MOS-GATED THYRISTOR BASED MARX GENERATOR FOR ACCELERATOR APPLICATIONS

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Abstract

At the Extreme Energy-Density Research Institute in the Nagaoka University of Technology. In recent times semiconductor switches have been considered as possible replacements due to their ease of maintenance and control. In general, it is difficult to achieve the same ratings of a gas switch with a single semiconductor device, so connecting many in series, parallel or a different scheme is often applied. We propose a study to evaluate a Marx topology using MOS-GATED thyristors capable of high current output. The attractive factors of these semiconductors are the low gate current required for turning on and a low resistance during the ON state [1], a four-stage prototype was built, and it achieved a peak output of 1 kV and 1 kA with a 2 µs pulse width. To improve the output voltage and current a ferrite core was implemented as a magnetic switch on every stage, this method has been used before to improve the efficiency of thyristors. However, not combined with circuit topologies like a Marx generator. Adding these magnetic switches increased the efficiency to 89 % (from 70%) and allowed an output of 2.2 kV and 2.2 kA without changing the shape of the pulse or the rise time.

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 2 µs. 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 Fig. 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.

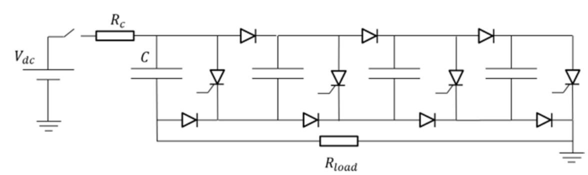

Figure 1: Marx circuit schematic.

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

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

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 [1]. Figure 2 shows the general layout of the circuit.

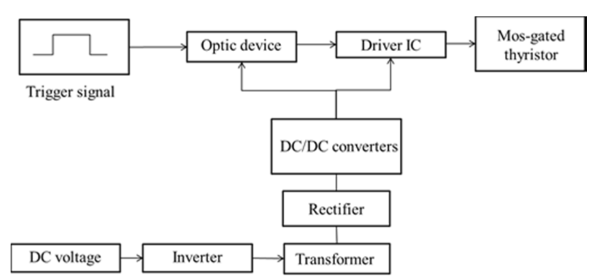

Figure 2: Gate Circuit layout.

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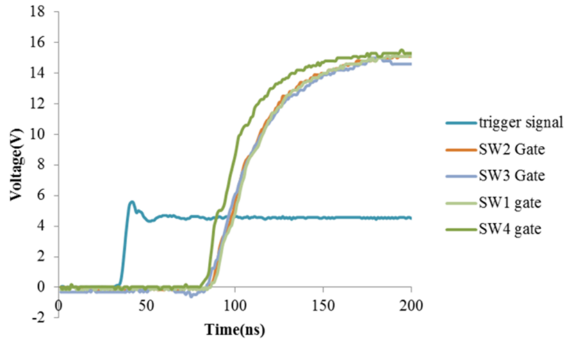

Figure 3: Gate circuit output.

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, Fig. 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.

MAGNETIC ASSIST

Initially, the new circuit with magnetic switches was tested on single stage operation to confirm the time delay. Figure 4 shows the schematic of this new circuit where the load resistance is the same as before (0.2 Ω per stage) and C is 5 μF.

The ferrite cores are wound with two turns in parallel to reduce the resistance and inductance of the winding. Figure 5 shows the theoretical time delay obtained from saturation values at 60 Hz and the experimental values obtained from the ferrite core voltage connected in series to the semiconductor switch in one stage operation of the Marx generator. Equation (2) was used, where V_0T is an approximation of the voltage time integral, N is the number of turns, 2 in our case, A is the cross section(119 mm^2) and ΔB is the flux swing of the core(2.3) [5]. For our magnetic switch an additional winding in which a DC current (6 A) is used to reset the magnetization of the core between shots.

$$T = (\Delta BNA)/V_0 \tag{2}$$

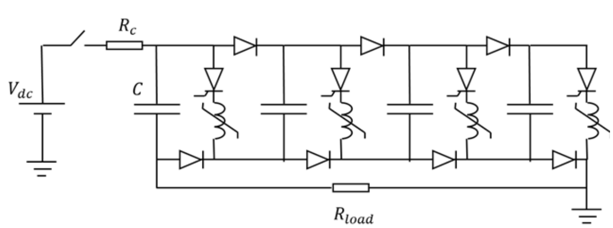

Figure 4: Schematic of the Marx generator with magnetic assist (four stages).

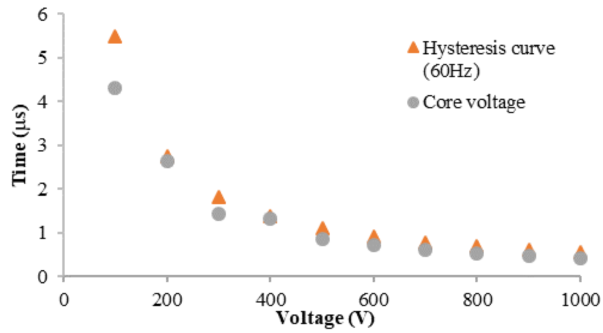

Figure 5: Magnetic switch delay.

EXPERIMENTAL RESULTS

The switching unit can be seen in Fig. 6, 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.

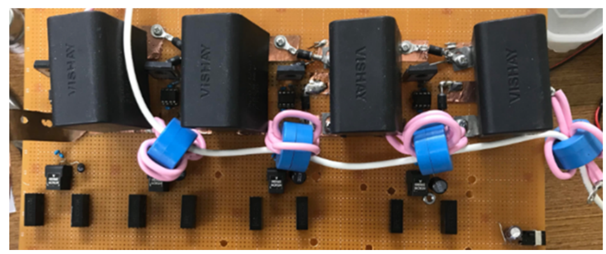

Figure 6: Marx circuit.

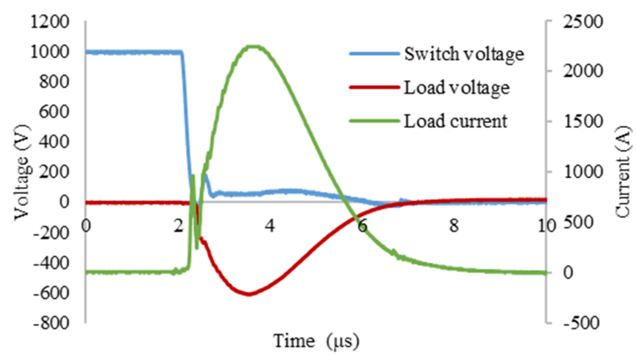

Figure 7: 1 stage Marx with magnetic assist.

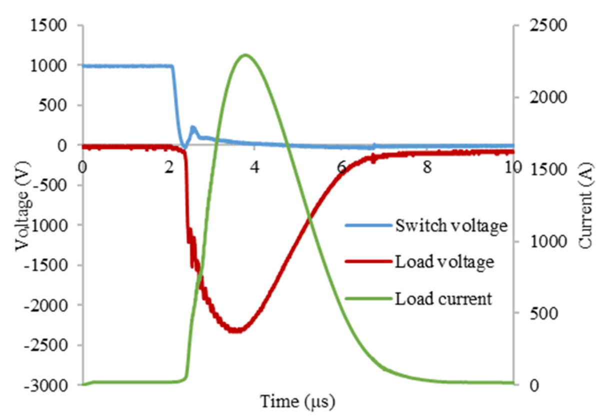

Figure 8: Four stage Marx with magnetic assist.

This circuit topology allows operation at 1 kV charging voltage. Figure 7 and Figure 8 show the waveforms obtained for one stage and four stage operation. The switch voltage was monitored using a differential high-voltage probe (Yokogawa, 701926).

The switching losses are much lower, and there is not much change in pulse shape, width (2.2 µs) or di/dt values. Which are 1.87 kA/µs for one stage operation and 2 kA/µs for four stage operation which is double of the values obtained for 500 V charging voltage, this proves that there is little effect on the rise time of the pulse due to the addition of the magnetic switches

CONCLUSION

A high current Marx prototype was built utilizing the parasitic inductance of the circuit and MOS-gated thyristors; a circuit construction allows a linear increase of the output voltage compared to the number of stages was confirmed.

The peak voltage and current were 1 kV and 1.1 kA respectively with a pulse width of 2 µs with an energy efficiency of 70% operating at four stages. The main limit of the circuit at this stage was catastrophic failure of the switches due to high di/dt of 1.2 kA/s and high inductance of 100nH per stage, these two elements combined cause a transient overvoltage that damaged the switch.

Ferrite cores were used to improve the switching conditions of the MOS-gated thyristors allowing to operate at higher charging voltages, peak values for voltage and current were 2.1 kV and 2.2 kA respectively

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.

It presents a limitation in repetition rate due to the time it takes the ferrite element to recover from the saturation state even when DC reset current is applied.

Linear addition of the voltage with a slope of 0.974 from one to four stages was confirmed. It is possible to scale up this circuit to achieve much higher voltages than the amount shown in this research while maintaining a current in the order of kiloamperes.

In future work, the performance of many of these modules will be evaluated.

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