Nanocrystalline to Suppress VFTO and VFTC for 245kV Gas Insulated Substations

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ABSTRACT

Switching of disconnectors (DS) and various faults in Gas Insulated Substation (GIS) causes number of pre-strikes and re-strikes happens. The short duration voltage collapse, traveling surges in busbar causes Very Fast Transient Over voltages (VFTO) and Very fast Transient Currents (VFTC) in the GIS substation. The main challenge is to reduce VFTO and VFTC amplitudes. Several methods have been proposed and examined in the past, such as damping Resistor and Ferrite rings. The VFTO and VFTC damping solutions utilizing damping Resistor, ferrite rings has been analyzed using most popular and widely used software package Electro Magnetic Transient Programming (EMTP). The simulation of mitigation methods like damping resistor and Ferrite rings shows that a damping effect can be achieved. The damping resistor suffers with the difficulty of inserting inside the busduct and the other one is Ferrite magnetic material rings goes easily into saturation, which complicates the design and reduces its general applicability and robustness. This paper investigates the new techniques to suppress the VFTO and VFTC in a 245kV GIS substation by considering the complete substation model for simulation using EMTP. Rings of a Nanocrystalline alloy placed around the GIS conductor were investigated, developed the equivalent model and simulated using EMTP. Prominent results have been achieved with the Nanocrystalline models.

Keywords

Damping Resistor, EMTP, GIS, Ferrite rings, Nanocrystalline rings, VFTC, VFTO.

1. INTRODUCTION

With ever increasing demand of electrical energy there is need for additional substations. For conventional substations, the yard equipment occupies comparatively large area in addition to the area required for construction of Control Rooms. It is estimated that Gas Insulated Substations require approximately one tenth of the area required for conventional substations in view of the fact that Gas Insulated Switchgear is enclosed in metallic chambers. The GIS systems suffer with some of the issues. Very Fast Transients (VFT) belong to the highest frequency range of transients in power systems [l]. These transients are originated within a gas-insulated substation as the result of the opening or closing of a disconnect switch [2], but other events, such as the operation of a circuit breaker, the closing of a grounding switch, or the occurrence of a fault, can also cause VFT. These transients have a very short rise time, in the range of 4 to 100 ns, and are normally followed by oscillations having frequencies in the range of 1 to 50 MHz [l],[2]. The travelling wave which is originated by an ignition propagates in the GIS and can result in VFTO and VFTC. The level and wave shape of VFTO and VFTC depends on the GIS configuration, the measuring point and the disconnector characteristics (speeds of contacts, asymmetry of inter contact breakdown voltage). For dielectric purposes, only the largest and steepest voltages are of concern; they are generated by those ignitions at the largest contact gaps, so only a few breakdowns need be considered [2]. Due to VFTO and VFTC's, the dielectric strength of SFs in the presence of free metallic particles is reduced considerably and may lead to flashover. VFTO can also influence the insulation of other GIS components such as transformers where the inter turn insulation may be stressed with a higher voltage than under chopped lightning impulse voltages [3]. Hence, there is a need to estimate the magnitudes of VFTO and VFTC generated during switching operations in GIS. This paper covers the estimation of VFTO at various locations in a GIS for different switching operations. Many researchers estimated the VFTO and VFTC by considering the busduct model of GIS [4]. A 245 kV GIS has been taken up for the simulation of VFT's during switching of various disconnectors and circuit breakers. Here a 245 kV GIS complete substation model is considered for estimation of VFTO and VFTC. VFT's suppression is proposed by many researchers using damping resistor and Ferrite rings [4] [5]. This paper introduces the new method of suppressing the VFTO and VFTC using Nanocrystalline rings.

2. MODELING OF 245kV GIS

To model GIS components, lumped elements and distributed parameters can be used, that is defined by surge impedances, wave velocity and lengths of GIS section. A one line diagram of the 245 kV GIS is shown in Figure.1 used for analysis of VFTO and VFTC in a GIS [5]. To model GIS components, lumped elements and distributed parameters can be used, that is defined by surge impedances, wave velocity and lengths of GIS section.

$$C = \frac{2\pi\epsilon_0\epsilon_r}{\ln b/a} \quad \text{--- (1)}$$

$$L = \frac{\mu \ln b/a}{2\pi} \quad \text{----- (2)}$$

$$Z_0 = \sqrt{\frac{L}{C}} \quad \text{--------(3)}$$

$$v = \frac{1}{\sqrt{LC}} \quad \text{-------(4)}$$

$$\tau = \frac{l}{\sqrt{LC}} \quad \text{-------(5)}$$

Where C is the Capacitance, L is the inductance, Z_0 is the surge impedance, ν is the propagation velocity and τ is the travelling time.

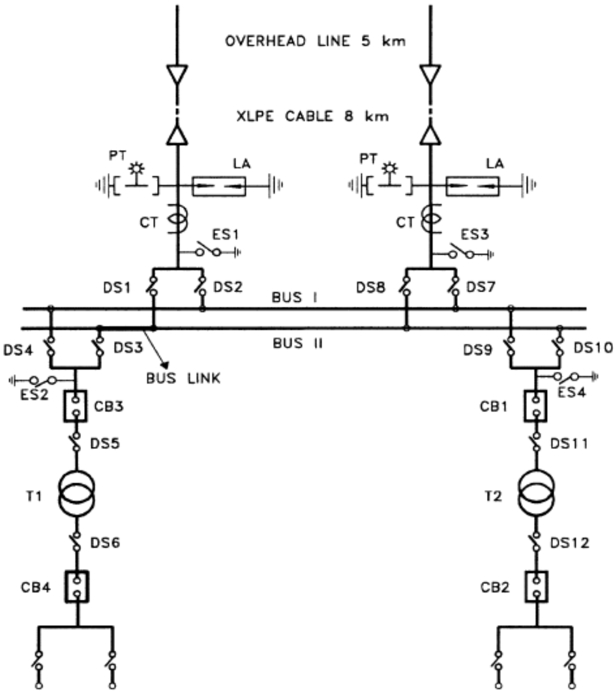

Fig.1 Single-line diagram of a 245-kV GIS.

The equivalent GIS components are given in Table1.

Table I. Electrical Equivalent GIS Components [6],[7],[8]

Spacers	Capacitance of 15pF towards ground
Open ends	Capacitance of 15pF towards ground
ES	Capacitance of 45pF towards ground
CT	Transmission line of surge impedance 70Ω and lumped capacitance of 50pF towards ground
PT	Capacitance of 100pF towards ground
LA	Capacitance of 200pF towards ground
DS	Transmission line of surge impedance 70Ω and capacitance of 30pF towards ground on either end of the contacts. In open condition, a capacitance of 30pF between contacts
CB	Transmission line of surge impedance 46Ω and capacitance of 30pF towards ground on either end of the contacts. In open condition, a capacitance of 50pF between contacts.
Gas to Air Bushing	Transmission line of surge impedance 250Ω and capacitance of 30pF towards ground on either end of the bushing.
XLPE cable	Transmission line of surge impedance 30Ω and propagation velocity is 150m/μs. Cable termination is simulated with a capacitance of 400pF towards ground.
TI	Capacitance of 2nF towards ground.

3. VFTO AND VFTC

VFTO appearing in GIS are caused not only by DS operation. Other events, such as the operation of a circuit-breaker, the occurrence of a line-to-ground fault or the closing of an earthing switch can also cause VFTO and VFTC [10]. However, during a DS operation a high number of re-strikes and pre-strikes occur due to the low operating speed of Disconnector compared to a circuit-breaker. A flashover or breakdown within GIS produces VFTO and VFTC. Therefore the breakdown to earth is of special concern during on-site testing. Because of the trapped charge voltage remaining on the busbar, a making operation of an earthing switch can produce VFTO. Circuit-breaker may also generate transients in GIS. But due to their very fast operation only a few number of strikes occur. VFTO occur during making of CB. Especially under out-of-phase conditions, the amplitude can reach values up to 3pu. A larger number of re-strikes may occur for the special case of switching of small inductive current during shunt-reactor switching. The parameters that characterize the VFTC are of more relevance for the protection of GIS controls and are the amplitude, attenuation of the amplitude, dominant frequency components and variation in the frequency content of VFTC with distance.

4. SIMULATION OF 245kV GIS

Due to the traveling nature of the VFTO the modeling of GIS makes use of electrical equivalent circuits composed by lumped elements and especially defined by surge impedances and traveling times. The quality of the simulation depends upon surge impedances and traveling times, and also on quality of the model of each individual GIS component. In order to achieve reasonable results highly accurate models for all internal equipment components connected to the GIS are necessary. Table I gives the electrical equivalent representations of various components of 245kV GIS. Fig. 2 shows the equivalent EMTP model diagram of a 245 kV complete GIS system.

The incoming line of the GIS is comprised of an overhead transmission line of 5-km length, an XLPE cable of 8-km length, PT, lightning arrester (LA), earth switch (ES), disconnector switch (DS), etc. The XLPE cable and the power transformer (T1) locations are assumed as source and load side of the switch being operated, respectively. The most onerous condition during a switching operation is given for a voltage collapse of 2 p.u. (i.e., 1 p.u. on the source side and -1 p.u. on the load side) and this has been simulated in the present study. The equivalent circuits for GIS components and the spark channel that develops between the switching contacts are essential for calculating the transient current levels. The gas breakdown between the switching contacts during its operation is simulated as a series connection of time-varying resistance and a fixed inductance of 5 nH. In the present study, time-varying resistance during the buildup of the spark channel is simulated by a fixed resistance in series with an exponentially decreasing resistance.

$$R = R_0\, e^{-t/\tau} + r \quad \text{--------(6)}$$

Where R_0 is 1012 Ω, τ is 1 ns and r = 0.5 Ω.

A fixed resistance of 2.5 Ω has been assumed for the spark channel after the spark collapse time. The amplitude and waveforms of the VFTO and VFTC have been estimated using EMTP.

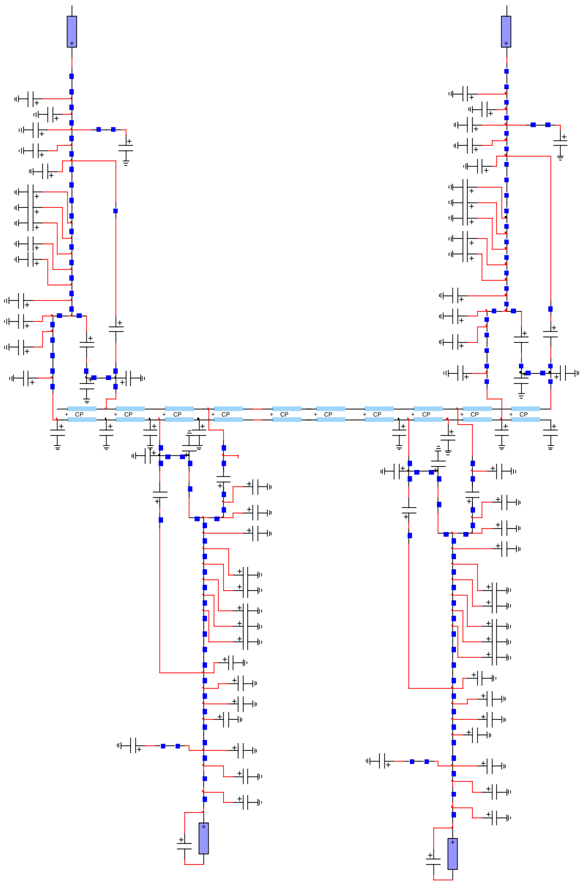

Fig. 2 Equivalent EMTP model for 245kV GIS.

5. SUPPRESSION METHODS

Suppression of VFTO and VFTC can be used with different methods. The damping of VFTO by integration of a damping resistor is a well proven technology [2]. Another method is by using Ferrite rings [4]. The new method is introduced for suppression of VFTO and VFTC in a 245kV GIS complete substation model.

5.1. Damping Resistor

The resistance of the damping resistor could be chosen and defined according to the maximum calculated VFTO and the required mitigation effect. The VFTO decreases with increasing resistance; and the dimension of the disconnector increases with increasing resistance. In addition special requirements regarding the rate of rise of the voltage across the resistor, the energy absorption and the branching behavior must be taken into account. A flashover across the resistor may lead to very high amplitude VFTO compared to a DS without such a damping resistor, and thus must be avoided. The way to overcome the drawback of such unwieldy designs is to use other internal damping measures. Based on previous research, select opening and closing resistance is 100Ω. Fig.3 shows the equivalent circuit for damping resistor.

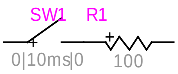

Fig.3 Equivalent damping Resistor model

5.2 Ferrite Rings

The Transient voltage and currents are possible to damp to the reasonable levels using ferrite rings has been proposed and investigated in the literature. Mostly the ferrite rings were tested under low voltage conditions or simulations were carried out [4]. In this paper the results of high voltage tests with different ferrite rings and ferrite arrangements are simulated. The rings were placed around the inner conductor inside the GIS. For the simulation tests the GIS setup with inductor and resistor are connected in parallel are considered as equivalent model for the ferrite rings. Fig.4 shows the equivalent model for Ferrite rings.

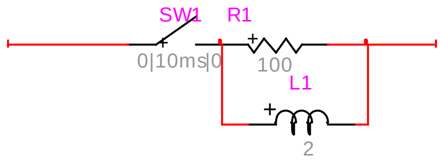

Fig.4 Equivalent Ferrite ring model.

In comparison to previous studies the current through the rings is much higher but represents the situation in real GIS. The impedance of the GIS setup is approximately 70 Ω. Therefore, the intensity of the magnetic field around the conductor is also very high. This high magnetic field saturates the ferrite material completely. As a consequence the damping effect is reduced to a marginal value. By layering of ferrite rings it is possible to increase the magnetic field strength at which the material saturates. On the other hand layering of rings with a material of lower permeability also reduces the effective permeability. Therefore, the damping efficiency of the whole ring arrangement decreases. Based on the test results it could be concluded that the damping effect of ferrite rings inside the GIS for HV applications is limited. The reason is the high current of VFTOs which causes a completely saturation of the ferrite material. Saturated ferrite materials lose their damping capability.

5.3 Nanocrystalline Rings

Very promising results were found by using rings of a Nanocrystalline alloy. To obtain VFTO and VFTC mitigation these rings are arranged around the inner conductor of the GIS like the ferrite rings. Experiments with different ring types, different sizes and different numbers of rings were carried out by ABB Switzerland [11].

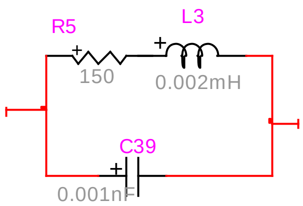

Fig.5 Equivalent Nanocrystalline ring model.

The equivalent models for Nanocrystalline materials are developed and used for simulation. Fig.5 shows the equivalent Nanocrystalline Rings model for simulation. In this model the values of R, L and C have been selected such that this will give better suppression results compared with other values. Finally the value of R is 150 ohms and L is 0.002mH and C is 1pF. This model response is compared with the real time test models response conducted by the ABB Switzerland and satisfactory accuracy obtained.

6. RESULTS AND DISCUSSIONS

Gas Insulated Substation is modeled 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 2.88pu during disconnector closing operation near the circuit breaker leads to more oscillation frequency shown in Fig.6. 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.7. The Damping resistor of 100Ω 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 1.71pu and lesser values of oscillation frequency shown in Fig.8. VFTC's with 100Ω are shown in Fig.9. Another method of suppressing VFTO's have been carried out by modeling the ferrite rings. The steepness and maximum peak values are reduced to considerable amount. The VFTO levels are reduced to 1.19pu and very less values of oscillation frequency shown in Fig.10. The effect of current oscillations is almost negligible with ferrite rings are shown in Fig.11. A new method has been implemented to further levels by using Nanocrystalline materials. The equivalent model is shown in Fig.5. With this model the simulations are carried out and the results are shown in Fig.12 and Fig 13. Figure 12 shows the VFTO with crystalline material, have drastic reduction of magnitude component of VFTO observed. Figure 13 show the VFTC with Nanocrystalline material. 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. But the ferrite rings suffers with saturation difficulties. The ferrite rings are easily got into saturation under operating conditions. Further investigations have been made to suppress the VFTO and VFTC in GIS. The Nanocrystalline material provides better solution under these conditions. The consolidated data of VFTO and VFTC without mitigation techniques and with different types of mitigation techniques are tabulated in Table. II. Result shows that Nanocrystalline materials in future are the better solution. Figures show VFTO's and VFTC's are greatly reduces its magnitudes and oscillations with Nanocrystalline rings in GIS.

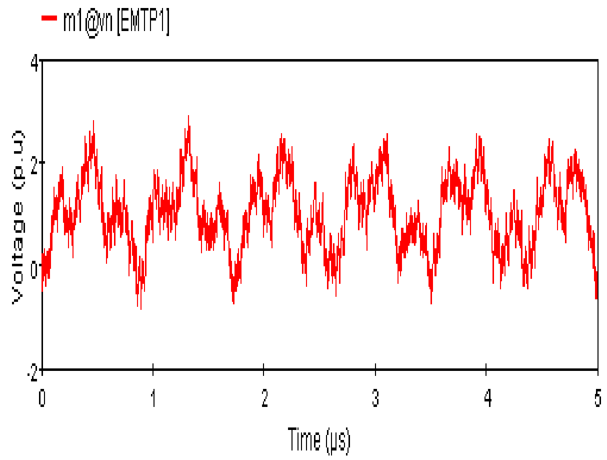

FIG.6 VFTO AT CB DURING DISCONNECTOR CLOSING OPERATION.

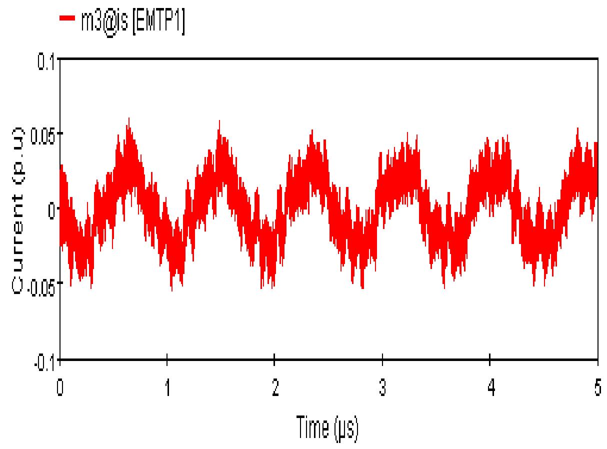

FIG.7 VFTC AT CB DURING DISCONNECTOR CLOSING OPERATION.

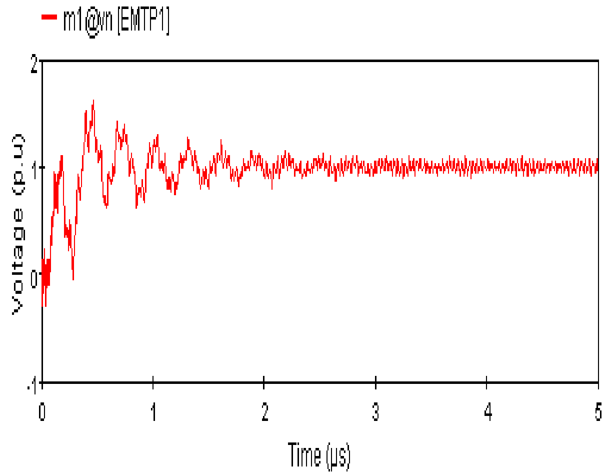

FIG.8 VFTO AT CB DURING DISCONNECTOR CLOSING OPERATION WITH DAMPING RESISTOR.

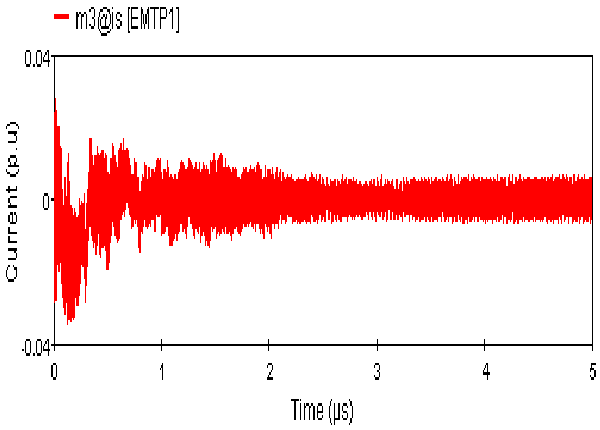

FIG.9 VFTC AT CB DURING DISCONNECTOR CLOSING OPERATION WITH DAMPING RESISTOR.

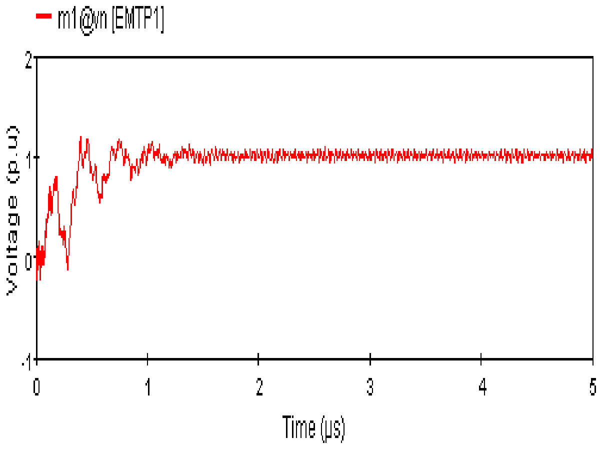

FIG.10 VFTO AT CB DURING DISCONNECTOR CLOSING OPERATION WITH FERRITE RINGS.

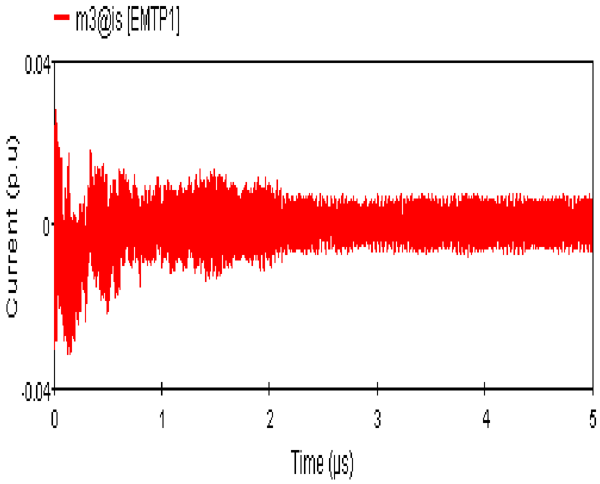

FIG.11 VFTC AT CB DURING DISCONNECTOR CLOSING OPERATION WITH FERRITE RINGS.

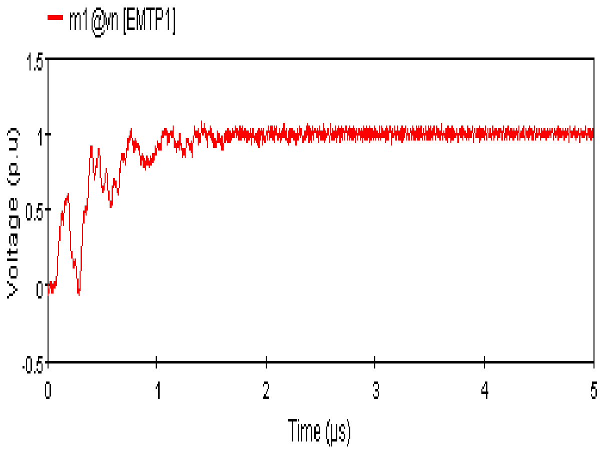

FIG.12 VFTO AT CB DURING DISCONNECTOR CLOSING OPERATION WITH NANOCRYSTALLINE RINGS.

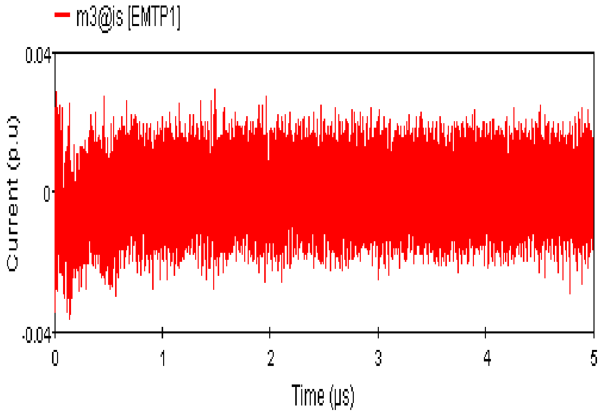

FIG.13 VFTC AT CB DURING DISCONNECTOR CLOSING OPERATION WITH NANOCRYSTALLINE RINGS.

Table II. VFTO and VFTC with different mitigation Methods.

S.No		VFTO (p.u)	VFTC (p.u)
1	Without suppression methods	2.88	0.0595
2	With Damping Resistor	1.71	0.0288
3	With Ferrite Rings	1.19	0.0275
4	With Nanocrystalline Rings	1.08	0.0270

7. CONCLUSIONS

The Transient behavior because of different switching scenarios are 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 VFTO's 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 new technique i.e Nanocrystalline rings. The steepness and maximum peak of the transient over voltages are reduced with application of Nanocrystalline rings are observed and provide the better solution than the damping resistor and Ferrite rings. It has been shown that there is a wide reduction of the peak magnitudes of the VFTO at the important nodes with the application of Nanocrystalline rings. With the effect of Nanocrystalline 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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