Dual Polarity MV Marx Generator System

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Abstract

Two compact MV Marx generators are arranged to fire into a common spark gap and designed to deliver pulsed voltages in excess of 3 MV. Each generator is characterized by 40 stages of 8.1 nF capacitance and a charge voltage from 20 – 40 kV, which results in an erected voltage of up to 1.6 MV and pulse energies of more than 250 J. Each generator has an integrated controllable power supply and pressure control, and is battery powered. The two generators are charged with opposite polarity voltages, which can result in a differential pulsed magnitude of 3.2 MV. A central thyratron trigger source is remotely located and is designed for delivering two simultaneous high voltage trigger pulses to each generator. Design considerations are presented, as well as experimental results.

I. INTRODUCTION

Compact Marx generators have been employed for many years as trigger generators for larger systems and intermediate sources for high voltage pulses designed to pulse-charge pulse-forming lines. These generators are typically designed with pulse characteristics of more than 200 kV in peak voltage, 3 – 4 ns rise times, 1 – 3 ns rms jitter and pulse widths of 10’s of ns. However, these systems grow in volume with increases in their erected voltages, since more Marx stages leads to higher source impedances and lower load voltage efficiencies.

Recent efforts, however, with compact Marx generators have brought faster rise times, higher peak voltages, and increased load voltage efficiencies, making them good candidates for direct RF generation and indirect RF generation [1].

This paper discusses a dual polarity Marx generator system capable of delivering a pulsed magnitude voltage of more than 3 MV and specifically designed for generating long streamers in air.

The application demands a compact pulsed high system capable of delivering more than 3 MV. To meet the compactness, two of APELC’s 1.6 MV generators are used in a differential configuration, with one generator having a positive charge voltage and the second generator having a negative charge voltage. To achieve alignment between the pulses, an external thyratron-based trigger unit was designed and fabricated to deliver two positive high voltage pulses to each generator with no pulse-to-pulse jitter.

Ultimately, the system is comprised of two battery powered 1.6 MV generators. Each generator integrates a high voltage power supply, a voltage controlled air pressure regulator, a front-panel user interface and controller logic. The two generators are simultaneously triggered by a remote thyratron trigger source. A fiber-optically connected hand-held control box provides the charge and fire control of the system.

II. Background and Design

A. The Wave Erection Marx Generator

Traditional and antiquated Marx generator designs simply fabricate the circuit based on the fundamental Marx circuit concept—i.e. charging a bank of parallel capacitors via resistors and then switching the capacitors into a series configuration via interconnecting spark gap switches for a voltage multiplication. This simple design leads to slow voltage rise times and relatively low load voltage efficiencies.

Newer design methodologies include a good ground plane and the consideration of the associated stray components. As shown in Figure 1, the complete Marx generator model with a ground plane includes the stray-to-ground capacitance at each stage, the series inductance due conductive materials and the switch physics, and the stage-to-stage capacitance. Designing the stray elements into the overall design can lead to a “wave erection”, in which an electromagnetic wave efficiently propagates the Marx circuit as the switches sequentially close. As a result, ultra fast rise times and high load voltage efficiencies can result [2].

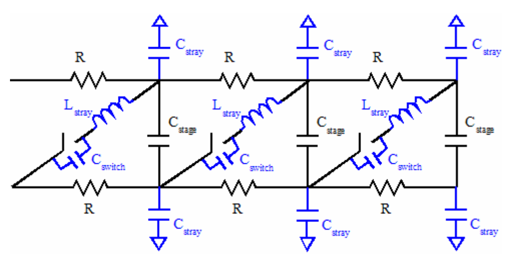

Figure 1. A schematic of the Marx generator considering the stray components.

B. The Basis Marx Generator

The basis Marx generator has been well defined in previous publications, compactly providing 40 Marx stages to deliver more than 800 kV onto a 50 Ohm load. The generator uniquely integrates the prime power, the high voltage power supply, the voltage controlled air pressure regulator, the front panel user interface and the control logic within the ancillary component housing.

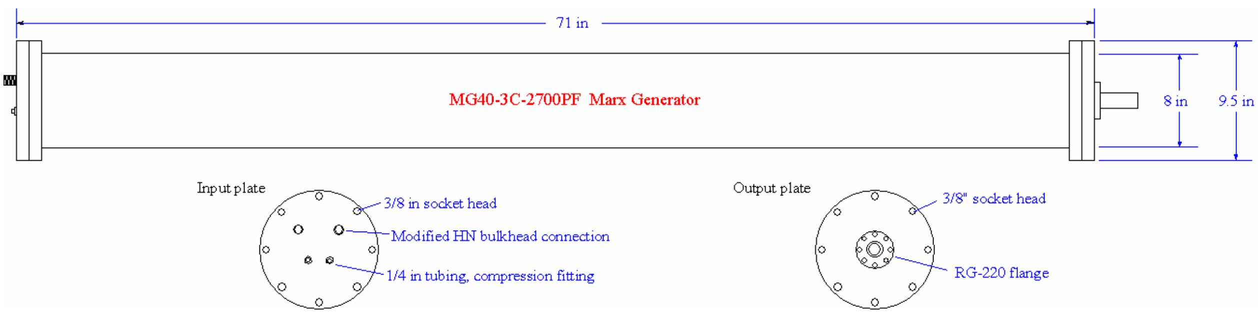

Figure 2. Mechanical view of APELC's MV generator

The core design employs three TDK UHV-6A (30 kV, 2.7 nF) capacitors per stage, for a stage capacitance of 8.1 nF. The capacitors are mounted to an ABS insulator that also fixes the brass electrodes and provides electrical interconnects. The Marx stages, once integrated, compactly slide inside the insulating medium, which is fabricated with nylon. The liner has an internal diameter of 5 ½ inches and an outside diameter of 7 ½ inches. The liner is encased in an aluminum tube that has a wall thickness of ¼ inches. The completed generator has a length of 42 inches, with a tube diameter of 8 inches (a collar diameter of 9.5 inches). A conceptual view of the housing is shown in Figure 2. The generator's electrical characteristics are provided in Table 1 and its mechanical characteristics are provided in Table 2.

Table 1. Electrical characteristics of the generator.

Parameter	Description	Value	Unit
V_{open}	Open circuit voltage	1600	kV
V_{ch}	Maximum charge voltage	40	kV
N	Number of stages	40	
N_{cap}	Number of capacitors per stage	3	
C_{stage}	Capacitance per stage	8.1	nF
C_{marx}	Erected capacitance	203	pF
L_{marx}	Erected series inductance	1	uH
Z_{marx}	Marx impedance	70	Ohm
EFF_{volt}	Voltage efficiency into 50 Ohm load	42	%
P_{power}	Peak power	15	GW
E_{marx}	Energy stored in Marx	260	J
T_{ch}^{*}	Time to charge	25	ms
T_{RR}^{*}	Maximum repetition rate	30	Hz
$P_{ave}^{\wedge}$	Average power	10	kJ/s

Table 2. Physical characteristics of the generator.

Parameter	Description	Value	Unit
D	Diameter	8	in
L	Length	72	in
Vol	Total volume	4600	in^2
W	Weight	300	lb

C. Ancillary Component Module

A block diagram of the ancillary component module is provided in Figure 3. This module is designed to incorporate much of the facilities required to operate the generator, including a battery pack for prime energy, a variable high voltage power supply, a voltage controlled air pressure regulator and control logic. The control logic board provides two functions, 1) to allow the user to preset the charge voltage and pressure level, and 2) to provide instantaneous charge voltage and internal pressure readings. In this manner, the control board interfaces with the individual components as well as with the front panel user interface, shown in Figure 4.

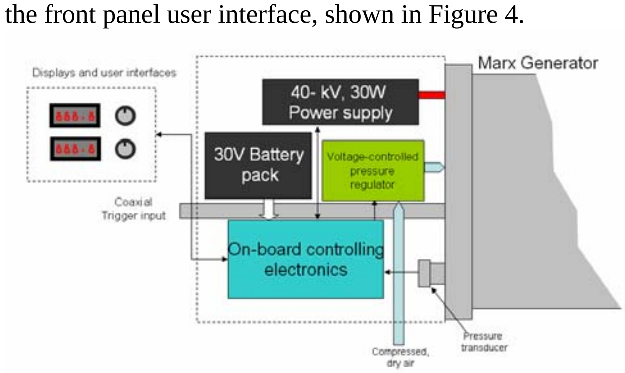

Figure 3. Block diagram of the ancillary component module.

Figure 4. Photograph of the front panel interface.

D. Trigger System

This effort requires that the temporal rms jitter between the output pulses of each Marx generator be less than 10 ns. This requirement means that the trigger source(s) to exhibit minimal temporal jitter, to be characterized by fast voltage rise times, and to have the ability to survive in an extremely difficult electrical environment. As a result, solid state solutions were immediately discounted, due to their slow rise times at voltages larger than 20 kV and their susceptibility to voltage transients. Pulse transformer solutions were also discounted due to the slow rise time.

The concluding solution removed the trigger source from each generator and into a single trigger switch design. As shown in Figure 5, a thyratron-based design is employed. The thyratron was chosen for its high voltage operation, 18 kV, and the ability to produce fast rise times. The thyratron switches two parallel high voltage capacitors to ground, causing the capacitors to dump their energy into two parallel coaxial cables, one for each Marx generator. Note that since a single thyratron switch is used, there is negligible temporal jitter between the two trigger pulses. Ultimately, the trigger unit was designed to deliver two 18 kV pulses, each characterized by a sub-20 ns rise time.

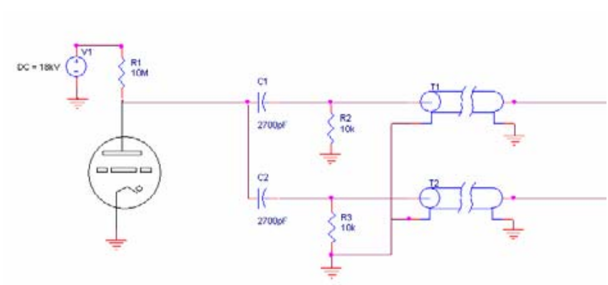

Figure 5. The central thyratron-based trigger unit.

C. System Overview

The complete system is illustrated in Figure 6, and includes the two 40-stage generators, each with its own ancillary component module, the external trigger unit, and a hand held control unit.

Operationally, the user presets each Marx generator's charge voltage and pressure levels. With the hand held control unit, the user may then simultaneously enable the charging of each generator, and once charged, initiate the trigger event.

IV. EXPERIMENTAL RESULTS

The trigger unit is tested for performance in temporal jitter, peak voltage into a high impedance load, such as with a trigatron spark gap, and the temporal separation of the two pulses.

The test arrangement is illustrated in Figure 7, and includes the trigger unit, a trigger generator, two Tektronix P5100 high voltage probes and a TEK TDS 5034 real time oscilloscope. A sample measurement is shown in Figure 8. The two pulses are well aligned in time. The peak amplitudes are approximately 30 kV and the rise times are 15 ns, measured on a 10 – 90% scale. The temporal jitter between the two output pulses is not measurable.

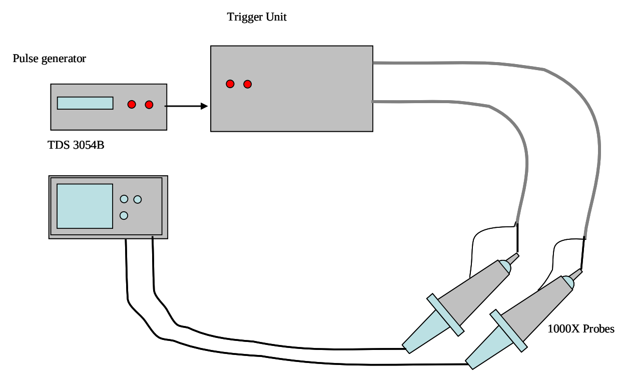

Figure 7. Arrangement for testing the trigger unit.

The full system was initially tested with each generator firing into a unique load comprised of a 50 ft. section of RG-220 and a 50 Ohm high power resistor. Located on each section of the coaxial cable is an inline Current Viewing Resistor (CVR), that provides a 1,500 attenuation. The signals from the parallel CVRs are fed into a Tektronix TDS 6604, 6 GHz real time oscilloscope.

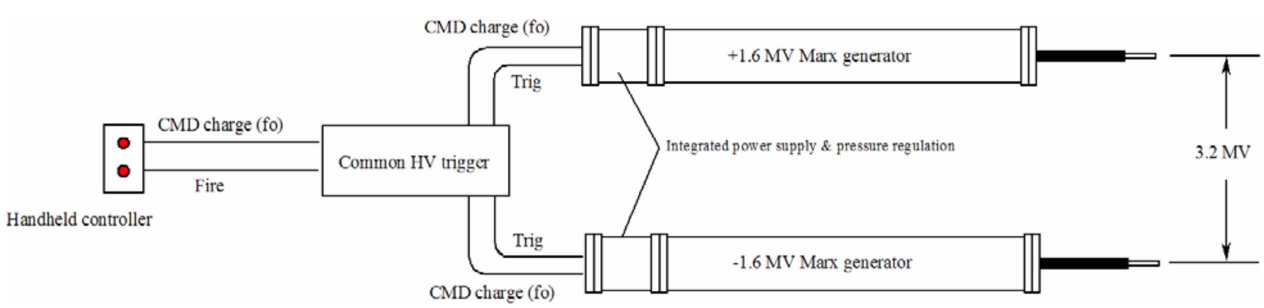

Figure 6. System schematic of the dual polarity MV Marx generator system.

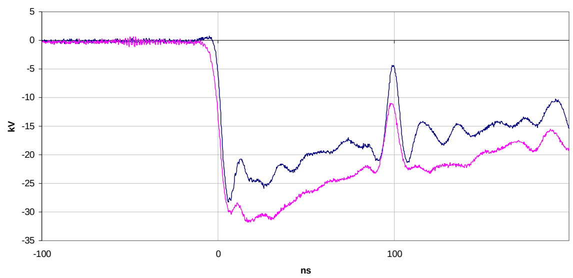

Figure 8. Sample measurement from the trigger unit.

A sample of the measured output of the dual polarity MV system is shown in Figure 9. The trigger pulses are synchronous when the generators are operated in the 30 – 40 kV charge voltage range, and at approximately 80% of their self breakdown level. The temporal jitter of each generator is not discussed in this paper; however, it was found that the jitter increases as the generators are operated at lower voltages, or lower on their respective Paschen curves. Also apparent from Figure 9 is the failure of the resistive loads which forms a short circuit. In the case of this experiment, short circuit formation was desirable to allow controlling electronics to be tested for extremely harsh voltage transients.

Ultimately, the cable loads were connected to a single and common load resistor. Obviously, very large arcs were witnessed.

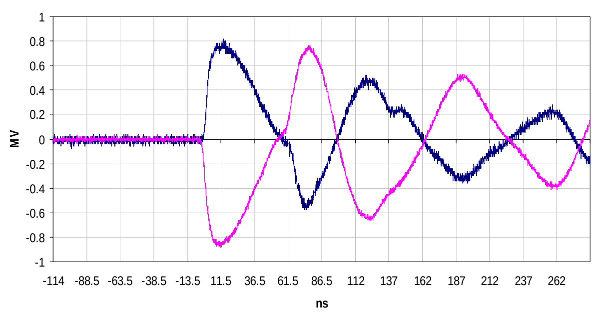

Figure 9. A sample waveform captured from the output of the dual polarity system.

V. CONCLUSION

Two APELC 1.6 MV Marx generators have been coupled together so as to generate a 3.2 MV differential pulse. To achieve this magnitude, one Marx generator is charged with a positive charge voltage, and the second Marx generator with a negative charge voltage. The output cables from each Marx generator share a common ground reference, and the differential between the respective center conductors produces the 3.2 MV pulse. Each Marx generator has an integrated ancillary module containing battery power, a high voltage power supply, a voltage-controlled pressure regulator, front panel user interface and control logic. To insure close temporal alignment of the voltage pulses, an external thyratron-based trigger source simultaneously triggers both Marx generators.

The dual polarity system has been tested and characterized for amplitude and control performance. The trigger unit provides an 18 kV pulse to each Marx generator, with no measurable temporal jitter between the two trigger signals.

Each Marx generator was optimally designed for a nominal charge voltage of 30 kV. As a result, charge voltages less than 30 kV increases the temporal jitter. However, charge voltages in excess of 30 kV results in a temporal jitter of less than 5 ns. Load voltages in excess of several MV were observed.

VI. REFERENCES

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2. D. Platts, GigaWatt Marx Bank Pulsers, Ultra-Wideband Radar: Proceedings of the First Los Alamos Symposium, Ed. Bruce Noel, CRC Press, 1991