Research the output characteristic of the 2MV very fast transient overvoltage generator

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Abstract. Very fast transient overvoltage has become an important research topic in international high- voltage field due to its generation, features and the influence of GIS on insulation breakdown characteristics. In this paper, the distributed parameter simulation model is established in view of the VFTO generator, based on the model to research the main parameters that influence the output characteristic, including of energy-storage capacitors, loop inductances, circuit resistances and load capacitances, and analyzing the impact of various parameters on the VFTO generator output characteristics. Results show that the relationship between each main parameter and the output characteristic of VFTO generator, which is an important reference for developing the VFTO generator matching with the actual production.

1. Introduction

Gas insulated switchgear (GIS) has been widely applied in power systems due to its significant advantages of small installation area, high operational reliability, long maintenance cycle, and so on. However, operating the disconnector and circuit breaker in GIS, will repeated occur breakdown and reignition between the switch contact that can generate a very fast transient overvoltage (VFTO), which is higher amplitude, high frequency and short duration. VFTO has a devastating effect on interior secondary system, winding type of equipment and primary equipment for GIS.

In order to grasp the ultra-high voltage (UHV) GIS insulation characteristics under the influence of VFTO, it is necessary to research VFTO simulated generator that can produce corresponding voltage amplitude. Test shows that VFTO in UHV GIS generally is not more than 2.5 pu, and the corresponding amplitude is 2.5MV. In this article, according to the existing 2MV very fast transient overvoltage generator, analysis is performed on the factors affecting of the VFTO generator output performance, make it can be measured accurately, at the same time it can provide theoretical basis for developing higher amplitude of the generator.

2. The structure of VFTO generator

VFTO generator mainly consists of four parts, namely simulation console, charging triggering device, Marx generator, GIS short bus (Sharpening clearance and the test cavity), shown in Fig.1. Through the impulse voltage generator is composed by charging triggering device and Marx generator, it can provide the impulse voltage waveform that the amplitude is up to 2MV, then realize sharping and control voltage through self-breakdown sharping clearance, because of the LC oscillator circuit and the reflection impact on short bus, so steepening waveform form the high frequency oscillation which is superimposed on the steep wave, eventually, VFTO waveform to meet the requirements is formed in the test cavity. If the sharpening clearance is short circuit, it can achieve to output the standard thunder electric wave through the front of the impulse voltage generator.

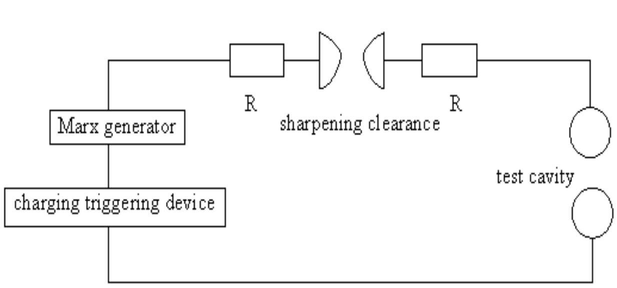


Fig.1 VFTO generator simplified model

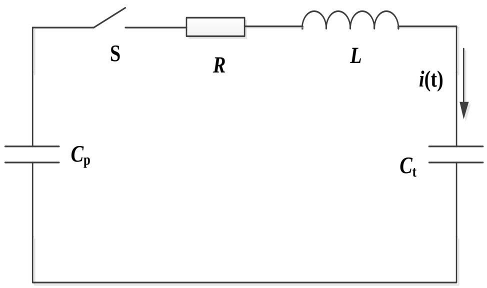


Fig.2 equivalent circuit diagram

In order to more clearly analyze the entire device from the perspective of circuit, the device can be simplified according to the each part electric property of VFTO generator. From the view of electricity, all of components that influence the waveform can be described through the R, L and C circuit. This means, at the moment of the sharpening switch is turning, Marx generator and back-end GIS bus bar make up resonance circuit, the principle of equivalent circuit can be simplified as shown in Fig.2, where Cp before the sharpening switch mainly refers to capacitance between Marx generator and sharpening clearance, namely the energy-storage capacitor (ISC), R is the total equivalent resistance of the circuit, L is the total equivalent inductance in circuit, Ct is the sum of capacitance to ground after sharpening switch, namely load capacitance.

3. VFTO generator simulation model

Compared with the actual situation, the degree of simplification is very large in Fig.2, which is not matching on actual situation, so it is necessary to establish detailed model according to the actual electrical parameters. And then, ATP-EMTP is used to establish distributed parameter model for the device circuit, further study of the influence of variable parameters(R、L and C) on the device output waveform. The simulation circuit diagram of distributed parameter as shown in Fig.3:

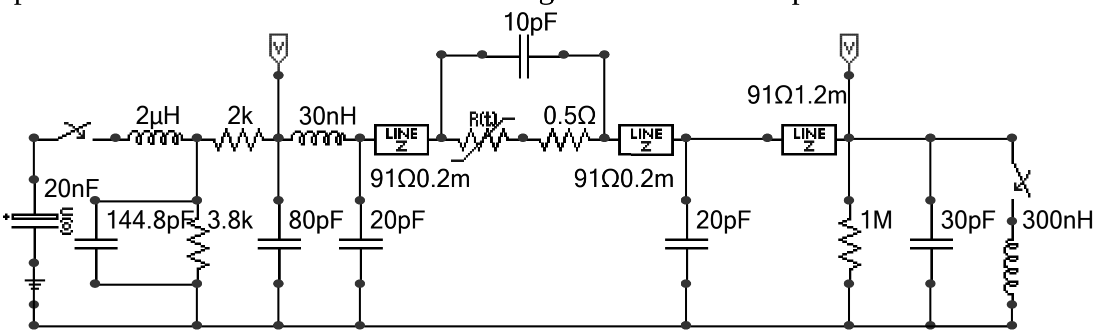


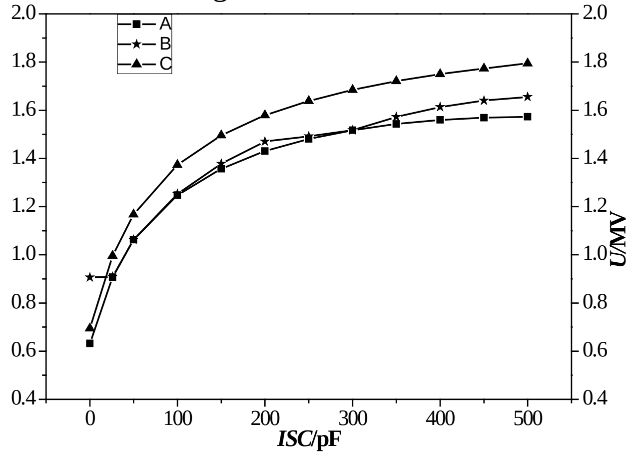
Fig.3 VFTO generator simulation circuit diagram of distributed parameter

Among them, the sharpening clearance is simplified into series connection of time-varying resistance and arc resistance and then parallel connection of capacitance, ground resistance of 1MΩ is used on the end of test cavity, and that can discharge residual charges. Moreover, test sample is simplified into series connection of sparks inductance of 300nH and time-controlled Switch then series connection of capacitance of 30pF. The disk insulator of sharpening clearance at both ends and interior of test cavity is substituted transmission line model, and according to the experience both take 20 pF.

4. Research the output characteristic of VFTO generator

4.1 The influence of capacitances on VFTO waveform

The adopted closed structure consequently reduces the dimension of the entire device, especially the Marx, and decreases the inductance value of circuit. However, the wave-head resistance of Marx exceeds the critical value of circuit under-damping, and the charge time constant of load that Marx capacitance give to sharpening clearance is too great, which means that this two kind of effect make the Marx capacitance remain beyond the wave front oscillation circuit. At the moment of sharpening switch is switching, the energy-storage capacitor has a very big effect on the amplitude of steepened VFTO. Due to the load capacitance has an opposite effect on VFTO waveform with the energy-storage capacitor, and meanwhile, the load capacitance has same effect on amplitude as energy-storage capacitor has, the effect on output waveform from energy-storage capacitor is simply analyzed here. Define the output efficiency of VFTO generator as the ratio of output VFTO amplitude to steepening lightening wave amplitude, and the relationship between output efficiency and energy-storage capacitor is shown in Fig.4.



A- The first wave amplitude VFTO,B- VFTO maximum voltage，C- Output efficiency

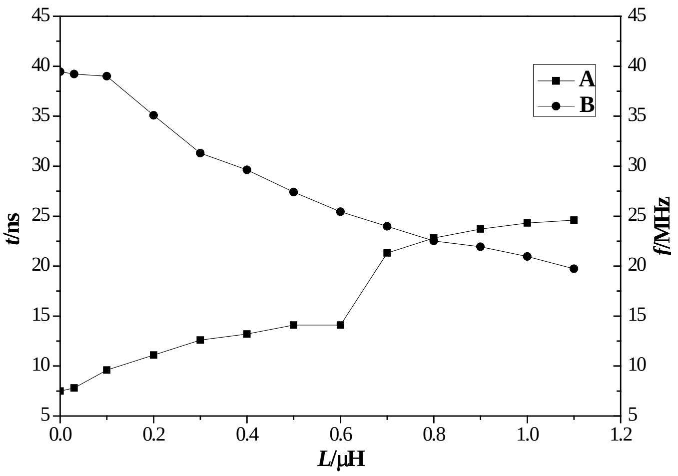
Fig.4 The relationship between output efficiency and energy-storage capacitor

It can be concluded from Fig.4, the output efficiency of VFTO generator increases rapidly at first and goes gradually saturated as the constant increase of energy-storage capacitor, and both the amplitude of first wave and the maximum voltage value of output VFTO wave show the same variation tendency. The aforementioned trend indicates that the voltage amplitude of output wave is mainly determined by the relative value of Cp and Ct, which means that as the energy-storage capacitor Cp is constantly increasing while the capacitance Ct on sharpening clearance load side remains constantly, the output efficiency increases and then gradually converges to 1. When the value of Cp is considerably greater than the Ct's, the generator's efficiency reaches maximized, which the maximum efficiency value approaches 2 to which the efficiency curve gets close (shown in Fig.4).

The higher efficiency, that is, the greater amplitude of VFTO is outputted by generator. It can be known through the aforementioned analysis that the choice of energy-storage capacitor is majorly taking the amplitude of VFTO generator's outputted while designing the device. Furthermore, energy-storage capacitor should better be chosen within the unsaturated range of efficiency curve.

4.2 The influence of loop inductances on VFTO waveform

Loop inductances mainly include the inductance of Marx generator, sharpening clearance and lead wire, where Marx inductance includes the inductance of charging capacitance, every stage switch and lead wire. If only sharpening clearance at the moment of the action, which will have a role of isolating Marx and post-stage circuit due to the wave-head resistance is too large, therefore, the oscillation loop inductance is mainly composed of sparks inductance of sharpening clearance and lead inductance after steepening. Because of the sparks inductance of sharpening clearance show little change, so the loop inductance refers to lead inductance in the circuit. It will be simulation analyzed that loop inductance has an effect on VFTO waveform as following, that is, analysis the effect of wave time and the main oscillation frequency, as shown in Fig.5:



A-The wave time， B- The main oscillation frequency

Fig 5 Wave time and main oscillation frequency of VFTO under different loop inductance

As apparent from Fig.5, with the increase of loop inductance, the wave time is gradually increased, and the oscillation frequency is gradually reduced, this is because the actual device circuit in addition to the main oscillator circuit, also includes other small RLC circuit, when the inductance is small, these small circuits may be in over-damped state, when the inductance is increased to a certain value, these small loop will oscillate, thus the wave time and oscillation frequency will be affected. From the above analysis, in order to obtain high-frequency oscillation and shorter rise time of VFTO, the loop induction should be as small as possible.

4.3 The influence of circuit resistances on VFTO waveform

Circuit resistances mainly include sparks channel resistance of Marx 5stage switch, capacitor internal resistance, wave-head resistance and sparks resistance of sharpening clearance, the main variable part in the distributed parameter circuit is wave-head resistance, and the rest of the resistances are relatively smaller, so only consider the influence of the wave-head resistance on VFTO waveform.

When the wave-head resistance is 200Ω, circuit oscillation decrease obviously, and the wave-head resistance will play a very good damping effect on VFTO waveform, but there are still violent oscillation at the wave head of lightning wave at this time. VFTO wave head rise time is close to 7ns, and the main oscillation frequency is 39.3MHz, the first wave amplitude is 1258.7kV, efficiency is 1.31. When the wave-head resistance is 2kΩ, the amplitude, rise time and main oscillation frequency are basically identical. As shown in Fig.6:

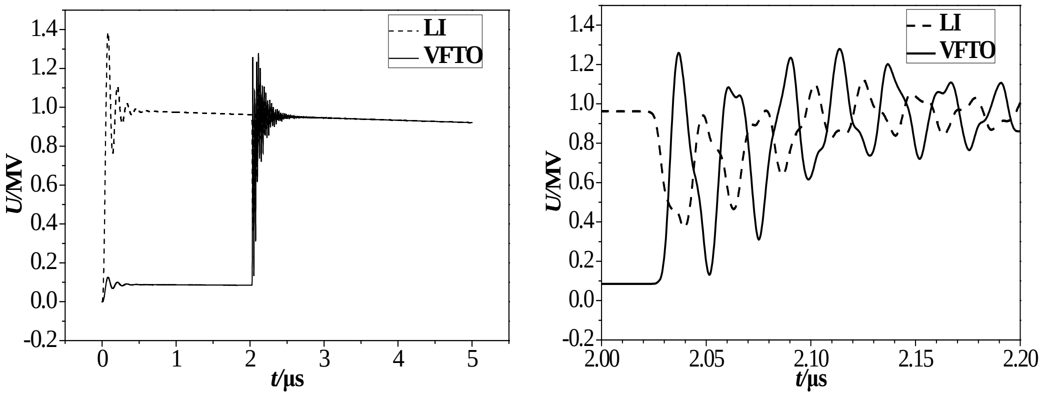


Fig.6 The wave-head resistance of 200Ω for VFTO full-wave and wave-head

When the wave-head resistance is greater than 200Ω, the wave-head resistance has little impact on VFTO oscillation circuit after steepening because of over damping effect of the wave-head resistance. So when the wave-head resistance is 200Ω or 2kΩ, the features of VFTO waveform are basically identical. When the wave-head resistance changes from zero to R0 (R0 is critical resistance, about a few hundred Ω), the greater the resistance is, the faster the VFTO oscillation damping will be. And when the wave-head resistance changes over R0, the greater the resistance is, the slower the VFTO oscillation damping will be.

5. Conclusion

In this paper, energy-storage capacitors, loop inductances, circuit resistances and load capacitances are researched through distributed parameter model of VFTO generator. It makes the following conclusion: The selection of energy-storage capacitor should be satisfied the standard of lightning wave parameters, and mainly pay attention to the amplitude of VFTO generator output. Energy storage capacitor should be selected within the range efficiency curve is not saturated before. Loop inductances should be as small as possible, in order to obtain high-frequency oscillation and shorter rise time of VFTO. Circuit resistance should satisfy $R<R0$, at the same time, the attenuation speed of wave tail and the main oscillation frequency should be considered.

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