Study of Very Fast Transient Overvoltages and Mitigation Techniques of a Gas Insulated Substation

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Abstact- **The very fast transient overvoltages (VFTOs) generated due to switching operations of gas insulated substations (GIS) are dangerous to the equipments connected to the substations. In special cases these transients may cross the Basic Insulation Level (BIL) of the GIS. In this paper, these transient voltages are investigated at the different sensitive locations of a 400 KV GIS. VFTOs of the GIS are calculated using EMTDC/PSCAD software. Hence, the suppression of the VFTOs is also an important field of interest. The suppression techniques to reduce the VFTOs are also discussed in this paper.**

Keywords- Very fast transient overvoltages (VFTOs), Basic insulation level (BIL), Gas insulated substation (GIS), Air insulated substations (AIS).

I. INTRODUCTION

In current secenerio, GIS are used extensivly due to several benefits over air insulated substations (AIS) i.e. compact size, small ground space requirement, easy maintenance, less field erection time, environment friendly, highly reliable etc. But GIS have a measure problem in the switching operations. These switching operations generates the transient overvoltages. These transient overvoltages increase very fast after the reflections at the junctions of the GIS [1]. The rise time of these transients is very short, which of the order of 4 to 100 ns and having the frequecny oscillations of the order of 50 KHz to 100 MHz [2]. The travelling waves are generated due to these transients overvaltages travels from the GIS bushing to external connected components. This may damage the internal insulation of the GIS also may damage the other components connected like insulation of transformers and other electronic devices in the substation. This also may be lead to mal-operation of the electronic devices in the substation. These very fast transient over voltages (VFTOs) also radiates the electromagnetic fields [3,4]. The electronics equipments and cables in the GIS may come under the influence of this transient electromagnetic field. The surge arresters used in the substations can not suppress the steepness of the wave because they are too slow to prevent the switching tansients having steep front [5]. The study of these VFTOs are done by simulating the equivalent model of the GIS. The GIS components are simulated by taking equivalent values of inductance and capacitances. The modeling of the GIS components has be discussed in [6,7,8]. The factors affecting the VFTOs are discussed in [9]. The mitigation of these VFTOs is a very important issue of the GIS. There are some mitigation techniques developed which has been extensively used by the industries like shunt resistors [10], ferrite rings [11-15] and RC filters [16] etc. There is still need to be more exploration in this area of the development of more reliable and effective techniques to mitigate the VFTOs of the gas insulated substation. Some important mitigation techniques which are mostly used by industries today are discussed in the paper.

In this paper very fast transient overvoltages generated due to the switching operations are investigated at the different junction pints of the gas insulated substation using EMTDC/PSCAD. The GIS is simulated by using the equivalent models of the different components of the gas insulated substation. The effect of trapped charges on the VFTOs is also discussed. The mitigation methods of these VFTOs are also discussed in this paper. Section-II describes the modeling of GIS componets.Section-III describes the results and discussions. In the section-IV, mitigation techniques of VFTOs are discussed. Finally, conclusion is given in section-V.

II. MODELING AND SIMULATION OF GAS INSULATED SUBSTATION

Different components of the GIS can be modeled in to lumped elements due to the traveling nature of the transients. These lumped elements are defined by surge impedances, GIS sections and wave velocity [6,7].

$$C = \frac{2\pi\varepsilon_\circ\varepsilon_r}{\ln R/r}, \quad L = \frac{\mu \ln R/r}{2\pi}, \quad Z_\circ = \sqrt{L/C},$$

$$v = 1/\sqrt{LC} \qquad (1)$$

Where C and L are the capacitance and inductance of the GIS busbar, $Z_\circ$ is the surge impedance, r and R are the outer radius of GIS busbar and inner radius of GIS enclosure. In Table-1, the equivalent circuit models used in the modeling of GIS components are given.

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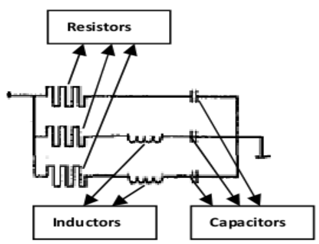
Table-1 GIS modeling data [6,9]

Componets	Values
GIS bus bar	Tramsission line with distributed parameters with $Z_\circ$=90 Ω, 270 m/µs
DS, CB and earthing switch	(a) Closed position (42 Ω), (b) Open position (4 pF) (c) During Operation eqn(2) 
Potential Transformer (PT)	300 pF
Current Transformer (CT)	300 pF
Power Transformer (Termination)	
Surge arrester	15 pf in series with grounding resistance of 0.1 Ω
Cable	Tramsission line with distributed parameters with $R_\circ$=0.0010679 ohm/m, $Z_\circ$=30Ω, v= 165 m/µs
Overhead transmission line	$Z_\circ$=350Ω, v= velocity of light

The behaviour of disconnector switch at the time of operation can be modeled by considering the arc resistance i.e. exponentialy decreasing resistance in series with the resistance of fixed magnitude as shown in eqn.(2). The graph of arc resistance can be seen in figure-1.

$$r = R + R_\circ e^{-t/\tau} \qquad (2)$$

Where $R_\circ = 10^{12}\Omega$, $R = 0.5\Omega$ & $\tau = 1$ ns

For input a ac voltage source of 1 p.u= $420*\frac{\sqrt{2}}{\sqrt{3}}$ = 342.9 KV is applied [1]. The layout of the GIS is shown in figure-2. The VFTOs are studied for closing opration of the disconnector. The circuit breaker CB2 is open and CB1 and CB3 are closed during the closing operation of disconnector.

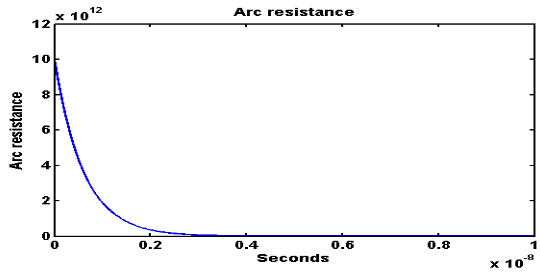


Figure-1 Arc resistance of disconnect switch

The total simulation time of 4 µs with the simulation step size of 0.1 ns is taken for the investigation.

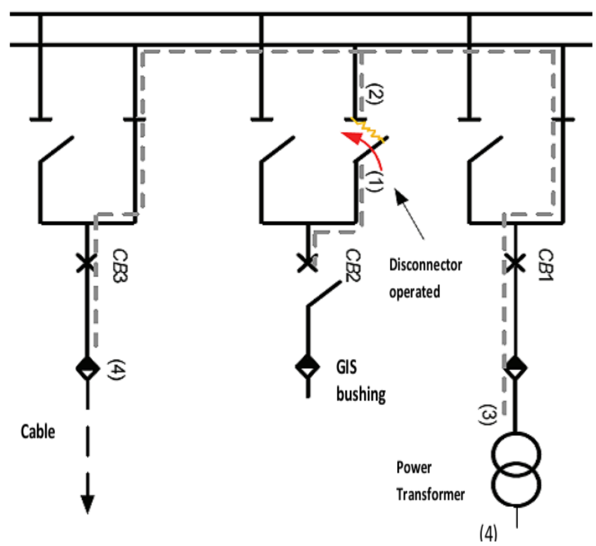


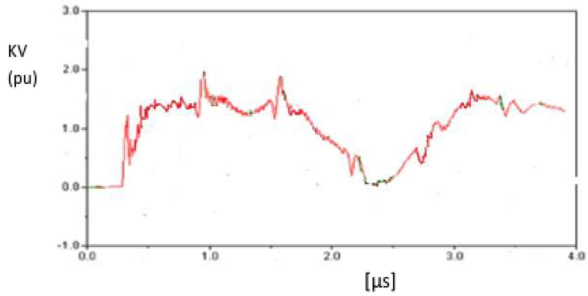
Figure-2 GIS layout for VFTOs analysis

III. RESULTS AND DISCUSSIONS

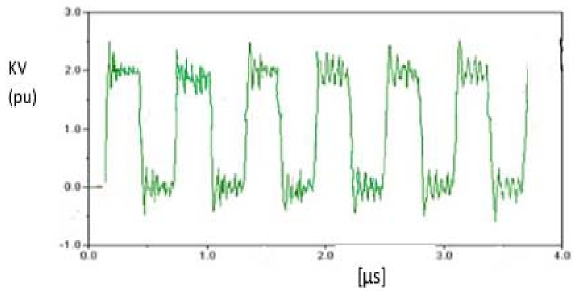
The waveforms of the VFTOs and their peak magnitudes obtained from the simulation studies of the GIS model are shown below.

(a) At the power transformer terminals:

The VFTOs are calculated at both primary and secondary side is that at position-3 and position-4 of the power transformer. The waveforms of the transients for 0 pu trapped charge only are shown in figure-3. All the peak values of the generated transients are shown in Table-2. It can be seen that in the worst case of trapped charge of -1 pu, the peak value can go up to 4.01 and 5.10 pu at the primary and secondary of the power transformer respectively. Hence it can be observed from the table that the peak magnitudes of the VFTOs are increasing as the value of trapped charge is increasing.



(a)



(b)

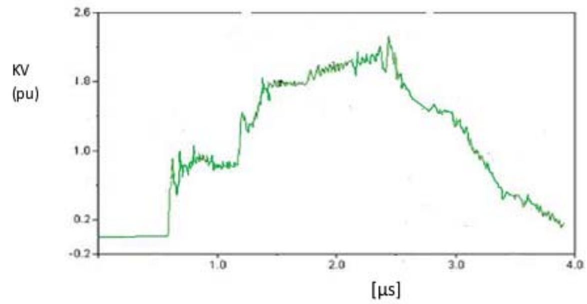
Figure-3 Power transformer transient waveforms (a) at primary side (b) at the open end (0 pu. trapped charge)

Table-2 Peak magnitude of VFTOs

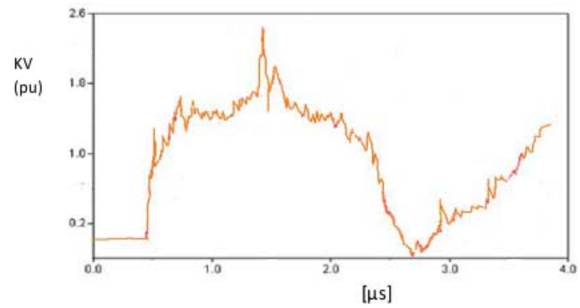
Trapped charge	0 pu	-0.5 pu	-1 pu
Primary side (position 3)	1.9 pu	2.98 pu	4.01 pu
Open side (Position 5)	2.4 pu	3.99 pu	5.10 pu

(b) For different terminal components connected to power transformer terminals (at position-3) in the GIS:

The terminal components connected to the GIS also affects the frequency and peak magnitude of the VFTOs [17]. These terminal components may be overhead transmission lines, gas insulated line (GIL) and cables. The proper selection of the components may reduce the transients considerably. The transients waveforms generated at the power transformer terminals (at position-3) for different terminal components (here cable &GIL is taken) are shown in figure-4. It can be seen from the figures that peak values of the transients are decreased when the cable is used in place of GIL for the same length of the connections. It is due to the fact that cable attenuates the transients due to its capacitance to ground. The VFTOs are also affected by the configurations of the plant.



(a)

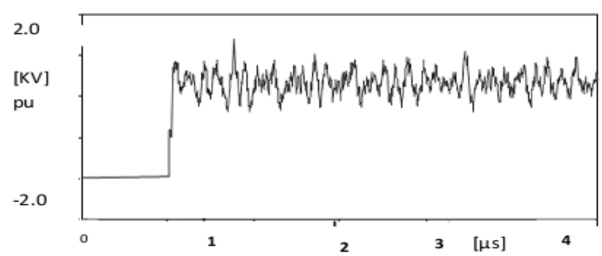


(b)

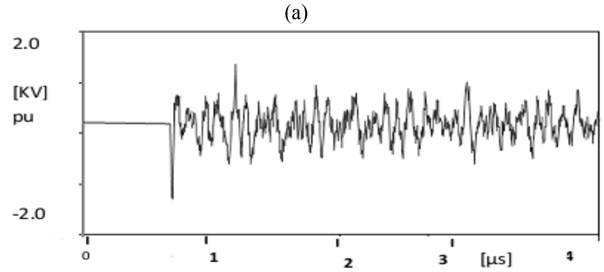
Figure- 4 Transient waveforms at power transformer terminals for (a) cable & (b) Gas insulated line (GIL) connection

(c) At the disconnector terminals(at position 1 & 2):

The transient over voltages at both load and source side of the disconnector are shown in figure-5. The load side of the disconnect switch is preloaded with the trapped charge of -0.5 pu. The transients have different peak magnitudes and frequency of oscillations at both side of the disconnect switch. As the trapped charge is increased to -1 pu., the peak values of the transients are also increased shown in Table-3.



(a)



(b)

Figure-5 VFTO waveforms of the disconnector at (a) load side & (b) source side (-0.5 pu trapped charge)

Table-3 Peak magnitude of VFTOs

Trapped charge	0 pu	-0.5 pu	-1 pu
Load side (position 1)	1.66 pu	1.8 pu	2.01 pu
Source side (position 2)	1.71 pu	1.9 pu	2.15 pu

(d) At the GIS-cable termination point:

The VFTOs waveforms at the GIS-cable termination point (at position-4) is shown in figure-6. The Table-4 represents the peak magnitudes of the VFTOs for the trapped charges of 0 pu, -0.5 pu and -1 pu respectively.

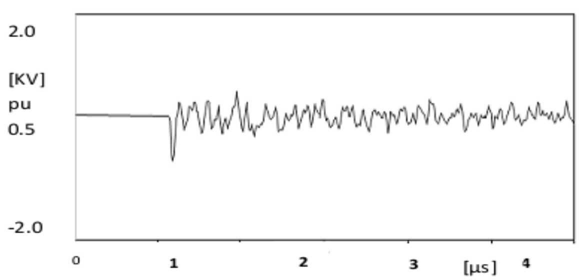


Figure-6 VFTOs at GIS-cable termination point

Table- 4 Peak magnitude of VFTOs

Trapped charge	0 pu	-0.5 pu	-1 pu
GIS cable termination (Position 4)	1.30 pu	1.45 pu	1.55 pu

The above simulation study shows the VFTOs waveforms and peak magnitudes generated due to the switching operations at the different junction points of the GIS. These VFTOs have different peak values depending the type and location of the point at which the VFTOs are calculated.

IV. VFTOs Mitigation Techniques

There are a lot of researches are going on to find the optimum methods to suppress these VFTOs. Generally, fast operating disconnectors are used to reduce the break down time. But still it cannot eliminate the VFTOs completely. There are some techniques which are used recently to reduce these VFTOs are discussed here.

(a) Disconnector switching using shunt/ damping resistors:

Using the shunt resistors with disconnector in closing and opening operations reduces the VFTOs in GIS [10]. Shunt resistor connected to disconnector is shown in figure-7. In the opening operation, the main contact breaks first. The remaining charge on the stationary contact leaks through shunt resistor, then vice contact breaks. In the closing operation, vice contact closes first. The current flows through the shunt resistor, and then main contact closes. The transient decay process is accelerated by shunt resistors. This method is also effective for the suppression of VFTOs at the open ends of the GIS components

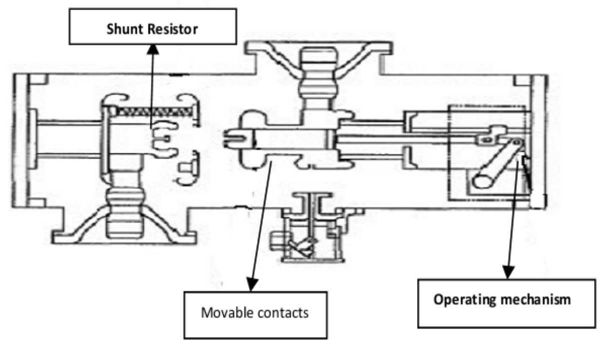


Figure-7 Disconnector with shunt resistor.

(b)Using Ferrite Ring:

Ferrite is magnetic material of high frequency, which is non-linear in nature. These rings are placed around the conductor shown in figure-8 [11-15]. These rings absorb the transient energy when the Pre/Re-strike occurs in the closing/opening operation of the disconnector switch. The ferrite rings can be represented by a nonlinear inductor and nonlinear resistor connected in series with the conductor of the GIS. The typical values of the equivalent resistance of ferrite rings is taken equal to the surge impedance of busbar while equivalent inductance value taken as 0.02 mH [12]. The main drawback of this method i.e. the ferrite rings may saturate at any instant due to high magnitude and high frequency of the VFTOs.

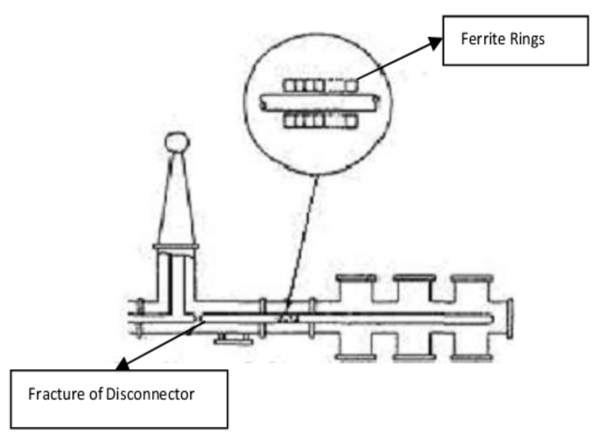


Figure-8 Ferrite rings used in disconnect switch [11-15] *(c) Use of RC filters:*

For the protection of loads RC filters are widely used. The resistance R is used to attenuate the energy while the capacitor C is used to reduce the oscillation frequency. These RC filters are paralleled next to the power transformer to protect it from the VFTOs. The typical values of R for different types of loads are in the range of 50 to 400 ohms and that of C in the range of 0.01 to 0.2 μF [16]. The RC filters can effectively suppress the VFTOs but they have no effects on the open ends of the GIS components. This method is used to protect the transformers only.

V. CONCLUSIONS

The magnitudes of the VFTOs are affected by the distances from the operating switch. The trapped charges in the switching operations also affect the peak magnitudes of the VFTOs. It was observed, with the increase in the trapped charge, the peak magnitudes of the transients are also increased. It can be seen that peak magnitude of VFTOs at the power transformer are increased by approximately by 110% as the trapped charge increased from 0 pu to 1 pu.

The VFTOs are considerably influenced by the length and type of the components used at the terminals of the GIS. It was observed that VFTOs generated at the terminals of the power transformer have lesser peak magnitudes in case of cable connection than that of gas insulated line (GIL) connection. In this way, the study of VFTOs at the different sensitive locations of a 400 KV GIS has been done. The different mitigation techniques of VFTOs were also discussed in this paper. It was found from the discussion that RC filter techniques have no effects on the open ends of the GIS while the ferrite rings may saturate due to high magnitude and frequency of VFTOs. Hence, the use of shunt resistors is more reliable than the other methods. These techniques are widely used by industries to suppress the VFTOs in the gas insulated substations.

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BIOGRAPHIES

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