Influences on very fast transients induced on secondary cables of GIS substation

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Abstract. In order to protect the secondary equipment of gas insulated switchgear (GIS) substation, study on the very fast transients (VFTs) induced on secondary cables during the disconnector operations of GIS is developed. Based on the custom-designed experiment platform which can produce VFTs, the influences on VFTs including are discussed and some protections are proposed. The regularity of the influences is given through simulation including the GIS size, the soil resistivity and the loads. The measures to protect secondary equipment from the VFTs are suggested.

1. Introduction
The very fast transients (VFTs) produced during the disconnector operations in gas-insulated switchgear (GIS) substation may threaten the secondary equipment[1-2]. VFTs transmitted from the GIS pipe to the cables cause electromagnetic interference to the devices responsible for monitoring, measuring and protection of the GIS or the lines[3-4]. Many studies on the VFTs mainly pay attention to the primary insulation problems of GIS based on plenty of measuring and statistics work[5-6]. Research on secondary problems caused by VFTs generally aimed at a fixed size and structure of GIS provide some data for reference [7-8]. However, the lack of the analysis and explanation to the influences of the VFTs in foregoing references makes us explore them further.

Based on the custom experiment platform designed to induce VFTs same with those in GIS, a simulation model is validated by the experiments. Through the model, three influences to VFTs including the GIS size, the soil resistivity and the loads, which are all not easy changed in a real GIS, are studied in this work. The results and conclusion may help us to take measures to protect the secondary equipment from the VFTs.

2. Experiment Platform
The test platform includes five components: the electromagnetic pulse (EMP) source, the 220 kV GIS pipe, the grounding grid, the secondary cable and shielding boxes as illustrated in Fig. 1. The EMP connected GIS pipe generates pulse voltage reflected in the pipe and then forms the VFTs like $u_1\sim u_5$ at the ports of GIS and cables. The peak of the pulse voltage with a 2~5ns rise-time can reach 20kV. The amplitude of the VFTs in the GIS pipe such as $u_1$ and $u_2$ are 20~40kV and the main frequencies includes DC and 7MHz. The amplitude of the VFTs like $u_4$ and $u_5$ induced on the cable ports are 0.1~0.5kV and the main frequencies are 7~25MHz. The amplitude of the VFTs like $u_3$ between GIS
and the ground is about 2kV and the main frequencies is 7~25MHz. More details of the experiment platform are introduced in reference [9] and also the effectiveness of it is verified.

Fig.1 The layout of imitated experiment platform

Using the experiment platform, the VFTs of all kinds can be available easily and the experiment conditions can be changed conveniently.

3. Circuit Models

3.1. Transmission-line network model
The equivalent circuit of the experiment platform is a transmission-line network with ports in Fig 2.

Fig.2 The equivalent circuit of the platform

The equivalent circuit of the GIS pipe is transmission-line Z1. The GIS shell and the ground also constitutes a transmission-line Z2. The cable equals to transmission-line Z3. More details of the platform base on the transmission-line theory are introduced and also the circuit model are fully proved in reference [10].

3.2. Cable model
The cable is built as a multi-conductor transmission-line model in Fig 3. The cable has four inner conductors made of copper shielded by one woven braid layer. The armor layer made of flexible conducting metal wrapped outside the insulation medium. The whole cable is enclosed in the metallic bellow. The whole cable system with the metallic bellow can be modeled as a “7+1” transmission- line as Fig. 10 shows. Four inner conductors are numbered 1-4 respectively. The shield layer is numbered 5. The armor is numbered 6 and the metallic bellow is no.7. The grounding grid is the reference conductor no.0. More details of the cable base on the transmission-line theory are introduced and also the circuit model are fully proved in reference [10].
4. Results and Discussion
Using the models in section 3 how the influences affect the VFTs can be easily explored by changing the simulation conditions including the GIS size, the soil resistivity and the loads connected to the ports.

4.1. GIS Size
The height of GIS is the distance between GIS shell and the ground. It mainly affects the wave impedance of transmission-line $Z_2$. The original height of GIS is 0.35m. Increasing the height and the change of VTF $u_3$ is listed in Table 1. The voltage level of $u_3$ increases with the height $h$ apparently.

Table 1. VFTs variation with the height $h$.

| $h$/m | $u_3$/kV |
|------|----------|
| 0.35 | 1.58     |
| 0.6  | 1.90     |
| 0.9  | 2.14     |
| 1.2  | 2.3      |
| 1.5  | 2.5      |
| 1.8  | 2.75     |
| 2    | 2.9      |

In different GIS substation the length of GIS pipe is different. The length of GIS pipe affects the wave impedance of transmission-line $Z_1$. With the different length $l$ of GIS in simulation the voltage $u_3$ is observed. The original GIS length of this experiment platform is 4m. Table 2 lists the values when $l$ is changed. The amplitude of $u_3$ increases with the pipe becoming longer mostly.

Table 2. VFTs variation with the length $l$.

| $l$/m | $u_3$/kV |
|------|----------|
| 4    | 1.58     |
| 5    | 1.48     |
| 6    | 1.67     |
4.2. Soil resistivity
Due to the transmission line Z2 consisting of the GIS shell and the ground, the soil resistivity of the ground also affects the impedance of Z2 mainly. Table 3 lists the VFTs variation with the resistivity of soil. The $u_3$ increases with the soil resistivity becoming larger.

Table 3. VFTs variation with the resistivity of soil.

| $\rho/(\Omega \cdot m)$ | $u_3/kV$ |
|------------------------|----------|
| 50                     | 1.58     |
| 100                    | 1.65     |
| 200                    | 1.70     |
| 500                    | 1.75     |
| 1k                     | 1.87     |
| 2k                     | 2.42     |

4.3. Loads
In a real GIS substation the equivalent loads of various secondary devices connected to the cable are different. The loads connected to the cable ports also affects the VFTs. Table 4 lists the Port disturbances $u_4$ variation of different load conditions. The value increases fast before the load comes to 1kΩ. When the resistance of the load is 1kΩ the amplitude of $u_4$ reaches the max value 124.8V. The resistance exceeds 1kΩ the voltage level become lower gradually.

Table 4. Port disturbances $u_4$ of different load conditions.

| Loads/$\Omega$ | $u_4/kV$ |
|----------------|----------|
| 50             | 49.2     |
| 100            | 63.9     |
| 1k             | 124.8    |
| 10k            | 89.6     |
| 0.1M           | 83.2     |
| 1M             | 82.9     |

5. Conclusion
According to the previous sections, the regularity of how the factors impact on VFTs are explored and several suggestions are concluded as follows:
(1) The GIS height should be designed as lower as possible to decrease the level of VFTs.
(2) The VFTs are affected by the GIS pipe length and it needs to be considered according to the specific conditions of GIS structure.
(3) The soil resistivity of the ground affects the VFTs. Thus, the local soil of the ground GIS substation built on should be considered widely including wet or dry conditions. The soil resistivity is closely related to them.
The port disturbance of the cable increases with the resistance becoming larger until the open circuit. Different isolation level should be designed aimed to different equivalent resistance of secondary devices.

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