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Analysis of Very Fast Transients in EHV Gas Insulated Substations

A.Raghu Ram, k. Santhosh Kumar
raghuram_a@yahoo.com,ksanthosheee@gmail.com

Abstract:* 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.

Index Terms— **Gas Insulated Switchgear, MATLAB-Simulink, Very Fast Transients Overvoltages.**

I. 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 addition, the GIS are totally enclosed and therefore is free from any atmospheric contamination. Hence, in general the GIS permit lower BIL rating than the conventional one.

The GIS require less number of lightning arresters than a conventional one. This is mainly because of its compactness. The basic consideration for insulation coordination is V-T characteristic. The V-T characteristic of SF_6 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, SF_6 exhibits a flat characteristic, thus the ratio of basic lightning impulse level is close to unity for GIS, where as for the conventional substations this ratio varies between 0.6 and 0.86.

VFTO is mainly generated due to the disconnector switching and line to ground faults in GIS. In the event of closing or opening operation of GIS disconnector, a large number of restrike or prestrike between the contacts may occur. The surge will travel away from both sides of the disconnector and in the way; will travel through other parts of the GIS section. Further, this surge will acquire reflections and refractions at each discontinuity within GIS; like open disconnector or breaker, 'T'-junction Spacers, Air Terminations etc. For these reasons, VFTO generated in a GIS should be considered as an important factor in the insulation design. In a GIS, Very Fast Transient Overvoltages (VFTO) is caused by two ways:

1) Due to switching operations and
2) Line to enclosure faults.

II. ORIGIN 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 1 show the simplified configuration used to explain the general switching behavior and the pattern of voltages on closing and opening of a disconnector at a capacitive load [2] [3].

During closing, as the contacts approach, the electric field between them will rise until sparking occurs. The first strike will almost inevitably occur at the crest of the power frequency voltage, due to the slow operating speed. Thereafter current will flow through the spark and charge the capacitive load to the source voltage. So, the potential difference across the contacts falls down and the spark will be eventually extinguished. The behavior on opening is very nearly a complete reversal of the above description. In case of a line-to–ground fault, the voltage collapse at the fault location occurs in a similar way as in the disconnector gap during striking. 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.

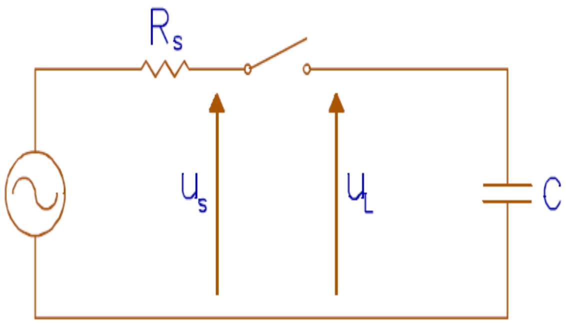


Fig. 1. Diagram Of Capacitive Circuit

III. MODELLING OF GIS COMPONENTS

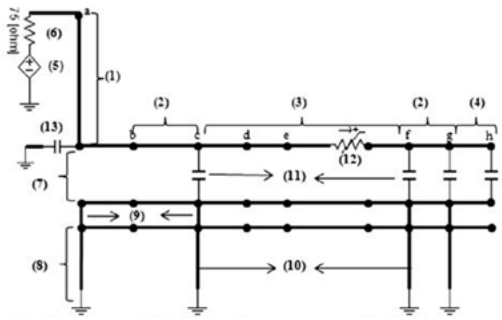
An 800kV GIS section of two phase line model as shown in Figure 2. Instead of considering complete layout, a small GIS section is considered containing all major parts that govern the characteristics of VFTO, disconnector, bushing, open end and earthing straps to enclosure. The modelling of individual parts of GIS section is also described with associated equations [4] [5].

A. Simulation Methodology:

For analysis of high frequency transients like VFTO or TEV, the distributed Line model is found to be the most accurate and hence is used for analyses [4] and [5]. Among all presentation available for distributed line model, the one which uses surge impedance and travel time of the distributed line with length is chosen for modelling as it is found to be the most suitable for study of high frequency over voltages.

For the conductor to internal surface of enclosure mode, the velocity of wave to evaluate the travel time is taken as 0.95 times that of speed of light considering the effect of high capacitive elements present in this mode [6]. However, for the external surface of enclosure to ground mode, speed of the light is directly used as velocity of travelling waves, as there will not be any highly capacitive element present in this mode.

Coupling of internal to external enclosure surface exists at air termination (bushing) and at spacers in the GIS section simulated. This coupling is represented by a direct connector of internal enclosure surface with the external surface at the said discontinuities of model of GIS [7].



(1) Bushing
(2) Bus duct
(3) Disconnector
(4) Open end
(5) Voltage
(6) Matching impedance
(7) Conductors to enclosure mode
(8) Enclosure to ground mode
(9) Conduction between internal and external surface of enclosure
(10) Earthing straps
(11) Spacer capacitance
(12) Spark resistance
(13) Bushing capacitance

Fig. 2. Two Phase Line Model For The Defined GIS Section

B. COMPUTATION OF GIS COMPONENTS

Computation of TEV

a) Conductor to Internal Surface Of the Enclosure Mode

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.

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Surge impedance

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

Positive sequence surge impedance

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

Zero sequence surge impedance

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

b) Spacer Capacitance

The capacitance of spacer that is connected between conductor and enclosure is represented with a lumped capacitance of value evaluated from the following equation.

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

R=internal radius of enclosure
r=external radius of conductor
ε_0=absolute permittivity of the medium
ε_r=relative permittivity of the medium

c) 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.

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

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

d) Earthing Straps

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 from the following equation.

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

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

e) Disconnector

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 r_s is selected based on the practical consideration as discussed by S.

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

$R_0=10^{12}\,\Omega$
R_f (fixed resistance) =0.5 Ω
T (spark time constant) =1 ns

f) Open end section of GIS

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

$$C = 2\pi\varepsilon_0\varepsilon_r * (R * r)/(R - r) \quad \text{-------- (8)}$$

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

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A simplified modelling may be used by representing the earthing grid as a low constant resistance. Advanced models for GIS components in computation of TEV might consider frequency-dependent impedance for ground straps, a frequency-dependent model for the enclosure-to-ground line (which could take into account earth losses) and the propagation of phase-to-phase modes on the three enclosures.

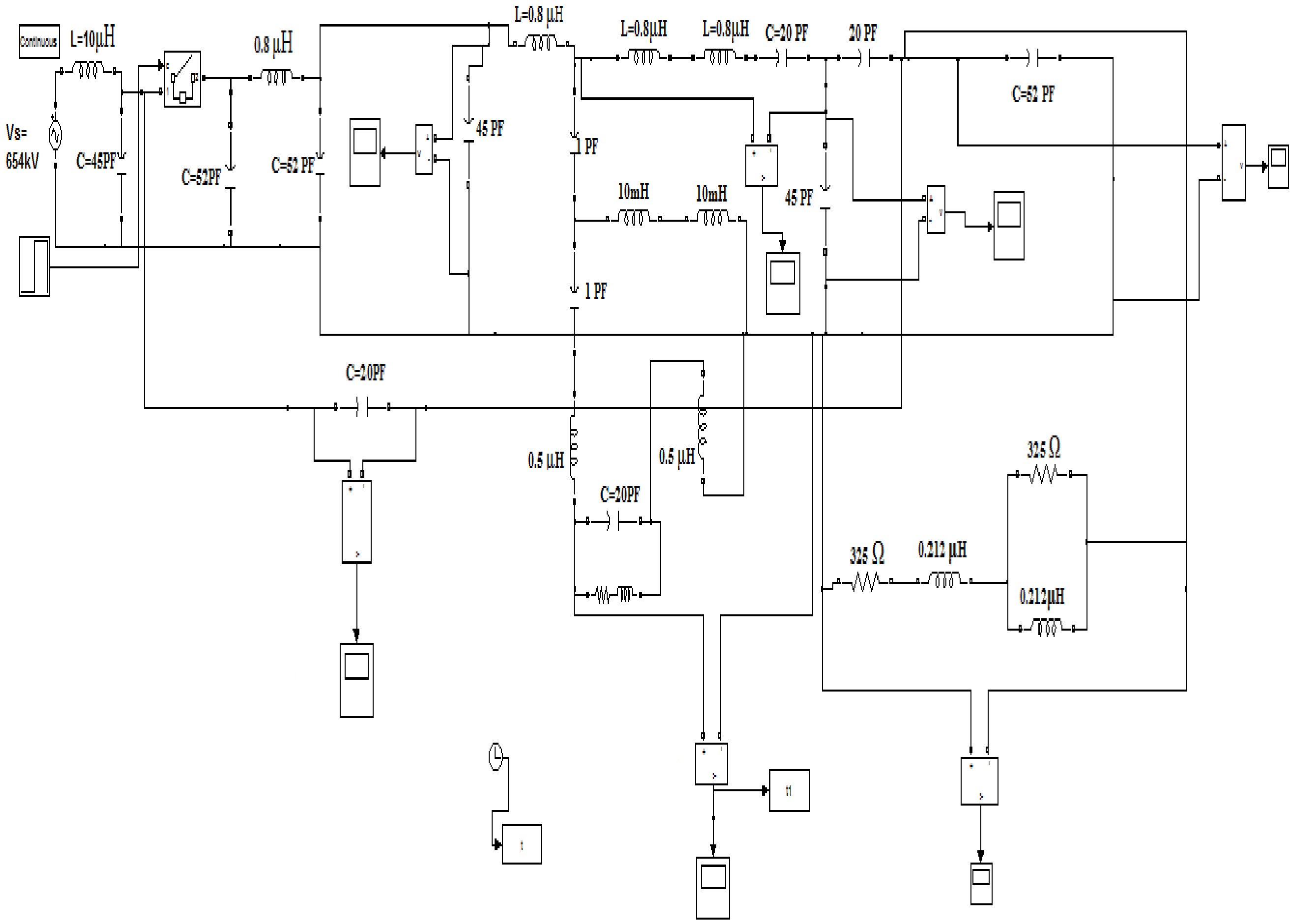

Fig. 3. Simulation Model of 800kV GIS

IV. Case Studies

As it has been explained above, the VFTOs in GIS are caused by dielectric breakdowns. The collapsing electric field during a breakdown produces travelling waves which propagates in both directions from the distribution location. This propagation can be analyzed and simulated using transmission line theory and assuming propagation losses are negligible. Travelling waves appear externally at enclosure transitions e.g. gas to air terminations. At these transitions, reflected waves travelling back onto the station and transmitted waves coupled onto the outside of the enclosure sheaths are generated. A case study is included in this section. The first one presents the simulation of VFT in an 800 kV substation generated by a closing operation of disconnector switch. The above simulation model includes current transformer, earthing strap. The design of 800 kV gas insulated substation will affect each and every component due to the very fast transient overvoltages caused by dielectric breakdown. In the modelling circuit of 800kV shown in figure 3, each component effect is captured by scope i.e. on bushing capacitance, earthing strap, bus duct spacer capacitance and open section of the enclosure.

V. Results and Discussions

Case Study-I

For 800 kV GIS

TEV effect on each component is shown below.

The effects of each component of GIS enclosure is shown in below figures 4,5,6,7, and 8 of earthing Strap, bushing Capacitance, Spacer Capacitance, Current Transformer and insulating flange respectively.

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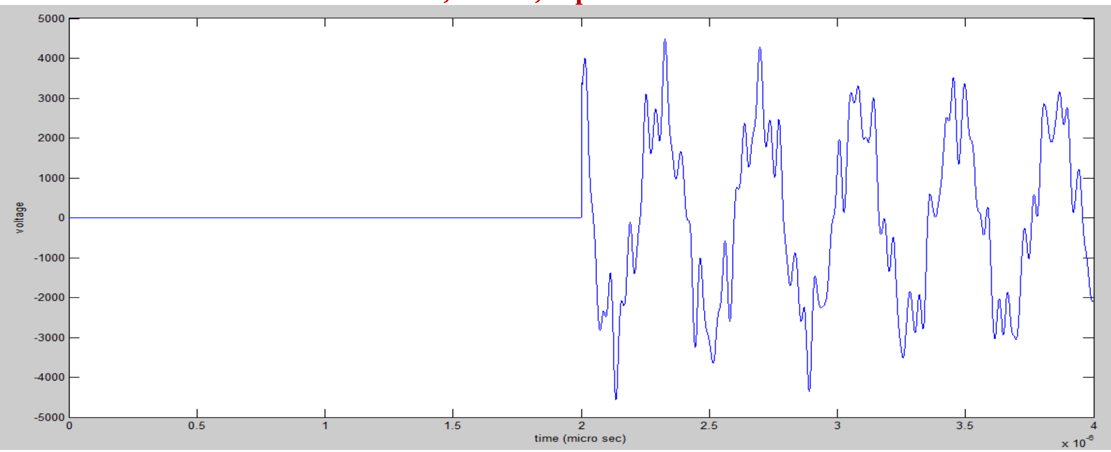

Fig. 4. Transient Enclosure Voltage Effect On Earthing Strap

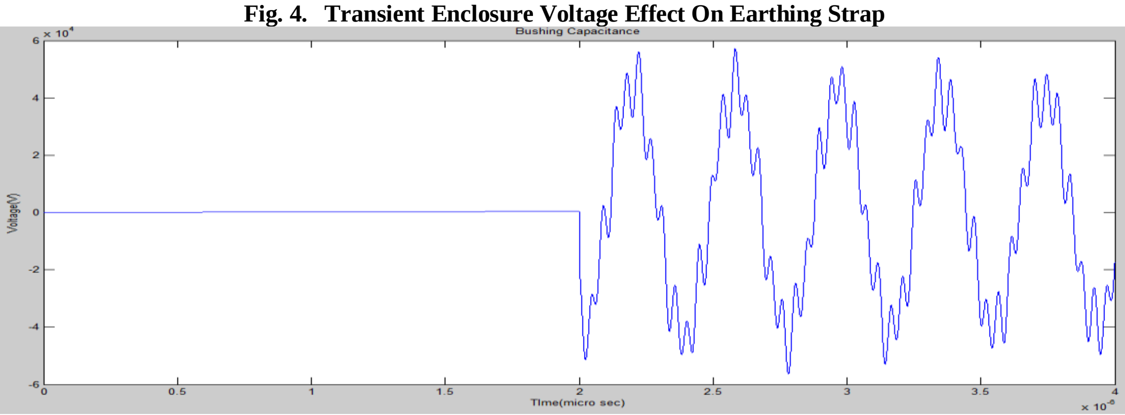

Fig. 5. Transient Enclosure Voltage Effect On Bushing Capacitance

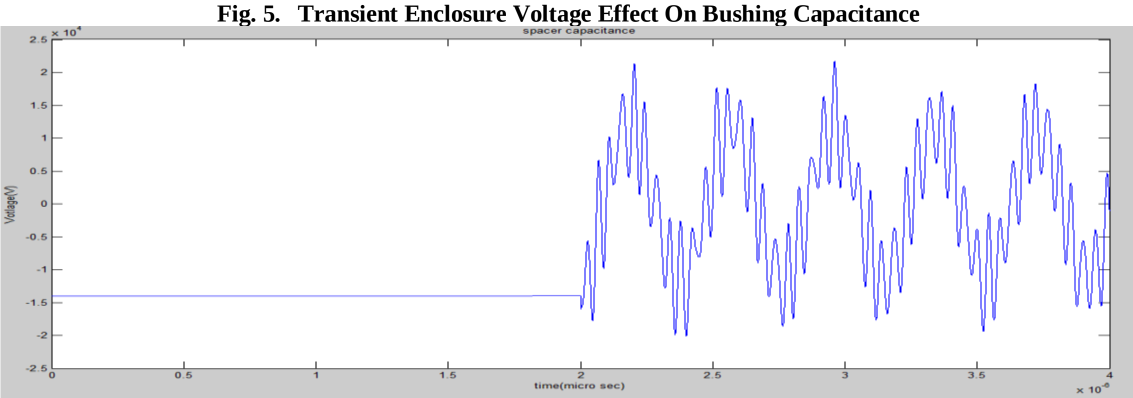

Fig. 6. Transient Enclosure Voltage Effect On Spacer Capacitance

The Simulation Model of 800 KV GIS is Included Current Transformer

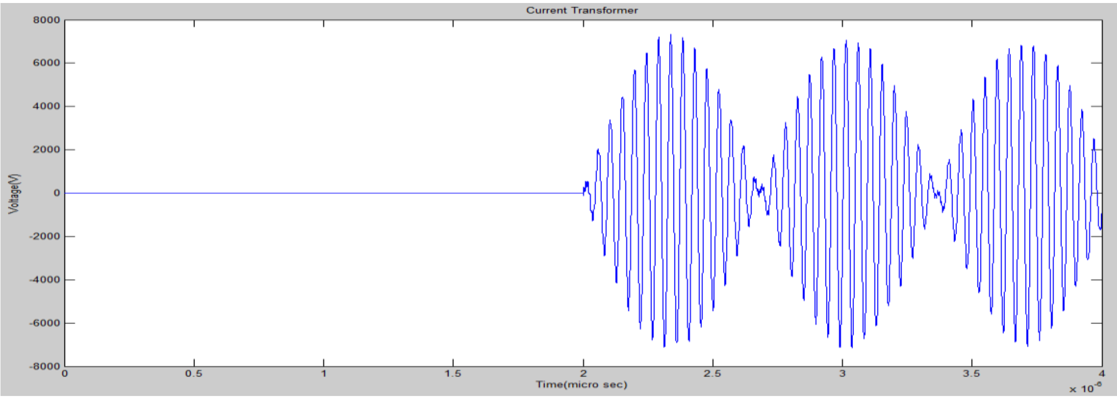

Fig. 7. Transient Enclosure Voltage Effect On Current Transformer

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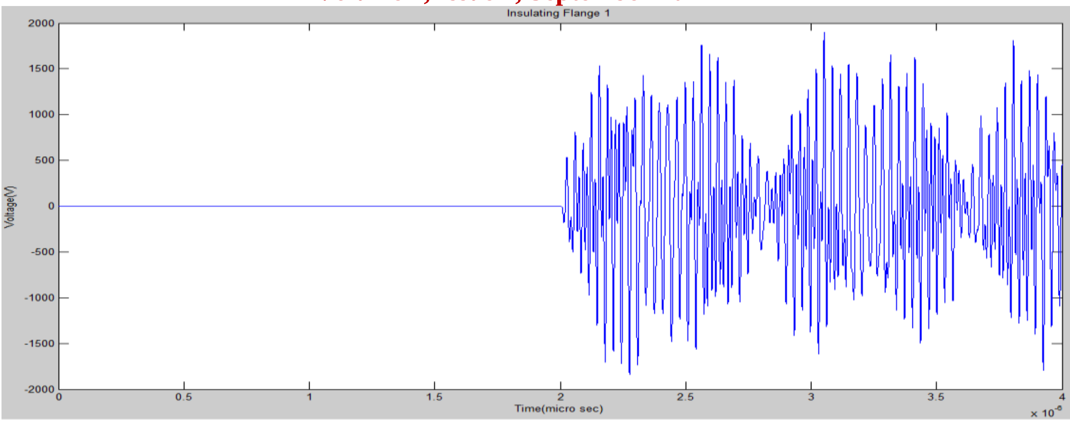

Fig. 8. Transient Enclosure Voltage effect on Insulating Flange

Table 1. Maximum Peak of the each 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

CASE STUDY-II

For 1000kV GIS

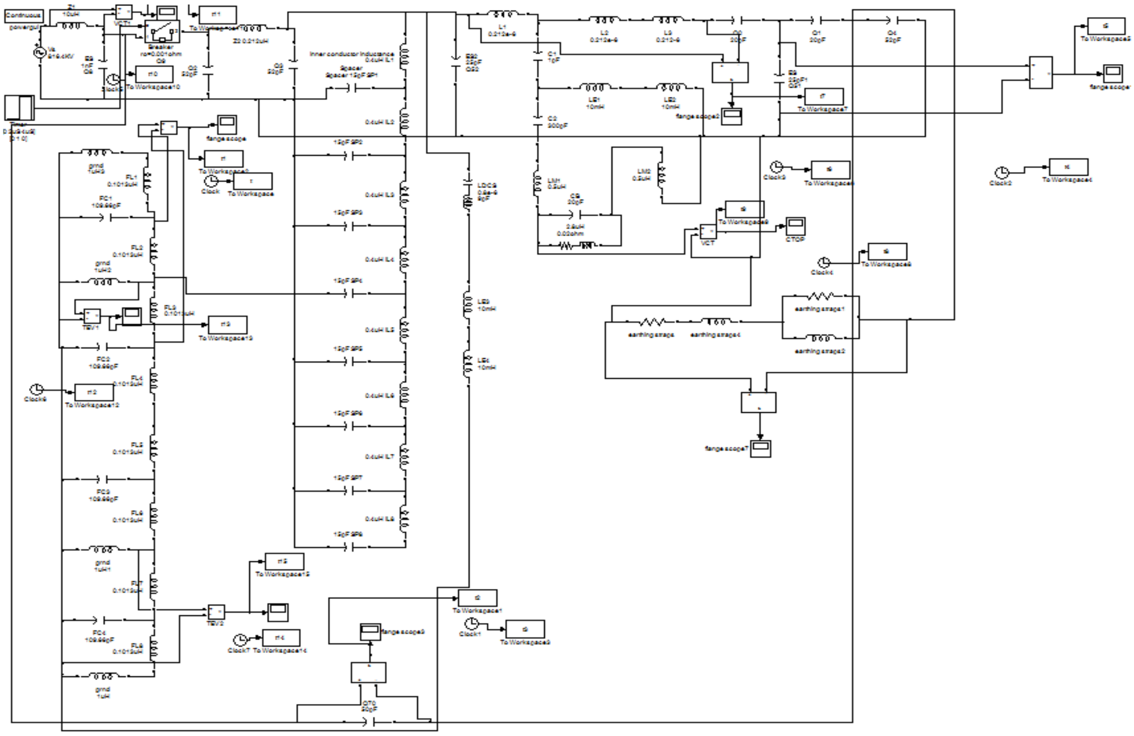

Fig. 9. Simulation model of 1000 kV GIS

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The effects of each component of GIS enclosure is shown in below figures 10,11,12,13,14 and 15 of earthing Strap, disconnect switch, open end section, surge impedance, bushing Capacitance, Current Transformer and insulating flange respectively.

EFFECT OF EARTHING STRAP:

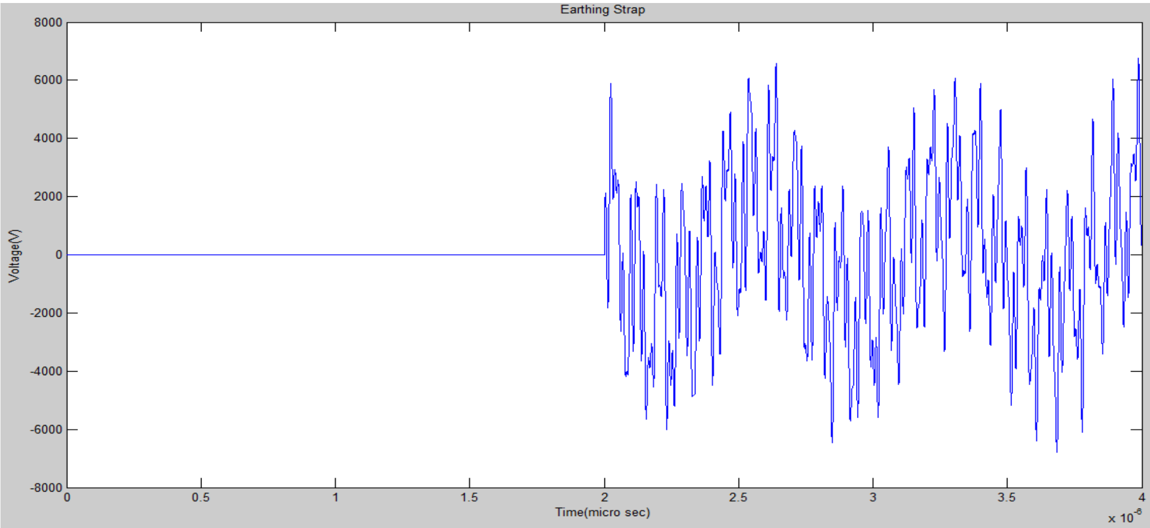

Fig. 10. Transient enclosure voltage effect on Earthing Strap

***EFFECT OF DISCONNECT SWITCH*:**

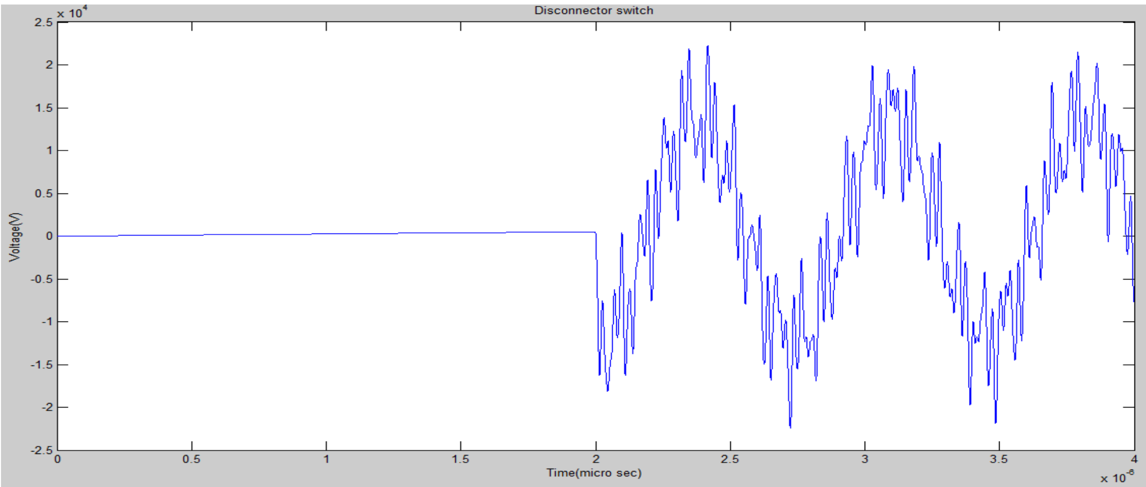

Fig. 11. Transient Enclosure Voltage effect on Disconnect Switch

EFFECT OF OPEN END SECTION:

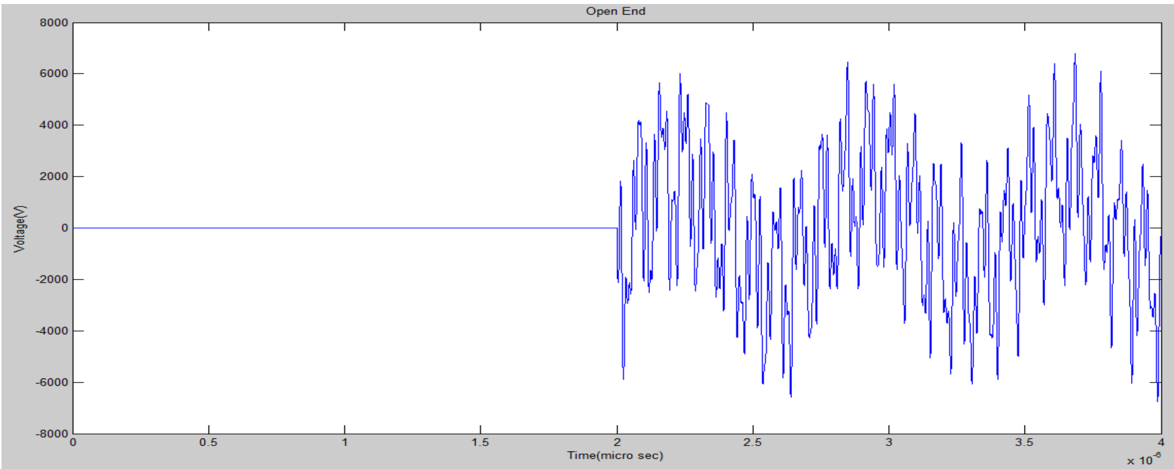

Fig. 12. Transient Enclosure Voltage effect on Open End Section

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EFFECT OF SURGE IMPEDANCE:

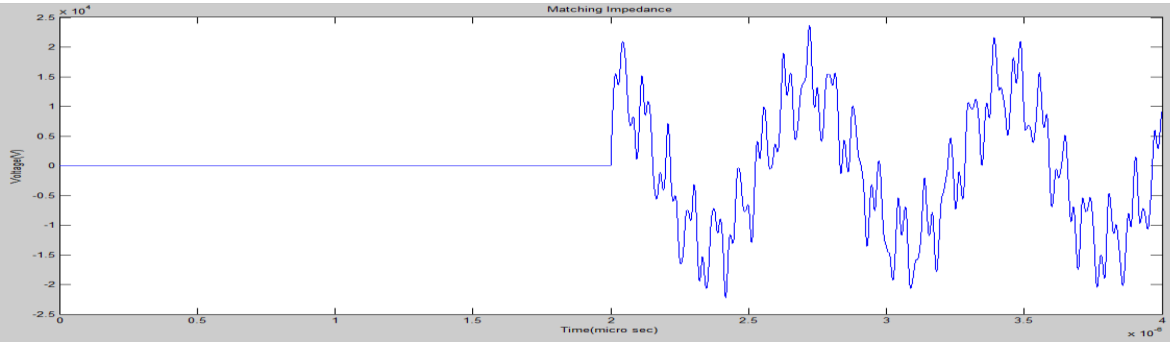

Fig. 13. Transient Enclosure Voltage effect on Surge Impedance

EFFECT OF CURRENT TRANSFORMER:

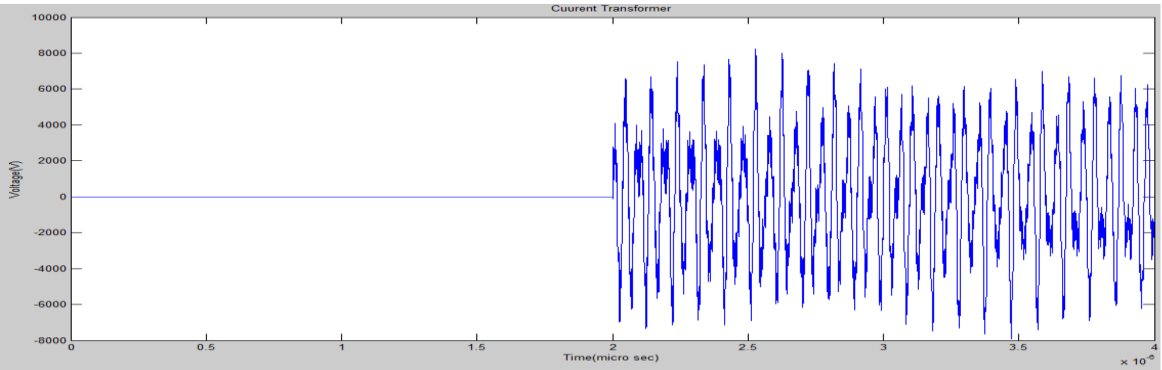

Fig. 14. Transient Enclosure Voltage effect on Current Transformer

EFFECT OF INSULATING FLANGE:

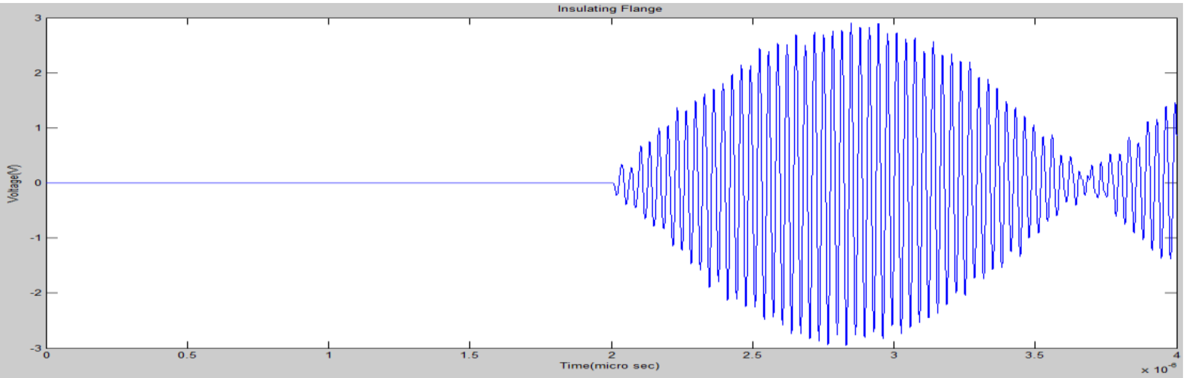

Fig. 15. Transient Enclosure Voltage effect on Insulating Flange

Table 2. Maximum Peak Of The Each Equipment For 1000kv GIS

S.No	Equipment	Maximum Peak
1	Earthing Strap	6.8kV
2	Disconnect Switch	$2.2x10^4$V
3	Spacer Capacitance	$3.3x10^4$V
4	Open end	7kV
5	Surge impedance	$2.4x10^4$V
6	Current Transformer	8kV
7	Bus Duct	$6x10^4$V
8	Insulating Flange	2.9v

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VI. CONCLUSION AND FUTURE SCOPE

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. Moreover, a description of the origin and main characteristics of VFT in GIS, as well as their effects on substation and adjacent equipment, has been summarized in this document. Modeling guidelines for digital simulation of GIS networks in VFT studies have been discussed. Their application was illustrated with two case studies. Although guidelines proposed in this document neglect propagation losses for many GIS components and very simple models are proposed for most components have shown. 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.

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AUTHOR BIOGRAPHY

A.Raghu Ram is working as an Associate Professor in Jawaharlal Nehru Technological University Hyderabad, College of Engineering since 2003. He obtained Ph.D from JNTUH, Hyderabad, A.P, INDIA. He has published National and International papers in High Voltage Engineering and areas of interest are High Voltage Engineering and Electrical Energy Conversation.

K.Santhosh Kumar is pursuing my Post Graduate in Jawaharlal Nehru Technological University Hyderabad, college of Engineering and areas of interest are High Voltage Engineering and Power Systems analysis.