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Research on High Frequency Amplitude Attenuation of Electric Fast Transient Generator

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Abstract

In order to solve the amplitude attenuation of electric fast transient (EFT) generator operating in high frequency, the charging and discharging process of energy storage capacitor in EFT generator are analyzed, the main circuit voltage variation mathematical model is established, the parameters of main loop circuit and the parameters of switch driving waveform which affect burst amplitude are discussed. Through the simulation, this paper puts forward effective methods to overcome burst amplitude attenuation in high frequency. The simulation results show that when the frequency is low, the duty ratio of drive signal have little effect on energy storage capacitor voltage amplitude attenuation. when the charging resistance is less than 500 Ω, the duty ratio of drive signal is less than 0.125, the repetition frequency of burst reaches 1.2 MHz, the amplitude attenuation of energy storage capacitor voltage is less than 9%, the amplitude of burst satisfies IEC61000-4-4 standards.

Keywords: *Electric fast transients burst, High frequency attenuation, Analysis, Simulation;*

1. Introduction

Electric fast transient generator is used to simulate pulse disturbance to test the capacity of resisting transient pulse disturbance for electronic equipments, and it is an important electronic equipment for pulse immunity test, therefore, electric fast transients burst generator is widely used in the electronics industry[1-3].

With the frequency increase of pulse disturbance generated by power load, the international electronic commission carry on the revision to IEC61000-4-4 standards, its main purpose is to increase the repetition frequency and energy density, enhance repeatability and comparability of transient pulse disturbance test with electric fast transients, satisfy user's requirements of simulation real pulse disturbance. However, the interference signal generated by existing electric fast transient generator is lower than the actual frequency, and it can not meet the user's anti-interference test requirements, therefore, improving output pulse frequency of electric fast transient generator is needed. But with the increase of the pulse frequency, the consistency of wave shape is low which leads to the high frequency amplitude attenuation of burst operating .

The mathematical model of energy storage capacitor voltage variation in charging and discharging process is established, the influence of main circuit parameters and driving parameters of switch K on amplitude attenuation are discussed by simulation in this paper.

2. Analysis of energy storage capacitor charging and discharging process

2.1. Principle of electric fast transients burst generator

Simplified main circuit of Electric fast transient generator are shown as in Figure 1[4].The circuit is composed of high voltage power supply E, charging resistance R_1, storage capacitor C_1, high voltage switch K, discharging switch K, impedance matching resistance R_3 and DC blocking capacitor C_2. L is the parasitic inductance, R_4 is the load impedance.

The energy storage capacitor C_1 is charged by high voltage power supply E through the current limiting resistor R_1 until its value is power supply voltage, when switch K closes, storage capacitor C_1 began to discharge through the discharge resistance R_2, a high voltage

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nanosecond level pulse is produced in the output port, when switch K disconnect, energy storage capacitor C_1 stop discharging, storage capacitor C_1 is recharged by high voltage power supply *E* to prepare the next discharge. According to the IEC61000-4-4 standards, electric fast transient generator produces pulse periodically, every 300 ms cycle produces 75 pulses continuously, the normalized single pulse waveform, the rise time $t_r = 5ns$, time-to-half value $t_d = 50ns$, which is shown in Figure 2, burst of schematic diagram is shown as Figure 3 [5].

After 75 continuous pulse generating, discharge switch K is off, storage capacitor is recharged by high voltage power supply for the next cycle discharge.

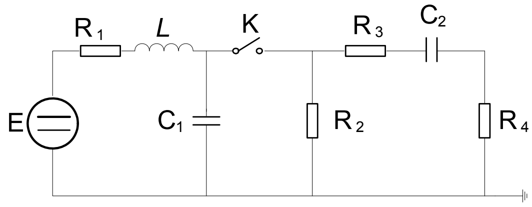

Figure 1. Simplified circuit diagram of a Fast Transient Generator

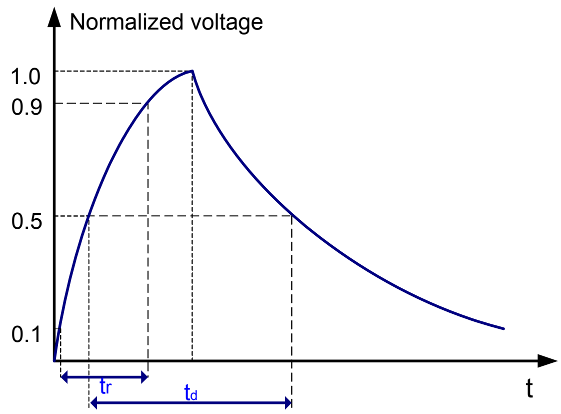

Figure 2 Normalized single transient pulse

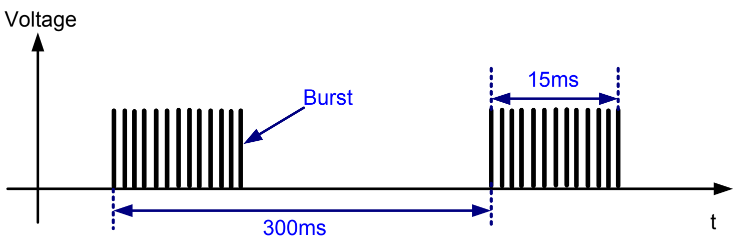

Figure 3 Specified fast transient waveform of burst

2.2. The analysis for the charging and discharging voltage variation of energy storage capacitor

In the drive of burst series, high speed high voltage electron switch K does the continuous charging and discharging to energy storage capacity, the open and close driving waveform of the switch are as shown in Figure 4. The discharging switch in the main circuit closes when in high voltage level, the energy storage capacity discharging, forming a high burst through the signal shaping circuit; the switch disconnects in low voltage level, the energy storage capacity charging. Recording to the IEC61000-4-4 standard, it needs to do 75 times charging and discharging in 300ms to produce 75 high voltage burst. Because that burst frequency made by electrics fast transient increases gradually, there is a great difference between the maximum repeat frequency and the minimum repeat frequency. When the repeat frequency is low, the main circuit parameter and the circuit driving parameter will not do amplitude attenuation. When the frequency is high, the restoring charging time of energy storage capacity is sufficient relatively and the voltage declines, making the consistency of burst amplitude worse and worse. Considering high frequency amplitude attenuation of the burst series, we take influencing factors of main circuit parameter and circuit driving parameter into consideration, analyzing charging and discharging process of the burst formation circuit.

For simplified mathematical analysis, the simplified model of charging and discharging circuit is shown as fig. 5. The circuit driving waveform is shown as fig 4, assuming the switch driving signal frequency is *f*, duty ratio is *k*, the power voltage is *E*, the voltage of energy storage capacity after m times discharging is V_{pm} , the voltage of energy storage capacity voltage after m times charging recovery is V_{qm}. Considering the influence of *k*, *f* , charging and discharging resistance, analyzing the voltage of energy storage capacity before the forming of the 75th burst to find the decline law that the burst amplitude vary with the parameter. In order to facilitate the analysis, assuming the system power as ideal voltage source, energy storage capacity has been charged full, it's amplitude is *E*, the frequency f and duty ratio k of the switch in main circuit remain unchanged.

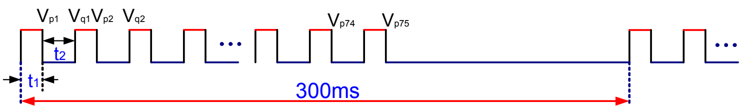

Figure 4. Drive signal waveform of switch

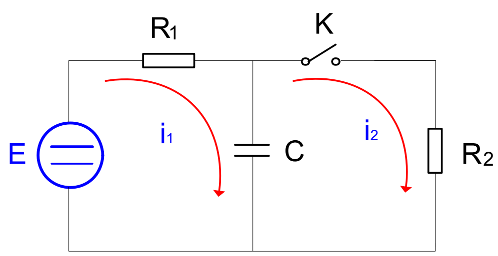

Figure 5. Charge-discharge circuit of Fast Transient Generator

(1) When the switch K closes for the first time, the main circuit begins to discharge, the discharge time t_{on} and the voltage V_{p1} of energy storage capacity after discharging are as following respectively:

$$t_{on} = k / f \tag{1}$$

$$V_{p1} = E \cdot e^{-\frac{t_{on}}{R_2 C}} = E \cdot e^{-\frac{k}{R_2 C f}} \tag{2}$$

(2) After the first discharge, the switch K disconnects, the energy storage capacity in main circuit begins the first recovery charge, the charging time t_{off} and the the voltage V_{q1} of energy storage capacity after charging are as following respectively:

$$t_{off} = (1 - k) / f \tag{3}$$

$$V_{q1} = V_{p1} + \left(E - V_{p1}\right)\cdot\left(1 - e^{\frac{-t_{off}}{R_1 C}}\right) = E\cdot\left[1 - e^{-\frac{1-k}{R_1 Cf}} + e^{-\left(\frac{k}{R_2 Cf}+\frac{1-k}{R_1 Cf}\right)}\right] \quad (4)$$

(3) When in the 2^{nd} discharging, the charging time ton remains the same, and the voltage V_{p2} is:

$$V_{p2} = V_{q1}\cdot e^{-\frac{1-k}{R_2 Cf}} \quad (5)$$

(4) When in the 2^{nd} charging, the charging time toff remains the same, and the voltage V_{q2} is:

$$V_{q2} = V_{p1} + (E - V_{p1})\left(1 - e^{-\frac{1-k}{R_1 Cf}}\right) \quad (6)$$

From the iteration, it can be got that the energy storage capacity voltage V_{qm} after the m times charging and voltage V_{pm} after m times discharging are as following:

$$V_{qm} = V_{p(m-1)} + (E - V_{p(m-1)})\cdot\left(1 - e^{-\frac{1-k}{R_1 Cf}}\right) \quad (m=2,3...n) \quad (7)$$

$$V_{pm} = V_{q(m-1)}\cdot e^{-\frac{k}{R_2 Cf}} \quad (m=2,3...n) \quad (8)$$

It can be seen that the remaining voltage in energy storage capacity after every discharging are decided by the last charging voltage, the driving signal frequency *f*, the duty ratio k, the energy storage capacity C and the discharging resistor R_2; The discharging voltage is decided by last remaining voltage, in charging, the drive signal frequency f, the duty ratio k, the energy storage capacity C and the charging resistor R_1; The optimizations of ratio k, charging resistor R_1 and discharging resistor R_2 can be done to overcoming the high amplitude attenuation.

3. The parameter simulation of charging and discharging processes

The energy storage capacitor charging and discharging processes in the main circuit were discussed in the last section. It showed the analytic expression of energy storage capacitor voltage at the end of the charging and discharging. By adjusting parameters, the voltage of the energy storage capacitor before 75^{th} discharge was solved, the suitable high-frequency burst parameters were found to reduce the high-frequency amplitude attenuation.

In order to research the influence that the duty ratio of the driving signal on the energy storage capacitor voltage high-frequency attenuation, the charging resistor R_1 was valued as 1000Ω, the discharging resistor R_2 was valued as 200Ω and energy storage capacitor C was valued as 1nF, according to the formula (7), the law of the energy storage capacitor voltage amplitude attenuation was found out through changing the duty ratio with the iterative algorithm. Figure 6 showed curves that the energy storage capacitor voltage varied with duty ratio. The curve B represented the change when burst frequency is 100kHz, The curve B represented the change when burst frequency is 500kHz and D is 1000kHz. In the Figure 6, the abscissa represents the duty factor k, the ordinate is the ratio of the last discharging voltage value of the energy storage capacitor to the power supply voltage.

The Figure 6 showed that the impact that the duty ratio of the driving signal to storage capacitor amplitude attenuation is little when the frequency is low, and that with the the increase of frequency, the energy storage capacitor voltage amplitude attenuation become larger. So, when the burst repetition frequency was higher, the energy storage capacitor voltage amplitude attenuation could be reduced by reducing the value of the duty ratio and extending the storage capacitor charging time relatively.

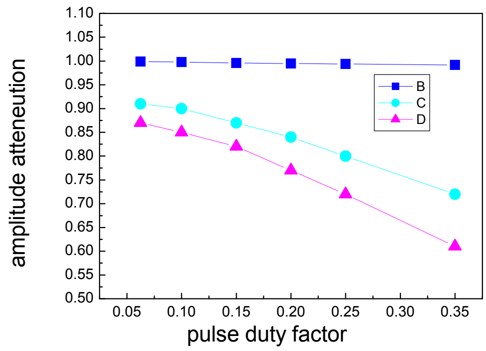

Figure 6. Amplitude attenuation changing with the duty cycle and frequency

The time-to-half value of t_d = 50 ns of burst was determined by the value of R_2 and C, which is constant in common. If the burst repetition frequency is very high and voltage amplitude attenuation was too high, the high-frequency attenuation issues could be solved by way of reducing the value of R_1, improving the charging speed and changing the duty ratio.

When set discharging resistor R_2 as 200Ω ,energy storage capacitor C as 1nF and burst frequency as 1.2 MHz, the parameter simulation of the energy storage capacitor voltage amplitude changes is showed in the Figure 7. The curve B showed the change when the charging resistor is 300Ω, the curve is 500Ω and D is 700Ω. The abscissa represented the duty factor, the ordinate is the ratio of the last discharging voltage value of the energy storage capacitor to the power supply voltage.

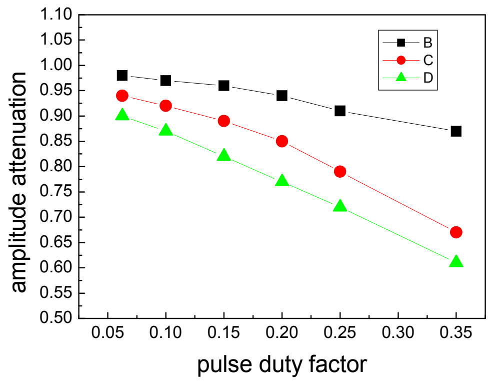

Figure 7. Amplitude attenuation changing with the different charging resistance

The Figure 7 showed that in the same duty ratio, the charging resistor R_1 is smaller, the voltage amplitude attenuation is smaller. When the charging resistor is less than 500Ω,duty ratio of the driving signal is less than 0.125 and burst frequency is less than 1.2MHz, the amplitude attenuation of the energy storage capacitor voltage is less than 9%, which is met IEC61000-4-4 standard.

4. Conclusion

Without considering the impact of the main circuit distribution parameters and parasitic parameters, the analysis and simulation that energy storage capacitor charging and discharging voltage of the electrical fast transient are studied in this article. The results of the simulation showed that the impact of the duty ratio of the driving signal on storage capacitor voltage amplitude attenuation was little when frequency was low. When the frequency of the driving signal is higher, charging resistor and ratio of driving signal have effect on the voltage, the high-frequency attenuation could be reduced by means of reducing the value of R_1, improving the charging speed and changing the duty ratio. When the charging resistor is less than 500Ω,duty ratio of the driving signal is less than 0.125 and burst frequency is less than 1.2MHz, the amplitude attenuation of the energy storage capacitor voltage is less than 9%, which is met IEC61000-4-4 standards.

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