# Modeling and State of Charge Estimation of Electric Vehicle Batteries

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## Introduction and Motivation

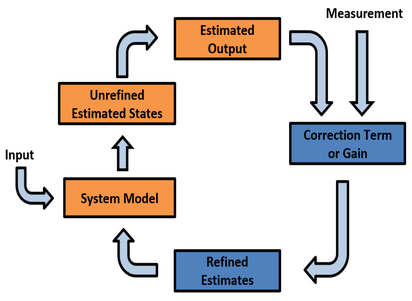
- Hybrid (HEVs) and battery electric vehicles (BEVs) represent a sustainable alternative in compare to conventional , fossil fuel-based vehicles.
- Battery pack is a major and the most expensive part of electric vehicles. It requires accuracy, real-time monitoring, and control.
- Parameters such as state of charge (SOC) and state of health (SOH) have to monitor accurately to guarantee battery safety and reliability and avoid overcharge or under-discharge conditions. These conditions can lead to irreversible capacity degradation and power fade.
- The estimation of the SOC is key for the successful operation of EVs, but the strong nonlinearity and complex electrochemical reactions of the battery provides some challenges.
- Aging and degradation have to account in battery models since they can affect the accuracy.


## SOC estimation Techniques

Estimation of SOC can be found in a direct or indirect way.

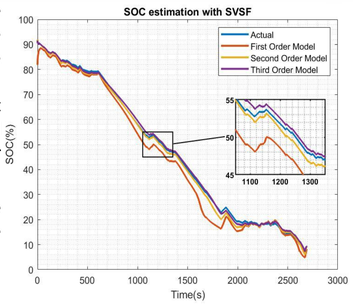
- Direct method are mostly based on data from tests Impedance measurement based (EIS), Terminal voltage based, Open circuit voltage (OCV) measurement based, Coulomb counting (CC) can be considered as direct methods.
- Indirect methods are based on battery model and estimation methods such as Kaman filter, Particle filter, Neural Network and a very recent method called Smooth Variable Structure filter (SVSF).

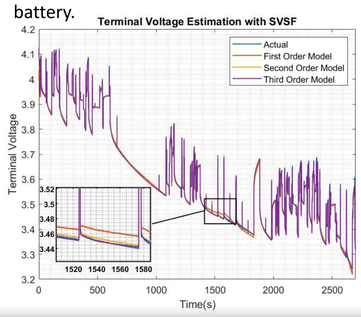
- SVSF is an estimation method based on the sliding mode concept
- It works in a predictor-corrector fashion
- Its gain forces the states to converge to a boundary close to the actual value
- The width of the existence space is a function of uncertain dynamics
- The method can be used for any linear and nonlinear systems that are observable
- This method has robustness against modeling and measurement uncertainties




## SVSF for Battery

- The SVSF has been used to estimate the state of charge and the battery terminal voltage with an equivalent circuit model (ECM) for the battery.
- Results indicate that the SVSF is robust provides higher accuracy for modeling and parametrization in compare with Kalman filter (KF) based methods.
- The SVSF can be used for real-time applications on board of an electric vehicle battery management system.
- Considering higher order battery model can increase the accuracy specially for an aged battery.

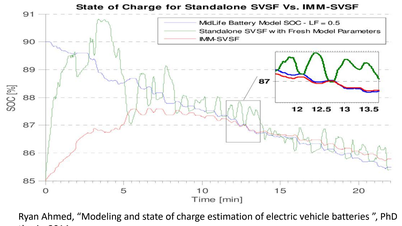


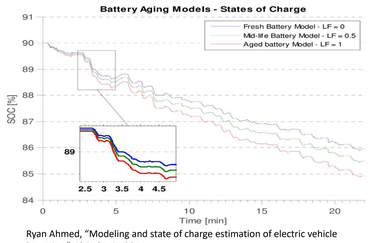

| Battery Model | RMSE for SVSF | RMSE for EKF |
|---|---|---|
| First order ECM | 0.0074 | 0.0185 |
| Second order ECM | 0.0036 | 0.0113 |
| Third order ECM | 0.0035 | 0.0097 |

## IMM-SVSF for aged Battery

- Battery model parameters such as internal resistance and capacity fade will change in different state of life.
- SOC for each state of life will be different if we use the same model.
- Since we need a more accurate model for aged battery. A second order ECM and a third order ECM have been considered for a mid-life and aged battery, respectively.




Ryan Ahmed, "Modeling and state of charge estimation of electric vehicle batteries ", PhD thesis, 2014

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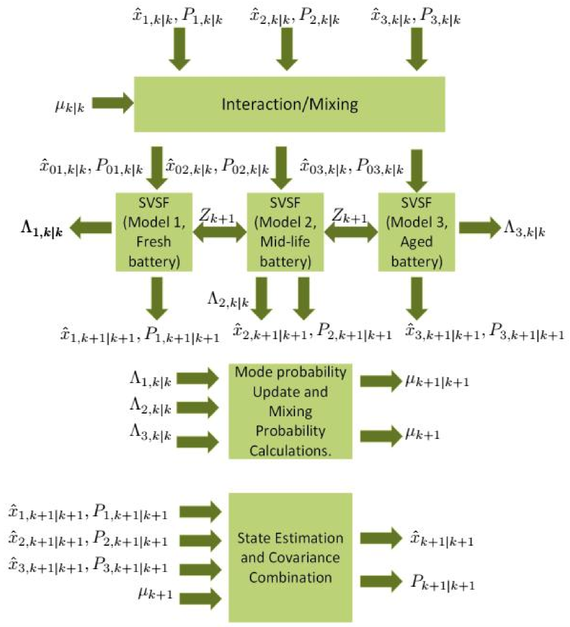
- A combination of IMM with SVSF can be used to enhance the accuracy and robustness of SOC and terminal voltage estimation.
- IMM uses information from each models to predict the real value

## Flowchart of proposed IMM-SVSF




## Conclusion and Future works

- A recent strategy has been used for SOC and terminal voltage estimation due to the aging problem
- Under normal condition, SVSF provides an acceptable estimation which can be used in BMS.
- When battery ages, the SVSF will fail to the changes in battery model.
- IMM-SVSF can provide more accurate results by considering more information from different models.
- Future work involves testing the new methodology on experimental data.
- The results of this work will be expanded to formulate more strategy for SOC estimation in different state of life based on SVSF.

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