



# Review of High Voltage Pulsed Power Supplies and Power Electronics in Pulse Power Generation

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## Abstract

Recently, pulse-shaped power supplies have become more popular. Pulsed power is versatile and useful as a supply method since it can take several shapes and has many pulse characteristics. The release of electrons, protons, and neutrons from an atom and the synthesis of molecules to generate ions or other molecules require a lot of immediate energy. Pulsed power is needed for decomposition, molecular fusion and material joining, radiation generation (e.g., electrons, lasers, radar), explosive processes for concrete recycling, wastewater and exhaust gas treatment, and material surface treatments. Industrial and environmental applications require pulsed power, which requires efficient and adaptive pulse modulators. Higher-quality repeating pulses are needed for plasma fusion and laser weapons. Marx Generators, Magnetic Pulse Compressors, Pulse Forming Networks, and Multistage Blumlein Lines have several uses. Pulse modulators use spark gap and hydrogen thyratron gas/magnetic switching technologies for their high voltage tolerance and low-rise times. These creatures are inefficient, unreliable, repetitious, and short-lived. These devices are heavy, bulky, and expensive. Solid-state switching technology can replace conventional devices, improving pulse supply. High-frequency switching repeats the pulsed power supply. These items are compact, efficient, affordable, reliable, and durable. Solid-state transistor applications may not meet switch voltage ratings and rise time constraints. Various power electronics configurations can produce solid-state high-voltage pulses.

**Keywords:** High Voltage, MARX Generator, Power Electronics, Pulsed Power

## 1. Introduction

Pulse power technologies have become increasingly prominent in recent years due to their ability to generate high-voltage and short-duration pulses, which have significant potential in various fields. Pulsed power is a technique that entails the accumulation of energy over a prolonged period, followed by its swift discharge, leading to a significant surge in the instantaneous power output. The term “pulsed power” is frequently used to describe this phenomenon. The concept of progressively amassing energy and subsequently releasing it rapidly facilitates the provision of a higher magnitude of instantaneous

power within a condensed period, while still upholding a consistent level of total energy. The widespread utilization of pulsed power in diverse applications might be attributed to its distinctive characteristics. Pulsed power system capacitors and inductors store energy. High-capacity flywheel alternators store mechanical energy. Explosives and high-current lead-acid batteries store energy. Power electronics-based pulse power technologies will dominate this introduction.

WWII radar technology invented pulsed power. Sandia National Laboratories in New Mexico conducted considerable post-war research and development. These efforts enhanced pulsed power applications<sup>1</sup>. Industrial,

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environmental, medical, and military sectors use pulse power technologies. Sector pulses vary.

Industrial and environmental pulsed power generators cycle. Moderate peak power generators are used in food processing, medical treatments, wastewater treatment, exhaust gas treatment, concrete recycling, ozone creation, material processing, particle acceleration, engine ignition, and ion implantation<sup>2,3</sup>.

## 1.1 Pulse Power Technology

Pulse power technology improved radar, electromagnetic launchers, high-power microwave generators, and laser cannons. Pulsed electric and electromagnetic fields may influence cancer cells, requiring medical treatment. New therapies resulted. Studies show pulsed power electroporation manipulates genes and kills cancer cells<sup>4,5</sup>. Environmental pulse power electroporation sterilizes bacteria<sup>6</sup>. Pulsed power technologies aid Plasma-Based Ion Implantation and deposition (PBIL and D), material ablation, surface annealing, innovative material synthesis, and solid material modification via laser ablation or heating.

Power electronics' efficiency and versatility have accelerated pulse power systems. Pulse power and power electronics have enabled new high-voltage and high-power applications. Pulse power technology includes power electronics and conventional methods. Energy is accumulated and discharged to generate pulsed power. Pulsed power systems store electrostatic, electromagnetic, mechanical, or chemical energy. Power electronics revolutionized pulse power technology.

Pulse power systems transform, control, and regulate energy via power electronics<sup>7</sup>. These devices customize pulses by precisely altering voltage and current waveforms. High-power switches (insulated gate bipolar transistors, thyristors) and fast-switching components improve pulse power system efficiency, response time, and controllability.

Advanced military pulse power electronics. Power electronic systems in radar, electromagnetic launchers, high-power microwave generators, and laser guns improve performance, efficiency, and reliability. Power electronics generate precision, high-voltage, high-power energy pulses. Military-grade capability.

### 1.1.1 Magnetic Pulse Compressor (MPC)

Multiple laser emissions utilize Multi-Photon Counting (MPC) techniques. The utilization of a solid-state MPC in conjunction with amorphous metals facilitated the

pulsation of a repetition-rated KrF excimer laser<sup>8</sup>. In a previous study, the authors<sup>9</sup> proposed the development of a switched multistage MPC system utilizing a Thyristor, specifically a Silicon Controlled Rectifier (SCR), for KrF excimer laser excitation. Due to its composition of solid-state elements, this exciter is expected to exhibit a prolonged lifespan when subjected to high repetition rates, in comparison to a power supply lacking a discharge switch. Shimada *et al.*<sup>9</sup> uses a saturable transformer in an MPC to reduce switching component stress in excimer laser excitation circuits. A two-stage MPC-equipped all-solid-state exciter pulsed a transversely excited atmospheric CO<sub>2</sub> laser at high repetition rates<sup>11</sup>. MPC and IGBT-based pulse generators achieve a similar goal<sup>12</sup>. Pulsing circuits with tens of kilowatts are needed for industrial excimer and CO<sub>2</sub> TEA pulse lasers with comparable optical powers. Laser excitation pulses must have 100 ns voltage rise times and 40 kV peak voltages.

For laser excitation, a 40 s pulse can be reduced to 150 ns using a four-stage series MPC. The paper<sup>13</sup> develops and experimentally verifies the efficiency, scalability, and repeatability of a pair of all-solid-state, high-efficiency two-stage MPC exciters for driving TEA CO<sub>2</sub> lasers.

### 1.1.2 All-Solid-State Marx Generator

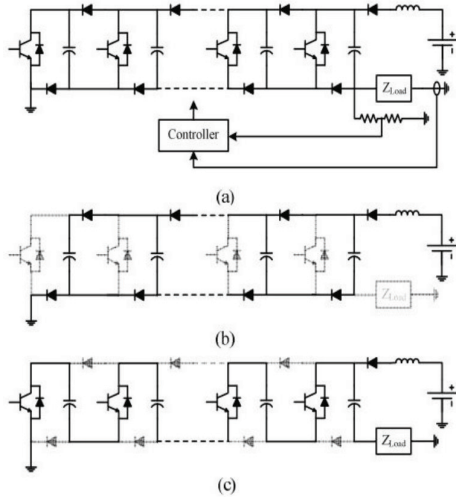
Solid-state technology has replaced the traditional usage of spark gaps or magnetic switches in Marx Generators (MGs), improving efficiency and reliability. The circuit schematics of a solid-state MG in both charging and discharging modes are shown in Figure 1. This section highlights recent solid-state MG applications.

One all-solid-state MG powers micro-plasma applications<sup>14</sup>. In this instance, BJTs close two parallel MGs. Avalanche mode speeds up these BJTs. The circuit design can produce positive or negative polarity pulses and greater or lower voltages by changing the output voltage.

Marx topology is used in many high-voltage applications due to its benefits. Bae *et al.*<sup>15</sup> describes a high-voltage bipolar rectangular pulse generator with a solid-state boosting front-end using H-bridge Insulated-Gate Bipolar Transistors (IGBTs). Pulses break algal cell membranes during oil extraction.

A magnetic pulse-sharpening circuit and discrete IGBT Marx modulator are proposed for an all-solid-state pulsed power generation<sup>16</sup>. The pulse-sharpening circuit compresses the Marx modulator's output pulse rising edge to increase pulse rise time and compensate for IGBTs' poor turn-on speed.

Solid-state technology has enhanced MG performance, efficacy, and dependability. From algal cell membrane rupture to micro-plasma energization to pulsed power generation, solid-state MGs are versatile and efficient.

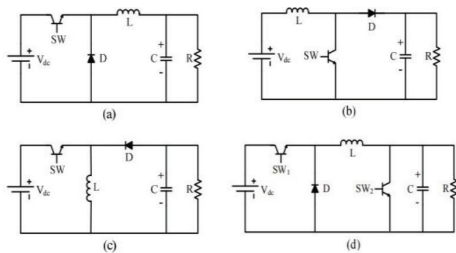


**Figure 1.** (a) A Marx generator that operates using solid state components (b) While charging (c)While discharging.

**1.1.3 DC-DC Converters**

Early power electronics topologies include DC-DC converters. Many applications require voltage change. Transformers convert voltage. Unlike transformers, DC-DC converters are simple, practical, and efficient. Despite their extensive use, these gadgets are becoming more popular in other fields<sup>7</sup>.

Nonlinear loads like Switched Mode Power Supplies (SMPS) can degrade supply-side power quality. When connecting and feeding equipment from the grid, current harmonics injection and reactive power flow must be considered. PFCs can fix these difficulties. Passive and active PFCs exist. Figure 2 shows buck, boost, and buck-boost



**Figure 2.** (a) Buck converter. (b) Boost converter. (c) Buck-Boost converter. (d) Positive Buck-Boost converter.

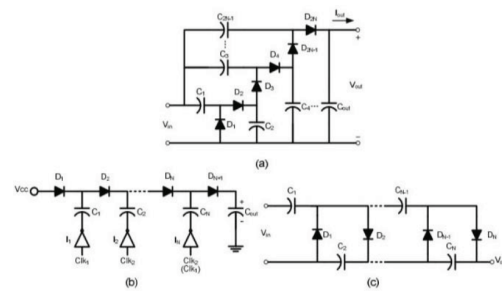
DC-DC converters as Active Power Factor Correction (PFC) devices. Single- or multi-stage converters are available.

PFC decreases harmonic currents and power consumption in Plasma Display Panels (PDPs)<sup>17</sup>. The interleaved boost converter, known for its great efficiency, demonstrates the ability to decrease conduction losses and address diode reverse-recovery issues within the framework of Continuous-Conduction-Mode (CCM) functioning. The technique of Zero-Current Switching (ZCS) involves the reversal of output diodes. A pragmatic converter control approach achieves a high power factor without input voltage sensing.

**1.1.4 Voltage Multipliers**

Space and communications use Capacitor-Diode-Based Voltage Multipliers (CDVM). Microelectronics applications including RF passive transponders, passive wireless micro-sensors, and battery-operated devices use the Cockcroft-Walton multiplier topology for voltage boosting<sup>18,19</sup>. Figure 3 shows three voltage multiplier configurations, including a Cockcroft-Walton N-stage schematic and a Dickson charge pump.

CDVM is tiny, lightweight, effective, and reliable in various applications. Touchscreen capacitance and delay are drawbacks. An ac-dc-ac converter at the multiplier input can enhance its working frequency<sup>20</sup>. Radio frequencies raise DC voltage with the Cockcroft-Walton multiplier. It simplifies circuits. Diodes and capacitors increase output voltage in increments. Gate-turning-free switches, transistors, control boards, and driving stacks minimize weight, complexity, cost, and reliability.



**Figure 3.** Capacitor diode voltage multipliers. (a) N-stageCockcroft-Walton VoltageMultiplier. (b) N-stage Dickson charge pump. (c) Another N-stage CDVM.

Circuits can accept different frequency input waveforms except pulse-shaped ones. The device handles sinusoidal, trapezoidal, and harmonically rich sinusoidal voltage waveforms. Input voltage stress (dv/dt) controls capacitor leakage current. CDVMs can handle pulsed power with these specs.

### 1.1.5 Pulse Generators based on Inverters

Modulating a repeated pulse shape waveform voltage over DC may improve output pulse control. Two-level or multilayer inverters can. Professionals thought of it, but DC-AC converters weren't. Pulsed power supply research uses inverters as lateral modules. Plasma system bipolar pulses result<sup>21,22</sup>. Another pulsed power system investigation used inverters. Run a silent-discharge ozone-generation tube<sup>23</sup>.

Circuits for converting power in ozonizers are coupled at high frequency. A voltage-source-fed full-bridge load resonant inverter using IGBT power modules, a three-phase active Power Factor Correction (PFC) rectifier, and an ozone-generation tube load with a series-compensating inductor make up the system. The load is connected to the inverter output using high-voltage, high-frequency transformers and series-compensating resonant inductors, according to Fujita, Akagi<sup>24</sup> and Shimizu *et al.*<sup>25</sup>. Key characteristics of load resonant inverter-type ozonizers include several, quicker than older models. The use of Insulated-Gate Bipolar Transistor (IGBT) modules with low-saturation trench gates and zero-voltage soft switching is made. Production of silent-discharge ozone is regulated by PDM.

Multilevel and multi-output inverters superseded conventional inverters. They outperform standard inverters. Multilevel converters improve high- and medium-voltage systems over two-level inverters. Lower semiconductor switching frequencies improve efficiency. It helps the converter attain a high voltage rating with less voltage sharing and switch voltage stress, reducing EMI.

### 1.1.6 Resonant Converters

Resonant converters are popular because oscillating inductive and capacitive components switch at zero-crossing. High-power applications benefit from these switching loss-reducing designs. Switching losses and a lack of high-power transformers limit switching frequency in high-power applications<sup>26</sup>. Resonant approaches have advanced soft switching.

High-voltage resonant converter applications are well-studied. The converter uses Hybrid Full Bridge (H-FB) Three Level (TL) and LLC resonant converters. This research examines phase-shifted regulation HF resonant converter technology. According to Lin *et al.*<sup>27</sup>, this method may be cost-effective for microprocessor Voltage Regulation Modules (VRMs).

Lin *et al.*,<sup>27</sup> analyze and design RF parallel resonant plasma drivers. The driver uses FB LC and variable inductor phase control. EMC regulation inhibits RF plasma module switching frequency changes. Trans-conductance amplitude controls load-current in variable-inductor control. The design allows for dead time to accomplish Zero-Voltage Switching (ZVS) with minimal LC parallel resonant tank circulating current to reduce switch conduction loss.

## 2. Conclusion

This study provided an analysis of pulse power technology and power electronic device integration. Pulse power systems, which store and release energy, have great promise across industries. Power electronics have transformed pulse power systems' efficiency, controllability, and adaptability.

Power electronic devices like high-power switches and fast-switching components help pulse power systems improve efficiency, response time, and voltage and current waveform manipulation. Integration has enhanced industrial, military, environmental, and medical uses.

Power electronics and pulse power technology have opened new high-voltage, high-power applications. Power electronics technology will improve pulse power technologies, providing new solutions for industrial, military, environmental, and medicinal applications. We may expect more advances and discoveries as we push power electronics integration and pulse power technologies to reach the full promise of high-power and high-voltage applications.

## 3. Acknowledgement

I would like to express my gratitude to both my supervisor, Dr. Amitava Roy, for the support and direction he has provided, as well as the APPD for the assistance they have provided.

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