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PROGRAMMABLE PULSE-POWER ARCHITECTURE FOR MULTI-PURPOSE, HIGH-POWER SPACE MISSIONS

Abstract

This paper presents a programmable pulse-power architecture termed the Dynamic Supercapacitor Network (DSN), extending conventional pulse-forming networks (PFNs) through modular energy storage, dynamic routing, and time-multiplexed discharge control. Unlike traditional PFNs with fixed hardware-defined pulse characteristics, the proposed architecture supports dynamic mission profiles by enabling reconfiguration of power levels and delivery schedules through software-defined shaping of power delivery profiles. Example applications may include lunar electromagnetic mass accelerators, in-situ resource utilization machines, and space beam systems.

The architecture consists of multiple supercapacitor banks interconnected via solid-state relays and governed by a microcontroller-based control layer. Power delivery is implemented through a time-multiplexed discharge strategy in which individual banks are sequentially connected to the load during their effective discharge intervals. The resulting sequence of controlled discharge segments forms a quasi-steady output profile. Because routing and scheduling are defined in software, output power levels and delivery durations can be adjusted without modifying hardware topology. At the network level, charging and discharging processes can occur concurrently across different banks, enabling reduced recovery time between discharge events. It also allows continued operation under partial bank unavailability through rerouting logic. System capability scales with the number of integrated banks and stored energy, with projected operation in the 1–50 kW range and configurable delivery windows (100 ms to 100 s per hour), subject to thermal constraints.

Upon conceptual formulation and mathematical analysis of discharge timing, a laboratory-scale proof-of-concept (PoC) model is developed. The PoC consisted of three supercapacitor banks controlled by an ATmega328P-based microcontroller implementing time-multiplexed switching logic. Oscilloscope measurements demonstrated a regulated 2.22 V output sustained for 8.1 seconds under a 5 W load, confirming the algorithm of the controlled time-multiplexed discharge and programmable routing. Scalability is assessed through LTspice circuit simulations performed at incrementally increasing power levels, with the objective of validating operation in the multi-kilowatt regime.