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Research Article

Design and Simulation of High Voltage Short Pulse Generator

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Abstract: High voltage pulse generators are widely applied in a many engineering fields. The aim of this paper is presenting a Design and Simulation of a high voltage short pulse generator using boost converter topology which is able to generate up to 5 kV for a varying resistive load of 5 to 20 Ω loads with a pulse width ranging from 1 to 10 µs. The switching frequency of the circuit is 30 kHz. Proposed converter is tested with different duty cycle and Resistance load (R_L) with a constant input voltage multilevel DC-DC Boost converter in only on Continuous Conduction Mode (CCM). The performance parameters of the DC to DC boost converter are analyzed. This paper briefly investigates the technology used in high voltage DC to DC conversion in short pulse generator for energy transfer and also to convert low voltage into high voltage from input side to output side. Here the Simulation workouts are carried out by the MATLAB/SIMULINK 2019 a version to validate the proposed system results.

Keywords: Boost Converter, MOSFET Switch, High Voltage, Pulse Generator, Pulse Width, MATLAB/ SIMULINK

1. Introduction

The advancement of the power electronics and devices has made it possible to varying frequency rate of the supply voltage easily, these are extending the huge use of a converters in HV line applications. HV short-pulse generator widely applied in many applications, like a military, medical equipment, HV industrial process, and also in electrical and electronics measurements and even in a various human living purposes also [5]. Pulse generator blocks are mostly applied in industry to attain HV in short time duration pulse like microsec, picosec and nano second [2]. In the advanced electrical and electronics topology, the production of HV Pulse Generator in microsecs is most complex and even also too costly to build [10]. High DC voltages is mostly used in the scientific research work and industry purpose also. The application of the high DC voltage is testing of a cables, compared to the AC voltages it will give higher capacitor rate and in AC voltage test it will takes large current, so mostly for industry applications High DC voltages are applied.

HV is very necessary in a many electrical engineering and electronics engineering applications like a power supplies, X-ray, Television system, Oscilloscope, scans and a Photomultiplier and CRT tubes and also in medical equipment are used in an industry for detection of the nuclear radiation [1-4].

In nowadays, DC -DC converter are widely applied in the electric and hybrid vehicle system (EV), battery cars, photovoltaic system (PV), Generators, Uninterrupted Power Supplies system (UPS), high voltage line (HV) and fuel cell system. Now, many HV line industry process, it would be most essential to convert the unregulated which means fixed dc voltage to regulated i.e. variable dc voltage. DC-DC converters is directly converts DC voltage into a DC voltage source and it also named as DC Converters or Choppers [1-3].

DC-DC converters are also named as the Transformer, because it also able to step up and step down the unregulated voltage into the desired regulator DC source voltage [1-3].Other name for Dc converter is DC equivalent to an AC transformer for vary the turn ratio in continuous conduction mode. DC Converters can also produce smooth acceleration control process, high efficiency rate, and good dynamic response. DC to DC converters uses in DC motors for Regenerative braking to get back the energy into the supply, it will provide the energy saving for the domestic and commercial uses. Converters are commonly applied in the inductor and also in magnetic fields to produce the Current (DC source) in Inverters i.e. Current Source Inverter (CSI) and also widely used in the Voltage Regulators [3].

Converters used a field magnetic inductor to store energy and release to the load with low losses and also provide overall efficiency higher, so it is good choice to choose in the converter uses. Inductors are also used to reduce the current ripple factor. Capacitor are connected to the output side of the converters to reduce output voltage ripple factor. The duty cycle of a pulse generator is varied to obtain the desired output voltage [1-3].

In this work, close loop boost converter is considered, to control the output voltage which will not exceed above the desired output voltage level. The proposed system has two stage of boost converter 1) charging stage 2) discharging stage, both are controlled by pulse generator.

Hence, HV and short pulse generator concept plays a very important role in the implementation of Boost Converter. This paper presents a technology of a high voltage short pulse generator using DC-DC Boost Converter depends on the power MOSFET switch topology to attain a desired High Voltage (HV).

In this paper, derivations for a boost converter are solved in the first section and in the second section, shows the simulated results using MATLAB/SIMULINK are carried out to verify the proposed system of high voltage boosting converter for short pulse generator topology.

In this paper, the following objectives are obtained by the required design specification parameters.

- To attain high voltage source short pulse generator by using boost converter.
- Dc to dc voltage source through the fixed (constant) input voltage by varying the load impedances and pulse generator.
- The aim of this work was to keep the pulse as small as possible and make it very simple.
- Here we use short pulse generator (in micro secs) and multilevel boost converter to obtain high voltage up to 5kv.
- Closed loop feedback control system are used to control the capacitor voltages to not exceed the desired voltages.

2. Experimental Setup

One goal of this paper was to keep the pulse generator (pulse time duration) as low and made the proposed system very simple to operate. For attain the desired 5kv HV, DC-DC Boost converters was applies here.

The main objective of this paper work was to obtain a 220v into 5kv, the switch MOSFET in microsecond (micropulser) with variable pulse durations of 1µs to 10µs with constant switching frequency rate (Sf) of 30 kHz. The proposed system can be broken down into three system of blocks: They are,

1) High voltage (HV) source block which means the Dc-Dc boost converter its step up the unregulated voltage into 5kv high output voltage and use the stored energy while the pulse are applied,
2) Switch block which means MOSFET pulse generator block for charging and discharging process using short pulse in microsecond (micropulse) to the load, and
3) Pulse Generator block which means the Switch S (MOSFET) is ON by applying a microsecond pulse to the load (Resistance $\mathbf{R_L}$),it will be shown in PWM signal waveform.

3. Operation Of Boost Converter

DC-DC Boost Converter are also called as step up converter, as shown in Figure 1.It is a power converter that gives the output DC voltage greater than the input (supply) DC voltage. It's also a part of switch-mode power supply (SMPS) and consists of minimum two semiconductor switches such as diode and transistor and minimum one energy storage device and also some components are added according to our requirement [1]. Filters are used to reduce the output voltage and current ripple factor here we use capacitor and inductor filters. Capacitor to reduce the voltage ripple and an Inductor to reduce the current ripple factor. This is the basic circuit buildup of a DC –DC Boost converter [3].

Switches are knowns as the MOSFET, IGBT or BJT. In this work, MOSFET switch is used, because MOSFET switch can have more advantages compared to the other switches. The advantages of power MOSFET are, high frequency rate, high speed in commutation and give high efficiency even during in the operation of low voltages also. The main advantage of MOSFET is, it have fast switching applications with the small Turn OFF losses, so we choose MOSFET switch in this present work [3].

The DC-DC Converters or Choppers have two different Modes, they are

i. Continuous Conduction Mode (CCM)
ii. Discontinuous Conduction Mode (DCM)

In this work, simulation studies are performed in CCM. Because it is more efficient in power conversion.

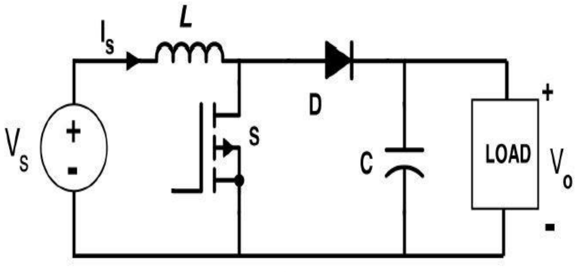


Fig .1. Basic design of a DC-DC Boost Converter

Basic operating function of a DC-DC Boost Converter consists of two modes, [3]

- Mode 1-ON-state which means Switch S is ON and the diode (D) is OFF, in this mode the current flows through the switch and come back to the dc source because of diode is OFF. This mode results in increase in the inductor current $(\boldsymbol{I_l})$ and also in continuous state [1-3].
- Mode 2- OFF-state which means Switch S is OFF the diode (D) is ON, in this mode the energy stored in the inductor can be released. The only path offered to an inductor $(\boldsymbol{I_l})$ flows through the fly back diode D otherwise some spark is produced across the switch S, it will cause the switch to damaged. To protect from that spark damage the Diode is used. Now the inductor current can flow freely through the diode D, the capacitor C and the R load. This mode results in stored energy transfer obtained during in the Mode-1 ON state into the capacitor C and to the Load

resistance [1- 3].

3.1 Mathematical Derivation Of Boost Converter

The mathematical derivation for a boost converter is solved as follows: [1]

Calculation model:

Output voltage expression of a DC to DC Boost converter can be obtained using voltage second balance equation across an inductor.

In switch 'S'- ON condition: Voltage across an inductor L,

$$V_L = V_{in}$$

In switch 'S'- OFF:

Voltage across an inductor L,

Therefore, $V_L = V_{in} - V_o$

Voltage second balance equation

$$[\boldsymbol{V_{in} T_{on}} + (V_{in} - V_O)\, T_{off}] / \mathrm{T} = 0$$

By solving these above equation, we obtained

$$\frac{\mathbf{V_o}}{\mathbf{V_i}} = \frac{\mathbf{1}}{(\mathbf{1-D})}$$

Here $\boldsymbol{V_O}$ = Output Voltage

$\mathbf{V_i}$ = Input Supply Voltage

D = Duty Cycle (pulse width)

For our requirement the following selection parameters are listed below,

Input voltage $\boldsymbol{V_i}$**= 220 V;** Output voltage $\boldsymbol{V_o}$**= 5000 V**

Mostly the operating frequency (i.e. switching frequency) determines the performance of Switch 'S'. The selection is probably based on the desired efficiency requirements. Therefore in the advanced research work process, supply voltage source increasing the switching frequency in their power supply designs. The switching frequency huge higher, which means results in, small in the physical size and the component value and also compact.

The switching frequency **f = 30 kHz**

Resistance **(R load) =5, 10, 15, 20 Ω**

3.2 Inductor Selection

The working process of the inductor is control the Current Slew Rate flows through the Mode-1 that is Switch 'S' in ON state. Therefore the inductance is monitored by the process of Inductor Current ($\mathbf{I_l}$) in Continuous Mode (CCM) Of DC-DC Boost Converter and it will never goes to Zero, maintain this condition for entire operation.

The inductance (L) can be calculated by the following equation in Continuous Mode (CCM), [1]

Inductor value **L =** $\frac{D(1-D)^2 R}{2f}$ **= 6.5 µH**

Here L = Inductor (minimum)

D = Duty Cycle (Pulse Width) R= $\mathbf{R_l}$ (Resistance load)

F = Operating (Switching) Frequency

3.3 Capacitor Selection

The selection of capacitor mostly depends on the switching frequency ($\mathbf{S_f}$).For the low frequency, the selection of capacitor value will be in a range of 1 to 200 µF and for the high frequency , the selection of capacitor normally in the range of 0.02 to 0.06 µF.

For the calculation of capacitor value is based on, by fixing a voltage ripple factor in 1%. Now the capacitor value be selected by following equation,

Capacitor value **C =** $\frac{D}{R_l V_r f}$ = 2 µF

Here C = Capacitor (minimum)

D = Duty cycle (Pulse Width)

R = Resistance load ($\mathbf{R_l}$)

F = Operating (switching) frequency

$\mathbf{V_r}$ called as Ripple Output Voltage Factor it can be expressed as

$$\mathbf{V_r} = \frac{\Delta \mathbf{V_o}}{\mathbf{V_o}}$$

4. Short Pulse Generator

Pulse generator are mostly used to drive an electrical devices like switches and all loads and it also widely applied in electronic devices like optical, lasers and modulators components [4-10]. The output of a pulse generator is commonly known as pulse width modulation signal (PWM). The aim of this paper is to maintain the pulse width duration as small as possible based on the desired requirement. To obtain this, high voltage DC-DC converters was selected in the work.

The designed specifications require pulse durations as low as 1 to 10 microseconds (ms), based on the pulse duration requirement here we chosen an extremely fast power MOSFET switch.

In this work, MOSFET switch is used, because MOSFET switch can be operated in high frequency rate, high commutation speed and also a high efficiency even operate in low voltages also. MOSFET also performing a fast switching applications with a very small turn-off losses.

5. Specifications Of Proposed System

The Boost Converter specifications are applied depends on a requirement of a desired HV output. Here we use multilevel Boost Converter for our requirement. The two boost converters as shown in Figure 2 are connected to the same R load (resistance). The DC-DC Boost Converter are used to boost the low input voltage into desired high output voltage upto 5 kv. In this work, closed loop boost converter has been adopted to control the output voltage not exceeding above the desired voltage level. The feedback control loop controls the pulse generator through pulse width in the input side of MOSFET switch.

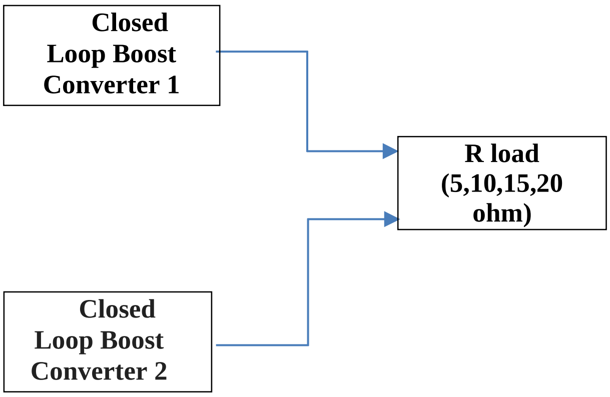


Fig. 2. Block diagram of the power converter

The designed specifications considered for the Boost Converter BC1 and BC2 are listed in the below table 1.

Table 1: Boost Converter (BC) 1 and 2 Specifications

Parameters	Mode	
	BC 1	BC 2
Input (supply)voltage (V_i)	110 V	110 V
Output voltage (V_o)	5000 V	
Switching Frequency(f)	30 kHz	
R load	5,10,15,20 ohm	
Voltage Ripple	1%	

Based on mathematical modeling calculations, the Boost Converter parameters are obtained for our requirements, the values of inductor (L) and Capacitor(C) for both Boost Converter 1 and 2 are arrived as shown in Table 2.

Table 2: Design values of L and C for BC1 and BC2

Boost converter	Inductor L in H	Capacitor C in F
1	6.5e-6	2e-6
2	6.5e-6	2e-6

Table 3: Design values of pulse generator for BC

Pulse Generators				
Parameters	S_{in}	S'_{in}	S_{out}	S'_{out}
Amplitude	1	1	1	1
Period sec	0.001	0.001	0.0001	0.0001
Pulse width %	90	90	2	2
Phase delay	0	0	0.0009	0.0009

Table 3 shows the pulse generation parameters of boost converter used in the present study. It is very important to monitor the constant output voltage, changes may happen easily, because of the changing in pulse generator i.e. time duration and loads. To controls this, mostly we use some control loops. The open loop control system not suitable to maintain the constant output voltage. So we prefer here, Closed Loop Control System, it will monitor the capacitor output voltage and compared with the output voltage to not exceed the desired output voltage level. If any changes in the voltage values we have to change the pulse time duration value. If any changes occurs in an output capacitor voltage would be tends to change in pulse width (duty cycle) in the pulse generator block i.e. Pulse Width Modulation.

6. Simulation Circuit

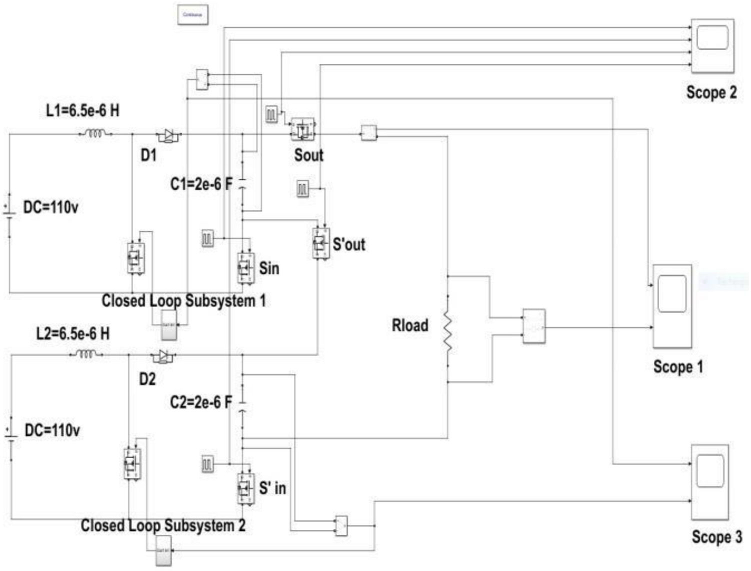


Fig.3. Simulation circuit for high voltage short pulse generator using Boost Converter.

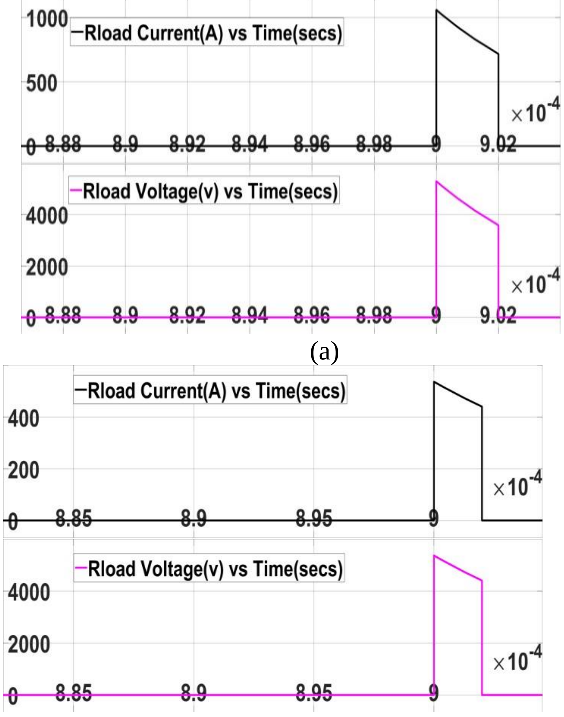
Figure 3 shows the simulation circuit used for the generation of high voltage short pulse using boost converter topology. Simulation is performed in the MATLAB/SIMULINK platform. Output voltage and pulse parameters are monitored in the scope.

7. Simulation Results

The simulation results of the high voltage short pulse generator using boost converter with different values of loads and pulse generator are shown below.

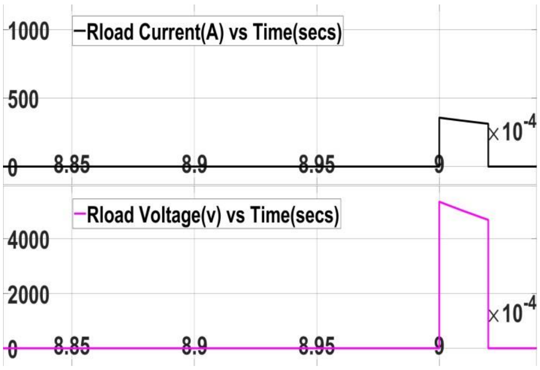
7.1 Variation of Output Voltage and Current w.r.t varying R_{load} at constant pulse duration

Figure 4 shows the output voltage and current waveform for the constant pulse width of 2 µs by varying the load values (2, 10, 15 and 20). Output voltage is reached upto 5 kV and current upto 1 kA.



(a)

(b)

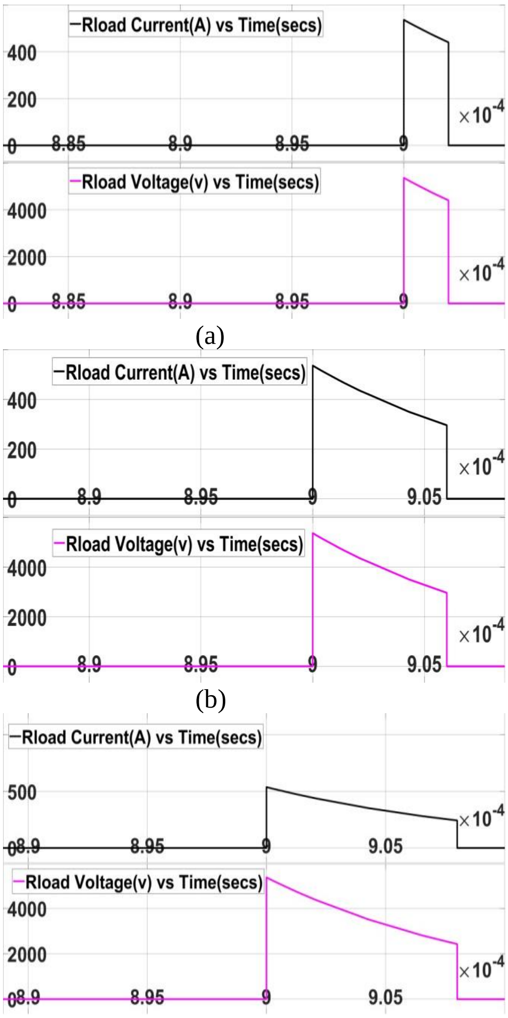


(c)

Fig.4. Variation of load voltage and output current waveform w.r.t increase in load (a) 5 Ω (b) 10 Ω (c) 15 Ω at a pulse width duration of 2 µs.

7.2 Variation of Output Voltage and Current w.r.t varying pulse duration at constant R_{load}

Figure 5 shows the output voltage and current waveform for a constant resistive load of 10 Ω and varying the pulse width through the time duration values of 2, 6, and 8 µs. Output voltage is reached upto 5 kV and current upto 500 A. It is also noted that a cascaded system of the boost converter is able to provide the required high voltage pulse width in the range of micro seconds.



(a)

(b)

(c)

Fig.5. Variation of load voltage and output current waveform w.r.t increase in pulse width duration (a) 2 µs (b) 6 µs (c) 8 µs at a resistive load of 10 Ω.

7.3 Variations in Capacitor Voltage

Figure 6 shows the variations in capacitor voltage waveform with respect to charging and discharging period, irrespective of all the load values (5, 10, 15 and 20 Ω) and also for all pulse width of time duration (2, 4, 6 and 8 **µs**). It is seen that both C1 and C2 achieves the rated output voltage of 2.5 kV within 0.1 ms, because of the closed loop system of boost converter. The closed loop system controls the capacitors not to exceed the desired output values. The cascaded system finally gives an overall output of 5 kV. Discharge time of capacitors is also noted to be in micro seconds for both capacitors C1 and C2. Since the cascaded system of high voltage short pulse generator is planned to provide a microsecond high voltage pulse output, capacitor should be fast charging and discharging type to meet the requirements.

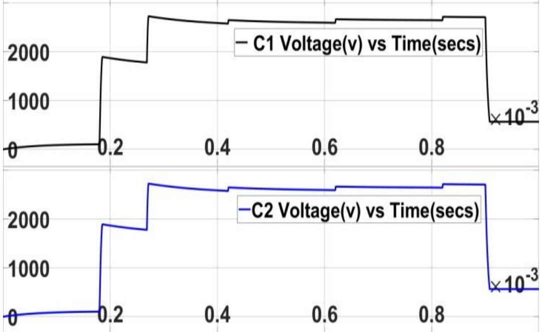


Fig .6.Variations in capacitor voltage of C_1 and C_2 for all loads and pulse width.

7.4 Variations in Switching Sequence of Pulse generator

Figure 7 and 8 shows the switching sequence of pulse generator at different pulse width and at different loads. It is noted that the MOSFET switches used in the simulation study is able to provide microsecond pulse switching needed for the generation of short HV pulses.

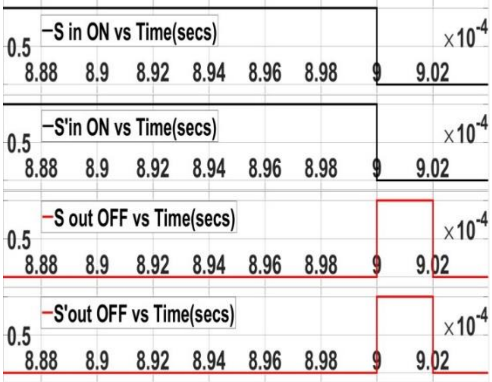


Fig. 7 Pulse Generator waveform for 2 μs at 10 Ω

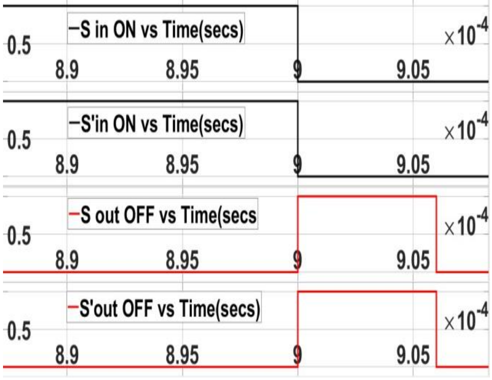
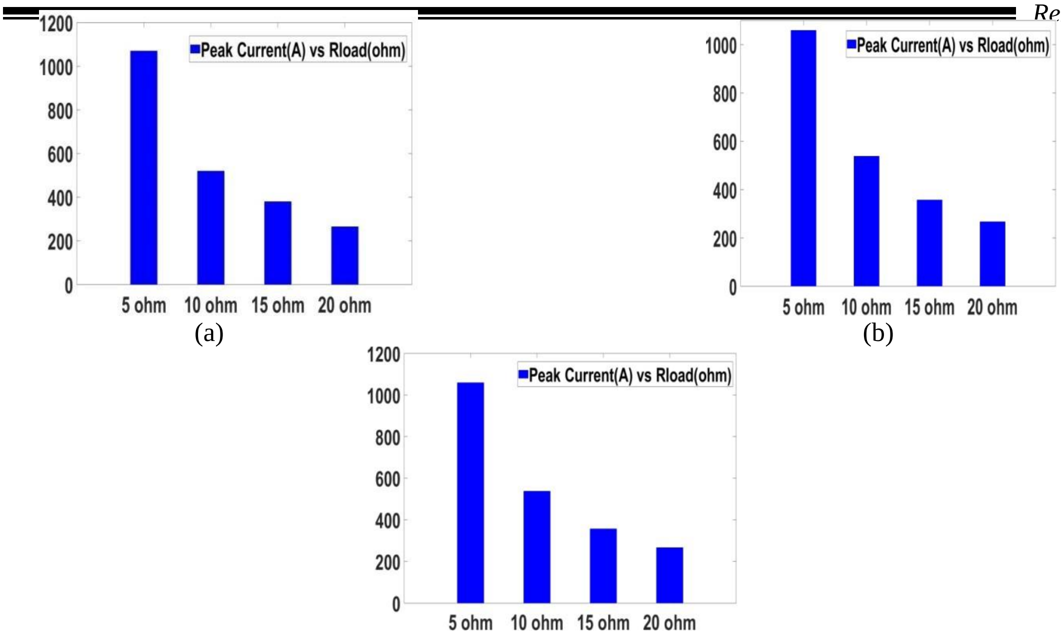


Fig.8. Pulse Generator waveform for 6 μs at 15 Ω

7.5 Variations in output pulse peak current w.r.t pulse duration and load resistance

Figure 9 bar chart shows the variations in output pulse peak current with respect to pulse duration and load resistance. In general, increase in load leads to reduction in the peak value of an output pulse current. However, there is no major variation in peak current with respect to increase in pulse duration in microseconds.



(a) (b) (c)

Fig. 9. Variations in output pulse peak current w.r.t increase in resistive load at pulse duration of (a) 2 µs (b) 6 µs (c) 8 µs.

From the results obtained, it is clearly observed that the HV short pulse generator using boost converter steps up the voltage from 220 v to 5 k volt and also meet the all desired specification conditions of a output voltage upto 5kv and short pulse in the ranges of 1 to 10 microsecs (µs) at the constant switching frequency of 30kHz. The resistive load impedances of the boost converter is varied upto 5 to 20 Ω. The above results are obtained by varying the resistive load ($Rload$) and pulse durations (µs) with constant input voltage Vin and frequency f. The obtained results of $Rload$ output voltage and current waveforms, Capacitor voltages C1 and C2 and the pulse generator waveforms are shown above.

8. Conclusions

In this paper, high voltage short pulse generator using cascaded boost converter topology was designed and simulated successfully using MATLAB/SIMULINK software which met all the design specifications of 5 kV. The performance of the high voltage short pulse generator was studied with respect to increase in load, increase in pulse width and increase in output voltage magnitude. Variations in capacitor charging and discharging voltage duration are also studied. Variations in output pulse peak current with respect to design parameters are studied. Switching pulse sequence of MOSFET switches show microsecond pulse output required for short duration pulse generator. It is also decided to setup a hardware system in order to validate the above proposed system of high voltage short pulse generator in the laboratory.

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