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Self-Powered Adaptive Switched Architecture Storage for Ultra-Capacitors

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OBJECTIVES
- Coupling energy harvesting & storage on supercapacitor (SC)
- Adaptive storage for early startup at charging (low capacitance value) and maximization of stored energy (high capacitance).
- Autonomy of the system and maximum energy usage rate.

Self-adaptive Architecture
The principle of this structure is to change the value of the total storage capacity according to the state of charge/discharge, to satisfy the objectives: fast charging time with a low capacitance $C_{eq}=C/N$ (series configuration), maximization of stored energy with $C_{eq}=C/N$ (parallel configuration).

Self-adaptive architectures under study
Each of the two types of adaptive structures consists of 4 identical supercapacitors (SC) + 9 switches + 3 Schottky diodes for structure B, allowing three possible configurations: Series (S), series-parallel (SP) and parallel (P), (The diodes allow a default serial structure).

Analysis of the two self-adaptives architectures
Both structures are identical, they have the same number of SCs, switches and configurations (S, SP, P). However, they differ in the SP configuration.

→ Impact of the dispersion in capacitance values on losses (worst case)

<table>
<thead>
<tr>
<th>Tolerance range</th>
<th>C=100mF±20%</th>
<th>Input</th>
<th>C1 (F)</th>
<th>C2 (F)</th>
<th>C3 (F)</th>
<th>C4 (F)</th>
<th>$E_{MAX}$ loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure A</td>
<td>0.12</td>
<td>0.08</td>
<td>0.08</td>
<td>0.12</td>
<td>2.08%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure B</td>
<td>0.08</td>
<td>0.08</td>
<td>0.12</td>
<td>0.12</td>
<td>2.16%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emax loss expressed in % of the stored energy

→ Balancing currents, simulation result of the worst case, High current in second switching SP→P (low current in first switching S→SP)

For these simulations, we model each switch by a resistor, and the ultra-capacitor by a capacitor in series with a resistor (C=100mF±20%, ESR=0.08Ω, $R_{load}=0.4Ω$).

Conclusion:
- Low losses → balancing circuit not necessary
- Structure B exhibits lower balancing currents

Self-powered and adaptive storage system

Experimental results
Energy harvester simulated by a Thévenin generator $E_{th}=5V$, $R_{load}=1kΩ$, $R_{load}=16Ω$, $C=100mF$, $C_{cap}=400mF$, $V_{th}=2V$, $V_{th}=1V$

Charge profile:
- The S configuration allows for a fast charging and startup (low Ceq).
- The P configuration allows for the storage of a large amount of energy (high Ceq).

Discharge profile:
The S configuration allows a maximum energy usage rate in the case of a system powered by an energy harvesting source.

Measurement and calculation of losses
Source and load modeled by a constant current source

Perspectives
Silicon integration of the self-powered and adaptive storage.

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