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# Capacitive Coupling Phenomena in Gas-Insulated Switchgear Disconnectors during Impulse Voltage Tests

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## Abstract

Gas-Insulated Substation (GIS) equipment has become increasingly significant due to its numerous advantages over conventional Air-Insulated Substations (AIS). These advantages include compact size, higher reliability, enhanced safety, superior dielectric performance, and reduced maintenance requirements. Such benefits make GIS suitable for urban areas and challenging environmental conditions where space and operational constraints are critical. Dielectric-type tests play a crucial role in ensuring GIS equipment's reliability and operational safety by validating its insulation's ability to withstand both impulse overvoltages, typically caused by lightning, and temporary power frequency overvoltages arising from switching operations or system disturbances. This study focuses on lightning impulse testing of a GIS disconnector switch across an open isolating distance, emphasising the challenges encountered in achieving compliance with the requirements specified in IEC 60060-1:2010. Key challenges include managing capacitive coupling effects, voltage drop mitigation, and maintaining waveform fidelity during the test. For testing the isolating distance of a 245 kV GIS disconnector, a method is presented to address the effective voltage drop observed during lightning impulse voltage tests. This method involves a combined approach utilizing high-voltage DC as a complementary voltage source without the requirement of synchronizing equipment and ensuring the required test voltage without much voltage drop across the isolating contacts of the GIS disconnector.

**Keywords:** Gas Insulated Switchgear, Dielectric Testing, Combined, Complementary Test Voltage, Isolating Distance

## 1. Introduction

Gas-Insulated Substations (GIS) are increasingly preferred over conventional Air-Insulated Substations (AIS) due to their numerous advantages, such as the superior insulating properties of the gas medium, compact design requiring less space, and ease of maintenance. Dielectric-type tests on GIS are critical to validate design parameters, such as the ability of the GIS to withstand impulse overvoltages caused by natural lightning and switching operations, as well as temporary power frequency overvoltages resulting from sudden load changes in the network. Impulse voltage testing on GIS is typically performed under dry conditions for both phase-to-ground insulation and across isolating distances or switching contacts, as specified in IEC 62271-203[1]. The test voltage required for isolating distances is higher than the phase-to-ground voltage, making testing across the isolating distance in GIS disconnectors a challenging task. To perform such tests, two primary methods are employed:

**Isolation of the entire GIS enclosure from the ground plane:** This method involves isolating the GIS enclosure and its internal busbars from the ground plane to facilitate testing. However, this approach is often complex due to uneven alignments within the GIS enclosure and busbars, which may lead to mechanical stress and potential failures (phase-to-ground flashovers) of the test sample during testing.

**The preferred method outlined in the standard IEC 62271-1[2]:** This method involves testing the open gap or isolating distance using two test sources applied at both ends of the isolating gap. The terminal of the disconnector to which the main part of the test voltage is energized with an impulse test voltage, while the opposite terminal of the disconnector

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to which the complementary test voltage is energized with another impulse voltage, a DC test voltage at its peak value, or a power frequency voltage. These voltages are applied in phase opposition—for instance, if the terminal of the disconnector to which the main part of the test voltage is applied with a positive polarity impulse, the complementary terminal is applied with a negative polarity voltage at the same peak instant. The combined test voltage, as specified in standards such as IEC 60060-1[3], IEEE Std 4[4] and IEC 62271-203, is characterized by the following critical parameters, which must be evaluated for compliance:

i. **Amplitude:** The peak value of the combined test voltage i.e. both the test voltages applied to either contact of the equipment.
ii. **Time delay:** The synchronization between the main and complementary test voltages.
iii. **Wave shapes:** The waveforms of the applied test voltages.
iv. **Voltage drops:** The reduction in voltage amplitude across the test setup due to coupling capacitance and other factors.
v. **Combined test voltage:** The resultant voltage across the isolating gap.

By adhering to these testing requirements and evaluating the specified critical parameters, the dielectric performance of GIS can be validated, ensuring the reliability and safety of the system under operational and fault conditions.

## 2. Lightning Impulse Test on the Open Gap of 245 KV GIS Disconnector

Combined voltage test arrangement with impulse voltage source as main source and power frequency voltage as complimentary voltage source, requires precise application impulse voltage at exact peak time of opposite polarity peak of power frequency voltage. The impulse generator shall be fired/triggered based on the feedback signal received from the peak detector of the power frequency voltage source. Delay in the peak detector signal or problems with phase synchronization will result in the reduction of effective combined test voltage across the isolating terminals during testing. At the same time, these two test sources shall be protected against each other in case of failure of the open gap of the disconnector using an arrangement of protective components in the test circuit. To overcome the phase synchronization and time delay of application of test voltages, this test may be performed with impulse voltage as main voltage and peak value of opposite polarity of DC voltage as a complementary test voltage. The test arrangement along with protective components to conduct the open gap testing is shown in Figure 1. Another problem associated with the combined voltage test is the coupling effect of both test sources via the capacitance of the open gap of the disconnector. The capacitance of the open gap / isolating distance forms a series of capacitances between the fixed and moving contacts of the disconnector with $SF_6$ gas as the insulating medium. This series capacitance may create the coupling phenomenon between two test sources and result in the voltage drop in complementary test voltage during the application of the main voltage. The voltage drop in the combined voltage shall be less than 5% of the total test voltage as per standard. The coupling effect was reduced by connecting a parallel load capacitor/shunt capacitor

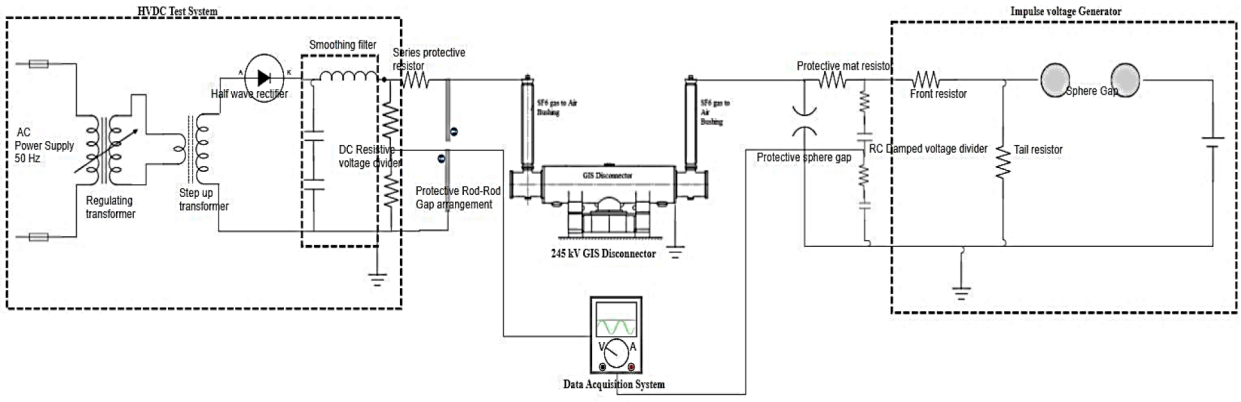



**Figure 1.** Schematic of the test set up along with protective component to perform the open gap testing.

across the complementary end terminal. If the voltage drop is still more than 5 % of the combined test voltage, the test voltage shall be increased at the complementary end not more than

a. $U_r\sqrt{2}/\sqrt{3}$ during lightning impulse test
b. $1.2\ U_r\sqrt{2}/\sqrt{3}$ for switching impulse test

## 3. Experimental Test Set-Up

The combined impulse voltage test is performed as a dielectric-type test across the isolating distance of a GIS disconnector. In this setup, an impulse voltage source is connected to the terminal of the disconnector which main part of the test voltage of the GIS disconnector, while a DC voltage source is connected to the opposite terminal of the disconnector to which the complementary test voltage. The schematic test setup for this combined impulse test, including the impulse and DC voltage sources and all protective elements, is shown in Figure 1. The protective elements are integrated into the test circuit to safeguard the test sources from potential damage in the event of a failure of the GIS isolating gap.

For safeguarding the test sources, the sphere gap with appropriate air gaps is connected at the terminal of the disconnector to which main part of the test voltage of the GIS disconnector at the impulse voltage end.

The rod-rod gap arrangement is arranged at the DC supply side. The air gap of the sphere gap shall be maintained as per the values provided in standard IEC 60052[5] for impulse voltage. The rod-rod air gap shall be calculated from the following equation 1.

$$V_0 = 2 + 0.534 * d \ldots\ldots\ldots (1)$$

where

$V_0$ is the disruptive discharge of DC voltage in kV

d is air gap distance in mm.

The protective series resistance value of 40 kΩ is connected at the complementary end of test circuits to reduce the short circuit test current. This higher value of the series resistor will attenuate the amplitude of impulse voltage at the DC test equipment side in the event of failure[6] or flash over across open isolating contacts of the test sample. Ultra High Voltage Research Laboratory, Central Power Research Institute, Hyderabad, India has a 5000 kVp, 500 kJ outdoor impulse voltage source and ± 1200 kV, 200 mA outdoor HVDC test system to carry out the dielectric tests on various equipment up to 800 kV system voltages. The experimental test arrangement along with protective components for testing the open gap / across isolating distance of 245 kV GIS disconnector is shown in Figure 2.




**Figure 2.** Experimental test set up for LI test on 245 kV GIS disconnector.

The combined test voltage specified in the IEC 62271-203 for testing the isolating distance of a 245 kV GIS disconnector is 1200 kVp. During testing, a lightning impulse test voltage of -1050 kVp is applied to the terminal of the disconnector which main part of the test voltage of the switchgear, while a complementary test voltage of +150 kV DC is applied to the opposite terminal of the disconnector to which complementary test voltage. However, test results

revealed an effective voltage drop of +100 kVp due to the coupling effects caused by the series capacitance of the open-gap disconnector and the interaction between the test sources. This reduction in the combined test voltage exceeds 10% of the specified total test voltage, necessitating corrective measures. The reduced combined voltage drop can be compensated by increasing the complementary test voltage. However, the increase should not exceed 179 kV DC to prevent excessive and unnecessary stress on the phase-to-earth insulation of the GIS. Beyond this limit, the phase-to-earth insulation may experience continuous over-stressing, compromising system integrity. An alternative solution involves connecting a parallel (shunt) capacitor at the complementary test terminal to mitigate the voltage drop and maintain the combined test voltage within the acceptable range.

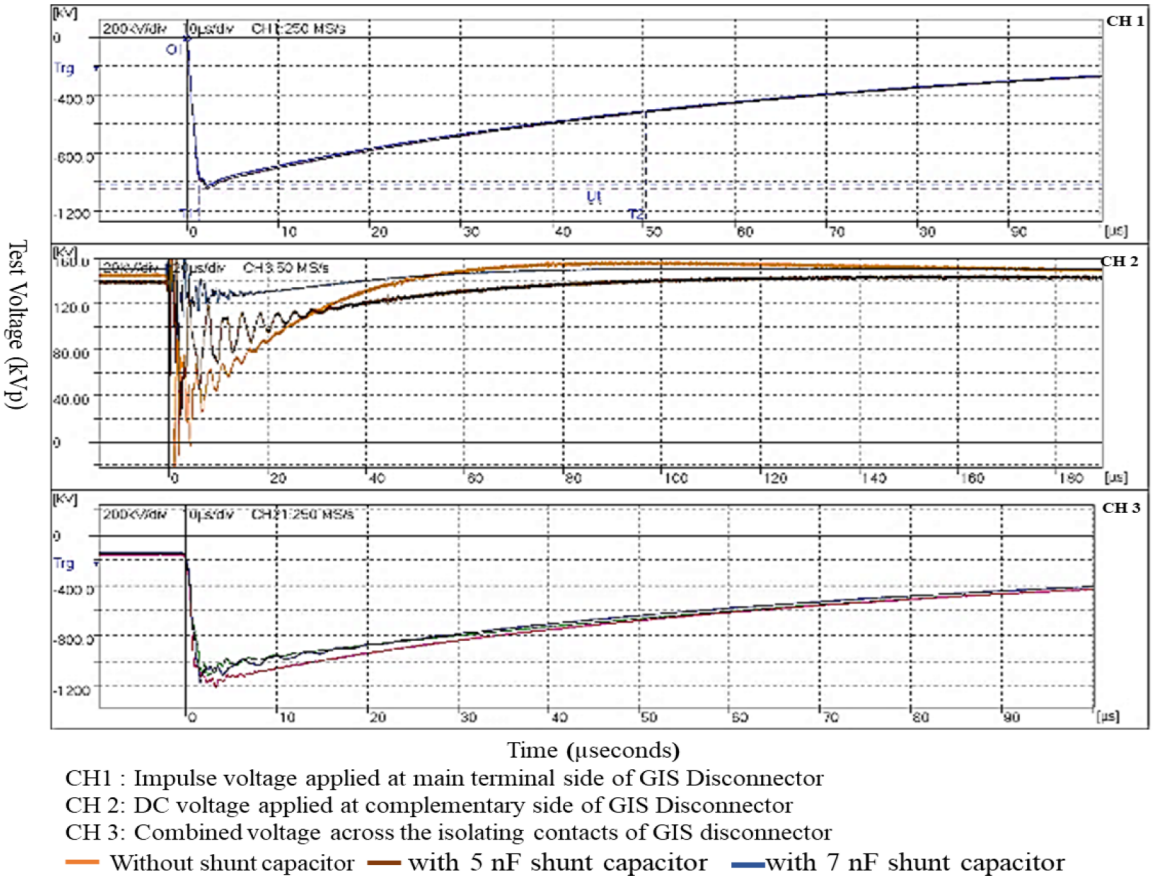



**Figure 3.** Waveforms of main (LI), Complementary (DC) and Combined test voltages during open gap testing with different load/shunt capacitors at complementary test sources.

The series capacitance of the open gap was measured using a low-voltage LCR meter, which operates based on the Wheatstone bridge principle. The capacitance value is displayed using a null detection method. From these measurements, the series capacitance of the open gap of the GIS disconnector was determined to be 18 pF, and the inductance of the high-voltage lead was 45 µH, based on the schematic test setup shown in Figure 1.

The experimental test setup for the combined test, incorporating shunt capacitors at the complementary test terminal, is shown in Figure 1. Analysis was conducted both without shunt capacitors and with shunt capacitors of 5 nF and 7 nF to evaluate their effectiveness. The observed voltage drops in the complementary test voltage were 100 kV, 60 kV, and 10 kV, respectively, for the cases without shunt capacitance, with 5 nF, and with 7 nF shunt capacitance. The waveforms of the main, complementary, and combined test voltages, along with the associated voltage drops, are presented in Figure 3.

From the experimental results, it was observed that a shunt/load capacitance of approximately 10 nF is effective in reducing the voltage drop in the combined test voltage to

within 5%, ensuring compliance with the test requirements for an open gap capacitance of 18 pF.

## 4. Effect of Trapped Charges

The continuous application of DC complementary test voltage may induce or form trapped charges at the open end of the busbar section. These trapped charges can be neutralized by applying an opposite-polarity test voltage for a specified duration or by applying at least five impulses at a reduced voltage level of the opposite polarity after swapping the test connections between the terminal of the disconnector to which main part of the test voltage and opposite terminal of the disconnector to which complementary test voltage. A minor voltage drop in the combined test voltage was observed during the initial two to three-impulse applications due to the presence of trapped charges at the open end of the busbar. However, this effect dissipated after the application of two initial impulses. This observation highlights the influence of trapped charges on the test circuit, warranting further studies to evaluate their long-term effects under continuous DC voltage application at the complementary terminal.

## 5. Conclusion

This study presents the combined test circuit arrangement, including protective elements, for testing GIS disconnectors using an impulse voltage source as the main voltage and a DC voltage source as the complementary voltage. This approach effectively addresses the time delay issues between the application of test voltages. The effects of capacitive coupling, caused by the open gap capacitance of GIS disconnectors, on the combined test voltage, are analyzed. A method for mitigating voltage drops in the combined test voltage by incorporating shunt/load capacitors at the complementary test terminal is demonstrated, along with experimental results for various shunt capacitor values. The findings indicate that a shunt capacitance of approximately 10 nF is effective in reducing voltage drops to within 5% of the combined test voltage for an open gap capacitance of approximately 18 pF. Additionally, the initial observations regarding trapped charges induced by the continuous application of DC voltage are presented. While the voltage drops caused by these charges diminish after the initial impulses, further studies are required to understand the effects of trapped charges during prolonged DC voltage application in GIS switchgear.

## 6. Acknowledgement

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## 7. References

1. IEC. IEC 62271-203:2022. High-voltage switchgear and control gear - Part 203: AC gas-insulated metal-enclosed switchgear for rated voltages above 52 kV. Geneva: International Electrotechnical Commission; 2022.
2. IEC. IEC 62271-1:2017 Edition 2.0. High-voltage switchgear and control gear - Part 1: Common specifications for alternating current switchgear and control gear. Geneva: International Electrotechnical Commission; 2017.
3. IEC. IEC 60060-1:2010 Edition 3.0. High-voltage test techniques - Part 1: General definitions and test requirements. Geneva: International Electrotechnical Commission; 2010.
4. IEEE. IEEE Std 4. IEEE Standard for High-Voltage Testing Techniques. New York: Institute of Electrical and Electronics Engineers; 2016.
5. IEC. IEC 60052:2002 Edition 3.0. Voltage measurement using standard air gaps. Geneva: International Electrotechnical Commission; 2002.
6. Jacob ND, Fattal FA. A practical test circuit for combined high direct voltage and switching impulse voltage multi-stress tests. In: 2016 IEEE Electrical Insulation Conference (EIC). Montreal, QC: IEEE. 2016; 427–430. https://doi.org/10.1109/EIC.2016.7548679