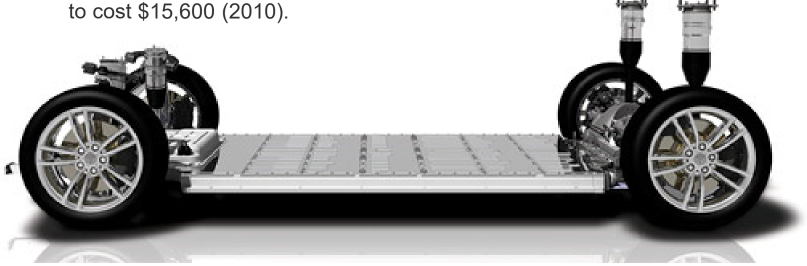
Introduction to Battery Modeling

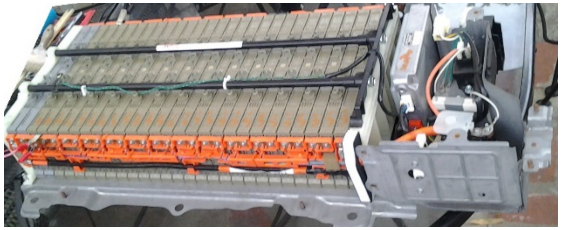
Example EV Batteries

Cutaway battery of Nissan Leaf electric vehicle. The Leaf includes a 24kWh lithium-ion battery with a city driving range of 160km (100 miles). The battery fits under the floor of the car, weighs 272kg (600lb) and is estimated to cost $15,600 (2010).



Tesla Model S frame-integrated battery. The Model S includes a 60-85kWh lithium-ion battery with a city driving range of 480km (300miles). The battery weighs 544kg (1200lb) and is estimated to cost $24-34,000.

Toyota Prius HEV Battery. The 2004 Prius included a 1.3 kWh NiMH battery consisting of 168 cells and with a $3K retail replacement cost



Cell Equivalent-Circuit Models

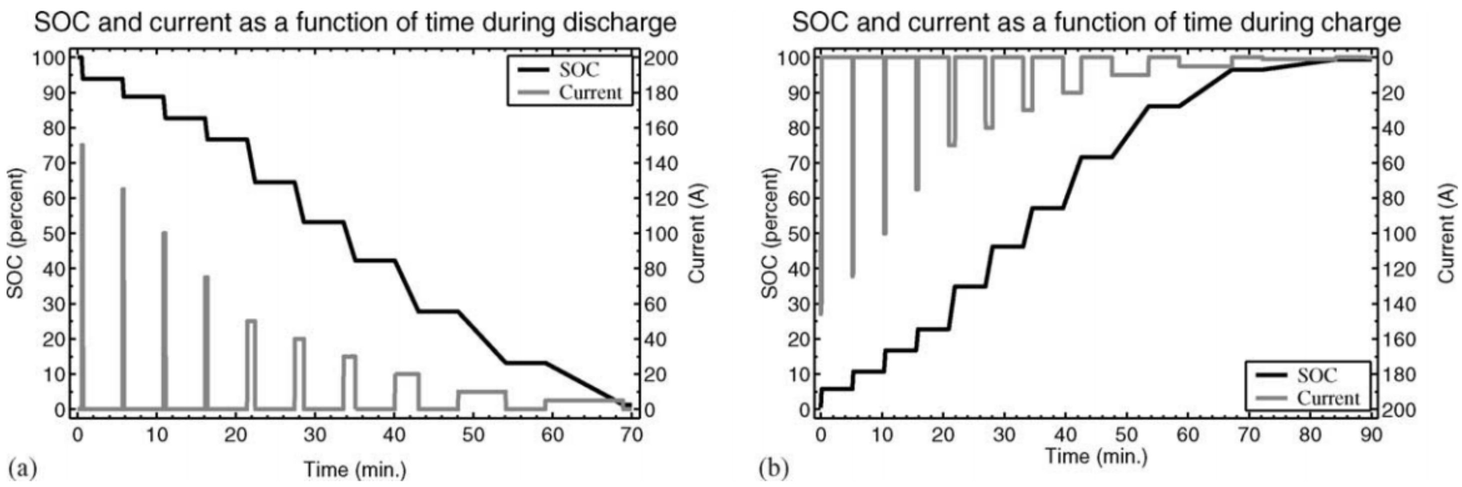
Objective:

- Dynamic circuit model capable of predicting cell voltage in response to charge/discharge current, temperature

Further key techniques discussed in [Plett 2004-Part 2] and [Plett 2004-Part 3]

- Model parameters found using least-square estimation or Kalman filter techniques based on experimental test data
- Run-time estimation of state of charge (SOC)

Approach: Pulsed current tests



[Plett 2004-2] G. Plett, "Extended Kalman Filtering for Battery Management Systems of LiPB-Based HEV Battery Packs—Part 2: Modeling and Identification," Journal of Power Sources, Vol. 134, No. 2, August 2004, pp. 262–76.

Battery Nomenclature

- Known beforehand:

Capacity C [Ah]

Nominal Voltage V_{nom} [V]

Max Charge Rate
Max Discharge Rate } specified as $k \frac{C}{1 hr}$

ex

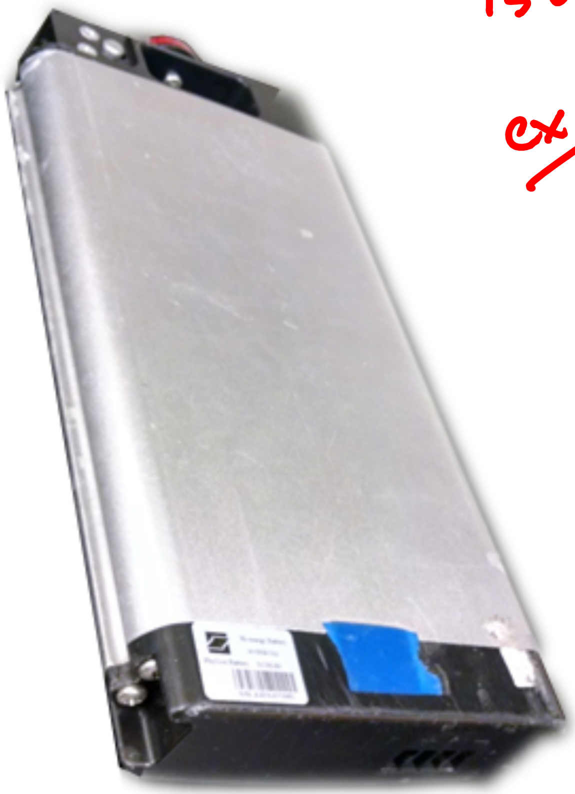
Max Charge = 1C

for 10Ah cell ⇒ 10A max charge

Max discharge = 5C

for 10Ah battery → 50A

Example Battery



"7s5p" → 7 cells in series, 5 in parallel

ex/ cells: { $V_{nom} = 3.4V$, $C = 2Ah$

max charge = 0.2C

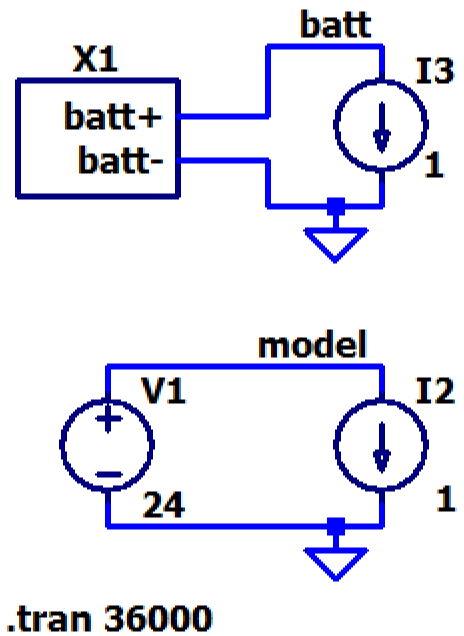
max discharge = 1.9 C

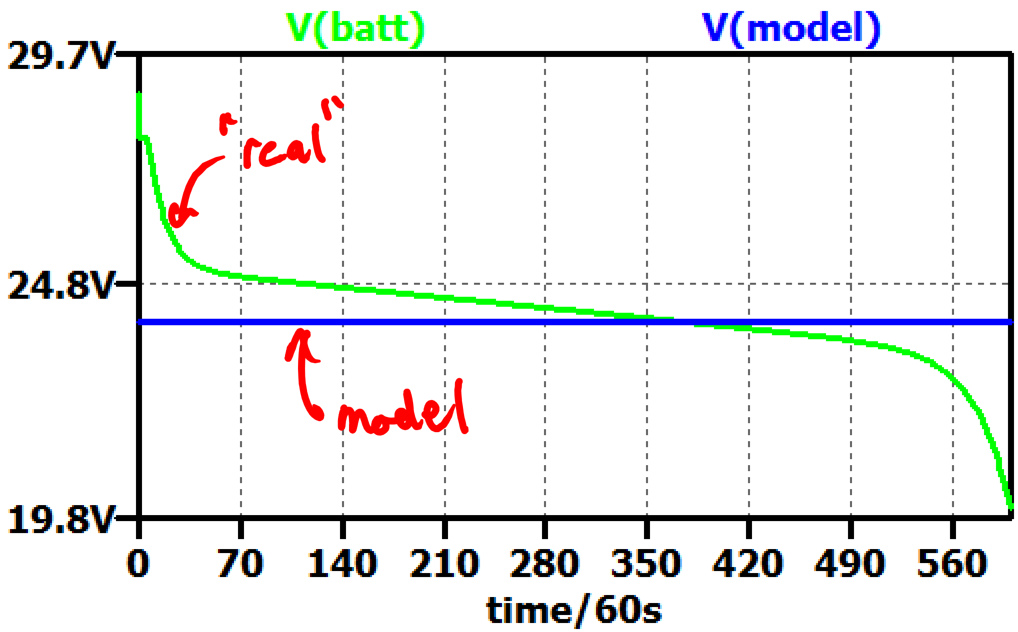
pack: { $V_{nom} = 24V$, $C = 10Ah$

max charge = 1C

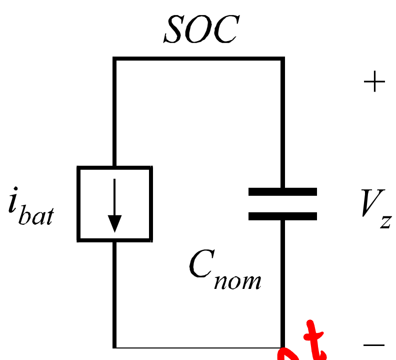
max discharge = 10C

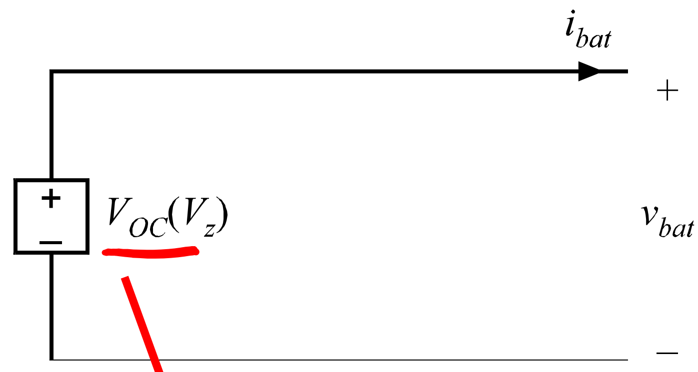
Model 0: Voltage Source





Model A: SOC and V_{oc}



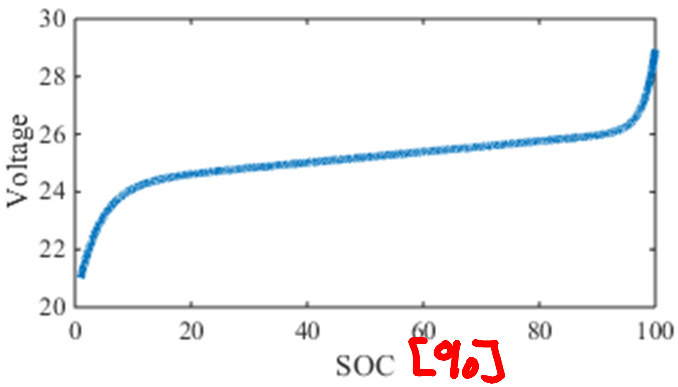


$$V_z = V_{z\phi} - \frac{1}{C_{nom}} \int_0^t i_{bat} \, dt$$

A·s

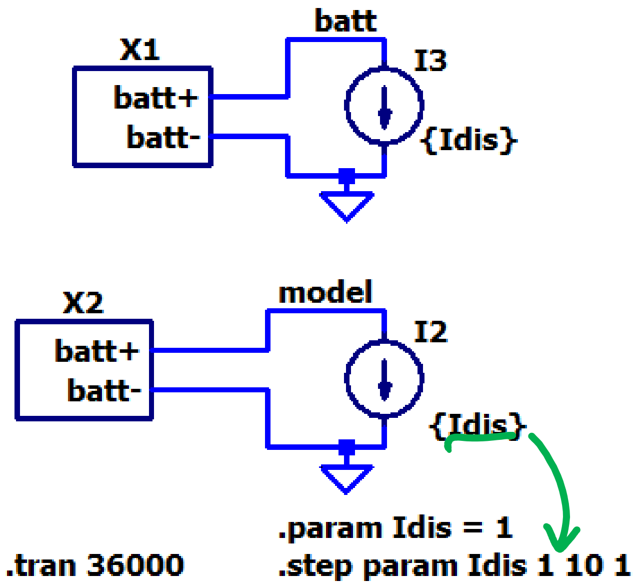
$\frac{A \cdot h}{C} = \Delta SOC$

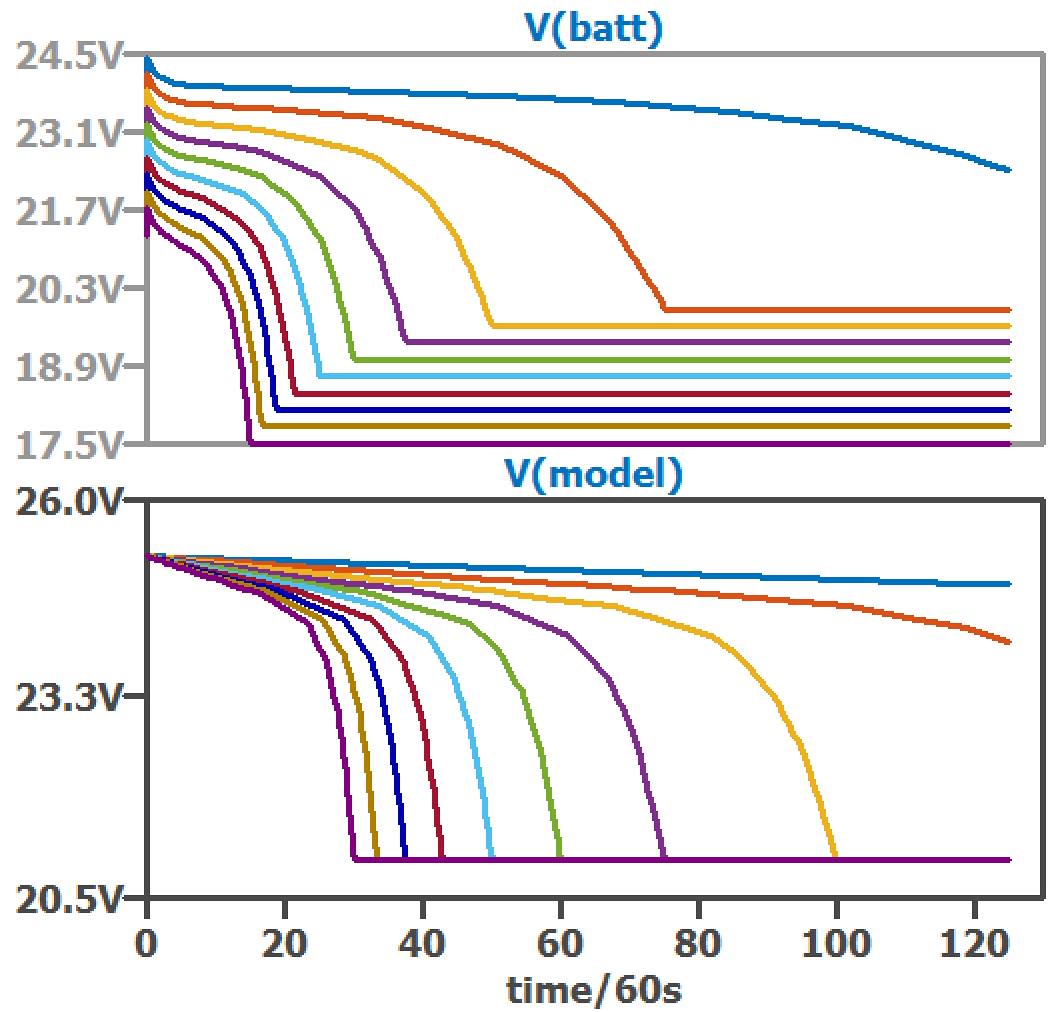
if I set $C_{nom} = C \cdot 3600$



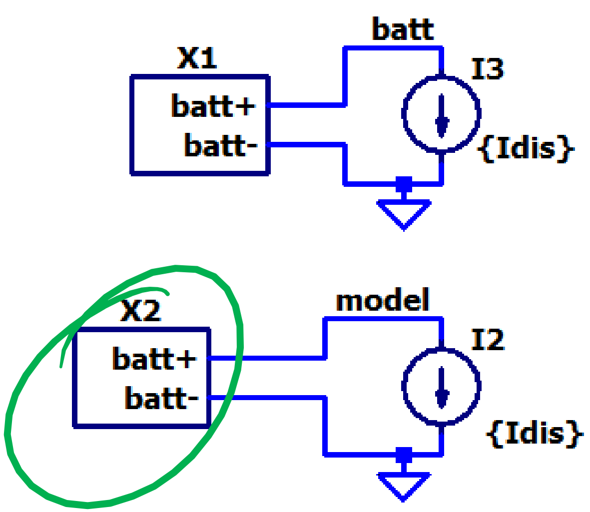
"state-of-charge"

Model B: Series Resistance



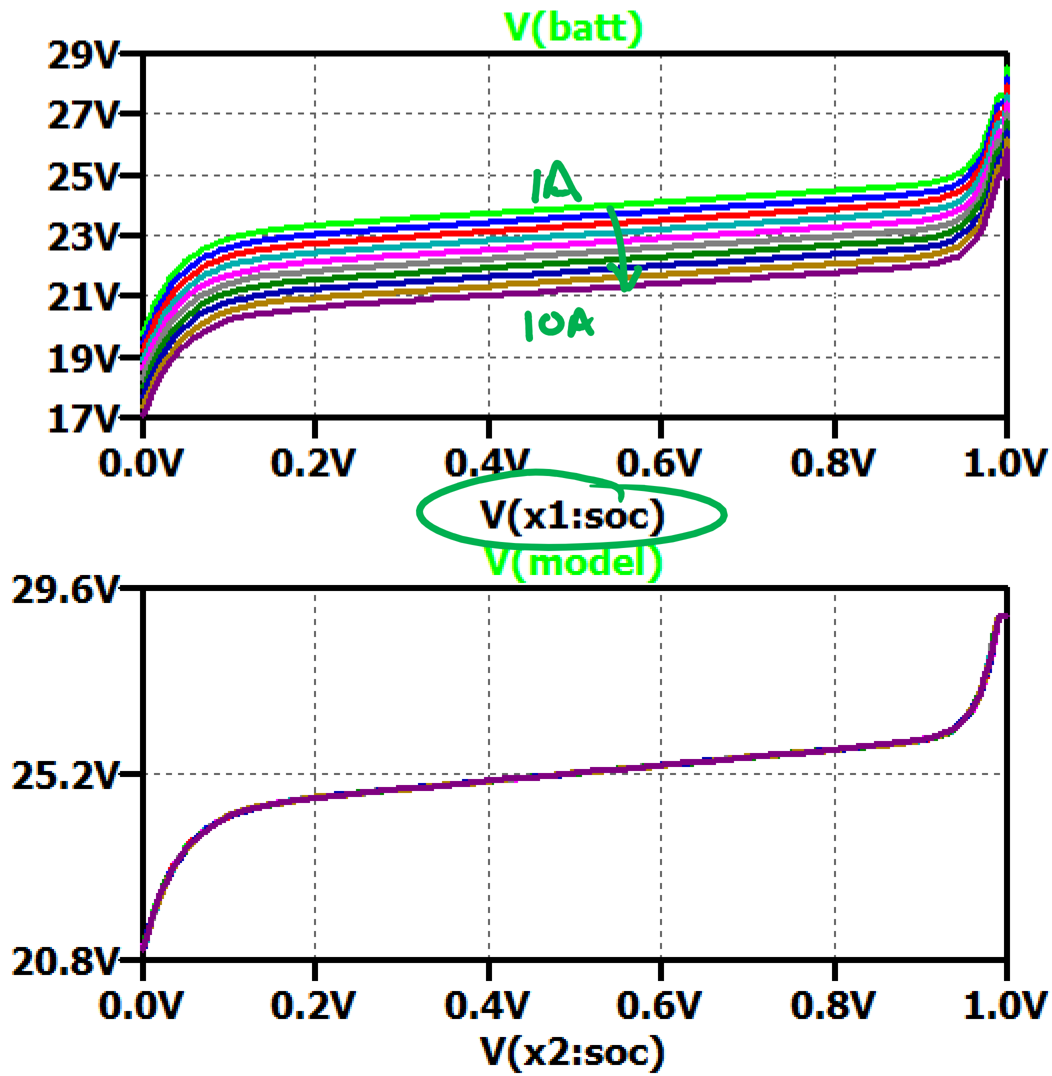


Model B: Series Resistance

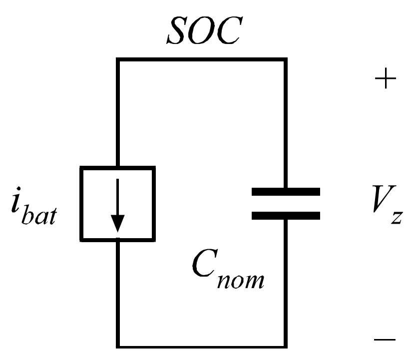


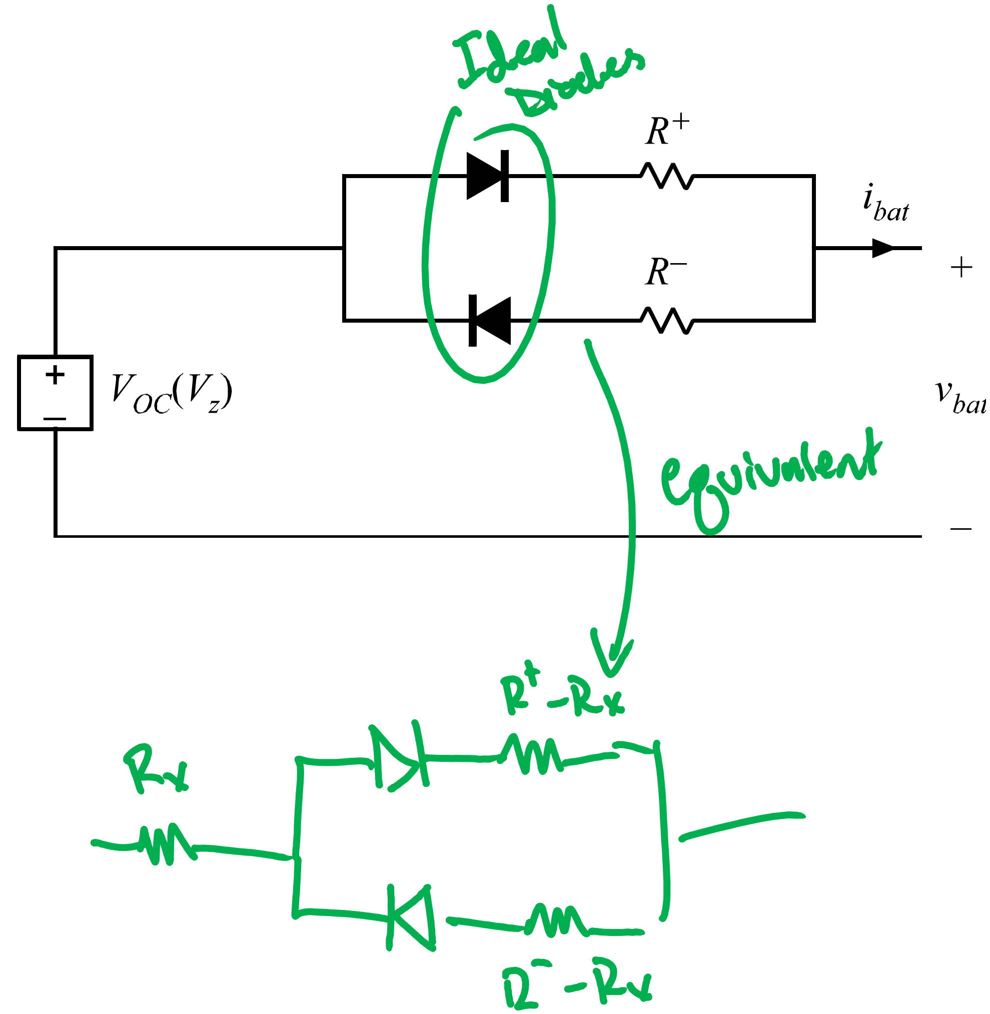
.tran 36000

.param Idis = 1
.step param Idis 1 10 1



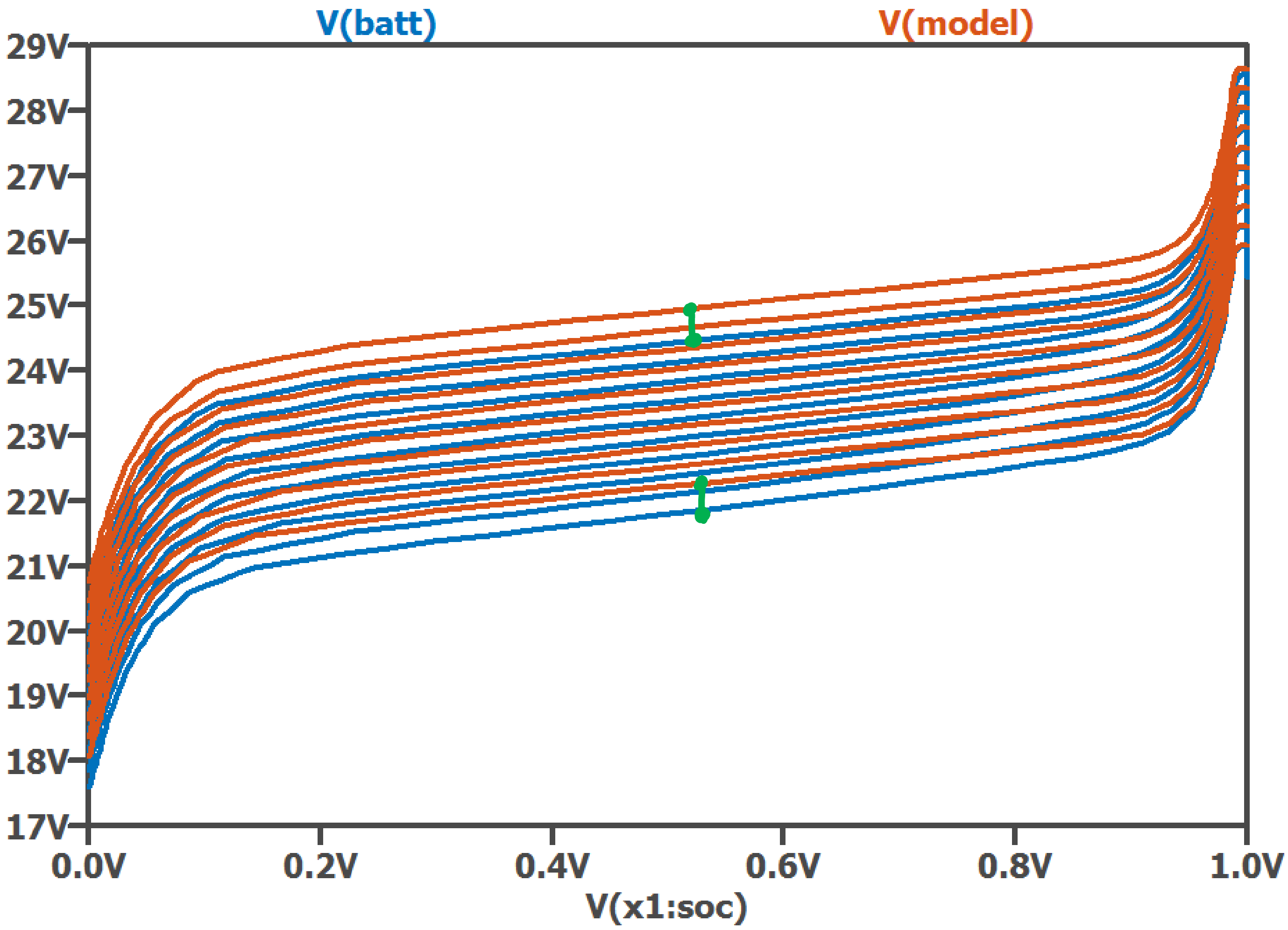
Model B: Series Resistance





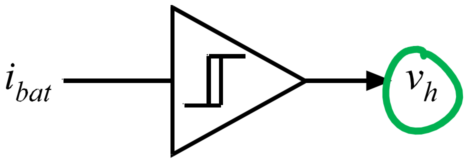
if $R_x \leq \min(R^+, R^-)$

Model B Performance

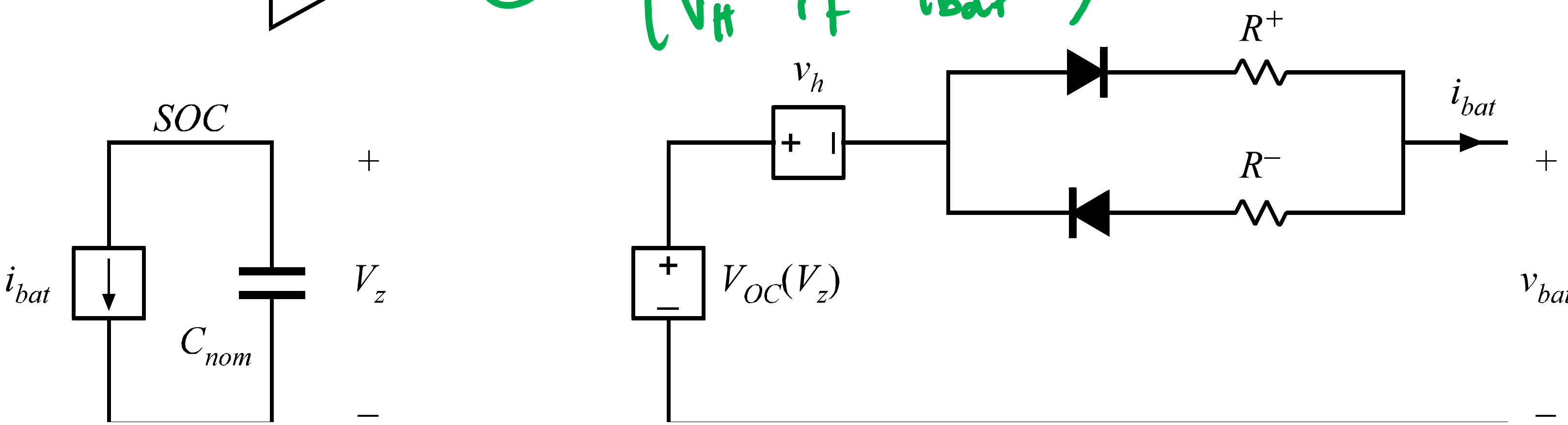


Model C: Zero-state Hysteresis

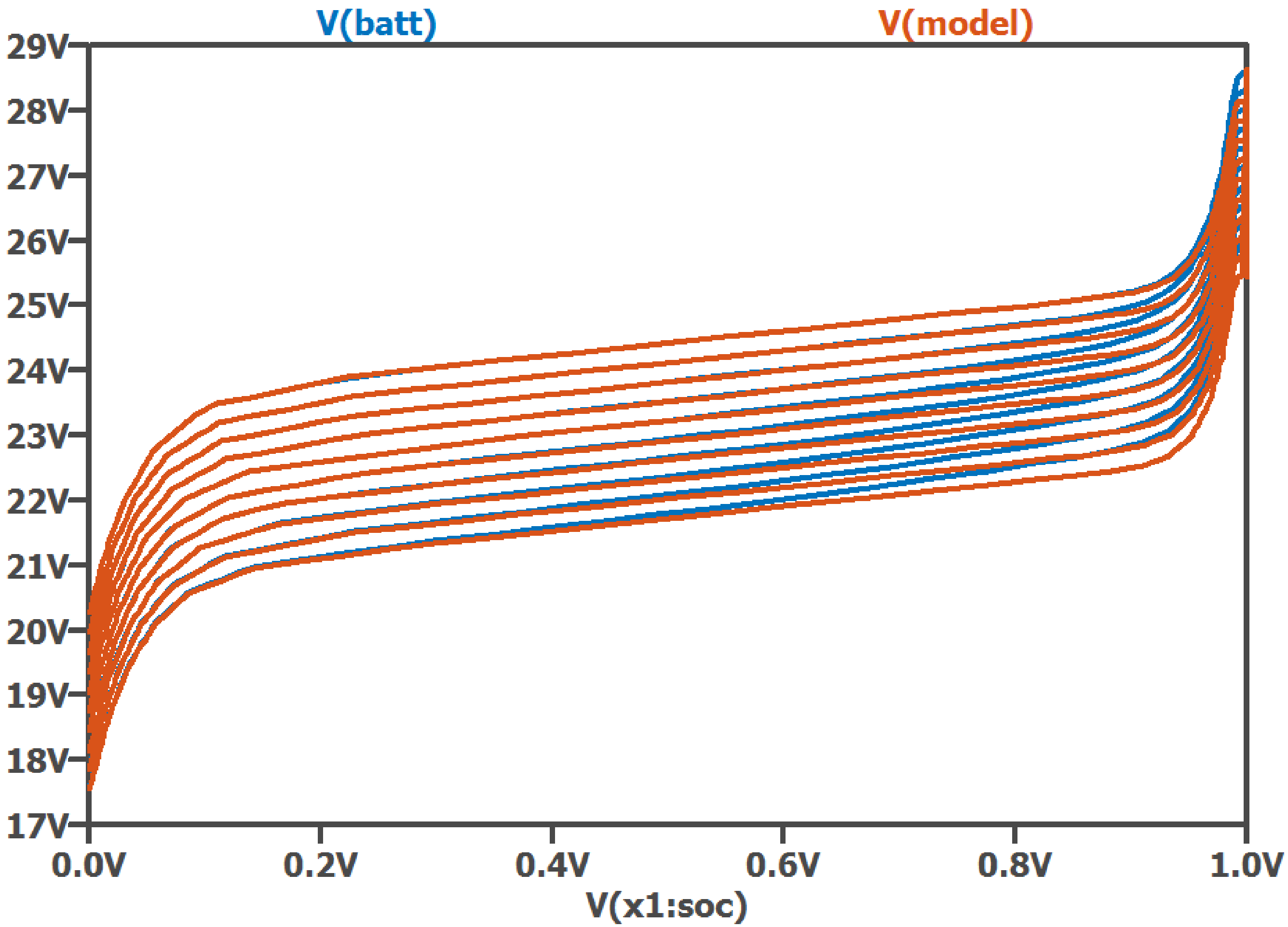
[Plett 2004]



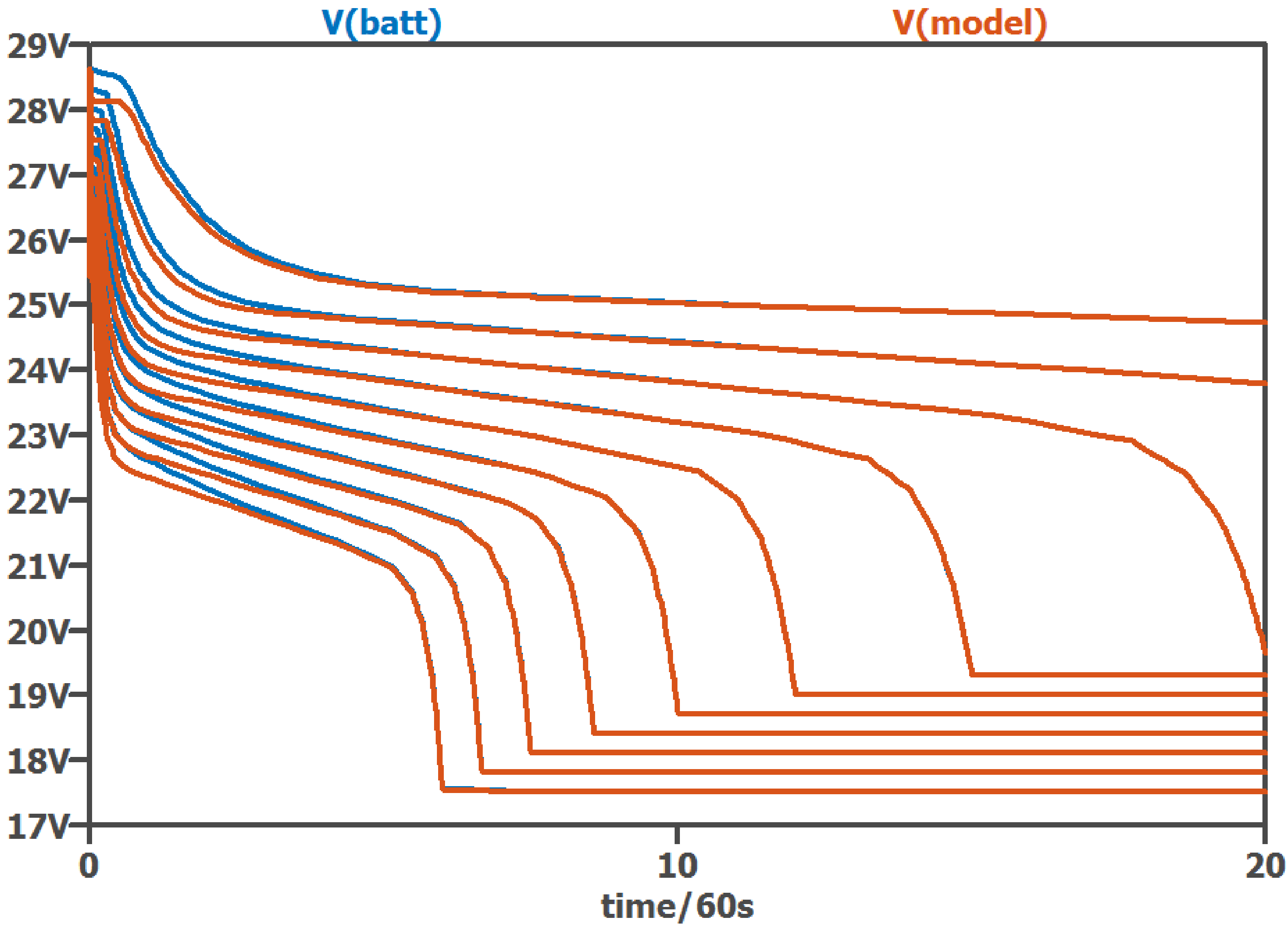
$$v_h = \begin{cases} V_H^+ & \text{if } i_{bat} > 0 \\ V_H^- & \text{if } i_{bat} < 0 \end{cases}$$



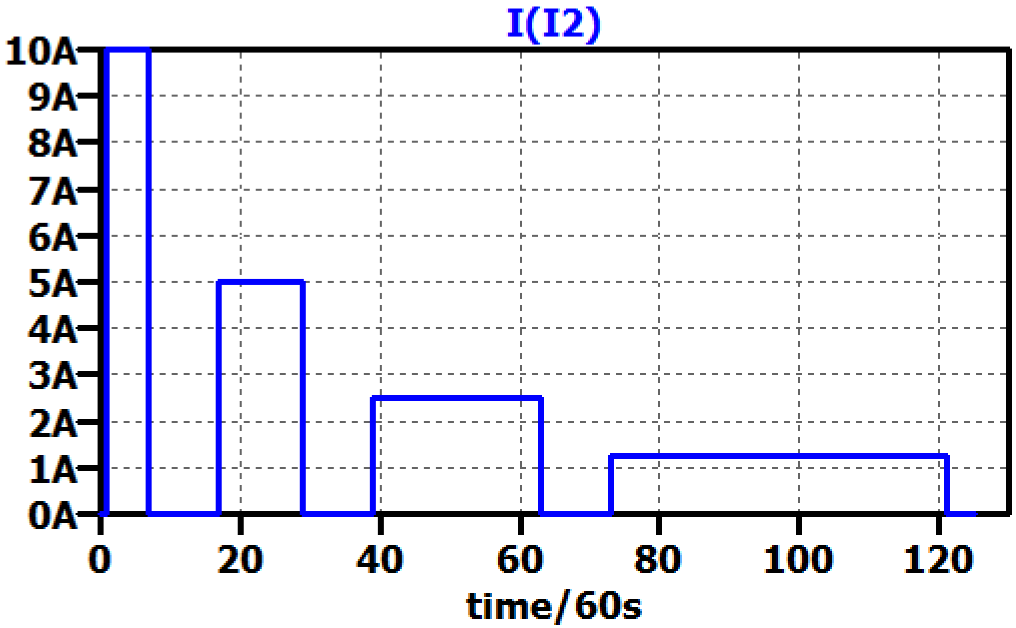
Model C Performance

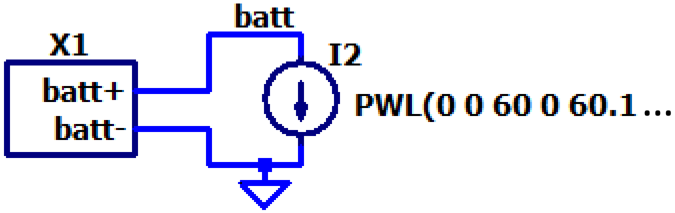


Model C Performance



Dynamic Performance

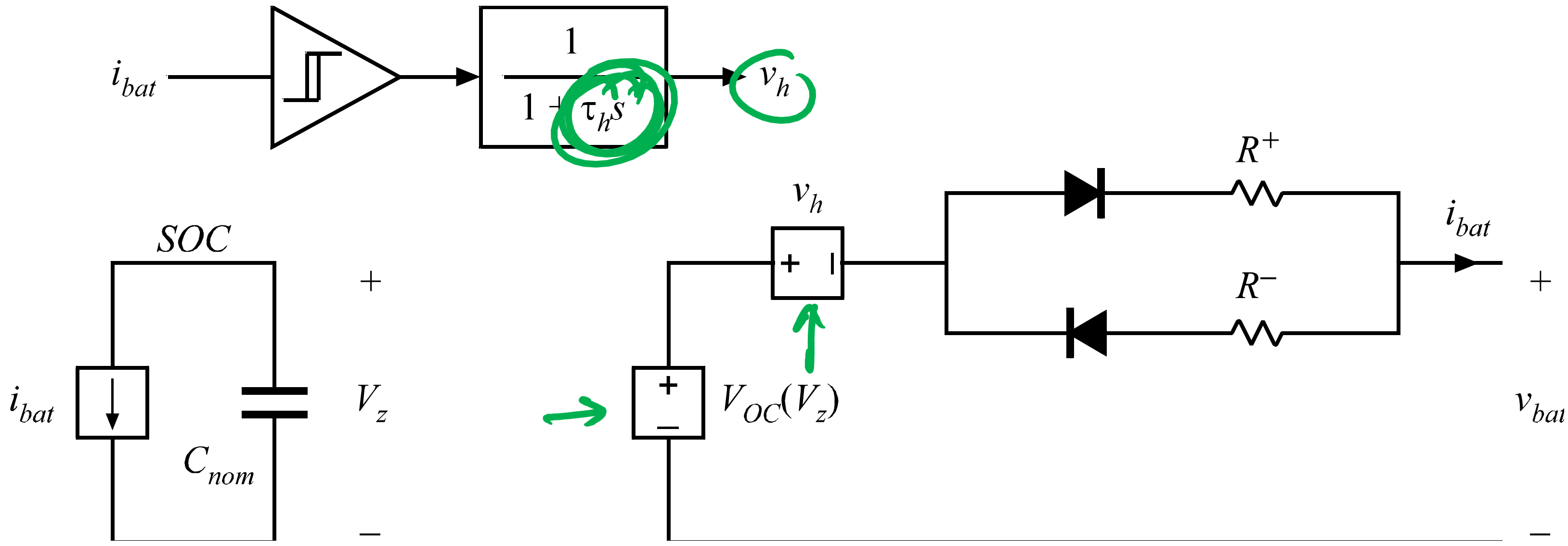




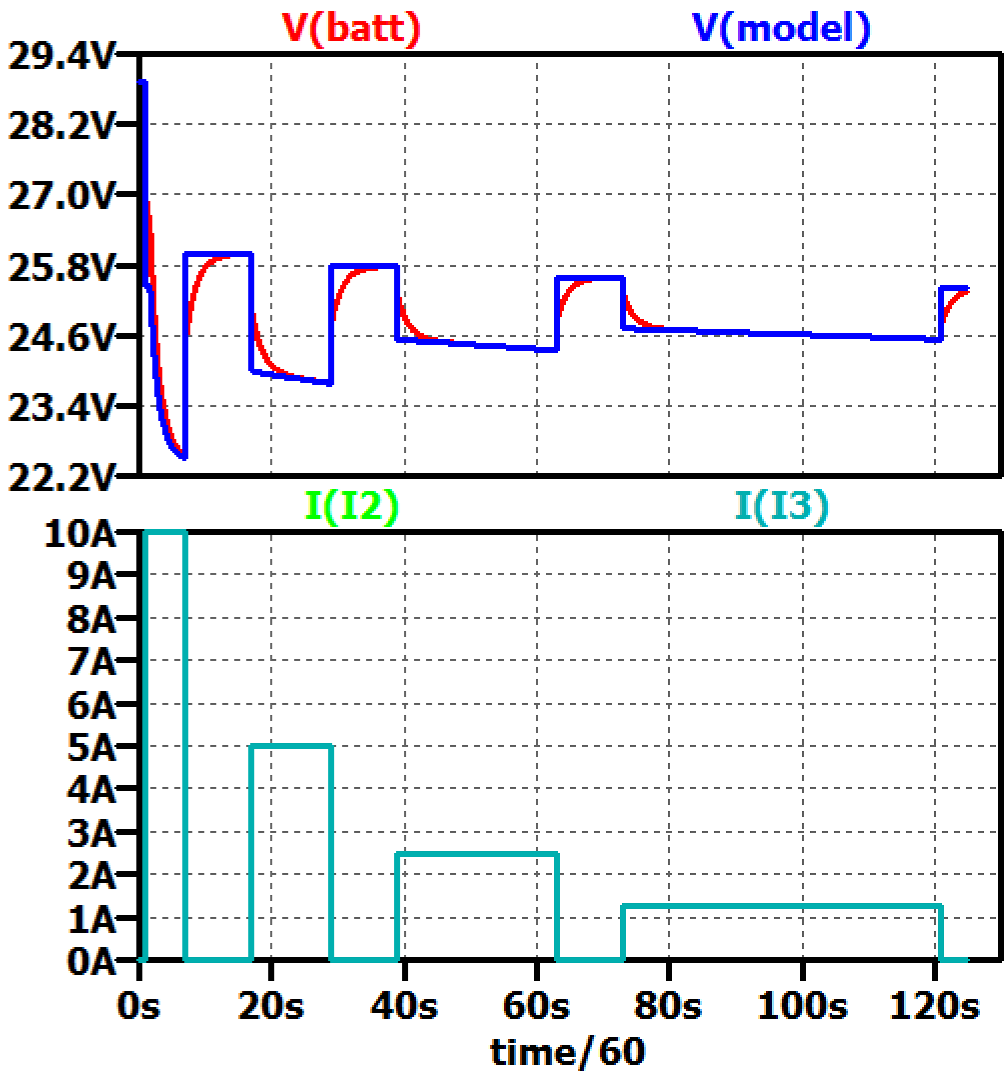
- Dynamic performance characterized by pulse train
- Constant percent of capacity per pulse [%Ahr] → not necessary

Model C1: One-state Hysteresis

[Plett 2004]

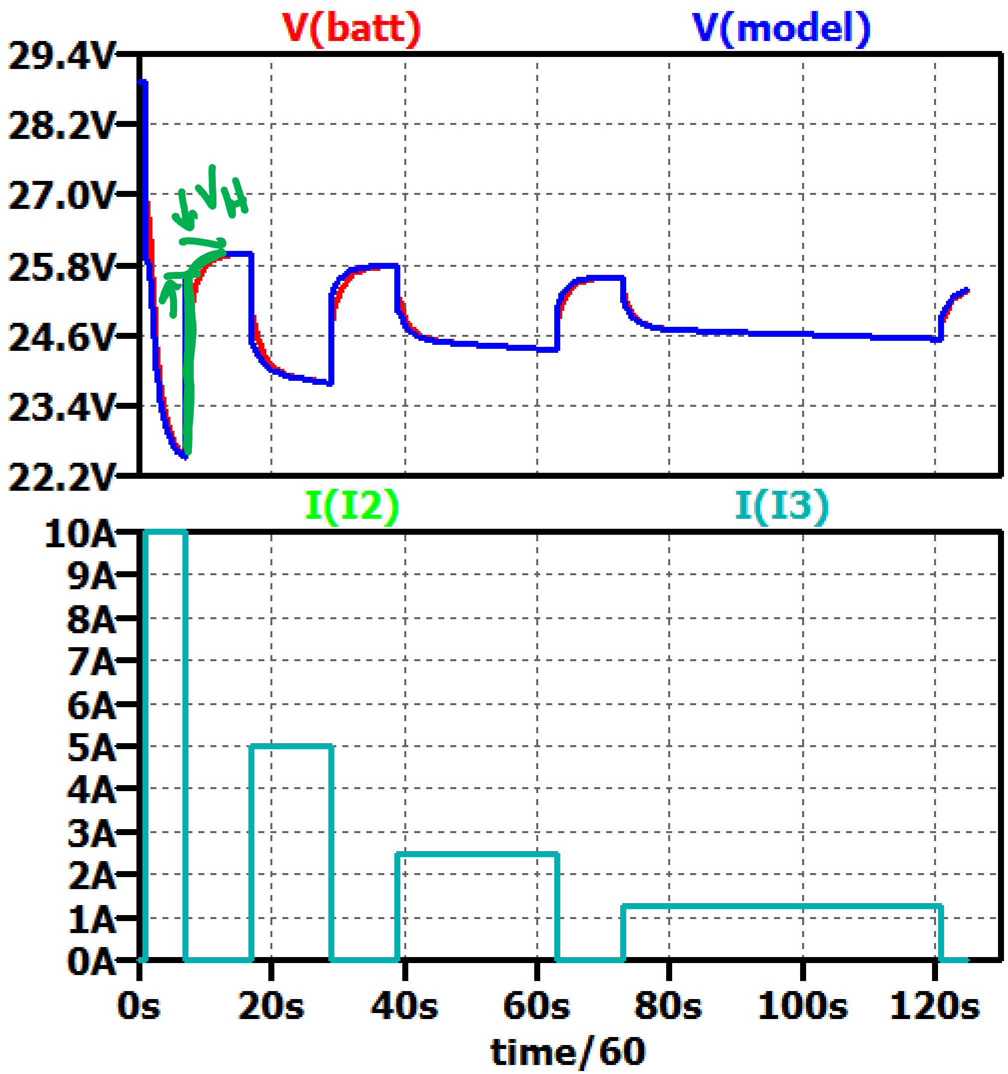


Model C1 Performance



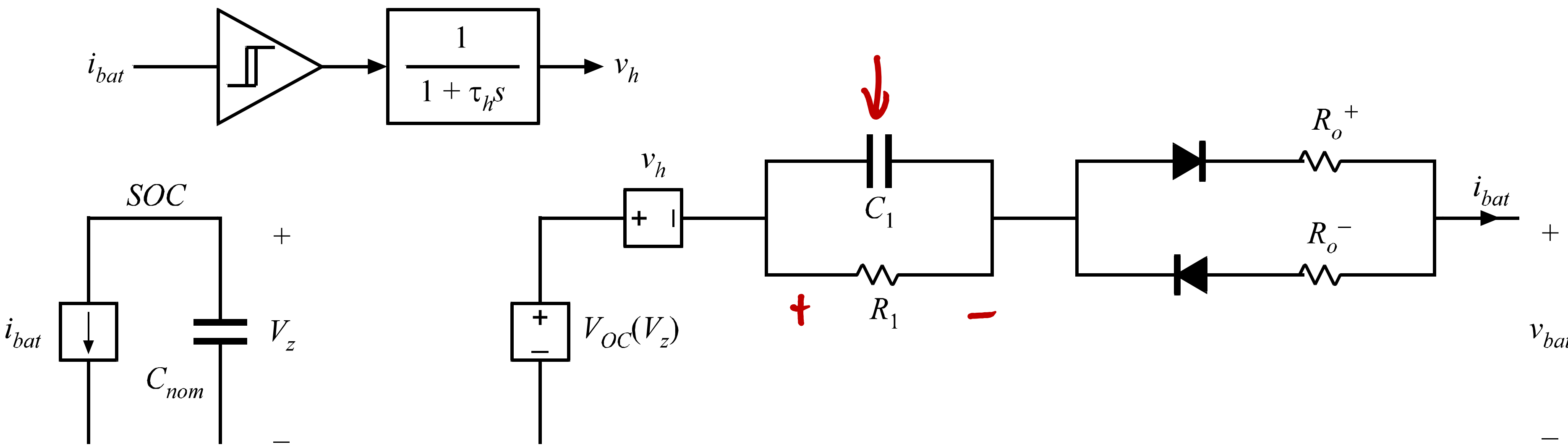
w/out dynamics of hysteresis

Model C1 Performance

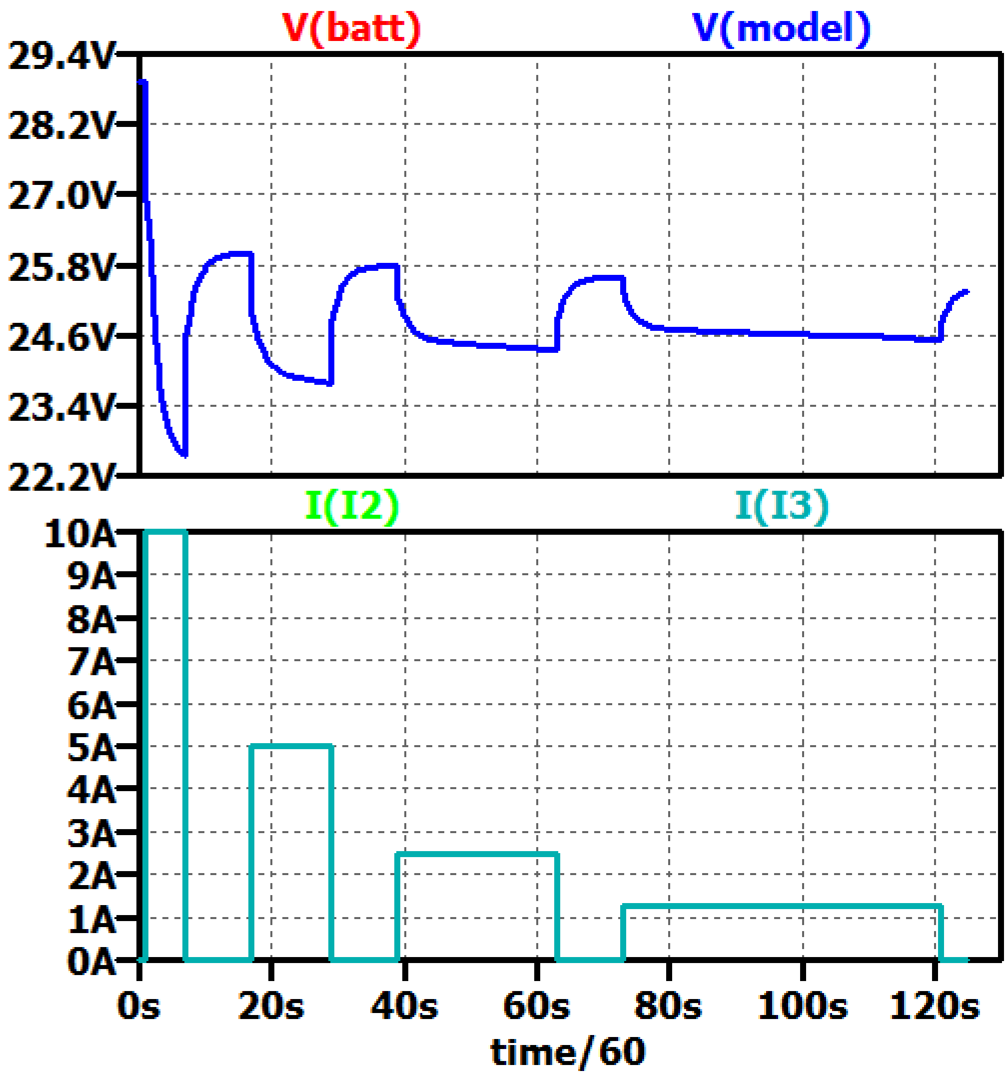


Model D: Diffusion (one-state)

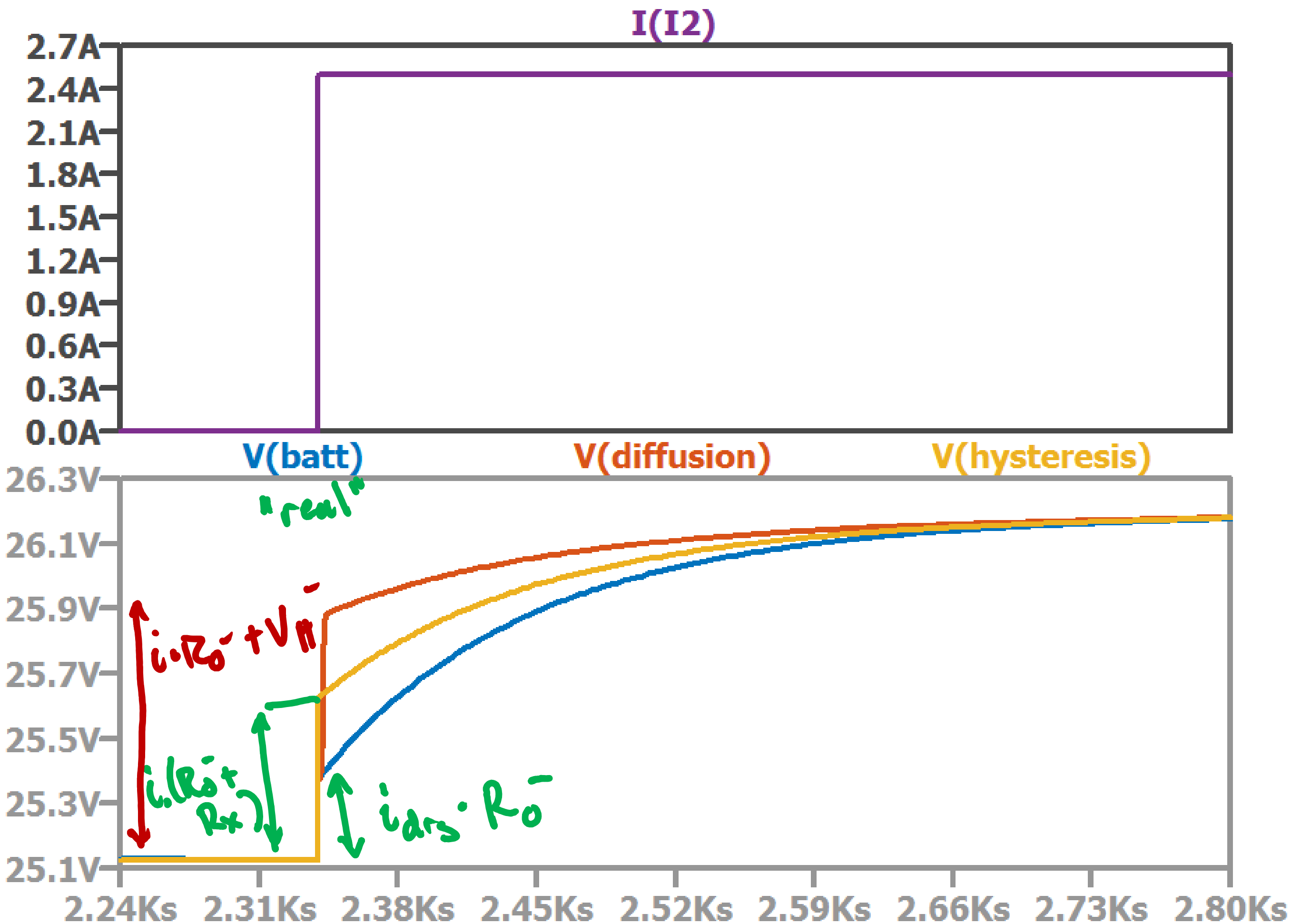
[Plett 2004]



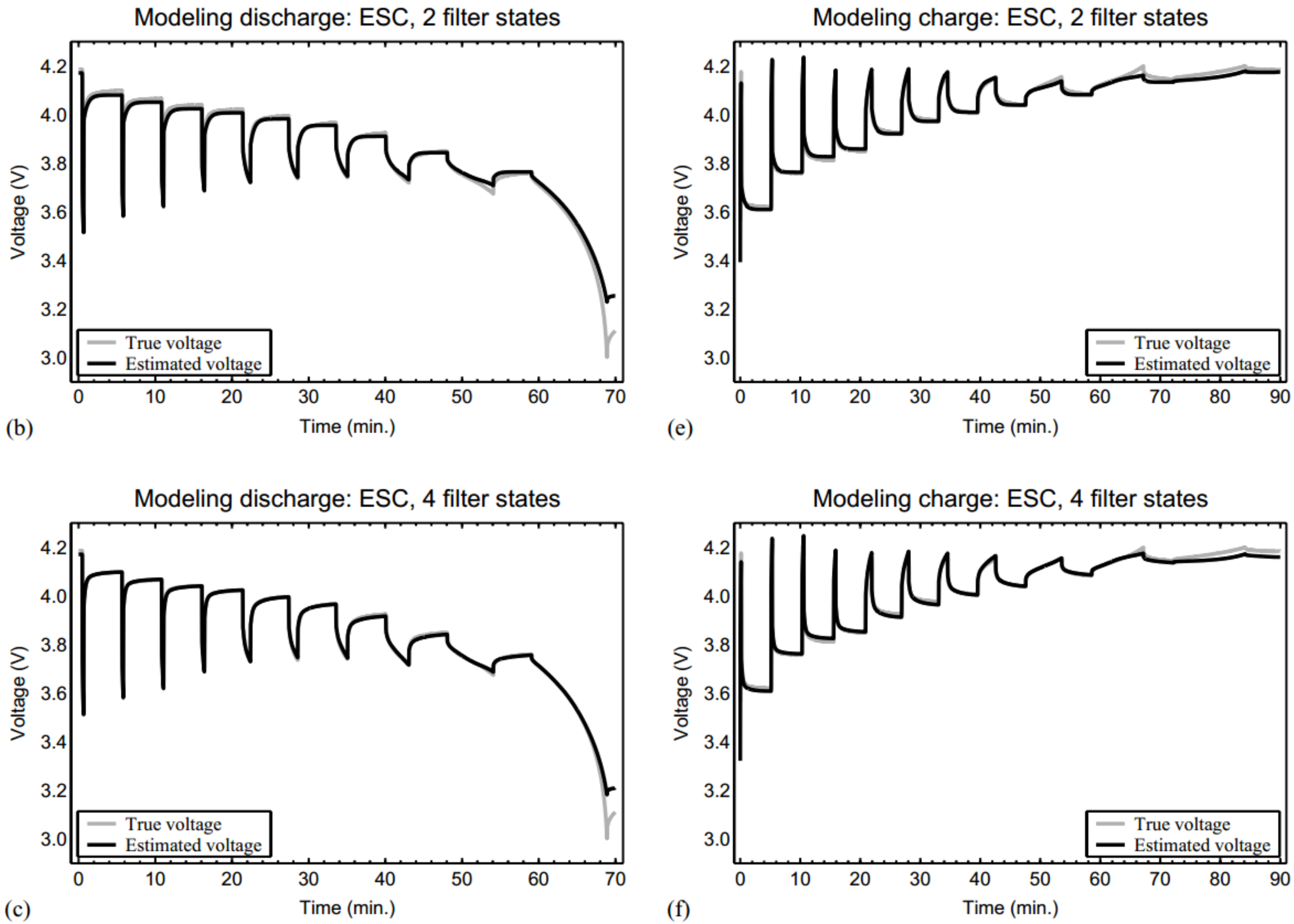
Model D Performance



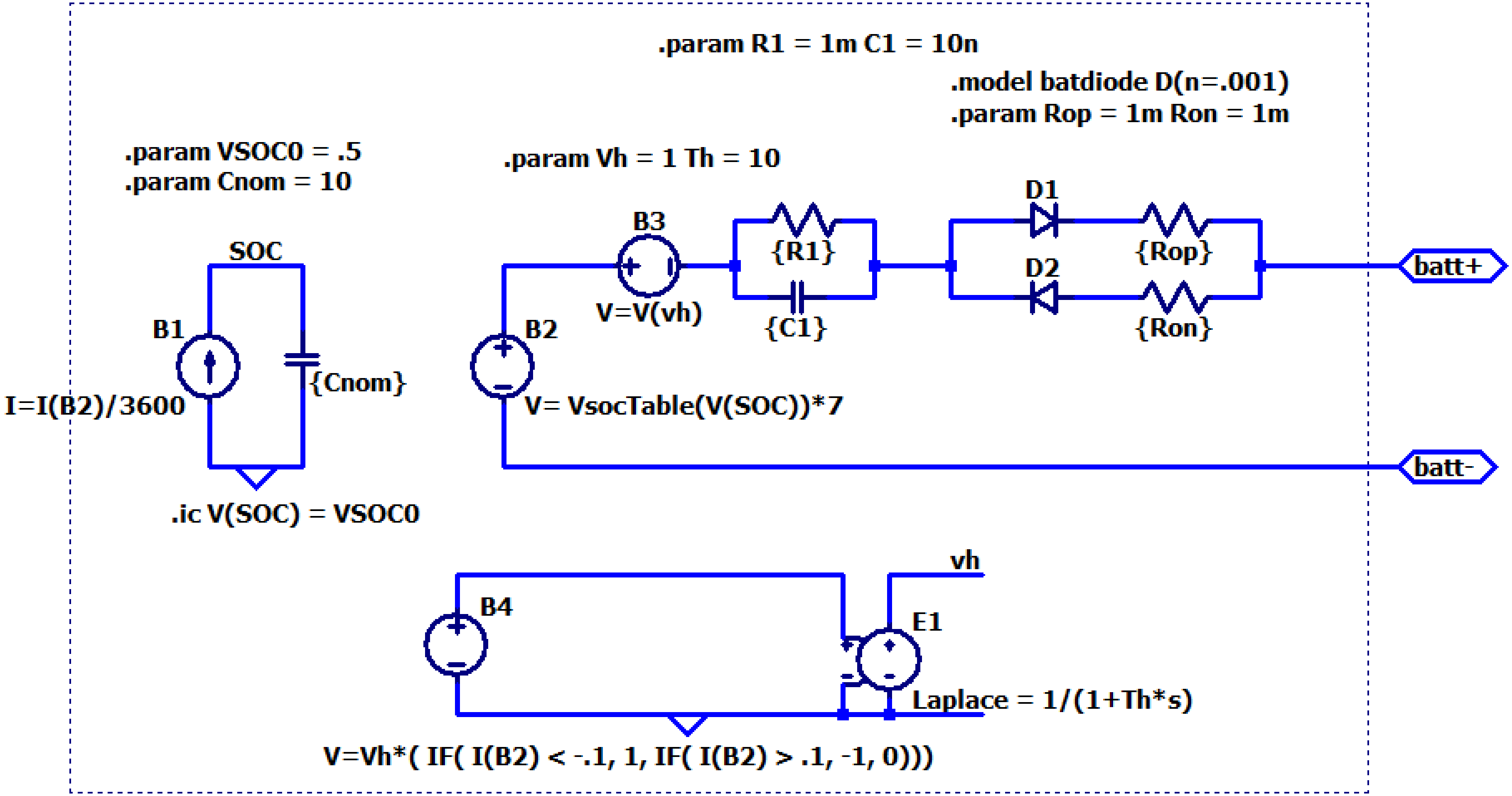
Diffusion Vs Hysteresis



Experimental Results



Implementation in LTSpice



.func VsocTable(x)= {table(x,0,3.0021, 0.01 , 3.108, 0.02 , 3.191, 0.03 , 3.257, 0.04 , 3.308, 0.05 , 3.3…