Design and Experimental Study of Traveling Wave Signal Generator for Distribution Network

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Abstract. Aiming at the problem of operation safety and stability of electrical equipment in distribution network caused by impulse voltage, this paper will study and analyze the traveling wave signal generator. Through the study of the standard lightning wave shape characteristics and the mechanism and characteristics of the existing lightning impulse voltage signal generator equipment, the working principle of the corresponding traveling wave signal generator was designed and the relevant parameters were calculated. Finally, the results of the research and analysis were simulated and analyzed with the Multisim simulation software. Test results show that the impulse voltage generated by the full waveform basic satisfy the provisions of this design is expected waveform, and consistent with the actual lightning wave shape, therefore, this thesis studies the traveling wave signal generator unit can meet the normal travelling wave signal of traveling wave positioning system requirements, verify the real effectiveness and practicability of this thesis research.

Keywords: Travelling wave signal generator, Lightning overvoltage, Operating overvoltage, Impact withstand test

1. Introduction
In the whole power system, the safe and reliable performance of the electrical equipment in operation has a significant impact on the power system. With the increasing types of electrical equipment and using more and more frequently, more and more unexpected faults will gradually appear from the design and manufacture out of factory to the later operation [1]. Therefore, in order to improve the safety and reliability of electrical equipment when it is put into operation, the industry is constantly studying and analyzing the detection methods of insulation performance and protection performance of electrical equipment, so as to ensure the safety and stability of power system operation [2].

At present, the power industry in many countries in the world is developing rapidly. It is known that many foreign high voltage research institutions have large impulse voltage generators, and the voltage emitted by the impulse voltage generator devices of some high voltage research institutions can reach up to megavolt level [3]. The impulse voltage generator with the highest rated voltage of 6MV has been built in China, which can perfectly match the requirements of voltage class of electrical equipment in the insulation test of electrical equipment and meet the constant progress of UHV transmission technology in China.

There are numerous traveling wave generators on the market, such as traveling wave generators designed with cable lines for delayed pulse ignition and delay devices. The delay time of traveling...
wave generators can be adjusted at will, so as to produce truncated waves meeting different needs [4]. With Buck+ bridge circuit as the main power and DSP controller combined with variable speed integral control, a bipolar transform direct stray surge generator is designed and produced to generate the specified standard surge test voltage [5]. In addition, a small MAX generator is used as the standard impulse voltage wave source to generate the full lightning wave required by the test equipment. This generator can be used to test the measurement system consisting of digital recorder and impulse resistance voltage divider [6].

The traditional impulse voltage generator generally adopts Marx loop model as the generator. However, due to its non-adjustable pulse, low frequency and easy ablation of electrode, the impact on the experimental effect is also increasing with the increase of the use time [7-9]. At present, traveling wave generators tend to develop in the aspects of high pulse, good reliability and strong controllability, etc., which has gradually become a challenge and problem for modern high-pressure test technology [10-13].

In order to meet the requirements of outdoor traveling wave installation equipment and the uneven capacitance energy storage of traditional impulse voltage generator, the theory of traveling wave generator is studied and analyzed according to the standard lightning wave shape in this paper, and the parameters of traveling wave generator are calculated, so as to generate the standard lightning impulse voltage waveform by simulation, which verifies the correctness and feasibility of the study in this paper and discusses and analyzes the existing problems.

2. Calculation of Basic Parameters of Traveling Wave Signal Generator

The standard lightning impulse voltage wave is an exponential attenuation wave, which is an aperiodic transformation. Its voltage $U$ can be expressed as equation (1):

$$u(t) = U_{2m} \left( e^{-t/T_1} - e^{-t/T_2} \right)$$  \hspace{1cm} (1)

In the wave head time range, it can be considered that equation (1) can be written as:

$$u(t) = U_{2m} (1 - e^{-t/T_2})$$  \hspace{1cm} (2)

Equation (2) is the expression of the output impulse voltage full-wave wave form.

According to the definition of the standard lightning wave shape and the linear relation, it can be seen that:

$$T_1 \approx 3.24 R_2 C_2$$  \hspace{1cm} (3)

Within the wave-tail time range, when the voltage drops to half of the peak time, the half-peak time $T_2$ relationship is as follows:

$$T_2 = 0.7 R_3 (C_1 + C_2) \approx 0.7 R_3 C_1$$  \hspace{1cm} (4)

The wave head time of the traveling wave generator can be adjusted by adjusting the triggering mode of voltage. Therefore, it is necessary to calculate the wave head resistance $R_2$, and wave tail resistance $R_3$, as well as the energy storage capacitor $C_1$, and wave head capacitance $C_2$ according to the designed waveform. In this design, the size of energy storage capacitor $C_1$ is chosen as 1μf, and the wave head capacitor $C_2$ is expected to use three capacitors of value 4.7nf in parallel into a capacitor of total capacity 14.1nf. Two traveling waves are expected to be emitted, a kind of for the first time was 1.2μs wave tail for 50μs standard lightning waveform, another for the first time for 5μs wave tail is 70μs custom lightning waveform.

Equation (3) and equation (4) for calculating wave-head time summarized above are used for calculation, and the prescribed standard traveling wave waveform time is substituted into them.

The calculation of wave-head resistance is shown in equation (5) and equation (6) respectively.
The calculation of wave-tail resistance is shown in equation (7) and equation (8) respectively.

\[ R'_3 = \frac{T'_{2}}{0.7C'_1} = 71.43 \Omega \]  
(7)

\[ R^*_3 = \frac{T^*_{2}}{0.7C'_1} = 100 \Omega \]  
(8)

According to the actual circumstance of market research and analysis, wave tail resistance is adopted in this design is 100 Ω, wave head resistance of 27 Ω respectively and 100 Ω analysis design.

The complete waveform of impulse voltage is shown in figure 1 and figure 2.

**Figure 1.** Schematic diagram of impulse voltage waveform.

**Figure 2.** Schematic diagram of impulse voltage wave-tail waveform.

### 3. Basic Principle of Traveling Wave Signal Generator

In the research scheme, the basic schematic diagram of the traveling wave generator is shown in figure 3.

**Figure 3.** Schematic topology diagram of TWT generator.
The output voltage of the high-voltage DC power supply is adjustable from 0 to 5000V. $R_1$ is the charge buffer resistance; $R_2$ is the wave head resistance; $R_3$ is the wave tail resistance; $C_1$ is the wave tail capacitance, that is, the energy storage capacitance; $C_2$ is the wave head capacitance; $K_1$ is reed pipe relay; $K_2$ is a small relay.

The 5KV high-voltage DC power supply module is used by traveling wave generator for power supply, and STM32F103C8T6 32-bit microprocessor MCU as the main control system, so as to logically coordinate and effectively control the whole generator system. The MOS tube conduction is controlled by single-chip microcomputer with instructions. And then output a low voltage to enable the $K_1$ reed relay to conduct. At this point, the energy storage capacitor $C_1$ is charged by the high-voltage DC power supply through the charging buffer resistance $R_1$, and will be filled later, the single-chip microcomputer gives instructions to the MOS tube module, closes the charging circuit of $K_1$ reed relay, and conducts the discharge circuit of $K_2$ small relay. Then, the electric charge on the energy storage capacitor $C_1$ began to discharge. Since the wave-tail resistance $R_3$ is much larger than the wave-head resistance $R_2$. Therefore, the energy storage capacitor $C_1$ first charges the wave-head capacitance $C_2$ through the wave-head resistance $R_2$, thus forming the needed wave head of the impulse voltage wave in this way, namely the wave head time. At the same time, when the voltage in the wave-head capacitor $C_2$ is equal to the voltage in the energy-storing capacitor $C_1$, wave-tail resistor $R_3$ discharges the energy-storing capacitor $C_1$ and wave-head capacitor $C_2$, forming the corresponding wave-tail of the impulse voltage wave, that is, the wave-tail time.

The working principle of the system is shown in figure 4.

Figure 4. working principle of traveling wave generator.

4. MCU Control System
STM32F103C8T6 32-bit microcontroller module is adopted in the control system of traveling wave signal generator, which combines the peripheral trigger circuit and charge and discharge circuit to form the integrated control of the system of the device.

The MCU control tasks are: control relay on and off, control energy storage capacitor charge and discharge, display the value of injected voltage, processing peripheral voice signal and wireless remote control communication, etc.

Figure 5 shows the main circuit diagram of MCU module. Among them, PB5 and PB7 ports complete the circuit processing of charging and discharging and output waveform. PA9 and PA10 ports complete the driving function of JQ8400 voice output; Ports PB12, PB13 and PB14 complete the remote control module of 315MHz to receive remote control signals; Port PA1-PA7 as the input of AD sampling circuit; PD0, PD1 port receives crystal vibration signal; BOOT0 port controls how BOOT is started.
5. Simulation Analysis

In order to ensure that the traveling wave generator can meet the insulation requirements of field test and produce standard lightning impulse waveform, after discussion and analysis, the corresponding circuit model of traveling wave generator is built for simulation analysis. Finally, the feasibility of the research scheme is verified through the simulation results. The simulation circuit is shown in figure 6.

![Simulation Model](image)

**Figure 6.** Simulation model of actual circuit of traveling wave generator.

The charging buffer resistance is 2.2 MΩ, the tail capacitance C1 is 1 μF, the wave head capacitance C2 is 14.1 nf, the tail resistance R3 is 100 Ω, and the wave head resistance R2 is 27 Ω and 100 Ω respectively. The simulation analysis is carried out respectively.

When the voltage regulation of high voltage DC power supply is 3000V, firstly, close switch S0 and charge wave tail capacitor C1. After fully charged, disconnect switch S0, close switch S0 and switch S3. At this time, the simulation results are shown in figure 7.

![Simulation Results](image)

**Figure 7.** Calculation of wave head and tail time at 3000v 27 Ω.

When R2 is 27 Ω, the wave head time is about 1.131 μs and the half peak time is about 52.761 μs.
Secondly, close the switch $S_0$ to charge the wave tail capacitor $C_1$. After fully charged, open the switch $S_{3b}$ close the switch $S_0$ and switch $S_2$. At this time, the simulation results are shown in figure 8.

![Figure 8](image)

**Figure 8.** Calculation of wave head and tail time at 3000v100 $\Omega$.

When $R_2$ is 100 $\Omega$, the wave head time is about 5.108 $\mu$s and the half peak time is about 73.693 $\mu$s. When the voltage of high voltage power supply is 5000v, the simulation method is similar to the above, and the simulation results are shown in figure 9 and figure 10.

![Figure 9](image)

**Figure 9.** Calculation of wave head and tail time at 5000v27 $\Omega$.

![Figure 10](image)

**Figure 10.** Calculation of wave head and tail time at 5000v100 $\Omega$.

The test results are listed in table 1.

| Voltage regulation size (V) | Wave head resistance $R_2$ ($\Omega$) | Wave head time $T_1$ ($\mu$s) | Wave tail time $T_2$ ($\mu$s) |
|-----------------------------|--------------------------------------|-----------------------------|-----------------------------|
| 3000                        | 27                                   | 1.131                       | 52.761                      |
| 3000                        | 100                                  | 5.108                       | 73.693                      |
| 5000                        | 27                                   | 1.415                       | 55.574                      |
| 5000                        | 100                                  | 5.250                       | 78.705                      |

According to GB/T16927.1 and the new IEC60060-1ED.3.0 standard, the standard wavefront time of lightning wave is 1.2 s ± 30%, and the half-peak time of pulse is 50 s ± 20%.

As can be seen from Table 1, when testing different voltages and different wave-head resistances, with the gradual increase of voltage and wave-head resistance, the wave-head time and wave-tail time will increase slightly correspondingly. However, the full-wave shape of impulse voltage generated is still within the specified range of waveform, which basically meets the requirements of waveform predicted in this design.

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**Table 1.** Parameter results of traveling wave voltage simulation analysis under different voltage and wave head resistance.
6. Conclusion
Aiming at the problem that the safety defect or fault cannot be detected in the electrical equipment during testing or operation, an experimental research scheme of traveling wave signal generator for distribution network is presented in this paper. The impulse voltage wave is simulated through the charge and discharge principle of the capacitance controlled by MCU. The working principle of the traveling wave signal generator is studied and analyzed, and its basic parameters are calculated, so as to build the corresponding simulation model. The results of comparison and analysis show that the waveform parameters of 1.2/50 μs and 5/70 μs are basically in accordance with the actual waveform parameters, and the predicted results are achieved. The reliability of this study is verified and the design conditions are met.

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