BATTERY ENERGY RELIABILITY AND CONSERVATION IN AUTOMOTIVE HYBRID APPLICATIONS

PhD topic**: Artificial Intelligence Automotive**

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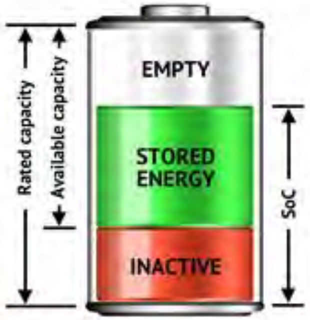
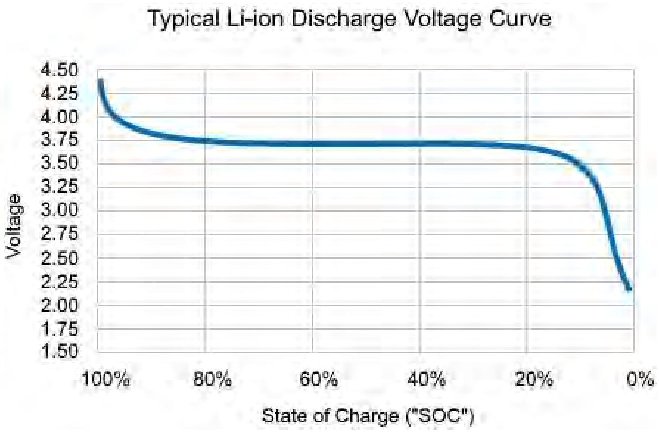
Research Objectives & Goal

- Experimentally validating the SOH estimation model (previously designed) and extending it to improve its generalization over a larger set of batteries.
- Understand and define the reliability criteria for safe and conservative battery operation in hybrid automotive applications.
- Development of experimentally validated battery thermal model for the range of operating battery state of charge (SOC)

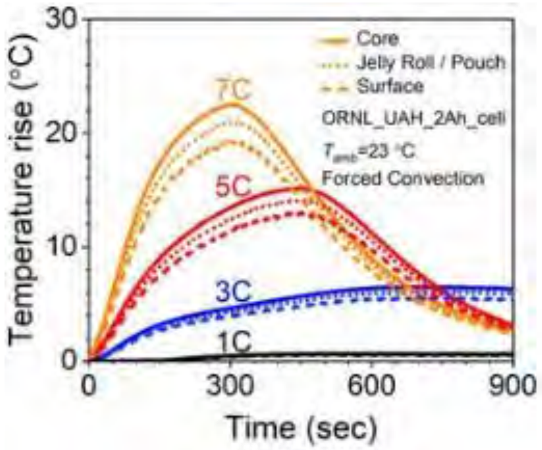
Problem Definition





- The battery **SOC** should be monitored to ensure that the battery is operated within the acceptable voltage operating range (**20%** - **80%** SOC) of the battery.
- Accurate measurement of **SOC** is only possible if the **SOH** of the battery is known
- Conventional Neural network SOH estimation model generalizes poorly over a larger set of similar batteries.

- In automotive hybrid applications, Lithium batteries are subjected to high peak current during charge and discharge cycles.
- The temperature of the battery should be measured and regulated to ensure efficient battery operation and to prevent thermal run away.



Experimentation

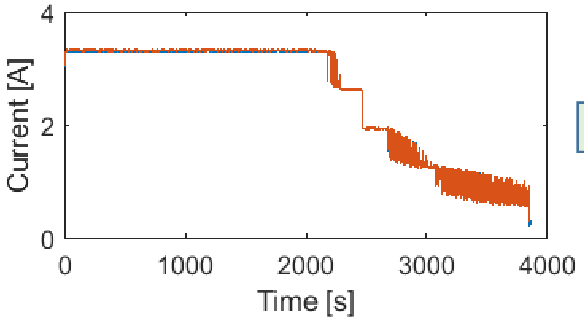
Elithion voltage (1PR0000) generic standard cell board for single cells terminal voltage meaasurement

Arduino Mega for data collection from voltage and temperature sensors

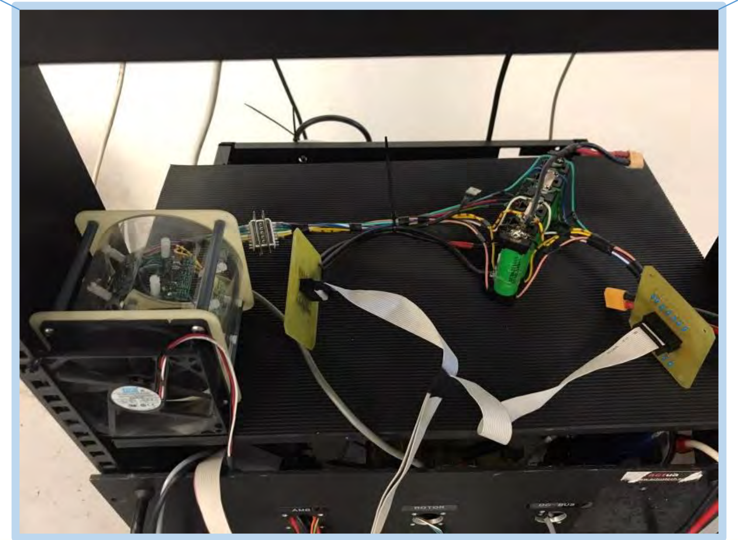
Temperature sensor (LM35) for battery surface temperature measurement

Battery description:
Model / Cell Type: NRC18650G-HOANA
Cell Capacity: 3300mAh
Operating Temperature:
charge: 10 ~ 45 °C
discharge: -20 ~ 60 °C
Standard Charging Current: 1.675 A
Norminal Voltage: 3.6V

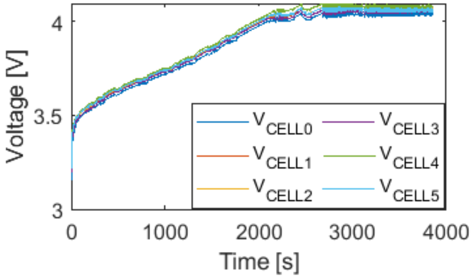
The **safe operation** of the battery is enhanced with the use of Elithion (Lithulmate) BMS.

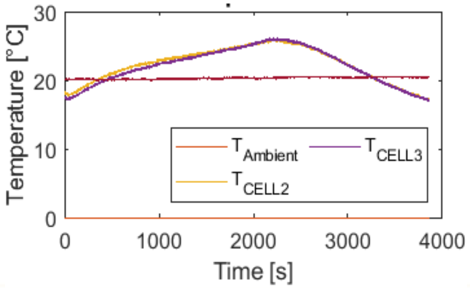


Input



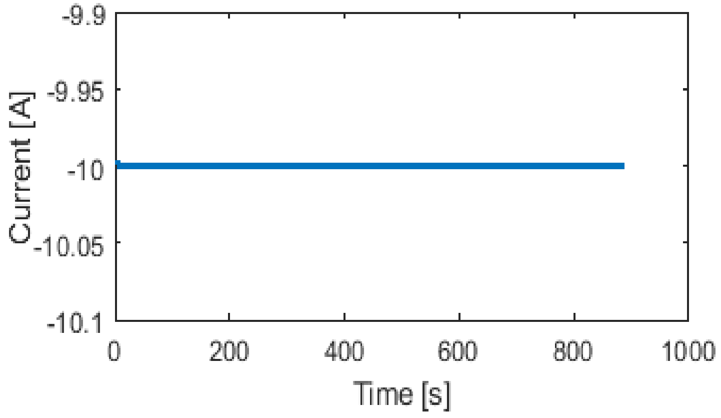
Output



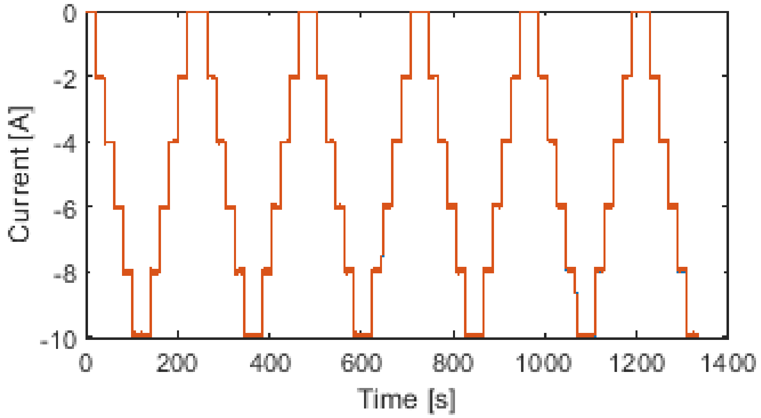


Other Used Current Profiles

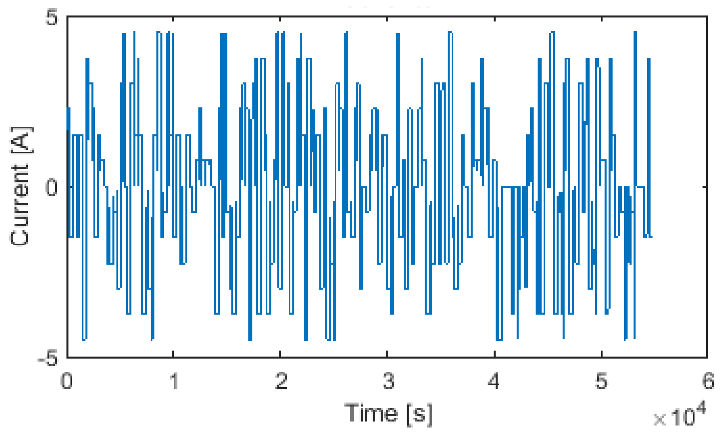
Constant Current Discharge



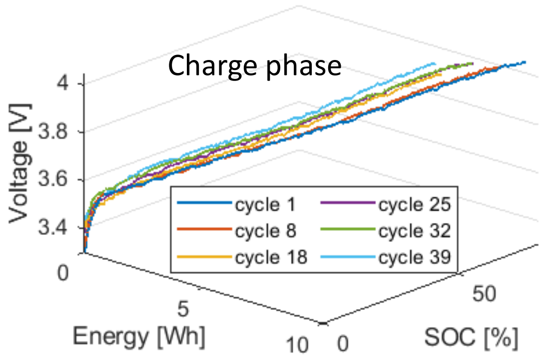
Step Discharge



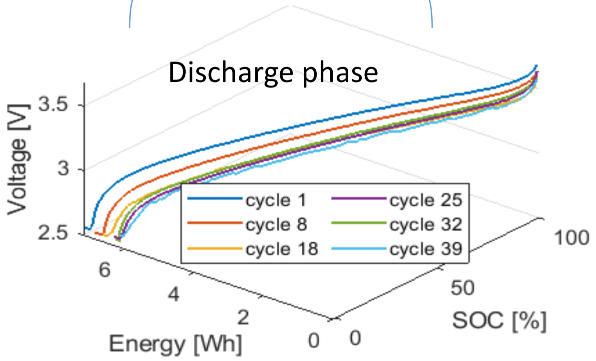
Random Walk Profile



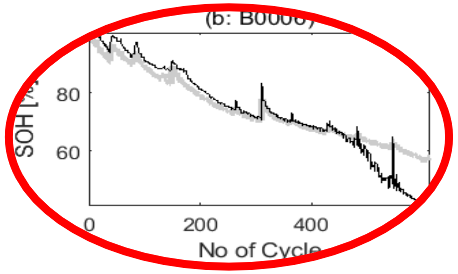
Experimental Characterization and SOH Estimation



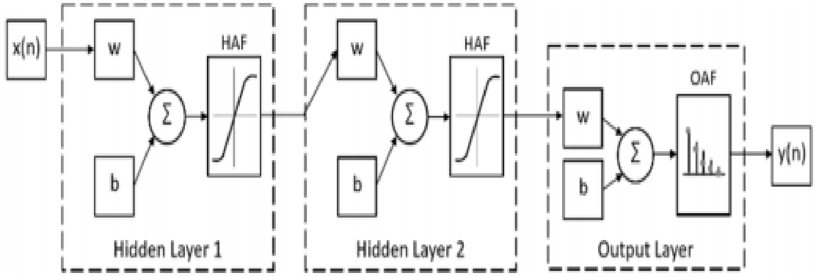
Voltage Drop (ΔV) [V]
SOC Variation (ΔSOC) [%]
Energy(ΔE) [Wh]



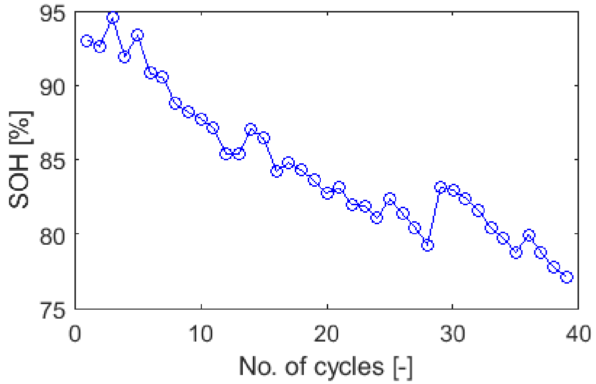
Experimental Variables:
Aging charge current: 3.3A (1C-rate)
Aging discharge current: 10A (~ 3C-rate)
Operating Temperature: Room temp.



2-layer Autoregressive exogenous (NARX) model



$$w_k \leftarrow w_k - \eta \frac{\partial C}{\partial w_k}$$
$$b_l \leftarrow b_l - \eta \frac{\partial C}{\partial b_l}$$



Improving Generalization through PL-ELM

- The immaturity of the battery industrial production result in high discrepancy across battery aging.
- A good model should generalize well across a large battery set
- A deterministic and stable PL-ELM model is designed to overcome the drift problem associated with conventional neural network model

$$\hat{\phi} = H^{+}y$$

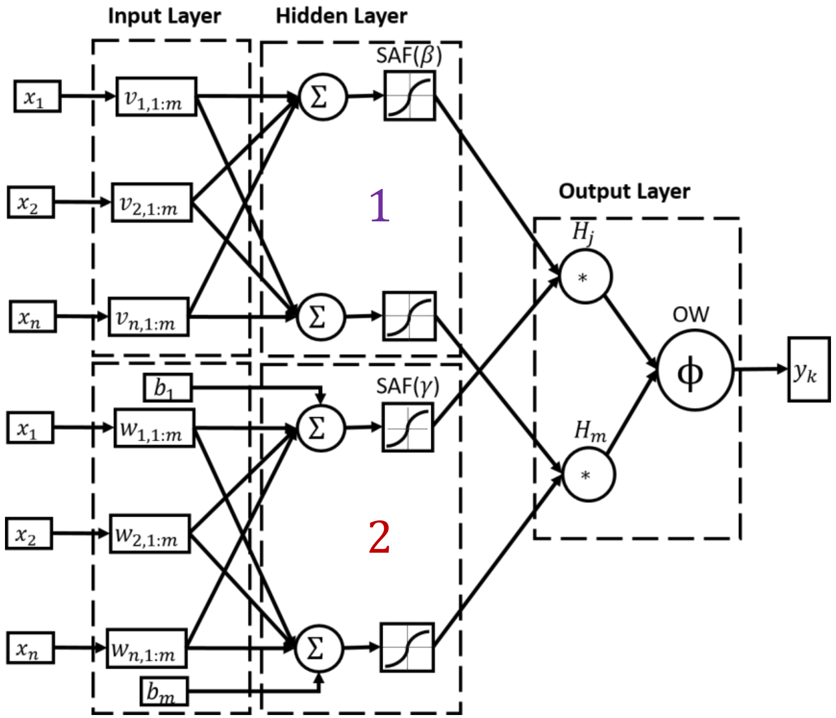
where H^{+} is the generalized Moore-Penrose inverse matrix

$$y_k = \sum_{j=1}^{m} \phi_j \, \beta(v_j x_k) \gamma(w_j x_k + b_j) \qquad for \;\; 1 \le k \le N$$

$$\boldsymbol{H}_1 = \begin{bmatrix} \beta(v_1 x_1) & \dots & \beta(v_m x_1) \\ \vdots & \vdots & \vdots \\ \beta(v_1 x_N) & \cdots & \beta(v_m x_N) \end{bmatrix} \in \mathbb{R}^{N \times m}$$

$$\boldsymbol{H} = \boldsymbol{H}_1 \circ \boldsymbol{H}_2$$

$$\boldsymbol{H}_2 = \begin{bmatrix} \gamma(w_1 x_1 + b_1) & \dots & \gamma(w_m x_1 + b_m) \\ \vdots & \vdots & \vdots \\ \gamma(w_1 x_N + b_1) & \dots & \gamma(w_m x_N + b_m) \end{bmatrix} \in \mathbb{R}^{N \times m}$$



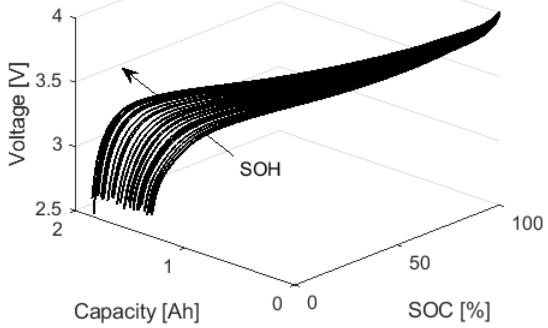
- The deterministic and low computational demand of PL-ELM positions it for online application.

Result of SOH estimation with PL-ELM

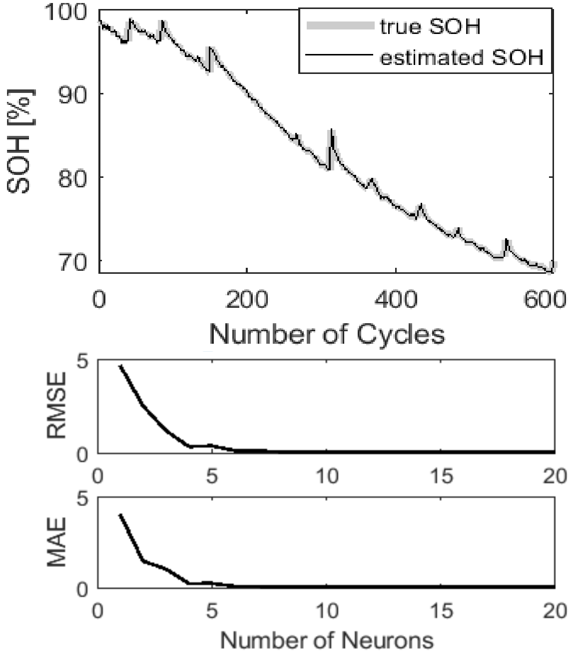
Battery Description:
2Ah capacity Li-ion dataset provided by Prognostic Centre of Excellence (PCoE) at NASA's Ames Research Centre for fault prediction and diagnostic studies.

Charge current: 1.5A (0.75C-rate)
Discharge current: 2A (1C-rate)
End of Life (EOL): 30% fade in capacity

SOH Characterization

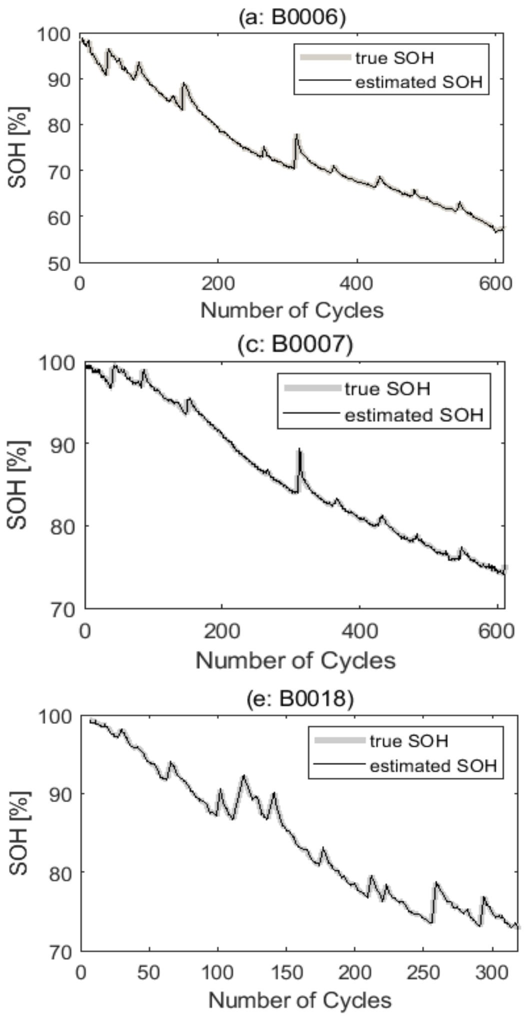


Trained PL-ELM model



	ELM Performance	
	SOH	
	RMSE	MAE
Trained model (B0005)	0.037	0.027
B0006	0.054	0.036
B0007	0.05	0.034
B0018	0.045	0.036

Validation of PL-ELM model



Battery Thermal Model

- **Lumped Battery**: This models the battery potential using the open circuit voltage and the derivative that depends on SOC. The voltage loses are medelled based on ***Arrhenius theory***.

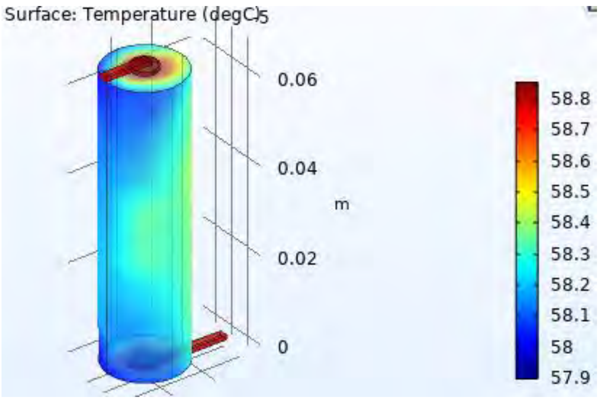
$$E_{cell} = E_{ocv}(\overline{SOC}, T) + \eta_{IR} + \eta_{act} + \eta_{conc}$$

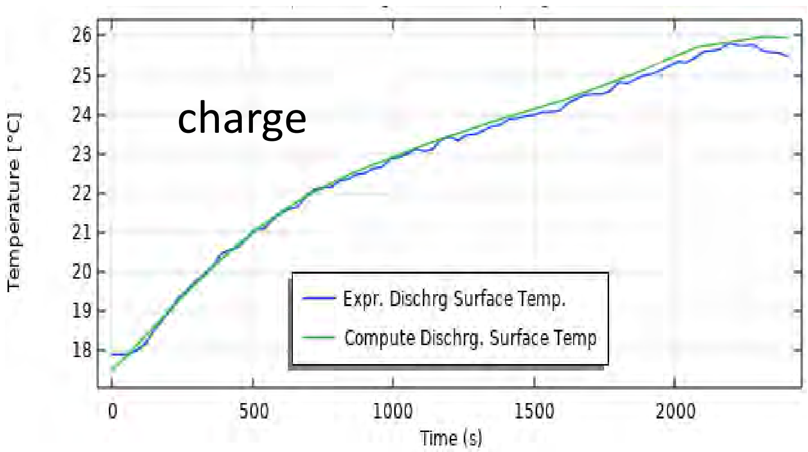
- **Heat Transfer in Fluids**: This models the heat transfer and the temperature.

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \boldsymbol{u} \cdot \nabla T + \nabla \cdot \boldsymbol{q} = Q$$

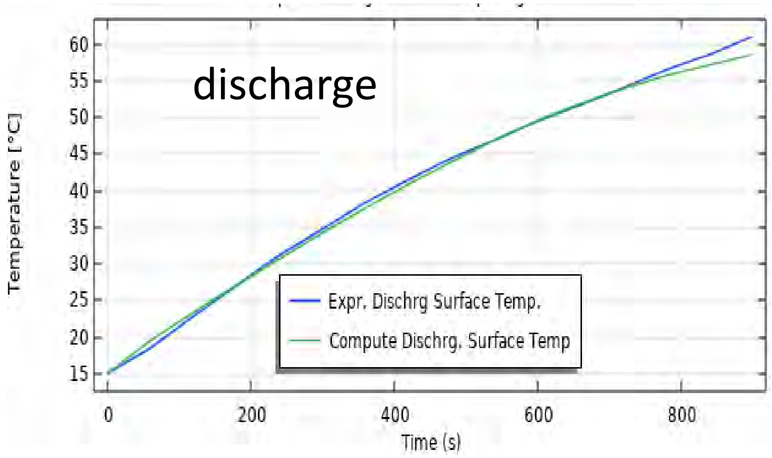
$$\boldsymbol{q} = -k \nabla T$$

The variations of internal energy in time are balanced by convection of internal energy, thermal conduction, radiation, dissipation of mechanical stress and additional volumetric heat sources.





The model generalizes well at the constant current load in the zone of operation : 20% to 80% SOC .



❑ Summary and Future Work

- ❑ An In-house testbench has been built to experimentally validate the SOH estimation model previously designed.

- ❑ SOH estimation model is designed with PL-ELM to enhance generalization across a larger set of batteries. The model is validated experimentally using dataset from the literature.

- ❑ Thermal model is developed and experimentally validated with dataset from the developed testbench

Future Work:

- ❑ The PL-ELM SOH model will be further validated with experimental dataset acquired from the testbench.
- ❑ The thermal model will be extended to model a 48V, 1kWh battery pack and the model validated with mild and aggresive profiles typical of the hybrid vehicles.
- ❑ Implementation of models in the control system that manages the torque request of hybrid vehicles

Publications:

- **State of Charge Estimation of Lithium Batteries for Automotive application with Artificial Neural Network**: *2019 Aeit International Conference of Electrical and Electronic Technologies for Automotive (Aeit Automotive)* - published July 2019

- **Energy saving from Electrification of cooling system**: *2020 IDETC-CIE International Design Engineering Technical Conferences & Computers and Information in Engineering Conference* – accepted for publication August 2020

Thank You

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