Pulsed Power Systems based on Supercapacitors

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Pulsed High Power Systems

**System Typical Requirements**

- Short power bursts: from 0.5 s to more than 100 s
- High power from tens kW up to several MW
- Low duty cycles: typically $\approx 1\%$ or less (in some industrial application from 5 to 10 %)
- Consequence: Low or very low average power

**System Constraints**

- The amount of electric power harvested from renewable sources is increasing
- Tolerance of utilities to active and reactive high power burst (flicker) is constantly diminishing
- Therefore, increasing operating costs add to investment costs, for systems connected to utilities on the basis of peak power requirements
Storage for Pulsed high power applications

Energy and power density in short term energy storage

Supercapacitors + conventional capacitors can combine high energy and power density with short times (ms range) for:

• High dynamic performance (short rise and fall times)

• High energy for long pulses in steady state or slowly varying currents
Supercapacitors in Pulsed Power Applications

- Effective capacitance depends on frequency range
  This property depends on the porous electrode structure and on the electrolyte's ion mobility
- The use of switching regulators (frequencies > 500 Hz), requires a low pass filter (with conventional capacitors)
A suitable decoupling filter is required between Supercapacitors modules and switching regulators.

(from S. Basu and T.M. Undeland, EPE 2009)
Its basic concept was presented one year ago at IEEE – EEEICon:

- Low impact
- Low pollution
- High power quality

- Low ripple
- Low overvoltage
- Stable parameters

Arbitrary Waveform

- $0 \div 2\,\text{kA}$
- $-120\div120\,\text{V}$

Supecapacitor Modules System
<table>
<thead>
<tr>
<th><strong>Electrical and mechanical characteristic</strong></th>
<th><strong>Output Characteristics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage Supply</strong></td>
<td>Maximum current (flat top)</td>
</tr>
<tr>
<td>230 Vrms</td>
<td>2.0 kA</td>
</tr>
<tr>
<td><strong>Input frequency</strong></td>
<td>Max voltage in ramp</td>
</tr>
<tr>
<td>50 Hz</td>
<td>± 350 Vdc</td>
</tr>
<tr>
<td><strong>Maximum input power</strong></td>
<td>Max duty cycle</td>
</tr>
<tr>
<td>1600 W</td>
<td>1.5/300 s/s</td>
</tr>
<tr>
<td><strong>Supercapacitor modules</strong></td>
<td>Operation</td>
</tr>
<tr>
<td>2 x 165 F (upgradable to 4)</td>
<td>2 quadrants</td>
</tr>
<tr>
<td><strong>Charging time of supercapacitors</strong></td>
<td>Load rated inductance</td>
</tr>
<tr>
<td>≤ 30 minutes</td>
<td>≤ 500 μH</td>
</tr>
<tr>
<td><strong>Recharging time between pulses</strong></td>
<td>Load rated resistance</td>
</tr>
<tr>
<td>≤ 5 minutes</td>
<td>≤ 5 mΩ (connections excluded)</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Current ripple at flat top</td>
</tr>
<tr>
<td>600 x 1200 x 1840 (h) mm</td>
<td>± 1.5%</td>
</tr>
<tr>
<td></td>
<td>± 30 A</td>
</tr>
</tbody>
</table>
Application: external coil of the Protosphera experiment

- Current rise and fall times in the 0.5 mH load are controlled over a wide range (5 ÷ 50 ms)
- Recovery of the coil energy at the end of pulse
- Potentially flexible to other applications
Peak power at start: ≈ 155kW (100 times the power from mains)

Steady state power: ≈ 42 kW (26 times the power from mains)

The power supply can be also used as a current amplifier (adopting proper control solutions) in order to:
- Follow a pre-loaded current profile
- Verify that the voltage and the energy stored are capable to produce the required current profile in the required load (here 0.5 mH, 5 mOhm)
Supercapacitor based Pulsed Power Supplies

Modular power supply system for high power and current

• Output current are limited mainly by switching semiconductor devices (3 ÷ 4 kA)
• Maximum current of present day supercapacitor modules achieves switching device current limits in many cases
• Supercapacitor modules are connectable in series up to 750 ÷ 1200 V without special isolated mechanical structures
• Steady state output of one single power supply module can potentially achieve 1.5 ÷ 2 MW

Using multiple power units

• Output currents up to 25 ÷ 30 kA are possible, putting up to 8 or 10 power supplies in parallel to the load
• Active current sharing techniques, based on power converters control, are preferable.
Supercapacitor based Pulsed Power Supplies

High Current (32 kA) Modular Pulse Generator

128 Modules: 4 s, 32p
(300 V, 33 MJ)

Each storage string has its own switch
or 2Q/4Q Converter (4 units x 8 kA)

Recharge: \(\approx 16 \div 18 \) kW for 30 minutes
Advantages

- Power levelling is feasible even with duty cycles < 0.3%
- Energy storage is effective in active power shaving
- No more reactive power peaks (affecting grid lines voltage), even with short bursts
- Energy recovery from the load is exploited without any power injection into the grid, even for very short times
- Modules withstand more than $10^6$ cycles (charging/discharging)

Issues not to be overlooked

- The power dissipation in supercapacitor bank shall be taken into account when evaluating the actually usable fraction of the stored energy (about 70 ÷ 75%)
- Because of the considerable voltage excursion, power converters are essential to optimize the use of supercapacitors
- Adequate thermal design is essential to limit the modules temperature below 65 °C
Thank you!

Supercapacitor based Pulsed Power Supplies