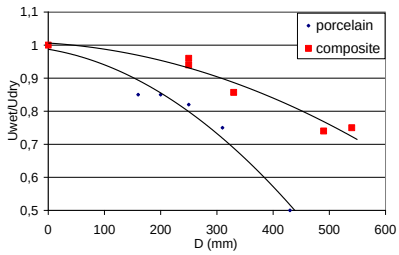

Figure 5: Station insulators. SI of positive polarity. Ratio of the flashover voltage under wet and dry condition as a function of insulator diameter [8].

The influence of standard rain on the strength of insulator sets can be even higher under AC and DC voltage. AC tests performed on single post insulator units and insulator columns have given a ratio between the strength under rain and that in dry condition of 0,76± 0.06 and 0.87± 0.12 respectively [9]. Under DC, flashover voltages as low as 170 kV/m were found under standard rain against a value of about 500 kV/m in dry conditions.

The influence of rain on the strength of clean insulators may be enhanced in non standard conditions. An indication of the influence of water resistivity and intensity on the flashover performance of clean insulators is reported in Figure 6 [10].

Rain can also be the most critical wetting condition for contaminated insulators as shown in Fig. 7 [11] which refers to vertical insulators in

contaminated conditions, tested with humidification of the layer with fog as in standard test and with rain.

A particular case is that of horizontal bushings under DC voltage where the flashover voltage was found to depend on the rain non uniformity, as shown in Figure 8 [2],[12]. In this case flashover voltages as low as 60 kV/m can be found in particular conditions.

It is evident from the above examples that the rain condition cannot be forgotten in design and in design assessment.

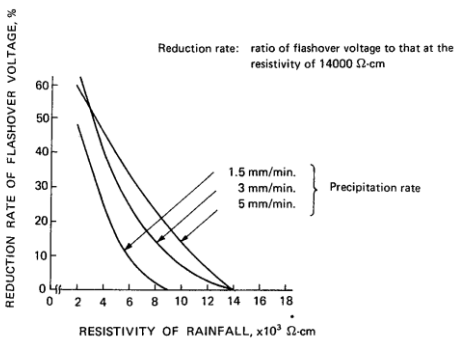

Figure 6: AC tests. Example of the reduction of the flashover voltage as a function of rain intensity and resistivity,

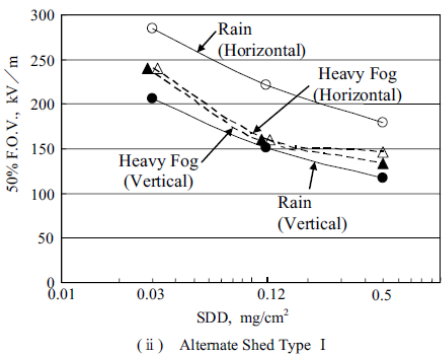

Figure 7: AC tests. Contaminated insulators. Comparison of the flashover voltage under heavy fog and rain

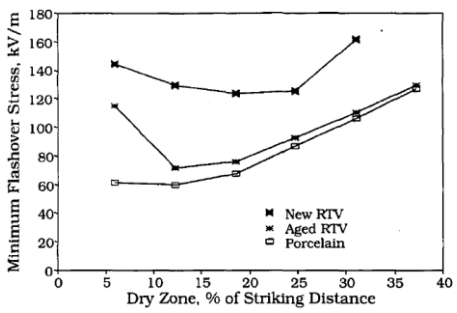

Figure 8: DC tests. Negative polarity. Evaluation of the relation between the minimum flashover voltage and the dry zone length of a bare ceramic wall bushing and a RTV coated one

4 STANDARDIZED RAIN TESTS ASPECTS

The last version of IEC 60060 Standards prescribes only rain tests on clean insulators with a precipitation rate of 1.5 mm/minute as an average and a resistivity of 10 kΩ cm.

4.1 Standard rain tests representativeness

Standard rain tests represent quite correctly the typical condition occurring under SI where the probability of a simultaneous occurrence of a high overvoltage and a high rain intensity and low rain resistivity is quite low (reference to Figure 2 and 3 is made).

In principle standard rain tests do not represent closely the phenomena which may occur under permanent AC and DC voltage, since in this case heavy rain conditions, as typical for instance of tropical environment, could lead to more critical conditions than under standard rain. It is in fact to be considered that the voltage is always applied, also when extreme non standard wetting occurs.

4.2 Standard rain tests repeatability

Unfortunately rain tests are rather complicate and it is not easy to control all the parameters which can affect the results, such as circuit parameters, droplet size, surface conditions, water resistivity, water temperature and especially the uniformity and repeatability of wetting.

The difficulty in creating repeatable test conditions may help to understand the large dispersion observed already for EHV insulators when comparing the data obtained in the same laboratory and in different laboratories. An example of the observed spread of the results is reported in Figure 9. SI tests of positive polarity on the same insulator (3.15 m post insulator in 3 units, shed spacing 45mm) gave flashover voltages ranging from 1075 to 1270, with a variation of about 20%.[7]

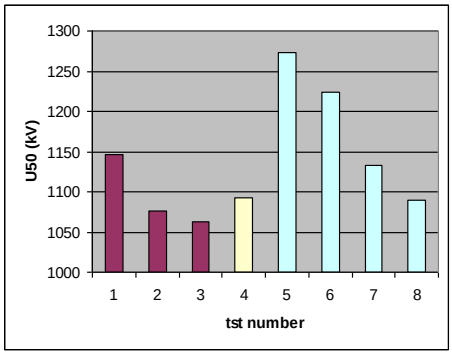

Figure 9: Tests to assess the repeatability of SI wet tests: tests in three different laboratories on the same test object

The repeatability of wet tests under AC and DC voltage was found significantly lower than under SI.

When considering UHV insulators, with lengths up to 10 m or more the difficulty to assure repeatable test conditions becomes even higher and thus higher dispersion in the results can be expected.

4.3 Test feasibility in the UHV range

Due to the dispersion of the tests it is deemed that the applicability of rain tests as type tests should be reconsidered, especially for UHV. SI tests according to the nowadays procedure are unpractical for the highest system voltage apparatus.

As an example some of the difficulties encountered to make the rain tests on a recently developed 800 kV DC bushing are reported in the following. The main characteristics of the wall bushings, with composite housing and SF6 insulation, are shown in Figure 10. The total bushing length is of 21.32 m [13].

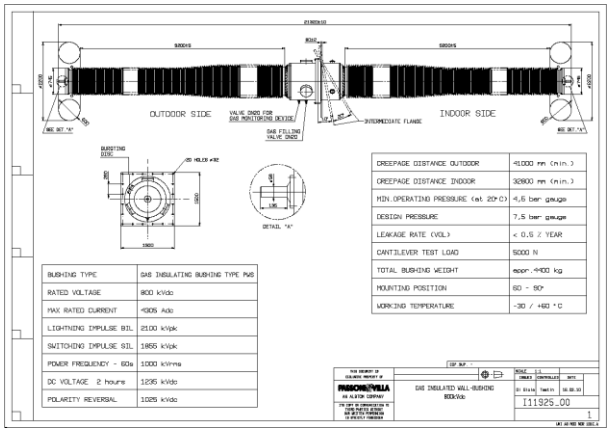

Figure 10: Main characteristics of the wall bushing tested

Due to the length of the bushing, tests were not possible inside the HV laboratory so that the SI wet tests had to be carried out outside. The test arrangement is shown in Figure 11, while the bushing picture under wet test is shown in Figure 12. SI of 1855 kV positive and negative polarity were applied. The bushing passed the wet tests performed by making all the possible efforts to comply with IEC requirements.

Some of the challenges encountered are here reported:

- A special rain apparatus had to be constructed (see Figure 13). The distance of the apparatus from the bushing had to be taken more than 10 m to avoid discharges to the apparatus itself at the applied voltage of 1855 kV. It has to be considered that for the new foreseen voltage level of 1100 kV DC under development, the necessary distance should be even higher (about 15 m)

Figure 11: 800 kV DC wall bushing. Configuration for SI wet test at Graz Laboratory, outdoor.

Figure 12: The bushing under wet tests

Figure 13 View of the ad hoc rain apparatus set up for the tests

- The optimal weather conditions (e.g. low wind conditions) had to be waited to achieve the required horizontal and vertical rain components as in the standard. The measurements of these rain components were very cumbersome due to the length and height of the apparatus and to its characteristics (the measurements on horizontal apparatus should be probably better specified). The obtainment of a sufficiently uniform rain all along the test object was a very strenuous target.

- It was hard to reach the rain rate specified by the Standard at the distance of 10 m or more. As suggested in the old version of the IEC 60060 standard, too high pressures are not advised since the water jet may break prematurely and cause an unsatisfactory spray at the test object. At the maximum advised pressure of 300-400 kPa the maximum jet length achievable by adjusting the diameter of the nozzle orifice is of the order of 10 m, already a limit for the object under test. Higher rate than the standard one cannot be easily achieved respecting the standard indications. The only practical way to get higher rain rate would be to make non standard arrangements (e.g. vertical rain).

5 NEEDS FOR NON STANDARD TESTS AND FOR AD HOC SPECIFICATIONS

5.1 General indications

As mentioned above the influence of rain on insulator performance can be remarkable and the design should take into account the performance under rain both under SI and under permanent voltage especially in environment characterized by heavy rain. However due to the many parameters involved, the complexity of the tests and the scarce test reproducibility it may be difficult to propose wet tests as type tests under DC and AC voltage and the actual need of the tests in these conditions should be verified. Even the performance of SI wet tests can be critical, especially when insulators for the upper limit of EHV and UHV are considered. Ad hoc procedures may have to be investigated and set up to make possible rain tests. As a complement to standard rain tests specifications for the selection of insulators under typical wet conditions similarly to what has been done for pollution could also be useful (IEC 60815). The Specifications should indicate, among others, the minimum insulator requirements to perform correctly under rain, giving also indications about the expected reduction of the strength under representative rain conditions with respect to the reference dry value. A lot of information on the dielectric strength under rain can be dug from the past. However the information is sparse and the preparation of the Guide would require massive additional investigations to improve the knowledge on the influence of the various parameters such as wetting conditions, degree of contamination, insulator profile, diameter, hydro repellency. Some suggestions about the future work toward the test adaptation and the setting up of specifications are reported here below.

5.2 Assessment of the insulation performance under SI wet

Standard test on clean insulators with rain intensities of 1.5 mm per minute as an average are to be considered adequate even for tropical environments, due to the very low probability to have at the same time high overvoltage values and high rain rates.

Derogation from the Standards may need to be permitted for applications in the UHV range. For example a vertical rain would be more than adequate and representative for the horizontal configuration of Figure 8, making at the same time the test easier to perform. Comparative tests could be useful to assess the relative performance under standard tests and the new possible derogations proposed.

5.3 Assessment of the need of wet tests under AC permanent voltage for EHV- UHV insulators

While some field experience seems to indicate the criticality of the insulators under AC wet, additional investigations could be useful to confirm the need of additional type tests. The following investigations are proposed on station insulators (ceramic and composites) who have passed the standard SI tests:

A. To verify the need of an AC wet test, the criticality of rain stress with clean insulators should be verified submitting the insulators to heavy rain tests, with rain intensity ranging from 1 to 5 mm/minute and possibly varying the water resistivity. The tests should be made on insulators having various distances between sheds starting from the minimum value advised by IEC 60815. The tests should permit also to identify the minimum distance between sheds necessary in case of tropical rain.
B. The need of a special pollution test with humidification by rain as an alternative to the standard fog humidification should be verified, implementing the available information [11]. The aim of the investigations should be again to verify if the standard solid layer test with clean fog humidification may be maintained as the only designing test, provided that minimum insulator characteristics are assured (e.g. minimum distance between sheds). For composite insulators the solid layer tests should follow the procedure being under development within CIGRE C4.03.03. For heavy wetting test, the pollution should be made somewhat more sticky to slow the washing process following the rain application.

5.4 Assessment of the need to implement wet tests under DC permanent voltage

Two cases are to be considered in DC:

- The general case of insulator sets (with special attention to station insulators)
- The specific case of horizontal wall bushings

For the first case the investigation as in point A and B of the paragraph 5.3 are suggested. In particular the tests should confirm the need of special tests with rain and contamination as suggested in [14]

For the second case (horizontal wall bushings) there is enough information to arrive at a Standardisation of the tests to be carried out on the full bushing, in clean condition, fixing the rain intensity, resistivity and extension of the dry band, (see [2], [12] and exemplification in Fig.8).

To get significant results the DC generator should be sufficiently stiff to contain the voltage drops in concomitance with pre-discharge phenomena.

5.5 Set up of specifications for insulator selection under rain

The analysis of the available results and the results of the new investigation could permit to better understand the influence of the insulator parameters both under standard and non standard rain condition.

On this base Specifications similar to the IEC 60815 ones could be set up, to limit the need of type tests.

6 CONCLUSIONS

- There are some indications from service experience that the standardized test methods for evaluating the performance of external insulation under rain may not be sufficient to qualify for all frequently occurring environmental conditions.
- Standard SI rain tests with standard rain rate represent quite correctly the typical condition occurring under SI, where the probability of a simultaneous occurrence of a high overvoltage and a high rain intensity is quite low.
- SI rain tests according to the available Standards are unpractical for UHV apparatus and suitable and reasonable derogation from the standards are to be agreed.
- Standard rain may not represent closely the phenomena which may occur under permanent AC and DC voltage, since in this case heavy rain conditions, as typical, for instance of tropical environment, may occur while the insulators are energised at full voltage, possibly leading to more critical conditions than under standard rain. The need of additional type tests should be assessed.
- On the basis of investigations on insulator units the insulator profile which could comply with heavy rain requirements can be determined.
- Non uniform rain tests on wall bushings for DC applications may need to be standardized.
- On the basis of the available results and of the new investigations performed a Specification for insulator selection under rain may be implemented, to reduce as much as possible the need of additional type tests.

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