Simulation Of Optimal Mitigation Technique to Suppress the VFTOS In 1000KV EHV GIS Substations

Dr.R. Durga Rao,
Associate Professor &Head,
Department of EEE,
JNTUH University College of Engineering Manthani,
durgarao@jntuh.ac.in

Abstract: Equipment in the gas insulated substation will be harmed due to very fast transient over voltages which are generated by the switching operation of disconnector switches or circuit breakers. Constants restrike and prestrikes occur at contacts of disconnector switch during switching operation. Arcing currents travel across the contacts of disconnector switches due to these restrike and prestrikes leads to breakdown of the voltage. These arcing currents generate high frequency transients which reduces the dielectric strength of the elements of substations. The VFTO growth is characterized mostly by the maximum value of transients, frequency, and the quantity of incidents through the disconnector opening or closing operations. The frequency components of VFTO are related to the time duration of the voltage breakdown in SF6 gas and to the travelling wave conditions along the GIS. It is considered necessary to decrease VFTOs generated in GIS based EHV substation. In this paper, four techniques are examined to mitigate the VFTOs in 1000KV substation by simulating in MATLAB/SIMULINK tool. Limitations while doing experimental study on the substations can be overcome by some extent in simulation study. Results generated in simulation are tabulated in terms of peak value, rise time and settling time of oscillations.

1. Introduction

The demand of power generation is increasing but existing space to install air-insulated substations is not enough and hence GIS substations gaining popularity. The benefit of using Sulphur hexafluoride in GIS as an insulation medium is less maintenance. Switches, circuit breakers, current transformers, and substation equipment are protected from corrosion, moisture, and pollution is by using SF6 gas as an insulator [1]. SF6 is nontoxic, nonflammable, noncorrosive, and inactive can be equipped in extra high voltage substations for both DC and AC transmission. Its efficient arc disruption property of SF6 gas, can make it possible for effective switching of circuit breakers and disconnector switches. SF6 is an efficient substitute to oil, and air in terms of space, maintenance, and dielectric strength [2].

GIS is gas insulated switchgear that involves high voltage devices like circuit breakers and disconnectors switches. The main disadvantage of GIS is generation of Very fast transient over voltages [VFTO] at contacts of disconnectors or circuit breakers during switching operation or process []. Flashovers in GIS lead to extended outage times and increased costs than in conventional air insulated substations. In these outages, 30 to 45% are due to conducting particles, generated by wearing between modules through assembly or operations, and accumulated on the exteriors of insulators, enclosures, or HV conductors [3]. The high frequency transients generated during switching operation damage components of switchgear and increases secondary breakdowns. Due to prolonged exposure to high frequency transients, contacts of spacers or disconnector switches can be effected by corrosion and become fragile. The leakage arcing currents between the contacts of switching devices increases the restrike frequency and hence VFTOs increases further and may reach 3 p.u of line voltage [4].

The reaction performance of surge arresters to fast transients is not well described and compared to rise time of VFTOs, the turn-on time of surge arresters may be much longer. Therefore, the conventional surge arresters cannot suppress the wave steepness since surge arresters do not behave swiftly enough to counteract the switching transients with steep front. Rise time of VFTOs generated in GIS, is in the range of 2 to 50 nano seconds and frequency of oscillations are in the range of 0.5MHz to 150MHz [5]. The peak values of VFTOs are generally less than basic insulation level (BIL) of equipment installed in GIS. BIL is the maximum value of typical lightning voltage that can be handled by the respective components. For EHV substations, ratio to the BIL and system rated voltage is higher and hence the high frequency voltage transients in GIS is of greater concern in case of extra high voltages [6]. Although the peak values of these transients are lesser than insulation levels of the equipment, they cause decline in the life of insulation in the system [7]. Moreover, the high frequency transients of VFTOs produce strain which is critical for internal components like spacers.

To protect the GIS equipment, VFTOs should be suppressed [8]. Time dependent resistor as an electric transient's discharge connected with disconnector switch is used to suppress VFTO and transient phenomena in power systems initiated by switching operation. Ferromagnetic rings can be attached on the conductors associated to the disconnector from both sides in order to efficiently control the gradient and the peak values of VFTO [9]. In [10] and [11] also, mitigation of VFTOs by ferromagnetic rings has been investigated. However, in these two references, the simulations and tests have been conducted out only on low voltages. This paper describes possible procedures for suppression of the peak value of high frequency voltage transients at disconnector switches and circuit breakers using combination of RLC components in 1000KV EHV substation. Four techniques are proposed and evaluated for suppression of VFTOs

2. Modelling of 1000 KV substation

A 1000KV EHV transmission system between Huainnan-Wannan substation [12] was constructed in MATLAB and VFTOs are investigated and suppressed by proposed techniques [13]. Substations which are employing GIS switchgear are developed using their behavior to high-frequency propagating waves. Figure 1 [14] represents a single-line schematic diagram of the Huainnan substation. The disconnector switches CB1- CB6 are applied with switching operation and VFTOs are studied on other equipment due to this switching operation. T1-T2 are autotransformers, while PT1-PT6 are voltage transformers. The length of each line and bus bar are given in the figure.

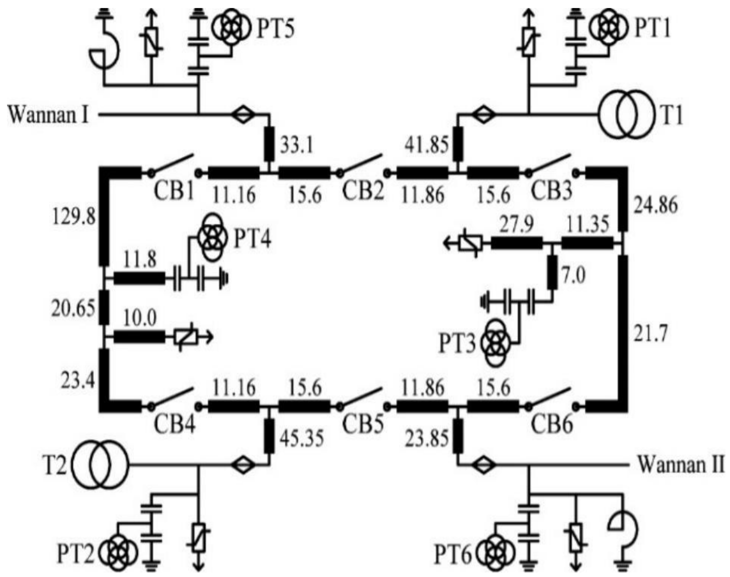


Figure 1. Single line diagram of 1000KV substation

The peak values of VFTOs and their suppression procedure is examined by operating six disconnector switches (CB1-CB6). The elements of GIS substation are assumed as lumped due to changing nature of high-frequency transients. A power transformer is modeled by using its change in characteristics for high frequency transients. While high frequency transients are propagating through transformer, with leading current transients it behaves like a capacitor. Hence transformer can be modelled as a shunt-connected branch with series-connected resistance, inductance, and capacitance. The modelled circuit of a power transformer is described in figure 2[15].

From the circuit, resistance is equal to the internal resistance of the winding, and inductance and capacitance can be calculated using the following equations [16].

$$L_{Tran} = \frac{\mu_o}{2\pi}\left[\log\frac{2l}{R} - 1\right] \quad (1)$$

$$C_{Tran} = \epsilon_o \epsilon_r \left(\frac{Wl}{d}\right) \quad (2)$$

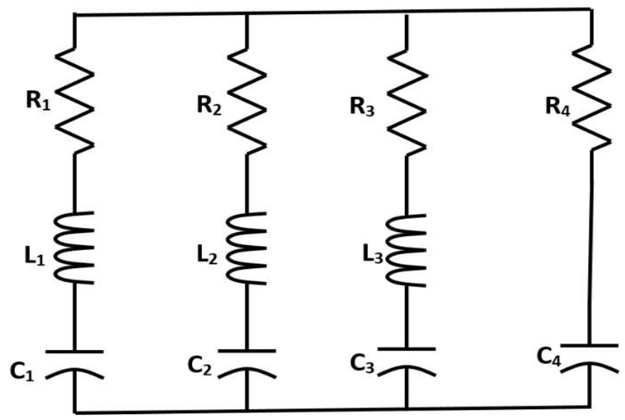


Figure 2. Power Transformer Model

Figure 3 shows the equivalent circuit of a disconnector switch. A series connected inductance and capacitance are adapted into the equivalent circuit. During ON state of the switch, performs like a lossless transmission line and is hence modeled as series-connected inductance and in the OFF position behaves like a capacitor and hence modeled as a series-connected capacitor. Because of the action of the contacts while switching on and off numerous pre and re-strikes occur. When contacts are closing, the charge between them increases and hence flickering happens.

An exponentially decaying resistance can be used to reflect the spark between contacts.

$$\boldsymbol{R = R_o e^{\left(\frac{-t}{\tau}\right)}} \quad (\mathbf{3})$$

R_{spark} is spark resistance,

R_0 is equal to 108Ω,

t is formative time,

r is time constant in range of 0.5 nano seconds.

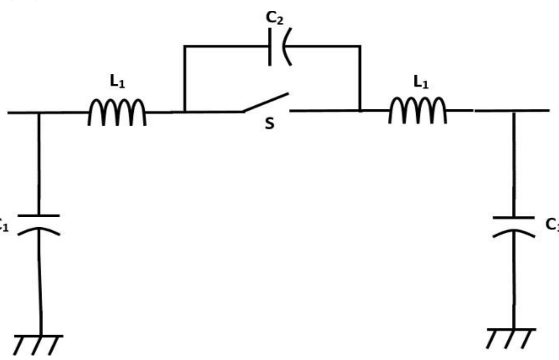


Figure 3. Disconnector Switch model

Circuit breaker can be modeled as a capacitor with small internal resistance in switch off state and as a lossless transmission line in switch on state. The modelled circuit of the circuit breaker to examine VFTOs is shown in figure 4.

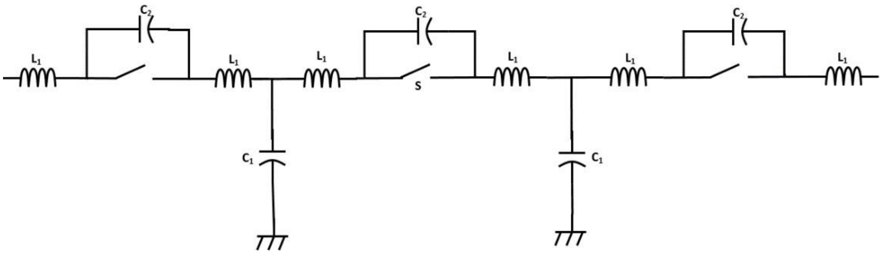


Figure 4. Circuit Breaker model

3. Suppression techniques

3.1. Suppression of VFTOs Using Resistance

Resistance to the propagation of high-frequency traveling waves can be increased by inserting an additional resistor in series with the disconnector switches during switching operation suppresses the VFTOs in GIS substation. VFTOS can be curbed, because of increased resistance in the path of travelling of propagating waves. This increased resistive path lessens the rate of change of magnitude and frequency of occurrence of refraction and retraction. Depending on the frequency of occurrence of these propagating waves and their magnitude, resistor value can be chosen.

Spark resistance between contacts of disconnector switch during switching operation is given as

$$\boldsymbol{R_{spark}} = \boldsymbol{R_0 e^{-\frac{t}{c}} + R_f} \qquad (4)$$

$\boldsymbol{R_0}$ is equal to 108Ω, $\boldsymbol{R_f}$ is the fixed resistance in the range of 0.5 Ω.

Leakage current through arc or spark between contacts can be decreased with increased spark resistance. Adding additional external resistance in series with a disconnector switch increases the resistance path of leakage current and hence reduces the maximum value of transient over voltages.

3.2. Using RC Filter

From the consumer side using an RC filter with load creates a low resistance path for high-frequency oscillations to earthing. Same as using an RC filter in parallel with a disconnector switch creates a low resistance path to high-frequency oscillations and hence transients will be grounded. Redirecting high frequency transients into the ground reduces VFTOs. Resistance is not frequency dependent; when the right value is chosen, it acts as an energy attenuator for high-frequency oscillations.

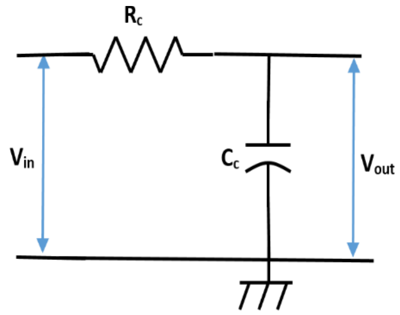


Figure 5. RC filter

The voltage gain of the RC filter is given as

$$\frac{v_{out}(s)}{v_{in}(s)} = \frac{\frac{1}{R_c C_c}}{s + \frac{1}{R_c C_c}} \qquad (5)$$

And frequency response of RC filter can be defined as

$$f_c = \frac{1}{2\pi R_c C_c} \qquad (6)$$

And time constant is given as

$$r = R_c C_c = \frac{1}{2\pi f c} \qquad (7)$$

3.3. Ferrite Rings

By applying ferrite rings over contacts of disconnector switches the VFTOs can be reduced in terms of their magnitude and gradient and this is more flexible fast, viable, efficient process. Ferrite rings can damp the travelling waves propagating through by employing around a conductor. By placing inductance and resistance in addition with disconnector switch, ferrite rings offer impedance to high frequency voltage transients. The impedance given by ferromagnetic material differs with frequency because of the permeability coefficient and inductance of the ferrite rings.

Impedance by ferrite rings on VFTOs is given as

$$Z_f = R_f + 2\pi f L_f = j2\pi f L_e \qquad (8)$$

L_e is equivalent inductance, f frequency of transients

$$Z_f = j2\pi f \mu_r L = j2\pi f L(\mu_s' - j\mu_s'') = 2\pi f L \mu_s'' + 2\pi f L \mu_s' \qquad (9)$$

Where L is inductance of the ferrite ring amd can be expressed as

$$L = \frac{\mu_o d}{2\pi} L \frac{R}{r} \qquad (10)$$

For the base frequency fundamental signals ferrite rings offer low impedance path, but for high frequency transients ferrite rings offer high impedance path. Ferrite ring uses the frequency response characteristics, loss and saturation characteristics, magnetic conductivity of the material as parameters. The equivalent circuit of a ferrite rings is shown in figure 6.

An appropriate equivalent inductance Lf is to be calculated which offer high to impedance to the travelling wave circulation. This inductance is affected by the magnetic conductivity and the geometry of the ferrite rings and the busbar. Material with a high magnetic conductivity is needed for high inductance values. If the ferrite ring's high frequency response is weak and there is a lot of failure, the equivalent resistance will be low. If equivalent resistance is zero, it provides negligible resistance to the travelling wave. That implies that even if the value of inductance is high, there will be no mitigation effect on VFTOs. When the equivalent resistance is extremely high or infinite, the ferrite ring only has an inductance effect. The steepness of VFTOs will be restricted, but the amplitude of VFTOs will not be affected. Resistance will absorb energy from travelling waves or voltage transients if the right value is chosen. There is a probability of high consumption of travelling waves energy and significant damping of voltage transients if the inductance and resistance values are well balanced. Since magnetic saturation of these materials would have a crucial impact on the mitigation effect of VFTOs, the ferrite material needed for the ferrite ring should be carefully selected to get the best matched inductance and resistance. As a ferrite ring approaches saturation, its corresponding inductance L disappears. Since the wave current varies in the kilo-amperes, the ferrite ring material should be carefully selected to prevent severe saturation when acted by the passing waves with that much current.

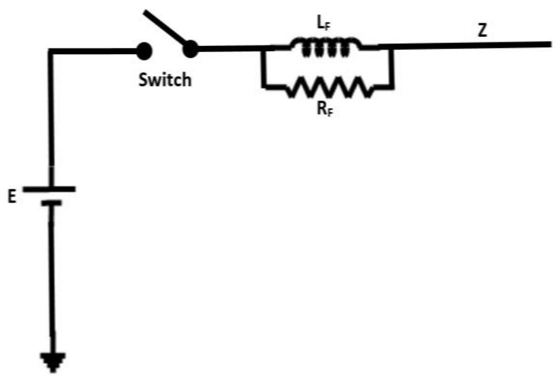


Figure 6. Equivalent circuit of Ferrite Rings

3.4. Nanocrystalline based Mitigation of VFTO

Nanocrystalline material is a polycrystalline with a crystallite size of only few nanometers. Improved rigidity, good electrical resistivity, less density, better flexibility, higher thermal expansion, lower thermal conductivity are some of the properties of nanocrystalline material. In this nanocrystalline, silicon, iron and boron materials are used and saturated in magnetic field. The current flow in conductors magnetic field strength of GIS is higher than saturation field strength of nanocrystalline material and there is no energy loss in nanocrystalline during the low frequency range. During propagation of high frequency VFTOs, energy loss due to the transients occur and hence mitigated. Due to the magnetic induction process, the rising anisotropy implementation of nanocrystalline rings created micro eddy currents. Losses occurred due to these eddy currents suppress the transients. Equivalent circuit of the nanocrystalline rings is shown in Figure 7. By simulating the GIS substations installed with ferrite rings, values of the resistance, inductance, and capacitance Rd, ***Ld***, and Cd can be optimized, and the values that reduce voltage transient can be taken.

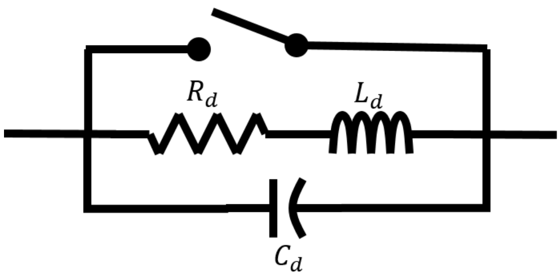


Figure 7. Equivalent Circuit of nanocrystalline ring

4. Simulation Results

simulations using MATLAB/SIMULINK tool is conducted on 1000KV substation shown in figure 1 to check performance of four suppression techniques to reduce very fast transient overvoltage's. Substation design for 1000KV studied in [17] is implemented and each element of the substation are developed using their behavior to high frequency transients as explained in section 2. Switching operation is performed on a disconnector switch and transients created at different places of the substation are compared for four mitigation techniques.

4.1. Mitigation of VFTOs in 1000 KV GIS by Resistance

To observe the variation of VFTOs, CB1 is switched off to get quick voltage transients and their impacts on another device. Figure 8 represents voltage transients at various substation locations after the switching of CB1. By simulating the substation model after adding numerous values of resistances and after optimizing, 530 ohm was taken as the resistor value to combine the disconnector switch for VFTO suppression. VFTOs at moment of closing of switches (CB1-CB6) of 1000 KV substation scheduled to switching operation of CB1 disconnector switch minus any diminishing device. VFTOs at potential transformers (PT1-PT6) of 1000 KV substation due to switching operation of CB1 disconnector switch minus any diminishing device

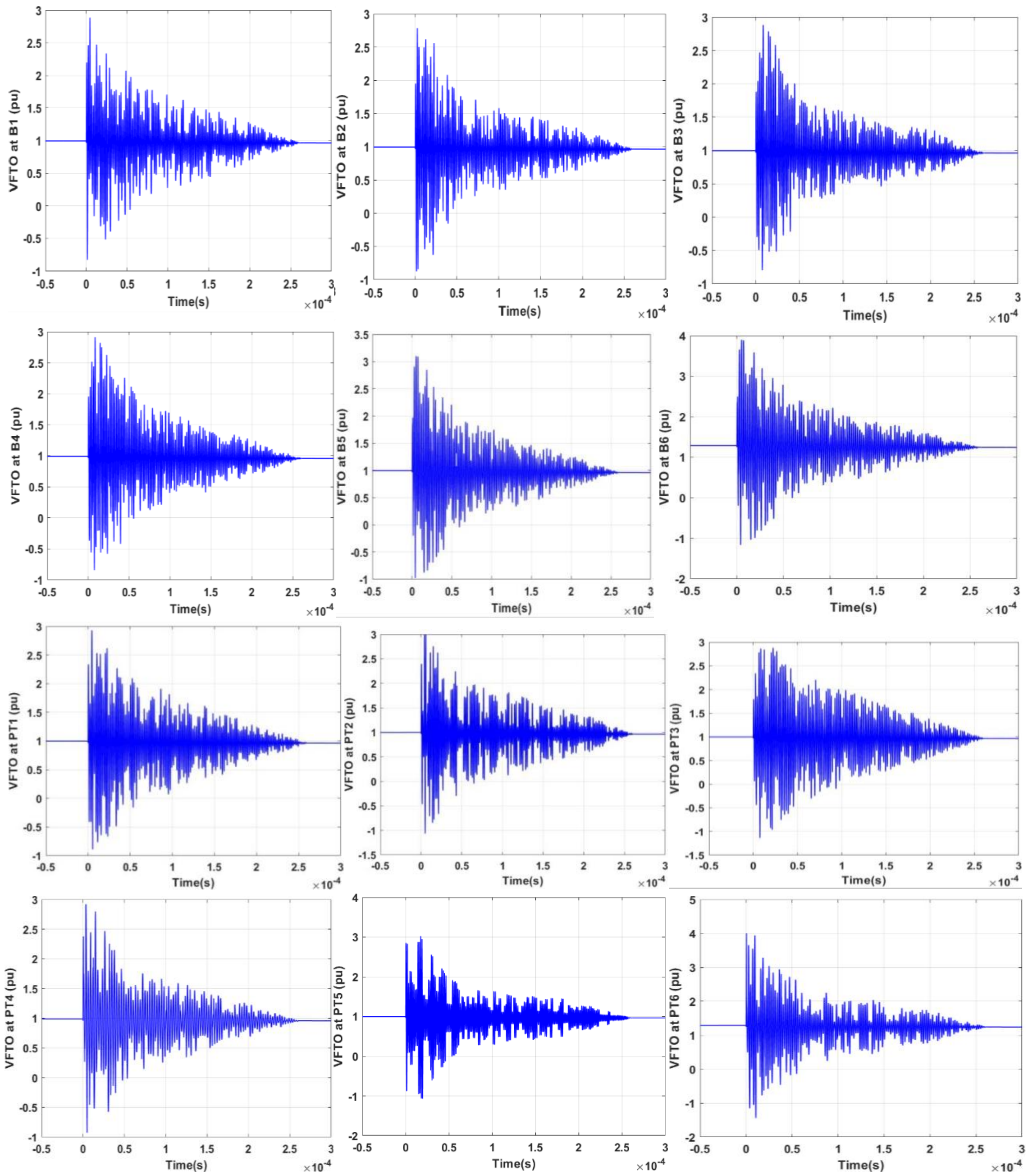


Figure 8. VFTOs at point of connection of switches (CB1-CB6) and at potential transformers (PT1-PT6) of 1000 KV substation due to switching operation of CB1disconnector switch without any mitigating device

Figure 9 shows the decrease in transients after using a 530 resistance to the disconnector switch. Figure 10 describes the effect of VFTO at the B1 and B2 locations for four resistances. The table 1 shows the magnitude of VFTOs, rise time, and settling time before and after using resistance as a diminishing system. The VFTOs are decreased by 10% and the settling time is decreased by 10 seconds after the resistor is utilized. VFTOs at point of linking of switches (CB1-CB6) of 1000 KV substation due to switching operation of CB1 disconnector switch with resistor as modifying device. VFTOs at prospective converters (PT1-PT6) of 1000 KV substation due to switching process of CB1 disconnector switch with resistor as diminishing device

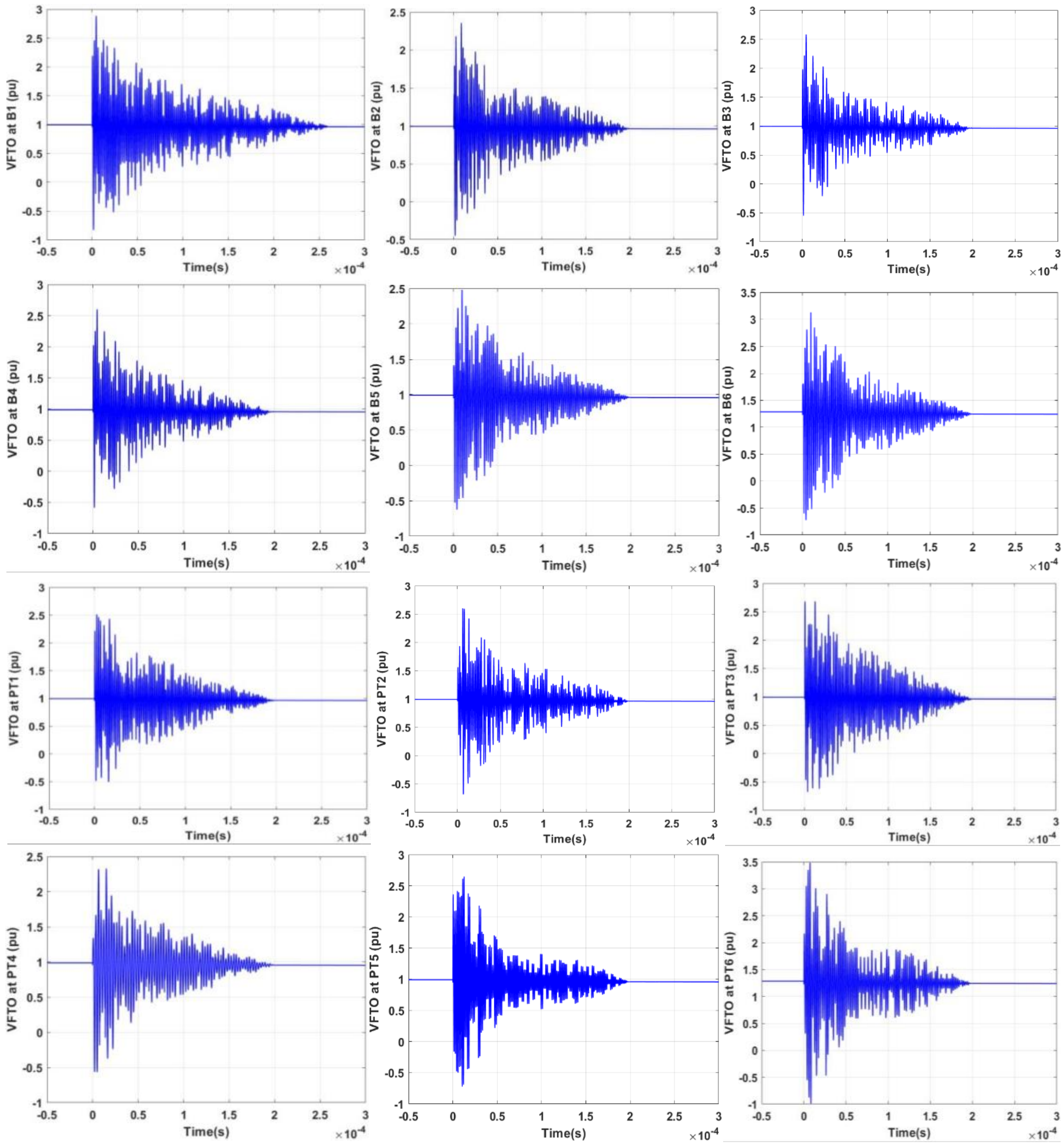


Figure 9. VFTOs at disconnector switches (CB1-CB6) and at potential transformers(PT1-PT6) of 1000 KV substation due to switching operation of CB1 disconnector switch with resistor as mitigating device

Table 1. Vftos Magnitude, Settling Time And Rise Time For 1000kv Substation Without And With Mitigating Device

Measured location	Without additional resistance			With additional resistance as mitigating device		
	Magnitude (p.u.)	Rise time (μ sec)	Settling time (μ sec)	Magnitude (p.u.)	Rise time (μ sec)	Settling time (μ sec)
CB1	2.85	1.68	255.1	2.7	1.33	250.1
CB2	2.63	1.69	251.0	2.38	1.21	198.3
CB3	2.88	1.75	258.15	2.55	1.29	197.5
PT1	2.9	1.66	253.8	2.5	1.32	180.3
PT2	3	1.66	255.7	2.55	1.29	185.0
PT3	2.86	1.70	255.32	2.58	1.28	181.56

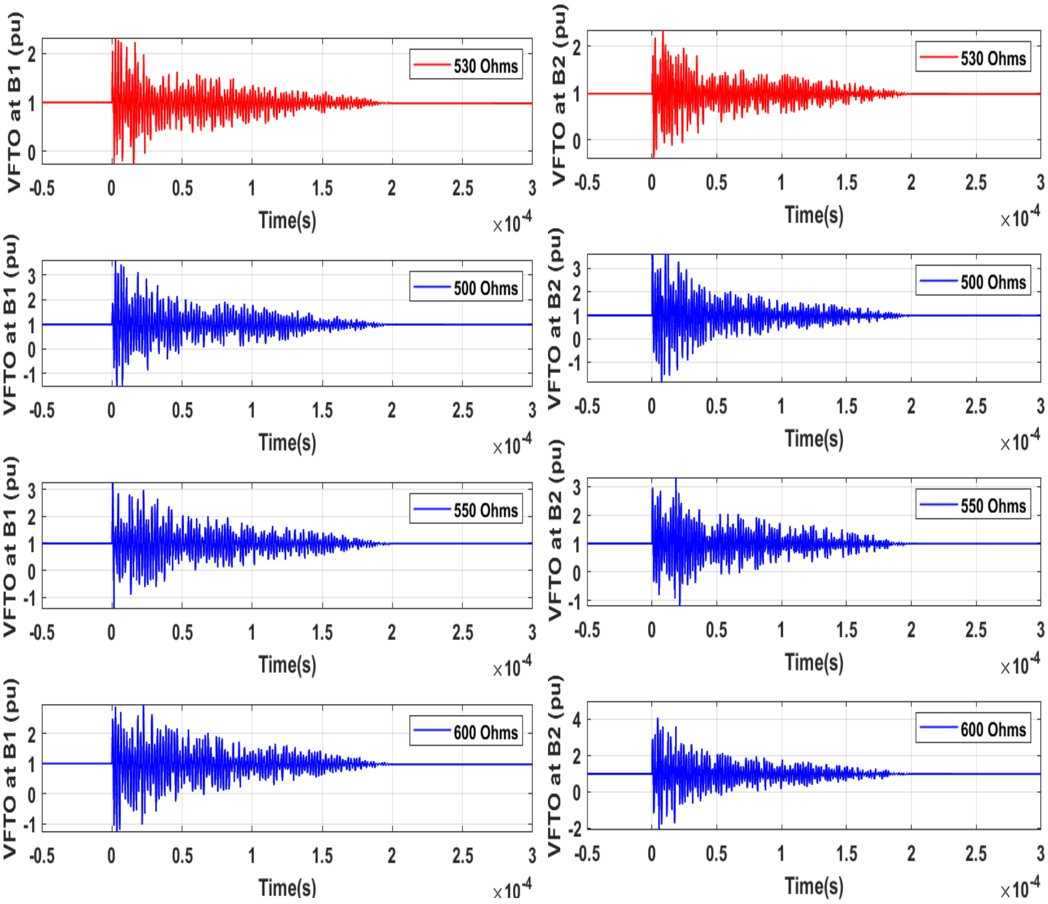


Figure 10. VFTOs at B1 and B2 locations of substation for 4 different values of Resistance

4.2. Suppression of VFTOs in 1000 KV GIS by RC Filter

Separate CB1 is switched off to explore the fast voltage transientsand the impacts of these transients on another devices. By increasing a resistor as a mitigating device, Figure 11 shows voltage transients atvarious points of the substation due to a CB1 switching case. Each disconnector switch has a 258 ohms resistance and a 0.85F capacitor RC filter, and voltage transients are described and shown in figure 12. Owing to effective redistribution of high frequency oscillations, the peak value of voltage transient when increasing resistance is in and about 2.5p.u., and this peak value is decreased to 1.8p.u. later changing resistor with RC Filter. Figure 13 describes the impact of VFTO at the B1 and B2 places for four distinct RC filter values. The table illustrates the magnitude of VFTOs, rise time, and settling time before and after adding conflict and RC filter as mitigating devices. The levels of voltagetransients are decreased by 34% and the dropping time is decreased by 30% when changing resistance with an RC filter as a mitigating device in the disconnector switch. VFTOs at disconnector switches (CB1-CB6) of 1000 KV substation due to switching operation of CB1 disconnector switch with resistor as mitigating device

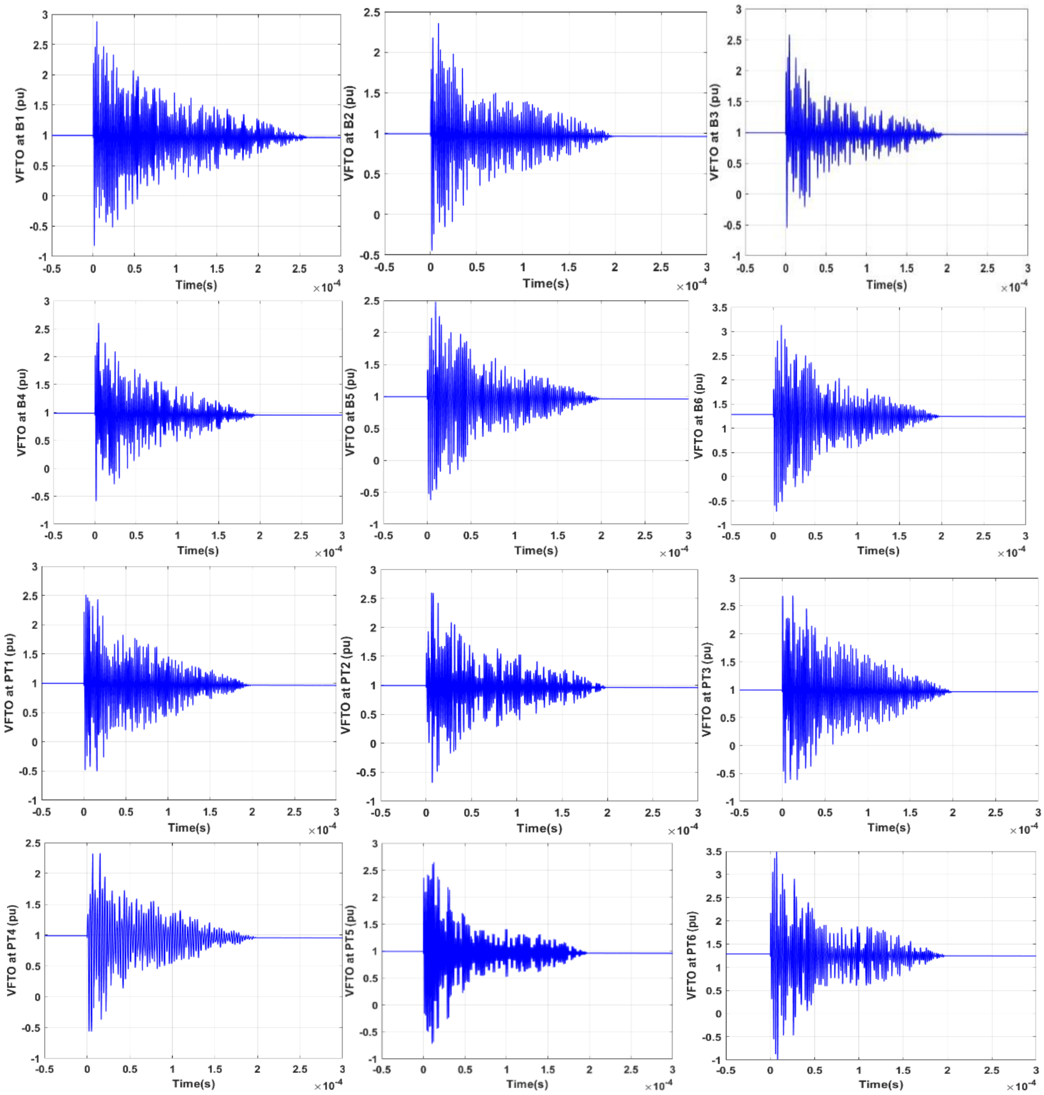
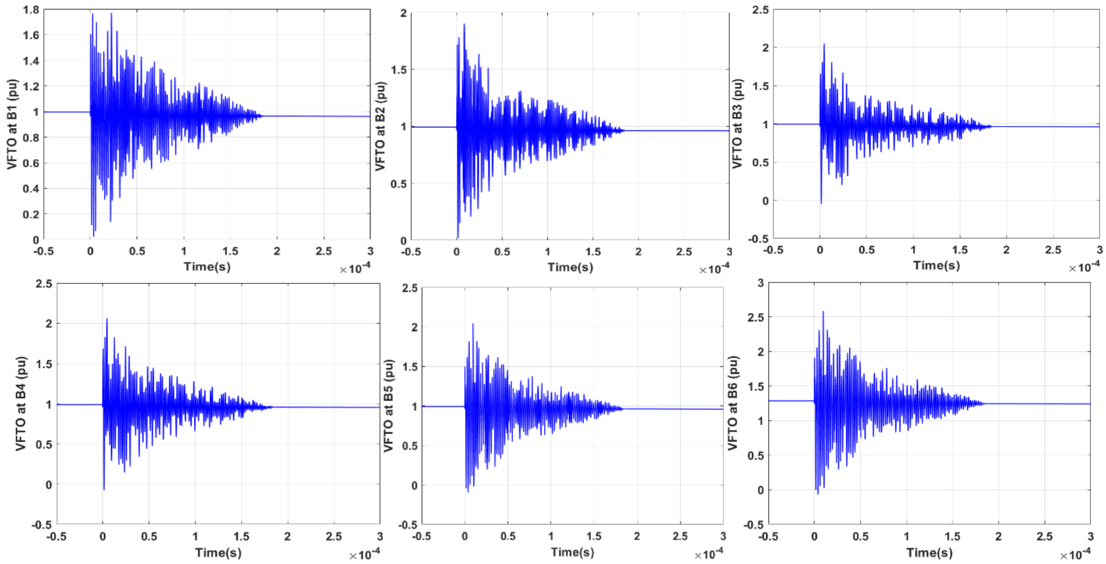


Figure 11. VFTOs at disconnector switches (CB1-CB6) and at potential transformers (PT1-PT6) of 1000 KV substation due to switching operation of CB1 disconnector switch with resistor as mitigating device

VFTOs at potential transformers (PT1-PT6) of 1000 KV substation due to switching operation of CB1 disconnector switch with resistor as mitigating device



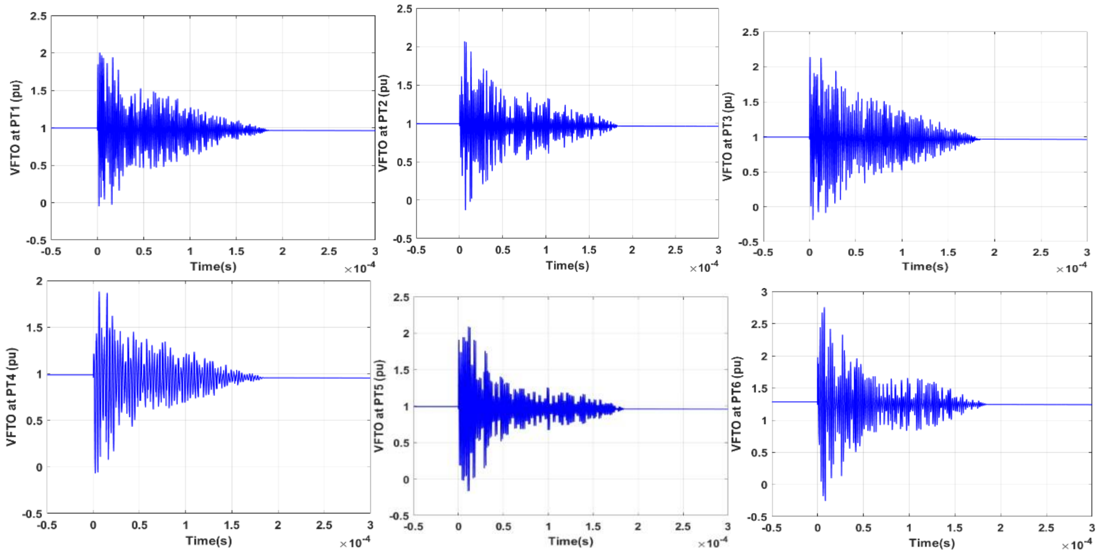


Figure 12. VFTOs at disconnector switches (CB1-CB6) and at potential transformers (PT1-PT6) of 1000 KV substation due to switching operation of CB1 disconnector switch with RC Filter as mitigating device

VFTOs at disconnector switches (CB1-CB6) of 1000 KV substation because of switching function of CB1 disconnector switch with RC Filter as mitigating device.

VFTOs at potential transformers (PT1-PT6) of 1000 KV substation because of switching function of CB1 disconnector switch with RC Filter as modifying device.

Table 2. VFTOs magnitude, settling time, and rise time for1000KV substation with resistor and RC filter as mitigatingdevice

Measured location	With additional resistance as mitigating device			With additional RC Filter as mitigating device		
	Magnitude (p.u.)	Rise time (µ sec)	Settling time (µ sec)	Magnitude (p.u.)	Rise time (µ sec)	Settlingtime (µ sec)
CB1	2.7	1.33	250.1	1.78	1.185	175.6
CB2	2.38	1.21	198.3	1.82	1.172	178.36
CB3	2.55	1.29	197.5	2.03	1.183	170.36
PT1	2.5	1.32	180.3	1.9	1.169	175.9
PT2	2.55	1.29	185.0	2.03	1.185	176.35
PT3	2.58	1.28	181.56	2.1	1.182	175.8

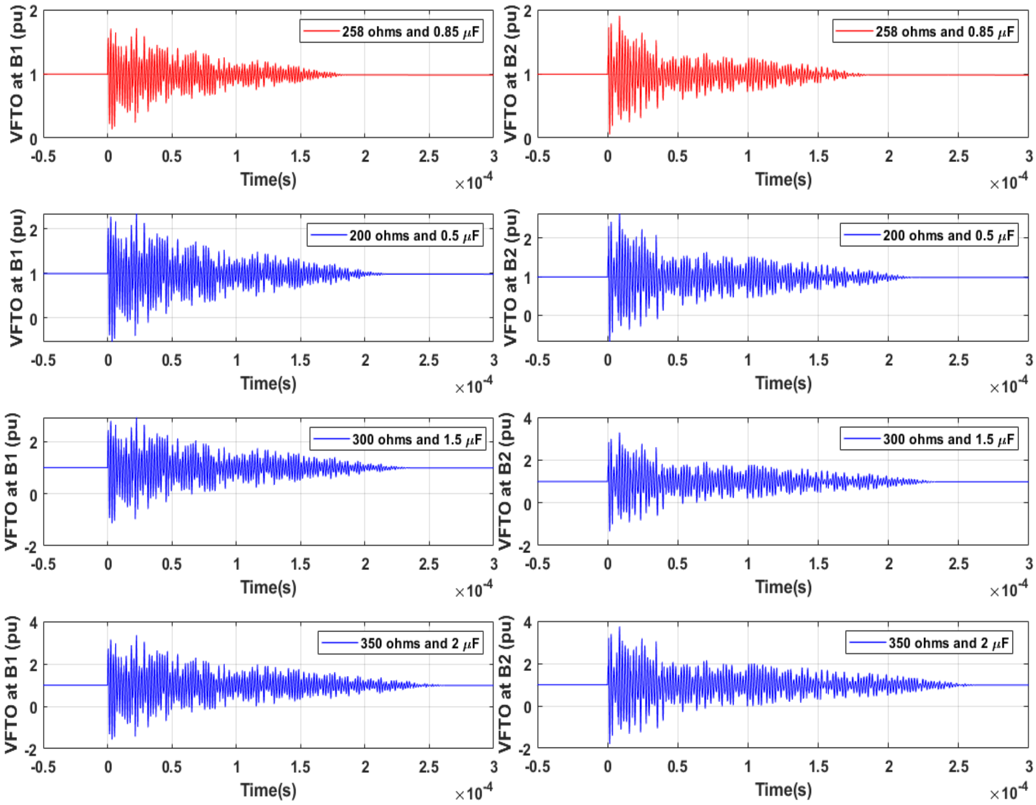


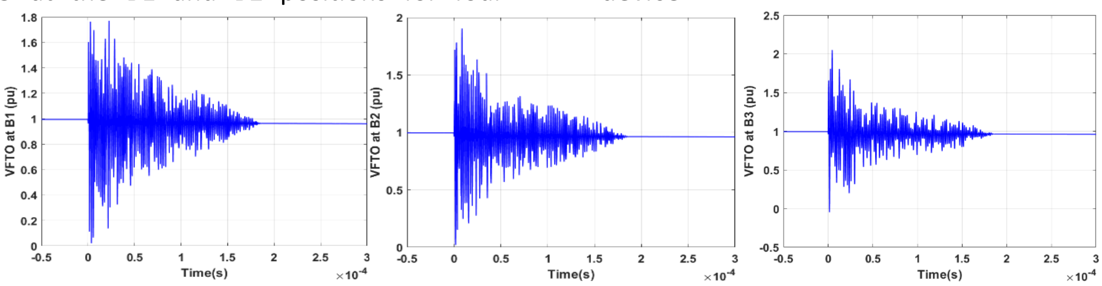
Figure 13. VFTOs at B1 and B2 places of substation for 4 distinct values of RCFilter

4.3. Suppression of VFTOs in 1000 KV GIS by Ferrite Rings

A switching event on disconnector switch CB1 is used, and VFTOs are listed and estimated to do for sure if replace extra equipment in a 1000 KV. Consequently, add up an RC Filter as a modifying unit, voltage transients at specific points of the substation directly to a CB1 switching event are shown in Figure 14. The improved values of ferrite rings are 115ohms resistance and 3.35mH inductance, are connected to all disconnector switch and voltage transients are defined and shown in figure 15.

Figure 16 shows the consequence of VFTO at the B1 and B2 positions for four different Ferrite ring values. The table shows the significance of VFTOs, rise time, and settling time before and after using an RC filterand Ferrite rings as justifying devices. By altering the RC filter by Ferrite Rings as a declining method in the disconnector switch, the magnitude of voltage transients is reduced by 17% and the falling time is decreased by 30-40 seconds. The peak magnitude of VFTOs varies between 1.7 and 2.1 p.u. later using an RC filter and 1.6 and p.u. when using of Ferrite Rings.

VFTOs at disconnector switches (CB1-CB6) of 1000 KV substation supposed to switching process of CB1 disconnector switch down by RC Filter as mitigating device



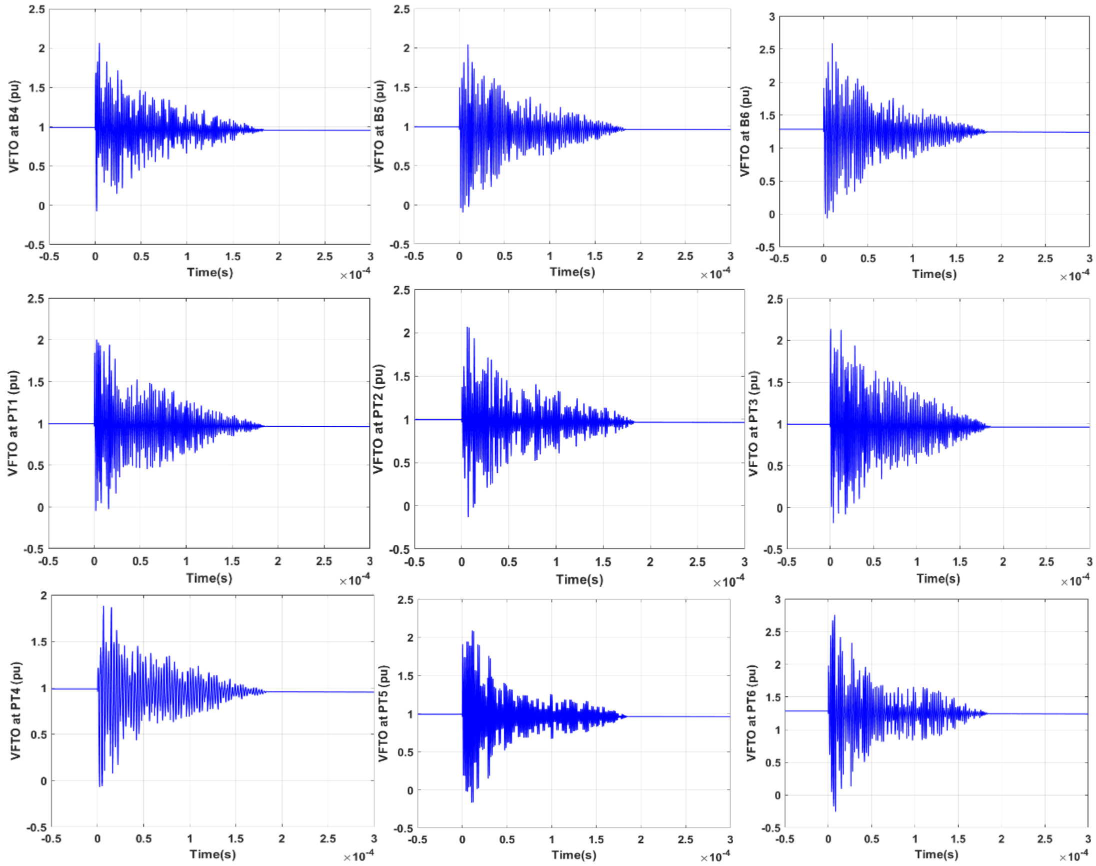
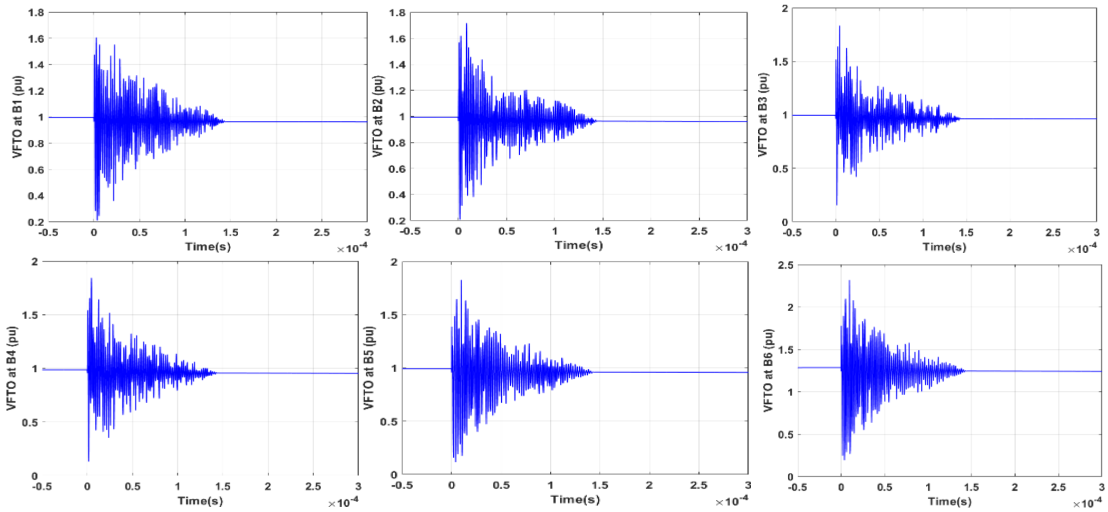


Figure 14. VFTOs on disconnector switches (CB1-CB6) and at potential transformers(PT1-PT6) of 1000 KV substation supposed to switching operation of CB1 disconnector switch through RC Filter as mitigating device

VFTOs at potential transformers (PT1-PT6) of 1000 KV substation expected to switching operation of CB1 disconnector switch by RC Filter as mitigating device.

VFTOs at disconnector switches (CB1-CB6) of 1000 KV substation scheduled to switching operation of CB1 disconnector switch by Ferrite Ring as mitigating device



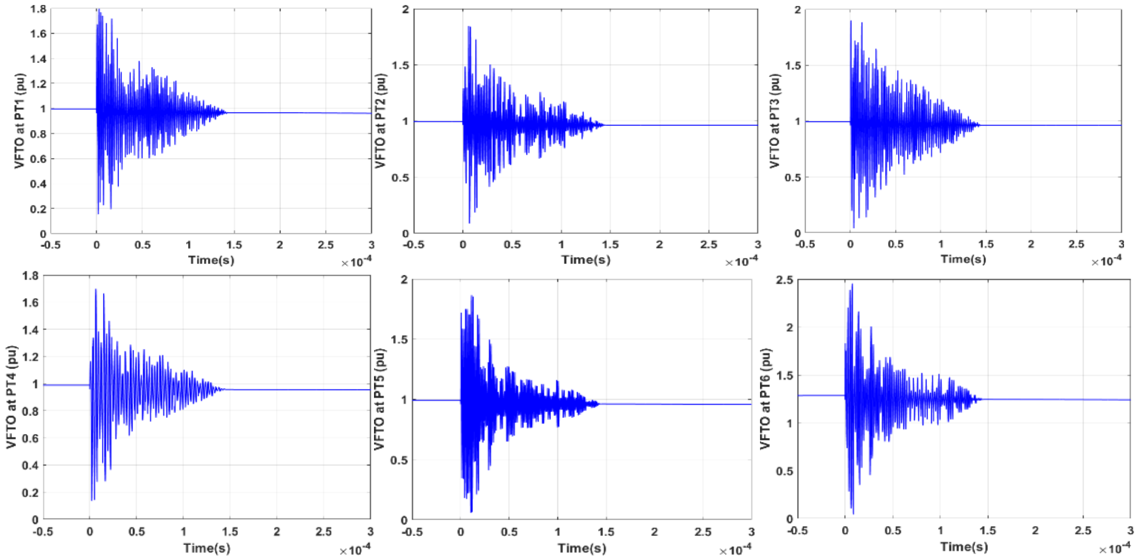


Figure 15. VFTOs at disconnector switches (CB1-CB6) and at potential transformers(PT1-PT6) of 1000 KV substation expected to switching operation of CB1 disconnector switch by Ferrite Rings as mitigating device

VFTOs at potential transformers (PT1-PT6) of 1000 KV substation among the switching operation of CB1 disconnector switch by Ferrite Ring as mitigating device

Table 3. VFTOs magnitude, settling time and rise time for1000KV substation with RC Filter and with Ferrite ring as mitigating devices

Measured location	With additional RC Filter as mitigating device			With additional Ferrite Ring asmitigating device		
	Magnitude (p.u.)	Rise time (µ sec)	Settling time (µ sec)	Magnitude (p.u.)	Rise time (µ sec)	Settling time (µ sec)
CB1	1.78	1.185	175.6	1.6	1.139	142.8
CB2	1.82	1.172	178.36	1.7	1.126	141.36
CB3	2.03	1.183	170.36	1.62	1.13	140.22
PT1	1.9	1.169	175.9	1.79	1.125	139.56
PT2	2.03	1.185	176.35	1.75	1.139	140.05
PT3	2.1	1.182	175.8	1.73	1.134	140.4

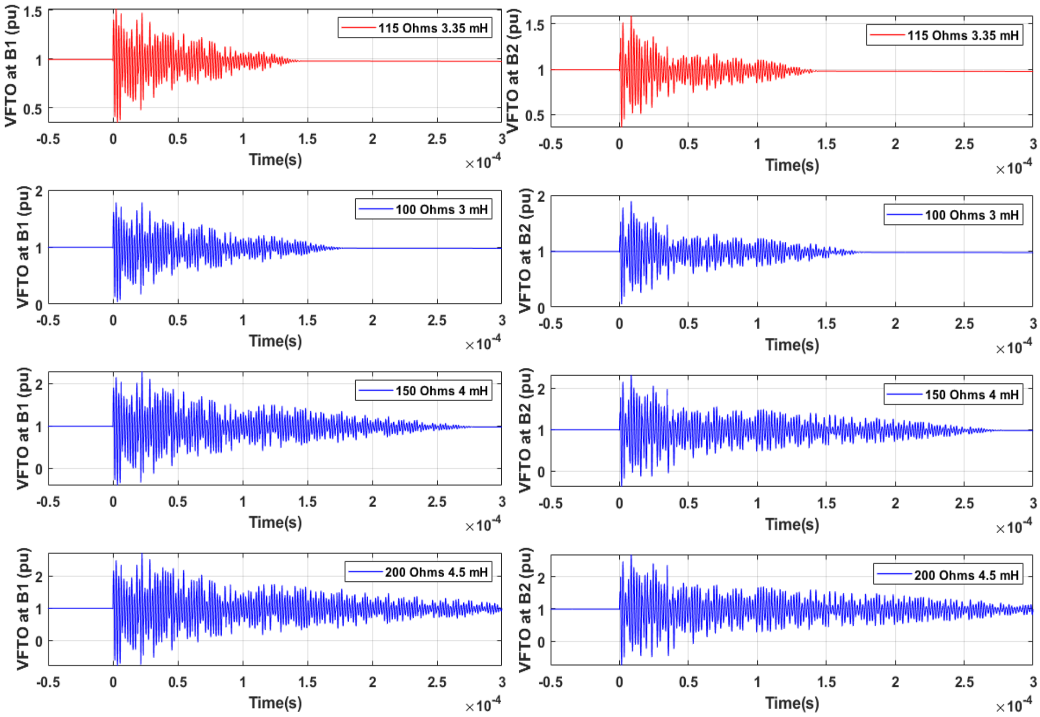


Figure 16. VFTOs at B1 and B2 locations of substation for four different values of resistor and inductor in Ferrite Rings

4.4. Mitigation of VFTOs in 1000 KV GIS by NanocrystallineRings

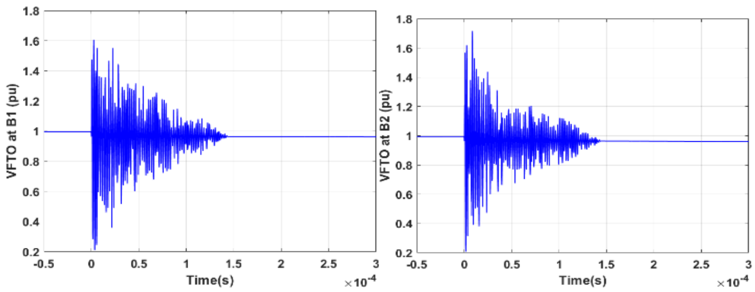
The values selected for resistance and inductance in ferrite rings for a 1000KV substation are 115ohms and 3.35mH, individually, and the outcomes of VFTOs are shown in figure 17. In this case, the peak value of voltage transients is decreased to 1.6pu. To reduce voltage transients, 109ohms, 3.98mH, and 4.02F are chosen for resistance, inductance, and capacitance,

VFTOs at disconnector switches (CB1-CB6) of 1000 KV substation owing to switching operation of CB1 disconnector

respectively, as a nanocrystalline unit,for mitigating voltage transients and outcomes are represented in figure 18. The peak value of voltage transients is decreased to 1.1pu.

Figure 19 describes the impact of VFTO at the B1 and B2 positions forfour distinct values of nanocrystalline rings. The table represents the magnitude of VFTOs, rise time, and settling time following introducing ferrite rings and nanocrystalline devices as mitigating devices.

switch along with Ferrite Ring as mitigating device



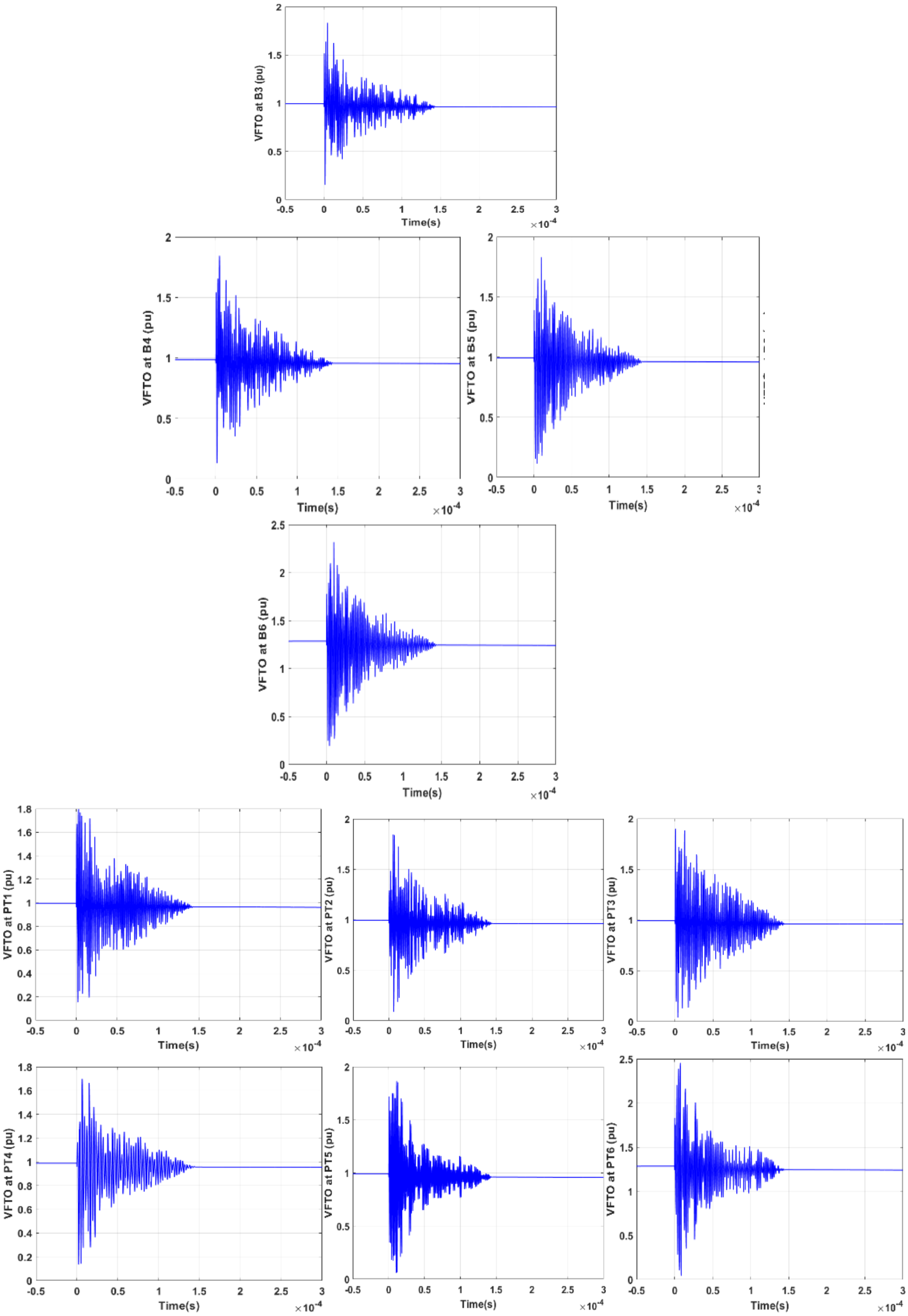
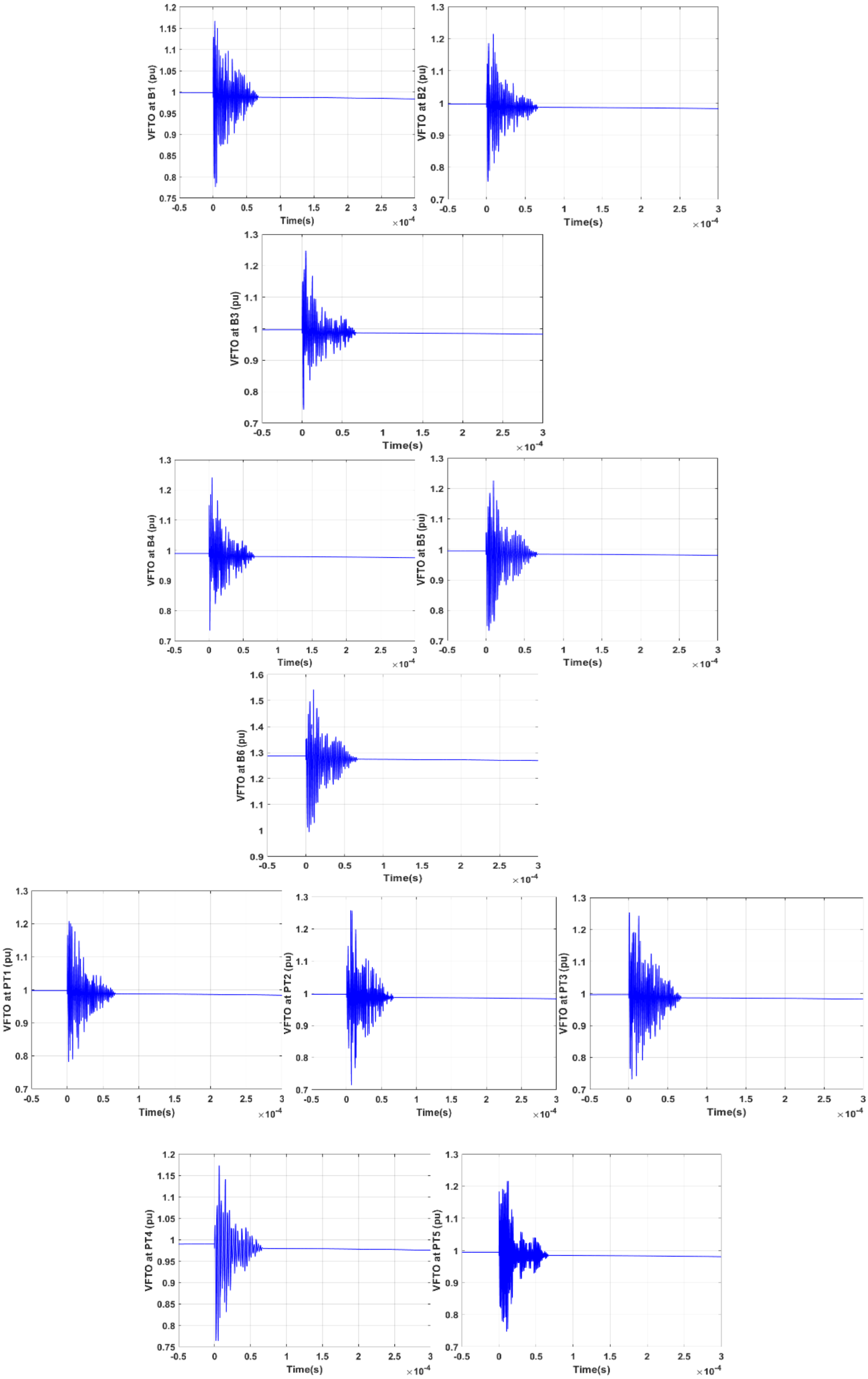


Figure 17. VFTOs at disconnector switches (CB1-CB6) and at potential transformers(PT1-PT6) of 1000 KV substation due to switching operation of CB1 disconnector switch with Ferrite Rings as mitigating device

VFTOs by potential transformers (PT1-PT6) of 1000 KV substation owing to switching operation of CB1 disconnector switch along with Ferrite Ring as mitigating device. CB1 disconnector switch along with nanocrystalline ring like mitigating device owning VFTOs at disconnector switches (CB1-CB6) of 1000 KV substation .


VFTO at B1 (pu)
Time(s)
VFTO at B2 (pu)
Time(s)
VFTO at B3 (pu)
Time(s)
VFTO at B4 (pu)
Time(s)
VFTO at B5 (pu)
Time(s)
VFTO at B6 (pu)
Time(s)
VFTO at PT1 (pu)
Time(s)
VFTO at PT2 (pu)
Time(s)
VFTO at PT3 (pu)
Time(s)
VFTO at PT4 (pu)
Time(s)
VFTO at PT5 (pu)
Time(s)

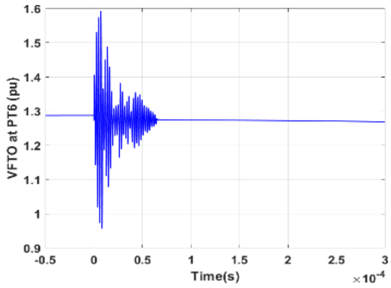


Figure 18. VFTOs at disconnector switches (CB1-CB6) and at potential transformers (PT1-PT6) of 1000 KV substation due to switching operation of CB1 disconnector switch with Nanocrystalline as mitigating device

switching operation of CB1 disconnector switch by Nanocrystalline Ring as mitigating device is owing by VFTOs at potential transformers (PT1-PT6) of 1000 KV substation.

Table 4. VFTOs magnitude, settling time and rise time for1000KV substation with ferrite ring and nanocrystalline asmitigating device

Measured location	With additional Ferrite Rings as mitigating device			With additional Nanocrystalline as a mitigating device		
	Magnitude (p.u.)	Rise time (μ sec)	Settling time (μ sec)	Magnitude (p.u.)	Rise time (μ sec)	Settling time (μ sec)
CB1	1.6	1.139	142.8	1.151	1.032	60.7
CB2	1.7	1.126	141.36	1.22	0.975	55.3
CB3	1.62	1.13	140.22	1.23	0.983	54.27
PT1	1.79	1.125	139.56	1.2	0.975	54.14
PT2	1.75	1.139	140.05	1.22	0.988	55.3
PT3	1.73	1.134	140.4	1.23	0.996	54.2

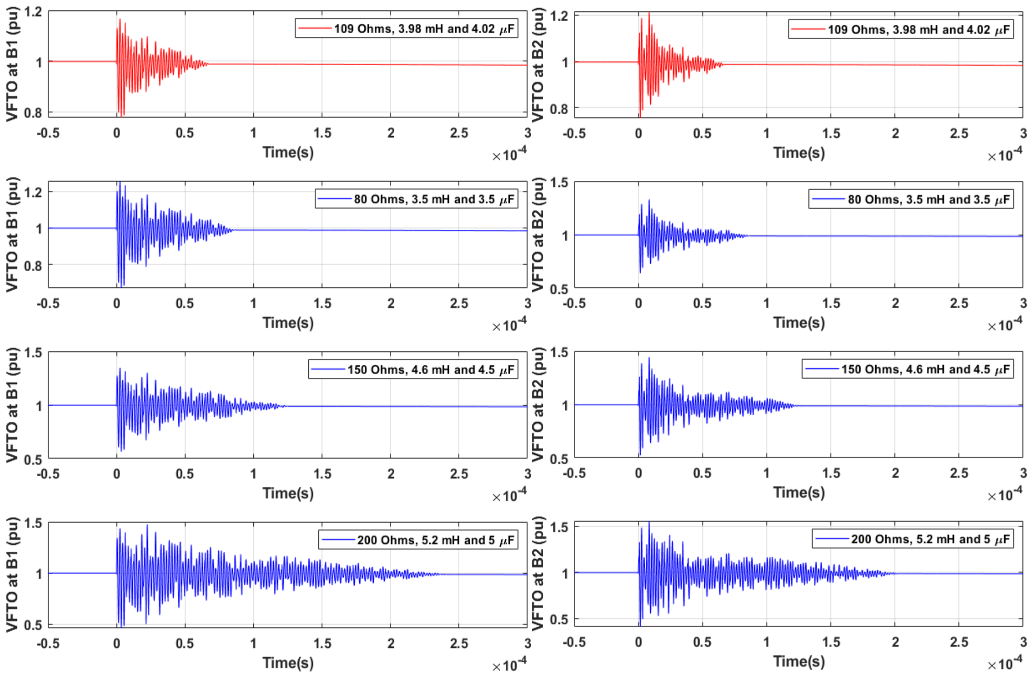


Figure 19. VFTOs at B1 and B2 locations of substation for 4 different values ofresistance, inductance, and capacitance in Nanocrystalline device.

5. Conclusion

VFTOs plays main role to in high voltage GIS substations, where the ratio among impulse withstand voltage and fundamental rated voltage is modest. Mitigating techniques need to be assumed to decrease impact of VFTOs on more equipment of substation. To restrain VFTOs in a 1000KV EHV substation four techniques are present, and outcomes are associated in terms of peak value, rise time and settling time of oscillations. Optimization of parameter values of these techniques is made by executing number of simulations on 1000KV substation. Sections of the substation are developed based on their performance for high frequency oscillations. From the simulation results and contrast, it can be assumed that presentation of nanocrystalline rings as mitigating devices is useful associated to other three techniques.

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