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COMPUTATION OF VFTOS IN TRANSFORMERS OF IN 800KV GIS WITH ATP/EMTP SOFTWARE

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Abstract

In order to determine the rate-of-rise of Very Fast Transient Overvoltage (VFTO) in a 800 kV GIS, simulations are carried out using EMTP-RV. Hence, it is necessary to estimate the magnitudes and the rate-of-rise of VFTO generated during switching operations for insulation coordination of GIS components.Gas insulated switchgear (GIS) has been in operation since last five decades due to its excellence in operation, high reliability and low maintenance. However, some of the problems like VFTO (very fast transient over voltages) are still in concern and need to be analyzed properly for insulation coordination, especially, in the case of EHV & UHV substations.. The simulations will be carried with the assumption that the enclosure is perfectly earthed. Effect of GIS earthing on TEV (Transient Enclosure Voltages) has been area of interest. To simulate TEV accurately, the modelling should present exact replication for the behavior of the enclosure surface of the GIS sections for all conditions which can cause initiation of VFTO & in turn, TEV in GIS. In this work, the GIS is modeled by a new approach to analyze the VFTO's across different equipment and the simulation is been carried out by using MATLAB simulink. Very Fast Transients (VFT) originate mainly from disconnector switching operations in Gas Insulated Substations (GIS). Each component of the GIS is modeled by distributed line model and lumped model based

on equivalent circuits.Also, the analysis of travelling wave using a lattice diagram is conducted to verify the simulation results.
Index Terms: TEV ,GIS, MATLAB, VFTO,EHV&UHV Sub stations,.

Introduction

A few GIS units are under various stages of installation in India because of their advantage compared to conventional substation [1]. The Basic Insulation Level (BIL) required for a gas insulated substation (GIS) is different from that of the conventional substation because of certain unique properties of the former. Gas insulated bus has a surge impedance (70Ω) more than that of the conventional oil filled cables, but much less than that of an over head line (300Ω - 400Ω). Further, the average bus run for a compact GIS is much less than that for the conventional station.In GIS, VFTOs are generated during the switching operation of a Disconnect Switch (DS) [2]or a circuit breaker as shown in Figure 1.. During the switching operation, a number of pre-strikes or re-strikes occur because of the slow speed of the moving contact of DS. These strikes generate VFTO with very high frequency oscillations [1-8]. Even though their magnitudes are lower than Basic Insulation Level (BIL) of the system, they contribute to the aging on the insulation of the system due to their frequent occurrences. Also, VFTO can influence on the insulation of other GIS equipment such as transformers [9-13].

Figure 1: High Voltage Circuit Breakers 3AP Type 72.5 kV to 800 Kv.

Hence, it is necessary to estimate the magnitudes and the rate-of-rise of VFTO generated during switching operations for insulation coordination of GIS components. This paper proposes a new method to calculate the rate of rise of VFTO and analyzes the magnitude and rate-ofrise of VFTO at transformer terminals in a 800 kV GIS using EMTP-RV. Firstly, the calculation methods of rate of- rise are discussed. Secondly, the modelling of each component in GIS is presented. Each component is modelled by distributed line models and lumped line models based on the equivalent circuits recommended by IEEE. Thirdly, the simulations with various switching conditions are performed. The waveform and rate-of-rise of VFTO for each case are presented. The simulation results of rate-of-rise are verified by analysis of travelling wave using a lattice diagram.[3,4] Finally, all the cases of the rate-ofrise of VFTO according to the simulation conditions are discussed.The V-T characteristic of SF6 is considerably flat compared to that of air. Air can withstand to very high voltages for very short time. However, as the duration of voltage increases, the withstand voltage falls off considerably. On the other hand, SF6 exhibits a flat characteristic, VFTO is mainly generated due to the disconnector switching and line to ground faults in GIS. In a GIS, Very Fast Transient Overvoltages (VFTO) is caused by 2 ways: 1) Due to switching operations and 2) Line to enclosure faults.

Rate-of-Rise of VFTO in GIS

VFT overvoltages are generated in a GIS during disconnector or breaker operations, or by line-to-ground faults, during a disconnector operation a number of pre-or restrikes occur due to the relatively slow speed of the moving contact. Figure ure 1 show the simplified conFigure uration used to explain the general switching behavior and the pattern of voltages on closing and opening of a disconnector at a capacitive load [5,6]. During closing, as the contacts approach, the electric field between them will rise until sparking occurs.The rate-of-rise of VFTO can be defined as the magnitude of voltage per microsecond, i.e. in kV/μs. In this paper, firstly, previous methods to calculate the rate-of-rise of voltage are discussed.

$$V = \frac{2Z_2}{Z_2+Z_1}V_1 + \frac{Z_1-Z_2}{Z_1+Z_2}V_2$$

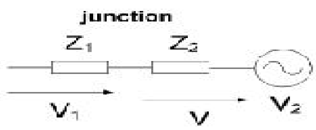


Figure 2: Equivalent circuit to verify result analysis.

First, if we assume V2=1pu in case of the closing pointon- wave from 0° to 180°, (I) can be written by

$$V = \frac{(2V_1-1)Z_2+Z_1}{Z_2+Z_1} \quad [I]$$

Let's 2V1-1=α, then change of V according to the change of Z2 by the number of parallel lines is

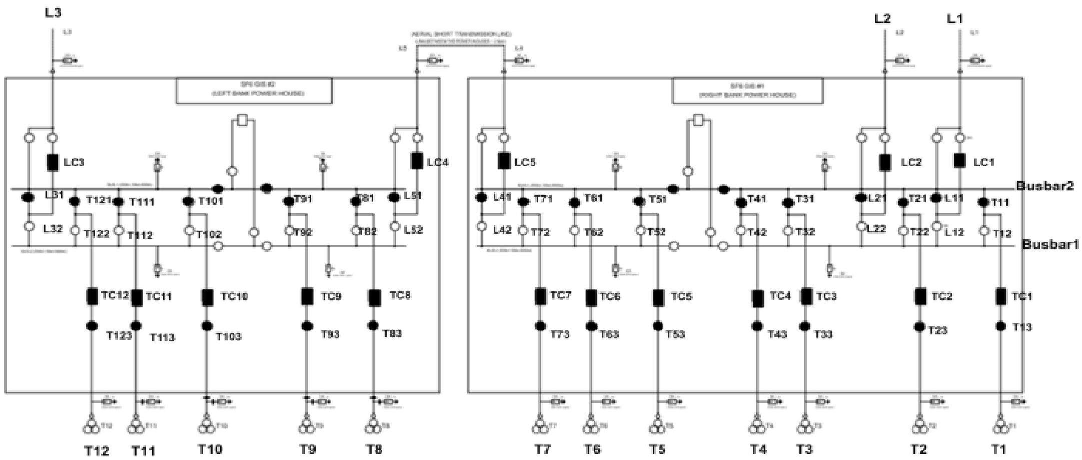
$$\Delta V = \frac{\alpha Z_2 + Z_1}{Z_2+Z_1} - \frac{\alpha(Z_2-\Delta Z_2)+Z_1}{Z_2-\Delta Z_2+Z_1} = \frac{Z_1\Delta Z_2(\alpha - 1)}{(Z_2+Z_1)(Z_2-\Delta Z_2+Z_1)} \quad [II]$$

In (II), the denominator is larger than 0 and Z1/Z2 in the numerator is also larger than 0 so that the sign of (3) depends on α-1, i.e. 2(V1-1). The magnitude of V1 is

$0<V1<1$, and hence $\alpha-1<0$, which means $/V<0$. This result indicates that more branches on the surge propagation route cause a bigger surge voltage and this leads to the lower rate-of-rise. Let's $2V1+1=\alpha$, then we can find the change of V by the method represented above.

$$V = \frac{(2V_1+1)Z_2 - Z_1}{Z_2 + Z_1} \qquad \text{[III]}$$

$$\begin{aligned}\Delta V &= \frac{\alpha Z_2 - Z_1}{Z_2 + Z_1} - \frac{\alpha(Z_2 - \Delta Z_2) - Z_1}{Z_2 - \Delta Z_2 + Z_1} \\ &= \frac{Z_1 \Delta Z_2 (\alpha + 1)}{(Z_2 + Z_1)(Z_2 - \Delta Z_2 + Z_1)}\end{aligned} \qquad \text{[IV]}$$



In (IV), the sign of (IV) depends on $\alpha+1$, i.e. $2(V1+1)$. The magnitude of V1 is $-1<V1<0$, and hence $\alpha+1>0$, which means $/V>0$. This result indicates that more branches on the surge propagation route cause a smaller surge voltage and this leads to the lower rate-of-rise .

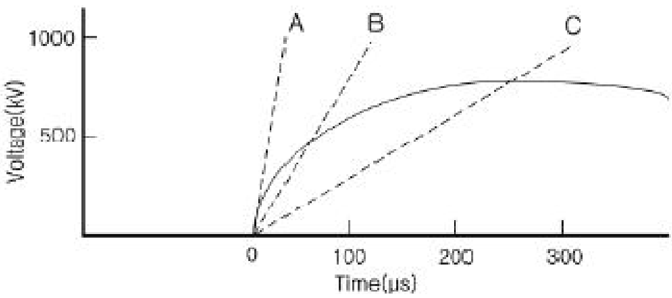


Figure 4: GIS model.

In Figure 3, the rate-of-rise can be calculated as follows: (1) A: the slope at t=0 (2) B: the average value of method A and method C, (3) C: the slope from t=0 to the first peak voltage.

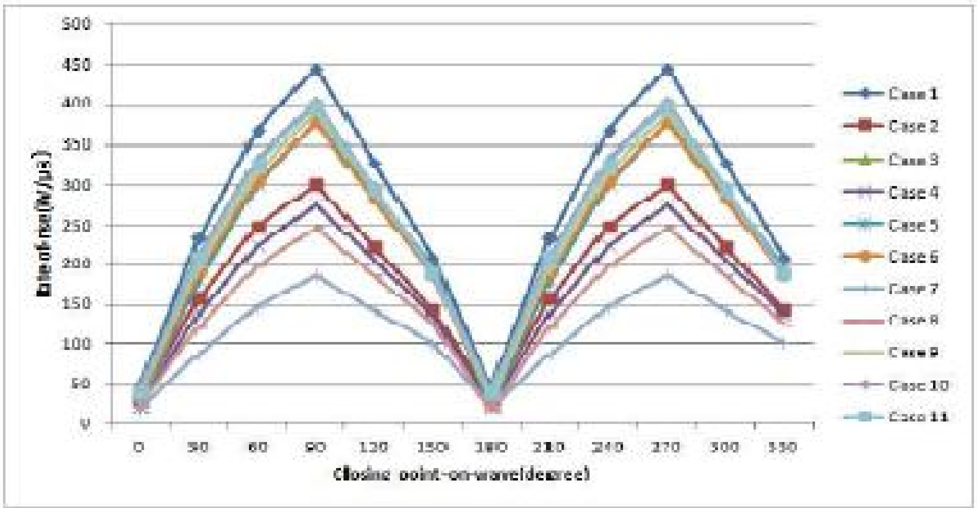


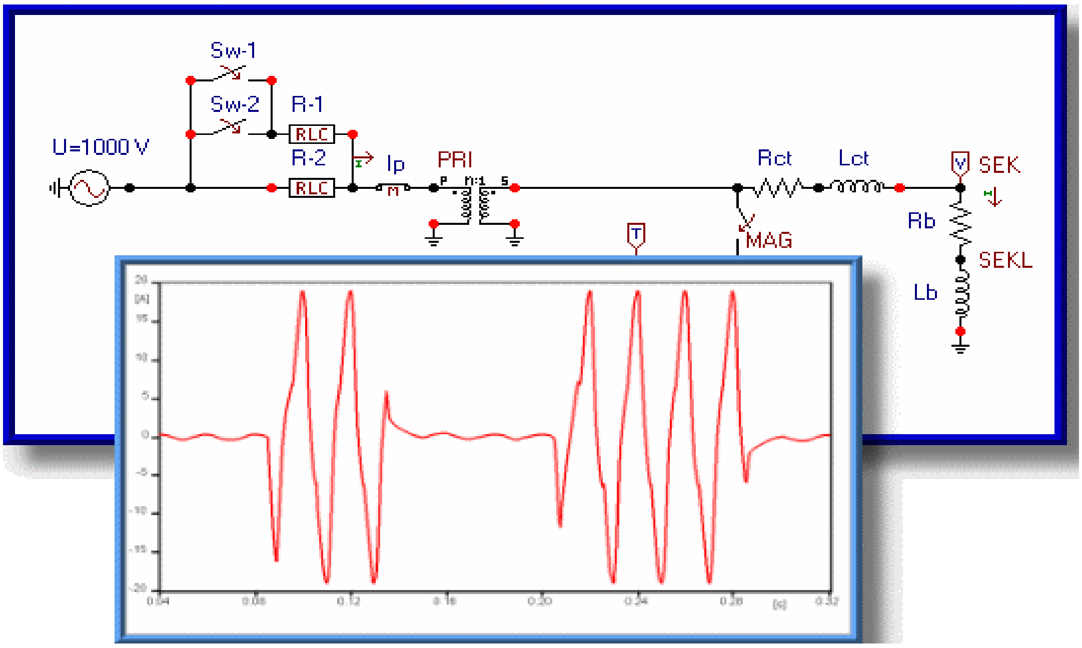
Figure 5: Rate of rise calculation.

This paper proposes the new method to calculate the rate-of-rise defined in (1). according to various closing points-on-wave Figure 3 shows the rate-of-rise calculated by method A and method C according to the various closing points-on-wave for all cases. As the closing point-on-wave approaches 90° and 270°, the rate-of-rise increases as shown in Figure 3. On the other hand, as[7,8] the closing point-on-wave approaches 0° and 180°, the rate-of-rise decreases. The rate-of-rise calculated by method A and C has similar patterns. Figure 5 shows the rate-of-rise calculated by proposed method in (1) for all cases.
The proposed method uses the second-order difference based on the moving window technique, which is used in transient analysis and protection algorithm[9,10]of power system. In this paper, a Δt Analysis of Magnitude and Rate-of-rise of VFTO in 800 kV GIS using EMTP-RV (timestep) is set as 50ns.

$$V_{Rate-of-rise} = \mathrm{Max}\left(\frac{V[i]-V[i-2]}{2\Delta t}\right) \quad [1]$$

Where V[i] and V[i-2] mean the voltage magnitude at present sample and the voltage magnitude of the sample at two times ago. Since method A and C look at only the beginning part of the VFTO waveform, there is a possibility to miss the maximum rate-of-rise VFTO which may occur after the first peak as the travelling waves arrive. This potential problem can be solved by the proposed method as it takes into account the entire VFTO waveform3.

2.1 ALTERNATIVE TRANSIENTS PROGRAM:Figure (a)ATP/EMTP SOFTWARE



Above Figure (a) shows EMTP is an acronym for ElectroMagnetic Transients Program. It is usually part of a battery of software tools targeting a slice of the spectrum of design and operation problems presented by Electric Power Systems to the Electrical Engineer, that of the so called "electromagnetic transients" and associated insulation issues.There are two basic streams of EMTP programs: those derived directly from codes written in BPA and in the Development Coodination Group of EMTP (DCG-EMTP), and those written from scratch. The ATP and MT-EMTP programs, for example, are based on the original BPA and DCG-EMTP versions. The recent EMTP-type programs are using new numerical methods and modeling approaches, and provide significantly improved capabilities and numerical performances. Examples of EMTP type programs are EMTP-RV, MT-EMTP, ATP, eMEGAsim and HYPERsim from Opal-RT Technologies, RTDS Technologies, and PSCAD-EMTDC.

Modeling of GIS using EMTP Software

Step-shaped travelling surges are generated and travelled to GIS lines connected to the collapse location. The rise time of these surges depend on the voltage preceding the collapse.The GIS in Figure 2 consists of DS, circuit breakers, earthing switches, feeders connected with transformer (TR feeders), feeders connected with transmission lines (T/L feeders), busbars, [11]coupling feeders, and etc. The rated voltage of GIS is 800 kV. The number of generators connected to transformers is 46 and the capacity of each generator is 83.34MVA. In Figure 2, L1~L5 indicate the T/L feeders and T1~T12 are the TR feeders. Also, circles signify the DS and rectangles express the circuit breakers. Figure 2 shows the switching conFigure uration at steady state. The black circles and rectangles illustrate the close state and the white circles and rectangles indicate the open state [12]. Modelling of each component in GIS Due to the travelling wave nature of VFTO in a GIS, modelling of the GIS components, such as a busbar, a circuit breaker, and a DS, makes use of electrical equivalent circuits composed of lumped elements and distributed parameter lines.The parameters such as resistance, surge impedance, and propagation time, of transmission lines, used to model the busbar, the circuit breakers, and the DS, are calculated by EMTP-RV using the geometrical and electrical data of a cable [13,14].

Modeling of transformer

The modelling of a transformer can be performed by the VFT transformer model as shown in Figure 3. In this model, low voltage terminals and neutral are grounded [15].as shown in below Figure 6 and 7

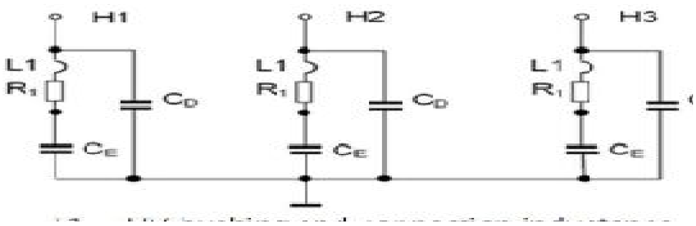


Figure (6)

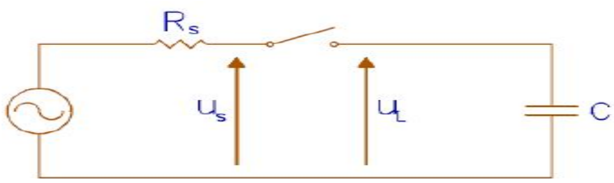


Figure (7)

Figure 6: VFT transformer model in this L1=HV bushing and connection inductance,R1=HV busing ohmic resistance,CD=HV bushing capacitance to earth,CE=winding capacitance Figure 4.capacitive inductance

Computation of GIS Components

Model parameters for two phase line model representing the conductor to enclosure mode are positive and zero sequence surge impedances. These are evaluated from the following equations.

Surge impedance

$$Z = 60 * ln(R/r) \qquad \text{---------------- (1)}$$

Positive sequence surge impedance

$$Z_1 = Z/2 \qquad \text{-------------------------- (2)}$$

Zero sequence surge impedance

$$Z_0 = 20000 - Z_1 \qquad \text{------------------ (3)}$$

b) Spacer Capacitance :The capacitance of spacer that is connected between conductor and with a lumped capacitance of value evaluated from the following equation.

$$C_s = (2\pi\varepsilon_0 \varepsilon_r)/ln(R/r) \qquad \text{------------- (4)}$$

R=internal radius of enclosure r=external radius of conductor with absolute permittivity of the medium with relative permittivity of the medium and Enclosure to Ground mode Another single phase line representing the enclosure to ground mode is governed by the modal parameters of surge impedance and travel time. The surge impedance of equation to enclosure to ground is evaluated from the following equation.

$$Z = 60 * ln(2h/R_e) \qquad \text{-------------- (5)}$$

h= mean height of the section above ground Re=external radius of the enclosure.

Earthing straps are modeled as a single transmission line model with modal parameters of surge impedance and travel time .surge impedance of the earthing is strap is evaluated equation.

$$Z = 60 * ln(2\sqrt{2}h/r_s) \qquad \text{-------------- (6)}$$

h= Mean height of the enclosure above ground rs =radius of the earthing strap

Disconnector is modeled in different in manner for open and close positions. In the closed position, it is modeled as a distributed transmission line. Open position of the disconnector is modeled by a series capacitor demonstrating capacitance between contacts of the disconnector. The sparking between disconnector contacts during its opening or closing operation is modeled by a non-linear resistance in series with a fixed resistance. Value of fixed resistance rs is selected based on the practical consideration as discussed by S.

$$R_s = R_0 * e^{-t/\tau} + R_f \qquad (7)$$

The open ended section of GIS Figure 8 is represented as a lumped shunt capacitance. Assuming the same as a coaxial hemisphere, its capacitance is evaluated from the following equation.

$$C = 2\pi\varepsilon_0\varepsilon_r * (R * r)/(R - r) \qquad (8).$$

R= internal radius of enclosure r=external radius of enclosure

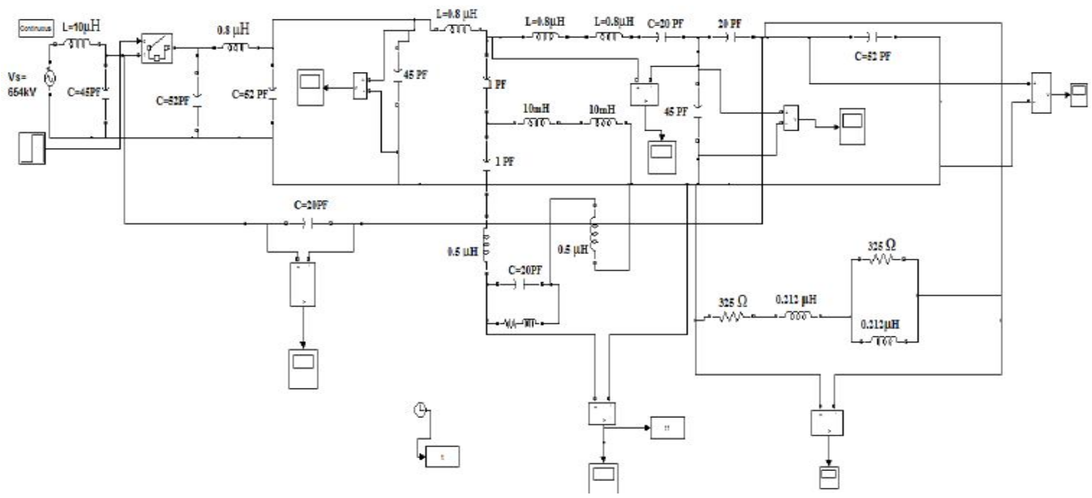


Figure 8:800kv GIS.

Simulation Results

For 800 kV GIS TEV effect on each component is shown below. The effects of each component of GIS enclosure is shown in below Figure ures 4,5,6,7, and 8 of earthing Strap, bushing Capacitance, Spacer Capacitance, Current Transformer and insulating flange respectively.

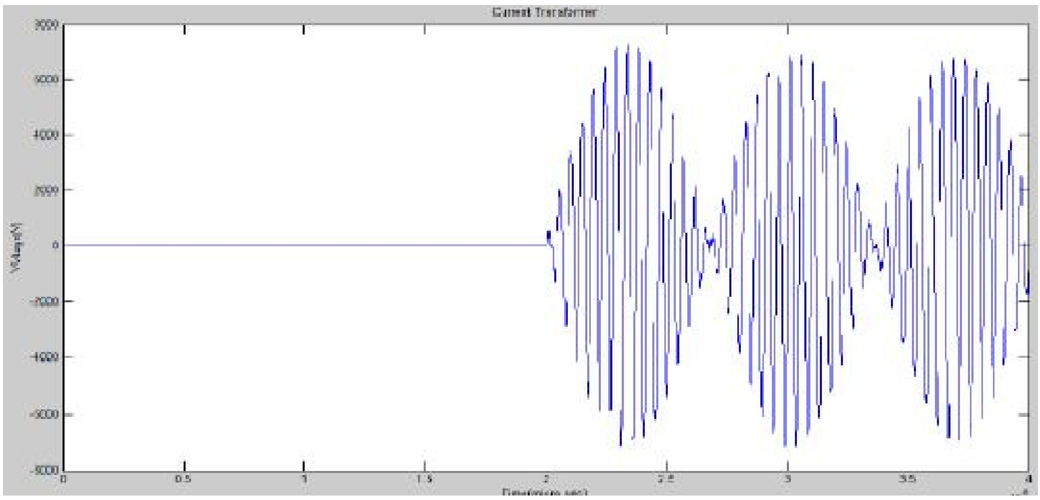


Figure 9:Transient enclosure voltage effect

Table1: Maximum peak equipment for 800KV GIS.

S.No	Equipment	Maximum Peak
1	Earthing Strap	4.5 kV
2	Disconnect Switch	$4x10^4$
3	Spacer Capacitance	$2.2x10^4$V
4	Open end	$0.9x10^4$
5	Surge impedance	$6x\ 10^4$
6	Current Transformer	7.6 kV
7	Bushing Capacitance	59.8kV
8	Insulating Flange	1.8Kv

On current Transformer and 800kv GIS

This paper conducts the simulation of VFTO occurred by closing a DS at each feeder of Table 1 shows the simulation conditions. Case 1, 2, 3, 10, and 11 are the cases of closing a DS at the T/L feeder L1, L2, L3, L4 and L5, respectively. Case 4, 5, 6, 7, 8, and 9 are the cases of closing a DS at the TR feeder T1, T4, T7, T8, T10 and T12, respectively. For each case, the simulations according to the various closing points-on-wave and the trapped charge are also performed.

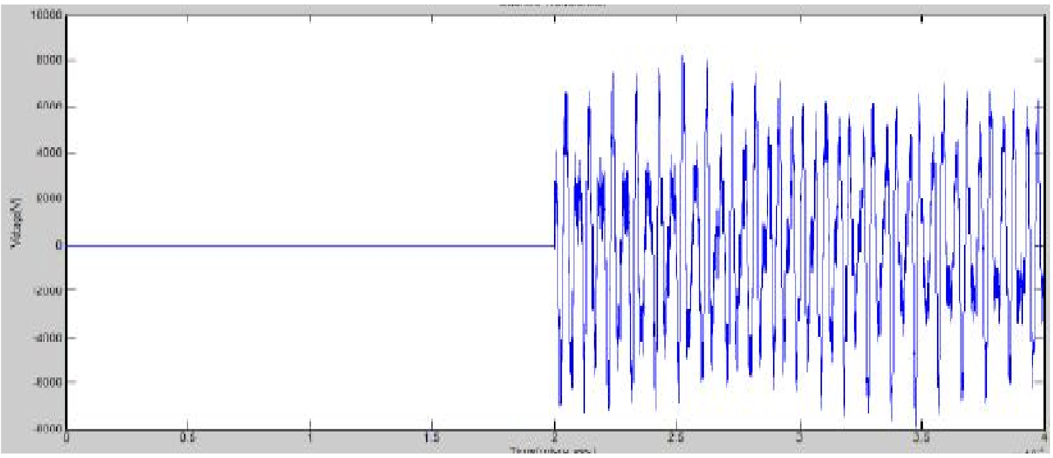


Figure 10: Effect of current transformer.

Case	Operating Disconnector
Case 1	L11 (LC1 kept open)
Case 2	L21 (LC2 kept open)
Case 3	L31 (LC3 kept open)
Case 4	T11 (TC1 kept open)
Case 5	T41 (TC4 kept open)
Case 6	T71 (TC7 kept open)
Case 7	T81 (TC8 kept open)
Case 8	T101 (TC10 kept open)
Case 9	T121 (TC12 kept open)
Case 10	L41 (LC4 kept open)
Case 11	L51 (LC5 kept open)

Figure 11: Simulation results.

Figure 7 shows the waveform of the VFTO measured at the transformer T1 when the closing point-on-wave for Case 1 is 90°. The VFTO waveform represents the characteristics of travelling wave and the maximum value of the VFTO is 1.515pu.

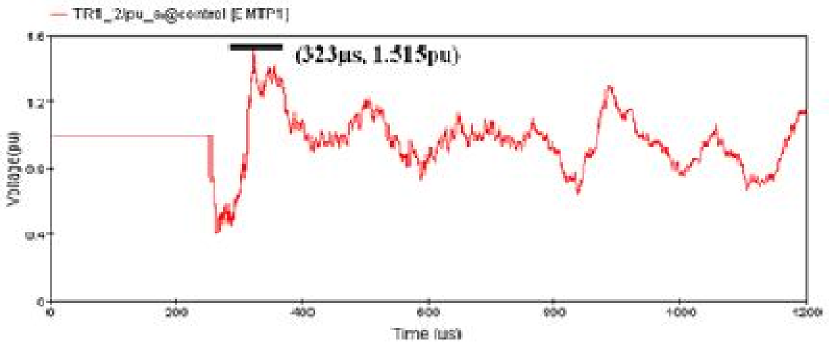


Figure 12: Waveform of the VFTO measured at the transformer.

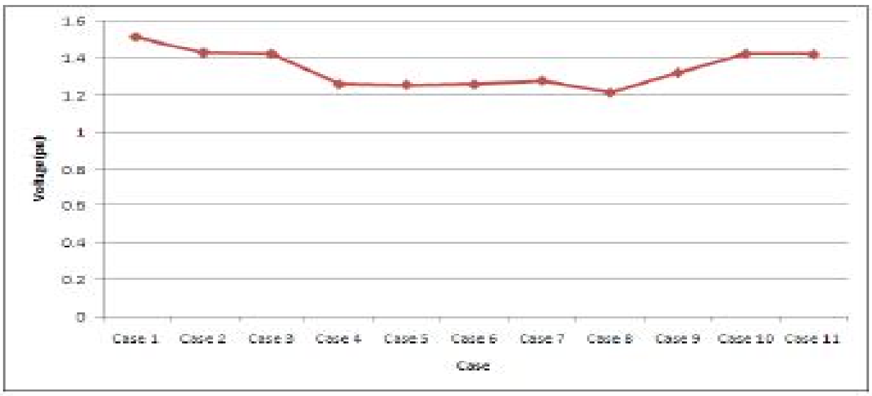


Figure 13: Magnitude of VFTO.

T1 when the closing point-on-wave is 90° The VFTO is analyzed by using a lattice diagram to verify the simulation results [15]. Figure 12 shows the result of the VFTO analysis for Case 1 using the lattice diagram. Because many transmission lines between the DS and the transformer terminal have various surge impedances and velocities, the analysis using lattice diagram from t=0 to the simulation time represented in Figure 13. Hence, this paper performs the VFTO analysis using the lattice diagram until the first surge waveform arrives at the transformer terminal. In Figure .13, α is the reflection coefficient and β is the refraction coefficient. Also, the subscript 1 indicates the direction of the surge wave from the DS toward the transformer terminal and the subscript 2 indicates the direction of the surge wave from the terminal toward the DS. Second, if we assume V2=-1pu in case of the closing point-on-wave from 180° to 360.

Conclusion

A new, more accurate, approach to the modeling of VFTO in GIS is proposed in this paper. In the proposed model, enclosure is split in two parts: Internal and External enclosure surface, which supports representation of the enclosure in more precise manner and helps to replicate its behavior for conditions causing VFTO initiation and in representation of the GIS enclosure also support in demonstrating the effect of GIS earthing on VFTO and TEV characteristics more effectively. In this paper, analysis of the rate-of-rise of VFTO was conducted using EMTP-RV. For GIS components, such as DS, circuit breakers, busbars, and etc., the modeling based on electrical equivalent circuits is performed using EMTPRV. Also, in case of the transformers, the VFT model given by the manufacturer is used. The various switchingconditions were simulated and the simulation results were verified by the lattice diagram. The analysis results can be summarized as follows; (1) The maximum value of the VFTO measured at the transformer terminal in the studied system is 1.515 pu in Case 1 and the minimum value of the VFTO is 1.216pu in As the number of branches on the surge propagation route is increased, the rate-of-rise is decreased and vice versa. (3) As the surge propagation length from the DS to the transformer terminal is shorter, the rate-of-rise is increased and vice versa. (4) As the closing point-on-wave approaches the maximum value of the surge voltage, i.e. 90° and 270°, the rate-of-rise increases, while as the closing point-on-wave approaches the minimum value of voltage, i.e. 0° and 180°, the rate-of-rise decreases. (5) In case of closing point-on-wave with positive half cycle (from 0° to 180°), the rate-of-rise is inversely proportional with the magnitude of the first waveform of the surge voltage. (6) In case of closing point-on-wave with negative half cycle (from 180° to 360°), the rate-of-rise is proportional with the magnitude of the first waveform of the surge voltage. (7) The trapped charge does not influence on the rateof- rise.We will study the transient phenomena caused by lightning surge and temporary surge using GIS model presented in this paper. More accurate models may be needed in some cases for which propagation losses at very high frequencies should not be neglected. The present work has been modeled for 800 kV and 1000 kV Gas Insulated substations by using Matlab software. The present work can also be extended for 1200 KV GIS by using EMTP/ PSCAD software.

References

[1] J. Meppelink, K. Diederich, K. Feser, W. Pfaff, "Very Fast Transients in GIS", IEEE Trans. on Power Delivery, Vol. 4, No. 1, pp. 223-233, January, 1989.

[2] V. Vinod Kumar, Joy Thomas M., M.S. Naidu, "Influence of Switching Conditions on the VFTO Magnitudes in a GIS", IEEE Trans. on Power Delivery, Vol. 16, No. 4, pp. 539-544, Oct., 2001.

[3] Yaswanth Vadrapalli, Urmil B.Parikh, Kalpesh Chauhan," A novel approach to Modeling and Analysis of Very Fast Transients in EHV Gas Insulated Switchgear" SWICON 2011.

[4] IEEE TF on Very Fast Transient (D.Povh, Chairman), "Modelling and analysis guidelines for very fast Transients", IEEEE Trans. on Power Delivery, vol. 11, no.4, October 1996.

[5] A. Ecklin, D.Schlicht and A.Plessl, "Overvoltages in GIS caused by the operation of isolators", Surges in high-voltage networks, K.Ragaller (Ed.) 1980.

[6] S. Yanabu *et al.*, "Estimation of fast transient overvoltage in gas-insulated substation", IEEE Trans. on power delivery, vol.5, no.4 1875-1882, October 1990.

[7] IEEE PES Special Publication, "Tutorial on Modeling and Analysis of System Transients using Digital Programs", IEEE Working Group 15.08.09, 1998.

[8] D. Povh, H. Schmeitt, O. Volcker, and R. Witzmann, "Modeling and Analysis Guidelines for Very Fast

[9] Transients", IEEE Trans. on Power Delivery, Vol. 11, No. 4, pp. 2028-2035, October, 1996.

[10] A. Tavakoli, A. Gholami, A. Parizad, H. M. Soheilipour, H. Nouri, "Effective Factors on the Very Fast Transient Currents and Voltages in the GIS", IEEE Transmission & Distribution Conference & Exposition: Asia and Pacific,

[11] Q. Liu, "Study of Protection of Transformer from Very Fast Transient Over-voltage in 750kV GIS", International Conference on Electrical Machines and Systems, Vol. 3, pp. 2153- 2156, 2005.

[12] Tian Chi, Lin Xin, Xu Jianyuan, Geng Zhen-xin, "Comparison and Analysis on Very Fast Transient Overvoltage Based on 800 kV GIS and 800kV GIS,November 9-13, 2008

[13] Hun-Chul Seo, Chul-Hwan Kim, "The analysis of power quality effects from the transformer inrush current: A case study of the Jeju power system, Korea", 21st Century, 2008.

[14] DCG-EMTP(Development coordination group of EMTP) Version EMTP-RV, Electromagnetic Transients Program. [Online]. Avaliable : http://www.emtp.com.
[15] Allan Greenwood, “Electrical Transients in Power Systems”, John Wiley & Sons 1991.
[16] Van der Sluis, “Transients in Power System”, John Wiley & Sons 2001.

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