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Study on Influence Factors of Lightning Impulse Test Waveform of UHV GIS Equipment

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Abstract. The lightning impulse withstand voltage test is a test item that must be carried out for type testing, factory test or even field test of electrical equipment such as gas insulated metal-enclosed switchgear (GIS).However, the factors affecting the lightning impulse test waveform are complex and diverse. In this paper, the discharge principle of the impulse voltage generator is studied. Combined with simulation, the influence of different factors on the waveform parameters of lightning impulse test of UHV GIS equipment is obtained. The common methods and improvement measures of waveform debugging are pointed out, and the main factors affecting the parameters of lightning waves are studied.

1. Introduction

The impulse test is a test that simulates the adverse effects of power systems and equipment on lightning strikes (direct lightning, inductive lightning or operating overvoltage) [1]. The purpose is to evaluate the insulation withstand strength of the equipment. Moreover, the GB/T 16927.1-2011 and IEC 60060-1 standards have strict requirements on the lightning impulse voltage waveform, that is, the wavefront time is 1.2μs±30%, the half-peak time is 50μs±20% of the full-wave lightning, and the oscillation Overshoot must not exceed 10% [2]. Whether the waveform parameters meet the standard requirements determines the degree of qualification of the lightning impulse test of power equipment, so it is very important to study the influencing factors of the lightning impulse test waveform parameters [3].

At present, China's UHV engineering 1100kV switchgear is all using GIS. GIS is one of the important components in UHV power grids [4]. Compared with traditional air-insulated switchgear, GIS concentrates many devices such as bus bars, disconnectors, circuit breakers, arresters and transformers in a closed grounded metal casing [5]. The utility model has the advantages of small occupied area, small influence by the natural environment, safe and reliable operation, and so on. GIS has been widely used in domestic and international power systems. The insulation performance of UHV GIS equipment plays an important role in the reliable and stable operation of the power grid [6], [7].The research content of this paper can provide an appropriate theoretical basis and important data support for the analysis of the influencing factors of the lightning impulse test waveform parameters and its overshoot coefficient suppression technology.

2. Lightning impulse test circuit

The lightning impulse voltage was generated by a impulse voltage generator and the test circuit was designed by Marx in 1923 [8]. In order to calculate the waveform or the various elements of the impulse circuit, the Marx generator is simplified to the equivalent circuit showed in figure 1. C_1 is the charging capacitor; R_d is the wavefront resistance; R_e wave tail resistance; L is the test circuit inductance; S is the discharge gap; C_2 is the load capacitance.Among them, when C_1 is charged to U_0, S is triggered, C_2 is charged through C_1, and attenuated by R_f.

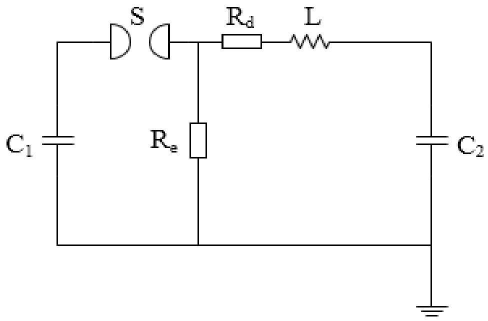


Figure1. Impulse voltage generator discharge equivalent circuit.

Since the maximum oscillation overshoot occurs near the peak of the lightning impulse, the wave tail resistance is large and has little effect on the waveform oscillation. The discharge equivalent circuit in the wavefront stage is shown in figure 2.

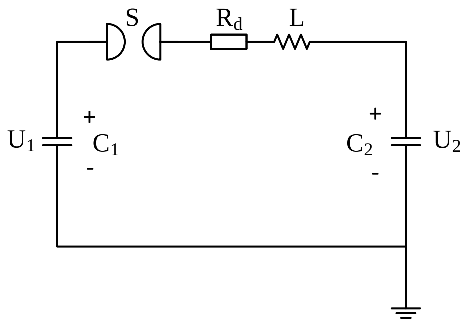


Figure2. Wavefront discharge equivalent circuit.

A inequation should be given as (1)if we want to obtain a non-oscillating wave

$$R_d \geq \left[\frac{4L(C_1 + C_2)}{C_1 C_2} \right]^{\frac{1}{2}} \tag{1}$$

Take the critical value

$$R_d = \left[\frac{4L}{C} \right]^{\frac{1}{2}} \tag{2}$$

In the equation (2), $C = \frac{C_1 C_2}{C_1 + C_2}$. The operational impedance under the Laplace transform for the entire circuit in figure 1 is

$$Z(s) = R_d + sL + \frac{1}{sC} \tag{3}$$

Finished up

$$U_2(s)=\frac{U_1}{sC_2L\left(s^2+\frac{sR_d}{L}+\frac{1}{LC}\right)} \tag{4}$$

Performing Laplace inverse transformation under critical damping, we get

$$u_2(t)=\frac{C_1U_1\left[1\text{-}(1+\frac{R_d t}{2L})e^{\frac{-R_d t}{2L}}\right]}{C_1+C_2} \tag{5}$$

According to standard wave definition, the wavefront time can be calculated

$$T_f\ =2.33R_dC \tag{6}$$

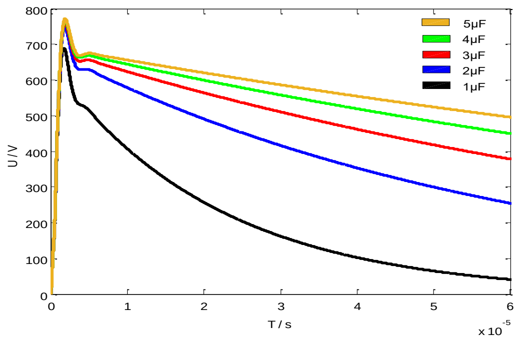
Put the critical damping condition $R_d=\left(\frac{4L}{C}\right)^{\frac{1}{2}}$ into equation (6)

$$T_f\ =4.66(LC)^{\frac{1}{2}} \tag{7}$$

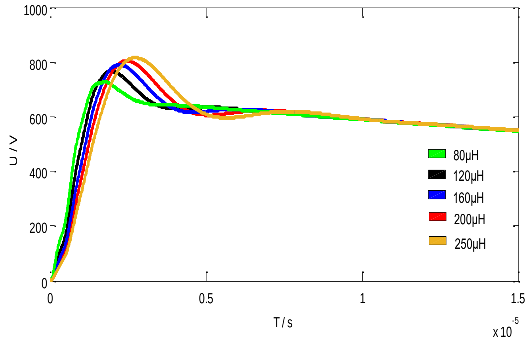
It can be seen from equations (7) and (8) that the wavefront time T_f is positively correlated with R and C. When T_f is constant, the load capacitance C_2 is also limited by the circuit inductance L.

3. Analysis on influencing factors of waveform parameters

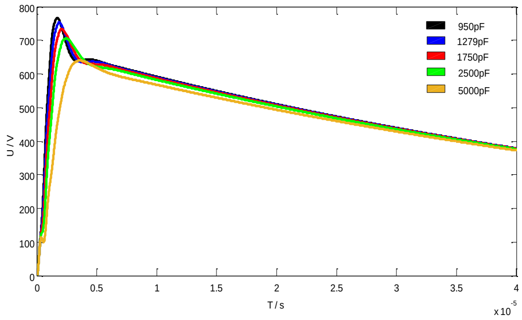
The waveform parameters of the lightning impulse test are mainly influnenced by the following factors: the main capacitance of the impulse generator, the inductance of the impulse test circuit, and the capacitance of the sample. The effect of various factors on the waveform of the lightning impulse test is shown in figure 3.



(a) Main capacitance change waveform diagram



(b) Circuit inductance variation waveform diagram



(c) Sample capacitance change waveform diagram

Figure3. Relationship between lightning waveform and main capacitor, impact test circuit inductance, and sample capacitance

From figure 3(a), (b) and (c), we can see that keeping the other conditions constant, the smaller the main capacitor value of the generator is, the steeper the tail portion is, and the overshoot is larger. On the contrary,the tail portion is smoother and the overshoot is smaller. The circuit inductance is positively correlated with the wavefront time and the overshoot. The capacitance of the sample is positively correlated with the wavefront time and is negatively correlated with the overshoot. However, when the sample has a large capacitance, the waveform will oscillate at the beginning.

4. Waveform debugging method

In order to effectively solve the problem that oscillation overshoot near the peak of the lightning impulse voltage, many work has been done at home and abroad. There are two main measures: one is to reduce the circuit inductance, the other is to improve the circuit method, that is, a low-pass filter circuit with parallel resistance and capacitance is connected in series at the output end of the impulse voltage generator, and the oscillation overshoot of the lightning waveform is improved by the filter circuit.

4.1 Reduce circuit inductance

In the test, the following methods are used to reduce the inductance of the circuit: (1) The arrangement of the wavefront resistors should be paralleled by multiple resistors; (2) Reduce the number of generators while satisfying the test voltage; (3) Use a low-inductance connecting wire as the high-voltage connecting wire.

4.2 Series low-pass filter

The reason why the lightning wave output be overshoot is that the lightning wave contains high frequency harmonic components. Based on the above discussion, this paper proposes an overshoot suppression circuit that is consist of a compensation circuit, a passive low-pass filter composed of a capacitor *C* and a resistor *R* in parallel, as shown in figure 4 .

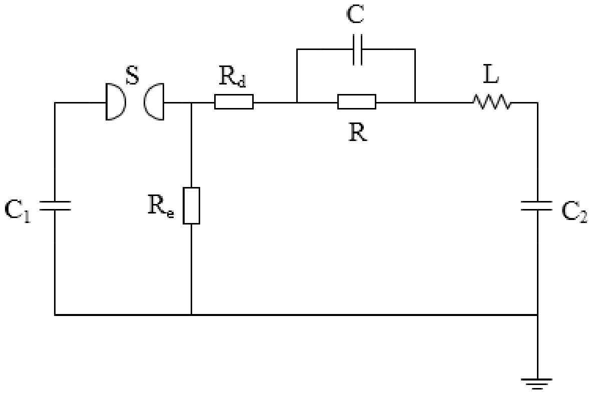


Figure 4. Circuit diagram of series low-pass filter device

By changing the values of the capacitance *C* and the resistance *R* of the damping device, the simulation can be concluded that the influence of the change of the capacitance *C* and the resistance *R* on the waveform is shown in figure 5 and figure 6.

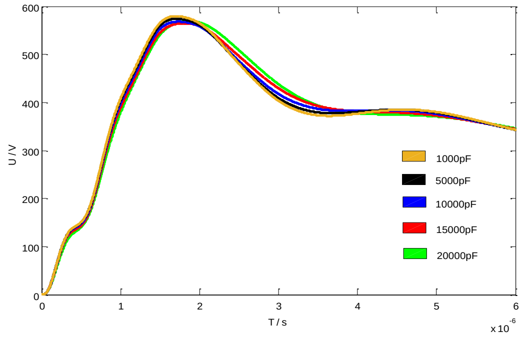


Figure 5. Filter device capacitance change waveform

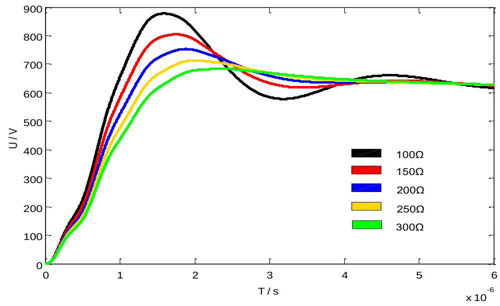


Figure 6. Filter device resistance change waveform

From the simulation results, it can be concluded that there is a contradiction between *C* and *R*. For products with large capacitance such as UHV switchgear, the larger the *C* is selected, the shorter the wavefront time can be effectively shortened, but the oscillation will be aggravated, and the capacitance will increase to a certain extent, which has no obvious effect on the wavefront time.At this time, once the wave head oscillation is intensified, it needs to be damped by *R*. As *R* increases, the oscillation can be attenuated, but the second peak after the oscillation is pulled high. If we simply increase *R* to reduce the overshoot oscillation, the second peak will exceed the first peak, and the calculated wavefront time will increase greatly, far exceeding the standard requirements. Therefore, in order to meet the requirements of the standard for waveforms, the selection of overshoot damping device parameters is particularly important. Due to the different capacitance of the UHV switch gear, the parameters of the device need to be adjustable within a certain range [9], [10].

5. Conclusion

- Increasing the main capacitor value of the surge voltage generator can significantly reduce the wavefront time.
- As much as possible to reduce the lightning impulse test circuit inductance to improve the test waveform is more effective.
- Adding a filtering device to the lightning impulse test circuit can significantly improve the waveform parameters, and there is an optimum value between the resistance value and the capacitance worth ratio in the resistance-capacitance device.

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Acknowledgments

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