

# RAPID CHARGER FOR HIGH REPETITION RATE PULSE GENERATOR \*

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## Abstract

The design and operation of a command resonant charger feeding a high repetition rate pulse generator using an advanced Pseudospark device is presented. An application – corona assisted flame ignition and combustion – is discussed briefly. This application requires operation of the Pseudospark switch at 30kV charging voltage and 1 kHz repetition rate. The charging time of the 6nF / 30kV quasi Blumlein pulse forming circuit capacitance is 50 $\mu$ s. Operation is burst mode, with maximum 100 pulses per burst.

## I. INTRODUCTION

Commercial applications of High Voltage (HV) pulse generators often require operation at significant pulse repetition frequencies. For example, corona assisted pollution abatement [1,2,3], flame ignition for combustion enhancement [4] and for Pulse Detonation Engines (PDE) need pulse repetition rates from 1 to several kHz. Higher repetition rates place special demands on the pulse generator switch as well as on the charging circuit feeding the HV energy storage capacitors. We consider here a pulse generator system based on a commercial Pseudospark as a HV switch. The Pseudospark is a glow-discharge switch that is an extrapolation of thyatron technology, using a different emission process than a traditional externally heated cathode. It is well suited for the present application due to low inductance, high peak current capability, relatively high repetition rate and long life. For reviews see [4, 5, 6, 7].

The charging circuit of this pulse generator system described here is of a command resonant type. It is capable of operating in burst mode with a maximum of 100 pulse bursts at 5 kHz pulse repetition frequency. The circuit can charge 6 nF of capacitance to 30 kV in 50  $\mu$ s. The repetition rate of the Charger / Pulse Generator system is presently limited by the Pseudospark switch to 1.5 kHz.

## II. DESIGN

There are two basic configurations of resonant charging circuits, the Forward converter based one which uses a closing switch and the Flyback converter based which uses an opening switch. The rapid charger is based on a forward configuration. Here, the energy is first stored in a capacitor bank and switched into the primary winding of the pulse transformer. The secondary current charges the load capacitance during the switch on-time (Fig. 1.).

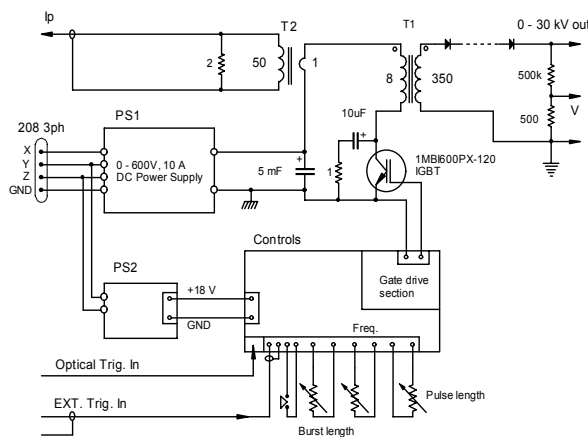


Figure 1. Rapid Charger block diagram

During the charging period the transformer leakage inductance forms a resonant circuit with the load capacitance. The output voltage wave shape of the charger is, therefore, a half sine wave. As the primary storage capacitance is much larger than the load capacitance reflected to the primary side it behaves as a constant voltage source. Charging is completed when the current in the resonant inductance returns to zero, thus all energy is transferred to the load capacitance. The nominal output voltage in the absence of any losses is twice the primary storage voltage times the turns ratio of the transformer.

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The charger circuit must deliver  $E = 0.5 C V^2 = 2.4 \text{ J}$  energy per pulse to the load which consists of the energy storage capacitors of the pulse forming network. Continuous operation at 1 kHz repetition rate implies a primary Direct Current (DC) power of  $\sim 3 \text{ kW}$ , assuming 80% overall efficiency. The primary power source is, therefore, a commercial 0-600V, 10A variable DC power supply, fed from 3 phase 208V mains.

Control functions are provided by the timing and synchronization circuit, based on three NE555 type timers. The trigger input can be either external, through an optical fiber for ground interference elimination, or internal, effected by a manual pushbutton. External trigger output is provided for the Pseudospark.

### A. Primary Energy Storage

The commercial DC power supply keeps the primary energy storage capacitor bank at a constant voltage. The bank capacitance is 5mF. It consists of 8 electrolytic capacitors, 2500 $\mu\text{F}$  / 350V each, in a series-parallel arrangement. With 100V safety margin, the bank can be charged to 600V, although it is used generally below 400V. A resistive voltage divider ensures that all capacitors are stressed equally. The capacitors were chosen according to the lowest equivalent series resistance, so efficiency loss due to non-ideal bank capacitance is minimized.

### B. Switch

The main switch is an Insulated Gate Bipolar Transistor (IGBT) 1MBI600PX-120 from FUJI Electronics. It is rated at 600 A maximum continuous current and 1200 V maximum collector potential. The switch can operate in pulsed mode at twice the rated current, but the voltage rating is quite rigid, so protection circuitry is essential for reliable switch operation. This protection is provided by the 1 $\Omega$  / 10W resistor in series with the 10  $\mu\text{F}$  / 900V capacitor connected across the collector and emitter terminals. As Figure 2 shows, the Flyback pulse at the end of the charging period does not rise above 600 V in normal operation. For the worst case, when the switch interrupts a fault current of  $\sim 1 \text{ kA}$ , the 1  $\Omega$  resistor limits the rising edge of the collector voltage to 1 kV. The stored energy in the magnetizing inductance of the transformer is then comfortably absorbed by the series capacitor, clamping the rest of the waveform below 1200 V.

Special attention must be paid to the gate drive of the IGBT. We use a 9 A rated driver IC, the NCP4422. The rising edge of the gate drive waveform must be short and the driver must be able to supply enough current to absorb the Miller capacitance charge due to the falling collector waveform reflected to the gate, hence the high current requirement from the IC.

It is important, that the IGBT stays fully on during the charging pulse. If the gate voltage falls below 10 V the IGBT dissipation increases significantly and the output voltage will decrease. In some cases damage to the IGBT may result as well.

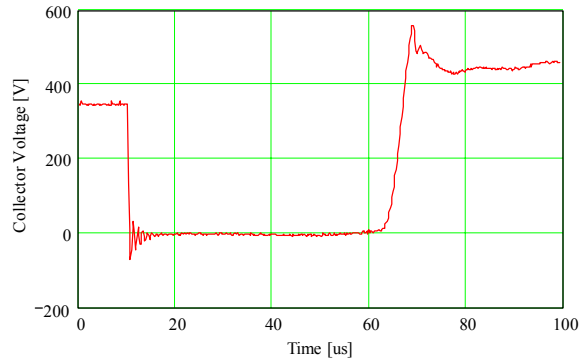


Figure 2. IGBT Collector Waveform

The pulse is applied through a series diode to the gate. This diode isolates the gate from the falling edge of the IC output and allows control of the falling edge of the gate voltage by a 50  $\Omega$  gate to emitter resistor. Slow turnoff allows the use of the IGBT as a high power resistor to absorb some of the Flyback energy, thereby reducing the power rating of the snubber resistor. The gate drive waveform is shown in Fig. 3.

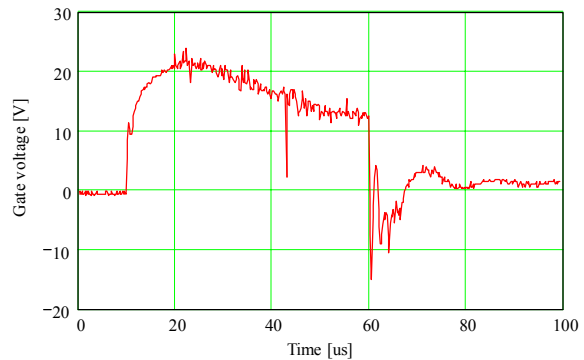


Figure 3. IGBT Gate Waveform

### C. HV Transformer

The HV transformer is wound on a 4" ID, 6" OD, 2" High toroidal core from Arnold Magnetics, Inc. The core is made of 4 mil silicon iron tape, and has a 1 mm gap. Gapping the core eliminates the need for a separate flux reset circuit, although the core size could be reduced and the efficiency improved due to the significantly higher magnetizing inductance without the gap. The core is epoxy coated. Further insulation is provided by five layers of Teflon tape.

The secondary winding is in three layers, the bottom layer is 200 turns of #22 awg magnet wire, the middle layer is 100 turns centered on the first layer, and the top layer is 50 turns centered on the second. Two layers of Teflon tape isolates the layers from each other and from the primary winding on top of the secondary.

The primary is 8 turns of #14 awg Teflon insulated wire, distributed evenly around the toroid in order to reduce the primary leakage inductance to a minimum.

The transformer is mounted on a 3/8" thick polyethylene sheet with Tie-wraps.

#### D. Diagnostics

Output voltage is monitored by a 1000 : 1 resistive voltage divider. The upper element is a 30 kV rated 500 k $\Omega$  resistor from CADDOCK, the lower is 500  $\Omega$ . Due to the relatively slow charging pulse a simple resistive divider is adequate.

The primary transformer current is monitored by a 50 : 1 current transformer. The transformer is made from a small, 1/2" OD ferrite toroid, the primary is a single turn, while the secondary is 50 turns of #26 awg magnet wire evenly spaced around the toroid. The secondary winding is terminated by 5 resistors in parallel, 10  $\Omega$  / 2W rated each, for a total load of 2  $\Omega$ . Thus, the current transformer will give a signal of 25 A/V.

### III. OPERATION

The charger has been operated successfully with the Pseudospark based pulse generator in a corona assisted combustion experiment. A sample output voltage in a single charging period is shown in Fig. 4.

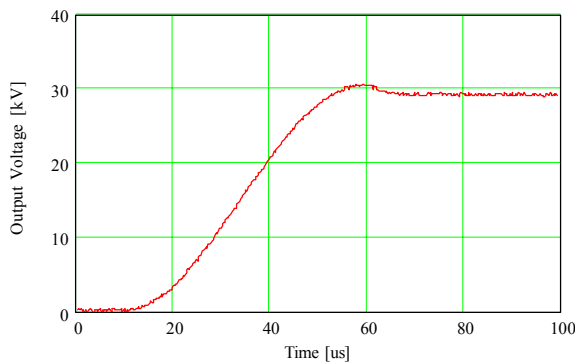


Figure 4. Output waveform in a single charging period

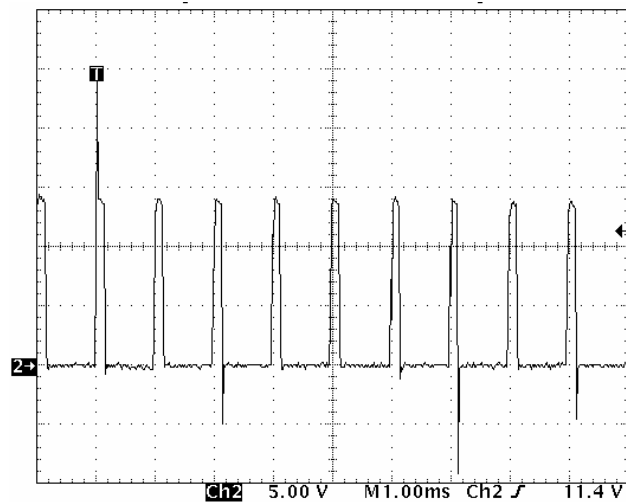


Figure 5. Output voltage, 2 kV/V, 1 kHz burst

Repetitive operation at 1 kHz is illustrated in Fig. 5. The pseudospark switch fires at  $\sim 100$   $\mu$ s, and as is seen on some of the pulses in Fig. 5, it sends a negative going voltage pulse propagating back along the coaxial cable connecting the charger to the HV Pulser.

In order to suppress spurious retriggering of the IGBT by this reflected pulse a terminating 100  $\Omega$  resistor and a series inductor is connected between the coaxial cable and the load capacitance. This resistor damps out any oscillations and cable ringing and the inductor reduces the initial voltage stress across the resistor

### IV. SUMMARY

We have described the design, construction and operation of a command resonant charging power supply used to energize a Pseudospark based pulse generator. Reliable long life operation is made possible by the robust IGBT solid state switch and toroidal HV transformer in the charger and by the Pseudospark switch in the pulse generator.

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