Prototype of a Plasma Generator for Electrosurgery

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***Abstract*— This document presents the design and construction of a plasma generator for electrosurgical applications. The generator is comprised of four main parts: DC power supply, topology push-pull, controller unit and plasma probe. First results generating plasma by repetitively-pulsed electrical discharges in sodium chloride saline solution are reported.**

Keywords*— *Electrosurgery; plasma; switching power supply; high-frequency.

I. Introduction

Plasma is one of the four fundamental states of matter and consists of highly ionized particles, it means, particles highly energized. Typically, plasma can be seen in neon lights or sudden electric discharges such as lightning or sparks. These ionized particles have sufficient energy (3 - 6 eV) to break organic molecular bonds within tissue. This property has been found useful for the application of plasma in surgeries as a cutting tool. Plasma has some advantages compared with other techniques for ablation (removal of tissue by cutting, vaporization, etc.), such as scalpel or electrocautery (cutting by vaporizating tissue applying an electric current), etc.

Using plasma, molecular disintegration is achieved at low temperatures between 40°C - 80°C with minimal thermal penetration and collateral tissue necrosis [1]. In comparison, electrocautery can reach hundreds of degrees causing collateral damage to the healthy tissue. Another advantage of plasma is the ability to cauterize at the same time, thus reducing the risk of bleeding and infections compared with scalpel.

Technology using plasma for tissue ablation, requires less electrical power to cut and cauterize, absence of pressure in the cutting tool, thus causing less damage to the tissue and reducing postoperative recovery time [2]-[3].

In practice, plasma for surgery purposes can be generated by high frequency electrical current flowing through two electrodes slightly separated. Electrodes should be immersed in a conductive medium (for example saline solution). The current flowing between electrodes heats the medium, producing vapor cavities around one of the electrodes and plasma is produced within these cavities with enough energy to be applied to biological tissues [4].

Due to many advantages of plasma, every day, surgeons from the entire world are finding new applications for plasma in the surgery field. Until now, applications of plasma in gynecology, gastroenterology, ophthalmology, urology, otorhinolaryngology, proctology, thoracic surgery, papillomatosis, etc., have been reported [5]-[6]-[7]. Research centers around the globe are investigating about plasma applications for surgery but, this research is still very limited may be due to the expensive price of the commercial devices and the relatively novel technology. Furthermore, commercial devices allow selecting only fixed values of frequency, and power. This is enough for surgeons who only want to use it but not for surgeons interested in research about plasma characteristics where the capability to change parameters such as frequency, voltage and current are of interest.

Table I shows the main characteristics of commercial devices for surgery using plasma. Some of them do not even give information about the voltage generated for plasma creation and other technical information is missing as well. However, it is possible to observe that the cost is above 7, 000 USD which is an elevated cost considering that it will be used for preliminary research purposes Overview of the four plasma generators.

TABLE I. CHARACTERISTICS OF COMMERCIAL PLASMA GENERATORS FOR SURGERY APPLICATIONS.

	Coblator II	Quantum	ARC400	ESG-400
Manufacturer	Smith&nephew	ArthorCare	BOWA	OLYMPUS
Voltage	0-300Vrms	0- 320Vrms	---	---
Frequency	-100 kHz	-100 kHz	330 kHz-	430 kHz
Cost (USD)	$ 7,725.00	$ 1,000.00	$9,000.00	$17,812.00

This document describes the design, constructions and first results of a low cost generator aimed for research purposes in the veterinary field.

II. Design and development

For plasma generation, square wave voltage pulses are used commonly, although other type of waves can also be used, the square wave is usually preferred because is easier to generate and control their parameters such as frequency and amplitude. Voltage range from 125 V-rms to 250 V-rms and frequencies between 10 kHz to 500 kHz are commonly used for plasma generation [8].

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In order to generate a power source capable to generate the voltage and frequencies needed for plasma generation, several topologies can be used, for example, boost type converters, bridge inverters and resonant converters, etc., together with auxiliary circuits. The block diagram presented in Fig.1 illustrates the main components of the prototype. The function of each block is described in the following sections.

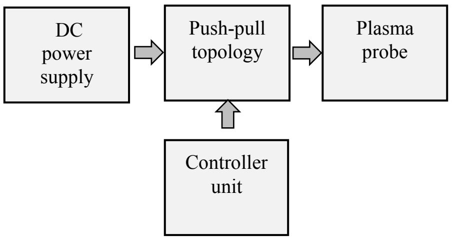

Fig. 1. Main components of the prototype for plasma generation

A. DC power supply

The prototype uses a common DC power supply made by a step-down transformer, a full wave rectifier and capacitors for reduction of ripple voltage. This DC power supply is capable to provide 25 volts and 2 Amperes. The step-down transformer provides electric isolation from the public electric network.

B. Push-Pull topology CS-PPRI and Controller unit

For high voltage generation the prototype is based on a current-sourcing push-pull parallel-resonance inverter (CS-PPRI). This topology has extensively described by Gulko et al. [9]- [10]. The basic topology (Fig. 2) includes a push-pull stage comprised by Q_1 and Q_2, a serial inductor (L_{in}) directly connected to the central tap of transformer (T_1) and a resonant network (capacitor C_1 and inductance L_r).

Interesting features of this topology for the purposes of electrosurgical applications are the capability to work with reactive and nonlinear loads, permitting an efficient operation at high frequencies (up to 1 MHz). Matching loads is simple and requires only a few components, making the source lightweight and inexpensive [11].

This inverter has three operational modes, depending on the switching frequency (F_s) and the resonance frequency (F_r), given by C_1 and L_r. These three modes are: quasi-resonance mode or normal mode ($F_r = F_s$), boost mode, ($F_r > F_s$) and buck mode ($F_r < F_s$) [9].

Most applications using this type of inverter use the normal mode, mainly because in the resonance mode the current flows almost entirely through the tank circuit reducing stress on the transistors. In the buck and boost mode, it is required a forced commutation forcing the transistors to support more energy. However, the boost mode has high efficiency and thus is a good alternative for applications requiring alternating current pulses for medium and high voltage [11].

Fig. 3 shows the implementation of the CS-PPRI. The controller unit consists of a PWM controller TL598 from Texas Instruments, two MOSFETS Q_1 and Q_2 (IRFP250 from International Rectifier) in a push-pull configuration. In this application, the circuit was set to work in boost mode generating CA voltage at 100 kHz.

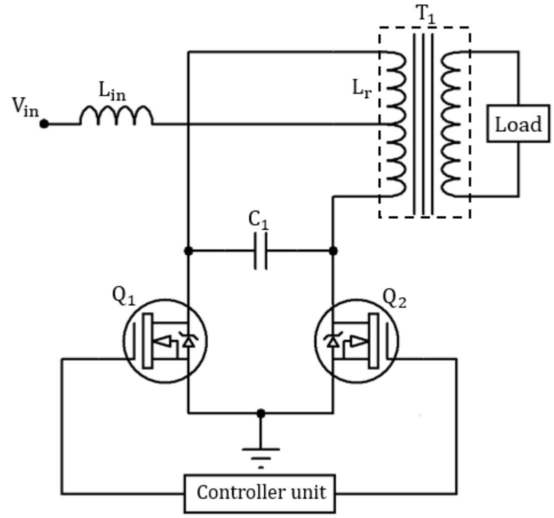

Fig. 2. Circuit Current-Sourcing Push-Pull Parallel Resonance Inverter (CS-PPRI).

The switching frequency is controlled by adjusting a variable resistor (R_6 in Fig. 3), which changes the oscillator frequency Fs according to the equation (1):

$$F_s = \frac{1}{2(R_6 + R_7)C_2} \qquad (1)$$

Using the selected values of R_7, C_2 and adjusting R_6, the frequency varied within the range from 20 kHz to 300 kHz. T_1 is a step-up transformer made with an E-type ferrite-core, with inductances of 20 µH for the primary winding and 2740 µH for secondary winding. The transform relationship is 1:10. The internal capacitance of transistors Q_1 and Q_2 (420 pF) was added to the capacitances of the circuit, giving an equivalent capacitance of $C_1 = 48$ nF.

Due to the capability of change the commutation frequency, this circuit can operate in normal mode, boost mode or buck mode. In this application it was selected the boost mode due to the better results obtained to generate plasma compared with the other modes. In order to increase or decrease the output voltage on the secondary winding of the transformer, the V_{in} is adjusted by changing the voltage provided by the DC power supply described on section A.

This prototype for plasma generation can provide a bipolar pulse wave voltage in boost mode or a sinusoidal wave in normal mode. The maximum output voltage for the boost mode is 350 V-rms at 100 kHz. In Fig. 4 it is shown a photograph of the plasma generator prototype.

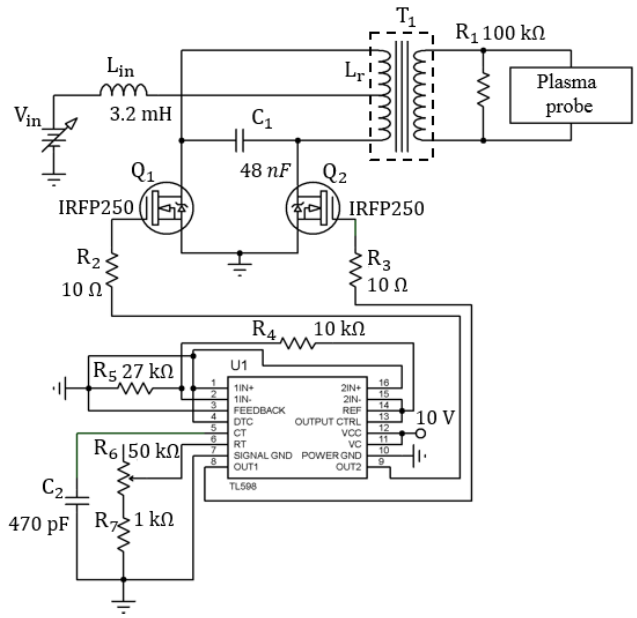

Fig. 3. Plasma generator circuit.

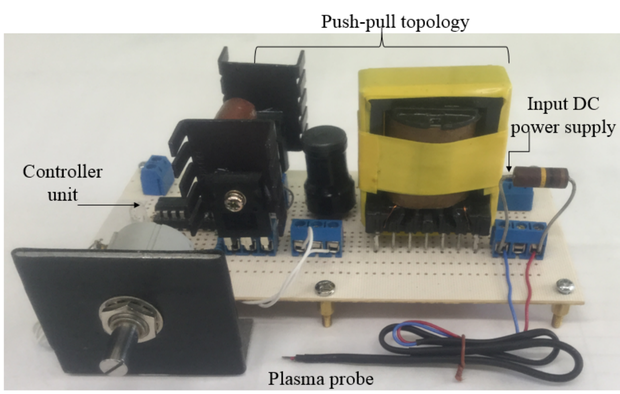

Fig. 4. Physical prototype of the plasma generator.

C. Plasma Probe

In order to probe if the high voltage generator was able to create plasma, an *ad-hoc* probe was made. The plasma probe (Fig.5) used to obtain preliminary results was made of two stainless steel electrodes, with a diameter of 1 mm each electrode, covered by a layer of plastic insulation with a separation between electrodes of 1mm.

Fig. 5. Photograph of the plasma probe.

III. Preliminary results

Electrical test was performed by using the probe describe before and the current and voltage waves applied to the probe were measured using a high voltage probe (model P4000) and a current probe (Tektronix model A622) and a digital oscilloscope Tektronix, model TDS2024C.

A. Glow discharges

When the probe is immersed in a saline solution containing 0.9% of sodium chloride, applying voltages below 150 V-rms to the probe, small vapor cavities around the active electrode can be observed. From 175 V-rms to 250 V-rms small light flashes occur in the active electrode. Applying voltages in around 350 V-rms an orange glow discharge is observed. This orange glow is typical for plasma. Values obtained and behaviors of the probe are typical for this type of plasma discharges and were described by Woloszko et al [6].

Fig. 6 shows the current and voltage waveforms measured while the probe was generating plasma. In Fig. 7, it is shown the probe generating plasma, driven at approximately 350 V-rms and 100 kHz.

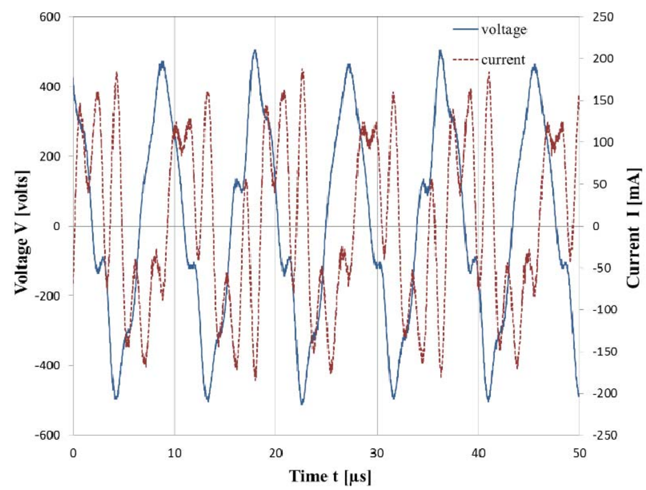

Fig. 6. Current and voltage waveforms measured through the plasma probe, driven at approximately 350 V-rms.

Fig. 7. Plasma formed in saline solutions .

IV. CONCLUSIONS

This article presents a prototype of plasma generator based on a current-sourcing push-pull parallel-resonance inverter (CS-PPRI).

Preliminary results are similar to those reported in the literature for plasma generation. It is supposed that plasma generated between electrodes is quite energetic and thus, it is capable to vaporize biological tissue. This can be used for debunking, cutting, cauterizing and other desired task in surgery.

The prototype developed has proven to have sufficient power to form plasma around stainless steel electrodes using saline solutions. It is necessary to improve the probe in order to generate a larger plasma field and then perform test on cadaveric biological tissue.

This work is intended to provide a tool for surgeons interested in research using plasma ablation at low cost with the possibility to know exactly which voltage and current are better for each task required on the surgery field (cauterize and cut) .

The approximate cost for the proposed device in prototype form is around 60 USD. Although it is not possible to compare directly the cost of this prototype with commercial devices, authors believe that the creation of this device will be helpful for increasing the research in the application of plasma for surgery tasks.

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