This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2020-9882C

Parameter Estimation of Lithium-Ion Battery Models Using a Novel Tanks-In-Series Approach

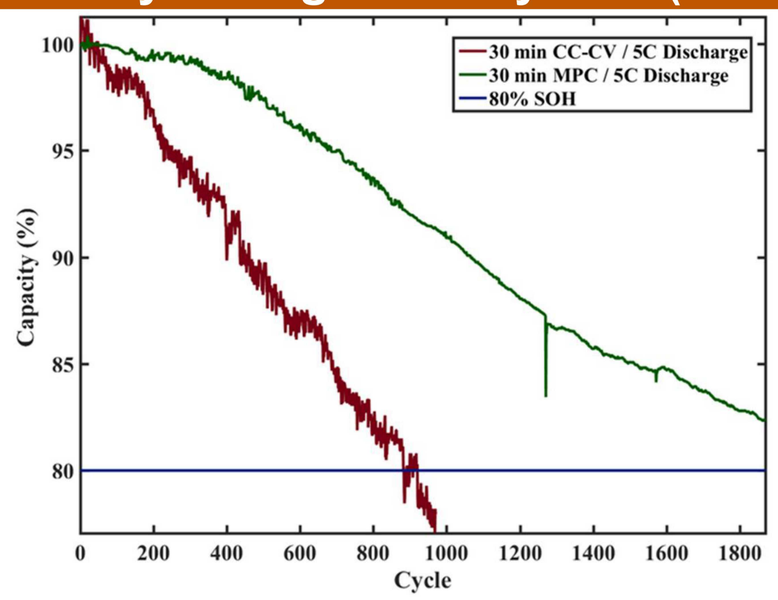
Prateek Mittal[1], Suryanarayana Kolluri[1], Krishna Shah[1], Yuliya Preger[2], and Venkat R. Subramanian[1,*]

[1]Walker Department of Mechanical Engineering & Material Science Engineering, Texas Material Institute, The University of Texas at Austin; [2]Sandia National Laboratories, New Mexico;

Objective

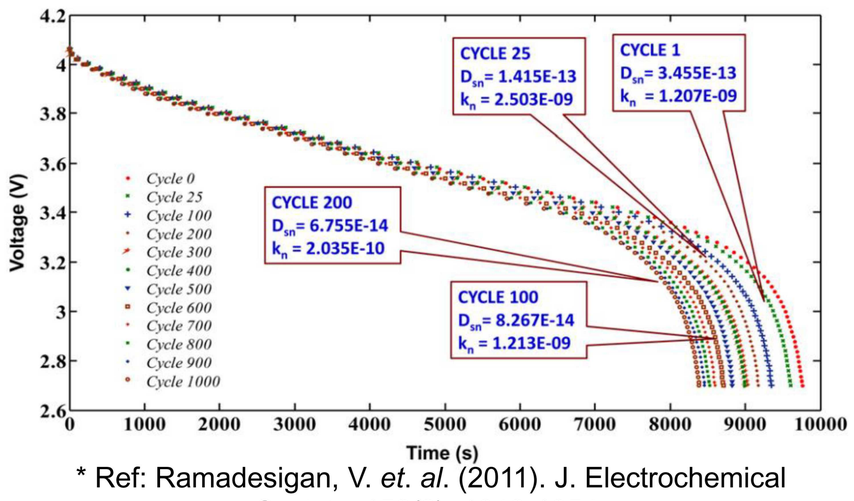
Develop an efficient framework for estimating parameters of lithium-ion batteries.

Battery Management System (BMS)



* Ref: Pathak, M. *et. al.* (2017). ECS transactions, 75(23), 51.

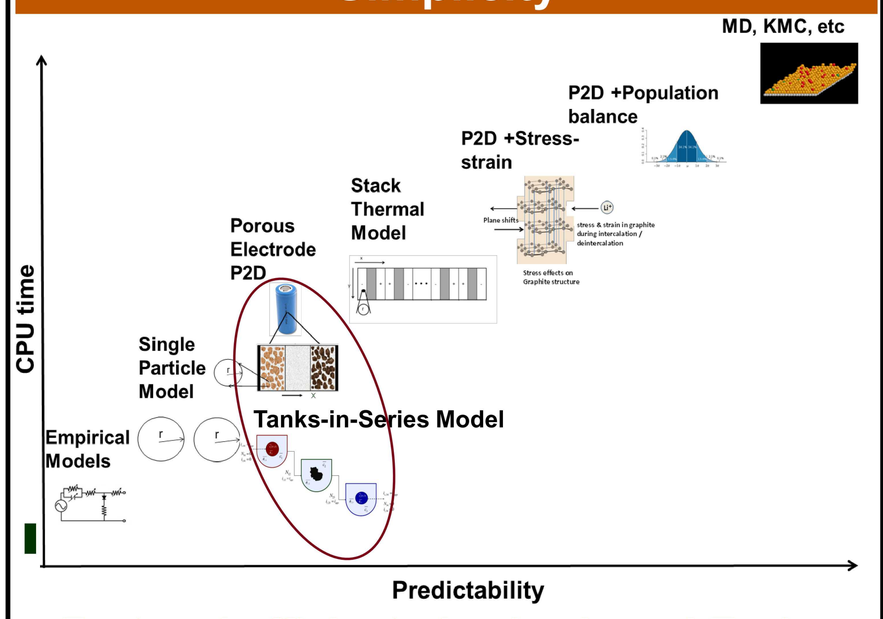
Model based BMS can double the cycle life



* Ref: Ramadesigan, V. *et. al.* (2011). J. Electrochemical Society, 158(9), 1048-1054.

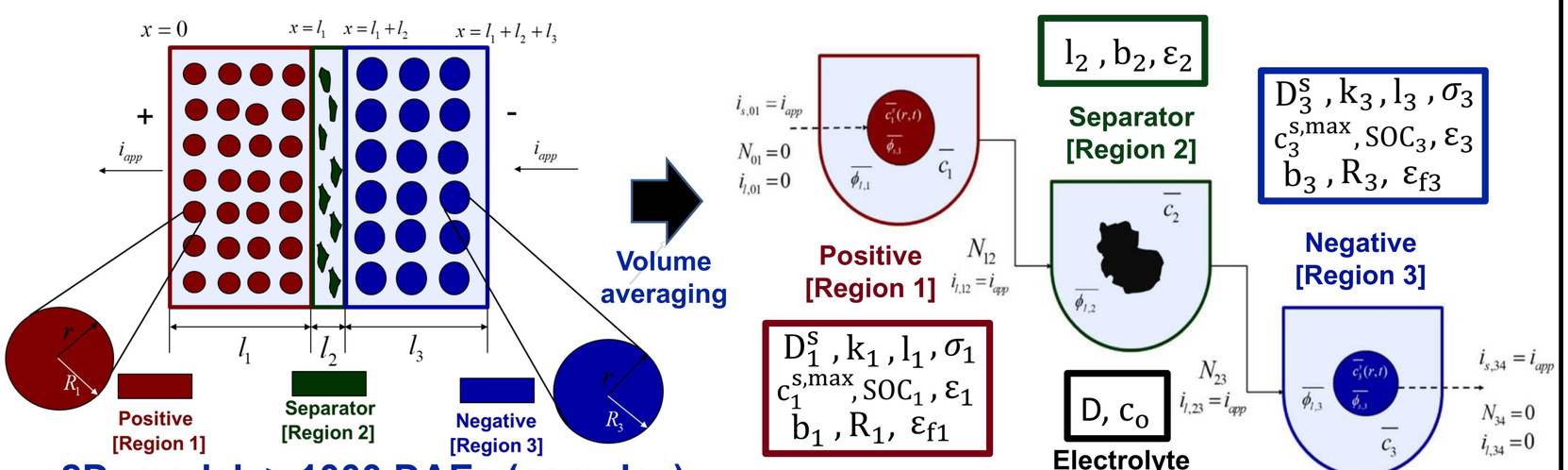
- **Parameters change over cycles**
- **Accuracy of the parameters determines model's predictability of internal states**

The Trade-off: Accuracy vs. Simplicity



- **Fast and efficient physics-based Tanks-in-Series battery model used in this work**

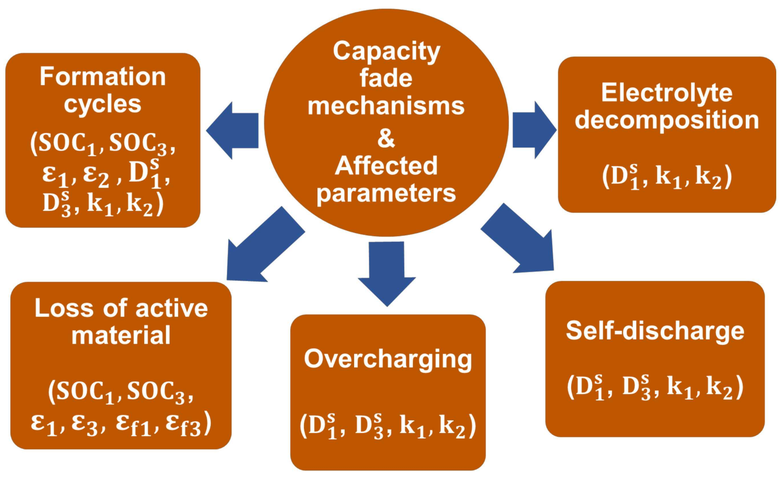
Novel Isothermal Tanks-in-Series Model



p2D model > 1000 DAEs (complex)

Parameter	Symbol
Electrolyte Diffusivity	D
Solid Phase Diffusivity	D_1^s, D_3^s
Reaction Rate Constant	k_1, k_3
Solid Phase Conductivity	σ_1, σ_3
Electrolyte Conductivity	κ
Electrolyte Concentration	c_o
Maximum Solid Phase Concentration	$c_1^{s,max}, c_3^{s,max}$
Initial SOC	SOC_1, SOC_3
Transference Number	t_+^0
Porosity	$\varepsilon_1, \varepsilon_2$
Filler Fraction	$\varepsilon_{f1}, \varepsilon_{f3}$
Bruggeman Constant	b_1, b_2, b_3
Thickness	l_1, l_2, l_3
Particle Size	R_1, R_3
index: 1 (+ve electrode), 2 (separator), 3 (-ve electrode)	

- **Tanks-in-Series model ~10 DAEs**
- **<1% error observed compared to existing physics-based battery models**



* Ref: Subramaniam, A. *et. al.* (2020). J. Electrochemical Society, 167(1), 013534.

Parameter Estimation

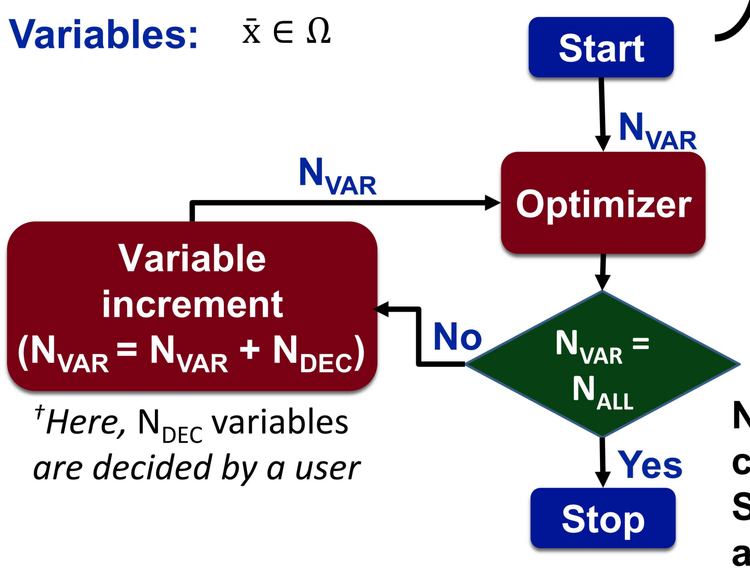
Sequential optimization approach

Objective: $$\min \sqrt{\frac{\left[\sum_{t_0=0}^{t_n=t_f}\left(V_{exp}(t_i)-V_{model}(t_i)\right)^2\right]}{N_{exp}}}$$

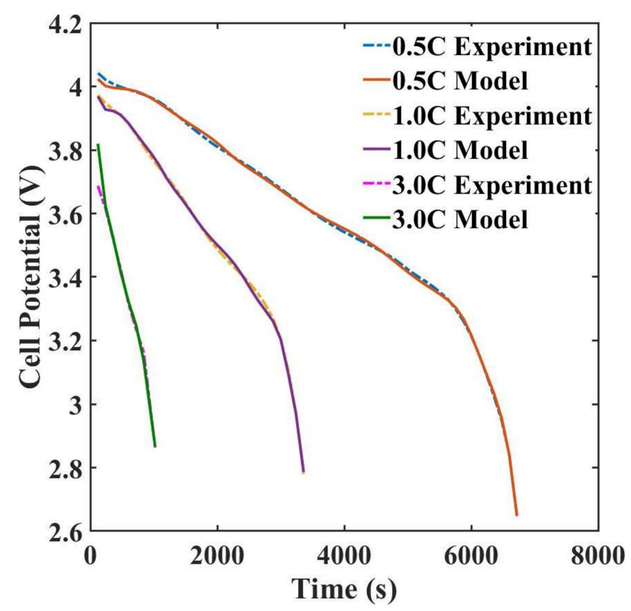
Subject to $$\frac{\partial}{\partial x} g_j(\bar{x}) = 0, \quad j = 1,\ldots,J$$

$$h_k(\bar{x}) = 0, \quad k = 1,\ldots,K$$

Variables: $\bar{x} \in \Omega$



†*Here,* N_{DEC} *variables are decided by a user*



Crate	RMSE (mV)
0.5	7.22
1.0	10.13
3.0	11.64

* All reported simulations are performed on Intel® Core™ i5-8265U CPU @ 1.6GHz 8 GB RAM machine

Note: Experiments are performed on 3Ah 18650 cylindrical cell (Cathode: NMC811 and Anode: Si-C) at different discharge rates (C/2,1C and 3C) at Sandia National Laboratories.

Summary

- **Novel Tanks-in-Series approach adopted to model the cell behavior at different discharge rates (0.5C, 1C, and 3C)**
- **Sequential optimization approach utilized to estimate the parameters required for the model with <12mV error**

Acknowledgements

This parameter estimation work based on Tank-in-Series battery model is funded by the U.S. Department of Energy Office of Electricity Energy Storage Program through Sandia National Laboratories, under the guidance of Dr. Imre Gyuk (PO 2105167).

**Email: venkat.subramanian@utexas.edu*

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.