EFFECT OF CHANGE IN THE LOAD PROPERTIES ON THE RECTANGULAR PULSE WAVEFORM OF THE PULSED ELECTRIC FIELDS SYSTEM

Chen Jie, Zhang Ruobing, Xiao Jianfu, Wang Liming, Guan Zhicheng

Graduate School at Shenzhen, Tsinghua University, P.R.China

Email: < j-c07@mails.tsinghua.edu.cn >

Abstract: Pulsed electric fields (PEF) non-thermal treatment is an important application of high voltage engineering and pulsed power technology in food processing area. The waveform of applied pulses owns a significant impact on the effect of PEF especially for rectangular pulses. However, the waveform is also influenced by load properties for a PEF system. In this paper, the effect of load properties on the rectangular pulse waveform is presented. Two different load characteristics: pure resistance, resistance parallel with capacitor were studied. The theoretical analysis and experiment results show that after the introduction of MS module, the rise time kept constant; the overshoot and oscillation in the leading edge were influenced by the value of resistance and capacitor; the trail of pulse in the simulation results was different with experiments which may because the nonlinearity of magnetization characteristics of the core material in pulse transformer.

1 INTRODUCTION

Pulsed electric fields (PEF) non-thermal treatment is an important application of high voltage engineering and pulsed power technology in food processing area. It applies short electric pulses and electric energy with high field strength to samples placed between two electrodes in a treatment chamber during a short time. In the process, the applied electric pulses can cause electroporation and electrofusion in cells without generating huge heat [1-3]. This technology could preserve quality attributes of food products such as sensory quality and nutritional value, as well as promote development of heat-sensitive food.

Many electrical parameters of PEF which influence the effectiveness of inactivation have been extensively studied over the past years. Moreover, according to the latest research result [4-6], the waveform of applied pulses owns a significant impact on the effect of PEF especially for rectangular pulses. For example, in reference [3], with shorter rise time, the sterilization effects become higher. In reference [6], a method of rectangular pulse rise time reduction has been reported. However, the effects of load characteristics on PEF output waveform are usually neglected.

In this paper, a pulse generator with a pulse –optimizing network is used as a pulse power of PEF system, the effect of the change in the load characteristic on the waveform of PEF is presented.

2 THEORETICAL ANALYSIS

2.1 Construction of the PEF system and steep leading edge rectangular pulse generator

Figure 1 shows the construction of the PEF system. This PEF consists of the steep leading edge rectangular pulse generator, treatment chambers, gear pump and measuring device. The pulse generator was developed by Graduate School at Shenzhen, Tsinghua University, here referred to as the THU-PEF4. The treatment chambers were two co-field flow PEF treatment chambers with a gap distance of 4 mm and an inner diameter of 4 mm. The voltage output was measured at the load resistance with a high voltage probe (P6015A) and a current monitor (Person current monitor model 2878) coupled to a digital oscilloscope (Agilent DSO7104A).

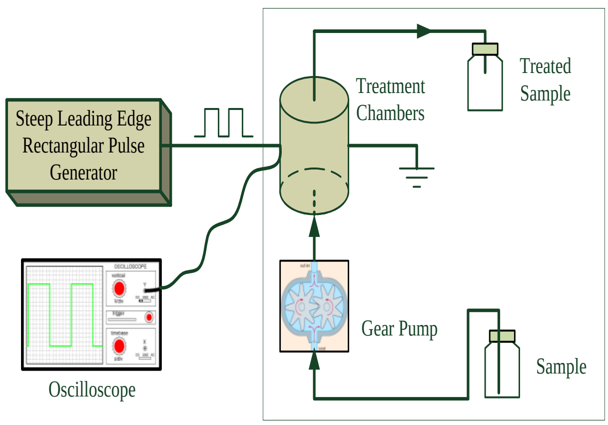

Figure 1. Diagram of PEF system

The steep leading edge rectangular pulse generator is schematically shown in Fig. 2. It consists of low-voltage charging unit, energy-storage capacitors, power electronic switches, control and monitor system and pulse transformer. Moreover, it contains a pulse optimizing unit which was constructed by magnetic switches and pulse capacitors. The value of magnetic switches and pulse capacitors were decided by reference [6].

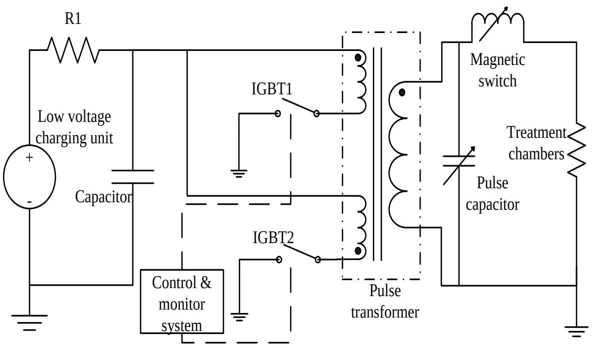

Figure 2. Details of THU-PEF4

2.2 Simulation analysis:

In order to analysis the influence of load characteristics on output rectangular pulses waveform, a PSPICE simulation circuit model was established. As shown in Figure 3, U′ is the output voltage of the low voltage pulse generator as referred to the output winding, Ri′ is the internal resistance of the pulse source as referred to the output winding, Ll′ and Lm′ are the leakage inductance and magnetizing inductance of PT as referred to the output winding, Cd′ is the effective distributed capacitance of the secondary winding, MS is the magnetic switch, Cp is the pulse capacitor, RL is the load resistance. The model of MS was designed by the authors utilizing a nonlinear magnetic components library Magnetic Core in PSPICE Model Editor. During MS modelling process, the B-H curve of magnetic core was acquired by measuring the characteristics of MS in experiment.

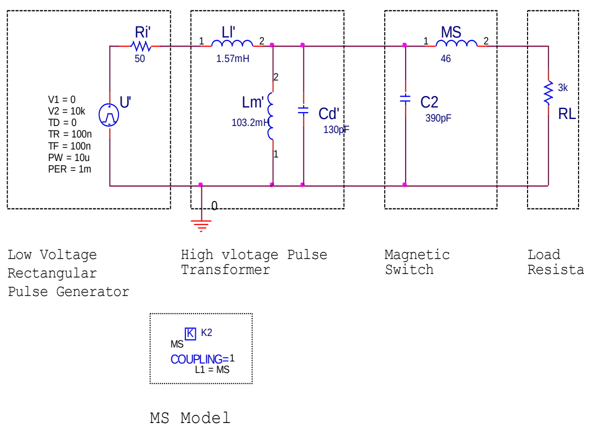

Figure 3. PSPICE simulation circuit

The value of magnetic switch, pulse capacitor in this simulation were N = 46, Cp = 390 pF in all this paper which was calculated as reference [6] for R_L = 3 kΩ. The electrical parameters of pulse transformer were measured using the method of [2], and the calculation results are: Cd′ = 130 pF, Ll′ = 1.57 mH, Lm′ = 103.2 mH. After the introduction of magnetic switch, the rise time of the load voltage has been reduced from 1.2 µs to 150 ns.

2.3 Influence of load properties on output waveform:

2.3.1 Resistance:

A parameter sweep of R_L was carried on using PSPICE, and the result is shown in Figure 4 and Figure 5 without and with MS module. The value of R_L changed form 2 kΩ to 4 kΩ with an increment of 1 kΩ every step.

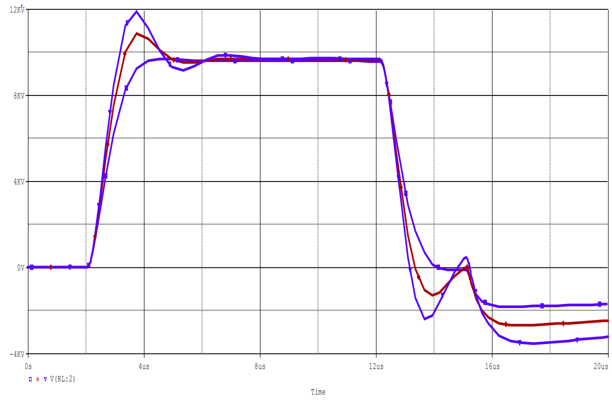

Figure 4. Simulation pulse waveforms on different load resistances without MS module, the value of RL were 4 kΩ, 3 kΩ and 2 kΩ from top to bottom.

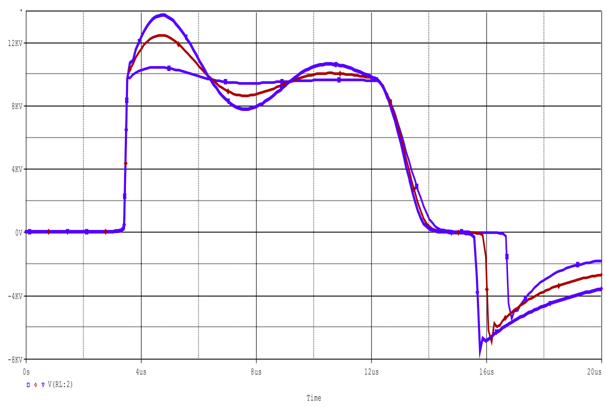

Figure 5. Simulation pulse waveforms on different load resistances with MS module, the value of RL were 4 kΩ, 3 kΩ and 2 kΩ from top to bottom.

It could be concluded from Figure 4 that R_L has significant influence on the output pulse waveform. When the value of R_L changed form 4 kΩ to 2 kΩ, the rise time of output pulses were lengthened from 1.2 µs to 2µs. However, after the introduction of MS module, the rise time kept constant while R_L changed which could be concluded from Figure 5. On the other hand, the leading edge and top of pulses were also influenced by R_L. When the value of R_L changed form 2 kΩ to 4 kΩ, the overshoot of pulse in leading edge became more notable.

2.3.2 Resistance parallel with capacitor:

In PEF system, the treatment chambers could be equivalent as a resistance parallel with a capacitor. So, the influence of capacitor characteristics on output rectangular pulses waveform was analysis in this paper. A parameter sweep of C_L was carried on using PSPICE, and the result is shown in Figure 6 and Figure 7 without and with MS module. The value of C_L changed form 50 pF to 150 pF with an increment of 50 pF every step. In this sweep simulation, the value of R_L was R_L = 3 kΩ.

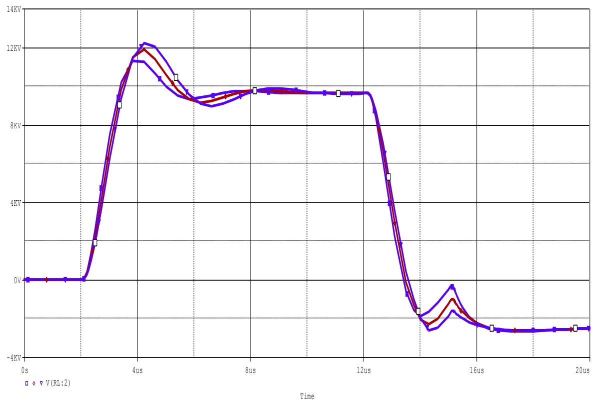

Figure 6. Simulation pulse waveforms on different capacitors without MS module, the value of C_L were 50 pF, 100 pF and 150 pF from top to bottom

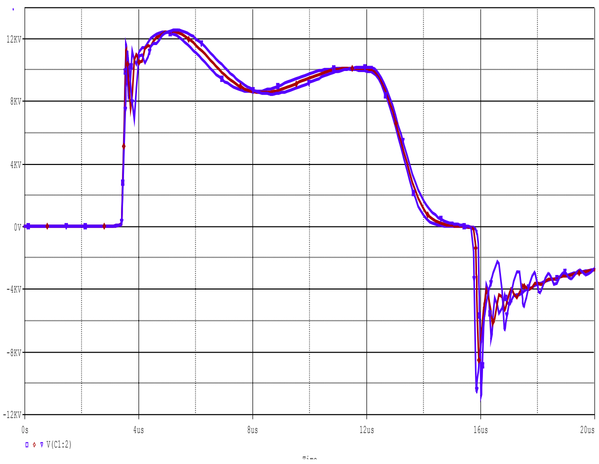

Figure 7. Simulation pulse waveforms on different capacitors without MS module, the value of C_L were 50 pF, 100 pF and 150 pF from top to bottom

It could be concluded from Figure 6 that R_L has significant influence on the overshoot of output pulse waveform. When the value of C_L changed form 50 pF to 150 pF, the overshoot of output pulses were increased from 1 kV to 2 kV. However, the rise time kept constant while C_L changed. This result could also be concluded from Figure 7 after the introduction of MS module. On the other hand, when the value of capacitor increased, the oscillation in leading edge became more seriously.

From Figures 4 and 6, it could be seen that there is a notable rise time length while the load resistance increase without MS module, and the overshoot in leading edge was influenced by resistance and capacitor. However, after the introduction of MS module, the rise time kept constant which could be concluded from Figures 5 and 7. On the other hand, there would be an oscillation in the leading edge which was determined by the value of capacitor after the introduction of MS.

3 EXPERIMENTAL

A couple of contrast experiments were performed to verify the PSPICE simulation results. These experiments were performed using THU-PEF4. The parameters values of resistances and capacitors were selected as simulation, which were that C_L change form 50 pF to 150 pF with an increment of 50 pF and R_L changed form 2 kΩ to 4 kΩ with an increment of 1 kΩ. The voltage output was measured at the load resistance with a high voltage probe (P6015A) coupled to a digital oscilloscope (Agilent DSO7104A).

3.1 Influence of resistance on the output waveform

The influence of resistance on the output waveform was shown in Figures 8 and 9 which corresponding to without and with MS module. The experiment results were closed to the simulation results in the leading edge and top of pulses. However, the trail of pulses in the experiment was different with simulation results. This is mainly because the nonlinearity of magnetization characteristics of the core material in pulse transformer caused the values of L_m' changing with the flux density in the core which was proportional to the current through PT. however, during the simulation, the value of L_m' was assumed kept constant, which enlarged the error in the simulation of the fall time and wave shape of the trail of the pulse.

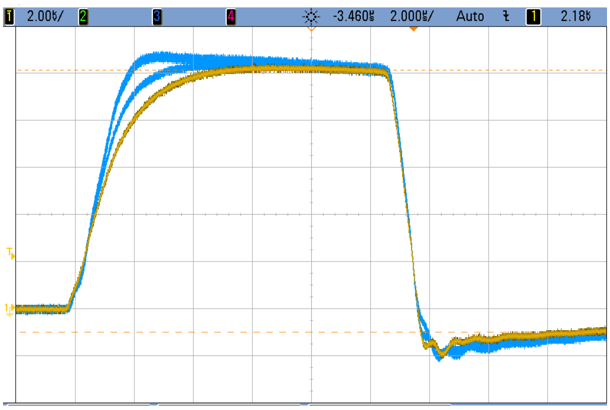

Figure 8. Experimental pulse waveforms on different resistances without MS module, the value of RL were 4 kΩ, 3 kΩ and 2 kΩ from top to bottom.

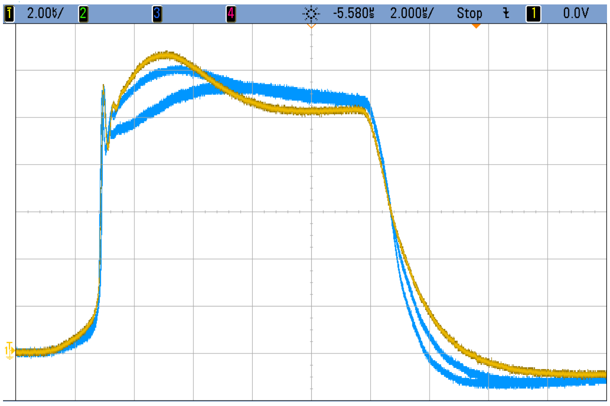

Figure 9. Experimental pulse waveforms on different resistances with MS module, the value of RL were 4 kΩ, 3 kΩ and 2 kΩ from top to bottom.

3.2 Influence of capacitor on the output waveform

Figures 10 and 11 show the experimental pulses while the capacitor changed from 50 pF to 150 pF with an increment of 50 pF. As shown in Figure 10, the overshoot increased with the value of capacitor increase while the rise time kept constant, which was similar to simulation results. However, after the introduction of MS module, the rise time kept constant which was also same to simulation results. Moreover, the oscillation in the leading edge was determined by the value of capacitor which was also same to simulation results. However, the trail of pulses in the experiment was also different with simulation results just as above experiments shown.

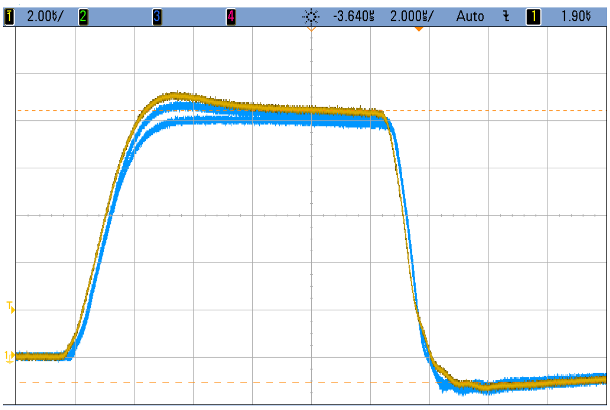

Figure 10. Experimental pulse waveforms on different capacitors without MS module, the value of C_L were 50 pF, 100 pF and 150 pF from top to bottom.

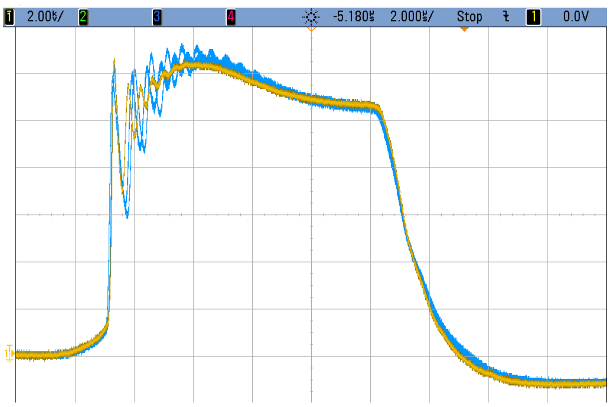

Figure 11. Experimental pulse waveforms on different capacitors without MS module, the value of C_L were 50 pF, 100 pF and 150 pF from top to bottom.

4 CONCLUSION

The influence of load characteristics on the output waveform was studied in this paper. Two different load characteristics: pure resistance, resistance parallel with capacitor was simulated according to a PSPICE model, and some contrast experiments were performed. The simulation and experiment results show that:

The rise time lengthened with R_L decreased, kept constant while C_L changed. However, after the introduction of MS module, the rise time kept constant and had no relationship with R_L and C_L.

There were notable overshoot in the leading edge when the THU-PEF4 without MS module which was determined by the value of R_L and C_L. After the introduction of MS module, there was dramatically oscillation in the leading edge which was mainly determined by the value of C_L.

The trail of pulses in the experiment was different with simulation results. This is mainly because the nonlinearity of magnetization characteristics of the core material in pulse transformer.

5 ACKNOWLEDGMENTS

This work was supported in part by the National High Technology Research and Development Program of China, Research Fund for the Doctoral Program of Higher Education of China （20100002110032） and project sponsored by Shenzhen Science and Technology Planning Project Fund (JC200903180542A).

6 REFERENCES

[1] K. H. Schoenbach, et al., “Bacterial decontamination of liquids with pulsed electric fields,” IEEE Transactions on Dielectrics and

Electrical Insulation, vol. 7, no. 5, pp. 637-645, Oct 2000.
[2] J. C. Weaver. "Electroporation of cells and tissues," IEEE Transactions on Plasma Science, vol. 28, no. 1, pp. 24-33, Feb 2000.
[3] R. B. Zhang, et al., "Inactivation effects of PEF on horseradish peroxidase (HRP) and pectinesterase (PE)," IEEE Transactions on Plasma Science, vol. 34, pp. 2630-2636, Dec 2006.
[4] H. Bluhm, *Pulsed Power System: Principles and Applications,* Berlin, Germany, Springer, pp. 179-184, 2006.
[5] J. Chen, R.B. Zhang, and J.F. Xiao, "Influence of pulse rise time on inactivation of Staphylococcus aureus by Pulsed Electric Fields", IEEE Trans. Plasma Sci., Vol. 38, pp.1935-1941, 2010.
[6] Rectangular Pulse Sharpening of High-voltage Pulse Transformer based on Magnetic Compressing Switch. J. Chen, R.B. Zhang, and J.F. Xiao, et al. IEEE Transactions on Dielectrics and Electrical Insulation. In press.