Modeling Improved Behavior in Stand-Alone PV Systems with Battery-Ultracapacitor Hybrid Systems

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Why Ultracapacitors

• Shelf and cycle life has been a problem with most types of batteries, but people have learned to tolerate this shortcoming due to the lack of an alternative.

• PV systems are not ideal for battery charging due to intermittency from weather and regional effects.

• The batteries are often deep discharged, which damages the battery and shortens its useful life. It is not possible to ensure an optimum charge/discharge cycle.

• Ultracapacitors have high power density and low energy density which makes them better suited for load matching at higher frequencies.
Why Ultracapacitors

<table>
<thead>
<tr>
<th></th>
<th>Ultracapacitor</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge Time</td>
<td>1-30 sec</td>
<td>0.3-3 hrs</td>
</tr>
<tr>
<td>Charge Time</td>
<td>1-30 sec</td>
<td>1-5 hrs</td>
</tr>
<tr>
<td>Life Cycle</td>
<td>&gt;500,000</td>
<td>500-2000</td>
</tr>
<tr>
<td>Efficiency</td>
<td>90-95%</td>
<td>70-85%</td>
</tr>
<tr>
<td>Power Density</td>
<td>1000-2000 w/kg</td>
<td>50-200 w/kg</td>
</tr>
<tr>
<td>Energy Density</td>
<td>1-10 Wh/kg</td>
<td>20-100 Wh/kg</td>
</tr>
<tr>
<td>Operating Temp.</td>
<td>-40 – 70°C</td>
<td>0 – 60°C</td>
</tr>
</tbody>
</table>
Why Ultracapacitors

PV Intermittency due to the day/night cycle

PV Intermittency due to cloud cover

Why Ultracapacitors

- Fluctuations in 10 min to several hr range are relatively larger for PV.
- Rapid and deep fluctuations from 10s to several min many be due to low, scattered opaque clouds.
- This paper proposes an ensemble of energy storage devices for different regions of the plot.
- the ultracapacitor could compensate for frequent, short, and high power disturbances, while the battery could provide compensation for longer-term less frequent events.

Battery-Ultracapacitor Hybrid system

Modeling Methodology using TRNSYS

- SURFRAD Data
- Stand-alone system Modeling
- Solar PV Model w/o Storage
- Battery
- Battery-Ultracapacitor Hybrid
- Preliminary Model
- Model Validation
  - VisSim 7.0
  - SolRayo's Ultracapacitors
  - TRNSYS Compatible
- Fortran Model
- Full System Simulations
- Comparison
Solar PV model w/o Storage

Power Generated by a PV system (437 kW) for a Typical Year in Pittsburgh

Simulation Time = 8760.00 [hr]
Ultracapacitor Models

- Adequately describes the capacitors performance in slow discharge applications (in the order of a few seconds).
- Equivalent series resistance (ESR) models the internal heating in the capacitor.
- The equivalent parallel resistance (EPR) models the current leakage effect.
Ultracapacitor Models

3-Branch equivalent circuit model

- Improves upon the classical equivalent model.
- Each RC branch has a different time constant and hence models over a wider range of frequencies.

Transmission line model

- A Transmission line model accounts for frequencies up to 10 kHz.
- The transmission line model has good accuracy over a wide range of frequencies.
Classical Equivalent Circuit-Mathematical Model

\[ \frac{dI_2(t)}{dt} = \frac{V_a}{CR_1 R_2} - \frac{1}{C} \left[ \frac{1}{R_1} + \frac{1}{R_2} \right] I_2(t) \]  
(Eqn.1)

\[ I_2(t) = \frac{N \int e^{Mt} V_a + C}{e^{Mt}} \]  
(Eqn.2)

\[ N = \frac{1}{CR_1 R_2} ; M = \frac{1}{C} \left[ \frac{1}{R_1} + \frac{1}{R_2} \right] \]  
(Eqn.3)
Simulation Results – Charging Cycle

Modeling Parameters:
Nominal Capacitance: 1500F
ESR = 0.47mΩ; EPR = 3.0mA; Source Voltage = 2.7V
Conclusions and Future Work

• By employing both ultracapacitors and batteries in a hybrid system one can promote the advantages of both technologies

• In this work suitable models for Ultracapacitors are studied and will be experimentally validated

• The validated models will be incorporated into TRNSYS to perform the stand-alone system simulation

• Load matching capabilities of cases with the battery and battery-ultracapacitor systems will be studied and compared.
Questions?!?
Traditional Capacitors

- Capacitor: Device That Physically Stores Electric Charge
  - No chemical reactions used to store charge
How they Work

\[ C \propto \frac{A}{d} \]

A = 1,000 or more m²/g

d = Angstroms