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

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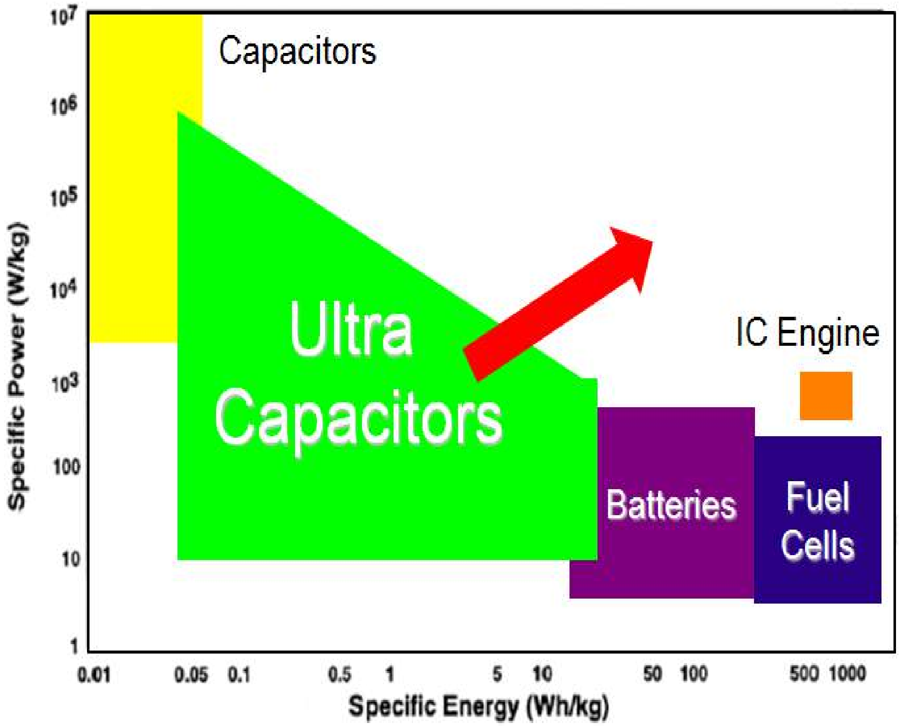
Why Ultracapacitors

- 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.

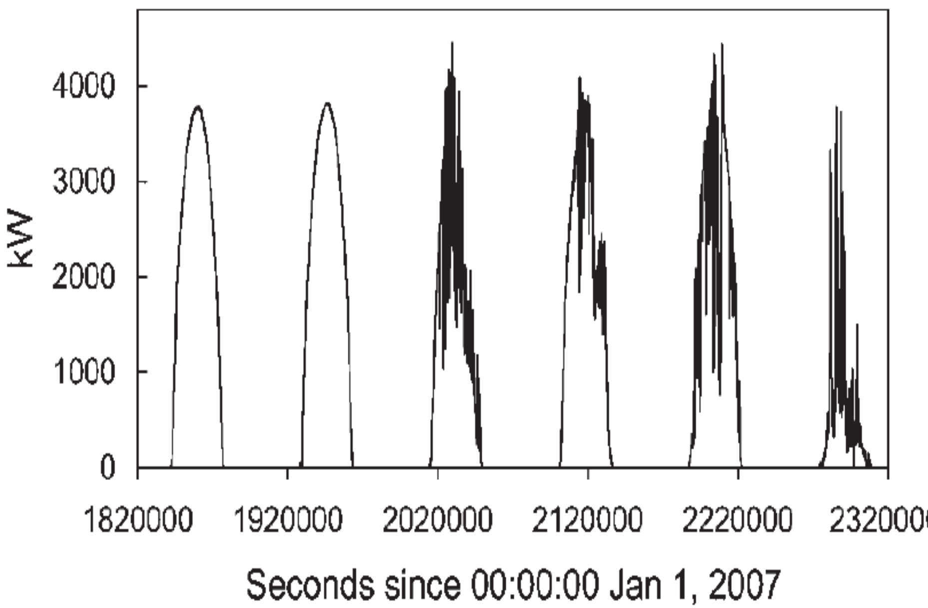
Why Ultracapacitors



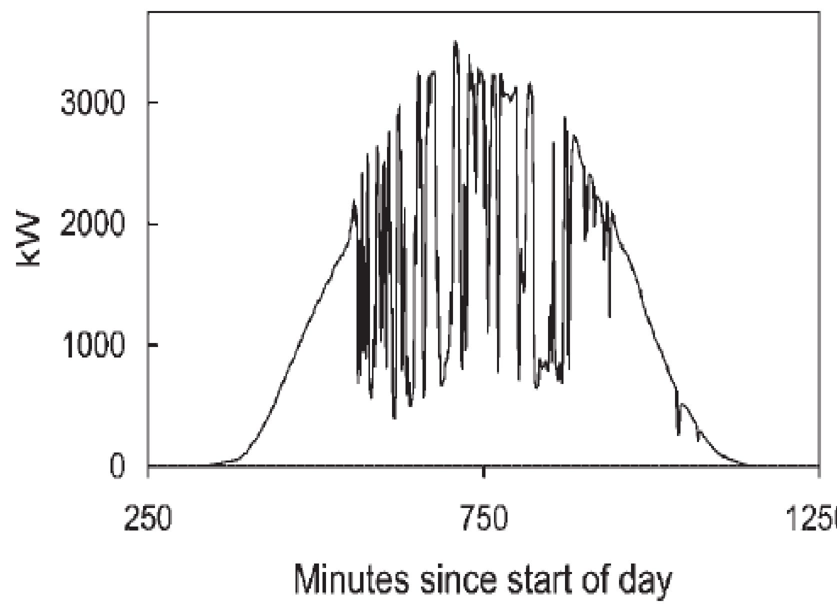
	Ultracapacitor	Battery
Discharge Time	1-30 sec	0.3-3 hrs
Charge Time	1-30 sec	1-5 hrs
Life Cycle	>500,000	500-2000
Efficiency	90-95%	70-85%
Power Density	1000-2000 w/kg	50-200 w/kg
Energy Density	1-10 Wh/kg	20-100 Wh/kg
Operating Temp.	-40 – 70°C	0 – 60°C

Why Ultracapacitors

PV Intermittency due to the day/night cycle



PV Intermittency due to cloud cover



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Why Ultracapacitors

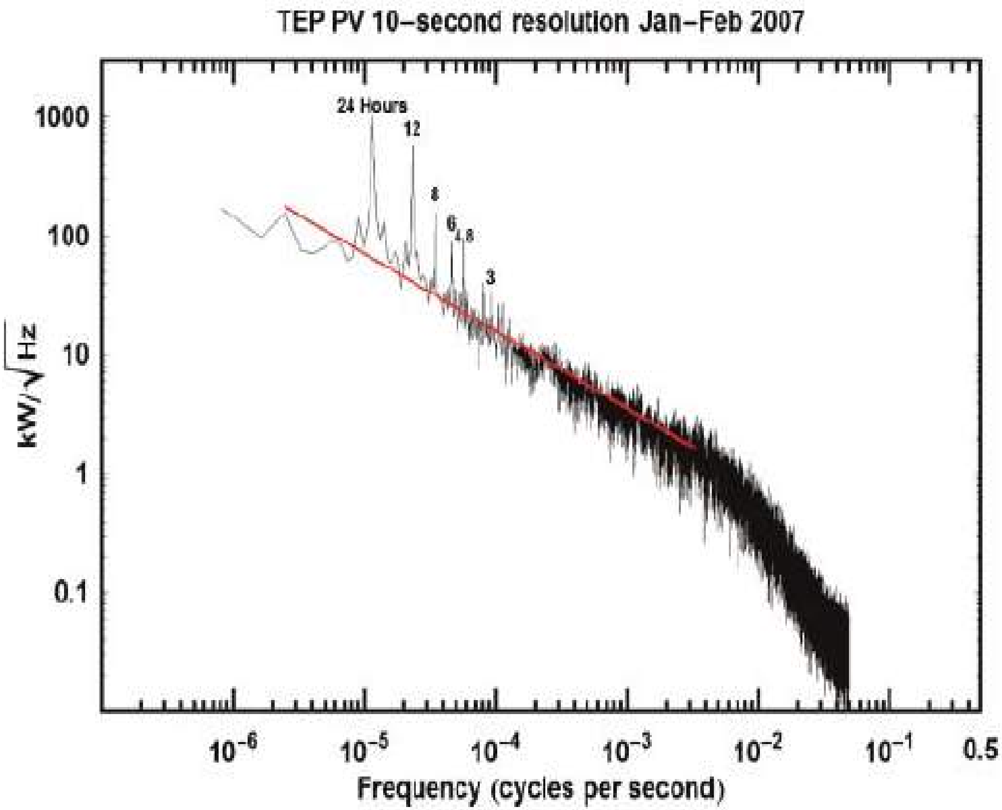

Figure 7. Power spectrum of TEP array over 2 months at 10-s sampling frequency with overlaid $f^{-1.3}$ spectrum

- 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

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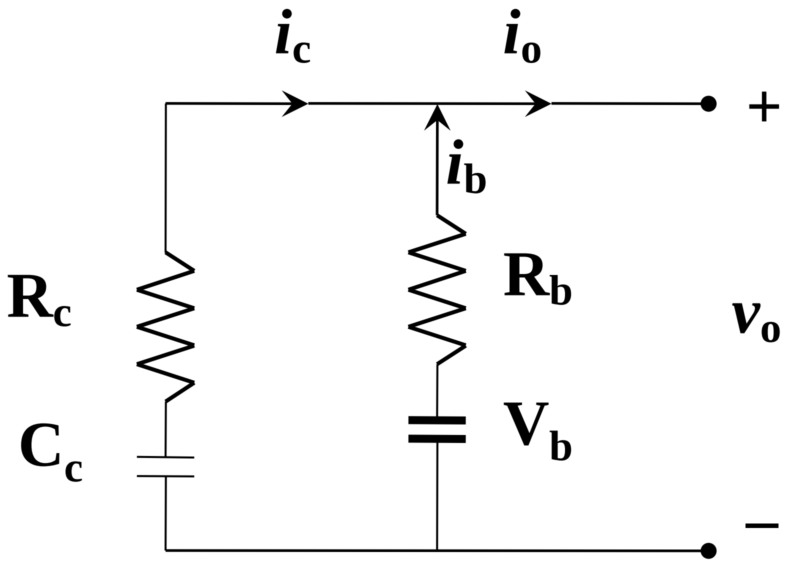
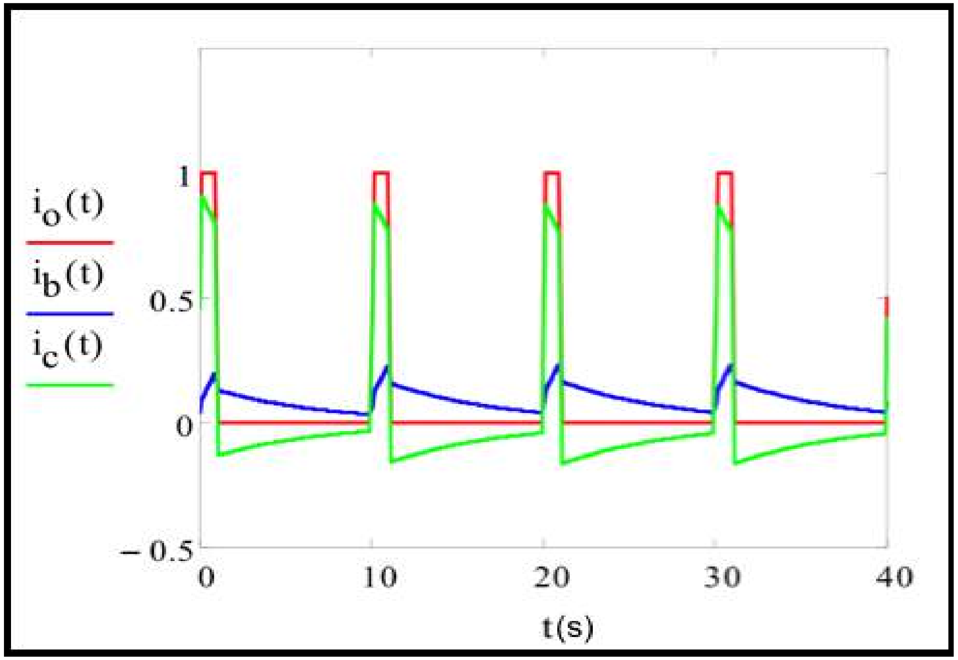
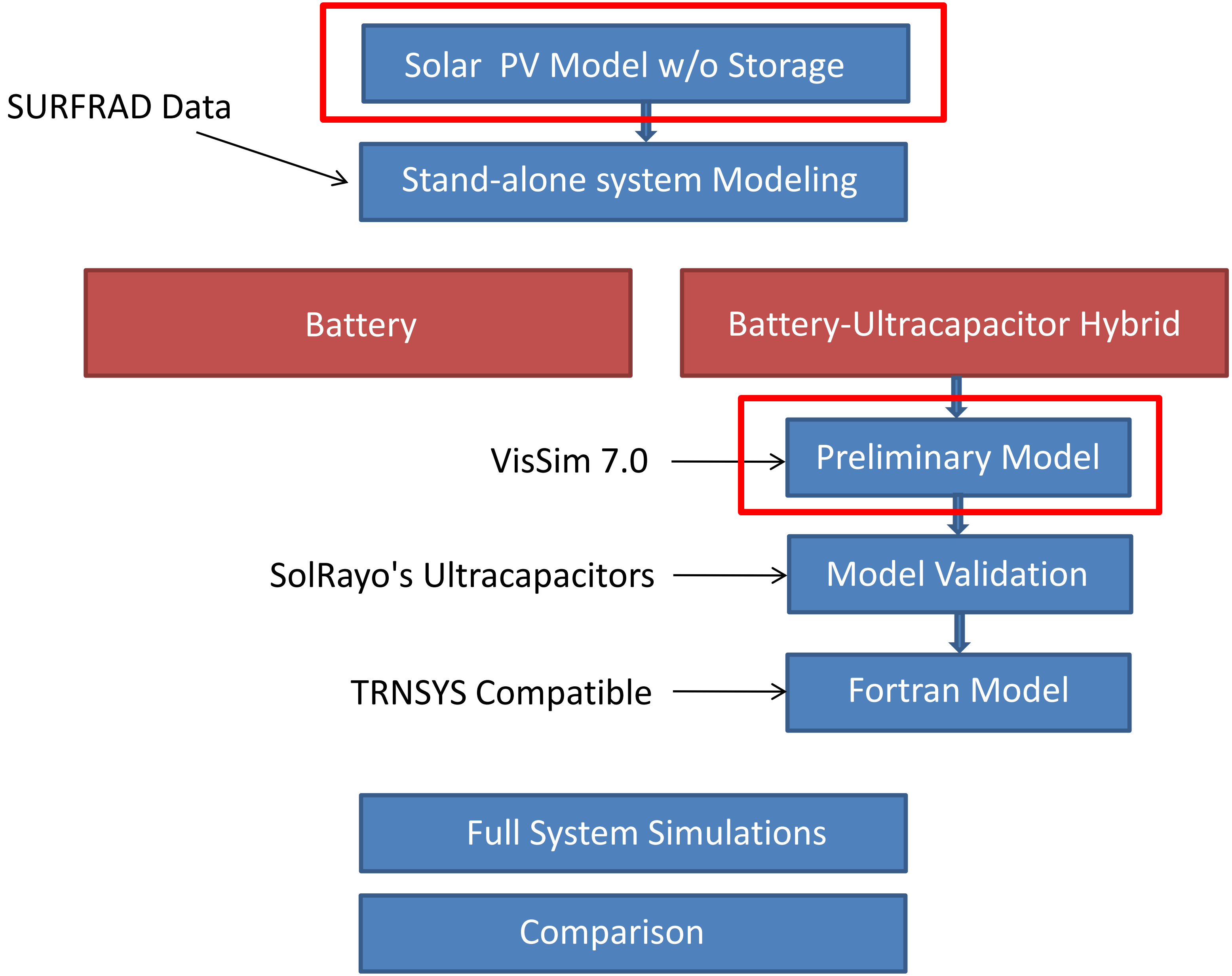
Battery-Ultracapacitor Hybrid system



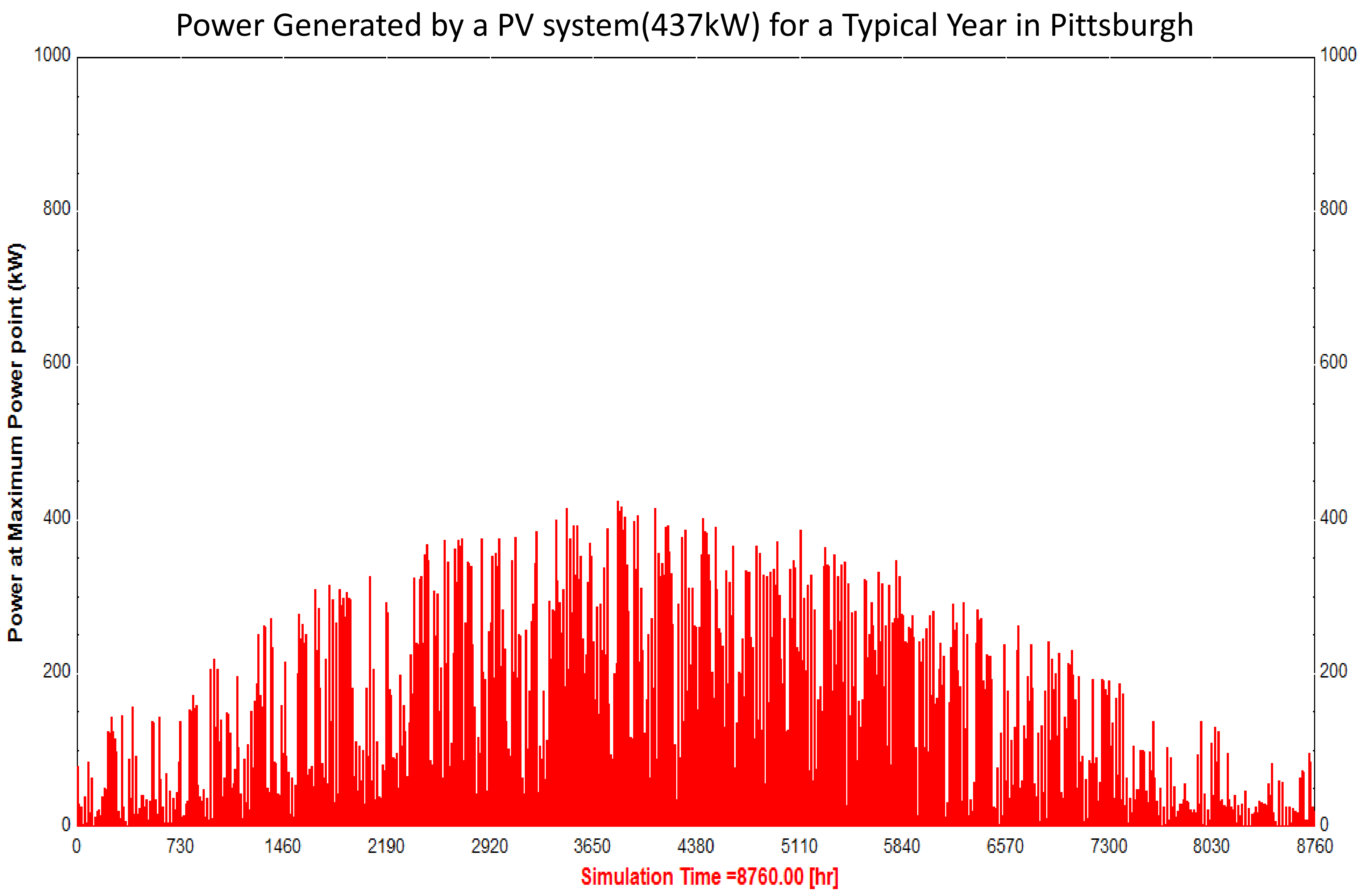


** Power and Life Extension of Battery – Ultracapacitor Hybrids by*
R.A. Dougal, Shengyi Liu and Ralph E. White, IEEE Transactions on Components and Packaging Technologies, Vol. 25, No. 1, March 2002, pp 120-131.

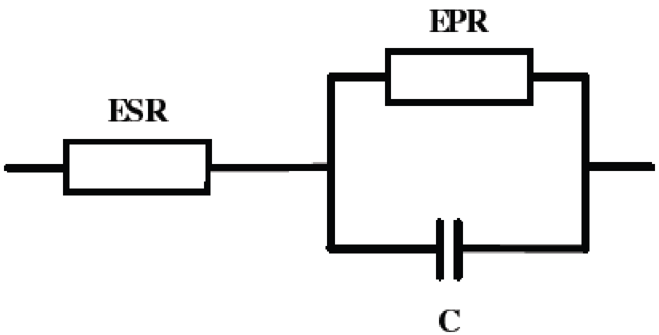
Modeling Methodology using TRNSYS



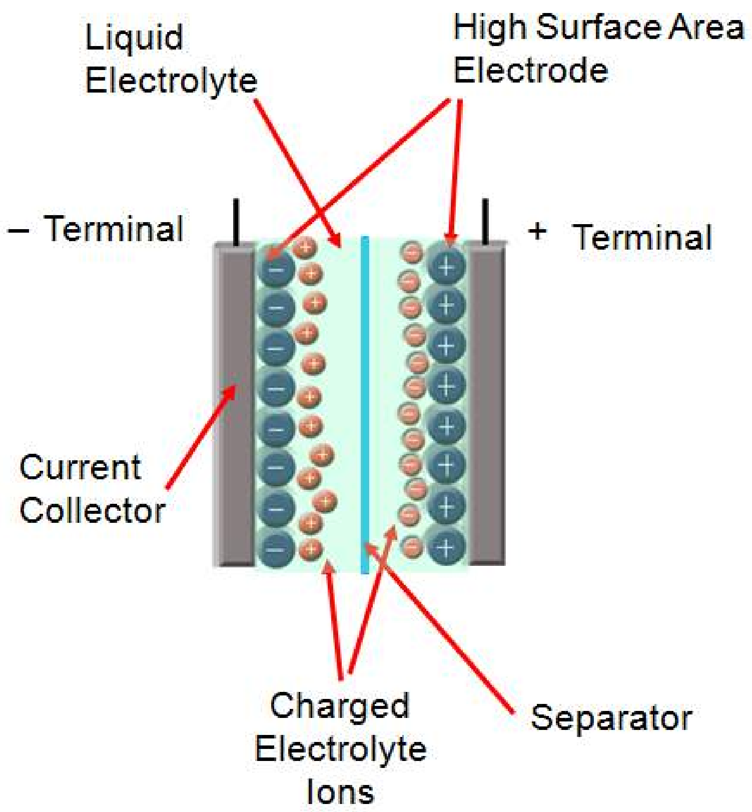
Solar PV model w/o Storage



Ultracapacitor Models



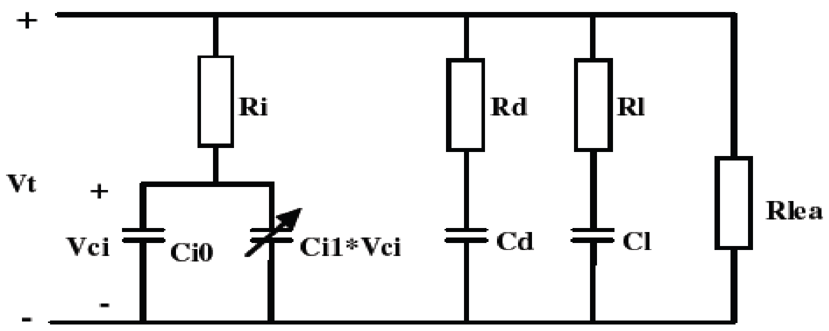
Classical equivalent circuit model



- 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

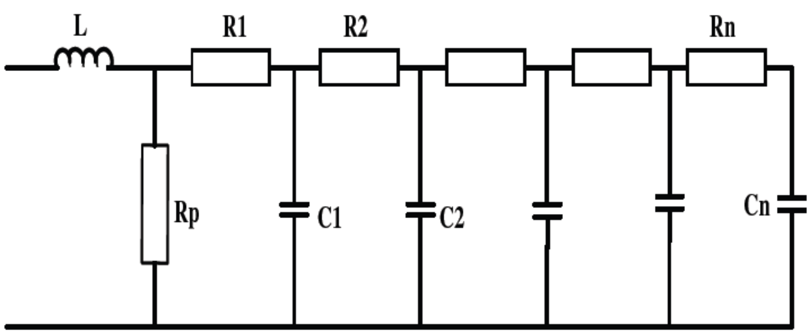
Ultracapacitor Models

3-Branch equivalent circuit model



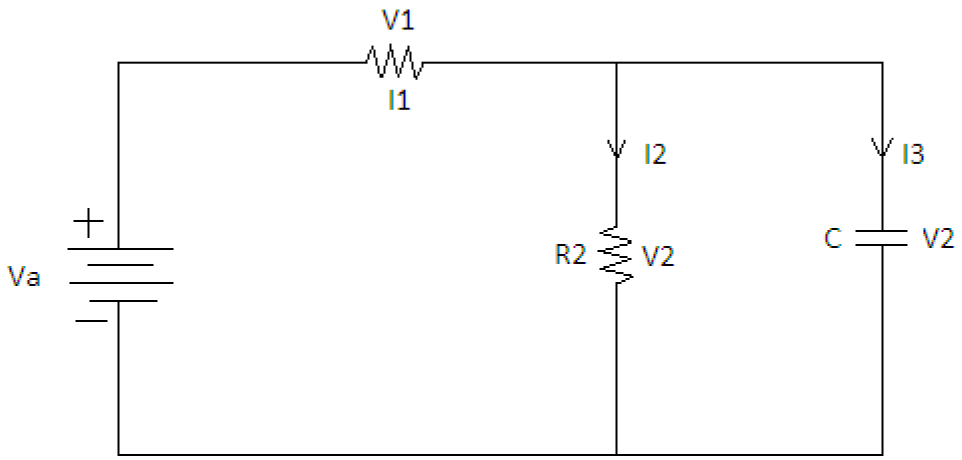
- Improves upon the classical equivalent model.
- Each RC branch has a different time constant and hence models over a wider range of frequencies

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



$$\frac{dI_2(t)}{dt} = \frac{V_a}{CR_1R_2} - \frac{1}{C}\left[\frac{1}{R_1} + \frac{1}{R_2}\right] I_2(t) \qquad \text{(Eqn.1)}$$

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

$$N = \frac{1}{CR_1R_2};M = \frac{1}{C}\left[\frac{1}{R_1} + \frac{1}{R_2}\right] \qquad \text{(Eqn.3)}$$

Simulation Results – Charging Cycle

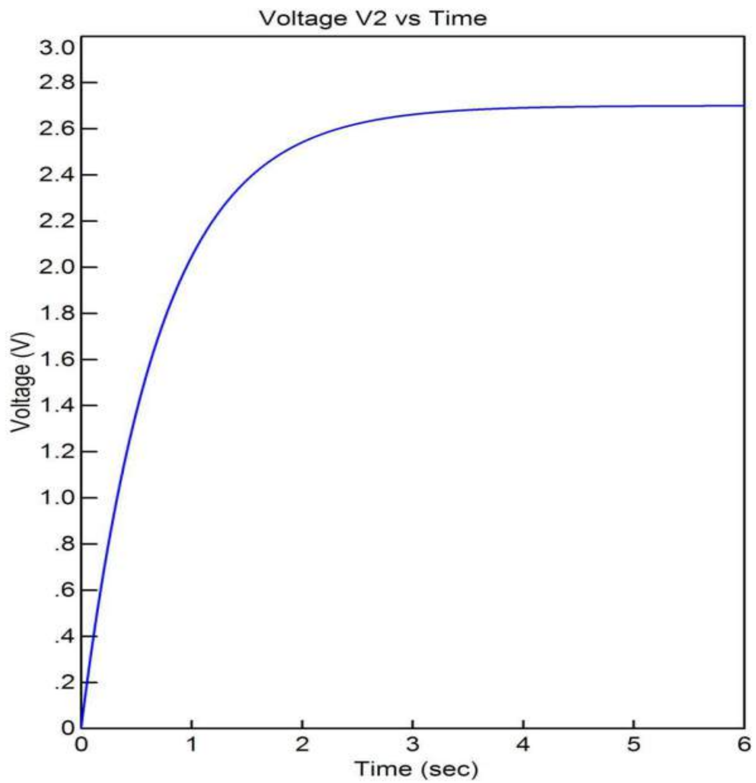


Fig.2 Voltage(V) vs Time(sec)

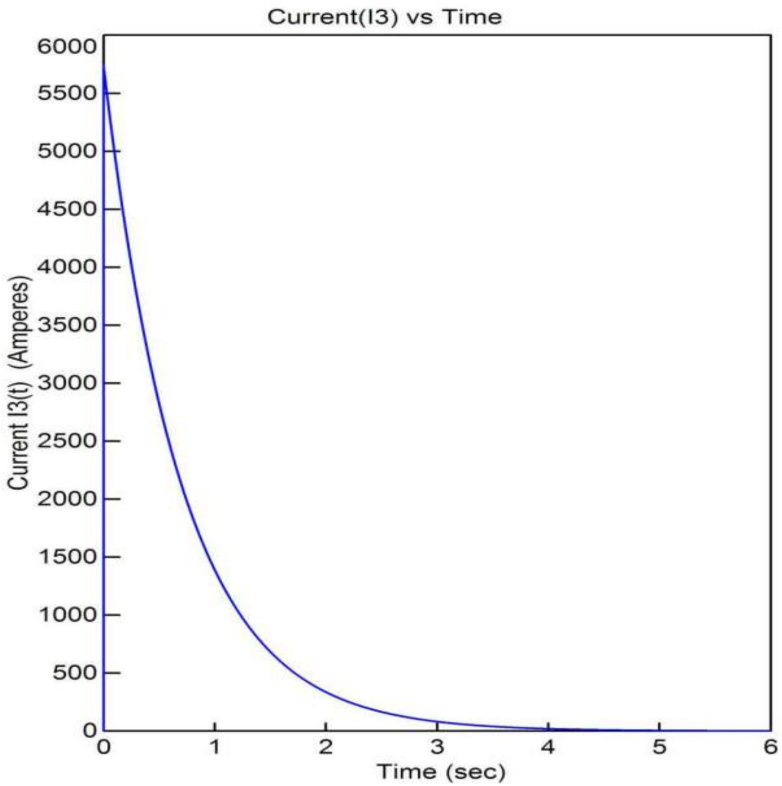


Fig. 3 Current(A) vs Time(sec)

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.

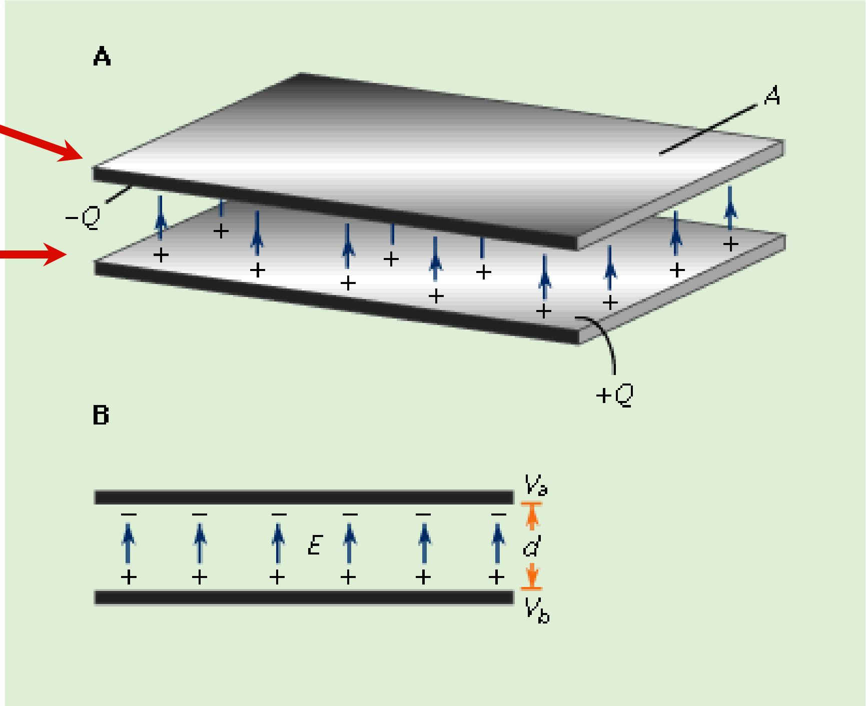
Questions?!?

Traditional Capacitors

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

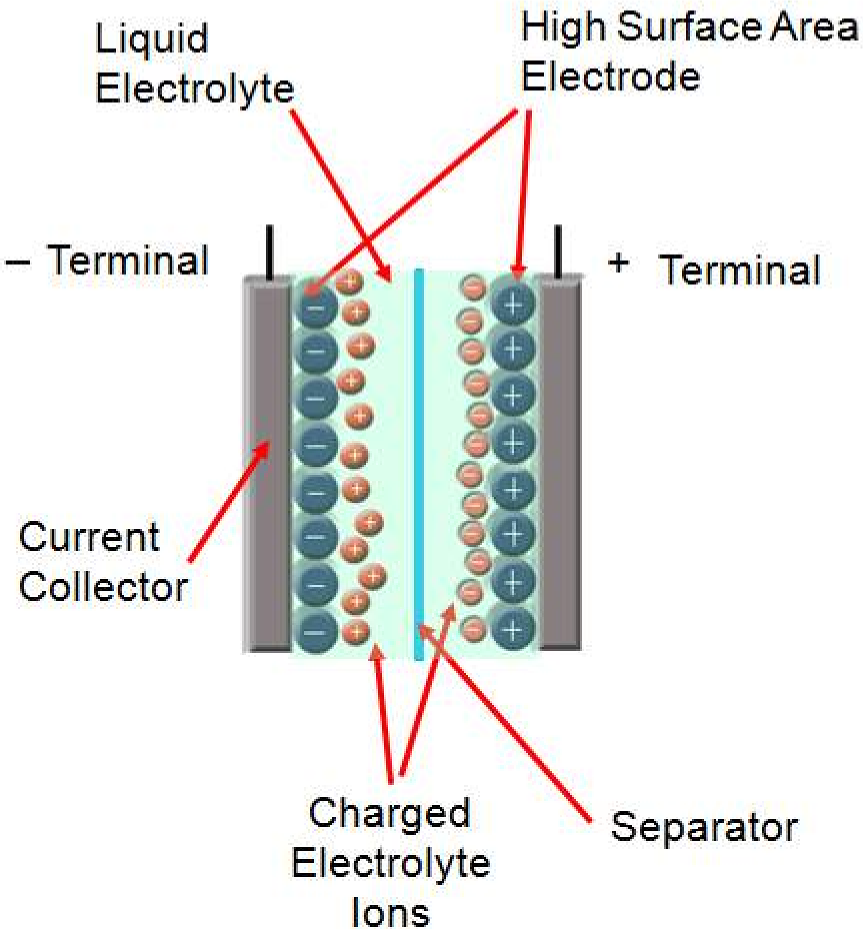
Negative Conductive Plate

Positive Conductive Plate



$$C \propto \frac{A}{d}$$

How they Work



$$C \propto \frac{A}{d} \quad \frac{\uparrow\uparrow}{\downarrow\downarrow}$$

A = 1,000 or more m^2/g

d = Angstroms