HIGH VOLTAGE BOOST CONVERTER FOR CAPACITOR CHARGING POWER SUPPLY

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ABSTRACT

One of the essential parts in flash lamp pumped solid-state pulse laser is its Capacitor Charging Power Supply (CCPS). The aim of this project is to develop dc-dc converter or power supply for charging the capacitor. In this attempt, switch mode power supply technique adopted dc-dc boost converter was employed. The converter used 12 V dc power supply as an input voltage and serial of three capacitors with capacitance of 470 μF and voltage rated of 450 V. The results obtained indicate that the developed converter was able to charge capacitor banks within 10 s and capable to convert variable output voltage in the range of 300-1000 V.

Keywords: switch mode power supply, boost converter, capacitor charging power supply

INTRODUCTION

In the solid-state pulsed laser system in which a flashlamp is used to excite the lasing material, the flashlamp needs to be energized by capacitor charging power supply (CCPS) [1]. One of the vital aspects in the CCPS is the capability to store energy in the capacitor banks from high voltage DC power supply. There are several methods to design the high voltage power supply [2], but in this project, concentration is on Switch Mode Power Supply (SMPS) technique. There are several topologies available to perform this function [2-5]. An appropriate topology for this project was the DC/DC boost converter power supply, this is because it is utilizes duty cycle of modulating switch to boost the output voltage and also it is transformerless.

In designing capacitor charging power supply the charging time must be taken into account and it needs to be as fast as possible. The challenge in this project is to increase the charging time of the energy storage in the capacitor bank which also acts as the filter capacitor in the boost converter topology. Therefore, several aspects need to be considered in constructing high voltage boost converter with high conversion ratio and also short charging time. They include switching frequency, duty cycle, inductance, power switching device and output rectifier.

THEORY OF OPERATION

The working principle of the boost converter topology is shown in Figure 1 [2-5]. When the gate of power MOSFET, Q1 is turned on, the inductor is connected directly across the input voltage source and this allows the current to build up in the inductor. The energy is stored in the magnetic field of the inductor. There is no current through diode, D.

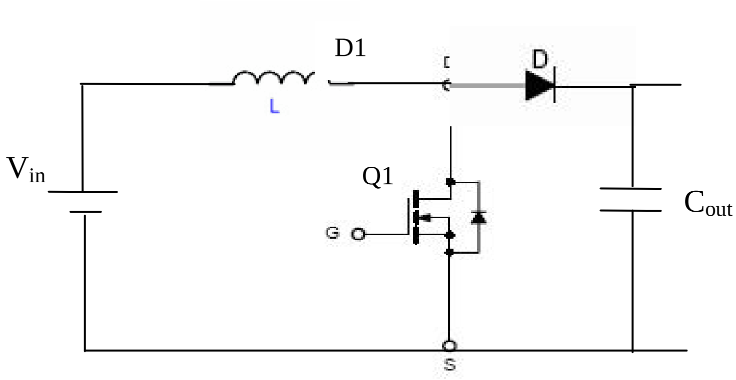

Figure 1: Boost converter topology

The peak current, i_{pk} occurs at the instant the power switch is turned off and is given by:

$$i_{pk} = \frac{V_{in}\, t_{on}}{L} \qquad (1)$$

where V_{in} is input voltage, t_{ON} is ON state of the switching frequency and L is the inductance. The stored energy in the inductor is defined by:

$$E_L = \frac{1}{2} i_{pk}^{2} L \qquad (2)$$

When the gate of power MOSFET is turned off, the energy from the inductor is then passed to the output capacitor. The output voltage is equal to:

$$V_{out} = \frac{1}{(1-D)} V_{in} \qquad (3)$$

where D is duty cycle of the Pulse Width Modulation (PWM).

EXPERIMENT

A high voltage power supply based on boost converter topology was built in order to charge the capacitor bank for solid-state laser driver. The work is divided into four main parts including a switching control unit, a DC-DC boost converter, an output over-voltage protection circuit and a capacitor bank. Figure 2 shows the circuit diagram of the high voltage boost converter power supply.

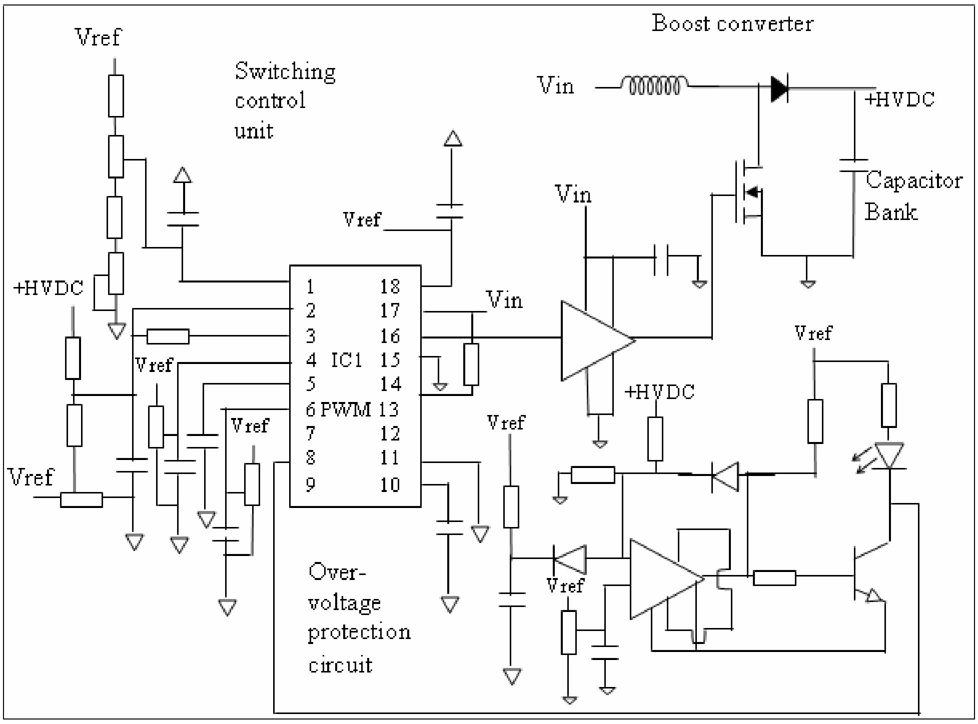

Figure 2: The circuit of high voltage boost converter power supply.

Switching Control Unit

Switching control unit works by making a pulsating dc square wave with variable on-to-off ratio or duty cycle. In this way a variable amount of power is transferred to the load. A single IC PWM controller and a MOSFET driver were used in constructing the switching control unit. The controller IC is the "brains" of the dc-dc converter. The output voltage of boost converter is controlled by varying the duty cycle and frequency of the PWM. An INSTEK digital oscilloscope with bandwidth 250 MHz was employed for measuring these pulses.

DC-DC Boost Converter

A power MOSFET with parameters of 1500V V_{DSS}, current I_D of 4 A and low resistance $R_{DS(on)}$ was used. An ultrafast diode which has forward current $I_{F(AV)}$ of 1 A and voltage V_{RRM} of 1000V was used as an output rectifier. The diode is able to sustain the high current necessary to supply the load and withstand the high reverse voltage and avoid burnout. The input voltage is +12 V from PC power supply. The inductor is a critical part in designing a boost converter. It needs to be matched with the switching frequency. Heat sinking is required for heat transfer from Q1.

Capacitor bank

The ability to store a large amount of energy is an essential criterion of pulse power technology. In this work the capacitor bank comprises three capacitors aligned in serial. Each of the capacitor has capacitance of 470 μF with voltage rating of 450 V. Thus, the maximum energy storage of the capacitor bank is 75 Joules.

Output over-voltage protection circuit

An over-voltage protection circuit includes a comparison circuit using operational amplifier that compares sensed voltages from the high voltage output and the reference voltage.

The circuit diagram in Figure 2 was designed on the Printed Circuit Board using RIMU PCB software. The circuit board image was printed with a laser printer. The circuit board is etched with ferric chloride solution. In this PCB layout, all power carrying traces were short and fat in order to minimize the inductive and resistive aspect of traces and reducing noise within the circuit.

RESULTS AND DISCUSSIONS

The PWM pulse from switching control unit was characterized using oscilloscope. The output frequency of the switching unit can be varied from 1.5 kHz to 25 kHz and the duty cycle can be varied from 0 to 50 %. The variable output voltage is obtained by regulating the ON time of the duty cycle. In this research, the switching frequency of PWM was set at 2 kHz and 50% duty cycle as shown in Figure 3. This allows high current flowing through inductor and reduces the charging time of the capacitor bank. The variable output voltage was achieved by adjusting the potentiometer in the over-voltage protection circuit. The high voltage output is maintained at desired level and is displayed on Fluke 37 digital multimeter. When the output voltage reaches the maximum setting the LED lights up and the PWM stops sending signal to the gate of power MOSFET as shown in Figure 4. Thus, the system shuts down automatically. This high voltage boost converter is able to generate output voltage from 300 V-1000 V from 12V input voltage. A typical result of an output voltage from this developed converter is depicted in Figure 5. The maximum power of boost converter is 100 Watts corresponding to the maximum input power. The charging time is approximately 10 s which stores 75 J energy into the capacitor bank. A photograph of the complete assembly of the high voltage CCPS in the real field is illustrated in Figure 6.

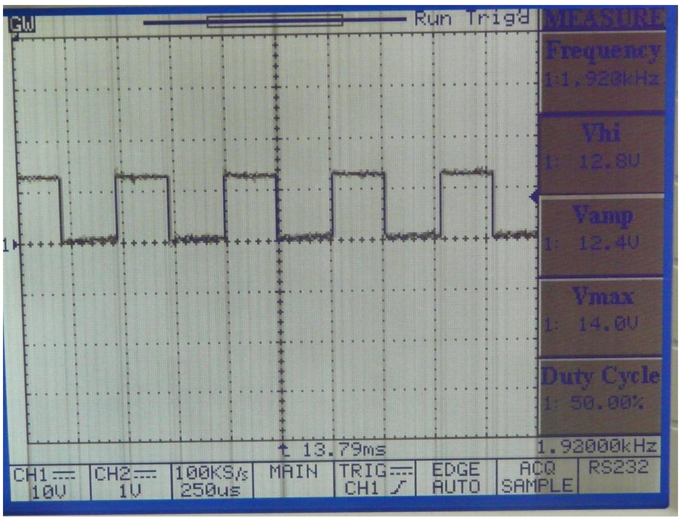

Figure 3 : Signal from switching control unit during charging time or when the output voltage is increasing.

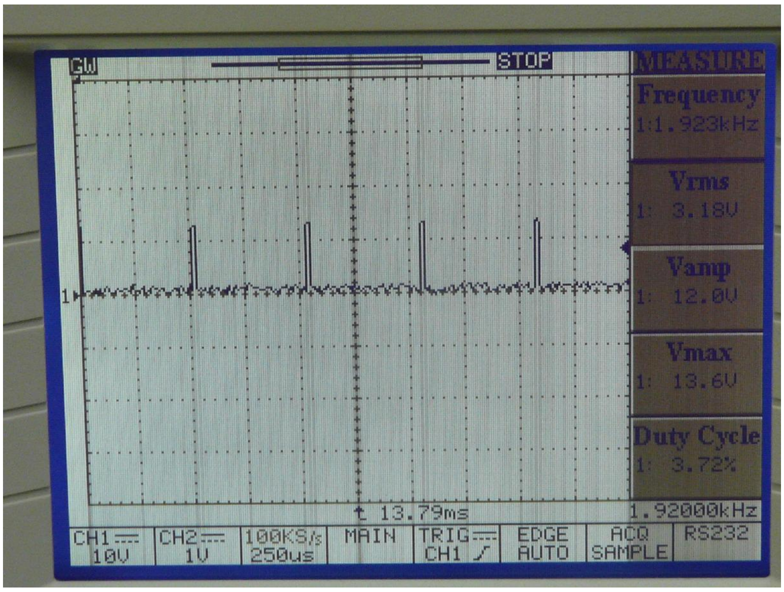

Figure 4 : Signal from switching control unit when the HV output reached its maximum setting value.

Figure 5: Example of the output voltage of boost converter at 904 V.

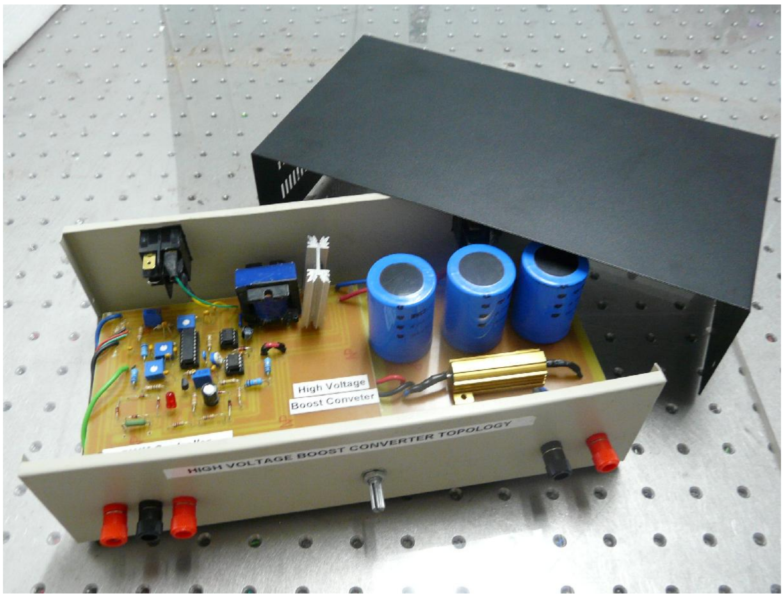

Figure 6: Photograph of the DC – DC Converter in the real field.

CONCLUSION

DC-DC boost converter power supply was designed and comprises four main parts: a switching control unit, DC – DC boost converter, protection circuit and capacitor bank. The input voltage of the converter is 12 V. The capacitor charging time is 10 s. The variable output voltage is achieved within the voltage range of 300 – 1000 V.

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