Analysis and Mitigation Methods for VFTO'S and VFTC'S in A 420kv GIS

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Abstract*— In a Gas Insulated Substation (GIS), Very Fast Transient Over voltages (VFTO) are generated due to switching operations and Fault conditions. These transient over voltages and the associated Very Fast Transient Currents (VFTC) develop transient Electromagnetic (EM) fields during its propagation through HT conductor in a GIS. The transient Electromagnetic fields due to VFTO's and VFTC's causes' great effect on the insulation of equipments connected to the GIS. These transients are associated with very short rise times in the nanoseconds range, and are normally followed by oscillations in the MHz frequency range. To evaluate the magnitudes at various locations, it must be performed an accuracy analysis on the wave shape and level of the VFTO and VFTC. In this paper the modeling of 420KV GIS station is carried out and analyzed the magnitudes, proposed the effective mitigation methods to suppress the level of the VFTC and VFTO is investigated and the beneficial approaches for the industry to finding the optimum approaches for VFT mitigation, is presented. Simulations are performed with more accurate modeling of GIS system model. Electro Magnetic Transient Programming (EMTP) is used to evaluate the VFTO's and VFTC's at the sensitive points in GIS. The different results are compared to determine the effective mitigation method.

***Keywords*— Disconnector switching, Ferrite Rings, GIS, mitigation techniques, VFTC, VFTO.**

I. INTRODUCTION

Gas-insulated substation (GIS) is widely used in electric power system in recent decades because of the advantages such as compact size, protection from pollution, a few maintenance, and high reliability. In spite of these advantages, GIS has its unique problems, due to reflections of switching transients at various junctions within the GIS the voltage increase very fast [1,2]. These transients are originated within a GIS any time there is an instantaneous change in voltage. These transients have a very short rise time, in the range of 4 to 100ns, and are normally followed by oscillations having frequencies in the range of 100kHz to 50MHz [2]. Internal transient create overvoltage between conductor and enclosure which can cause stress on the internal insulation of the GIS. This wave will travel from GIS bushing to external components, which can lead to damage the insulation of internal busbar and transformer, which influent the operating reliability of GIS, accelerate aging of transformer insulation and reduce transformer life [1-3]. Also Very fast transient over voltages (VFTOs) associated with very fast transient currents (VFTCs) radiate electromagnetic fields during its propagation through the coaxial GIS bus section. The transient electromagnetic fields get coupled to the control equipment or data cables present in the GIS [4]. This paper investigates the very fast transient overvoltages resulted from the operation of disconnector switches and faults at different sensitive points in the GIS and some of effective factor affect on generation of VFTO and VFTC. There are methods to suppress the stresses created by VFT from the source side. Damping resistor and Ferromagnetic rings can be mounted on the conductors linked to the disconnector from both sides in order to effectively suppress both the steepness and the amplitudes of VFT [5]. However, these methods are suitable before installing the substation and during the substation design period. This paper presents feasible methods for suppression of the overvoltage magnitude caused by VFTO and VFTC in a GIS. Simplicity, low cost implementation as well as minimum changes in the installed GIS (which are currently under operation) are the main characteristics of these methods. The EMTP package program is used in simulation through this work.

II. MODELLING OF 420KV GIS

Due to the traveling nature of the transients the modeling of GIS makes use of electrical equivalent circuits composed by lumped elements and especially by distributed parameter lines, defines by surge impedances and traveling times. The inner system, which consists of the high voltage bus duct and the inner surface of the encapsulation, has been represented thoroughly by line sections modeled as transmission lines with distributed parameters. Table.1 displays the electrical equivalent circuits and related information for modeling of GIS component. The equivalent circuit parameters are derived from the following calculations [6].

$$L = 0.001 \times l \times \left[ln\left(\frac{r_1}{r_3}\right) + ln\left(\frac{r_2}{r_1}\right) + ln\left(\frac{r_4}{r_3} + 2 * \frac{\left(\frac{r_2}{r_1}\right)^2}{1-\left(\frac{r_2}{r_1}\right)^2} * ln\left(\frac{r_1}{r_2} - 1\right)\right)\right] \quad ---- -(1)$$

The inductance of the bus duct can be calculated by using the equation (1), where r_1, r_2, r_3, r_4, are the radii of the conductors in the order of decreasing magnitude and 'l' is the length of the section.

The Capacitance is calculated with the assumption that the conductors are Cylindrical.

Capacitance is calculated by using the standard formulae given below.

$$C = \frac{2 * \pi * \varepsilon_0 * \varepsilon_r * l}{2.3 * ln_{10}\left(\frac{b}{a}\right)} \quad ------(2)$$

Where 'ε_o' is taken as 8.854 * 10^{-12}, 'ε_r' is relative permittivity of aluminium 'b' is outer cylinder radius, 'a' is inner cylinder radius and' $'l'$ is length of the section. Spacers are used for supporting the inner conductor with reference to the outer enclosure. They are made with Alumina filled epoxy material whose relative permittivity (ε_r) is 4. The thickness of the spacer is assumed to be the length of the capacitance for calculation. The typical lengths of a GIS bus are much smaller than an ordinary substation and also, at high frequencies in the range of few hundreds of kHz to MHz, the GIS bus acts like a transmission line with a finite transit time and propagation velocity. The value of surge impedance of GIS bus bar which is modelled as transmission line can be obtained from the relation

$$Z = 60\ ln\left(\frac{b}{a}\right)\ \Omega ------(3)$$

Where 'a' is the diameter of the HV bus and 'b' is the inner diameter of the enclosure and is found to be 64.2Ω.

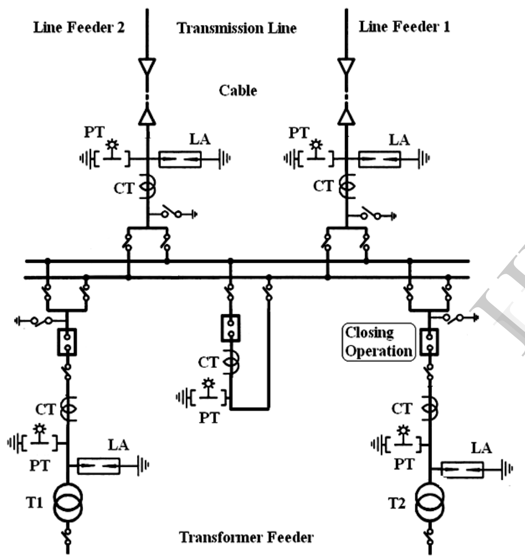

FIG. 1 ELECTRICAL EQUIVALENT CIRCUIT OF A 420KV GIS

Figures 1 show the Electrical equivalent circuit of a 420kV GIS. Also the trapped charge is considered at 1.0 p.u. During the closing operation of switches, the sparks is modeled by a fixed resistance in series with an exponentially decreasing resistance [6].

$$R\,t = R\,e^{-t/\tau} + r_0 \qquad (4)$$

TABLE. 1 ELECTRICAL EQUIVALENT CIRCUIT COMPONENTS

COMPONENTS	EQUVALENT VALUES
GIS Bus Bar	z_0 = 90 ohm v = 270 m/μs
CB, DS, and Earthing Switch	In the closed position: impedance (70 ohm)
	In the open position: capacitance (45 pF)
Potential Transformer (PT)	300 pF
Current Transformer (CT)	300 pF
Capacitive Voltage Transformer (CCVT)	5 nF
Bushing	400 pF
Power Transformer	2 nF
Arrester	Discharge Voltage (10kA):870kV
Cable	R_0 = 0.0010679 ohm/m z_0 = 30 ohm v = 165m/us

III. CONCEPT OF VFTO AND VFTC

Due to the travelling wave behaviour of the VFT the over voltages caused by the disconnector switches show a spatial distribution. Normally the highest overvoltage stress is reached at the open end of the load side. The maximum value of the local VFT overvoltages is dependent on the voltage Δv at the disconnector just before striking and on the location considered. For the calculation of the VFT stress the trapped charge remaining on the load side of the disconnector must be taken into consideration. For a normal disconnector with a slow speed the maximum trapped charge reaches 0.5 pu resulting in a most unfavourable voltage collapse of Δv = 1.5 pu. For these cases the resulting over voltages are in the range of 1.7 pu and reach 2.0 pu for very specific cases. In case of a high speed disconnector the maximum trapped charge could be 1.0 pu and the highest overvoliages reach values up to 2.5 pu. In some cases extreme high values of more than 3 pu have been reported. It can be shown, however, that these values have been gained by calculation using unrealistic simplified simulation models.

The amplitude of VFTC, attenuation of the amplitude of VFTC with distance and time, dominant frequency components of the VFTC, variation in the frequency content of VFTC with distance are the parameters that characterize the VFTC are of more relevance for the protection of GIS controls.

IV. SUPPRESSION METHODS

4.1. Damping Resistor

As the DS movement is relatively slow, and do not have the ability of arc extinction by itself, easy to arc resignation, the actual GIS in practical application is usually use of co-gate resistance. Based on previous research, select opening and closing resistance is 500Ω. Compare to no opening and closing resistance, the amplitude is 461.43kV which is decrease to 4.2%. But the max steepness of waveform is much lower, only 0.222MV/μs.

4.2. Ferrite rings

Ferrite material has different characteristics of saturation magnetic conductivity, frequency response and loss. These characteristics influence the VFTO suppression effect. The suppressing effect on VFTO is determined by equivalent inductance of magnetic ring that relate to the size and the magnetic conductivity of ferrite ring. Because of the high frequency character of the ferrite ring, fixing it on the GIS conductor bar is equivalent to connecting impedance and inductance between the switch and bus bar. So, it is modeled as resistor and inductance, when the equivalent resistor of the ferrite ring is equal to the surge impedance of GIS bus bar and the equivalent inductance is 0.02mH. Figure 2 shows the equivalent circuit of ferrite ring [7].

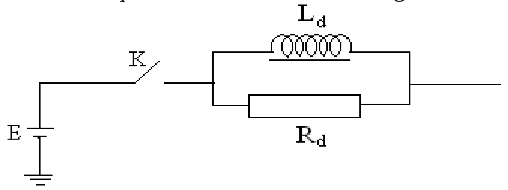

FIG. 2 EQUIVALENT CIRCUIT OF THE FERRITE RING.

For effectively suppressing VFTO, the saturation magnetic flux density and the initial magnetic conductivity of the ferrite ring should be large enough. To suppress the effect of VFTO and VFTC the ferrite rings are installed at all the four GIS system near the operating switch (i.e. CB3) for the switching event.

V. RESULTS AND DISCUSSIONS

Gas Insulated Substation is modelled with an accurate component values. The simulation of VFTO's and VFTC's are performed using EMTP. Voltage levels at various locations are observed. It has been observed that VFTO levels are 2.84pu during disconnector closing operation near the circuit breaker leads to more oscillation frequency shown in Fig.3. The VFTC's observed that it is more oscillatory. The effect of VFTC's are observed from EMTP simulation near the Circuit breaker as shown in Fig.4. The Damping resistor of 500Ω is included in the switching operation of the disconnector and observed the VFTO levels at different places. It is observed that VFTO levels are reduced to 2.5pu and lesser values of oscillation frequency shown in Fig.5. VFTC's with 500Ω are shown in Fig.6.New method of suppressing VFTO's have been carried out by modelling the ferrite rings. The steepness and maximum peak values are reduced to considerable amount. The VFTO levels are reduced to 2.10pu and very less values of oscillation frequency shown in Fig.7. The effect of current oscillations is almost negligible with ferrite rings are shown in Fig.8. Similarly the measurement of VFTO's and VFTC's are observed from the simulation at different locations in the GIS. A result shows that the VFTO and VFTC levels are reduced with damping resistor. Difficulty with the Damping Resistor is its heat losses during the operation and maintenance issues. Ferrite Rings provides the better solution to suppress the VFTO's and VFTC's and also over comes the drawbacks with damping resistor. Figures show VFTO's and VFTC's are greatly reduces its magnitudes and oscillations with ferrite rings in GIS.

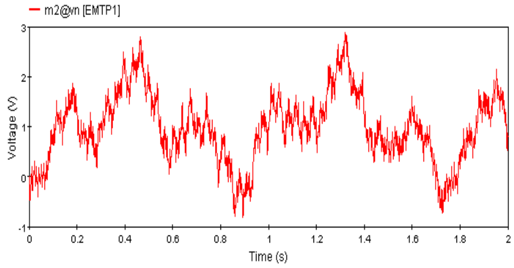

FIG. 3 VFTO AT CB DURING DISCONNECTOR CLOSING OPERATION.

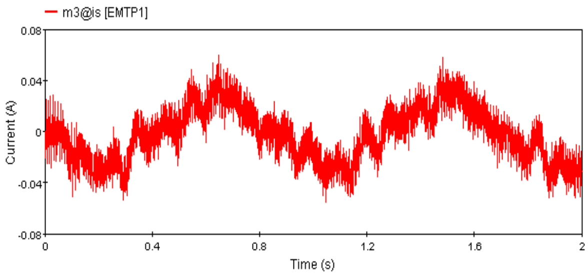

FIG. 4 VFTC AT CB DURING DISCONNECTOR CLOSING OPERATION.

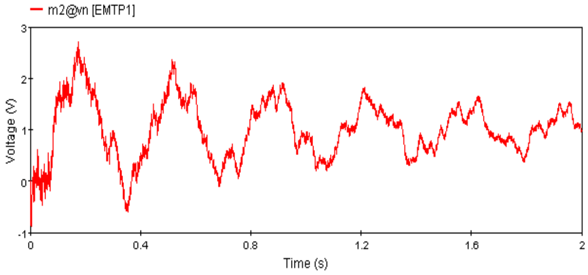

FIG. 5 VFTO AT CB DURING DISCONNECTOR CLOSING OPERATION *WITH DAMPING RESISTOR*.

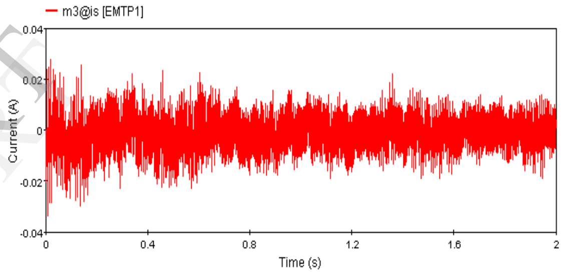

FIG.6 VFTC AT CB DURING DISCONNECTOR CLOSING OPERATION *WITH DAMPING RESISTOR*.

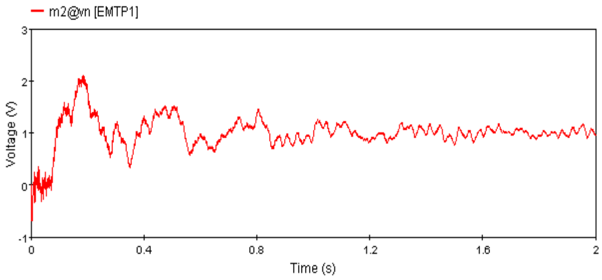

FIG.7 VFTO AT CB DURING DISCONNECTOR CLOSING OPERATION *WITH* FERRITE RINGS.

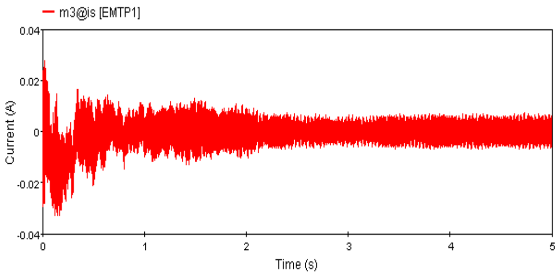

FIG.8 VFTC AT CB DURING DISCONNECTOR CLOSING OPERATION W*ITH* FERRITE RINGS.

VI. CONCLUSIONS

Detailed electro-magnetic simulation studies on different switching scenarios should be conducted to provide necessary information for assessing the risk and developing appropriate mitigation measures to protect equipment from being damaged and to ensure supply reliability to customers. The VFTOs and VFTC's obtained due to switching operations in various GIS are simulated. In this work an attempt is made to reduce the peak magnitude of VFTO's and VFTC's using ferrite rings. The steepness and maximum peak of the transient over voltages are reduced with application of ferrite rings is observed. It has been shown that there is a reduction of 26% in the peak magnitudes of the VFTO at the important nodes with the application of ferrite rings. With the effect of Ferrite rings VFTC's at the different points are observed to be reduced and most importantly the oscillations of the currents are reduced drastically. With effective design and use of the same can effectively reduce the steepness and maximum peak of VFTO generated and much VFTC oscillations.

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