A Prototype of a Pulsed Electric Fields Treatment for Solid Foods in Batches

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***Abstract*—In this work a Pulsed Electric Field (PEF) prototype is developed. A 10 stage Marx generator for HV pulses was designed and implemented. A batch chamber suitable for small quantities was built and a 3000V, 5µs pulse was measured. The system was tested with dried grape marc and works as expected.**

***Keywords*— PEF, Pulsed Electric Fields, HV generator**

I. Introduction

Recent trends in food consumption have resulted in the development of different technologies to treat food that can pasteurize food without using the traditional high temperatures, that causes alteration in tastes, smells and several other desirables proprieties. Among the proposed technologies, the use of really short pulses of very high electric fields has been in continue development for the last decades. The Pulsed Electric Field (PEF) treatment consist in applying very short (a few microseconds) pulses of high intensity electric fields (around 1MV/m) to different kinds of foods [1-3]. Previous works have reported the occurrence of electroporation which if its high enough it destroys bacteria but using fields of lower intensity results in and increase of extraction of high added value compounds [4-6]. Even though, there are some commercial products in the market, most of these require a large initial investment (in order of the tens of thousands of USD dollars) and though it has limited application in the local food business and startups. In recent years the rapid reduction on prices of HV electronic components, have enabled the development of low cost and smaller prototypes that can be used for development of new products or even small productions.

In this work a Marx Generator designed to be powered by 230V AC and capable of generating microseconds square pulses of up to 10kV using 10 stages is presented. Also, a 400cm^3 batch type treatment chamber to be used with the generator was designed and initial test for the treatment of grape marc were conducted. In section II the electrical design of the HV pulse generator is shown, in section III the chamber design and implementation are presented, while in section IV simulated and measured preliminary results are shown. Finally, some conclusions and future work are included.

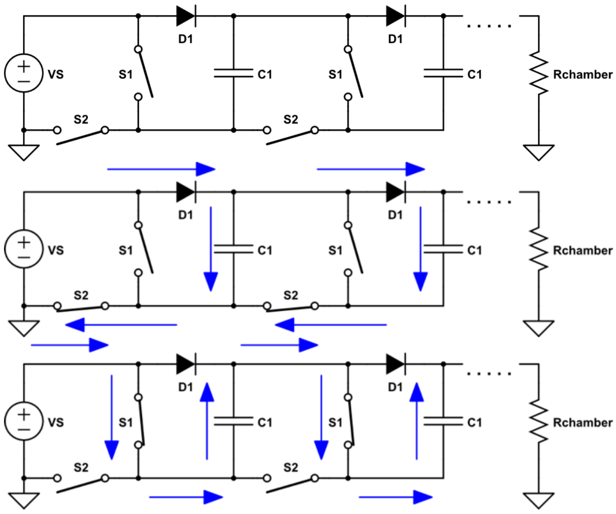

Fig. 1. Marx Generator of two stages. Top: **Idle** state, no current is flowing. Middle: **Charging** state, S_1 is opened and S_2 is closed; each capacitor is charged through the diodes D_1. Bottom: **Discharging** state, S_2 is opened and S_1 is closed, the chamber (modeled as a resistor) receives the sum of all the capacitors in series.

II. HV Pulse Generator

There are several ways to generate HV pulses, but if extremely low rise and fall times (less than 1µs) there are fewer options. The Marx Generators Family [7] have been used previously for PEF treatments [8] because they can be implemented in stages so adding flexibility to the system (maximum HV value can be increased just adding mire stages). Figure 1 shows a two stage Marx generator, based on [9]. The generator works in three different states. During **charging** state: the switches S_1 are opened, and switches S_2 are closed, and current flows from the voltage source through the diodes into each capacitor. If we consider negligible the voltage drops in the diodes, all capacitors are charged to the same voltage as the source. The **discharging** state: the switches S_1 are closed, and switches S_2 are open. The current cannot flow through the diodes; therefore, all capacitors are connected in series with the source and a HV pulse is generated. Finally, the **idle** state: where all switches are open. It is important for safety to always include a small **idle** state between **charging** and **discharging**, as both switches in the stage can never be closed at the same time or a big spike of current will occur. By controlling the time in the **charging** state, the final voltage of the capacitors can be adjusted, and if greater voltages are required, then more stages can be added.

To implement the complete electrical system, the following specifications were selected.

TABLE I. PEF PROTOTYPE SPECIFICATIONS

System	Batch
Pulse Type	Unipolar, square
Maximum Voltage	10 kV
Maximum Voltage (stage)	1000 V
Stages	10
Maximum Peak Current	5A
Maximum Power	20W

The complete system requires a 1000V DC source that was implemented using first a transformer as an AC/AC converter and then a full diode bridge to rectify the signal, as shown in Fig. 2. An already available standard transformer with a gain of 3V/V was used, that was not designed for this application. The maximum peak current corresponds to a 2kΩ chamber, but a maximum of 50 pulses per seconds are allowed, resulting on the low power consumption.

A. Stage Design

When designing a Marx Generator, the most important aspect is the design and characteristics of each stage. In this case the maximum value of 1000V per stage was selected, as the price of capacitors, diodes, switches and drivers which can support this voltage is relatively low and the number of required stages is not too high. Figure 3 shows the schematics of each stage (there is only one microcontroller, but for clarity it is shown in this figure). The microcontroller which commands

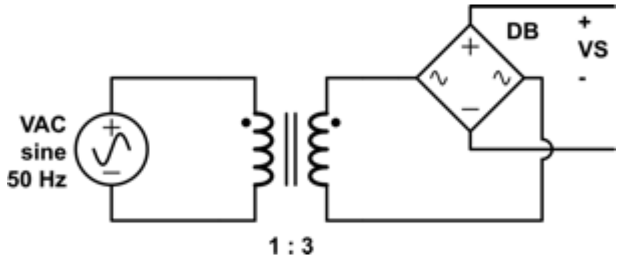

Fig. 3. HV source that generates aprox 1000V from the 230V AC standard.

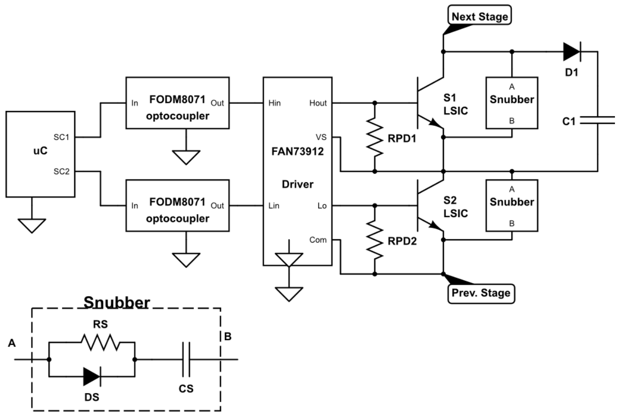

Fig. 2. Schematic of one stage of the marx generator. There is only one microcontroller no matter how many stages are present. The optocouplers aisalate the microcontroller from the HV circuits. The selected driver can be used for both SiC nmos transistors in parrallel. The snubbers help reduce current peaks when switching. Some minor components for generating the bootstrap and for current protection not included for clarity.

the prototype is connected to the drivers of the switches using two optocouplers, to electrically separate the microcontroller from the HV system. The selected driver (FAN73912 [10]) can be used to control both switches and has a bootstrap circuit to generate the voltage difference for S1 (not shown for clarity). The driver also incorporates a shoot-through protection, that turns off both transistors in case both signals are on by mistake. As the switches, NMOS SiC (Silicon Carbide) transistors [11] were used which are fast (t_{rr} = 25ns, t_{on} = 10ns, t_{off} = 16ns) and can whist stand up to 1.2kV. A Schottky diode (for fast response) and a 150nF capacitor [12] complete the stage. A RDC snubber (R = 2.2kΩ, C = 220pF) was put in parallel with both switches to reduce peaks, as shown in Fig. 3.

III. Treatment Chamber

To ensure an even distribution of the electric field on all the target food, the design and implementation of the treatment chamber must be carefully designed. The three must common chambers used are the parallel plates, coaxial cylinders and coaxial chambers. The last two are mainly used when using continuous treatments (for liquid food for example) and parallel plates for batch systems [13].

For this application, a 1x20x20 cm chamber was designed and simulated using electromagnetic simulation software, and then fabricated. Two Zinc electrodes were encapsulated in an acrylic (PMMA) isolating structure as shown in Fig. 4. Several screws were included in the structure to properly adjust and close the chamber. The food to be treated must have a resistivity of at least 8kΩ/m (so the

Fig. 5. Implemeted PEF chamber. Top: disarmed chamber. Bottom: Chamber ready to be used. Note this is only the chamber, the circuit is not included in this image.

equivalent resistance is larger than 2kΩ) and measurements of the dry grape marc resistivity showed it was above 100kΩ/m, making it safe to be used in this chamber.

IV. Measurements and Simulations

Figure 5 shows a photograph of a two stages Marx generator prototype and the measured test of a 5μs pulse of almost 3000V. It's important to note the very fast rise and fall time, ensuring a proper application of the PEF pulses. It is also important to consider that the capacitors voltage drop during the discharge is minimal, as the time are really small. This avoids large current peaks when the charging stage start again. Nevertheless, a negative pulse (off around 600V) appears at the start of the new charging state. This pulse could be longer and of a higher voltage but the addition of the snubbers in the switches, reduced the pulse to a safe value that does not damage any component. The test was done with dried grape marc.

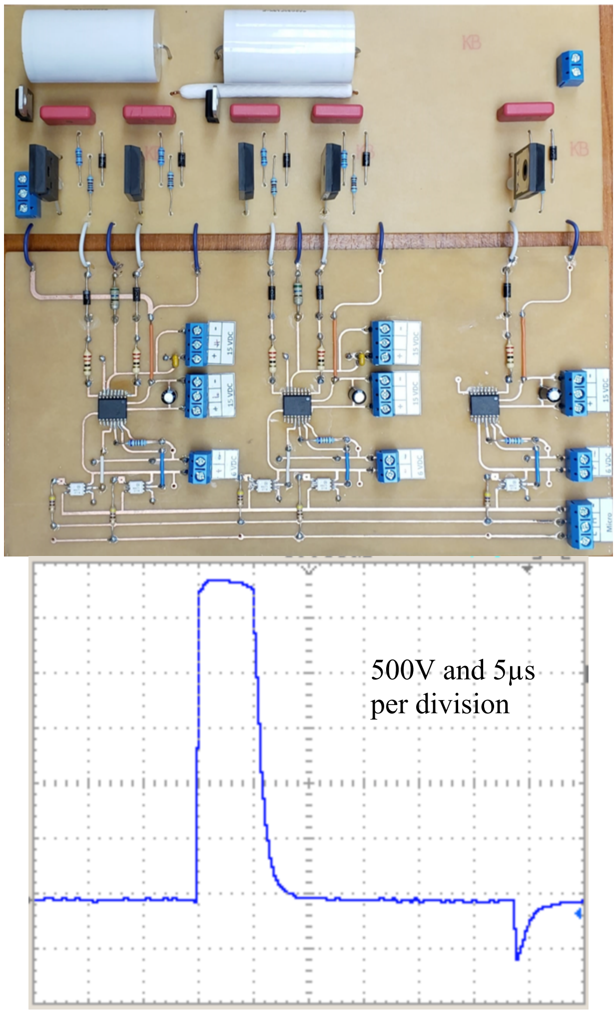

Fig. 4. Max Generator Implementation. Top: photograph of two stages of the Marx generator prototype. Bottom: Measured results of a 3 stage marx generator pulse of 5μs and almost 3000V.

V. Conclusions

A PEF prototype using a Marx generator for the HV pulses was presented. A design for a 10 stage Marx generator was simulated while only a 3-stage generator was implemented at the moment due to the COVID-19 pandemic. With a cost of less than 100 USD per stage (prototype cost), the prototype is accessible for small food business and startups. Once we regain access to the laboratory, the 10 stages generator can be implemented and the effect on the food verified, both as a way to extract compounds and as a "cold pasteurization" system.

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