COMPACT, DC-POWERED 100Hz, 600KV PULSED POWER SOURCE

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Abstract

A DC-powered, compact source capable of delivering in excess of 300 kV into a matched load is realized driving a 16-stage Marx generator with a 10 kJ/s rapid capacitor charger. The system is capable of delivering 100 J per pulse at a maximum pulse repetition frequency of 100 Hz. The Marx generator and capacitor charger are housed in a cylindrical package with approximate dimensions of 12”X60”. The pair are powered from a 300VDC bus. The unit is controlled remotely via a fiber-optically isolated micro-controller which provides the gate drive signals and user interface for the rapid capacitor charger. Performance data for the Marx generator and the capacitor charger is presented in this paper.

I. INTRODUCTION

Recent interest in electronic warfare in the modern day battlefield has generated a need for power sources which are capable of generating thousands to millions of volts in the form of short duration, fast-rising pulses. These sources can produce RF radiation in the form of a damped sinusoid or an ultra-wideband pulse when used in conjunction with radiating antennas, and can also drive loads capable of generating High-Power Microwave (HPM) bursts[1].

Coupling power from these systems into a targeted electronic device can cause failure in two predominant ways: 1.) Disruption by inducing a high electric field between a circuit trace and/or component and ground plane resulting in an erroneous signal which temporarily halts the operation of the device. 2.) Destruction by inducing a current onto the components of the system, resulting in ohmic heating and a consequential failure, or by electric breakdown within a component caused by high electric field levels.

The Marx Generator has been identified as an ideal source for driving RF and HPM loads capable of generating the high peak-power levels required for disrupting or destroying electronic devices. The resulting systems are robust, deployable, low-impedance, and capable of rep-rated operation.

The purpose of this effort is to construct a source which integrates a rapid capacitor charger, Marx generator, and triggering system in a single package which can be powered from a 250-300 VDC bus and is capable of 100-Hz operation.

This paper presents experimental data from the 10-kJ Rapid Capacitor Charger developed at Texas Tech University connected directly to an APELC MG16-3C-2700PF Marx generator, and operated at 100 Hz, 40 kV charge.

II. BACKGROUND

A. The Wave Erection Marx Generator

The Marx Generator is a means of generating high voltages by charging capacitive elements in parallel and then switching them into a series configuration, resulting in a voltage multiplication of (Nstages)*(Vcharge).

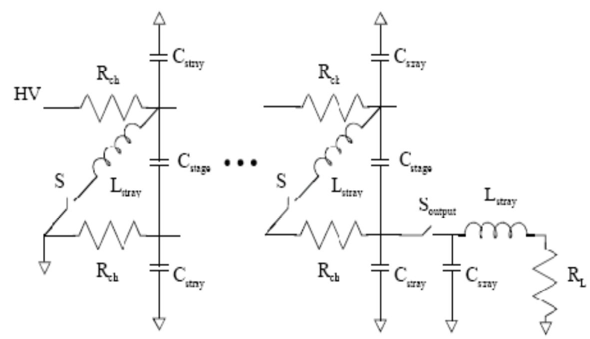

Figure 1. Schematic of the Wave-erection Marx Generator

J.R. Mayes demonstrated that the Wave Erection Marx generator with specifically designed stray capacitances and inductances was capable of directly sourcing RF loads[2].

Figure 1 demonstrates schematically how the stray capacitances act as a coupling mechanism between stages, and the stray inductances contribute to the pulse shape and total erected impedance of the generator. The MG16-3C-2700PF Marx generator is such a device, and is used in this effort to generate a 600kV (open-circuit), 50 ns wide pulse.

An inductor was designed to provide an inter-stage charging element capable of providing a sufficiently high-impedance isolation element between stages during firing, while handling 40 kV and 4 amps of charge current. The inductor is a crucial element in the design, allowing fast charging of the capacitors without breaking-down/failing during discharge events.

B. Rapid Capacitor Charger

Previous work by Texas Tech University has yielded a rapid capacitor charger capable of charging the parallel capacitance of the APELC Marx generator in well under 10 ms, resulting in 100 Hz or greater repetition rates[3].

The charger utilizes an IGBT-based H-bridge topology as a solid state driver to provide a 30-40 kHz PWM signal to a high frequency transformer constructed by *Stangenes Industries*. The output from the transformer is rectified by a *HVCA* multi-tap rectifier, providing up to 50 kVDC from a 300 VDC bus [2].

The timing of the gate drive signals for the IGBTs and the firing rate for the trigger generator are conducted by a *Freescale* HCS12 microcontroller. The microcontroller can be operated via an LCD front panel display and keypad accessible voltage and shot-number settings.

Figure 2. Marx Generator with Attached Capacitor Charger

III. EXPERIMENTAL ARRANGEMENT

Table 1. MG16-3C-2700PF Parameters

Symbol	Parameter	Value	units
N	Number of Marx generator stages	16	-
E_{pulse}	Maximum Marx energy per pulse	100	J
-	Maximum vessel pressure	150	PSI
V_{ch}	Marx peak charge voltage	40	kV
V_E	Peak Erected voltage	640	kV
Pmax	Peak Power (matched load)	4.45	GW
C_{stage}	Capacitance per Marx stage	8.100	nF
C_E	Erected capacitance	506	pF
Z_m	Marx Impedance	23	Ohm
L	Marx Generator Length	42	In.
D	Marx Generator Diameter	8.5	In.
RR_{max}	Maximum Repetition Rate	100	Hz

Figure 3 shows the layout for the experimental test-bed. The rectified 208 VAC yields 290 VDC to the capacitor charger rail. When the button is depressed on the fiber-optically isolated remote, the controller sends the timing signals to the gates of the IGBT H-Bridge, switching the 290 VDC, providing the PWM signal for the high-voltage transformer.

The rectified voltage from the transformer secondary charges the capacitance of the Marx generator, an event which is monitored by a fiber-optically isolated voltage feedback circuit. When the charge voltage on the capacitors reaches the voltage preset by the user, an optical signal is broadcast to the trigger generator and the Marx is erected. During rep-rated operation, air is flowed through the Marx to purge the gaps, and the controller sends the above sequence for the duration of the shot burst.

The output of the generator is fed into a 50-Ohm coaxial cable and monitored by a cable-mounted current-viewing resistor (CVR).

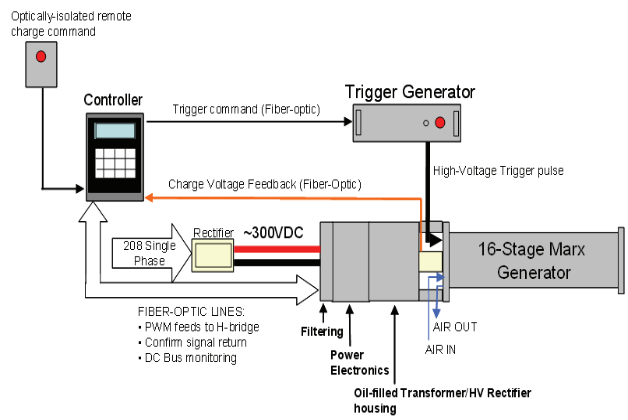

Figure 3. Experimental Arrangement

IV. EXPERIMENTAL RESULTS

Compressed dry breathing air is used as an insulating medium in the APELC line of marx generators due to its cost, availability, and non-reactive nature. In order to remove particulate matter generated by ablation of the spark gaps, a constant flow of air is maintained within the system.

An iterative shot sequence was performed over the 8-40 kV operating regime of the Marx generator system. Upper and lower limits were determined for each operating point in 5kV increments by firing the generator at a given pressure and determining where the generator would breakdown prematurely (self-break), or would not erect due to too high of a pressure.

An ideal combination of the charging time, time between shots, pressure, and flow-rate of the insulating gas was found experimentally in order to achieve stable operation at 100 Hz. This combination was noted to be the fastest possible charge time (~8ms), a short 20 us hold time, and the remainder of the 10 ms interval utilized as clear time between shots. This allowed ample time for hot gas and particulate matter to be carried away from the spark gap region before the next charging cycle occurred.

The Marx generator was pressurized to 110 psi, and a flow rate of 3 scfm was set to ensure the correct balance between flow-rate and insulating gas-pressure. Figure 5 shows the resulting waveforms for this shot sequence, while Figure 4 demonstrates an un-optimized shot sequence containing two self-breaks occurring out of the 20 shot burst.

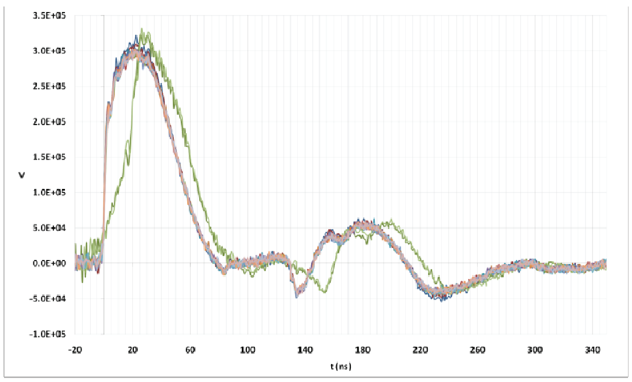

Figure 4. 20 Shot Overlay, 100 Hz/40 kV- Unoptimized

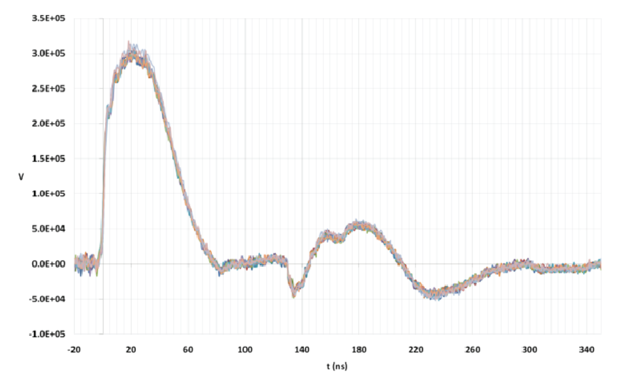

Figure 5. 20 shot overlay, 100 Hz/40 kV- Optimized

The trigger and charge voltages are available via low-voltage analog signals coming from each supply (Figure 7). These signals were used as a corroborating diagnostic along with the CVR signal. If the charge voltage dropped to zero before the 8ms interval was reached, it could be assumed that a self-break had occurred. Conversely, if the charge waveform maintained a constant, or slowly decaying voltage beyond the 8ms interval, it was determined that the pressure was too high to allow the Marx to erect.

Figure 6 shows the final operating curve for the system. A distinct difference is noted between the curve for single shot and rep-rated operation. During a single shot test, a DC supply is used to charge the generator. It is thought that the longer charge times associated with this mode allow for high-voltage creep to occur and therefore a higher pressure is required for insulation.

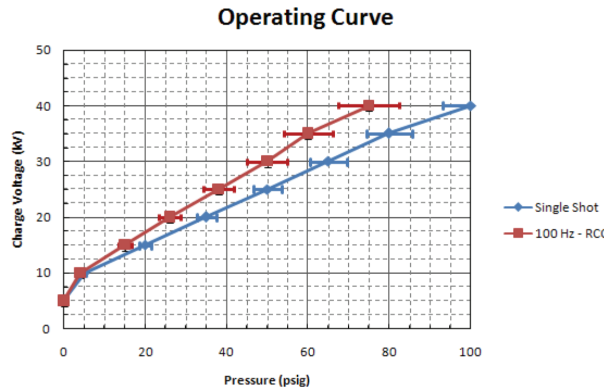

Figure 6. Optimized P-V Curve for 100 Hz Operation

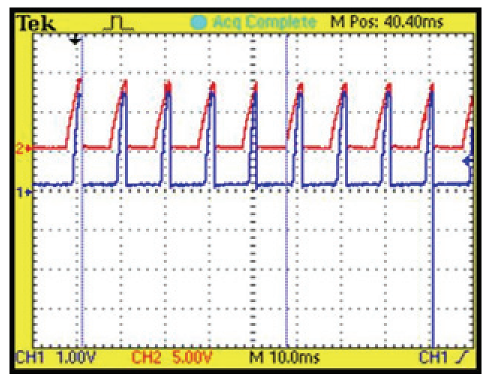

Figure 7. Marx and Trigger charge voltage- 100 Hz

V. SUMMARY

A 16 stage marx generator was attached to a 10 kJ/s Rapid Capacitor charger and tested for operation at 40 kV charge and 100 Hz repetition rate.

The conclusion was made that this system is capable of operation at these benchmarks provided proper air flow, good charge inductor design, and correct timing values for the charge and discharge sequences.

VI. REFERENCES

[1] R.J. Barker and E. Schamiloglue, High-power microwave sources and technologies: IEEE Press Piscataway, NJ, 2001.

[2] J.R. Mayes & W.J. Carey, "The Generation of High Electric Field Strength RF Energy Using Marx Generators", Conference Record for the 25th International Power Modulator Symposium, 2002.

[3] Giesselmann, M., McHale, B., Heeren, T. “New Developments in High Power Capacitor Charging Technology,” Conference Record of the Twenty-Sixth International Power Modulator Symposium, 2004 and 2004 High-Voltage, 23-26 May 2004, Pages: 395-398.