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Design and Implementation of High Voltage Generator for Medical Applications

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Abstract- A high voltage power supply is a very useful source which can be effectively used in many medical applications like medical imaging devices, blood analyzers, DNA equipment, robotic surgical devices and Electrocautery. In this study designing of High voltage circuit (*2000 V*) is proposed which can be used for medical applications. Generation of high voltage low current can be determined by using Fly back converter as an optimum method which can improve the design of the device to make it smaller in size, simple and cost effective. The Fly back converter principle is analyzed to find the suitable design of the device in this study. A new Electrocautery high voltage circuit is designed and implemented in this paper which consist of four main stages, Step-down Transformer *12 V* Output, *AC –DC* converter, flyback transformer driver circuit (oscillation circuit) and flyback transformer high voltage output.

Keywords- *DC-DC Converter, Electrocautery, Flyback Converter, High Voltage, Power Supplies, Switching Stage*

I. INTRODUCTION

Nowadays Biomedical Engineering (BME) plays an important role in understanding the fundamental principles of human life sciences, especially those related to health care and clinical medicine. BME is the application of engineering principles and approaches to solve problems that related to living systems by integrating biology and medicine with engineering to advance health care treatment. The emphasis is on the application of the principles of electrical and electronic engineering, especially high voltage power supply to each of biology and medicine at the health facilities and research. The chosen and specification of high power supplies for medical applications is a function that must be addressed with great care. It must be taking into consideration the safety standards and environmental criteria for medical equipment, particularly, nowadays that are undergoing essential changes that will impact broad sectors of the medical industry. There are some of the high voltages techniques in biomedical engineering that includes; Electrocautery Fluoroscopy, Electron Microscope, Ultrasound [1- 3], in this study we will focus only about Electrocautery. The study is structured as follows: Section II gives a brief review of the Electrocautery as well as presents some of literature reviews. Section III focuses on the DC-DC converter methods. Section IV presents the designing and implementation high voltage circuit. Finally, conclusions are drawn in Section V.

II. ELECTROCAUTERY

Electrocautery is a thermal cautery process in which a direct current is passed through a resistant metal wire electrode for generating heat; during this process current does not enter into the patient's body [4]. The electrode is heated over a fire and then applied to the tissue; this would cause tissues and blood to heat swiftly to extreme temperatures that causing coagulation of the blood and thus controlling the bleeding [5]. Electrocautery can be used in many diverse minor surgical procedures in dermatology, otolaryngology, plastic surgery, urology and ophthalmology. Thus, it is utilized in 80% or more of all surgical procedures, besides that the serious uses in small operations in the outpatient sector of the hospital [6-8]. The main importance using for Electrocautery in surgical procedures is to remove unwanted or harmful tissue. As well as it used to burn and seal blood vessels, this process leads to reduce or stop bleeding during surgery. Normally a small electrode is used to burn or destroy the tissue and a grounding pad is placed on the body before the surgery to protect the patient from the harmful effect of the electricity [9-10]. Electrocautery device can deliver heat at a range of temperatures, between $100^0\mathrm{C} - 1200^0\mathrm{C}$. Thus, at Low temperatures, it can be used for the treatment of superficial and relatively avascular lesions after the superficial tissue destruction as the following cases [11-13].

- Verrucae
- Acrochordons
- Molluscum
- Syringomas
- Small angiomas

While at high temperatures are effective and highly efficient in removing thicker skin lesions, as the following cases:

- Hemostasis of vessels during surgery
- Sebaceous hyperplasia
- Pyogenic granulomas

The Fig.1 shows the example of Electrocautery.

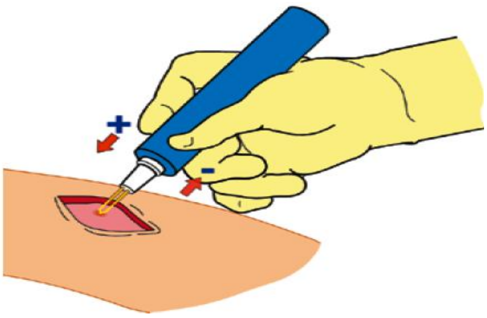

Figure 1. Example of electrocautery [14].

Electrocautery has been introduced around since 1928, when William T. Bovie introduced the technique that used for removing a tumor from a patient's head; this technique assisted Dr. Cushing to remove the mass of tumor with very little bleeding [15]. Fervers has described electrosurgical adhesiolysis by using laparoscopically directed electrosurgery [16]. John Wesley used direct current (*DC*) as a technique firstly to heat the electrode and then applied to tissue, causing a tissue effect secondary to passive heat transfer. The resulting is coagulation and desiccation of the tissue [17]. Jacques-Émile Rioux introduced a newer generator with isolated circuits and monitoring systems for the early detection of separation of the dispersive or electrode from the patient, and named it laparoscopic bipolar instruments [18].

III. DC- DC CONVERTER

DC-DC converters are power electronic circuits that convert a dc voltage to a different dc voltage level. The Figure 2 shows a block diagram of *DC-DC* converters.

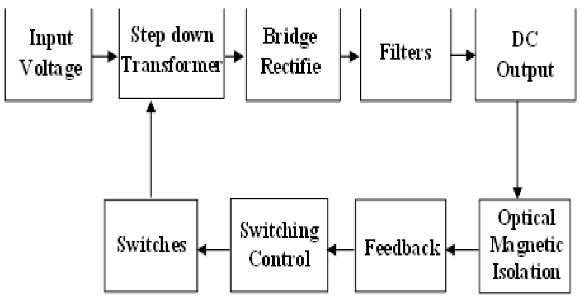

Figure 2. A block diagram of DC-DC converters.

The four basic DC-DC converters considered for analysis are [19-20]:

- Buck converter
- Boost converter
- Buck-Boost converter
- Cuk converter

The table 1 represents a comparison of DC- DC Converters.

TABLE I. COMPARISON OF DC- DC CONVERTERS.

Buck converter	**Boost converter**	**Buck-boost converter**	**Cuk converter**
step-down	step-up	step-up/step-down	step-up/step-down
has one switch	has one switch	has one switch	has one switch
simple, high efficiency greater than 90%	simple, high efficiency	simple, high efficiency	simple, high efficiency
provides one polarity output voltage	provides one polarity output voltage	provides output voltage polarity reversal	provides output voltage polarity reversal

The figures (3-6) show the circuit diagram for four types of *DC-DC* converters [21].

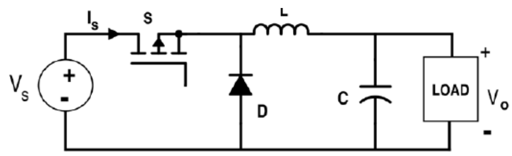

Figure 3. Circuit diagram of Buck Converter

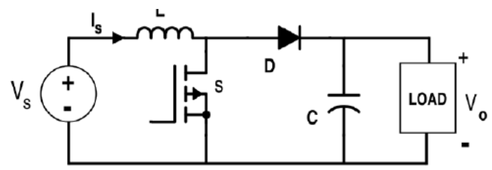

Figure 4. Circuit diagram of Boost Converter

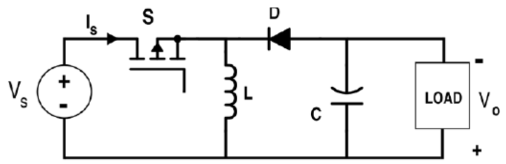

Figure 5. Circuit diagram of Buck-Boost Converter

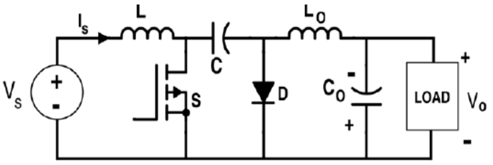

Figure 6. Circuit diagram of Cuk Converter

A basic disadvantage of four types of DC-DC converters is the electrical connection between the input and the output. If the input supply is grounded, that same ground will be presented at the output. A more efficient method of providing electrical isolation between input and output of a dc-dc converter is to use a transformer in the switching scheme [22-24]. The switching frequency is much greater than the ac power-source frequency, enabling the transformer to be small.

A. *Flyback Converter*

A more efficient method for dc-dc converter that provides isolation between input and output, low power, simplicity and low cost is the flyback circuit Figure 7.

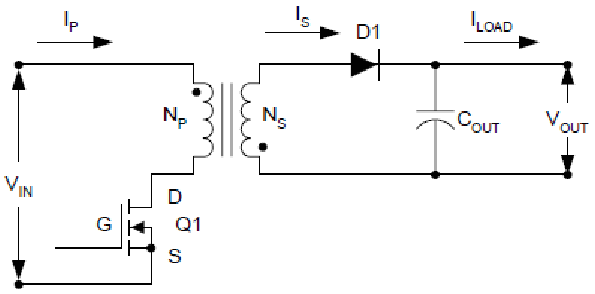

Figure 7. Circuit diagram of Flyback Converter

The Flyback converter circuit is analyzed for both switches (*Q1*) positions to determine the relationship between input and output. The analyses for the switch (*Q1*) ON are [21]:

- Current builds up in the primary winding
- Secondary winding has the opposite polarity *D1* OFF
- C maintains the output voltage, supplies load current

The analyses for the Switch (*Q1*) OFF are:

- The polarity of the windings reverses
- Diode *D1* conducts, charging *C* and providing current to the load
- Secondary current falls to 0 before the next cycle begins

The relation between input and output of the flyback converter is given by the following formula: (note: V_s=V_{in} and $V_0 = V_{out}$)

$$V_0 = V_s\left(\frac{D}{1-D}\right)\left(\frac{N2}{N1}\right) \quad (1)$$

IV. Designing and Implementation OF High Voltage Generator

A block diagram of a high voltage DC generator of our work is shown in Figure 8, which have consisted of into four stages; *AC* mains 220-240*V*, Step-down Transformer 12 *V* Output, AC –*DC* converter, Flyback transformer driver circuit (oscillation circuit) and Flyback transformer high voltage output.

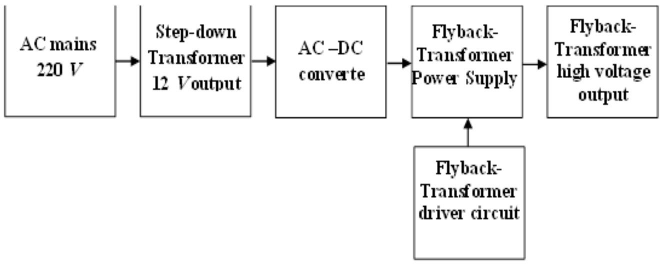

Figure 8. A block diagram of generating a high voltage

A schematic circuit diagram of a high voltage *DC* generator of our work is shown in Figure 9.

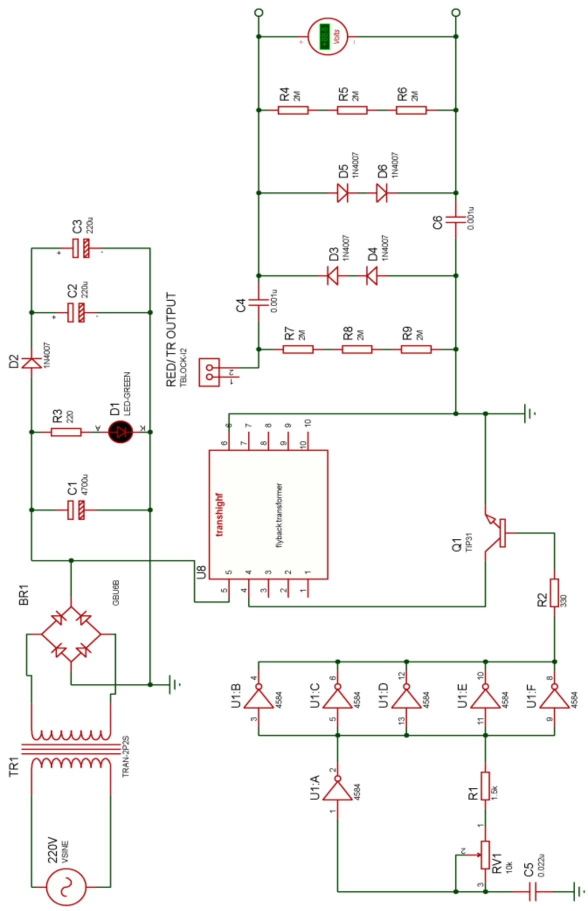

Figure 9. A schematic circuit diagram of a high voltage

A *PCB* Layout Diagram of a high voltage *DC* generator of our work is shown in Fig.10.

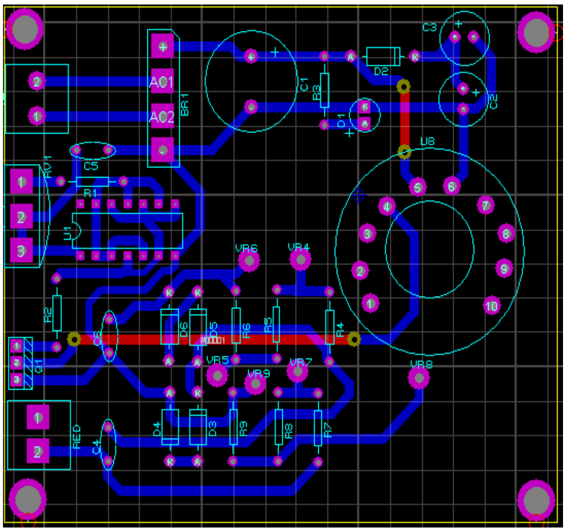

Figure 10. A *PCB* Layout Diagram of a high voltage DC generator

The mains power was connected to a fuse and the two main switches to control this circuit and put the PCB circuit in a black box as shown in Figure 11.

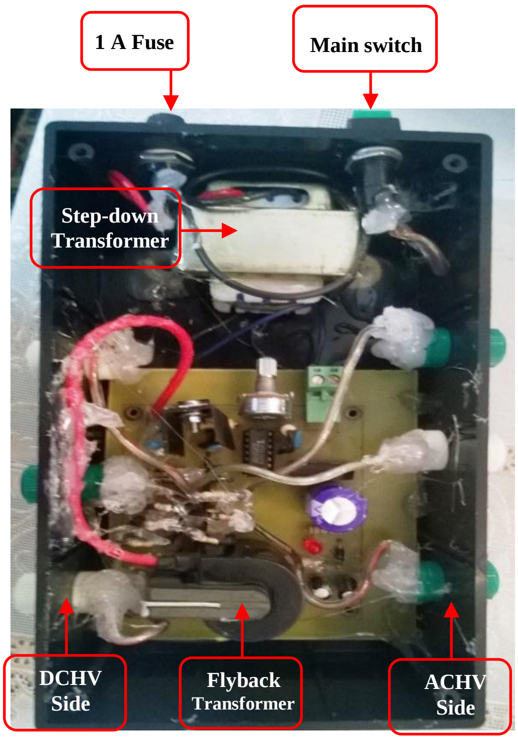

Figure 11. A PCB circuit printed inside box

A. AC mains 220 V

It is Supply voltage (220*V*/50HZ) and input source of our design circuit of high voltage generating.

B. Step-down Transformer 12 V Output

This is basically a transformer that connects to the *AC*-main, steps the voltage down, and gives an output voltage of approximately 12 V_{rms}. It has high power and the current flows in the secondary winding more than the current that through into the primary winding so the secondary wire must be thicker, since this is a step-down transformer .

C. AC –DC Converter

After down the 220 *V* main by using a high power step-down transformer (T1) and a full-wave bridge rectifier (BR1), which converts 220 *V* AC to (14-16 *V DC*) approximately. Capacitor (*C1*) represents in this circuit as a filter.

D. Flyback Transformer Driver Circuit (Ocillation Circuit)

The main part of oscillation circuit is *U1* (*CD4584* Schmitt trigger hex inverter) which is considered the heart of this circuit. The essential action of oscillation circuit is to simulate a pulsed (square-wave) to form an oscillator, high frequency input of the flyback transformer high voltage that runs at approximately *15 kHz* which then allows it to work. Capacitor *C5*, resistor R1, and potentiometer *RV1* are connected to one gate of the inverter (*U1:A*) is configured as a square-wave pulse generator. The output of (*U1: A*) (a pulsating *DC* voltage) at pin 2 is fed to the inputs of *U1:B* to *U1:F*, which are connected in parallel to increase the available drive current. The pulsating output of the paralleled gates is fed to the base of *Q1* (*TIP31*) through *R2*, causing it to toggle on and off in time with the primary winding of *T2*. The other end of *T2* is connected directly to the positive terminal of the power supply *12 V DC*. The square wave output is used to drive the switching transistor *Q1* (*TIP31*). The pulsating DC output at the secondary winding of T2 (*1000 VAC*) and then applied to voltage-multiplier circuit which consist of *(D3- D6 1N4007*) and capacitors (C4 & C6) to generate *2000 V DC*.

V. CONCLUSION AND FUTURE WORK

This work has proposed a new and advanced methodology for designing and implementing a high voltage, high frequency with a low current circuit that used in the biomedical area, especially in Electrosurgery and electrocuttery devices that are used for surgical cutting or to control bleeding by causing coagulation (hemostasis) at the surgical site. This proposal designed is capable of producing a cutting and coagulating clinical effect on patient tissue. This proposal interested the design of a high-voltage *DC-DC* converter capable of converting *220V AC* into *2000V DC* and delivering *250W* of power. The design is based on a flyback converter topology. In order to ensure getting a high efficiency of this circuit, the frequency of the square-wave (oscillation circuit), and therefore the signal applied to the voltage-multiplier circuit, must take into consideration. For future work, expanding of this design circuit to generate high voltage *DC* more than *2000V* reach to *30000V* by increasing the numbers of diode and capacitors in voltage-multiplier circuit that are used in industrial application, or using another method either a Cockcroft-Walton or Greinacher cascaded voltage doubler that presents better stabilization for high voltage applications.

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