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State of Charge Estimation of Lithium-Ion Battery using Sliding Mode and Super Twisting Observers

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I- Introduction

- The performance of Electric Vehicles (EVs) is significantly influenced by various battery characteristics like operating voltage, temperature, rate of charge or discharge, SOC, and aging.
- Among the different types of batteries suitable for EVs, the lithium-ion battery (Li-ion) is widely acknowledged as the top choice because of r high-energy density, high-power density, and longevity.
- Accurate SOC information is crucial for controlling battery charge/discharge currents thus direct measurement is not possible as there are no sensors available for this purpose, it must be estimated from physical measurements by some mathematical algorithms.
- This project focus6t5 on the sliding mode observer (SMO) and super twisting observer (STO) designs for estimating the battery (SOC).

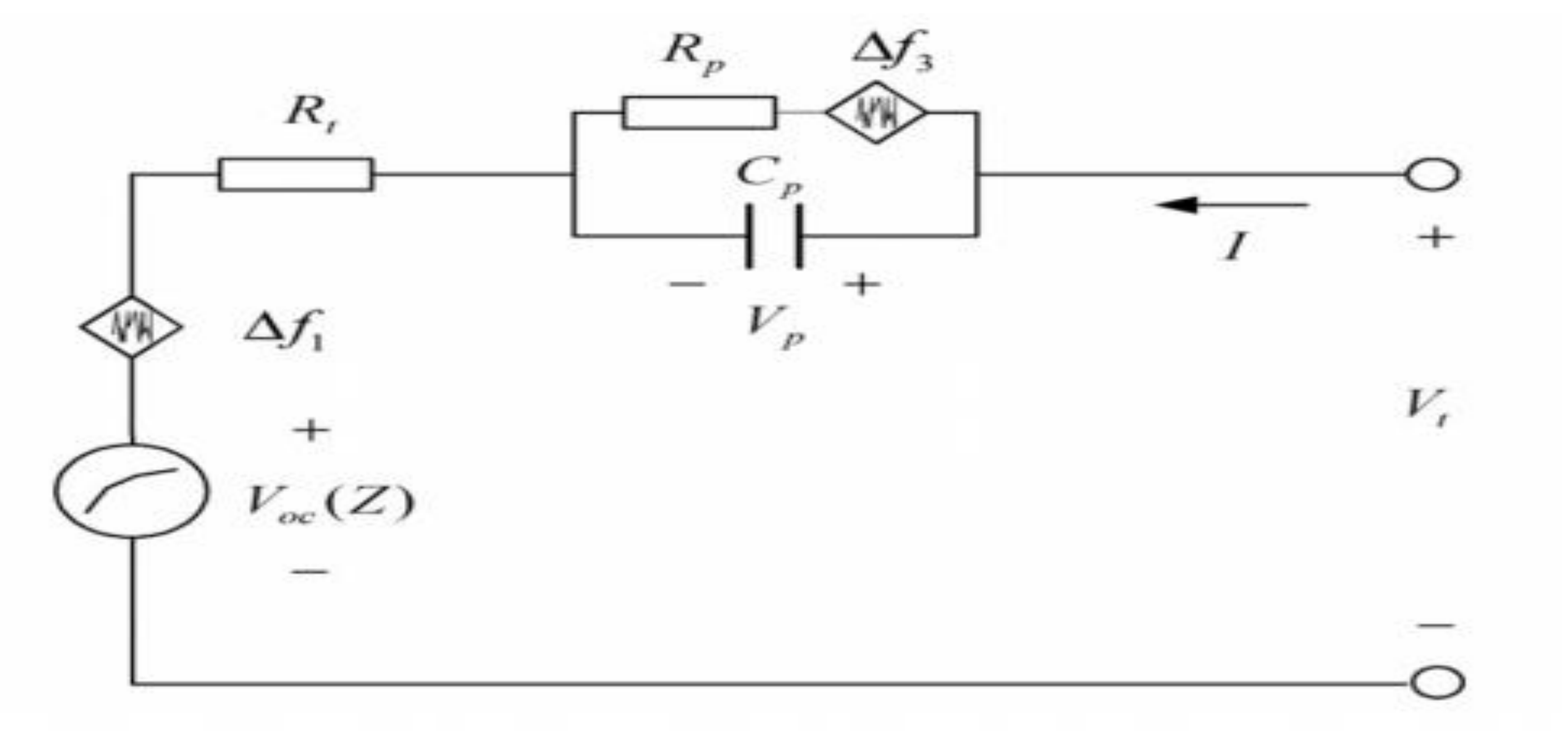
II- Objectives

- To Develop an Accurate SOC Estimation Method for Lithium-Ion Batteries
- To Utilize advanced observer-based techniques, namely the Sliding Mode Observer and the Super Twisting Observer, to enhance the precision of SOC estimation in lithium-ion batteries

III- Methodology

- Selection of Battery Model
- Development of Observer Models
- Algorithm Implementation

IV- Battery Modelling



The lithium-ion battery's behavior is modelled using a fundamental resistor-capacitor (RC) framework[1]. factoring in uncertainties.

The terminal voltage $V_t = V_{oc}(Z) + IR_t + V_p$

The linearized model is defined as : $Voc(Z) = kZ + d$

$$\dot{V}_t = \dot{V}_{oc}(Z) + \dot{V}_p$$

The linearized state model for $\dot{V}_t$, $\dot{Z}$ and $\dot{V}_p$ is represented as:

$$\dot{V}_t = a_1V_t + a_1kZ + b_1I + \Delta f_1$$
$$\dot{Z} = a_2V_t - a_2kZ - a_2V_p + \Delta f_2$$
$$\dot{V}_p = a_1V_p + b_2I + \Delta f_3$$
$$y = [1\ 0\ 0][Vt\ Z\ Vp]^T$$

Where: $a_1 = 1/(Rc\,Cp)$, $a_2 = 1/(Rt\,Cn)$, $b_1 = k/Cn + Rt/(Rp\,Cp) + 1/Cp$, and $b_2 = 1/Cp$.

V- Implementation of the Observers

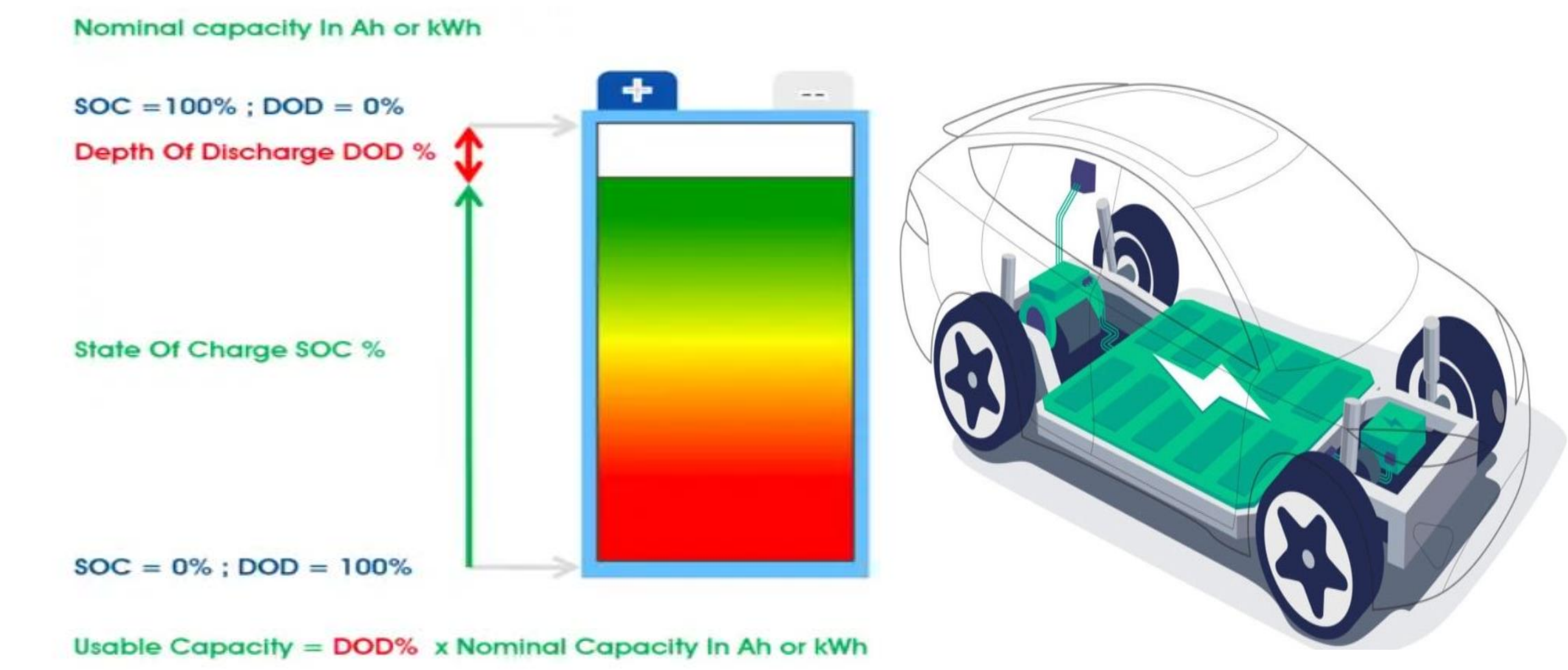
Sliding Mode Observer

$$\dot{\hat{X}} = A\hat{X} + Bu + Hsign(y - \hat{y})$$

where $y - \hat{y}$ is **the estimation error** (e_1)
and $e_1 = V_t - \hat{V}_t$

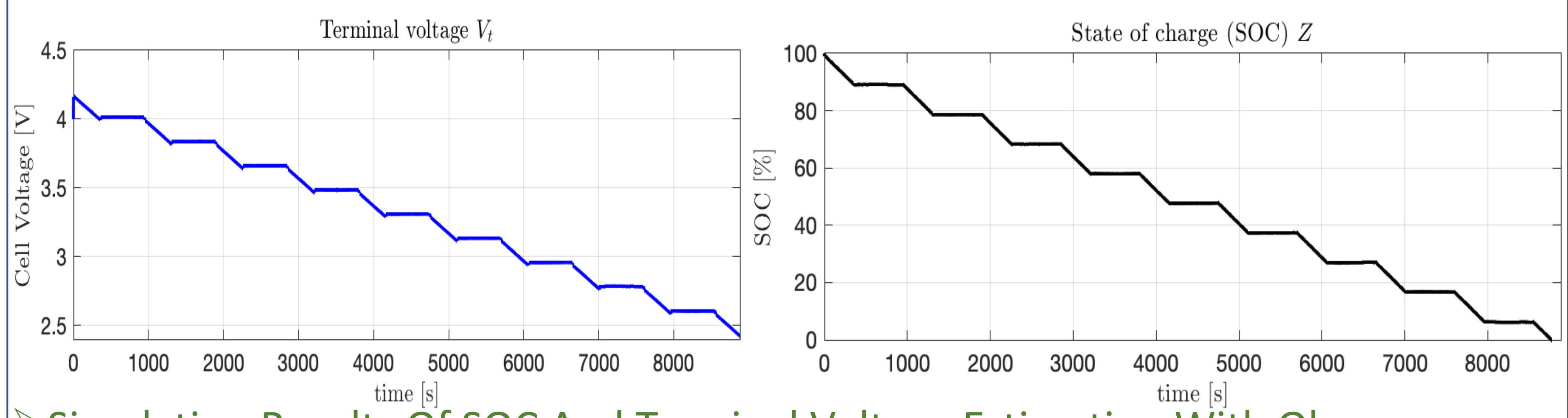
Super Twisting Observer

$$\dot{\hat{V}}_t = -a_1\hat{V}_t + a_1k\hat{Z} + b_1I + h_1|e_1|^{2/3}sign(e_1)$$
$$\dot{\hat{Z}} = a_2\hat{V}_t - a_2k\hat{Z} - a_2\hat{V}_p + h_2|e_1|^{1/3}sign(e_1)$$
$$\dot{\hat{V}}_p = -a_1\hat{V}_p + b_2I + h_3sign(e_1)$$

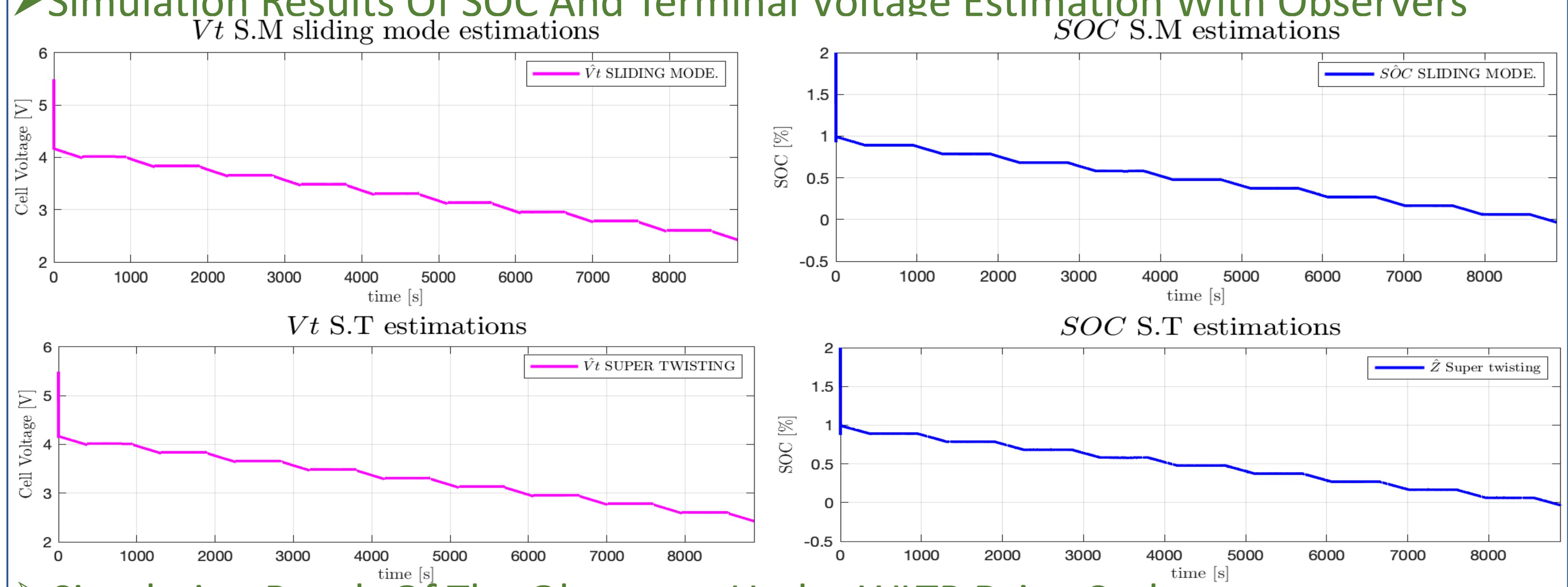


VI- Simulation Results

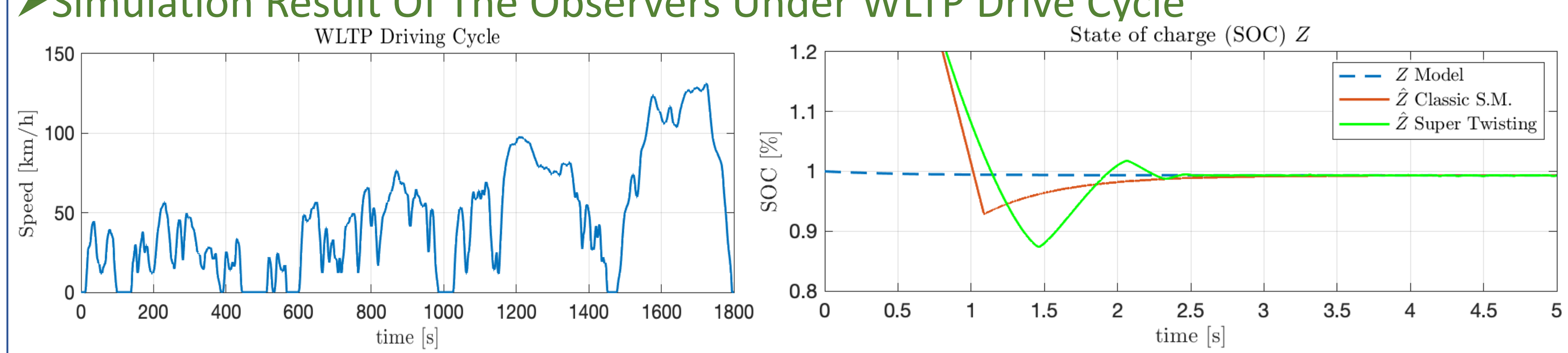
Simulation Result For The Battery Modelling



Simulation Results Of SOC And Terminal Voltage Estimation With Observers



Simulation Result Of The Observers Under WLTP Drive Cycle



VII- Conclusion

- This project emphasizes the crucial role of accurate State of Charge (SOC) estimation in EV battery management, with the Sliding Mode Observer (SMO) being particularly effective against modeling errors and uncertainties.
- Performance comparisons between the two observers showed the SMO is the fastest in convergence, closely followed by the Super Twisting Observer (STO), with similar error metrics observed across all models.
- The SMO's rapid convergence and the STO's high-frequency actions make them preferred choices for real-world applications, with adjustable gain values for enhanced precision.

VIII- References

[1] I.-S. Kim, "The novel state of charge estimation method for lithium battery using sliding mode observer," J. Power Sources, vol. 163, no. 1, pp. 584–590, Dec. 2006, doi: 10.1016/j.jpowsour.2006.09.006.
[2] X. Chen, W. Shen, Z. Cao, and A. Kapoor, "A novel approach for state of charge estimation based on adaptive switching gain sliding mode observer in electric vehicles," J. Power Sources, vol. 246, pp. 667–678, Jan. 2014, doi:10.1016/j.jpowsour.2013.08.039.