

Simulation and Test Study on Very Fast Transient Overvoltage in 1000kV GIS Substation

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Abstract. Disconnecter switching in gas insulated switchgear (GIS) generates very fast transient overvoltage (VFTO). VFTO may damage the insulation of GIS equipment. This paper studies the VFTO of a 1000kV GIS substation. The simulation models are obtained according to the configuration of GIS. Operation modes of disconnecter were summarized. The characteristics of VFTO were obtained. During the system commissioning test of the substation, VFTO were measured during disconnecter switching. Comparison was made between the test and simulation results. The simulation results were in agreement with the test results. The accuracy of the simulation model is verified. Simulation and test study shows that it is safe to do switching operation of disconnecter in this GIS substation without damping resistor.

1. Introduction

During the switching of the disconnecter(DS) in gas insulated switchgear (GIS), a number of strikes occur and will generate very fast transient overvoltage(VFTO)[1,2]. VFTO may damage the insulation of GIS as well as adjacent equipment. As the increase of rated voltage, the harm of VFTO to insulation of GIS becomes more severe. Because of the rapid development of ultra high voltage(UHV) transmission in China, VFTO has received great concern.

Jindongnan–Nanyang–Jingmen project is the first UHV AC project in China. It has three substations. GIS were adopted in one substation. Damping resistors were installed on DS in GIS substation to mitigate VFTO. Huainan-Shanghai project is the second UHV AC project in China. All the four substations will adopt GIS. In one substation, the DS is designed without damping resistor. To insure the safety of the equipment, it is necessary to study the VFTO generated by DS switching.

In this paper, VFTO caused by DS switching of the UHV substation were studied. The simulation models were given according to the configuration of GIS. The characteristic of VFTO were obtained. During the system commissioning test, DS switching tests were carried out and VFTO were measured. The measured results were given. Comparison was made between the test and simulation results to verify the accuracy of simulation models.

2. Substation configuration and simulation models

2.1. Configuration of substation

Figure 1 shows the configuration of 1000kV GIS substation. It has one 1000kV transformer and 4 1000kV lines. Shunt reactor are installed on 2 lines. The configuration is one and half circuit breaker system. A total of 9 circuit breakers and 21 sets of DS are installed. Three separate DS are installed for



future upgrade and are only for connection at current stage. The rated voltage of GIS is 1100kV. The lightning impulse withstand voltage (LIWV) of GIS is 2400kV.

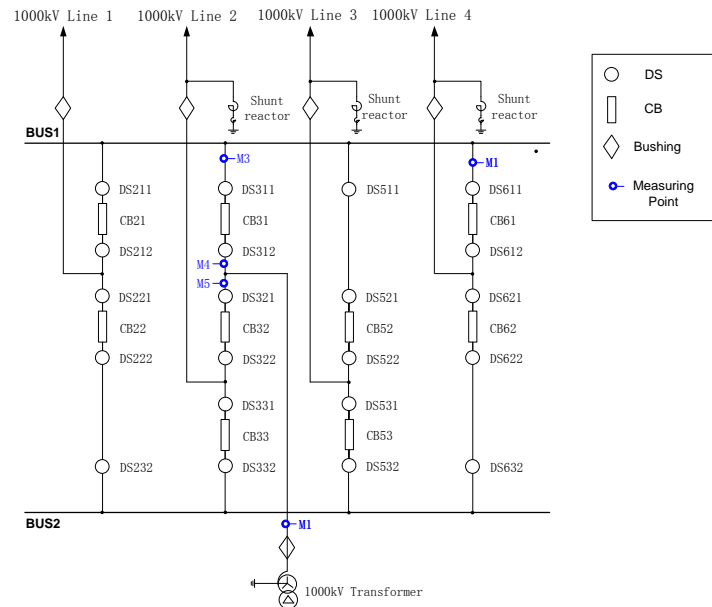


Figure 1. Configuration of 1000kV GIS substation.

2.2. Simulation models of 1000kV GIS equipment

The simulation model and parameters of GIS components are very important for accuracy of VFTO simulation. Studies have been done on the simulation models. In this study, simulation models were based on the modelling method presented in [2]. The parameters were obtained according to the structure and dimension of 1000kV GIS components.

The GIS bus duct is modelled as distributed parameter line. The surge impedance can be obtained by equation (1), in which R represents the inside diameter of GIS enclosure and r represents the outside diameter of GIS bus bar. According to the structure and dimension of bus duct, the surge impedance is calculated as 73Ω .

$$Z = \ln(R / r) \quad (1)$$

Overhead lines are also modelled as distributed parameter line. The surge impedance can be obtained by equation (2), in which h represents the average height of the conductors and r_e represents the equivalent radius of conductor. According to the height and dimension of conductors, the surge impedance is calculated as 250 to 300Ω .

$$Z = 60 \ln \frac{2h}{r_e} \quad (2)$$

SF6 to air bushing is used to connect the GIS and overhead lines. The model of bushing is important in VFTO simulation. SF6 to air bushings are modelled as distribution parameter line with ground capacitor at the air side. According to the calculation of the capacitance is 100pf. Surge impedance is simulated with 150Ω .

Closed DS is modelled as distributed parameter line. An opened DS is modelled as two grounded capacitors connected with a capacitor. Figure 2 shows the simulation model of opened DS. Capacitor C1 and C2 represent the capacitance of moving and fixed contact to ground separately. The capacitor C12 represents the capacitance between moving and fixed contacts.

Closed circuit breakers are also modelled as distributed parameter line. An opened circuit breaker is modelled a number of grounded capacitor connected with capacitors. The number of capacitor is determined by the number of grade capacitors. Figure 3 shows the simulation model of opened CB. Capacitor C1 to C4 represents the capacitance of each contact to ground. The capacitor C12 to C45 represents the graded capacitor between contacts.

Transformers and shunt reactors are modelled as capacitors to ground.

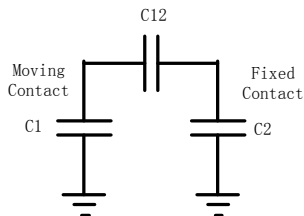


Figure 2. Simulation model of opened DS.

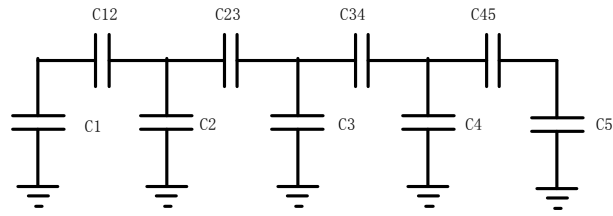


Figure 3. Simulation model of opened CB.

3. Simulation study of VFTO

3.1. Operation modes

The operation mode of DS has a great influence on VFTO. The main factor that affects VFTO is the GIS layout on both sides of DS. On the load side of DS, it is generally a short bus duct between DS and CB. On power source side, the GIS layout may be different with different operation modes. The status of DS and CB on power source side will affect the characteristic of VFTO.

The number of operation modes can be calculated with combination method. Assuming that there are N sets of CBs in the substation, 2 DS are connected on both sides of each CB. One CB and its connected two DS are considered as one group. For each DS, the CB connected to it is open during its switching. All other groups may be in two states: close or open. For this single DS there are $2^{(N-1)}$ operation modes.

A comprehensive simulation for all the operation modes was carried out. For some operation modes, VFTO were generally higher. According to the actual operation of the substation, three types of summarized operation modes for VFTO calculation were given in table 1. These operation modes are most common and generally result in higher VFTO.

Table 1. Summarized operation modes of DS with higher VFTO.

DS	Operation mode
DS connected to transformer	Switching of DS fed by transformer. All other CBs and DS are opened.
DS connected to transmission line	Switching of DS fed by transmission lines. All other CB and DS are opened.
DS connected to Bus	Switching of DS connected to a bus, which was fed by transmission lines or transformer. The CB and DS between bus and line or transformer are closed. All other CB and DS are opened.

3.2. Simulation results

Simulation was done for each DS with different operation modes. VFTO at different equipment was obtained. In the simulation, the trapped charge voltage on the load side was considered as 1p.u. to obtain the highest VFTO. The maximum VFTO generated by each DS were shown in table 2.

Table 2. Maximum VFTO for each DS switching.

DS	VFTO (kV)	VFTO (p.u.) ^a	DS	VFTO (kV)	VFTO (p.u.)
DS211	1733	1.93	DS332	1846	2.06
DS212	1947	2.17	DS521	1730	1.93
DS221	1854	2.06	DS522	1854	2.06
DS222	1637	1.82	DS531	1950	2.17
DS311	2032	2.26	DS532	2025	2.26
DS312	2016	2.24	DS611	1919	2.14
DS321	2055	2.29	DS612	1951	2.17
DS322	1922	2.14	DS621	1853	2.06
DS331	1947	2.17	DS622	1663	1.85

$$^a 1\text{p.u.} = 1100 / \sqrt{3} \times \sqrt{2} \text{ kV}$$

The maximum value of VFTO generated by DS operation is 2055kV (2.29pu). It is generated during the switching of DS321 fed by transformer with all other DS and CBs opened. The maximum voltage appears in DS312 and the VFTO waveform is shown in figure 4. The main oscillation frequency of VFTO is 6.5MHz.

Because the insulation level of GIS under VFTO was not available in any standards, LIWV were used for the insulation co-ordination of GIS under VFTO. The LIWV of 1000kV GIS is 2400kV. In the case of non-installed damping resistor, the VFTO peak value of GIS generated by DS in all operation modes does not exceed the LIWV of GIS equipment. The safety margin between VFTO and LIWV exceeds 15%, which can meet the requirements of insulation co-ordination standards of China. Limitation measures, such as damping resistor, were not necessary for this GIS substation.

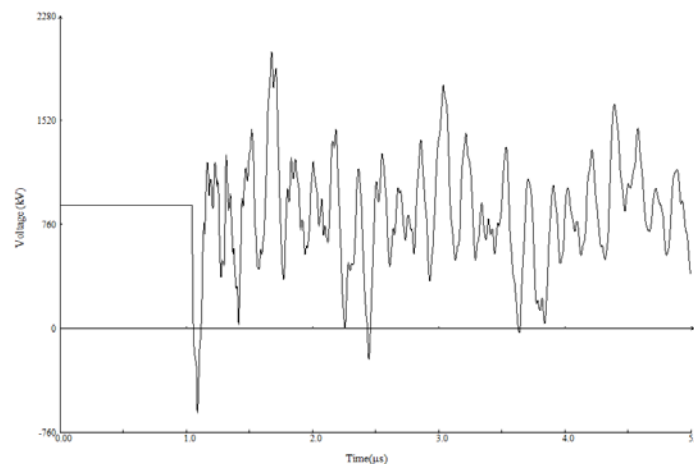


Figure 4. Wave form of VFTO at DS312 during switching of DS321 fed by transformer.

4. VFTO measurement during DS switching test

During the system commissioning test, special test were carried out in the substation to measure the VFTO generated by the switching of DS. VFTO were measured with the measuring system in [3-5]. The measuring points were shown in figure 1.

The VFTO generated by the switching of DS312, DS321, DS611, DS521 and DS211 was measured respectively. The operating mode of the isolation switch is shown in table 3.

Table 3. Operation modes of DS switching test.

DS	Operation mode
DS321	DS321 was fed by transformer with all DS and CB opened
DS312	DS312 was fed by transformer with all DS and CB opened
DS611	BUS1 was fed by transformer through CB31. All other DS and CB opened.
DS521	BUS1 was fed by transformer through CB31. All other DS and CB opened.
DS211	BUS1 was fed by transformer through CB31. All other DS and CB opened.

The measured results and simulation results were shown in table 4. In the table, the maximum value of VFTO is calculated. It is considered that the trapped charge voltage on load side is 1p.u. and the break down voltage across DS is 2p.u.. It is the most serious case. Because of the limited number of switching tests, it is difficult to produce the most serious case. The maximum measured value is lower than the maximum simulation results. For further comparison, simulation was made with the same trapped charge voltage and break down voltage of the test condition. The VFTO calculated from the measured results is given. The simulation result is basically in agreement with the measured VFTO.

Table 4. Operation modes of DS switching test.

DS	Measuring point	Measured VFTO (p.u.)	Simulated VFTO(p.u.)	
			Test condition	Severest condition
DS321	M1	1.32	1.37	1.80
	M4	1.32	1.49	1.85
	M5	1.31	1.31	1.62
DS312	M1	1.28	1.41	1.87
	M4	1.24	1.22	1.51
	M5	1.39	1.53	1.91
DS611	M3	1.15	1.16	1.47
	M2	1.48	1.58	1.63
DS521	M3	1.11	1.19	1.50
	M2	1.43	1.58	1.59
DS211	M3	1.26	1.29	1.49
	M2	1.36	1.45	1.50

VFTO measured and simulated waveforms were compared. Figure 5 shows the comparison between simulation and test waveforms of VFTO at measuring point M2 during DS521 switching. Figure 6 shows the comparison between simulation and test waveforms of VFTO at measuring point M2 during DS211 switching. It shows that the measured waveform and simulation waveform are in agreement.

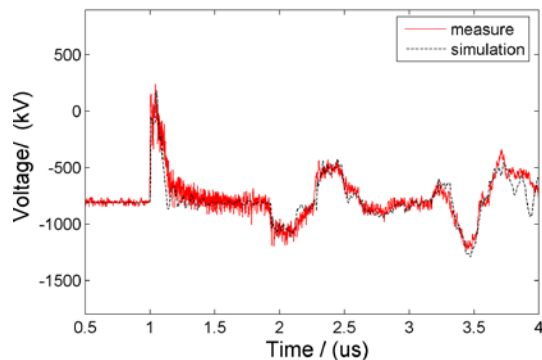


Figure 5. Comparison between simulation and test waveforms of VFTO at measuring point M2 during DS521 switching.

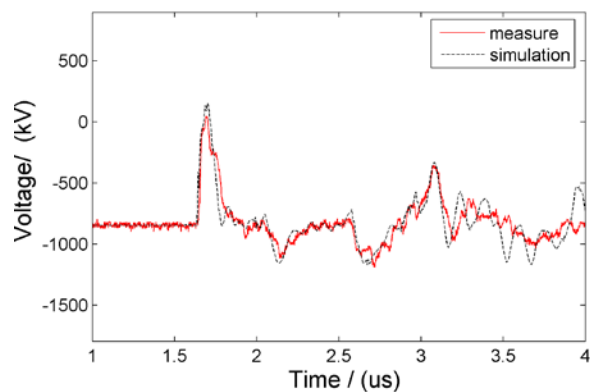


Figure 6. Comparison between simulation and test waveforms of VFTO at measuring point M2 during DS211 switching.

5. Conclusion

Simulation study on VFTO was carried out for 1000kV GIS substation. The simulation models and parameters are obtained according to the configuration of 1000kV UHV GIS. Operation modes of DS with higher VFTO were summarized. The characteristic of VFTO were obtained by simulation. Simulation results show that the maximum VFTO is 2055kV for the severest case. The maximum VFTO does not exceed the LIWV of 1000kV GIS. The safety margin between VFTO and LIWV exceeds 15%. Damping resistor is not necessary for this substation.

During the system commissioning test of the substation, VFTO were measured during DS switching test. The measured maximum VFTO is 1.48p.u.. Comparison was made between the measured and simulation results. Under same condition, the simulation amplitudes of VFTO were in agreement with the measured ones. The characteristics of simulation and measured VFTO waveforms are in accordance. The accuracy of the simulation models is verified. Simulation and test study shows that it is safe to do switching operation of DS in this GIS substation without damping resistor.

References

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