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Analysis of Very Fast Transient over Voltages in 750kV Gas Insulated Substation

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Abstract*— Due to the opening or closing of circuit breakers and disconnect switches in Gas Insulated Substations (GIS), Very Fast Transient Over-voltages (VFTO) are generated. This paper describes the 750 kV GIS of power system. The variations of VFTO magnitudes at different locations in 750 kV GIS during different switching operations have been calculated by using Matlab/Simulink. In this paper the effective factors such as residual charges, resistance, spark resistance and entrance capacitance of transformer are considered to determine the level of VFTO at different locations in 750kV GIS.

Index Terms — **Gas Insulated Substation, Very Fast Transient over voltages, Matlab/Simulink.**

I. INTRODUCTION

The increase in demand for electricity and growing energy density in metropolitan cities have made it necessary to extend the existing high voltage networks right up to the consumers . Stepping down the voltage from transmission to the distribution level at the substation located near the actual consumers not only produces economic advantages, but also ensures reliable power supply. The main reason for use of gas insulated substation, is that the GIS has small ground space requirements and has easy maintenance (nearly zero Maintenance) less field erection time & less erection cost.

This paper describes the 750 kV GIS of the power system. The variations of VFTO magnitudes at different locations in 750 kV GIS during different switching operations have been calculated by using Matlab/Simulink.

Very Fast Transients Over voltages (VFTO) belong to highest frequency range of transients in power systems. These transients are originated within a gas-insulated substation (GIS) any time there is an instantaneous change in voltage. This generally occurs as the result of the opening or closing of a disconnect switch, but other events, such as the operation of a circuit breaker, the closing of a grounding switch, or the occurrence of a fault, can also cause VFTO. These transients have a very short rise time, in the range of 4 to 100 ns, and are normally followed by oscillations having frequencies in the range of 1 to 50 MHz's.

During the operation of the DS, a small capacitor connecting to the breaker will be switched. The velocity of DS contacts is small (generally more than 0.6s), before the completion of switching operation, the arc reigniting or prestrike occurs, which is the main cause of VFTO. Figure.1. shows the equivalent circuit of VFTO during switching operation

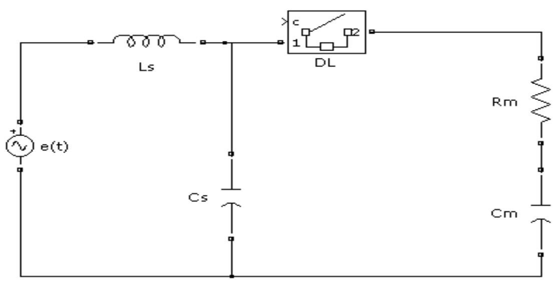

Fig 1.The Equivalent Circuit of VFTO during switching operation

Ls is the system equivalent reactance, Cs is the capacitor of system, DL is the circuit breaker, Cm is the bus capacitor and R_m is the leakage resistor of the bus. During a disconnector operation a number of prestrike-restrikes occur due to the relatively low speed of the moving contact. During closing as the contacts approach, the electric field between them will rise until sparking occurs. The first strike will almost occur at the crest of the power

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frequency voltage, due to the slow operating speed. There after current will flow through the spark and charge the capacitive load to the source voltage. As it does, the potential difference across the contacts falls and the spark will extinguish.

II. MODELLING OF GIS

The quality of the simulation depends on the quality of the model of each individual GIS component. In order to achieve reasonable results even for longer time periods of some microseconds or for very complex GIS structures highly accurate models for each of the internal equipment and also for components connected to the GIS are necessary. Due to travelling wave nature of VFTO, modeling of GIS components make use of electrical equivalent circuits composed of lumped elements and distributed parameters lines.

A GIS system comprising of an input cable, circuit breakers, disconnector Switch, Bus bar, power transformer, surge arrester. To simulate the Very Fast Transient over voltages occur at Disconnect switch in GIS, Matlab is used. The Matlab/Simulink equivalent circuit of 750 kV GIS is shown in figure 2.

Power transformer with bushing can be modeled by entrance Capacitance where entrance capacitance has been calculated in lightning test. Here the entrance capacitance of power transformer should be kept as a 5000pF. The surge impedance of a transmission Line is 350Ω and travel time is 300m/µs. The GIS Bus Bar can be represented as a lossless π- line for a 50 Hz frequency. The surge impedance is 80 Ω and travel time is 231m/µs [2]. The Cable can be represented as a lossless π- line for a 50 Hz frequency. The surge impedance is 68.8 Ω and travel time is 103.8m/µs. Metal Oxide surge arresters are used to protect medium and high voltage systems and equipment against lightning and switching over-voltages.

The surge impedance of a transmission line can be obtained from the relation

$$Z = 60 \ln \frac{b}{a} \ \Omega \qquad (1)$$

$$\text{Capacitance } C = \frac{2\pi \in_o \in_r}{\ln \frac{b}{a}} \qquad (2)$$

$$\text{Inductance } L = \frac{\mu \ln \frac{b}{a}}{2\pi} \ \text{H} \qquad (3)$$

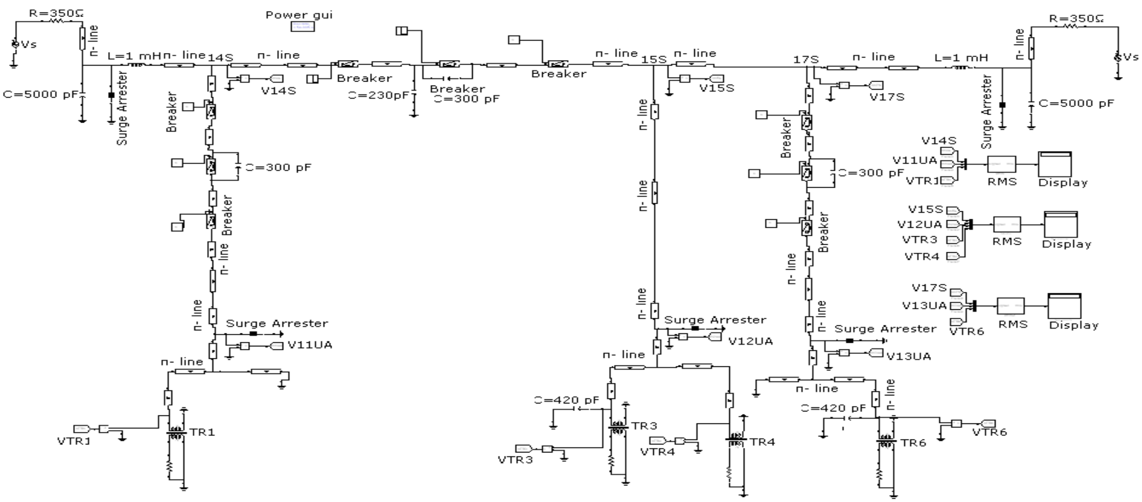

Fig 2.The Equivalent Circuit Used For Simulation of 750kv GIS

The Metal oxide Arrester obeys the equation

$$I = KV^{\alpha}, \ \alpha > 1 \qquad (4)$$

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$$\frac{V_i}{V_{ref}} = K_i \left(\frac{I_i}{I_{ref}}\right)^{\frac{1}{\alpha_i}} \quad (5)$$

Where,
I current through arrester
V voltage across arrester
K ceramic constant (depending on arrester type)
α nonlinearity exponent (measure of nonlinearity).
The Characteristics of surge arresters [3] are showed in Table 1 and Table 2

Table 1.Characteristics of 444kV Surge Arrester

Current(A)	Voltage(kV)
0.003	20000.0
628.0	1161.0

Table 2.Characteristics of 420 kV Surge Arrester

Current(A)	Voltage(kV)
0.008	594.0
20.0	674.5
10000	932.0

The other parameters are shown in figure 2.

III. Results and Discussions

Against the difference of switch operation mode and their position in GIS sub-station, the Very Fast Transient Over-voltages [VFTO] are calculated [4] [5] for three conditions in the Matlab/simulink modeling circuit shown in figure 2. Such operation mode has two forms when opened and closed. When open recovery voltage between contacts is much higher and VFTO is higher correspondingly since the other contacts have residual charges.

- **VFTO caused by DS-50543**

When the Disconnect switch-50543 is opened before that the switches DS-50546 and CB-5054 are already opened then the VFTO level at different points is shown in Table 3. The Source voltage is 750 kV.

Table 3.VFTO caused by operating of DS-50543 for 750kV GIS

Voltage to ground of bus bar (kV)	V14s	729.7
	V15s	780.5
	V17s	963.1
Voltage to ground of surge arrester (kV)	V11UA	748
	V12UA	860.1
	V13UA	0.032
Voltage to ground of Transformer (kV)	VTR1	644.3
	VTR3	649.3
	VTR4	645.2

From table 3, it is observed that due to opening of DS-50543 the maximum voltage to ground of bus bar near the switch reaches 1.57p.u; the maximum voltage to ground of surge arrester reaches 1.40 p.u; the maximum voltage to ground of transformer reaches 1.06p.u.and the corresponding results are as shown in figures from fig3 to Figure 8.

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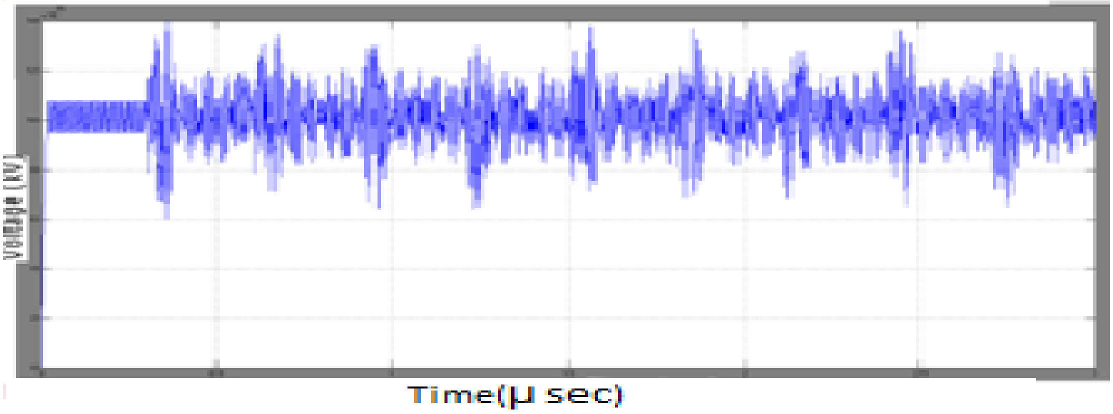

Fig 3 Voltage to Ground of Bus Bar at 14S.

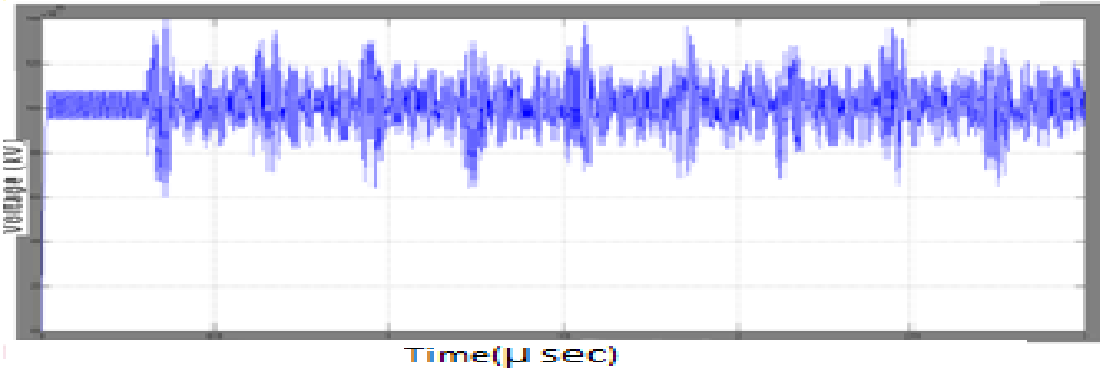

Fig 4 Voltage to Ground of Bus Bar at 17S

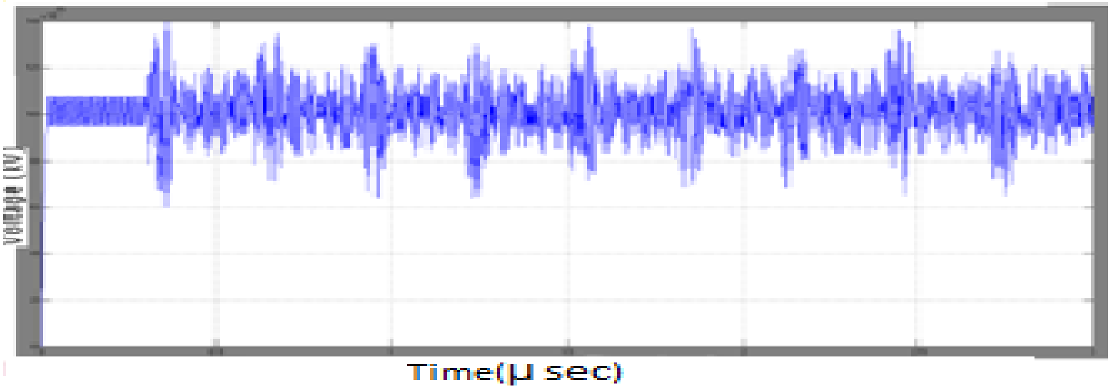

Fig 5.Voltage to Ground of Surge Arrester at the End of Transformer Unit 3&4

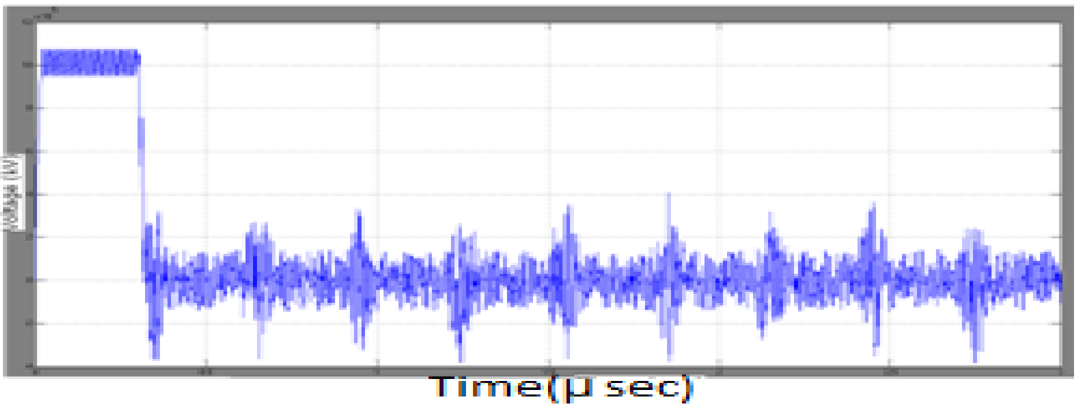

Fig 6.Voltage to Ground of Surge Arrester at the End of Transformer Unit 6

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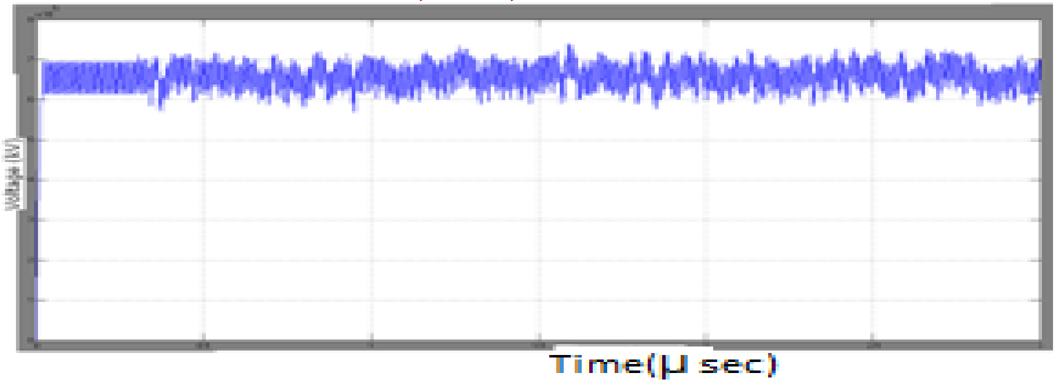

Fig 7.Voltage to Ground of Transformer at Unit 3

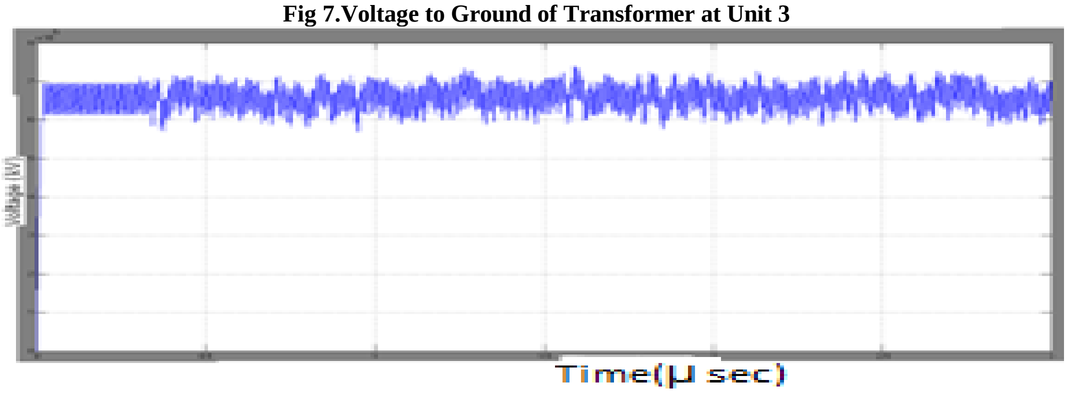

Fig 8.Voltage to Ground of Transformer at Unit 4

- **VFTO caused by DS-50121 when DS-50122 open**

When the Disconnect switch-50121 is opened before that the switches DS-50122 and CB-5012 are already opened then the VFTO level at Different points in GIS is shown in Table 4.

Table 4.VFTO Caused By Opening of DS-50121 Open for 750kv GIS

Voltage to ground of bus bar (kV)	V14s	971.5
Voltage to ground of surge arrester (kV)	V11UA	921.9
Voltage to ground of transformer(kV)	VTR1	673.5

From table-4, the maximum voltage to ground of bus bar near the switch reaches 1.58p.u; the maximum voltage to ground of surge arrester reaches 1.50p.u; the maximum voltage to ground of transformer reaches 1.09p.u.

- **VFTO caused by DS-50121 when DS-50122 closed**

When the Disconnect switch-50121 is opened before that the switch DS-50122 is closed and CB-5012 is already opened then the VFTO level at Different points is shown in Table 5. From data in table 5, it is observed that when DS -50122 is still closed VFTO caused by opening DS-50121 will spread all over 750kv GIS.

Table 5.VFTO caused by opening of DS-50121 open when DS-50122 is closed for 750kV GIS

Voltage to ground of bus bar (kV)	V14s	767
	V15s	757.7
	V17s	705.2

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Voltage to ground of surge arrester (kV)	V11UA	736.9
	V12UA	753.8
	V13UA	698.4
Voltage to ground of Transformer (kV)	VTR1	640.9
	VTR3	623.3
	VTR4	623.3
	VTR6	625.2

From the above tables, it has been observed that the transient voltage levels are different at different points on GIS.

IV. Effective Factors on VFTO Levels

The level of VFTO in GIS is determined by the factors including residual charges, series resistance, spark resistance, entrance capacitance of transformer.

Table – 6 Simulation result of residual charges influence on VFTO at bus bars

	Voltage to ground of Transformer(kV)		
Residual Charges(p.u.)	**VTR1**	**VTR3**	**VTR4**
-1.0	**644.3**	**643.9**	**639.9**
-0.5	**633.5**	**633.2**	**630.1**
0	**622.6**	**622.5**	**620.5**
0.5	**611.8**	**611.8**	**610.7**

- **Influence of Residual Charges**

When DS opens on line, it may be have some charges residual on the line that will influence the level of VFTO [6]. Consider the first condition i.e. when DS-50543 is opened then the residual charges voltages of line side of transformer range from -1.0p.u to 0.5p.u, then the VFTO levels at different points are shown in Table 6. From table 6, it is observed that the maximum voltage to ground of bus bar at 17s range from 949.9 kV to 688.2 kV for residual charges. So, the level of VFTO decreases along with the variation of residual charges. So, the residual charge has function of suppression of VFTO.

Table 7.simulation result of residual charges influence on VFTO at Transformers

	Voltage to ground of Bus-bar (kV)		
Residual Charges(p.u.)	**V14s**	**V15s**	**V17s**
-1.0	**729.7**	**780.5**	**949.9**
-0.5	**697.5**	**735.5**	**862.6**
0	**665.5**	**690.7**	**775.5**
0.5	**633.2**	**646**	**688.2**

The maximum voltage to ground of transformer at TR4 ranges from 639.9 kV to 610.7 kV. So, the level of the maximum voltage to ground of transformer at TR4 ranges from 639.9 kV to 610.7 kV. So, the level of

- **Influence of Resistance**

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For 750kV for increasing the series resistance the VFTO levels decreased. The simulation results are shown in the table 8 and 9.

Table 8.Simulation Result of Resistance Influence on VFTO at Bus Bars

	Voltage to ground of Bus-bar (KV)		
Resistance(Ω)	V14s	V15s	V17s
100	4264	5963	11570
200	2132	2982	5786
300	1422	1988	3858
500	853.3	1193	2315
1000	427	595.9	1158

Table 9.Simulation Result of Resistance Influence on VFTO at Transformers

	Voltage to ground of Transformer (kV)		
Resistance(Ω)	**VTR1**	**VTR3**	**VTR4**
100	**1433**	**1424**	**1298**
200	**715.7**	**712.3**	**649.2**
300	**478**	**475.1**	**433**
500	**287.1**	**285.3**	**260.1**
1000	**143.8**	**143**	**130.3**

- **Influence of Spark Resistance**

When restriking transient happens, spark resistance can have effect on damping over voltages. Spark resistance is an exponentially decaying resistance. Table 10, 11 are the simulation results of the spark resistance influence on VFTO

Table 10.Simulation result of spark resistance influence on VFTO at bus bars

	Voltage to ground of Bus-bar (kV)		
Spark Resistance(Ω)	**V14s**	**V15s**	**V17s**
0.1	**732.8**	**783.2**	**956.3**
25	**729.7**	**780.5**	**950**
10	**721.3**	**772.4**	**931.9**
50	**689.8**	**738.8**	**861.1**
100	**650**	**697.1**	**772.6**
200	**571.9**	**613.4**	**595.5**

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Table 11.Simulation Result of Spark Resistance Influence on VFTO at Transformers

Spark Resistance(Ω)	VTR1 [kV]	VTR3 [kV]	VTR4 [kV]
0.1	644.7	644.6	652.4
25	644.3	643.9	639.9
10	642.8	642.2	638.4
50	636.3	634.8	632
100	628.1	625.6	624.1
200	611.7	607.2	608.1

- **Influence of Entrance Capacitance of Transformer**

The simulation results transformer entrance capacitance influence of VFTO is shown in tables 12 and13.

1) When DS-50543 opened

The VFTO levels decreased along with the increasing the entrance capacitance of transformer in 750kV.

Table 12. Simulation result of transformer entrance capacitance influence on VFTO when DS-50543 opened

	Voltage to ground of Transformer(kV)		
Transformer Entrance Capacitance(pF)	VTR1	VTR3	VTR4
5000	644.2	643.9	639.8
10000	621.5	628.9	625.8
15000	618.2	624.8	622.6
20000	614.8	620.6	619.4
25000	611.5	616.4	616.2

2) When DS-50121 opened (DS-50122 closed)

Table 13.Simulation Result of Transformer Entrance Capacitance Influence on VFTO When DS-50543 Opened

	Voltage to ground of Transformer(kV)			
C(pF)	VTR1	VTR3	VTR4	VTR6
5000	640.9	623.3	623.3	625.1
10000	625.8	613.3	613.2	615.3
15000	622.7	609.5	609.4	611.9
20000	619.5	605.7	605.5	608.6
25000	616.3	601.9	601.6	605.2

V. Conclusion

The 750kV Gas Insulated substation system have been modeled and studied for VFTO's at different locations in GIS by using Matlab/Simulink software. The following conclusions have been made from the above study.

1. If the disconnect switch is opened/closed at two locations i.e. DS-50543, DS-50121, then the values of the VFTO's are measured at different locations are V14S, V15S, V17S, V11UA, V12UA, V13UA, VTR1, VTR3, VTR4, and VTR6. The voltage levels measured at all of these locations is less than 2 p.u.
2. As the residual charges are increased from -1.0 p.u. to 0.5 p.u., the magnitude of VFTO levels of bus-bars are decreased
3. As the spark resistance is increased from 0.1 to 200Ω, the magnitude of VFTO levels of bus-bars and voltage to ground of transformers are decreased.

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4. As the resistance is increased from 100 to 1000 Ω, the magnitude of VFTO levels i.e. voltage to ground of bus-bars and voltage to ground of transformers are decreased.
5. As the entrance capacitance of transformer is changed from 5000 to 25000 pF, the magnitudes of VFTO levels of transformers are decreased.
6. Finally, it can be concluded that the factors residual charges, spark resistance, resistance and the entrance capacitance of transformer have functions of suppression of VFTO.

VI. FUTURE SCOPE OF THE WORK

The calculation of VFTOS can be extended to a system voltage of 1000 kV with the different switching conditions by using SCADA/ EMTP Software.

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