

## Research Article

### Modeling of 420 kV GIS Substation and Research on Very Fast Transient Overvoltage (VFTO)

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**Abstract:** This study conducts simulation of a 420 kV GIS substation in order to study on Very Fast Transient Overvoltage (VFTO) caused by disconnect or Switches operation. All components and its connected equipment in this GIS substation are modeled in EMTP-RV software. The various disconnect or switch operation conditions are considered and the results are presented. Finally, the effect of trapped charge on VFTO magnitude is discussed.

**Keywords:** Disconnect or switch, EMTP-RV, Gas Insulated Substation (GIS), VFTO

#### INTRODUCTION

The switching overvoltage is a typical concern in high voltage power systems. VFTO is generated during the switching operation of a Disconnect or Switch (DS), as well as other events likes operation of Circuit Breaker (CB) or Earth Switches (ES) in GIS (Tavakoli *et al.*, 2009).

During the switching operation, a number of pre-strikes or re-strikes occur because of the slow speed of the moving contact of disconnect or switch (Jian *et al.*, 2010; Kumar *et al.*, 2001). These transients are characterized by every short rise time in the range of a few ns and followed by high frequency oscillations in the range of a few hundreds of KH to about a few tens of MH (Chi *et al.*, 2008). VFTO influence the operating reliability of GIS and causes great threat to the insulation of high-voltage equipment. Therefore, research on magnitude of VFTO in a GIS is necessary. In this study, GOTVAND 420 kV GIS has been taken up for the simulation of VFTO during various disconnections operation to find critical conditions.

The effect of trapped charge on the magnitudes of VFTO is analyzed. Computer simulations have been done using EMTP-RV software.

#### MODELING OF GIS SUBSTATION

**Introducing of GOTVAND substation:** GOTVAND is a 420 kV GIS substation with double bus arrangement (with by-pass disconnect or). Its capacity is 1000 MVA. The number of its one-phase transformers is 12 and the capacity of each one is 100 MVA. There are four outgoing feeder lines from the substation. (The distances are 130 km Ahvaz, 58 km

Shooshtar1, 28 km Shooshtar2, 316 km Shazand). Figure 1 shows the single line diagram of this substation.

**Modeling of GIS components:** Because of high frequency of VFTO, most of components have their capacitances dominating the other parameters (Povh *et al.*, 1996).

To model GIS bus duct lumped elements and Distributed parameters can be used, surge impedances, wave velocity and lengths of GIS section define that. The parameter can be calculated from the physical dimensions of the duct. In following equation, C and L are self-Capacitance, inductance, Z is surge impedance and V is wave velocity in GIS (Kondalu *et al.*, 2011; Thompson, 1999):

$$C = \frac{2\pi\epsilon_0\epsilon_s}{\ln\left(\frac{d}{a} + \sqrt{\frac{d^2}{a^2} - 1}\right)} l \text{ F/m} \quad (1)$$

$$L = \frac{\mu_0}{2\pi} \ln\left(\frac{a_1}{a}\right) l \text{ H/m} \quad (2)$$

$$Z = \sqrt{\frac{L}{C}} = \frac{\sqrt{\mu_0\epsilon_0}}{2\pi} \ln\left(\frac{a_1}{a}\right) = 60 \ln\left(\frac{a_1}{a}\right) \quad (3)$$

$$V = \frac{1}{\sqrt{LC}} \quad (4)$$

where, d is vertical distance between earth and center of the enclosure, a is inner radius and a<sub>1</sub> is outer radius and l is the length of enclosure. In addition:

$$\epsilon_0 = 8.85418782 \times 10^{-12}, \epsilon_s = 1.0024, \mu_0 = 4\pi \times 10^{-7} \text{ H/m}$$

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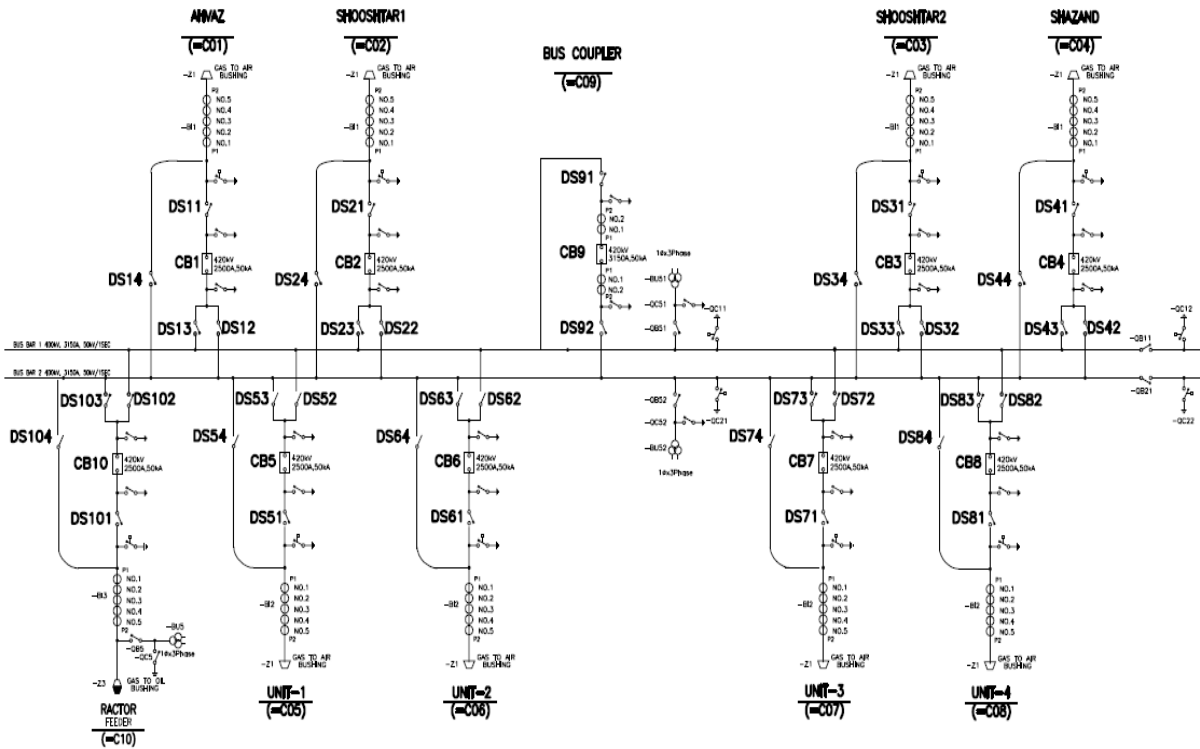


Fig. 1: Single line diagram of GOTVAND 420 kV GIS substation

Experimental results show that the propagation velocity in GIS ducts is close to 0.95 - 0.96% of the speed of light, it is considered 290 m/μs (Povh *et al.*, 1996).

Surge impedance is also about 60 ohm. According to equation 5 the mutual capacitance between enclosure and conductor is about 43 pF/m .the mutual inductance is considered zero.

$$C_{12} = C_{21} = \frac{2\pi\epsilon_0\epsilon_s l}{\ln\left(\frac{a_1}{a}\right)} \quad \text{F/m} \quad (5)$$

Power transformer is modeled as a capacitance to ground of 5227 pF and neglects the other details (Haznadar *et al.*, 1992). Voltage transformer is modeled as a capacitance to ground of 24.6 pF too. The effect of current transformer is negligible. Circuit breakers are modeled as a switch parallel with grading capacitor of 4000 pF; the capacitance to ground is taken as 46.7 pF. Disconnect or model is a switch similar to circuit breaker when opened the capacitance between contacts is 20 pF. The capacitance to ground is 34.7 pF for the side connected to overhead line or transformer feeder and 21.7 pF for the side connected to bus bars. The spark is modeled as an exponentially decaying resistance and a small resistance in series to take care of the residual spark resistance (Tao *et al.*, 2008).

$$R(t) = R_0 e^{-\frac{t}{\tau}} + r \quad (6)$$

Table 1: Simulation conditions

Case	Operating disconnect or	Open switch
Case1	DS11 DS12	CB1
Case2	DS21 DS22	CB2
Case3	DS31 DS32	CB3
Case4	DS41 DS42	CB4
Case5	DS51 DS53	CB5
Case6	DS61 DS63	CB6
Case7	DS71 DS72	CB7
Case8	DS81 DS82	CB8

where,  $R_0$  is  $10^{12}$  ohm,  $r$  is 0.5 ohm and  $\tau$  is 1ns.

Bushings and spacer are modeled as a capacitance to ground of 500 pF and 12.26 pF respectively (Naveed and Amaranath, 2008).

The transmission line is represented as FD line mode in EMTP-RV. Because of the high frequency of VFTO, the main capacitance of surge arrester must be considered, so it is modeled as capacitance to ground of 50 pF.

## SIMULATION

The VFTO level in this GIS substation under eight different disconnect or switches operation

conditions has been studied. Four cases are the closing DS at the lines feeders cases and four cases are the closing a DS at the unit feeders cases. For each case operation of two DS has been presented.

Table 1 shows simulation conditions. Calculating time for simulation is  $5\mu s$  and the time step is  $1ns$ .

VFTO has been measured at five points of GIS: two sides of operating DS, circuit breaker,

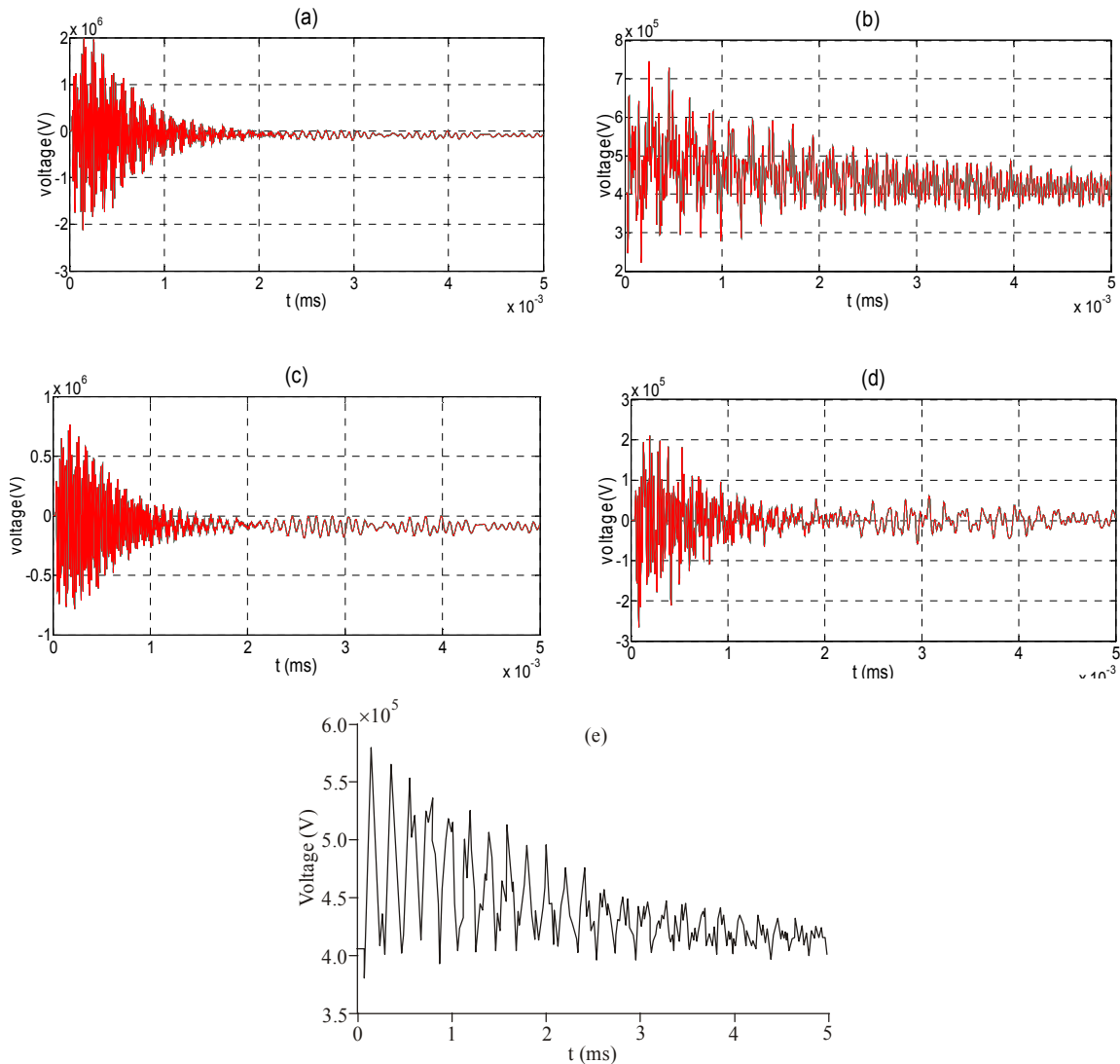


Fig. 2: VFTO waveforms at DS21 operated; a) VFTO at busbar side of operating disconnector DS21; b) VFTO waveform at line side of operating disconnector DS21; c) VFTO waveform close to circuit breaker; d) VFTO waveform close to DS22; e) VFTO waveforms at junction of the GIS with overhead line

Table 2: VFTO magnitude of 8cases

Operating disconnector	VFTO in points: (kV)				
	Operating disconnector (busbar side)	Operating disconnector (unit or line side)	Circuit breaker	Disconnect or in other side of CB	Junction of the GIS with overhead lin
DS11	1000	710	420	130	540
DS21	2000	750	812	210	580
DS31	1955	730	760	200	600
DS41	1950	715	762	300	544
DS51	1000	530	350	350	430
DS61	1600	1100	700	200	670
DS71	1400	980	630	280	700
DS81	1560	608	625	220	470

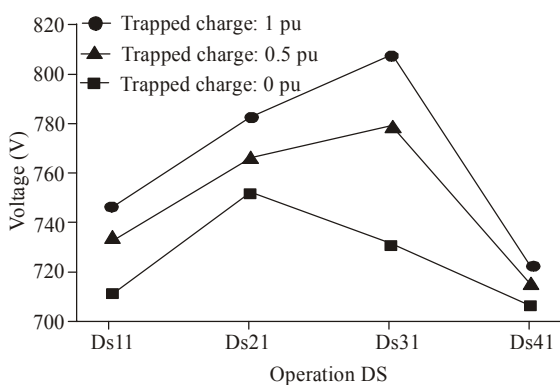


Fig. 3: Effect of trapped charge on VFTO magnitude at line side of operating disconnect

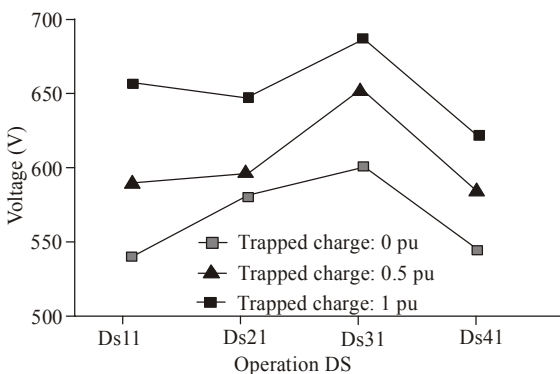


Fig. 4: Effect of trapped charge on VFTO magnitude at the junction of GIS with overhead line points

the DS in other side of breaker and the junction of GIS with overhead line. Figure 2 shows VFTOs for the case 2 in mentioned points.

It can be observed that the maximum VFTO is 2000 kV and it has been generated at bus side of operating DS21.

Table 2 shows the VFTOs of eight cases that have the most magnitude. In these cases the disconnect or near units or lines is operating.

According to IEC 62271-203 rated switching impulse withstand voltage in 420 kV GIS is 1575 kV. Therefore, as shown in Table 2, measured VFTOs at four points is larger than standard in this GIS substation, which may brings great threat to equipment insulations.

As can be shown from Table 2, the dangerous VFTOs occur near bus side of operating disconnect in all cases. The minimum overvoltage's are generated near disconnect or in other side of circuit breakers.

### EFFECT OF TRAPPED CHARGE ON THE VFTO LEVELS

Depends on disconnect or switch design for a normal speed disconnect or switch it can be about 0.5

pu. In the high speed disconnect or the maximum trapped charge could be until 1.0 pu. For circuit breakers, it could be as high as 1.2 pu (Tavakoli *et al.*, 2009; Kumar *et al.*, 2001).

Studies have shown the trapped charge increase the VFTO magnitude at junction of the GIS with overhead line and line side of operating disconnect or and it has negligible effects on other parts. Figure 3 shows effect of 0.5 and 1 pu trapped Charge on the VFTO magnitudes for four cases of operating disconnect or (DS11, DS21, DS31, DS41) at line side of operating disconnects. Figure 4 shows effect of 0.5 and 1 pu trapped Charge on the VFTO levels at the junction of GIS with overhead line points for the same cases.

### CONCLUSION

Simulation of VFTO for eight different switching conditions of DS in GOTVAND 420 kV GIS substation has been done by EMTP-RV. It was observed that the VFTO magnitude at four points is larger than rated switching impulse withstand voltage in 420 kV GIS. The waveforms of maximum VFTO have been presented. The most magnitude of VFTO is 2000 kV and it has been generated at bus side of operating DS21. The results showed that the maximum peak of the VFTO appears on the bus side of the operating disconnects in all cases. The magnitude of Trapped charge increment cause to increase peak magnitude of VFTO at junction of the GIS with overhead line and line side of operating disconnect or and it has negligible effects on other parts.

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