

## Effect of Humidity on the Breakdown of Air Gaps under Oscillatory Switching Impulse Voltages

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**Abstract:** Experimental investigations were carried out to study the effect of humidity on the breakdown of rod-plane gaps subjected to both uni-directional and bi-directional oscillatory switching impulse voltages. The humidity ranged from 14.1 - 36 gm/m<sup>3</sup> at a constant temperature of 40° C. The gap subjected to uni-directional 5.3, 10, 19 kHz and bi-directional 4.2, 10, 20 kHz oscillatory switching impulse voltages. The gap distance was varied from 8 to 30 cm. The experiments were carried out in a controlled atmospheric room. The results indicate an increase in breakdown strength with increase in humidity. The results are of great relevance at atmospheric conditions existing in Tropical countries.

### INTRODUCTION

Switching surges are produced when a circuit breaker closes or re-strikes. These surges are generally uni-directional in nature with double exponential wave-shapes. Recent investigations have however shown generation of oscillatory switching surges [4] because of the inductance associated with a transformer or a machine or a line and capacitance of line or cable. The magnitude and frequency of these surges depend on the system parameter and their waveform depends on the system parameter and switching conditions. Depending on the switching condition, the oscillatory switching impulse voltages (OSIV) are categorized as uni-directional  $\pm(1-\cosine)$  and bi-directional ( $\pm sine$ ) [3,4].

The IEC has recommended testing of all equipment designed for operating voltages above 300 KV with standard switching impulse voltage (SSIV) of 250/2500  $\mu s$  [1]. However, recent studies, have found that at least for one frequency the breakdown voltage under OSIV is lower than that of SSIV [2]. Since the breakdown of air gaps is considerably affected by atmospheric conditions, a knowledge of effect of hu-

midity on OSIV becomes essential.

Information is available in literature on the effect of humidity on rod-plane gaps subject to switching impulses of varying time to front [6,7] but data under OSIV has not been reported. The present paper proposes to study the effect of humidity on rod-plane gaps subjected to OSIV. The uni-directional 5.3, 10, 20 kHz and bi-directional 4.2, 10, 19 kHz oscillatory impulse voltage was applied to the test gap. These frequencies are in the reported frequency range of OSIV [4].

### EXPERIMENTAL SET-UP

Experiments were conducted in a controlled atmospheric room of 6m x 6m x 6m dimensions. The humidity was varied from 14 - 36 gm/m<sup>3</sup> and the temperature was kept constant during the experiment (at 40°). This was done to prevent breakdown voltage from being influenced by change in temperature.

Oscillatory switching voltages were generated by modification of a 10 stage, 500 KV, 6.25 kJ impulse generator with adaption of inductance for wave-shaping [5]. The uni-directional OSIV was generated by introducing an inductance in series with the front resistor. To generate the bi-directional OSIV the wave-shaping inductance was introduced in parallel to the tail resistor. The test gap used was a Rod-Plane with the rod of 12.5 x 12.5 mm cross-section as high voltage electrode and plane of 90 cm diameter as ground. The rod was suspended vertically from a suspension insulator inside the controlled atmospheric room. The wave-shapes of OSIV used for the study :

- 4.2 kHz bi-directional OSIV, time to front

( $t_f$ ) 10  $\mu s$ .

- 10 kHz bi-directional OSIV,  $t_f$  7  $\mu s$ .
- 19 kHz bi-directional OSIV,  $t_f$  3.8  $\mu s$ .
- 5.3 kHz uni-directional OSIV,  $t_f$  88  $\mu s$ .
- 10 kHz uni-directional OSIV,  $t_f$  42  $\mu s$ .
- 20 kHz uni-directional OSIV,  $t_f$  24.5  $\mu s$ .

The Up and Down method as per IEC-60 was used to find the 50% breakdown voltage ( $V_{50}$ ).

The voltage was measured using precision damped capacitor divider with a ratio of 424 and a peak voltmeter [5]. A 100 MHz digital storage oscilloscope was used for the detailed study of the waveform.

## RESULTS AND DISCUSSION

### Results

Figure 1 shows some typical oscillogram of breakdown. The result of breakdown studies have been shown in Figure 2 to 5. The effect of time to front on breakdown of OSIV is given in Figure 6.

With bi-directional waves, the polarity quoted is the initial polarity and the voltage measured was the first peak of that polarity.

### Discussion

The oscillograms in Figure 1 show the peculiar phenomenon that the breakdown does not always take place on the first peak of the OSIV. The breakdown is observed to take place even in second and subsequent peaks where the voltage is much lower than that of first peak. Similar phenomena has been reported by Couper [3]. This indicates that the mechanism of breakdown, with OSIV is different than that of SSIV.

For gap spacing of 8cm it was also observed that the breakdown was always taking place in the second peak of the negative bi-directional. With increase in gap distance the breakdown was also observed in first peak but the probability of breakdown in second or subsequent positive peaks remained very high.

In case of positive bi-directional the breakdown was mostly observed to take place in the first peak.

With negative uni-directional the breakdown occurred on or just after the first peak for small spacings and in the second for larger spacing. With positive uni-directional the breakdown occurred mostly in the first peak.

Figure 2 and Figure 3 show effect of humidity on breakdown of positive OSIV. With a gap distance of 15 cm the  $V_{50}$  breakdown voltage increases with humidity. The 10 kHz bi-directional is showing very steep increase in breakdown voltage with increase in humidity but as the humidity increases above 28  $gm/m^3$  the breakdown voltage decreases with further increase in humidity. Similar observation was made with 20 kHz bi-directional. With uni-directional the breakdown voltage showed steady increase with increase in humidity. With gap distance of 30 cm the breakdown voltage first increased at high rate but as humidity increased beyond 28  $gm/m^3$  the rate of increase came down.

Figure 3 and Figure 4 show effect of humidity on breakdown of gap subjected to negative OSIV. The breakdown voltage under negative bi-directional OSIV was much less than that under uni-directional OSIV as was reported in literature [2,3]. With 8 cm rod-plane gap the breakdown voltage of 10 kHz bi-directional shows increase with increase in humidity. Since the breakdown takes place in positive peak (second peak) with bi-directional, the  $V_{50}$  increase with increasing humidity. However, no appreciable effect of humidity was observed on breakdown voltage with gap of 15 cm

Figure 5 shows the plot of  $V_{50}$  as function of time to front of OSIV. A 'U' curve with minimum 10  $\mu s$  is obtained.

## CONCLUSIONS

1. The influence of humidity on the flashover voltage of rod-plane for gap length of 8-30 cm and humidity range of 14-36  $gm/m^3$  has been studied. The breakdown voltage increased by 0.6-3% / $gm/m^3$  increase in humidity under positive OSIV.
2. The magnitude of breakdown under positive bi-directional voltage was not much affected by humidity beyond 28  $gm/m^3$ .
3. Humidity was observed to have an effect on the breakdown under negative bi-directional, but more experimental data is required for determining exact effect of humidity.
4. In general, the negative bi-directional OSIV

breakdown is appreciably less than uni-directional.

5. The critical time to front of the bi-directional OSIV which produces the minimum breakdown voltage was  $10 \mu s$  for a gap spacing of 30 cm at humidity of  $18.9 \text{ gm/m}^3$ .

## REFERENCES

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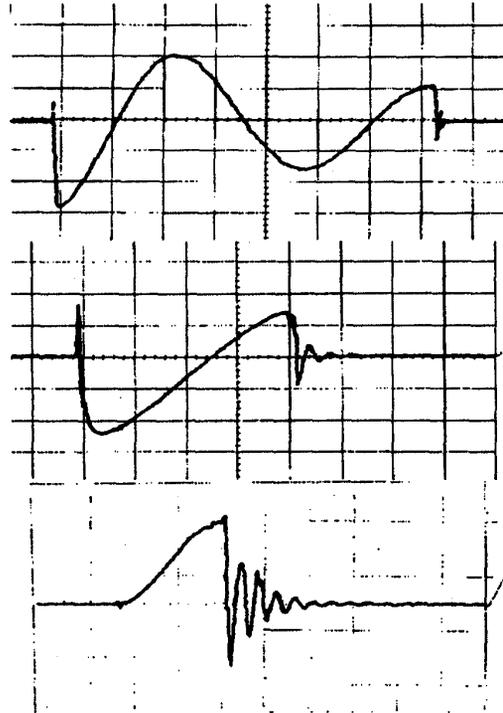


Figure 1. Oscillograms of breakdown under OSIV, (top-bottom)

4.2 kHz negative bi-directional fourth peak breakdown  
 10 kHz negative bi-directional second peak breakdown  
 20 kHz positive uni-directional first peak breakdown

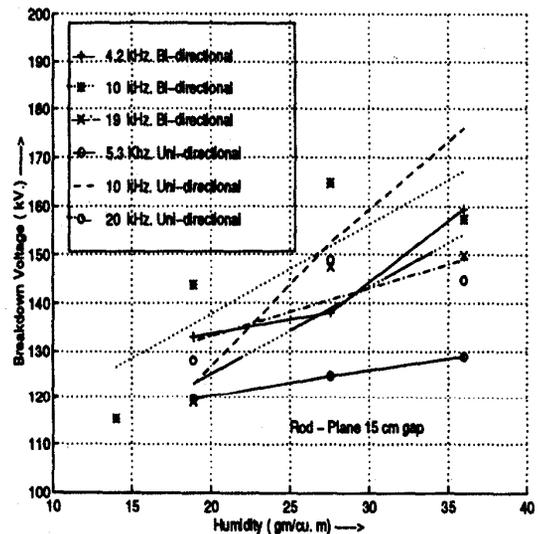


Figure 2. Breakdown voltage  $V_{50}$  vs. Humidity under positive OSIV (gap distance 15cm)

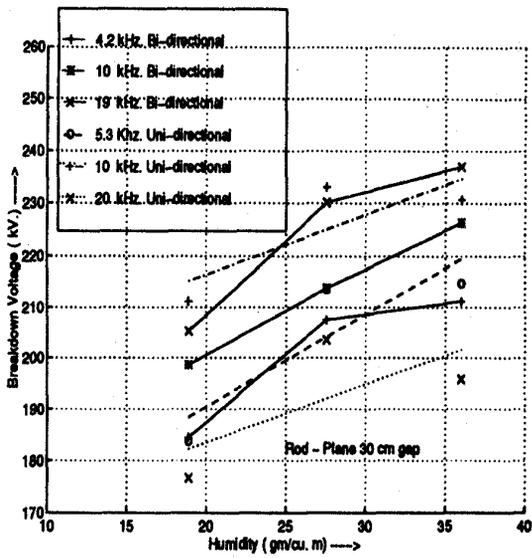


Figure 3. Breakdown voltage  $V_{50}$  vs. Humidity under positive OSIV (gap distance 30cm)

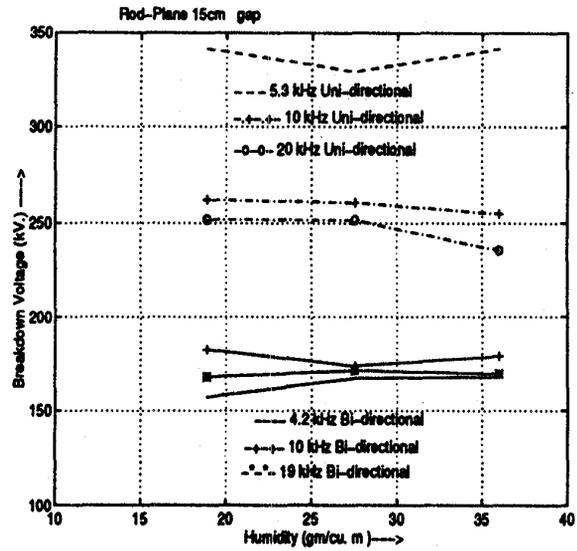


Figure 5. Breakdown voltage  $V_{50}$  vs. Humidity under negative OSIV (gap distance 15cm).

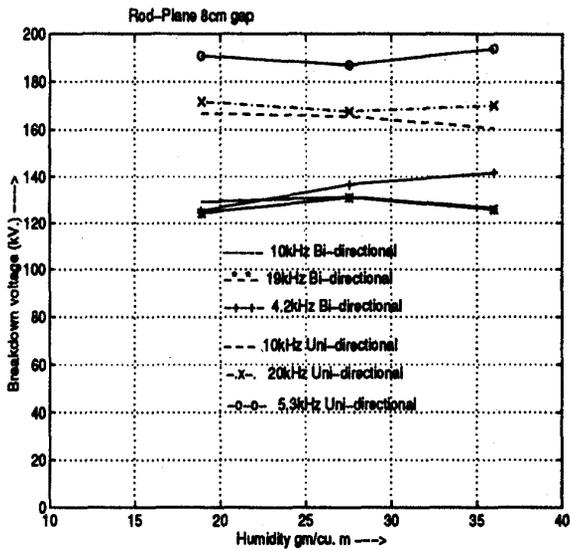


Figure 4. Breakdown voltage  $V_{50}$  vs. Humidity under negative OSIV (gap distance 8cm).

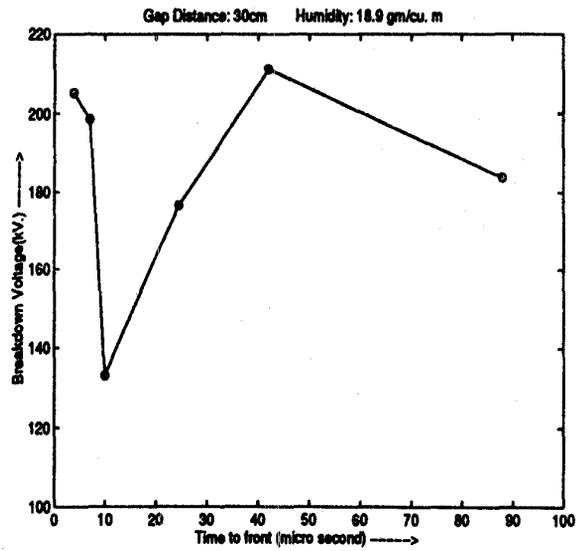


Figure 6. Breakdown voltage vs. time to front for positive OSIV (gap 30cm, humidity 18.9  $gm/m^3$ )