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Self-Powered Adaptive Switched Architecture Storage for Ultra-Capacitors

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CONTEXT: Autonomous battery-free wireless sensor node

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-adaptable 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>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>
</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>
</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 simulation, we model each switch by a resistor, and the ultra-capacitor by a capacitor in series with a resistor ($C=100\text{mF} \pm 20\%$, $R_{sh}=0.08\text{Ω}$, $R_{bal}=0.4\text{Ω}$).

- 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 $E_{in}=5\text{V}$, $R_{sh}=1\text{KΩ}$, $R_{load}=16\text{Ω}$, $C=400\text{mF}$, $V_{out}=2\text{V}$, $V_{in}=1\text{V}$

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

- 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

<table>
<thead>
<tr>
<th>Input</th>
<th>$M/C_{eq}$ (l/l)</th>
<th>$M/C_{eq}$/l/l</th>
<th>$M/C_{eq}$/l/l</th>
<th>$M/C_{eq}$/l/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure A</td>
<td>12.25</td>
<td>12.25</td>
<td>11.05</td>
<td>12.18</td>
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<tr>
<td>Structure B</td>
<td>12.46</td>
<td>12.89</td>
<td>11.01</td>
<td>12.23</td>
</tr>
</tbody>
</table>

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

Acknowledgments
This work is carried out within the framework of the European project SMARTER funded by the CHIST-ERA program, "Green ICT, towards Zero Power ICT".