Mitigation of Very Fast Transient Overvoltages at the More Sensitive Points in Gas-Insulated Substation

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Abstract: Switching operations in a gas insulated substations generate very fast transient over voltages (VFTO) which are dangerous for the transformer and the system insulation because of their short rise time. Under special circumstances the terminal over voltages can arise close to the transformer BIL. The suppression of VFTO is very important in GIS systems. Different techniques are applied to 245 kV GIS model. The simulation used ATP-EMTP package program to evaluate the VFTO at the sensitive points in GIS. The different results are compared to determine the effective mitigation method. The results show that the wave steepness and the amplitudes of VFTO can be reduced to about 1Pu with less oscillation frequency.

Keywords: Gas-insulated substation (GIS), very fast transient overvoltages (VFTOs), very fast transient currents (VFTCs), Mitigation techniques.

1. 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]. These transients cause traveling wave internally inside 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 overvoltages (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].

In fact, the response behavior of zinc oxide (ZnO) surge arresters to such VFT is not well characterized, and the turn-on time of ZnO surge arresters may be much longer than the rise times of the VFT. Therefore, the traditional ZnO surge arresters cannot suppress the wave steepness because surge arresters do not act fast enough to prevent the switching transients with steep front [5].

This paper investigates the very fast transient overvoltages resulted from the operation of disconnector switches at different sensitive points in the GIS and some of effective factor affect on generation of VFTO.

Several methods are introduced to suppress the generated VFTO. Comparison between the results of using different methods is presented and discussed. The ATP-EMTP package program is used in simulation through this work.

Received: May 24th, 2012. Accepted: October 30th, 2012

2. Gas Insulated Substation Modeling.

Due to the traveling nature of the transients, the different components can be modeled by lumped elements such as distributed parameter lines, surge impedances and traveling times. Each GIS section can be simulated by its equivelant capacitance and inductance, which can be determined as follows [6].

$$C = \frac{2\pi\varepsilon}{\ln R/r} \qquad (\varepsilon \approx \varepsilon o) \qquad F/m \tag{1}$$

$$L = \frac{\mu \ln \frac{R}{r}}{2\pi} \qquad H/m \tag{2}$$

$$Z0 = \sqrt{L/C} = \frac{\sqrt{\varepsilon\mu}}{2\pi}\ln\frac{R}{r} \approx 60\ln\frac{R}{r}\ \Omega \tag{3}$$

$$v = \frac{1}{\sqrt{LC}} \qquad \text{M/s} \tag{4}$$

Where, C and L are the capacitance and inductance of GIS bus bar, respectively, r is the outside diameter of GIS bus bar, R is the inner diameter of GIS enclosure, Z_0 is the surge impedance and v is the propagation frequency.

The layout of the substation under study is illustrated in Figure1. Equivalent circuits of the different GIS components and the values of the different parameters in the simulation are summarized and presented in Table1. ATP/EMTP is used to simulate the substation under study. The Simulation time step is taken 0.5ns.

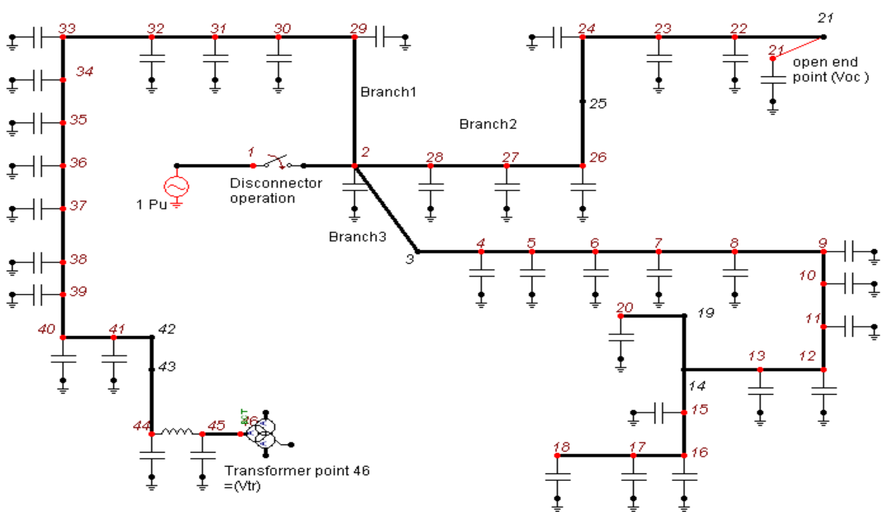
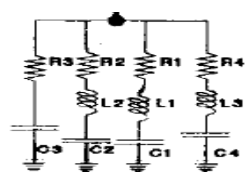


Figure 1. Typical GIS Substation layout

Table.1 Information for equivalent circuit

Component	Equivalent circuit	Data in simulation
GIS BUS between all node Length=5m	 distributed parameter transmission line	z0 = 110 ohm, v = 270 m/µs
GIS BUS between node(9,10),(10,11) Length=5m		z0 = 70 ohm, v = 270 m/µs
OH TL between node (45,46), Length =1m		z0 = 250 ohm, v = 300 m/µs
Spacer, Elbows , spherical shields , Voltage transformer, open end and Open earth switch		(C= 20 to 30 pF) depending on its location within GIS
Disconnector during sparking		$R(t) = R(0)e^{\frac{-t}{\tau}} + r$ Where R_0 is taken as 10^{12} , t is 1ns, and r=0.5Ω.
Power transformer (termination)		transformer data R1=20.5, R2=22.5, R3=300, R4=29.5 ohm C1=.77, C2=1.26 nf, C3=33.8, C4=940 pf L1=4.02, L2=55.5,L3=7.37 µH
line trap		.1 µH

3. Results and Discussions

The VFTO is calculated at the primary side of the power transformer, Vtr, and at the open end, Voc. The level and waveshapes of the generated VFTO is shown in Figure2. It is observed that the peak magnitude of the generated VFTO at the primary side of the power transformer is about 2.06 P.u, while it is about 2.63 P.u. at the open end.

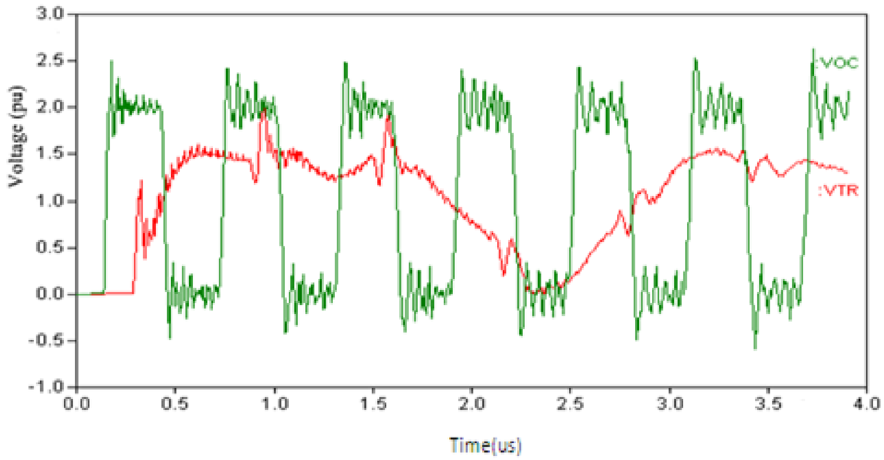


Figure 2. VFTO at open end, Voc, and at transformer, Vtr.

A. Factors affecting on VFTO Generated

It is clear that the highest peak magnitude of VFTO occurs at Voc, where it is near the operating switch. Many factors are affected on the VFTO peak magnitudes.

A.1 Effect of Trapped Charge on VFTO

The trapped charge, which is in the floating section, depends on switch type and load side. For a normal slow speed disconnector with the maximum trapped charge, it can be about 0.5 pu. In the high speed disconnector the maximum trapped charge could be reach to 1.0 pu [3]. The effect of trapped Charge on the VFTO Levels is shown in table 2. It is noticed that the VFTO at the power transformer terminal increases from about 2.06 to about 4.12 Pu with increasing the trapped charge from 0 to 1pu, respectively. In the same time the VFTO at the open end increases from about 2.36 to about 5.26 Pu with increasing the trapped charge from 0 to 1pu, respectively.

Table 2. Effect of trapped charge on VFTO

Measuring	**Trapped charge**			
	0Pu	**.4Pu**	**.8Pu**	**1Pu**
Vtr (Pu)	2.06	2.88	3.71	4.12
Voc (Pu)	2.36	3.68	4.74	5.26

*A.2 Effect of terminal component connected to GIS***.**

The peak magnitude and frequency content of VFT depends on the terminal component connected to the GIS. The terminal components can be a cable or a gas-insulated line (GIL) or an overhead transmission line (OHTL). The attenuation of VFT with time is depending on the switching configuration and terminal component connected to the GIS [8]. Therefore, the VFT can be mitigated with replacement of the appropriate terminal. Simplicity, low cost implementation as well as minimum changes in the installed GIS.

The VFTO waveform generated for the different terminals at the power transformer is illustrated in Figure3, with considering the same length (50m) for the different connection terminals. Fig 4 shows the variation of the peak magnitude of the VFTO with length for the different terminals at the power transformer.

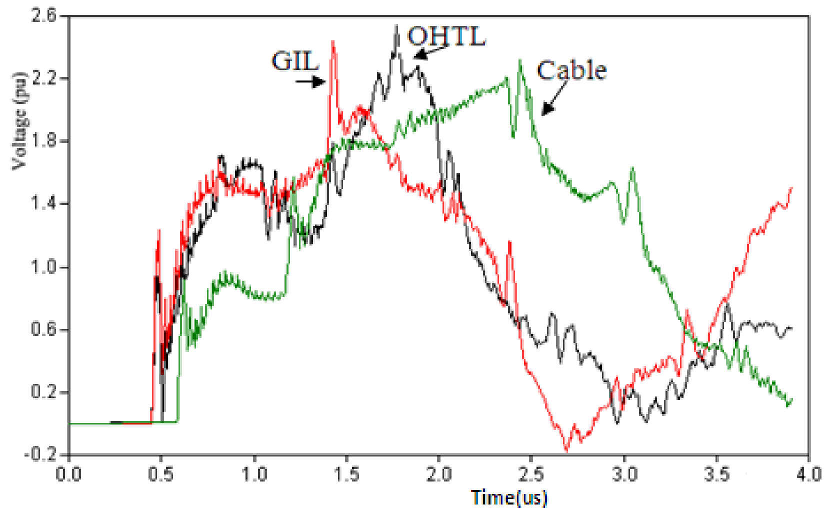


Figure 3. VFTO waveforms at the power transformer for different terminal

It is clear that the lowest values occur with using a cable termination. Also, the peak values decreased with increasing the cable length. These can be explained as; the cable attenuates the VFTO due to its capacitance to ground, which effectively reduced the VFTO magnitude. At the same time the maximum values of the VFTO with using GIL is greater than that when using OHTL till a length of about 200m. When the connecting terminal is greater than 200m the maximum values of the VFTO with using GIL is smaller than that when using OHTL.

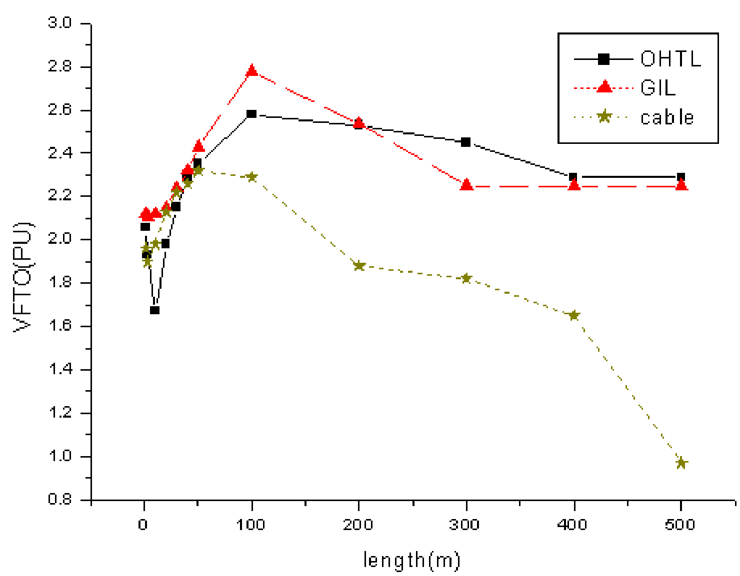


Figure 4. Variation of the VFTO peak magnitude with load-side terminal length at the power transformer

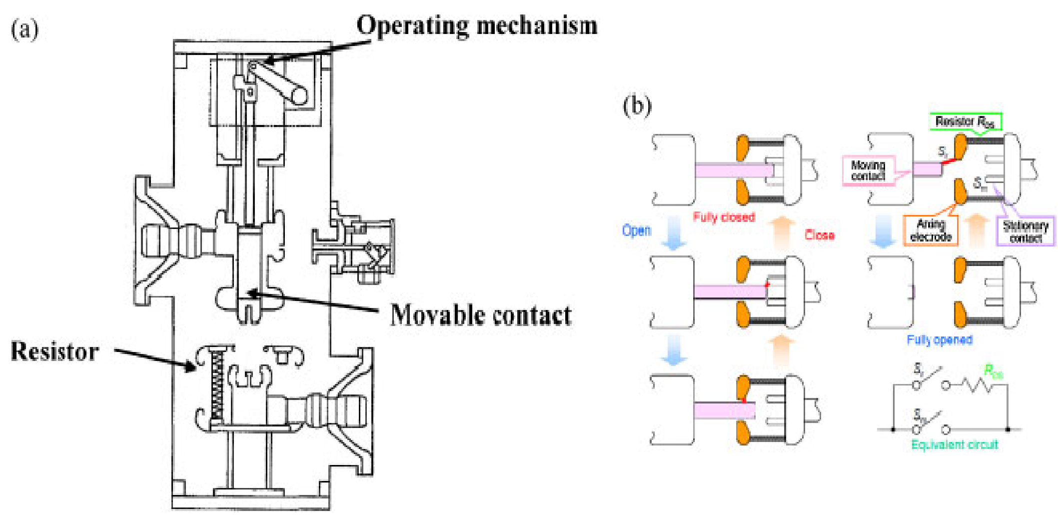
B. VFTO suppression Techniques

Up to now all researchers forward to find an optimum technique for suppressing VFTO. Fast operating disconnector switches are usually used to reduce time of the breakdown; however, it cannot eliminate the harm of the VFTO.

Several techniques used to reduce the harmful effects of the VFTO. These different techniques are used in this work to choice the suitable technique to suppress the values to a safe one.

B.1. Shunt Resistor Disconnector Switching

The installation of opening and closing resistor has a certain application in order to inhibit the generated VFTO in GIS. Figure3 shows the internal structure and the operating process of disconnector with shunt resistor [9]. The on and off resistor may share the same one. When the disconnector breaks, the main contact breaks first, the remaining charge on the stationary contact leaks through the shunt resistor branch, then the vice contact breaks. When the disconnector closes, the vice contact closes first, current will flows through the shunt resistor branch, then the main contact closes. In both operations, the shunt resistor acts as a buffering element to the transient process, leaking the remaining charge and absorbing the overvoltage energy. Shunt resistance accelerates the decay of the transient process.



(a) Structure of disconnector (b) working principle and structure of DS with resistor.

Figure 5. EHV DS with resistor

The opening and closing resistor of the disconnector used in the calculations is taken as 100 ohm, so that to reduce VFTO to its critical damping. The VFTO waveform at the transformer terminal, Vtr, and at the open end, Voc, with and without using the switching resistor are shown in Figs.6 and 7, respectively. The figures show that the amplitude of VFTO is clearly decreased. The peak value of the generated VFTO at transformer, Vtr, is reached to about 1.04 P.u., i.e. it decreases by about 49%. At Voc the peak value of the VFTO is reached to about 1.07 P.u., i.e it decreases by about 54%.

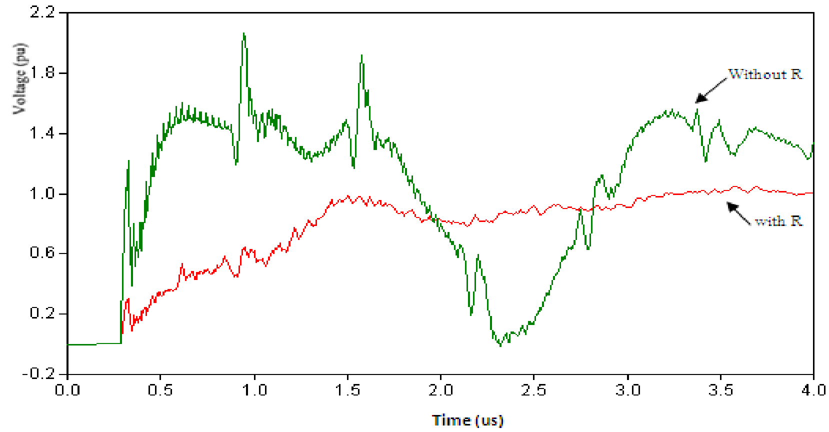


Figure 6. VFTO amplitude at transformer, Vtr, with and without using shunt resistor

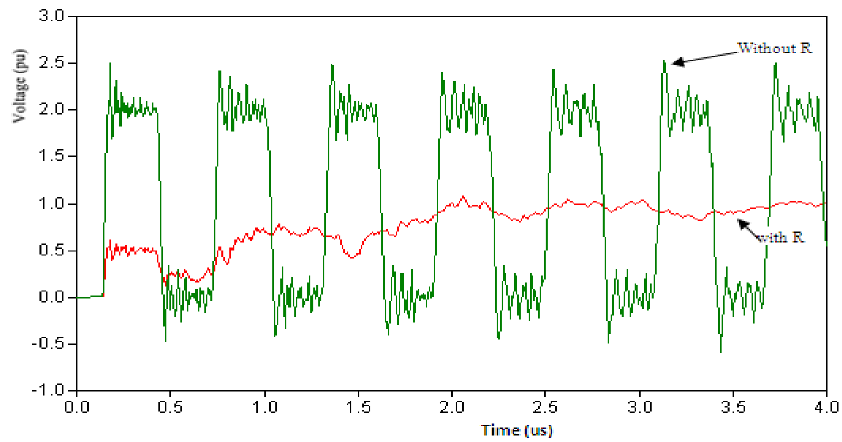


Figure 7. VFTO amplitude at open end, Voc, with and without using shunt resistor

B.2. Ferrite rings Technique

Ferrite is a kind of high-frequency magnetic material, which is nonlinear. Using ferrite rings around a GIS conductor as in Figure 8, can absorb the transient energy when the disconnecting switch restrikes to inhibit the VFTO. The ferrite rings around a GIS conductor can be simplified to a set of nonlinear inductance and nonlinear resistance, in series with GIS conductor as shown in Figure9

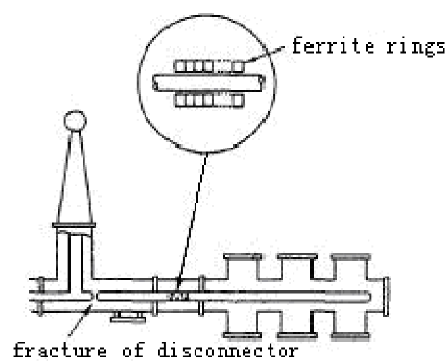


Figure 8. Ferrite rings Application Diagram

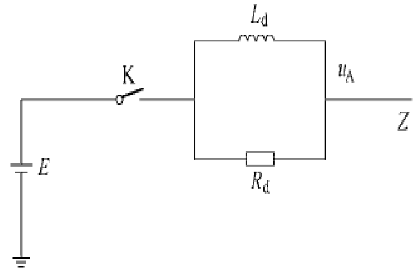


Figure 9. Equivalent circuit of ferrite rings

The equivalent resistor of the ferrite ring is taken equal to the surge impedance of GIS bus bar, while the equivalent inductance is taken as 0.02mH [7, 8]. Figs.10 and 11 show the VFTO generated at Vtr and Voc points, respectively. The figures illustrate that the using of the ferrite rings will suppress the peak values of the VFTO. At Vtr the peak value of the VFTO is decreased to about 1.31 P.u, i.e. it decreases by about 36.4%. While at Voc it decreases to about 1.33 P.u., i.e. it decreses by about 43.6%. The ferrite rings at any instant can be saturated, due to high frequency and high magnitudes of the VFTO, hence it has no effect on VFTO.

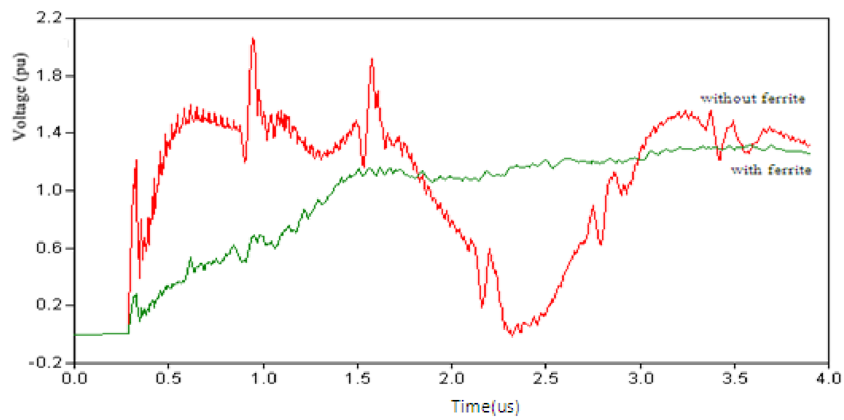


Figure 10. VFTO amplitude at transformer, Vtr, with and without using ferrite rings

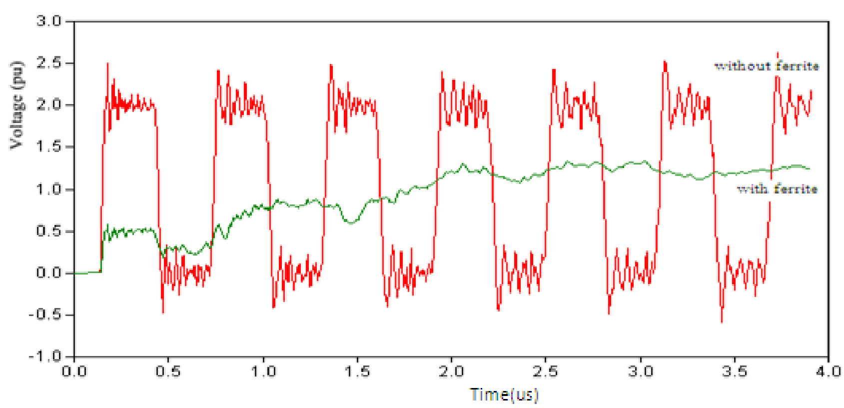


Figure 11. VFTO amplitude at open end, Voc, with and without using ferrite rings

A.2. Using R-C filter

RC filters, i.e. R parallel with c, have been widely used to protect load. Also, RC filters have been widely used in vacuum circuit breakers to suppress the over voltages of the arcing [7]; its principle is to use R to make energy attenuate and capacitors C to reduce the circuit oscillation frequency. In this work RC filter is paralleled next to the main transformer to protect it. For different kinds of load, the resistance R is ranged from 50 to 400 ohm and the capacitance C is taken from 0.01 to 0.2 uF [7]. The changing in VFTO values with changing the values of R and C is shown in Table 3. The optimum mitigation is found at R equal 50 ohm and C equal .2uF. The voltage amplitude and steepness drop faster.

Table 3. Effect of R and C on VFTO magnitude

Capacitance values (uF.)	Resistance values (ohm)					
	50	100	110	150	200	400
.01	1.24	1.51	1.54	1.64	1.71	1.84
.03	1.38	1.63	1.65	1.74	1.80	1.90
.07	1.41	1.61	1.63	1.68	1.71	1.79
.1	1.28	1.42	1.43	1.47	1.50	1.54
.2	.88	.94	.94	.95	.96	.98

The VFTO at the transformer, Vtr, is illustrated in Figure12. It is seen that the peak value of the VFTO is reduced to about 1.28pu, i.e it decreases by about 37.9%. This method has a problem that it is protect the transformer only.

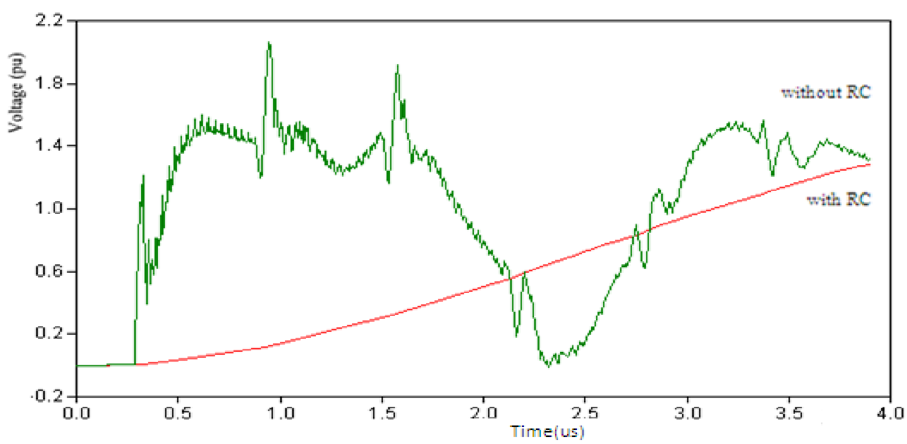


Figure 12. VFTO amplitude at transformer, Vtr, with and without R C Filter

Table 4 shows a comparison between the effects of the different techniques for VFTO suppression used. The using the switching resistor is effectively reduced the VFTO at the open end and at the transformer. The using R-C filter is effectively reduced the VFTO at the transformer, but it has no effect at the open end.

Table 4. Comparison of the different techniques

Proposed Method	VFTO in Transformer (pu)			VFTO at open end (pu)		
	Before	After	Reduction (%)	Before	After	Reduction (%)
Using opening and closing resistors	2.06	1.04	49%	2.63	1.07	54%
Using ferrite rings	2.06	1.31	35%	2.63	1.33	49%
Using R-C filter	2.06	1.28	37.9%	2.63	non	non

4. Conclusion

VFTO magnitude depends on distance from switching operation. Therefore, switching operation is selected where it is nearby to notable equipment for investigation of VFTO on it. Trapped charge increment cause to increase peak magnitude of VFTO. The VFTO at the power transformer is increased by about 100% with increasing the trapped charge from 0 to 1pu, while at the open end it increases by about 123%.

Type and length of terminal components in GIS have considerable influence on VFTO. The peak magnitude of overvoltages at transformer terminals depends on the terminal component connected to the GIS. The attenuation rate is high with using a cable termination. The peak values are also decreased with increasing the cable length. The maximum values of the VFTO with using GIL is greater than that when using OHTL till a length of about 200m. When the connecting terminal length is greater than 200m the maximum values of the VFTO with using GIL is smaller than that when using OHTL.

The using the switching resistor is effectively reduced the VFTO at the open end and at the transformer. The using R-C filter is effectively reduced the VFTO at the transformer, but it has no effect at the open end. When using the resistor switching the peak value of the generated VFTO at transformer is decreased by about 37.9%, while at open end it decreases by about 53.2%. With using the ferrite rings the peak values of the VFTO at transformer is decreased by about 35%, while at the open end it decreased by about 49%. The ferrite rings at any instant can be saturated, due to high frequency and high magnitudes of the VFTO, hence it has no effect on VFTO. With using R-C filter the peak value of the VFTO is reduced by about 37.9%. This method has a problem that it is protect the transformer only.

Acknowledgment

The first author wish to thank the helpful comments and suggestions from my teachers 2nd and 3hd auther

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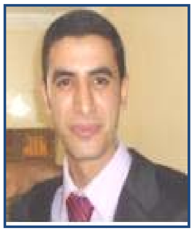

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