MOS-GATED THYRISTOR BASED MARX GENERATOR FOR ACCELERATOR APPLICATIONS

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Abstract

In the field of pulsed power, gas switches have been widely used due to their high operating voltages and currents. One example of these gas switches is the thyratron, which is in use for some particle accelerators even today. At the Extreme Energy-Density Research Institute in the Nagaoka University of Technology such devices are in use.

We propose a study to replicate the conditions of one of the ETIGO-IV generator switching units, currently a thyratron, on semiconductor switches. One of these thyratron units operates at 30kV peak voltage, 10kA peak current with a pulse width of 2µs. These parameters are very difficult for a single semiconductor device, so connecting many devices makes it possible to overcome the limitations. A Marx generator is proposed, this guarantees that each switch only operates at one fraction of the total voltage unlike traditional series connections which can cause stress on a single device. Discharge experiments of a single unit yield 2.5kA peak current and 400V peak voltage on a 0.2Ω load with a pulse width of 2µs at 1kV charging voltage.

INTRODUCTION

Traditionally, the need of faster, more compact, reliable and cheap pulsed power generators have led to the development of new techniques and devices; semiconductor devices are one example. However, this trend leads to a tradeoff; usually a faster more compact device doesn't have the same potential than its predecessors in switching parameters (maximum voltage and current). The development of completely new devices has allowed to venture into the usage of semiconductors in a new way which aims to replace common solutions for high power switching.

In the Extreme High Energy Density Research Institute in Nagaoka University of Technology, there is currently a pulsed power generator known as the ETIGO-IV [1]. This device utilizes thyratrons as the closing switch. A way to replace the switching unit with semiconductor devices is being studied.

One of the simplest ways to increase the output voltage is by using many switches connected in series; the drawback of this scheme is that in the case of failure of one of the switches, there is high risk of applying high voltage to just one switch. One measure that is possible to take in this situation is to use a MARX generator scheme [2].

The device we have chosen is the MOS-gated thyristor due to its high di/dt current characteristics and relatively fast turn on time, which is ideal for this application [3].

The objective of this research is to evaluate the possibility of generating a high voltage, high current pulse with a pulse width of 2µs. The parameters explained before are difficult to achieve with a single device so we propose circuit topologies that help expand the capabilities of each switch.

MARX TOPOLOGY

The basic layout of the MARX generator used in this research is shown in Figure 1. Considering the output pulse we desire it is possible to estimate the values of the capacitance C, the load resistance and in this case the amount of inductance the circuit can have.

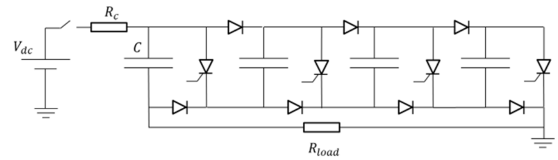

Figure 1: Marx circuit schematic.

To estimate de desired value of C we used Equation (1 with an inductance value of 100nH per stage. This yields a result close to 5µF

$$\tau = \sqrt{LC} \tag{1}$$

GATE CIRCUIT

MOS-Gated thyristors are controlled in the same way as MOSFET devices, providing a positive voltage between the gate and the source with enough current so that the ON state is stable. Even if it is only during the discharge most of the circuits are not connected to ground and need high voltage isolation, to achieve this galvanic isolation and DC/DC converters are employed, for the trigger signal an optic device is used. Figure 2 shows the general layout of the circuit.

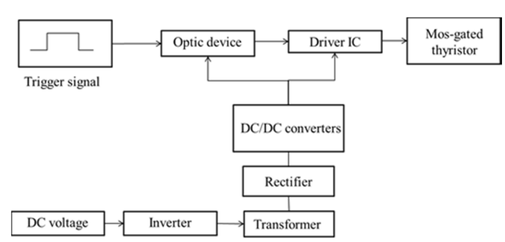

Figure 2: Gate circuit layout.

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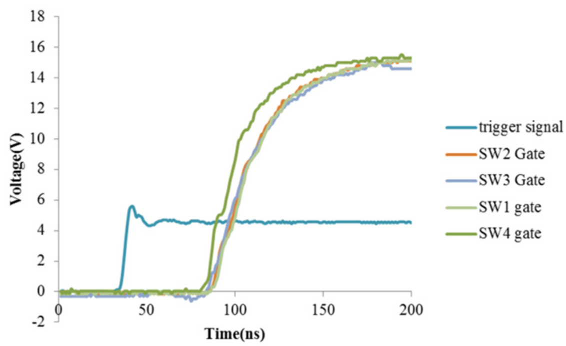

Figure 3: Gate circuit output.

For this circuit to operate properly it is important to ensure that all the switches turn on at the same time to apply the superimposed voltage to the load, Figure 3 shows the output of each gate circuit, from this it can be seen that the delay is in the order of 10 ns at most.

EXPERIMENTAL RESULTS

The switching unit can be seen in

Figure 4 the load resistance is the number of stages multiplied by 0.2 Ω this ensures that every switch operates in the same conditions as when only a single stage unit was being tested.

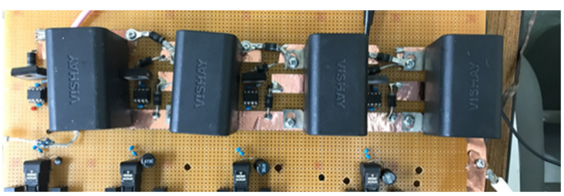

Figure 4: Marx circuit.

Figure 5 to Figure 7 show the output for each number of stages respectively this is to demonstrate that the Marx scheme is piling the voltage as it would be expected. It can be seen that the load voltage is approximately 2µs. Finally in Figure 8 the charging voltage was raised to 1kV

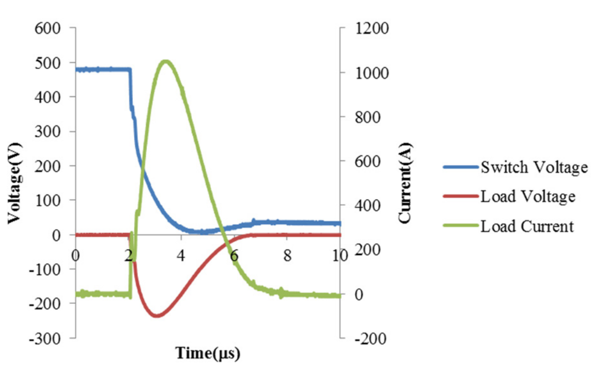

Figure 5: Output waveform 1 stage Marx.

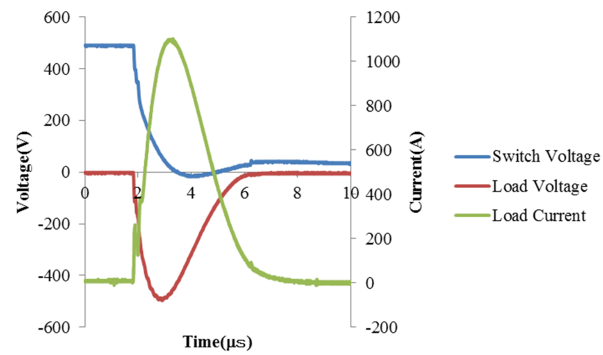

Figure 6: Output waveform for 2 stage Marx (500V charging voltage).

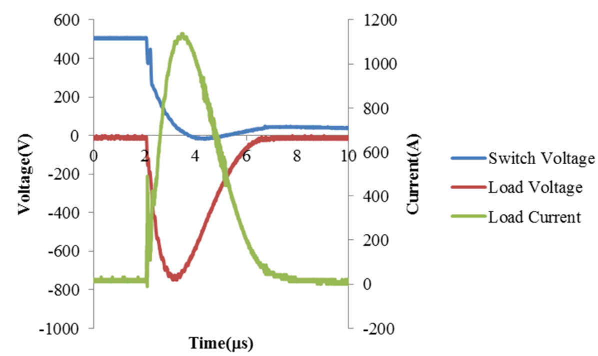

Figure 7: Output waveform for 3 stage Marx (500V charging voltage).

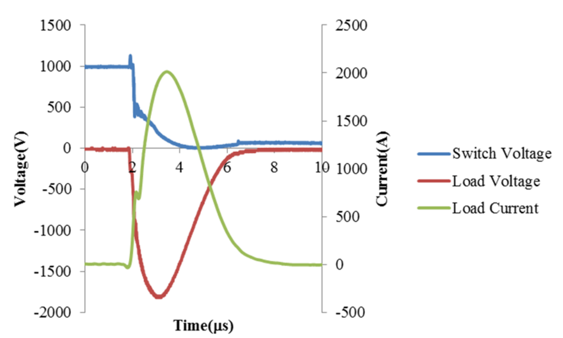

Figure 8: Output waveform (1kV charging voltage).

CONCLUSION

A Marx based generator was constructed using MOS-gated thyristor the output at 4 stages was a maximum of 1.8kV and 2kA.

There was little effect on the pulse width of the as the number of stages increased, this indicates that the total inductance of the circuit increased close to the expected 100nH per stage.

As the number of MARX stages increases the peak load voltage increases proportionally in this case with a decrement of 5% of the expected value, 1.9 for 2 stages, 2.9 for 3 stages and 3.9 for 4 stages.

The voltage efficiency, in this case the ratio between charging peak voltage and peak load voltage is low (50%) in other works it has been stated that a high load impedance leads to high voltage efficiency [4]. In our study the requirements for the pulse width and high peak current limit how high the load impedance can be.

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