

Suppression of VFTO and VFTC in GIS using Ferrite Rings

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Abstract

In Gas Insulated Substations (GIS) a large number of restrikes occur across the switching contacts when disconnector switch or circuit breaker is operated. Each strike leads to generation of a Very Fast Transient Overvoltage (VFTO), having rise-times in the range of a few ns and is followed by high frequency oscillations. Such overvoltages can cause malfunctioning of protection and control circuits and also initiates faults and influence on other components. Suppression of VFTO is very important in GIS. In this paper the computer simulations were done on 245 kV GIS for switching configuration and the suppressing of VFTO by ferrite ring is put forward. The same procedure is applied on 420 kV, 550kV and 800kV GIS and results are compared and analysed.

Keywords: GIS, EMTP, Ferrite Rings, VFTO and VFTC

Introduction

Gas Insulated Substations have found a broad range of applications in power systems because of their high reliability, easy maintenance, small ground space requirements etc. In spite of these merits GIS has its unique problems, among which is susceptibility of the insulation system under Very Fast Transient Overvoltages (VFTO) caused by switching operation [1]. VFTO generated in a GIS should be considered as an important factor in the insulation design. For designing a substation it is essential to know the maximum value of VFTO [2].

Even though their magnitudes are lower than Basic Impulse Level (BIL) of the system, they contribute to reduction in the life of insulation in the system due to their frequent occurrences. VFTO can also influence the insulation of other GIS equipments such as transformers where the inter-turn insulation may be stressed with a higher voltage than under chopped lightning impulse voltages of same peak value [3]. Hence, there is a need to estimate the magnitudes of VFTO generated during switching operations in GIS.

This paper covers the estimation of VFTO and VFTC at various locations in a GIS for different switching operations. The approach used in the present study can be extended to any other GIS also regardless of the size, rating, type, etc. EMC problems due to VFTC are of most concern for system voltages above 245 kV and at these voltages, segregated - phase GIS is normally used. Hence, such a system has been taken up for the study.

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 even for longer time periods of some micro seconds highly accurate models for each internal equipment and also for components connected to the GIS are necessary. Table I gives the electrical equivalent representations of various components of 245kV GIS [5-8].

Fig. 1 shows the shows the single-line diagram of a segregated-phase 245-kV GIS used for the VFTO and VFTC studies. 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 [6][7].

$$R(t) = R_0 e^{-\left(\frac{t}{\tau}\right)} + r \quad (1)$$

Where R_0 is $10^{12} \Omega$, τ is 1 ns and $r = 0.5 \Omega$.

A fixed resistance of 2.5Ω 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.

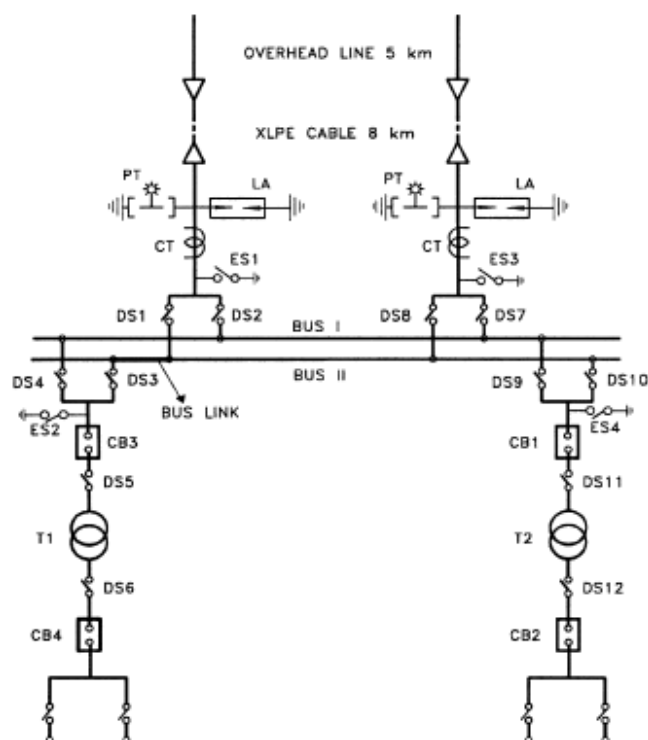


Figure 1: Single - line diagram of a 245-kV GIS.

Table I: Electrical Equivalent Representation of GIS Components.

Spacers	Capacitance of 15 pF towards ground.
Open ends	Capacitance of 15 pF towards ground.
ES	Capacitance of 45 pF towards ground.
CT	Transmission line of surge impedance 70Ω and lumped capacitance of 50 pF towards ground.
PT	Capacitance of 100 pF towards ground.
LA	Capacitance of 200 pF towards ground.
DS	Transmission line of surge impedance 70Ω and capacitance of 30 pF towards ground on either end of the contacts. In open condition, a capacitance of 30 pF between contacts.
Circuit Breaker (CB)	Transmission line of surge impedance 46Ω and capacitance of 30 pF towards ground on either end of the contacts. In open condition, a capacitance of 50 pF between contacts.
Gas-to-air Bushing	Transmission line of surge impedance 250Ω and capacitance of 30 pF towards ground on either end of the bushing.
XLPE Cable	Transmission line of surge impedance 30Ω and propagation velocity is 150 m/μs. Cable termination is simulated with a capacitance of 400 pF towards ground.
T1	Capacitance of 2 nF towards ground.

The switching event of the Closing operation of the circuit breaker CB3, when disconnecter switch DS6 is open is considered in the study. The peak magnitude of VFTO and VFTCs generated during switching events changes from one position to another depending on the switching operation in GIS. The waveshapes of VFTO and VFTC at different components of the GIS changes with each switching operations. To understand the effect of high surge capacitance components on the peak magnitude of the transient currents, the switching operation has been considered. In table II, the peak magnitudes of the VFTO and VFTC at different GIS component for the switching operation are tabulated. It is clear that the highest magnitude of the transient current occurs at 1.9m from the switch (load side of CB3).

Table II: VFTO in p.u. and VFTC in kA at Different GIS Components.

S. No.	GIS Component	VFTO	VFTC
1	GIS–Cable Junction	1.04	6.93
2	CT	1.19	7.06
3	DS1	1.20	7.19
4	Bus Link	1.21	8.51
5	DS3	1.63	8.73
6	CB3	1.61	9.86
7	1.9 m from CB3	2.0	10.37
8	DS5	-	8.88
9	T1	-	7.41

Simulation of different rating of GIS

As the effect of VFTO and VFTC are of most concern for system voltages above 245-kV, the same procedure can be applied to 420kV, 550kV and 800kV. The electrical equivalent representation of various components of 420kV, 550kV and 800kV GIS are obtained from [9], [10] and [4] respectively and shown in the table III .

Table III: Electrical Equivalent Representation of GIS System.

S. No	GIS Component	ELECTRICAL EQUIVALENT PARAMETERS		
		420kV [9]	550kV [10]	800kV [4]
1.	Spacers	15pF	15pF	15pF
2.	Open ends	15pF	15pF	15pF
3.	ES	45pF	45pF	45pF
4.	CT	300pF	400pF	100pF
5.	PT	300pF	400pF	100pF
6.	LA	C = 15pF R = 0.1 Ω	19pF	120pF
7.	Cable termination	400pF	400pF	400pF

8. Transformer	2nF	9nF	9nF
9. GIS Bus Bar	$z_o = 90\Omega, v = 270\text{m}/\mu\text{s}$	$z_o = 84\Omega, v = 297\text{m}/\mu\text{s}$	$z_o = 92.7\Omega, v = 277\text{m}/\mu\text{s}$
10. XLPE Cable	$z_o = 30\Omega, v = 165\text{m}/\mu\text{s}$	$z_o = 30\Omega, v = 104\text{m}/\mu\text{s}$	$z_o = 30\Omega, v = 150\text{m}/\mu\text{s}$
11. DS	$z_o = 42\Omega, C = 30\text{pF}$	$z_o = 84\Omega, C = 30\text{pF}$	$z_o = 92.7\Omega, C = 30\text{pF}$
12. Circuit Breaker (CB)	$z_o = 42\Omega, C = 30\text{pF}$	$z_o = 55\Omega, C = 30\text{pF}$	$z_o = 60.2\Omega, C = 30\text{pF}$

By keeping the length of the above three GIS as same as that of the base system (i.e. 245kV), the peak magnitude of the VFTO and VFTC are estimated. For this study the same switching event of the Closing operation of the circuit breaker CB3 is considered.

Mitigation Technique

The suppression of VFTO and VFTC is important in GIS systems. Installation of ferrite rings at conductor pole of the disconnect switch in order to damp traveling wave, which opens up a new way for inhibiting VFTO is put forward in [9].

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 [2].

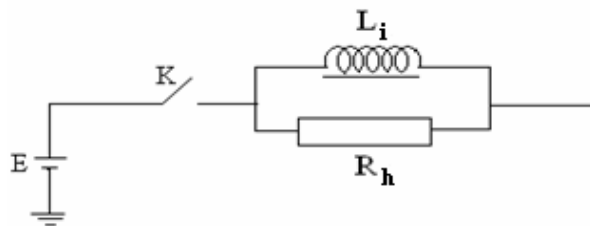


Figure 2: Equivalent circuit of the ferrite ring.

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. Figures 3-6 shows the waveforms of the VFTO and VFTC without ferrite rings (i) and with ferrite rings (ii) at different GIS components in 245kV, 420kV, 550kV and 800kV GIS respectively.

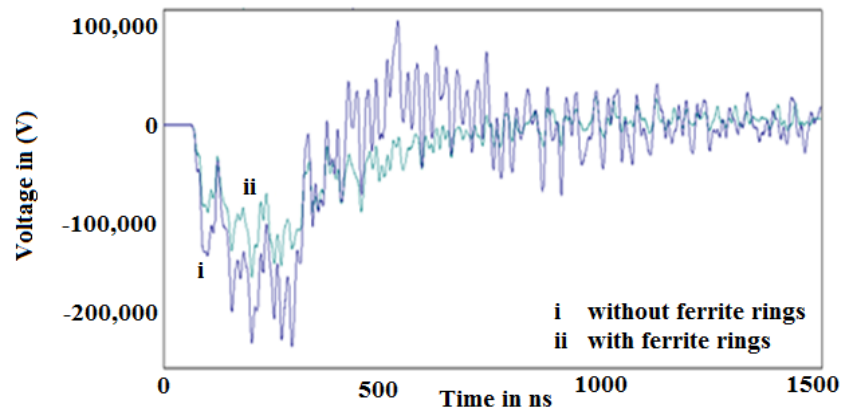


Figure 3(a): VFTO waveforms at CT for switching operation in 245kV GIS.

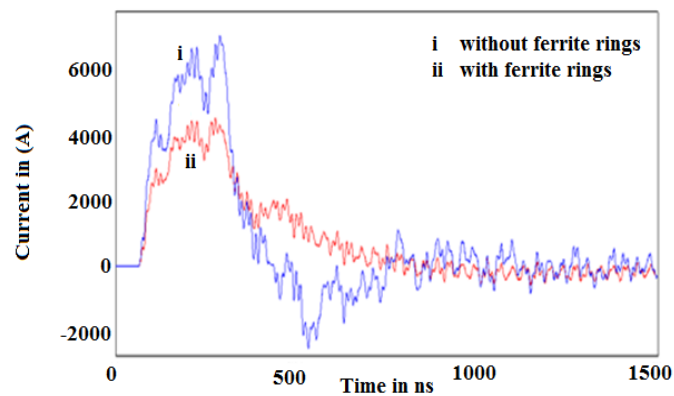


Figure 3(b): VFTC waveforms at CT for switching operation in 245kV GIS.

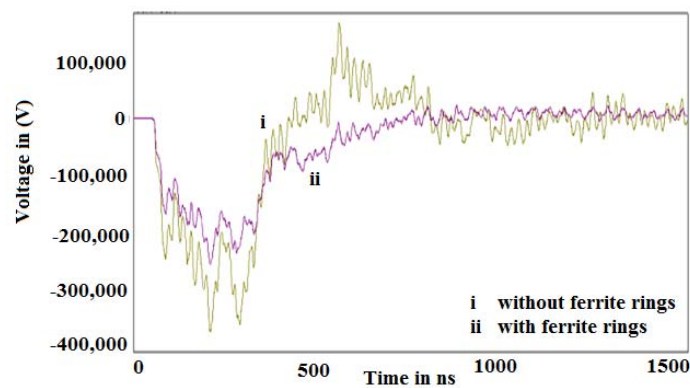


Figure 4(a): VFTO waveforms at DS1 for switching operation in 420kV GIS.

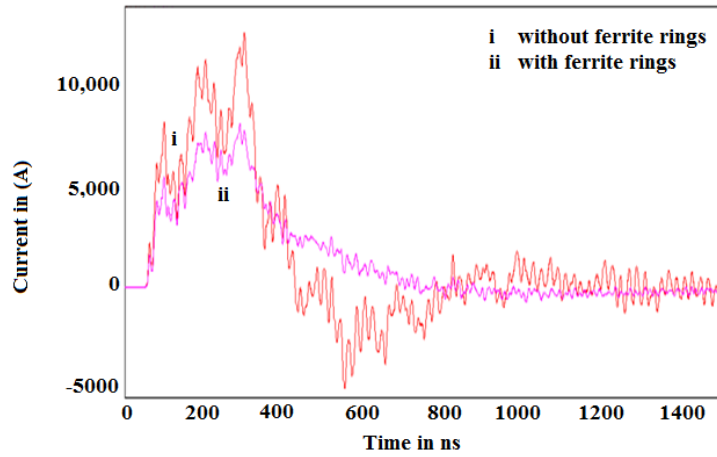


Figure 4(b): VFTC waveforms at DS1 for switching operation in 420kV GIS.

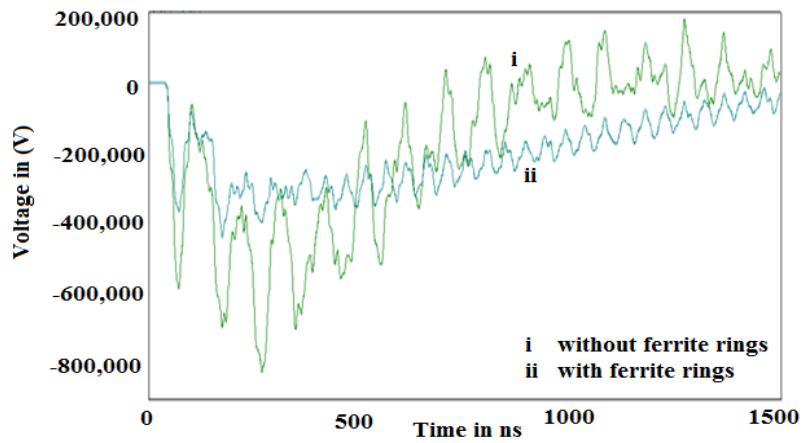


Figure 5(a): VFTO waveforms at buslink for switching operation in 550kV GIS.

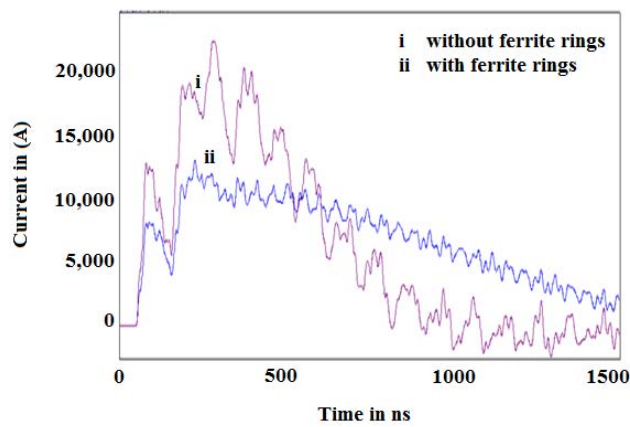


Figure 5(b): VFTC waveforms at buslink for switching operation in 550kV GIS.

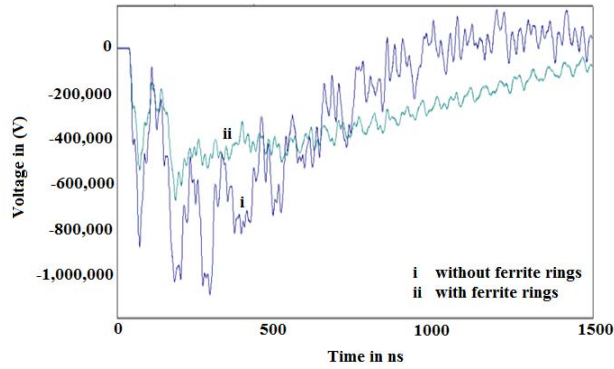


Figure 6(a): VFTO waveforms at DS3 for switching operation in 800kV GIS.

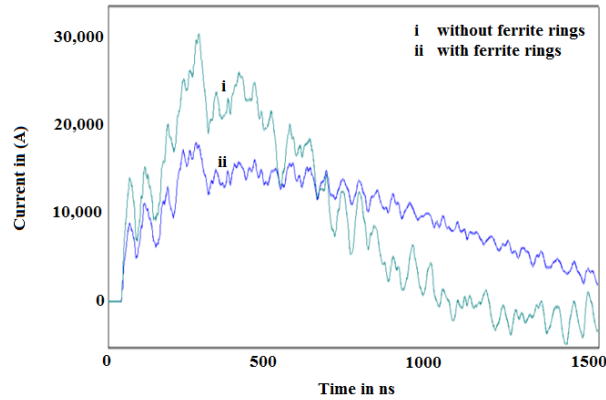


Figure 6(b): VFTC waveforms at DS3 for switching operation in 800kV GIS.

The tables IV and V shows the reduction in peak magnitude of VFTO and VFTC respectively due to the installation of ferrite rings near the switch in 245kV, 420kV, 550kV and 800kV GIS. Figures 7 and 8 show the graphical representation of reduction in peak magnitudes of VFTO for 245kV and 420kV system respectively. Figures 9 and 10 show the graphical representation of reduction in peak magnitudes of VFTC for 550kV and 800kV system respectively.

Table IV: Peak magnitudes of VFTO in p.u at various nodes for GIS systems with ferrite rings.

S.No.	Nodes	245kV	420kV	550kV	800kV
1.	DS1	0.72	0.74	0.95	0.92
2.	Bus Link	1.05	1.04	1.07	1.06
3.	DS3	0.96	0.93	1.05	1.04
4.	CB3	0.99	1.03	1.03	1.13

Table V: Peak magnitudes of VFTC in kA at various nodes for GIS systems with ferrite rings.

S.No.	Nodes	245kV	420kV	550kV	800kV
1.	DS1	4.849	8.356	13.99	18.84
2.	Bus Link	5.067	7.586	12.85	17.36
3.	DS3	5.750	8.257	13.88	18.18
4.	CB3	7.353	11.49	15.40	27.48

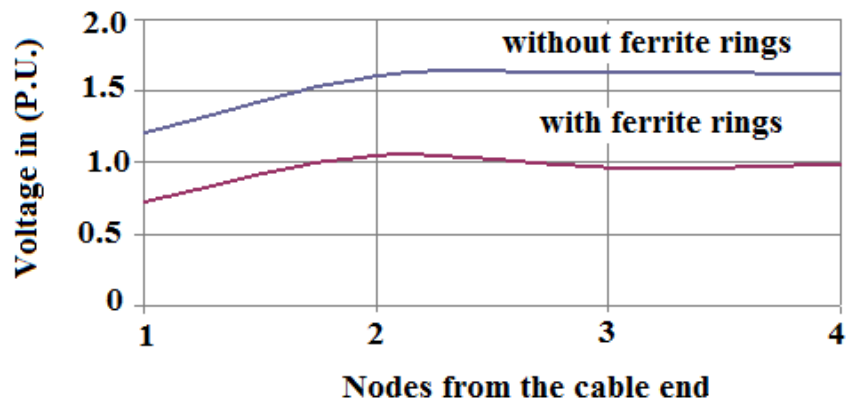


Figure 7: Reduction in peak magnitude of VFTO for 245kV at different nodes.

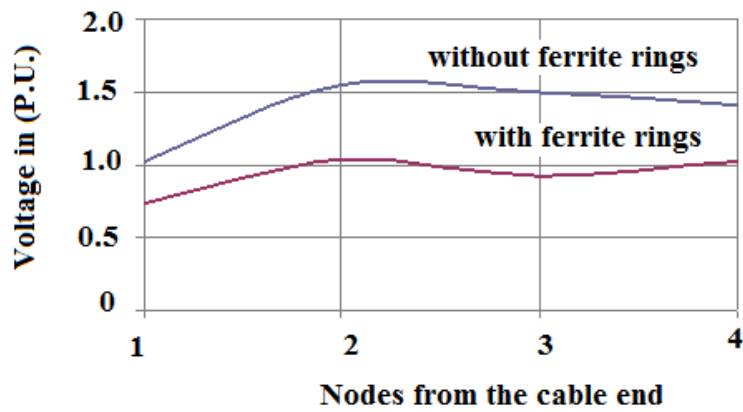


Figure 8: Reduction in peak magnitude of VFTO for 420kV at different nodes.

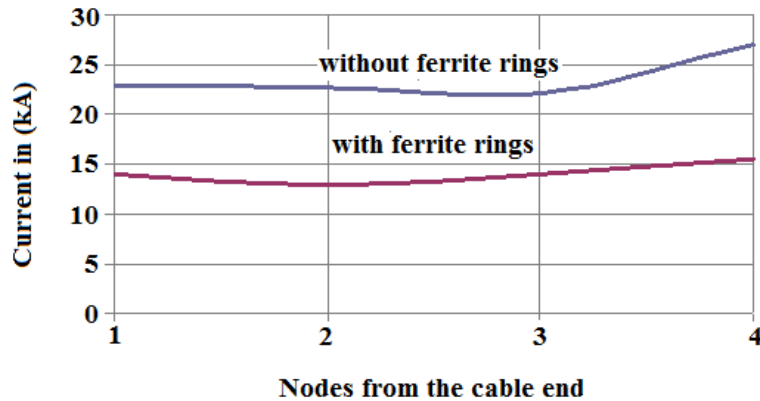


Figure 9: Reduction in peak magnitude of VFTC for 550kV at different nodes.

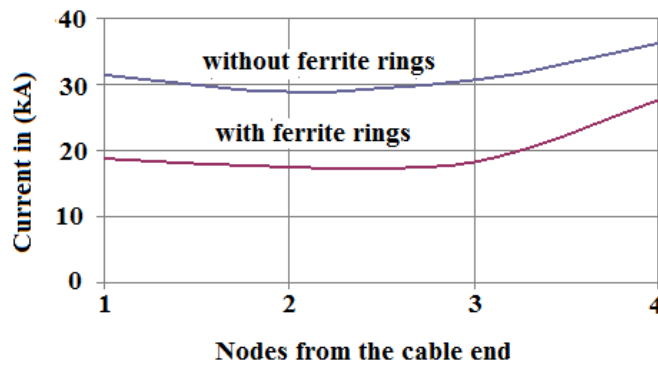


Figure 10: Reduction in peak magnitude of VFTC for 800kV at different nodes.

Conclusion

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 VFTCs that are 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 49% in the peak magnitudes of the VFTO and VFTC at the important nodes with the application of ferrite rings. With effective design and use of the same can effectively reduce the steepness and maximum peak of VFTO and VFTC generated.

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