Introduction to Battery Modeling

Cell Equivalent-Circuit Models

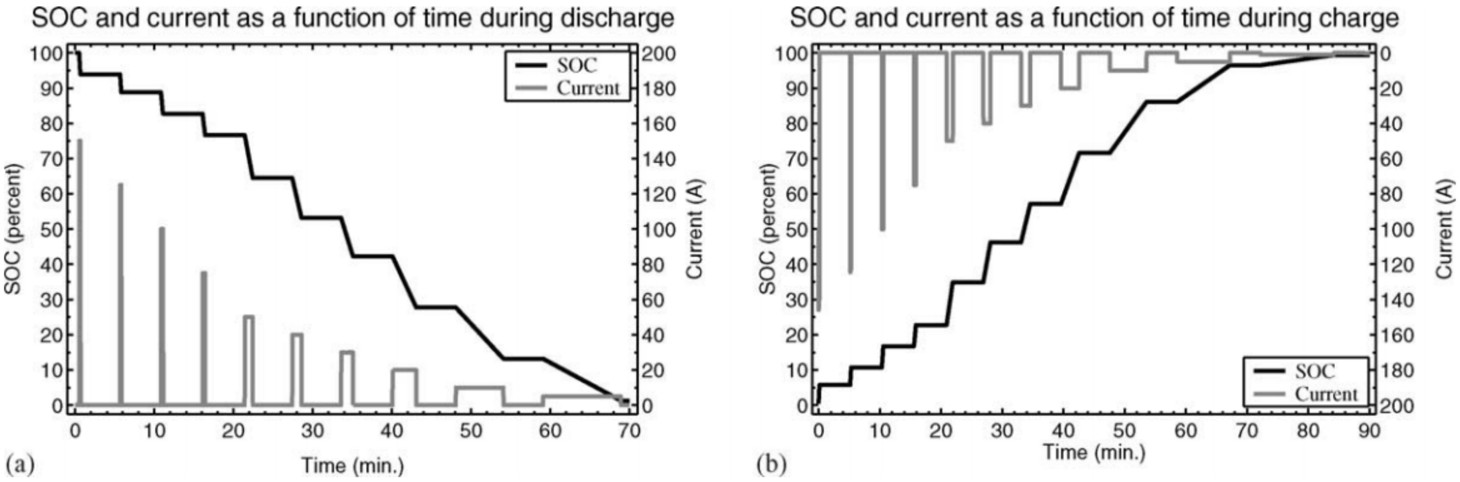
Objective:

- 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)

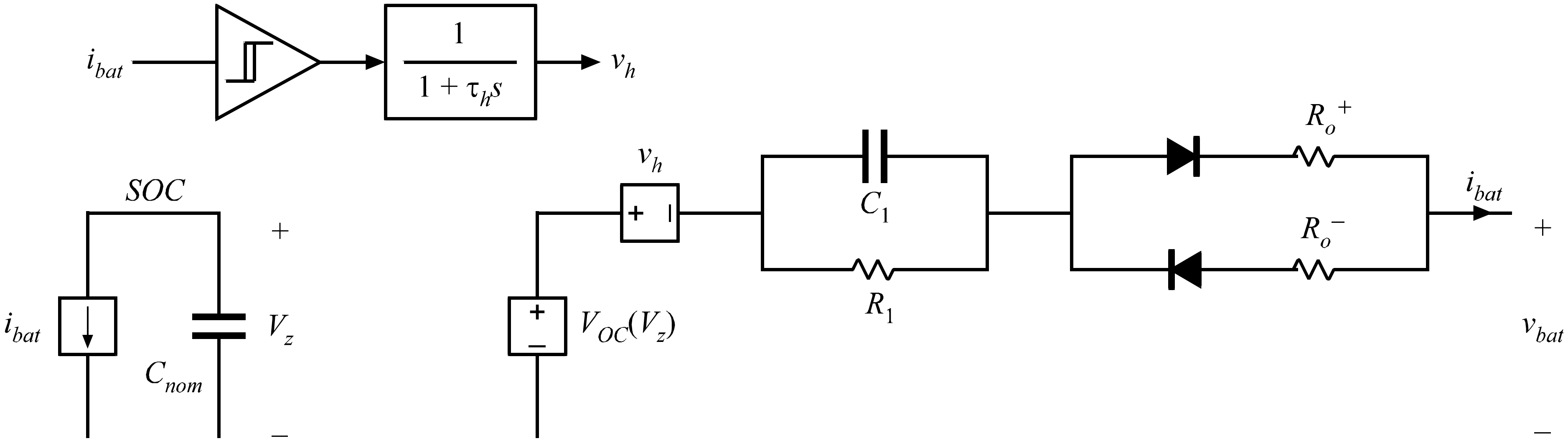
Approach: Pulsed current tests



[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.

Model D: Diffusion (one-state)

[Plett 2004]



Battery Nomenclature

- Known beforehand:

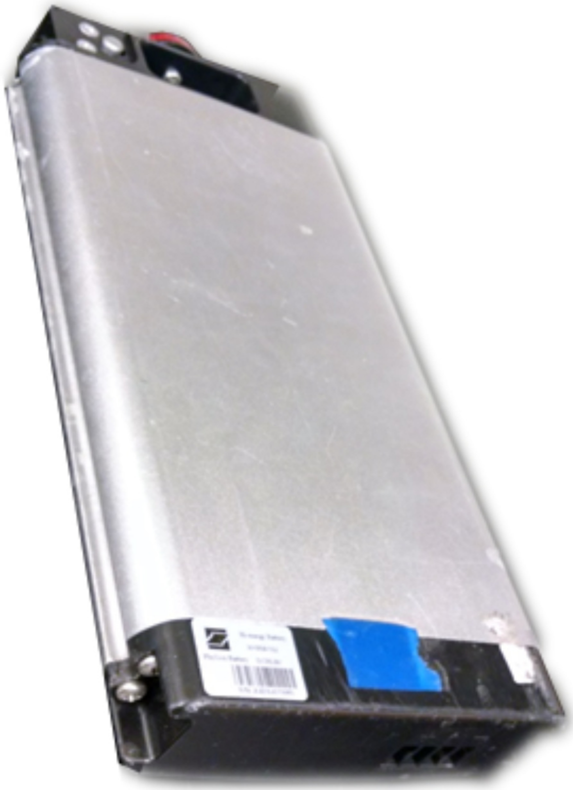
Capacity C [Ah] → May degrade over time

Nominal Voltage V_{nom} [V]

Max Discharge Rate
Max Charge Rate } Specified as "C" rate
- what current will completely charge / discharge the battery in 1 hr

ex For a 10 Ah = C cell,
a 2C discharge rate means 20A max discharge
A 0.5C charge rate means 5A max charge current

Example Battery



Battery packs characterized by arrangement of cells

" $\underline{N_s}\, s\, \underline{N_p}\, p$ "

N_s = # of cells in series

N_p = # of cells in parallel

ex 7s5p → 7 in series, 5 in parallel

35 total cells in the pack

Pack voltage determined by # of cells in series

Pack capacity determined by # in parallel

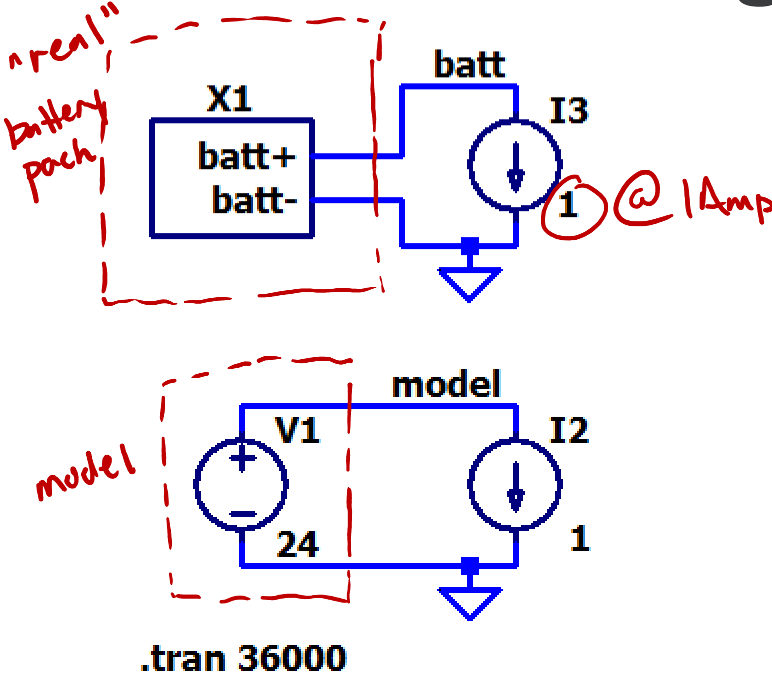
ex cells have

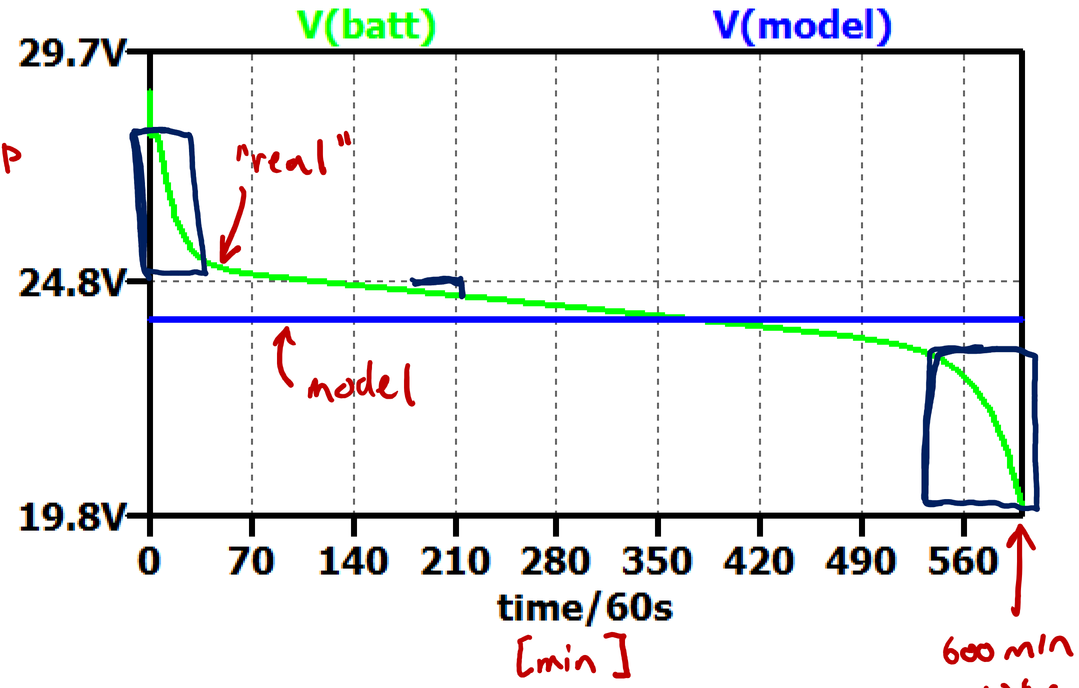
- $V_{nom} = 3.4V$
- $C = 2Ah$
- max charge : $0.2C = 0.8A$
- max discharge : $1.9C = 3.8A$

A 7s5p pack will have

- $V_{nom} = 23.8V$
- $C = 10Ah$
- max charge : $0.2C = 4A$
- max discharge : $1.9C = 19A$

Model 0: Voltage Source



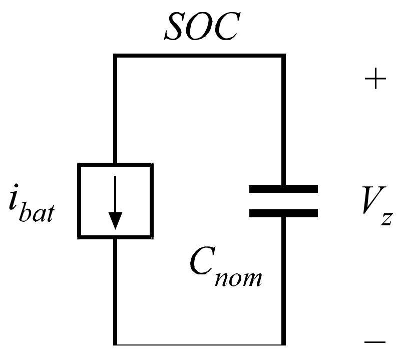


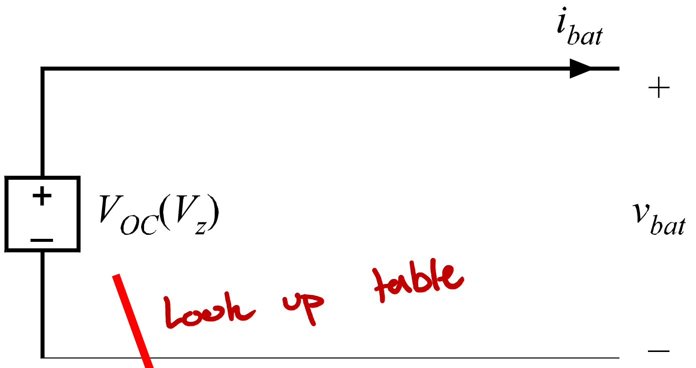
@ 1Amp

$\boxed{C = 10Ah}$

- Revise model to include charge-dependent voltage

Model A: SOC and V_{oc}





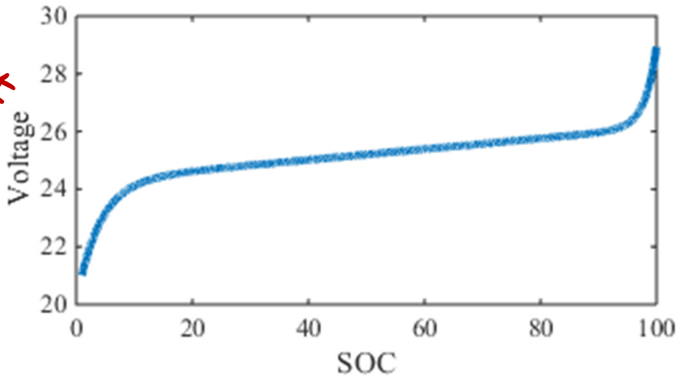
Look up table

Battery current integrator

$$V_z = V_{z0} - \frac{1}{C_{nom}} \underbrace{\int_0^t i_{bat}\, dt}_{\text{total charge in/out in A}\cdot\text{s}}$$

↑ I.e.

↓ scale factor

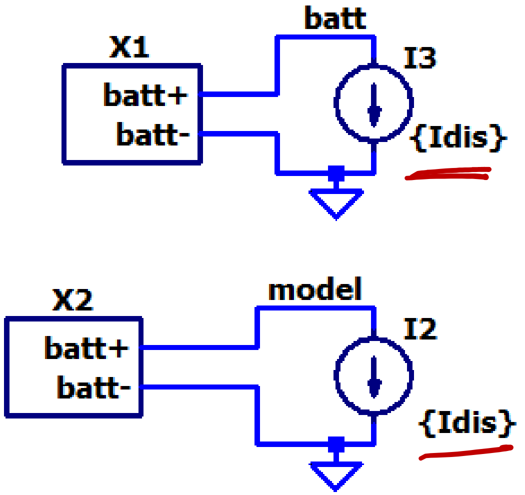


Open-circuit

If we set $C_{nom} = C \cdot 3600 \frac{sec}{hr}$

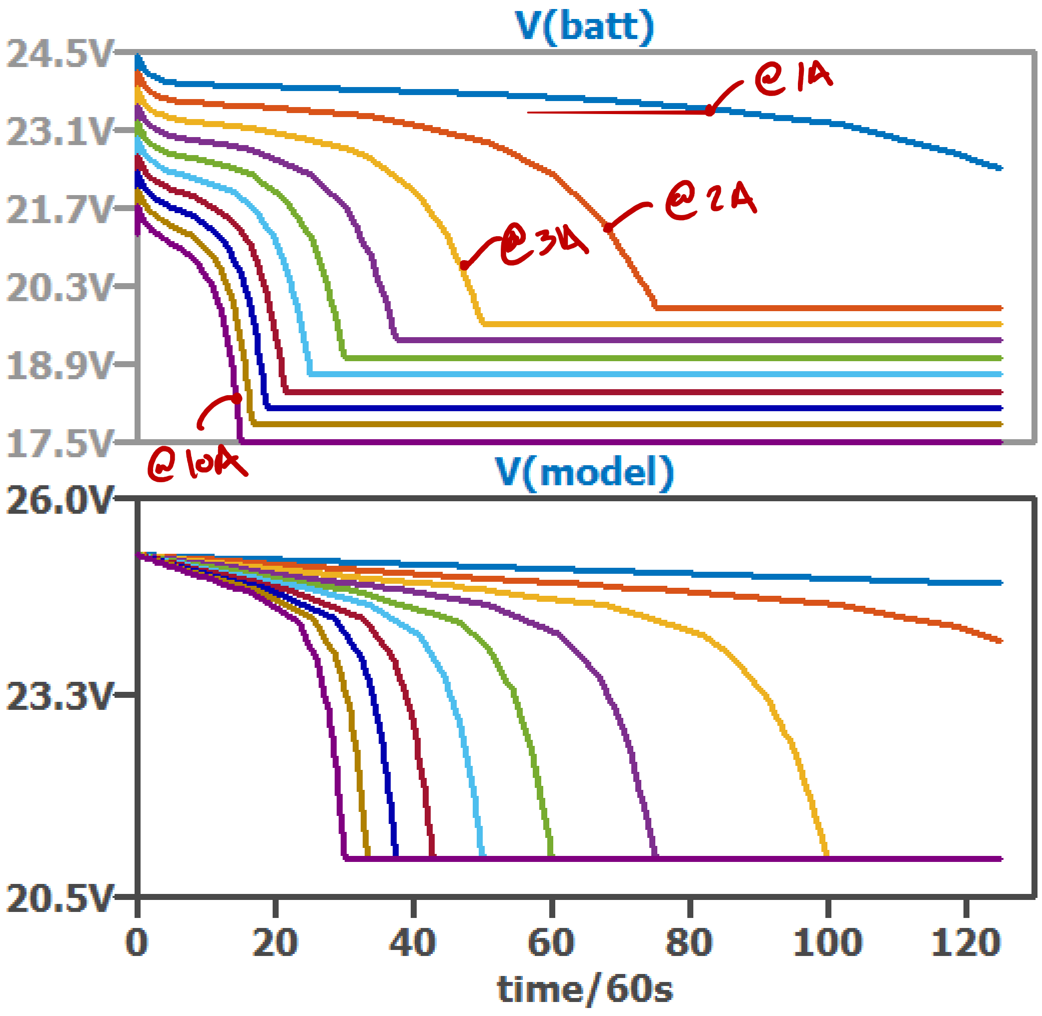
$0 \le V_z \le 1$ → proportion of full capacity remaining → State-of-Charge [%]

Model B: Series Resistance

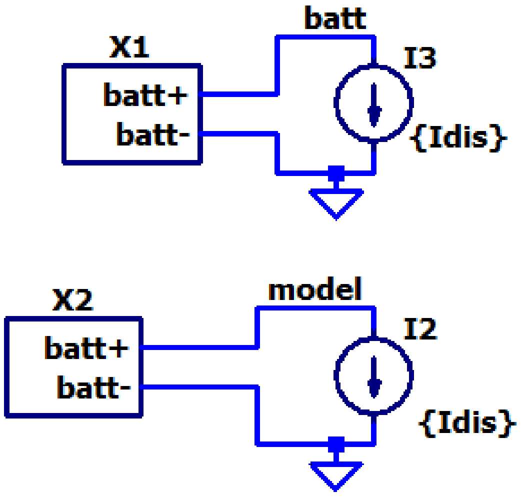


.tran 36000

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



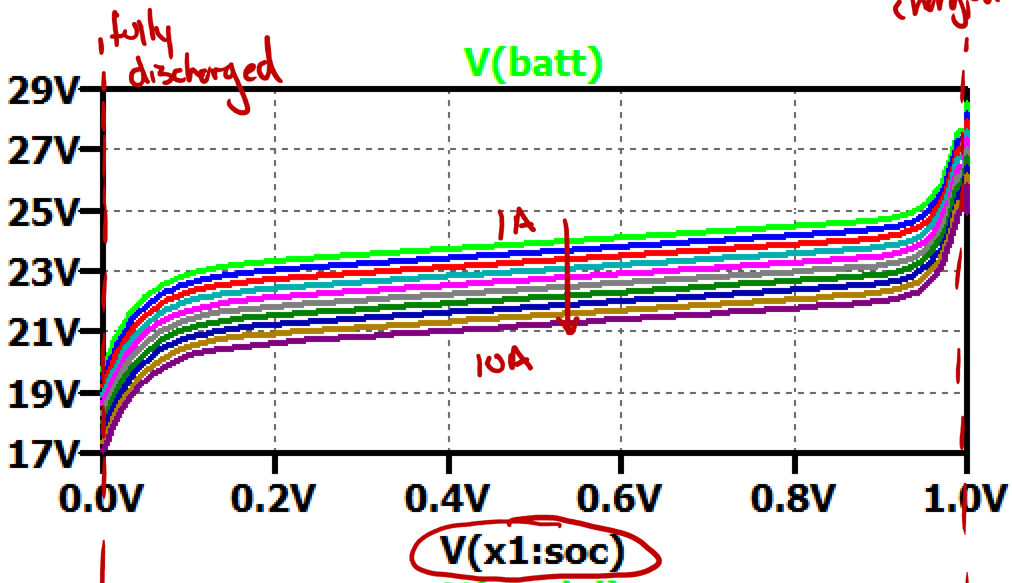
Model B: Series Resistance

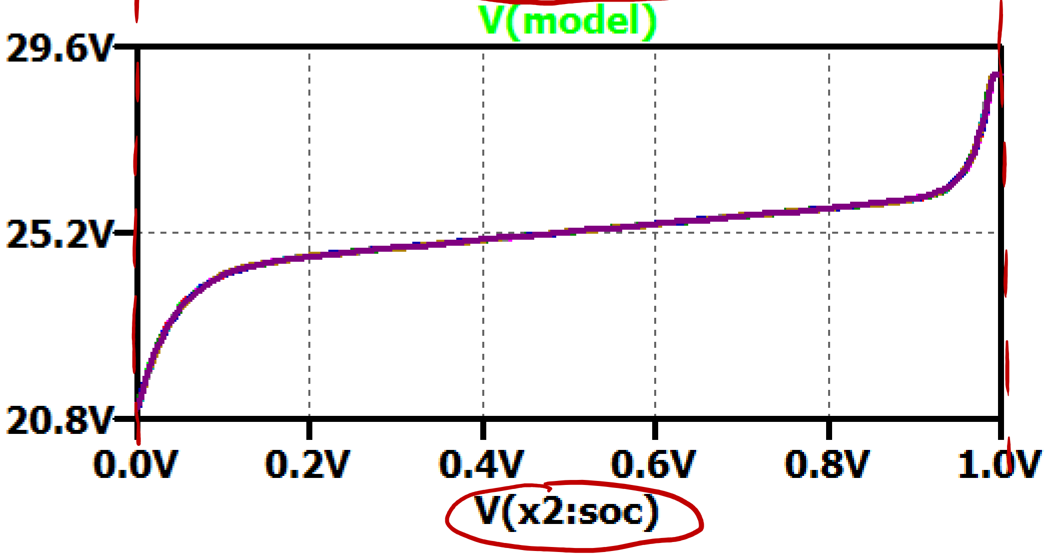


```
.tran 36000
.param Idis = 1
.step param Idis 1 10 1
```

offset in pack voltage proportional to discharging current

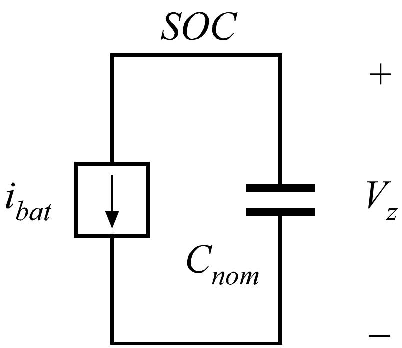
$\Delta V = I_{dis} (R)$

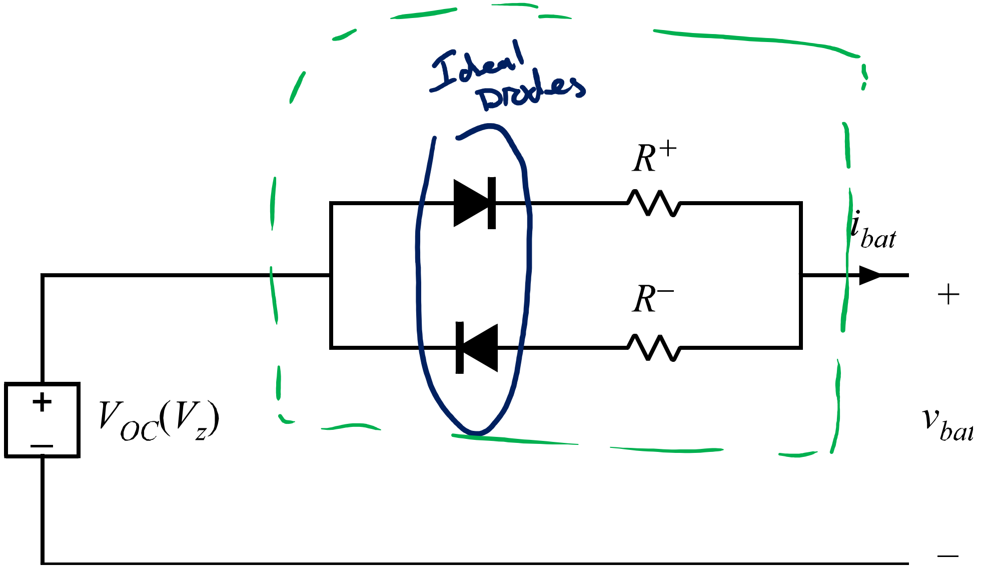




plotting vs SOC instead of time

Model B: Series Resistance

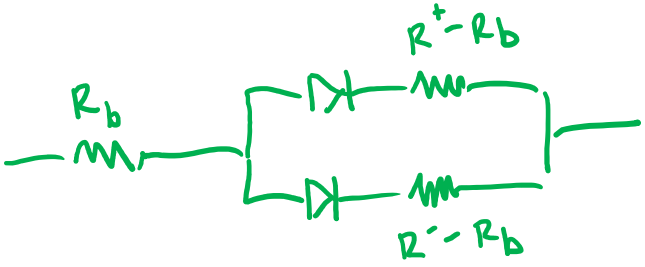




R^+ = discharging resistance

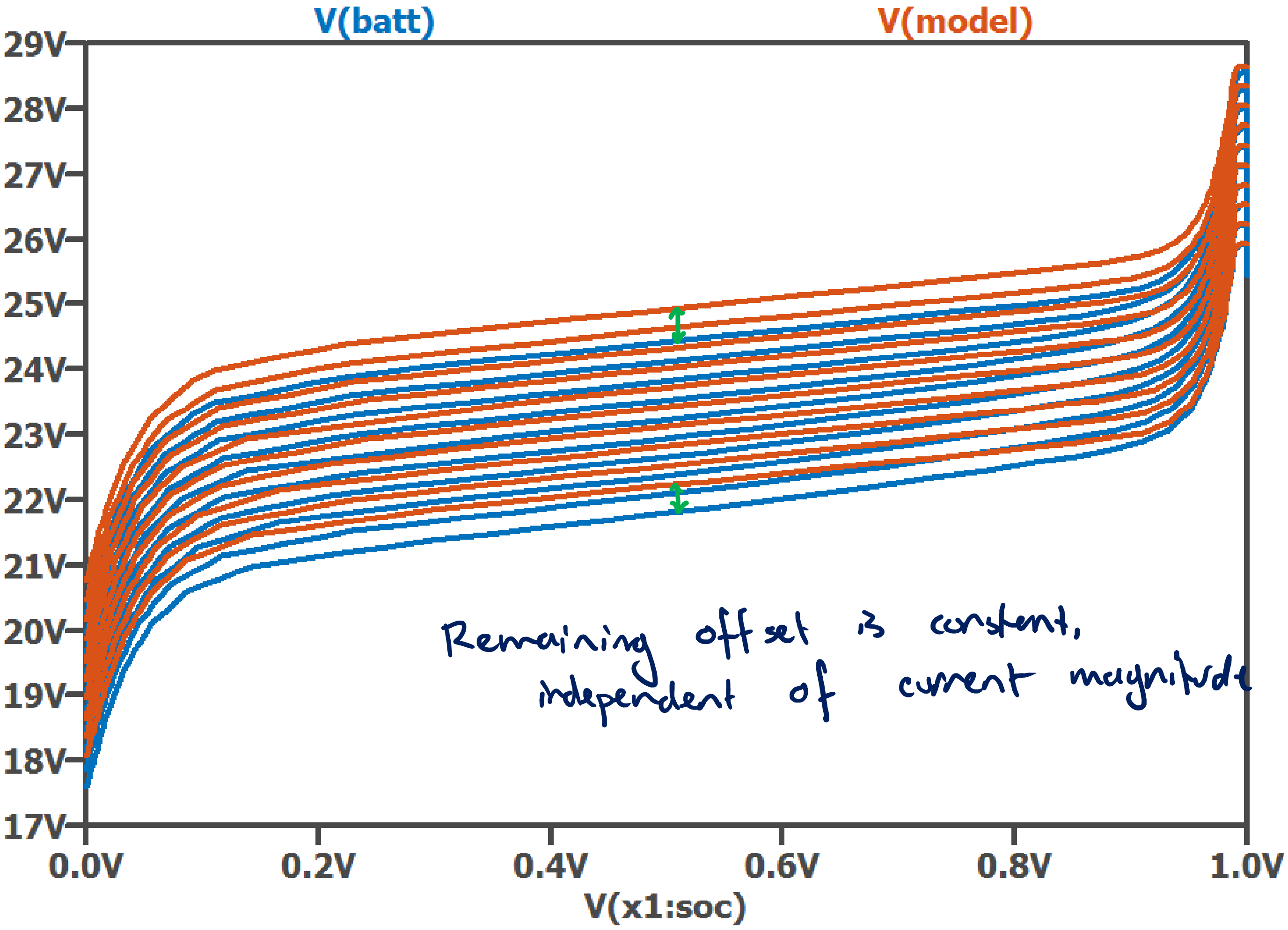
R^- = charging resistance

Equivalent Model



$R_b \le \min(R^+, R^-)$

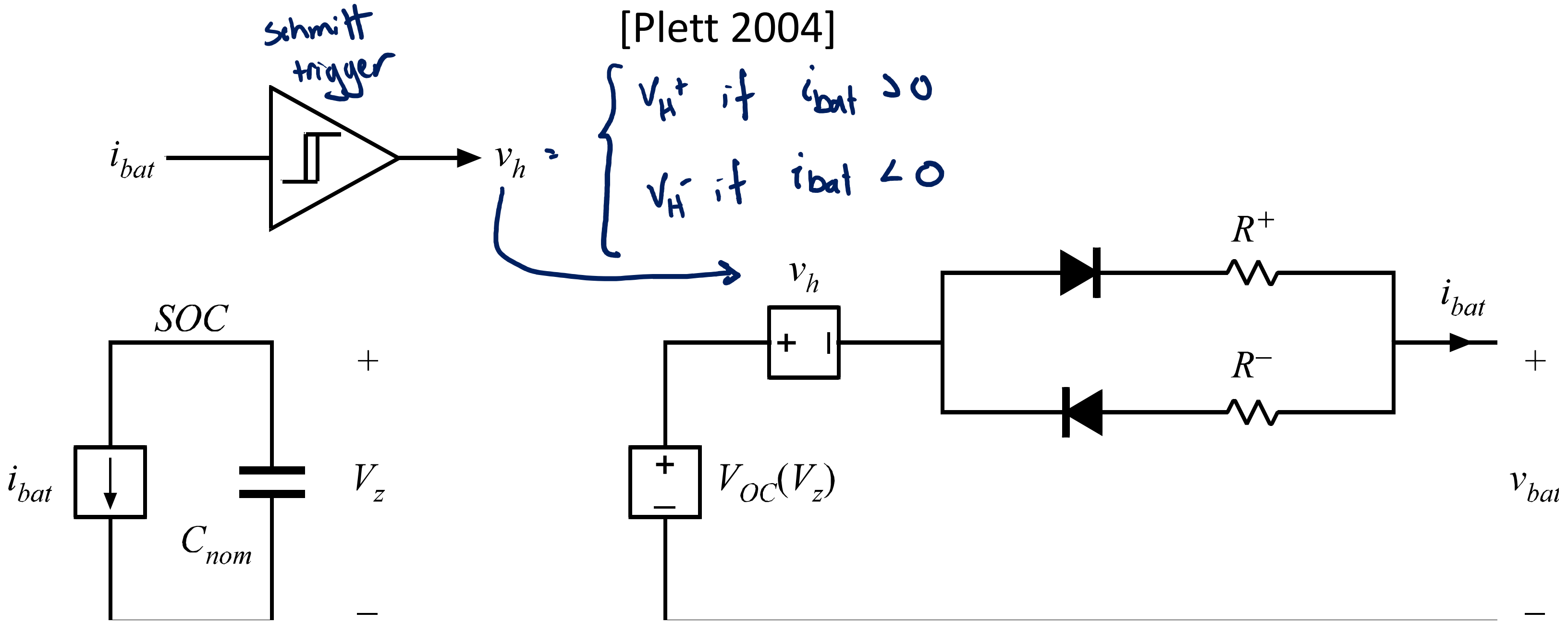
Model B Performance



Remaining offset is constant,
independent of current magnitude

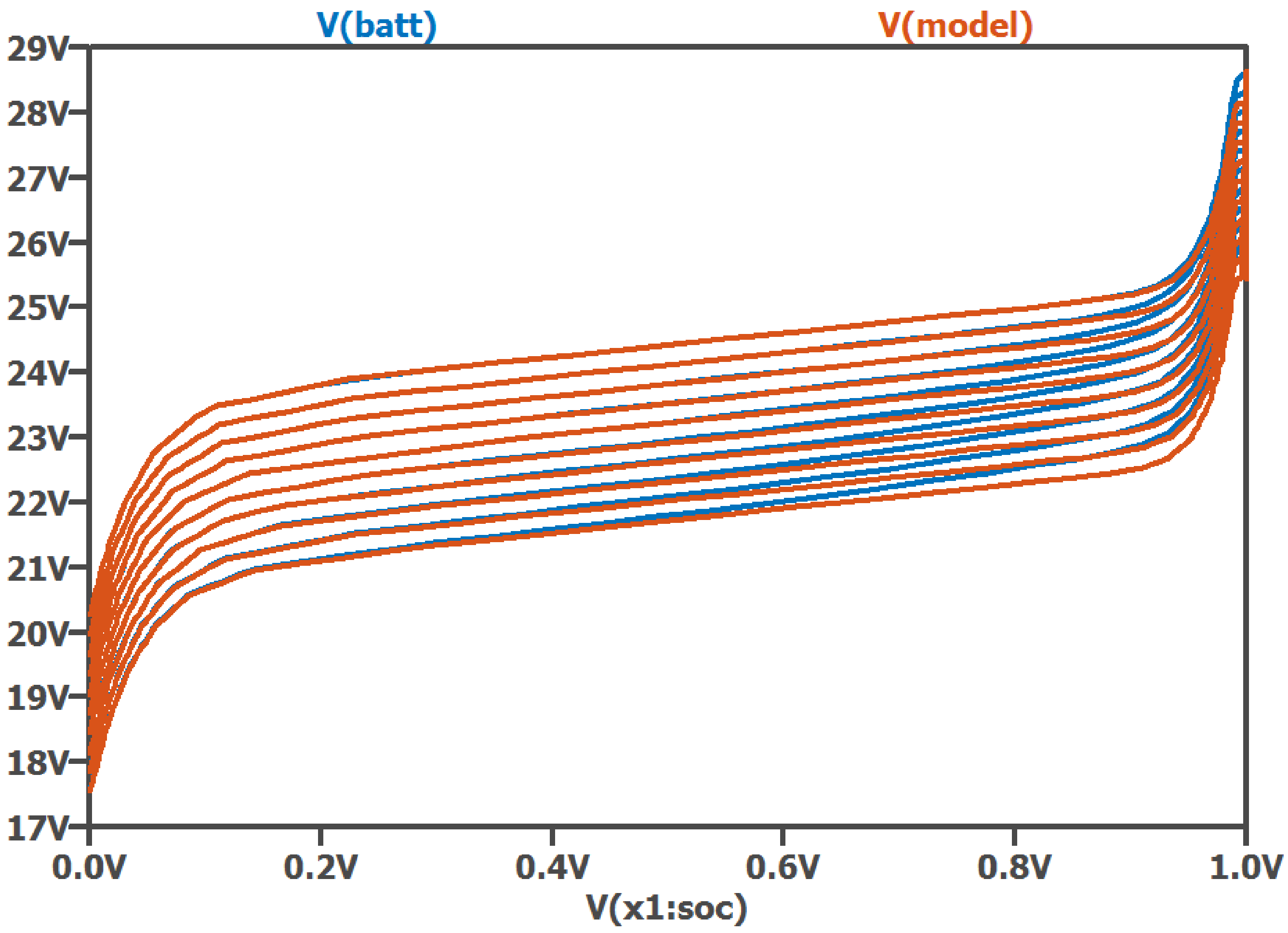
Model C: Zero-state Hysteresis

[Plett 2004]

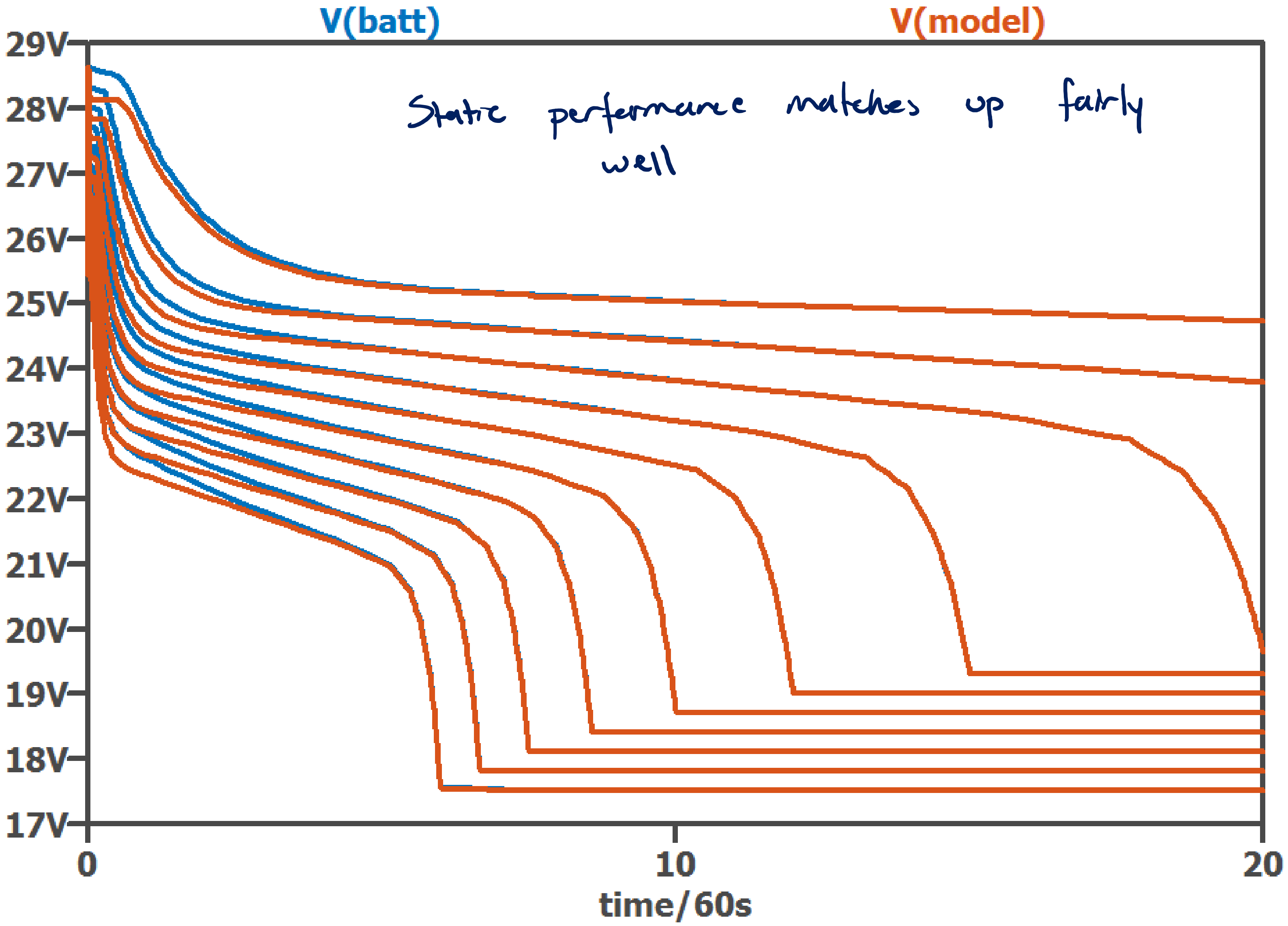


$$v_h = \begin{cases} V_H^+ & \text{if } i_{bat} > 0 \\ V_H^- & \text{if } i_{bat} < 0 \end{cases}$$

Model C Performance

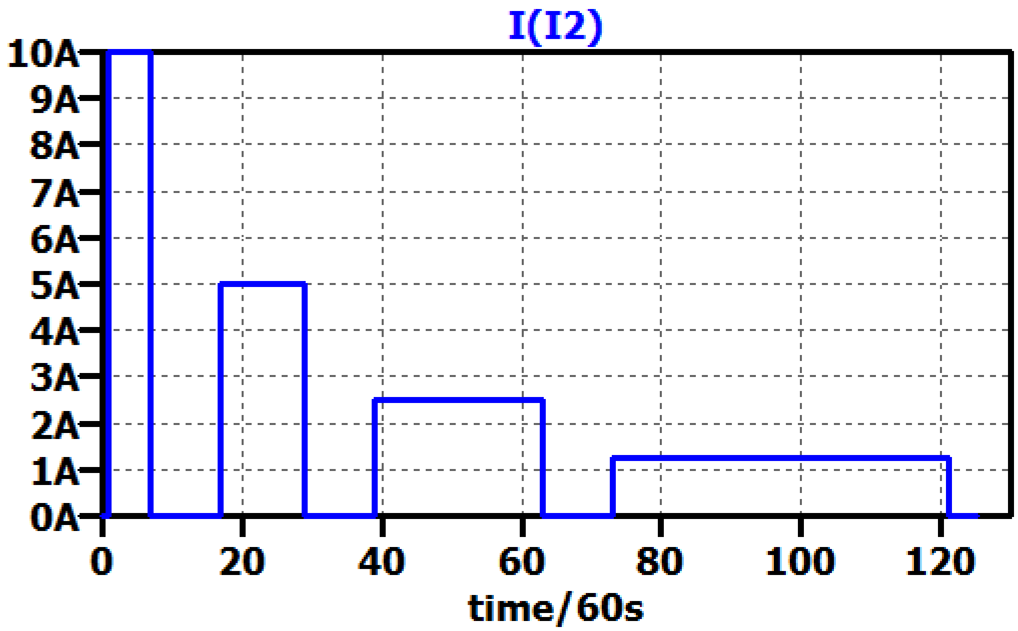


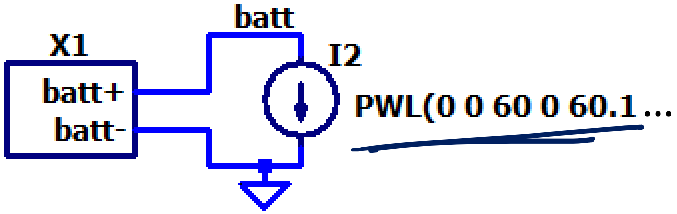
Model C Performance



Static performance matches up fairly well

Dynamic Performance

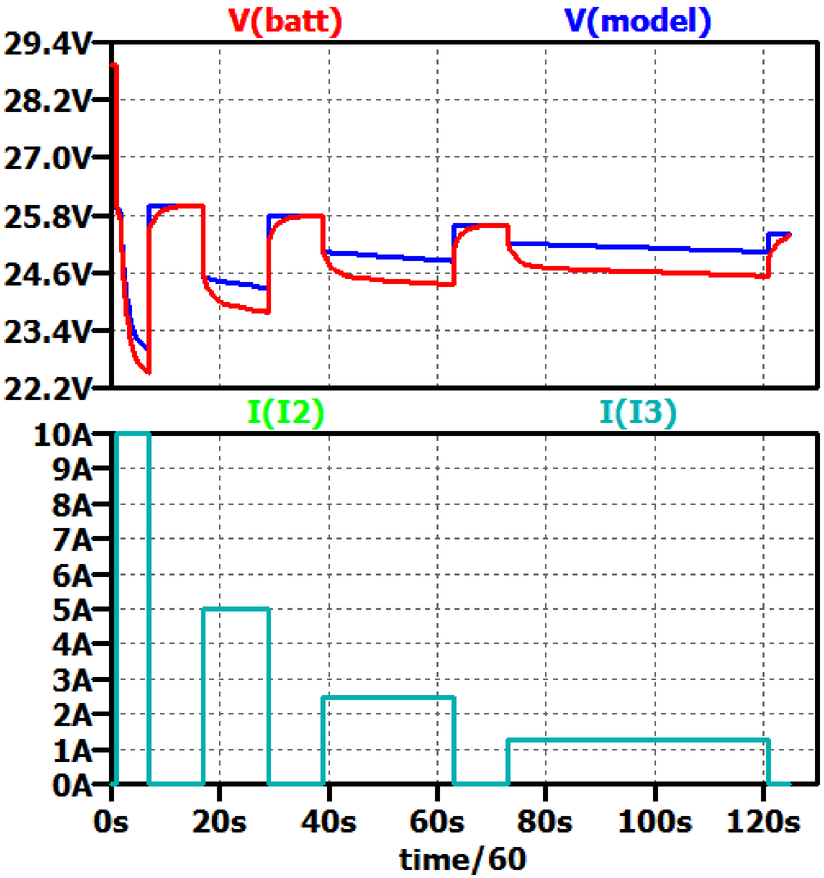




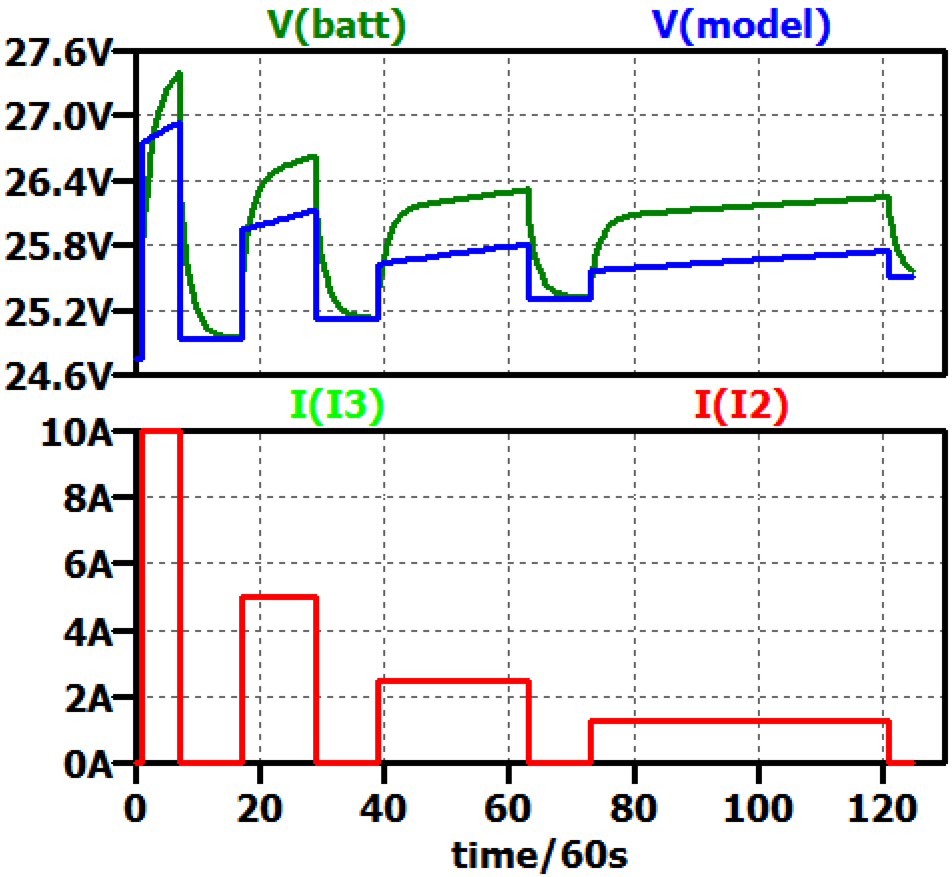
- Dynamic performance characterized by pulse train
- Constant percent of capacity per pulse [%Ahr] → Not a necessity

Dynamic Performance

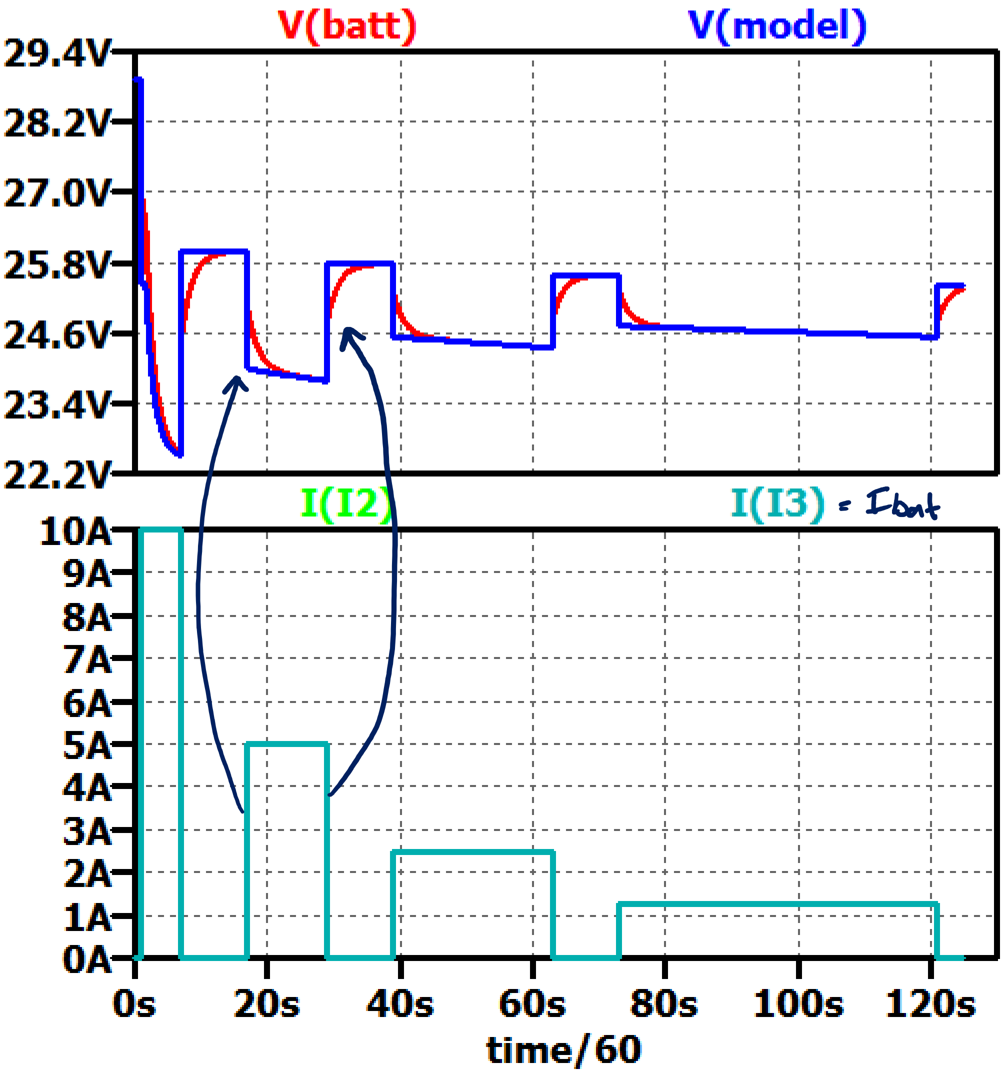
Discharge



Charge

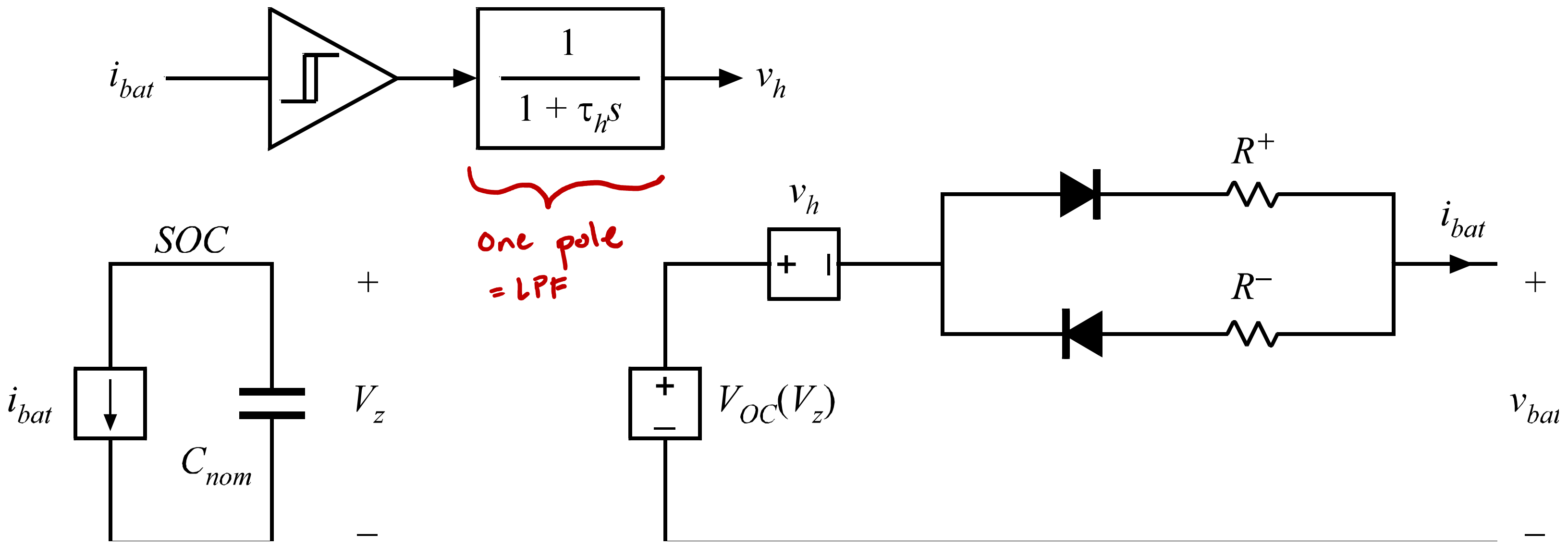


Model C Performance



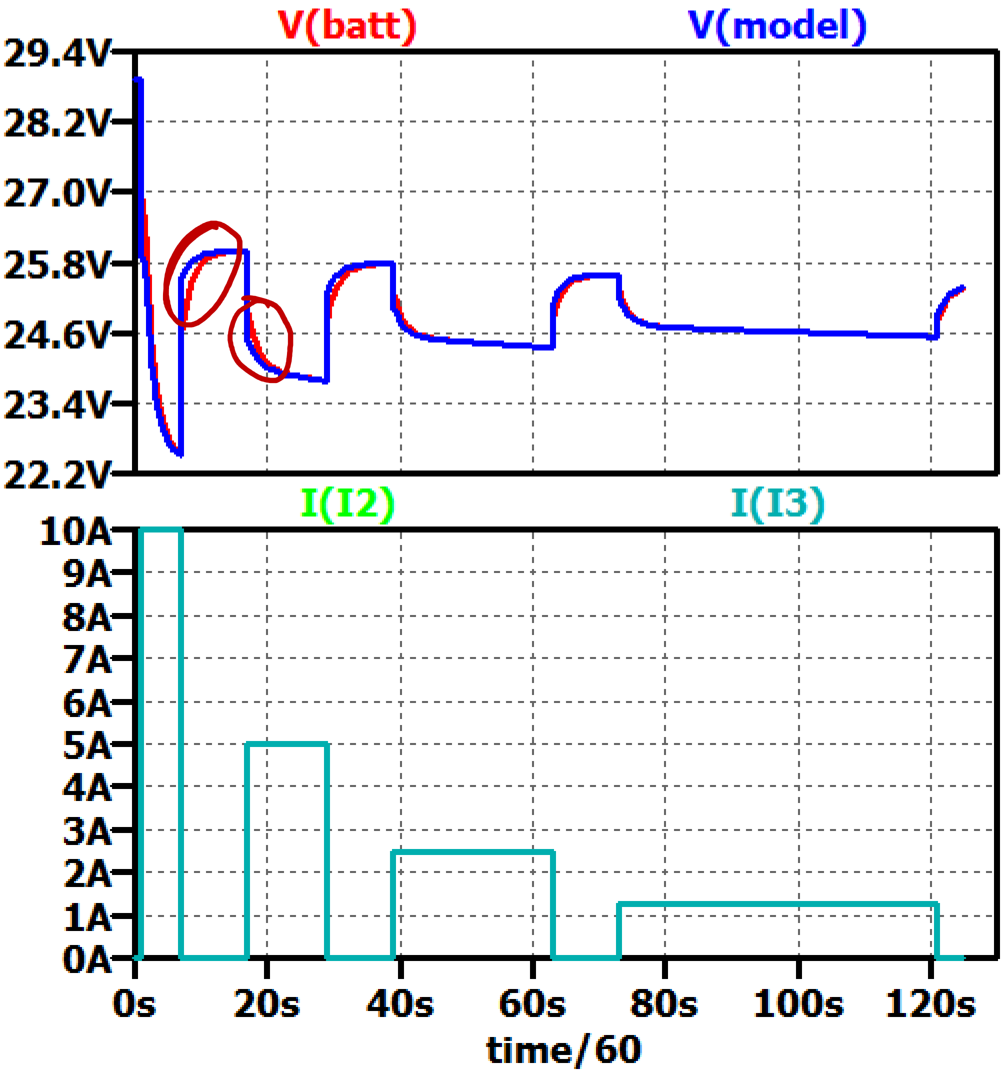
Model C1: One-state Hysteresis

[Plett 2004]



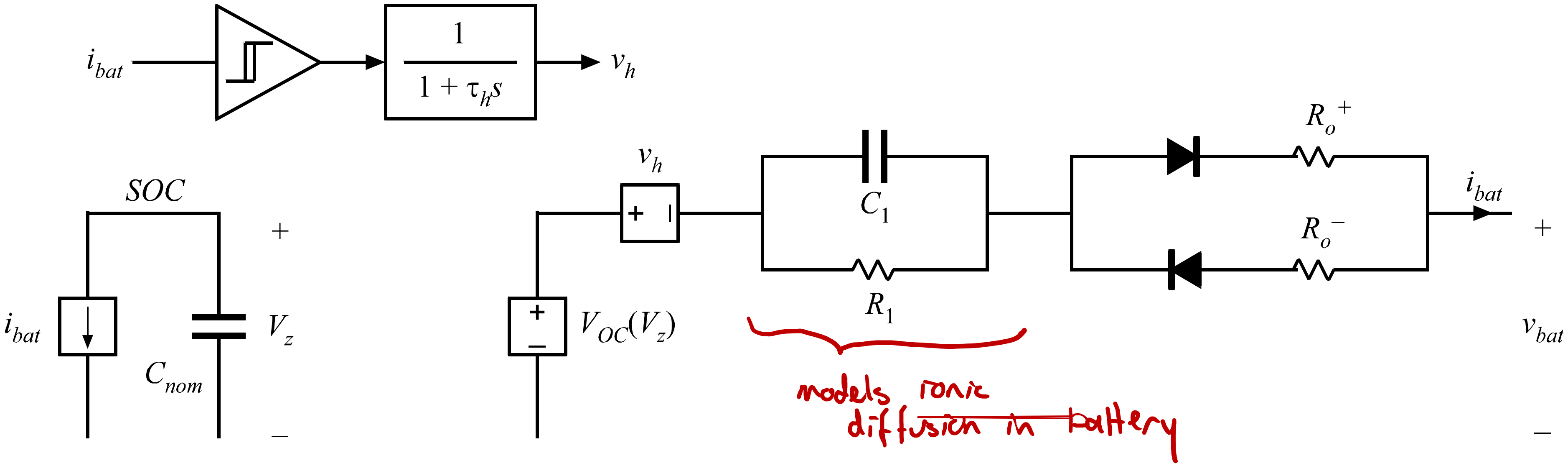
One pole = LPF

Model C1 Performance



Model D: Diffusion (one-state)

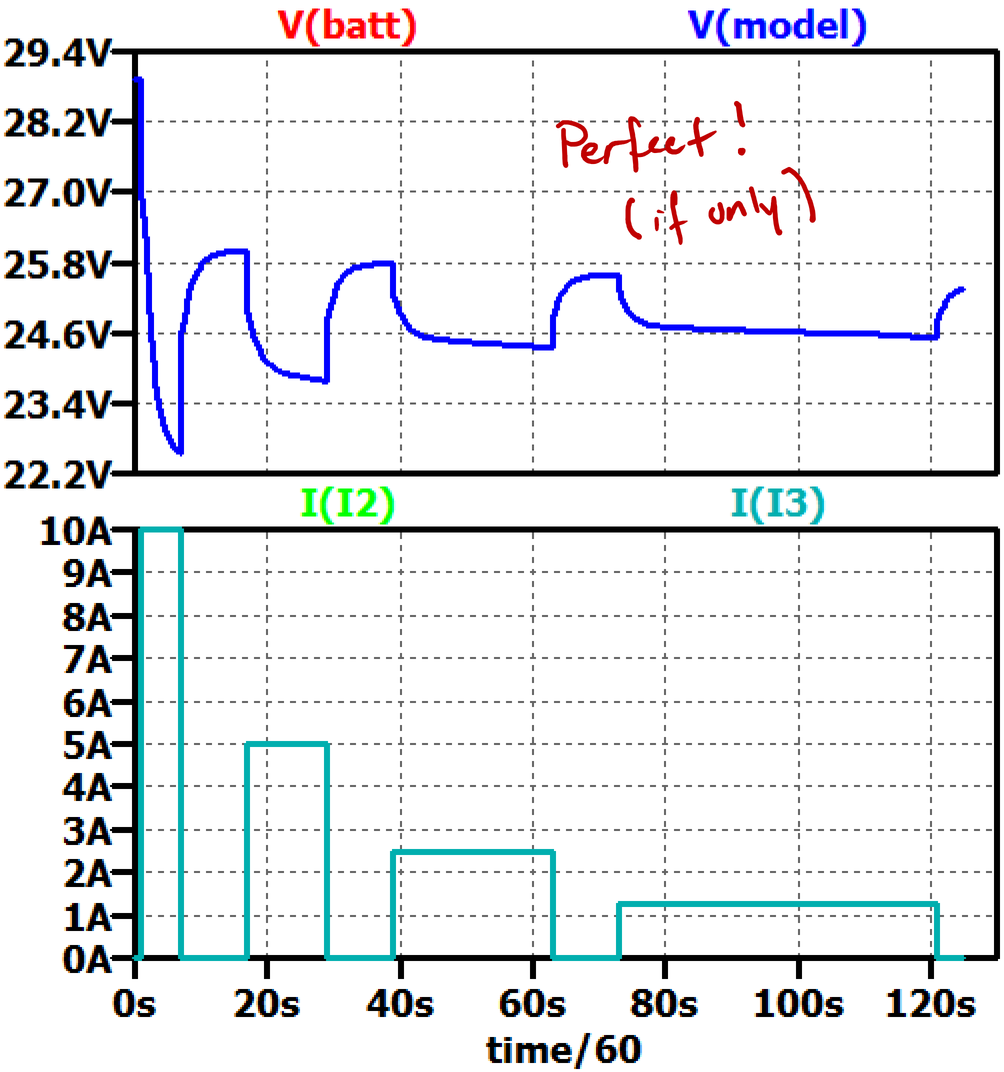
[Plett 2004]



models ionic diffusion in battery

R_1 → removed from R^+/R^- so total steady-state resistance doesn't change

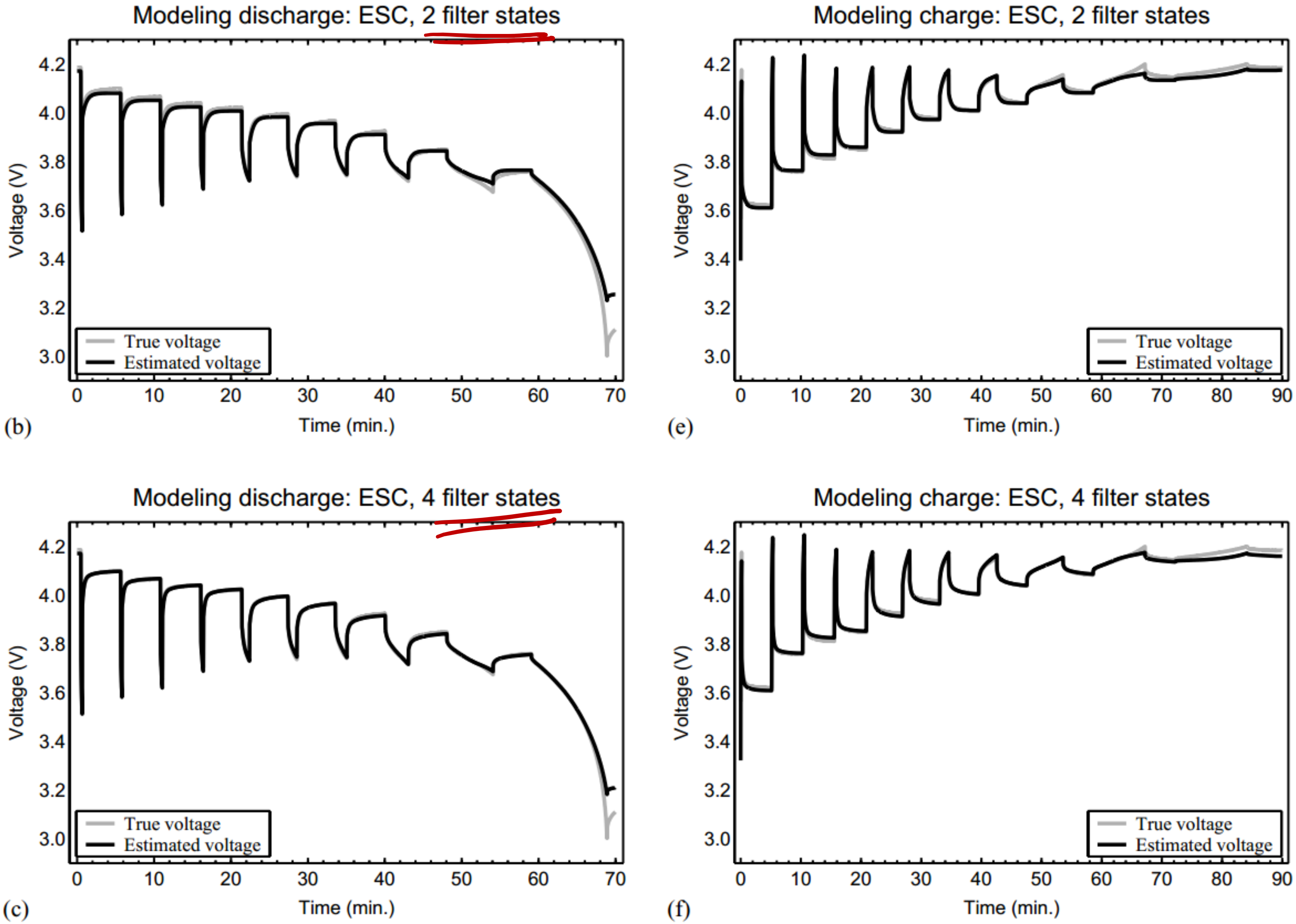
Model D Performance



Perfect!
(if only)

Experimental Results

Very good matching



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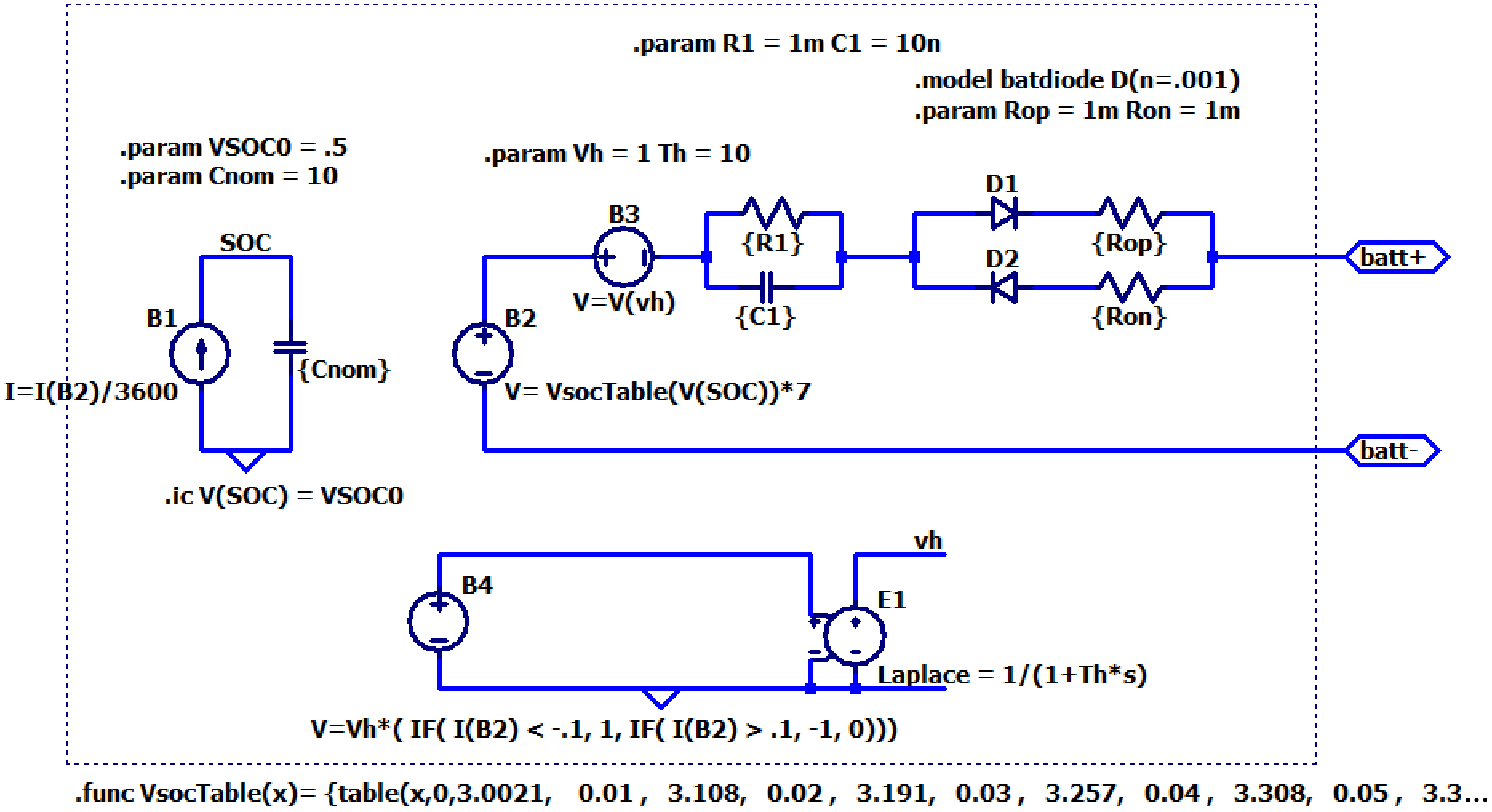
Implementation in LTSpice



```
.param R1 = 1m C1 = 10n
.model batdiode D(n=.001)
.param Rop = 1m Ron = 1m
.param VSOC0 = .5
.param Cnom = 10
.param Vh = 1 Th = 10
.ic V(SOC) = VSOC0
.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...
```