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Analysis of VFTO and Its Mitigation in a GIS through Additional Earthing Grid

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Abstract: Very Fast Transient Overvoltages (VFTOs) are one of the major insulation stress phenomena encountered in Gas Insulated Substations (GIS). VFTOs are generated primarily during disconnector switching operations and are characterized by extremely steep wavefronts, high frequency oscillations, and short durations. These transients can cause insulation degradation, electromagnetic interference, transformer winding stresses, and flashover incidents in GIS installations. According to IEC classifications, VFTO frequencies typically range from tens of kilohertz to several tens of megahertz. This paper presents a practical case study from the GIS Installation, where an additional copper flat based earthing grid was installed to enhance grounding performance. Following the implementation of the supplementary earthing system, no flashover incidents were observed. An engineering analysis is presented to explain how the improved grounding system reduced the magnitude and impact of VFTOs. The advantages, limitations, and field observations are discussed, providing guidance for future GIS design and retrofitting projects.
Keywords: GIS, VFTO, Earthing Grid, Grounding System, Flashover, Disconnector Switching, Electromagnetic Transients.

I. INTRODUCTION

Gas Insulated Substations (GIS) are extensively used in modern power systems due to their compact footprint, high reliability, low maintenance needs, and efficient land utilization. However, switching operations involving disconnectors and earthing switches can generate Very Fast Transient Overvoltages (VFTOs).

VFTOs are caused by repeated prestrikes and restrikes across disconnector contacts, producing high frequency transient waves that propagate through the GIS structure. These oscillatory overvoltage's can attain magnitudes of about 1.5 to 2.0 p.u., depending on the system configuration.

The consequences of VFTO include:

- Internal insulation stress.
- Transformer winding insulation deterioration.
- Bushing failure.
- Electromagnetic interference with control and protection circuits.
- Flashover of weak insulation locations.
- Accelerated aging of equipment insulation.

II. VFTO GIS FLASHOVER AT A 765 KV GIS INSTALLATION

A. Incident:

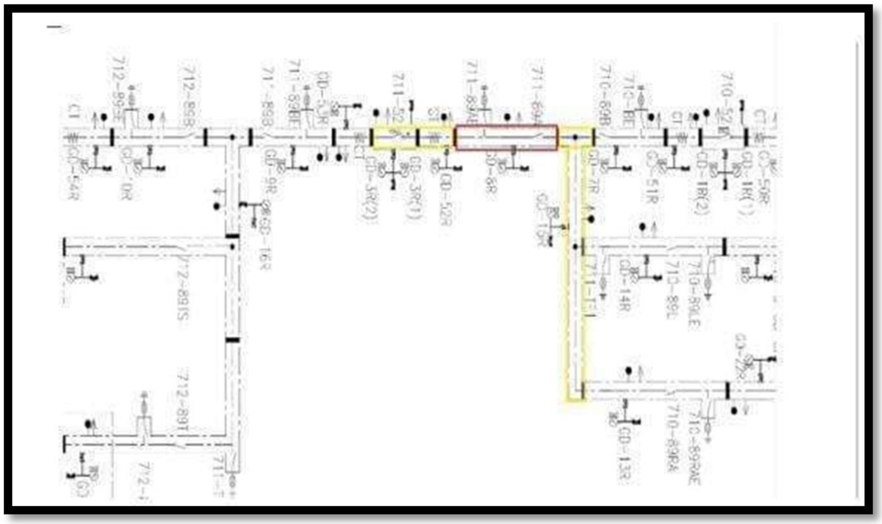
Tripping of a 765 kV transmission line during first-time charging of an ICT in a GIS installation @ 00:19Hrs on 30.12.2023

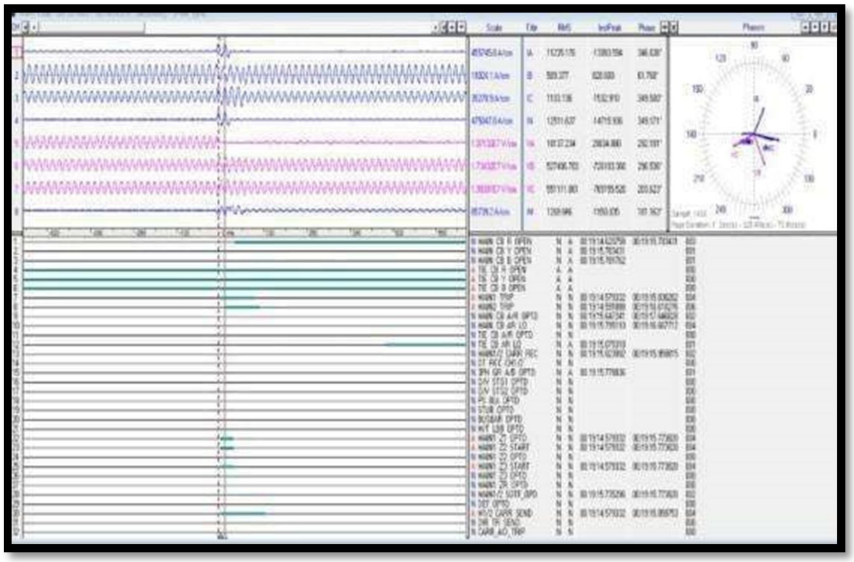
B. Details of Incident

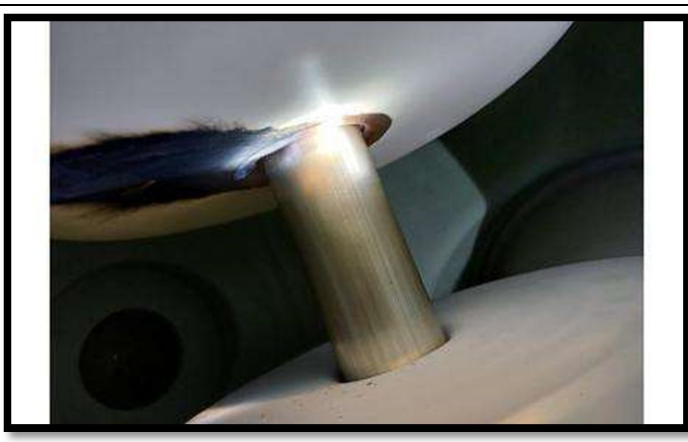
During closing operation of isolators for first time charging of ICT#3,71152R Phase CB (existing tie CB of 765kV line line#2 and ICT#3elements) flash over occurred in 711 89A R Ph DS/ES Gas compartment at 00:19hrs on30.12.2023 and lead to tripping of 765kV line#2 on distance protection.

The fault current was observed to be 13.9kA. SO2 content was observed in Isolator/DSES 71189A (R Ph), 711CTA (R Ph towards line #2) and 71152 CB (R Ph)

Flash Over or burnt marks appeared in 711 89A R Ph DS/ES Gas compartment (Highlighted in RED color in Gas SLD). Powder remanent was observed inside the DS chamber.







SO2 Content was measured in the chambers and the results are as follows

S.No	Compartment ID	SO2 in ppm	Defective Chamber details
01.	711-52 CB RPh	77.76	Tie CB
02.	711-CTA RPh	51.54	CT (A) towards line2 side
03.	711-89A R Ph	21.99	DS/ES

The SF6 parameters after filling :-

Chamber ID	Pressure MPa	Dew Point deg C	Moisture ppm	Purity (%)	SO2 ppm
R-Ph DSES (GD 8R)	0.57	-45	71.99	99.75	0
GD15R (adjacent chamber)	0.56	-52.24	29.16	99.90	0

At GIS installation, flashover related concerns and transient stress indications prompted the installation of additional grounding conductors using copper earth flats interconnected with the existing earth mat. Subsequent operation revealed a noticeable improvement with no further flashover occurrence.

III. GENERATION MECHANISM OF VFTO IN GIS

Following is SOE during disconnector operation:

- Contact gap gradually changes.
- Arc restrikes occur repeatedly.
- Each restrike injects a steep front travelling wave.
- These waves reflect and refract at GIS discontinuities.
- Superposition increases local overvoltage stress.

The VFTO characteristics are:

TABLE I
VFTO CHARACTERISTICS

Parameter	Typical Range
Rise Time	4 ns – 100 ns
Frequency	100 kHz – 50 MHz
Duration	Few microseconds
Magnitude	Up to 2.0 pu

These high frequency components also create significant transient enclosure voltages (TEV) and transient ground potential rise (TGPR).

IV. EXISTING CONDITION AT GIS INSTALLATION, PRIOR TO GROUNDING ENHANCEMENT

The existing earth grid was designed primarily to provide effective grounding for power frequency fault currents and to ensure personnel safety during fault conditions. However, its performance under very high frequency transient phenomena such as VFTO is comparatively limited.

The high frequency transient currents generated during VFTO events require low impedance discharge paths for rapid dissipation. In the absence of dedicated high frequency grounding measures, these currents may not be effectively discharged to ground.

At high frequencies, the inductive characteristics of grounding conductors become significant, resulting in a higher effective ground impedance. Consequently, the conventional grounding system may not offer an adequate path for the dissipation of VFTO induced currents.

Due to this increased impedance, transient voltage gradients can develop along the GIS enclosure and associated metallic structures. These localized transient voltage rises may lead to potential differences between adjacent grounded components.

The resulting overvoltage's increase electrical stress across insulation interfaces, spacer assemblies, cable terminations, and equipment bushings. Over time, this can accelerate insulation ageing and elevate the risk of partial discharge activity, flashovers, and insulation failures within the GIS installation.

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V. ADDITIONAL EARTHING IMPLEMENTATION

The mitigation measure consisted of:

A. Copper Earth Flat Installation

Additional copper earth rods were installed at multiple locations around:

- GIS equipment
- Ground grid intersections

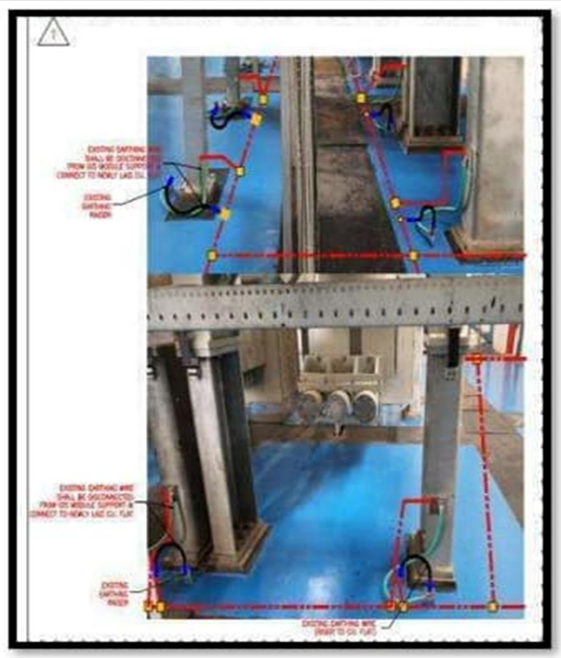
B. Interconnection

The rods were bonded to the existing earth mat, creating:

- Multiple parallel grounding paths
- Reduced earth impedance
- Lower inductive reactance
- Better current distribution

C. Effective Grounding Area Increase

The grounding network area was significantly increased, leading to improved dissipation of high frequency surge currents.



VI. ANALYSIS OF VFTO REDUCTION DUE TO ADDITIONAL EARTHING

A. Reduction in Ground Impedance

For VFTO frequencies reaching several MHz, grounding systems behave predominantly as R L networks. The transient voltage can be approximated as:

$$V = L\,(di/dt) + IR$$

- V = transient voltage
- L = grounding inductance
- R = grounding resistance
- Effective resistance (R)
- Effective inductance (L)

Since VFTO currents have extremely high di/dt values, even small inductances generate substantial voltage rises. Additional earth rods reduced, thereby lowering the transient voltage rise.

B. Reduction in Transient Enclosure Voltage (TEV)

The GIS enclosure experiences capacitive coupling with the energized conductor. With improved grounding:

- Enclosure potential became more stable.
- TEV magnitude decreased.
- Enclosure to earth voltage difference reduced.

Consequently, insulation stress at flanges, spacers, and accessories decreased.

C. Improved Dissipation of High Frequency Currents

VFTO energy seeks the lowest impedance path. Before enhancement, VFTO current encountered a limited ground path, resulting in local voltage rise and consequent flashover risk. After enhancement, VFTO current is distributed across multiple earth paths, enabling fast energy dissipation and reduced voltage stress.

The additional copper strips acted as distributed grounding electrodes, enabling rapid removal of transient energy.

D. Reduction of Ground Potential Rise (GPR)

Transient Ground Potential Rise occurs when VFTO current flows through grounding impedance. The additional grounding system:

- Increased current sharing.
- Reduced local ground voltage rise.
- Improved equipotential conditions.

This significantly reduced flashover probability between metallic parts and grounded structures.

VII. FIELD OBSERVATION AT GIS INSTALLATION

A. Observed Practical Result

After installation of the supplementary grounding network:

- No flashover incidents observed.
- Improved operational reliability.
- Stable switching performance.
- Reduced transient disturbance indications.
- Increased confidence during disconnector operations.

The practical observations align with published studies indicating that enhanced earthing is an effective VFTO mitigation measure in EHV GIS installations. A recent experience from POWERGRID GIS Installation also identified enhanced earthing among successful VFTO mitigation measures, with reliable operation achieved after implementation.

VIII. ADVANTAGES OF ADDITIONAL EARTHING FOR VFTO SUPPRESSION

A. Technical Advantages

- Reduction of transient ground impedance.
- Decreased transient enclosure voltage.

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- Better dissipation of VFTO energy.
- Reduced flashover probability.
- Improved insulation coordination.
- Lower electromagnetic interference.
- Improved personnel safety.

B. *Operational Advantages*

- Increased GIS reliability.
- Reduced maintenance outages.
- Lower equipment aging rate.
- Increased transformer insulation life.

C. *Economic Advantages*

- Low-cost implementation.
- No major GIS modification required.
- Reduced failure related costs.
- Improved asset life cycle.

IX. LIMITATIONS

Although additional earthing provides substantial improvement, certain limitations remain.

1) *Does Not Eliminate VFTO Generation:* The grounding system reduces the impact of VFTO but does not remove the fundamental source, namely disconnector restrikes.
2) *Site Dependency:* Effectiveness depends on soil resistivity, earth rod depth, grid geometry, and moisture content.
3) *High Frequency Grounding Complexity:* A grounding system that performs well for 50 Hz fault current may not always perform optimally at VFTO frequencies.
4) *Measurement Challenges:* Direct VFTO measurement requires specialized sensors and high bandwidth recording equipment.
5) *Additional Space Requirement:* Installation of extra rods may be constrained in compact urban GIS facilities.

X. RECOMMENDATIONS

For future GIS projects:

- Detailed study of VFTO phenomenon during EMTP/PSCAD studies.
- Include high frequency grounding analysis during design.
- Install additional earth flat grid near critical equipment.
- Minimize ground lead lengths.
- Improve bonding between GIS enclosures.
- Periodically measure grounding resistance and integrity.
- Evaluate TEV and VFTO performance after major modifications.

XI. CONCLUSION

A field assessment conducted at the 765KV GIS Installation indicates that the installation of an additional copper flat earthing grid significantly improved the grounding characteristics of the substation. The enhanced grounding reduced ground impedance, transient enclosure voltages, transient ground potential rise, and electromagnetic disturbances caused by Very Fast Transient Overvoltages. The most important practical observation was the absence of flashover incidents after commissioning of the supplementary grounding system. From both theoretical analysis and field evidence, it can be concluded that the improved earthing network provided an effective low impedance path for high frequency transient currents, thereby reducing insulation stress throughout the GIS.

This case study demonstzates that enhanced grounding is a practical, economical, and effective mitigation technique for VFTO suppression in EHV GIS installations and should be considered as part of comprehensive insulation coordination and reliability improvement programs.

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