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NAGOYA 2015

Increase risk on the safety clearance in UHV stations

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SUMMARY

The increment of high voltage transmission levels has produced the rise of the switching withstand requirements, the unified specific creepage distance, among other parameters. Consequently, the size of the equipment to be located in the switching yards has increased considerably. For UHV applications apparatus can have a length of tenths of meters. Such equipment should be located in a switchyard providing safety clearance distances for living beings and nearby equipment during operation and under overvoltage stress.

In this paper the authors re-examine the problem of coordination between multiple gaps throughout the results of a series of fifty percent breakdown tests performed on UHV arrangement size with varied gap spacing and varied height. The flashover probability for the multiple gaps is investigated.

Experimental results show that albeit secondary and third gaps, e.g., walls and floor are located at long distances from the high voltage connection of the equipment, breakdowns of low probability (< 20%) appear as statistical events. In addition, it is observed that for equipment with insulation length longer than 8 m installed on top of a pedestal of 2.4 m is impossible to ensure that breakdowns will strike only the pedestal.

Based on the analysis of the experimental results and in order to warrant the safety of living beings at UHV stations, it is highly recommended to prohibit the presence of humans and animals in the switchyards during operation. Living beings shall only be allowed when the switchyard is completely disconnected and properly grounded.

KEYWORDS

Breakdown voltage, low probability, safety clearance, switching impulse.

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1. INTRODUCTION

The clearance distances in a switching yard are designed taking into account the different voltage stresses and ambient conditions. The safety clearance distance shall minimize the risk of direct or indirect impact to human beings and/or other equipment. The recommended practice for safety clearance distance of apparatus in switchyards is to place the equipment at a certain height from ground level by means of a pedestal, such that no fencing, railing or protecting screens are needed.
International standards provide a guide for safety clearances, including the minimum height to lowest edge of insulators, minimum distance for a person to approach to a live metal, among others [1], such minimum clearances can be also determined by each country national standards e.g. for DIN standards [2] the pedestal should be at least 2250 mm height for operational voltages of 1000 V and above.

The increment of high voltage transmission levels has yielded the rise of the switching withstand requirements, creepage distance, among others. Therefore, for UHV the size of the equipment has increased significantly. In order to reduce electrode surfaces stresses and improve voltages withstand capabilities, electrodes with a curvature radii are widely used in high voltage apparatus and interconnections. Experimental investigations [3 - 6] have shown that long insulation apparatus settled on a pedestal under switching impulse voltage stress may lead to flashovers at a gap longer than the apparatus, e.g. towards ground level, nearby equipment or other grounded point.

In this paper switching impulse breakdown tests for UHV arrangements, composed of spherical electrodes on top of insulators and pedestal are reported. Spherical electrodes of different diameter and various insulators lengths were tested. Clearance distances to one nearby wall and floor were changed. Special attention is given in this manuscript to breakdowns of low probability, i.e., breakdowns towards far walls and breakdowns to floor.

2. TEST METHOD

All the tests reported in this paper were performed with switching impulse of positive polarity for arrangements top electrode, insulator and pedestal. The switching impulse voltages were generated by a Haefely 25-stage Marx generator at standard waveform 250/2500 μs. Voltage measurement uncertainty was circa 2%. All tests were conducted indoors.

The test object consisted of porcelain post insulators installed at 2.4 m metallic pedestal and a high voltage electrode of spherical shape of different diameter on top of the insulators. The top electrodes were spheres commonly used for interconnections of UHV stations, such as, sphere of 1.3, 1.6 and 2.0 m diameter. In all cases, the test object was installed with a distance of at least 16 meters to the farthest wall of the laboratory and variable distance to the other wall.

The tests were executed according to the up and down method. 30 switching individual impulses were applied for each test. When minimum 10 valid points were obtained, the voltage level of 50% breakdown probability and the standard deviation of the test were determined. During the test, the applied voltage and the waveform of the voltage were recoded. Two digital cameras were used to record the trajectories of the discharges.

3. TEST RESULTS AND DISCUSSION

The results of the switching impulse test for the different configurations tested are summarized in Table I. Information regarding the set-up configuration, the distance to floor, the insulation length, pedestal height, wall distance, the respective 50% breakdown voltage corrected to atmosphere conditions in p.u., total number of breakdowns to wall, to floor and to pedestal and its corresponding probability are included in the table.

The probability is calculated as the ratio of the total number of breakdowns striking to a specific point over the total number of individual switching impulses applied. To each set-up 30 switching impulses were applied, from this shoots a certain amount ended as breakdown and its striking point was identified using the photographs taken during testing.

Table I. 50% breakdown voltage for different kind of configurations with insulators and with/ without top electrodes and pedestal

Top electrode	Total gap length to floor [m]	Insulators length [m]	Pedestal length [m]	Wall distance [m]	Wall / Floor distance	$U_{50\ \text{atmospheric correction}}$ [p.u]	σ %	# Breakdowns				Probability %		
								Total	To wall	To floor	To pedestal	To wall	To floor	To pedestal
2 m diameter sphere	11	8.5	2.4	17	1.54	1.38	10.5	10	0	4	6	0	13.3	20
2 m diameter sphere	11	8.5	2.4	14	1.27	1.25	2.3	13	2	2	9	6.7	6.7	30
1.6 m diameter sphere	13	10.6	2.4	16.1	1.24	1.31	2.8	15	3	5	7	10	16.7	23.3
1.6 m diameter sphere	11	8.6	2.4	16.1	1.46	1.20	4.3	26	6	5	15	20	16.7	50
1.3 m diameter sphere	7	4.6	2.4	8	1.14	1.14	3.6	16	1	0	15	3.3	0	50

As part of the coordination of the multiple gaps and to ensure that the majority of breakdowns impact the main gap, it is recommended practice to design clearance distances in a way that the secondary gap and/or third gap are located at a longer distance than the main gap. The test reported in this paper, considers the main gap between the base point of the high voltage top electrode and the base of the pedestal, i.e., the length of the insulators; the secondary gap between the base of the high voltage electrode and the floor, i.e. length of insulators plus the pedestal of 2.4 m; and the third gap between the high voltage electrode and wall, defined as a certain times the distance the secondary gap. In figure 1, is possible to identify the breakdown trajectories of the main gap (towards pedestal), secondary gap (to floor) and the third gap (to wall).

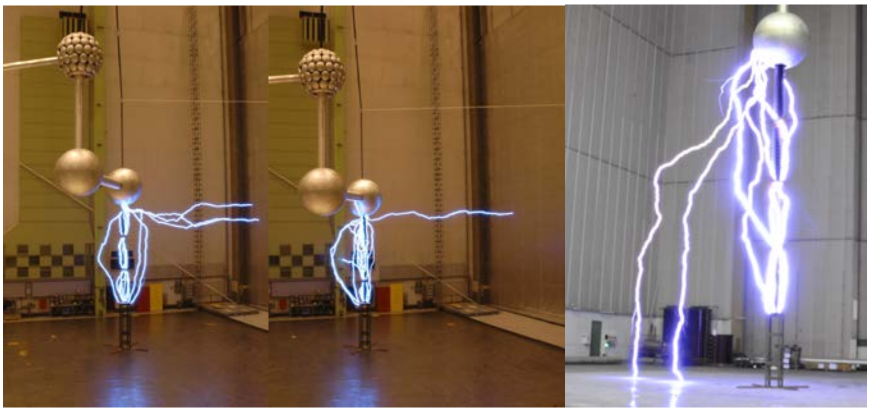

Figure 1. Photograph of breakdown trajectories on different set – ups. From left to right two pictures of the test of with top electrode a sphere of 1.6 m diameter and one picture of sphere of 2.0 m diameter.

From photographical observations is possible to pinpoint the different path of the discharge for some tested set-ups. Even though the majority of breakdowns impacted the pedestal, breakdowns to the secondary or third gaps (wall, floor) were also registered. In general, for each tested set-up the highest probability of breakdowns, more than 20% impacted the pedestal.

For a better understanding, the data summarized in Table 1 is analyzed from two different aspects the impacts to the third gap (wall) and the strikes to the secondary gap (floor).

3.1 Breakdown probability for the gap towards wall

Figure 2 illustrates the breakdown probability to wall, floor and pedestal for each test set-up vs. the relation distance to floor over distance to wall.

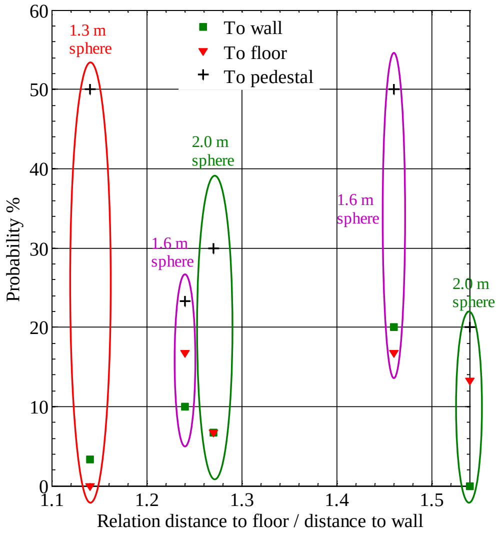

Figure 2. Probability of breakdown vs. relation distance to floor/ distance to wall for different top sphere diameter. Probability is represented by the sign plus (+) for breakdowns to pedestal, triangles for breakdowns that impacted the floor and squares for breakdowns to wall.

From the results illustrated in Figure 2, it is possible to make the following observations:

- The longer the distance to wall, the highest the probability that the strike ends in the pedestal and/or that the probability to strike the wall will be reduced. For the test with the sphere of 1.3 m a clearance to the wall of 1.14 times the distance to floor was sufficient to evince breakdowns to wall of probability lower than 3.3%; for test with the sphere of 1.6 m diameter a relation of 1.46 is adequate to observe 50% of breakdowns impacting the pedestal; for the test with the sphere of 2.0 m diameter a wall located 1.54 times distance to floor was adequate to observe very low probability breakdowns to the wall, circa 0%. This behavior is because the electric field intensity towards the wall will be reduced as long as the clearance distance to wall increases. If the electric field towards the wall is reduced then the probability to strike the wall will decrease as well.

- Although in all the tested cases the third gap (wall) was located at longer distance than the floor (secondary gap), in some tests the probability to impact the wall became equal to or higher than the probability to impact the floor. These events can be classified as statistical events of low probability and are due to the competitive effect of both gaps; however, a clear explanation based on the propagation phenomena of the discharge is still not clearly understood in literature.

3.2 Breakdown probability for the gap towards floor.

Figures 3 illustrates the breakdown probability for each test vs. the relation distance to floor, distance to pedestal (insulators length).

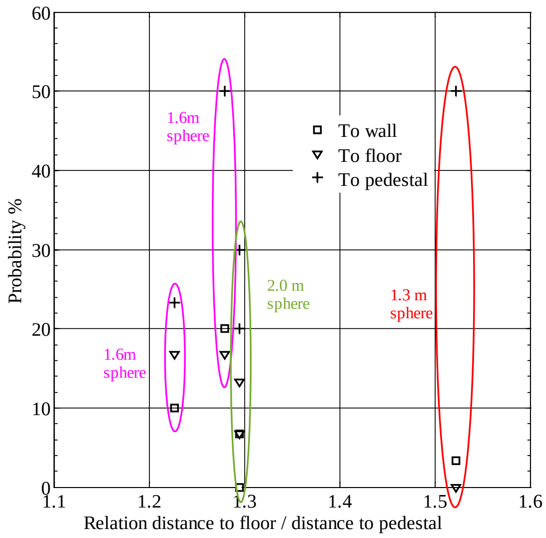

Figure 3. Probability of breakdown vs. relation distance to floor/ distance to pedestal for different top sphere diameters. The data is symbolized as sign plus (+) for probability of breakdowns to pedestal, triangles for probability of breakdowns that impacted the floor and squares for probability of breakdowns to wall.

Following remarks can be done based on Figure 3:

- To increase the distance to floor increasing the length of the insulation part of the arrangement may reduce the probability of breakdowns directly to floor until certain point, e.g., the arrangement with the sphere of 1.3 m diameter and 4.6 m insulation length with a distance to floor 1.5 times the distance to pedestal, did not show any breakdown to floor. However, the test results show that for insulation distances longer than 8 m is not possible to warrant "zero" breakdowns to floor.
- The case of the sphere of 2.0 m diameter shows that albeit the relation distance to floor and distance to pedestal is identical, the distance to wall will affect the breakdown probability towards floor; the probability of impact the floor is 13% for a distance to wall 1.56 times the main gap, and 7% for a distance to wall 1.3 times the distance of the main gap. It is clear evidence that the coordination of gaps cannot be performed individually. The electric field distribution will be affected by the location of the wall, therefore, the closer the wall the higher the electric field stress towards the wall, and the higher the probability that some breakdowns will strike the wall instead of the floor.
- It is recommended practice for safety clearance distance to install the apparatus on pedestal of at least 2250 m height [1, 2] test results indicate that even with pedestal of 2.4 m exists a probability (between 7 to 16%) that in case of an overvoltage type switching impulse, the breakdown could impact the ground floor instead of the pedestal.

4. CONCLUSIONS

The test results for arrangements with insulators, top electrode and pedestal of UHV size, indicate that breakdowns towards secondary and third gaps can occur despite the fact the shortest clearance distance is located towards the pedestal. To reduce the probability of breakdowns striking other gaps different than the main gap, certain clearance distance equivalent to times the main gap is required. However, it is observed that for equipment with insulation length longer than 8 m installed on top of a pedestal of 2.4 m is impossible to ensure that breakdowns will not strike directly to floor.

Based on the analysis of the experimental results and in order to warrant the safety of living beings at UHV stations, it is highly recommended to prohibit the presence of humans and animals in the switchyards during operation. Living beings shall only be allowed when the switchyard is completely disconnected and properly grounded.

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