Indian Institute of Technology (BHU) Varanasi

Department of Chemical Engineering

Project Report

(Exploratory Project)

Li-ion Battery-pack Degradation

Project synopsis submitted in Mid-Term

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❖ Aim

Modelling of a Li-ion Battery Pack.

❖ Objective

a. Configure a battery as per Li-ion battery data Sheet.
b. Stimulate the Single cell model in the presence of constant discharge current at 100A (1C rate), 50A (0.5 C rate), and 25A (0.25 C rate) as per the given look-up table, and comment on SOC and Voltage.

❖ Theory

There are various types of modeling used in different fields to represent complex systems, Electrical Equivalent Circuit Modelling (**EECM**) is a specific type of modeling used to represent electrical systems, particularly in the context of devices like batteries. It simplifies the complex electrochemical processes within these devices by using a circuit made up of basic electrical components like resistors, capacitors, and ideal voltage sources.

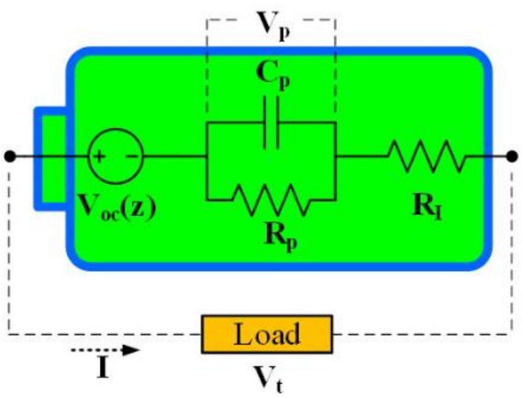

Figure 1: EECM representation of an electrochemical cell

For example, in a Li-ion battery, EECM might represent the internal resistance of the battery with a resistor *(R_I, R_P)*, its energy storage capability with a capacitor *(C_P)*, current flowing into or out of the battery during charging and discharging, with current source *(I)*, and its voltage potential with an ideal voltage source. By combining these elements in various configurations (Figure 1), EECM captures the essential electrical characteristics of the battery, enabling analysis, simulation, and prediction of its behavior under different conditions.

Types of EECM

Within EECM, various models offer increasing complexity to capture a Li-ion battery's behavior. The simplest, the **Rint model**, represents the battery with its internal resistance (Rint) in series with an ideal voltage source (Voc). This basic model is useful for understanding voltage response under load but offers limited dynamic analysis (Figure 2).

Thevenin RC models build upon the Thevenin model by incorporating RC (resistor-capacitor) elements. The *Thevenin 1RC model*, with a single resistor (R1) and capacitor (C1), provides a basic first-order representation of battery dynamics. R1 reflects limitations to charge transfer, while C1 captures short-term energy storage and transient behavior (Figure 3).

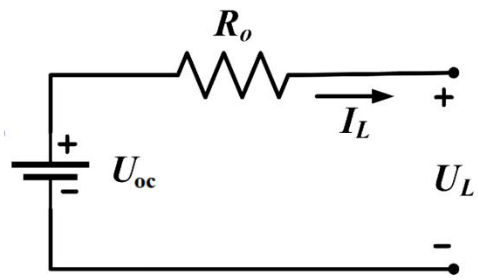

Figure 2: Rint Model

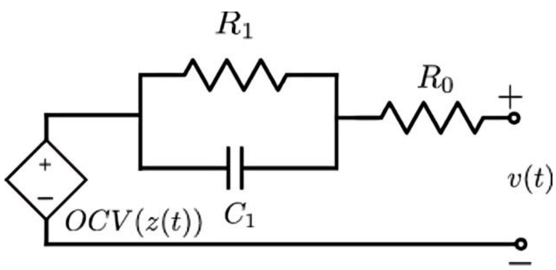

Figure 3: Thevenin 1RC Model

More complex models like the *Thevenin 2RC model* utilize additional RC pairs (R2, C2) to represent intricate internal dynamics. The generalized *Nth RC model* extends this concept further, using N resistor-capacitor pairs for a comprehensive characterization.

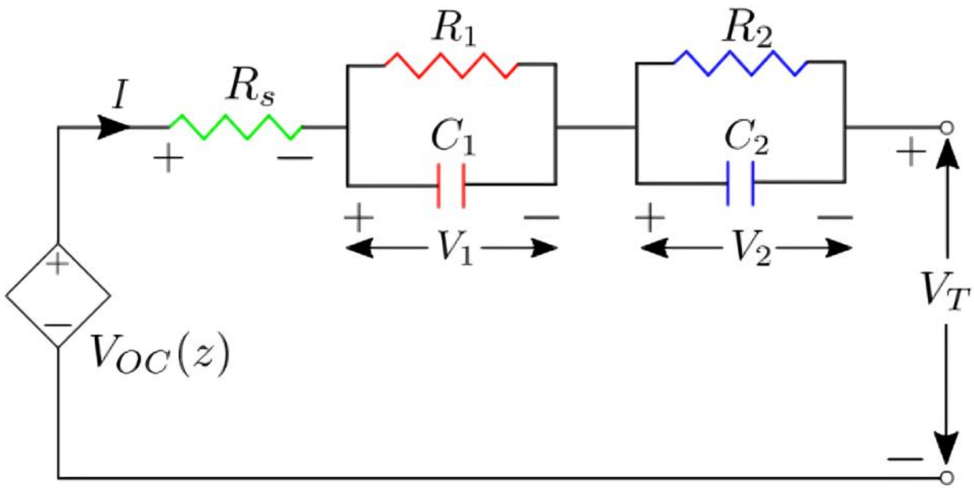

Figure 4: Thevenin 2RC Model

For even higher fidelity simulations accounting for non-ideal behavior, The **Dual polarization model** introduces elements like Warburg impedance to represent diffusion effects within the battery electrolyte.

In the Practical cases Thevenin 2RC model is generally used, considering optimal dynamic representation and less complexity.

Important Terms

- **SoC** (State of Charge): This refers to the remaining battery capacity as a percentage of its total capacity. It indicates how much charge is left in the battery at a given time.
- **OCV** (Open-Circuit Voltage): This is the voltage measured across the battery terminals when no current is flowing (the battery is in an open circuit). The OCV is directly related to the SOC, meaning a higher OCV indicates a higher SOC.
- **SoH** (State of Health): This reflects the overall health and capacity degradation of the battery compared to its original capacity. As a battery ages and undergoes cycles of charging and discharging, its SOH decreases.
- **Polarization Voltage**: This voltage loss occurs within the battery due to internal resistances of Electrodes and limitations during charging and discharging, like over-potential.

- **Over Potential**: It is the difference between the ideal battery voltage (calculated based on Nernst equation; OCV) and actual voltage observed during charging and discharging.
- **Cell Aging**: This is the natural process of capacity degradation and performance loss in a Li-ion battery over time and use. Factors like cycle count, temperature, and depth of discharge can accelerate aging.

❖ Governing Equations

Table of equations for SOC, R-int Model, Thevenin RC Model. Open Circuit Voltage, **OCV**, is measured experimentally.

- State of Charge, SoC

Equations	Terminology
Coulomb Counting Technique $SoC(t) = SoC_o + \frac{1}{Q_{norm}} \int_0^t i(\theta)d\theta$ SoC α Total amout of charge flown out of the battery	$SoC(t)$ - SoC at instant time t SoC_o - Initial state of charge (at t =0) Q_{norm} - battery's rated capacity in Ampere-hours (Ah). $i(\theta)$ - Current flowing at any instant of time though the battery θ − dumy variable

- R-int Model (Internal Resistance Model)

Equations	Terminology
$U_L = U_{OC} - I_L R_o$	U_L - Terminal Voltage U_{OC} - Open-circuit Voltage I_L - Load Current (+discharging, -charging) R_o - Internal Resistance

- Thevenin 2-RC Model

Equations	Terminology
Voltage in 1-RC Branch $U_1 = \frac{-U_1 R_1}{R_1 C_1} + \frac{i_1}{C_1}$ Voltage in 2-RC Branch $U_2 = \frac{-U_2 R_2}{R_2 C_2} + \frac{i_2}{C_2}$ Voltage in Main Branch $U_{batt} = U_{OC} - U_1 - U_2 - i_{batt} R_o$	U_{batt} - Battery Terminal Voltage U_2 - Voltage in 2-RC branch U_1 - Voltage in 1-RC branch R_2 - Polarization Resistance on second Branch C_2 - Polarization Capacitance on second branch i_2 - Current across capacitor C_2 i_{batt} - Current across battery

❖ **Look-up Tables 1**

- Single cell constant current discharging.

	1 OtherUsefulInformation	2
1	"Ambient temperature [K]: 25 + 273.15,"	
2	" Current function [A]: 100,"	
3	" Upper voltage cut-off [V]: 4.2,"	
4	" Lower voltage cut-off [V]: 3.2,"	
5	"Cell capacity [A.h]: 100,"	
6	"Initial SoC: 0.5,"	
7		
8		
9		
10		
11		

Table 1: Cell information

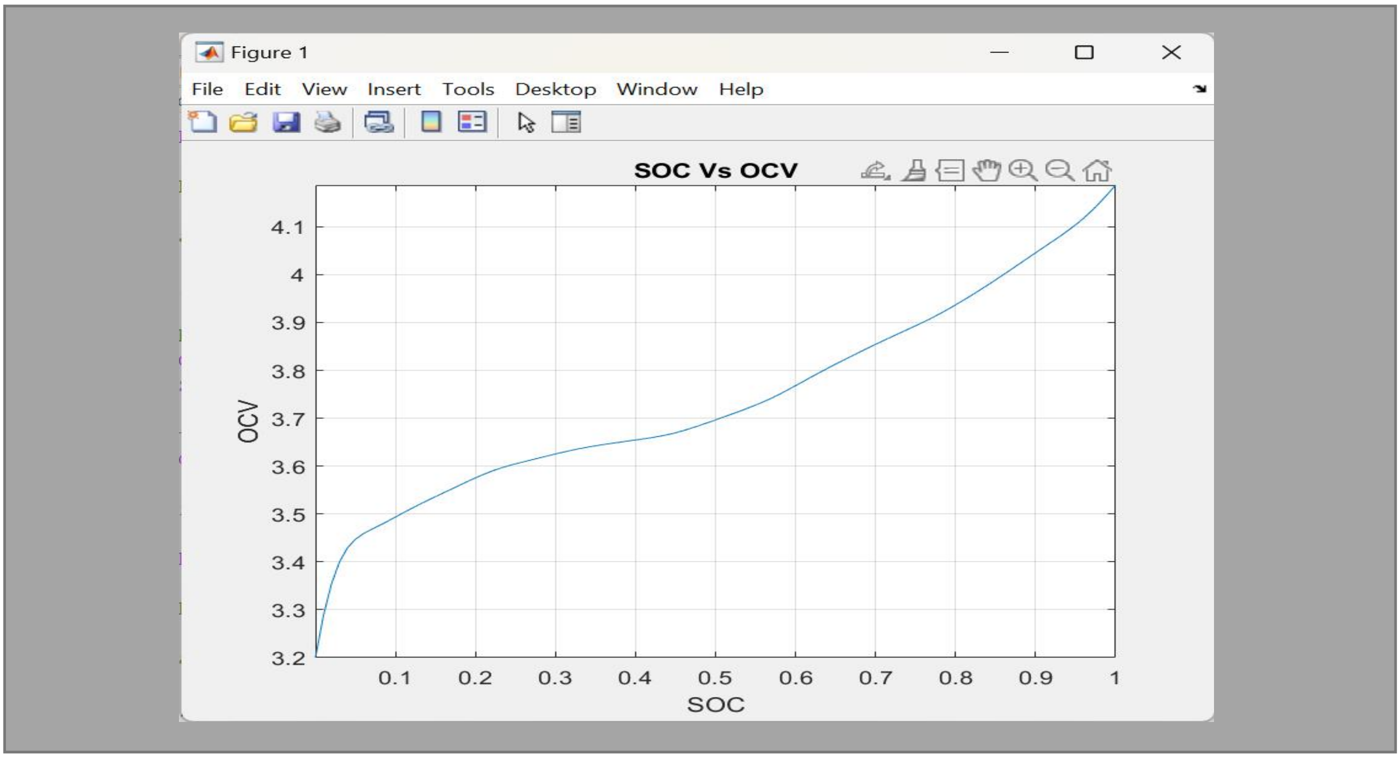

Table 2: SOC Vs OCV

	A	B
	RClutVardaanS1	
	SoC	R0Ohm
	Number	Number
1	SoC	R0 [Ohm]
2	0	4.5521e-04
3	0.0500	4.3525e-04
4	0.1000	4.1739e-04
5	0.1500	4.0163e-04
6	0.2000	3.8798e-04
7	0.2500	3.7642e-04
8	0.3000	3.6697e-04
9	0.3500	3.5961e-04
10	0.4000	3.5436e-04
11	0.4500	3.5121e-04
12	0.5000	3.5016e-04
13	0.5500	3.5121e-04
14	0.6000	3.5436e-04
15	0.6500	3.5961e-04
16	0.7000	3.6697e-04
17	0.7500	3.7642e-04
18	0.8000	3.8798e-04
19	0.8500	4.0163e-04
20	0.9000	4.1739e-04
21	0.9500	4.3525e-04
22	1	4.5521e-04

	A	B
	RClutVardaanS2	
	SoC	R1Ohm
	Number	Number
1	SoC	R1 [Ohm]
2	0	6.8281e-04
3	0.0500	6.5287e-04
4	0.1000	6.2609e-04
5	0.1500	6.0245e-04
6	0.2000	5.8197e-04
7	0.2500	5.6463e-04
8	0.3000	5.5045e-04
9	0.3500	5.3942e-04
10	0.4000	5.3154e-04
11	0.4500	5.2682e-04
12	0.5000	5.2524e-04
13	0.5500	5.2682e-04
14	0.6000	5.3154e-04
15	0.6500	5.3942e-04
16	0.7000	5.5045e-04
17	0.7500	5.6463e-04
18	0.8000	5.8197e-04
19	0.8500	6.0245e-04
20	0.9000	6.2609e-04
21	0.9500	6.5287e-04
22	1	6.8281e-04

	A	B
	RClutVardaanS3	
	SoC	C1F
	Number	Number
1	SoC	C1 [F]
2	0	4.3936e+04
3	0.0500	4.5951e+04
4	0.1000	4.7917e+04
5	0.1500	4.9797e+04
6	0.2000	5.1549e+04
7	0.2500	5.3132e+04
8	0.3000	5.4501e+04
9	0.3500	5.5615e+04
10	0.4000	5.6440e+04
11	0.4500	5.6946e+04
12	0.5000	5.7117e+04
13	0.5500	5.6946e+04
14	0.6000	5.6440e+04
15	0.6500	5.5615e+04
16	0.7000	5.4501e+04
17	0.7500	5.3132e+04
18	0.8000	5.1549e+04
19	0.8500	4.9797e+04
20	0.9000	4.7917e+04
21	0.9500	4.5951e+04
22	1	4.3936e+04

Table 3: SOC Vs R0/R1/C1

❖ Observation 1

- Single cell constant current discharging

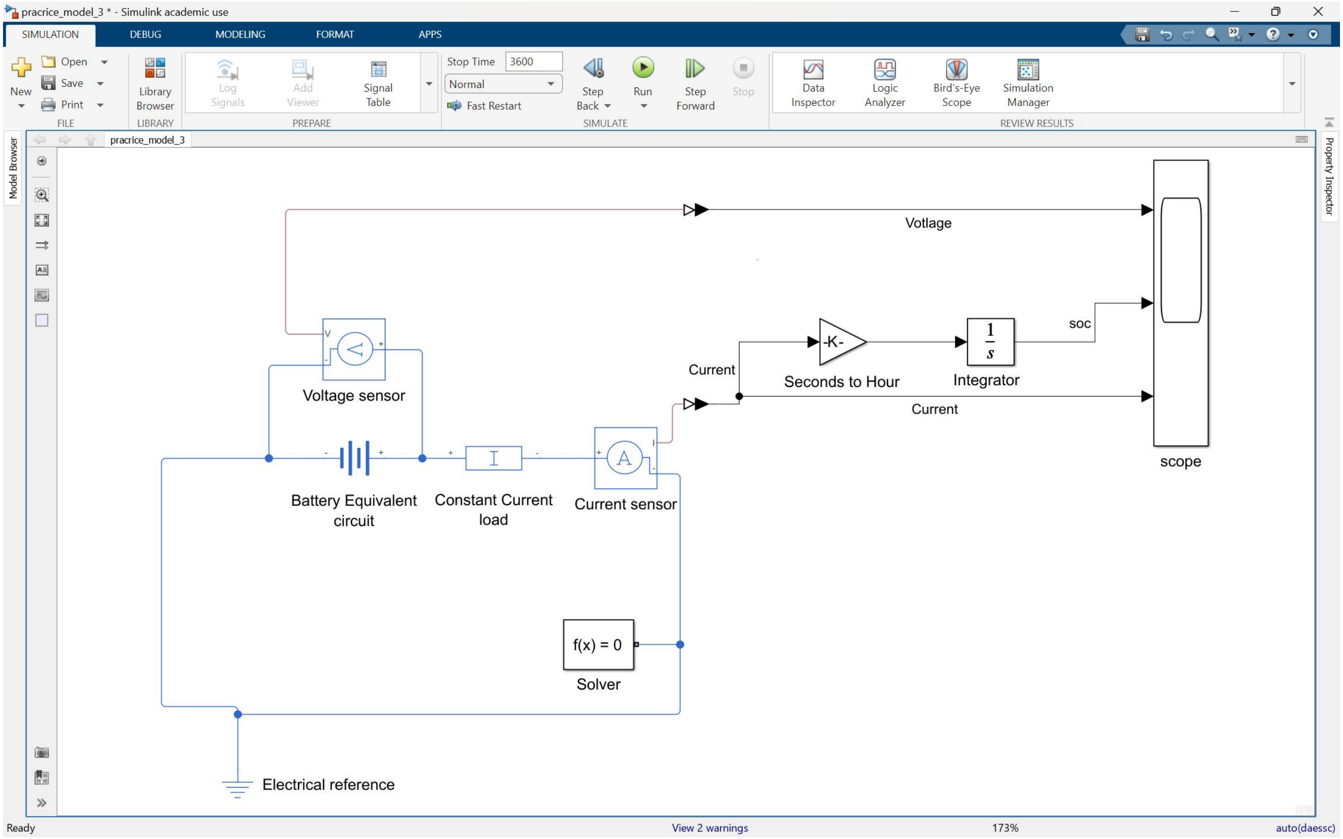

Figure 5: EECM of Single Electro-chemical Cell Simulation

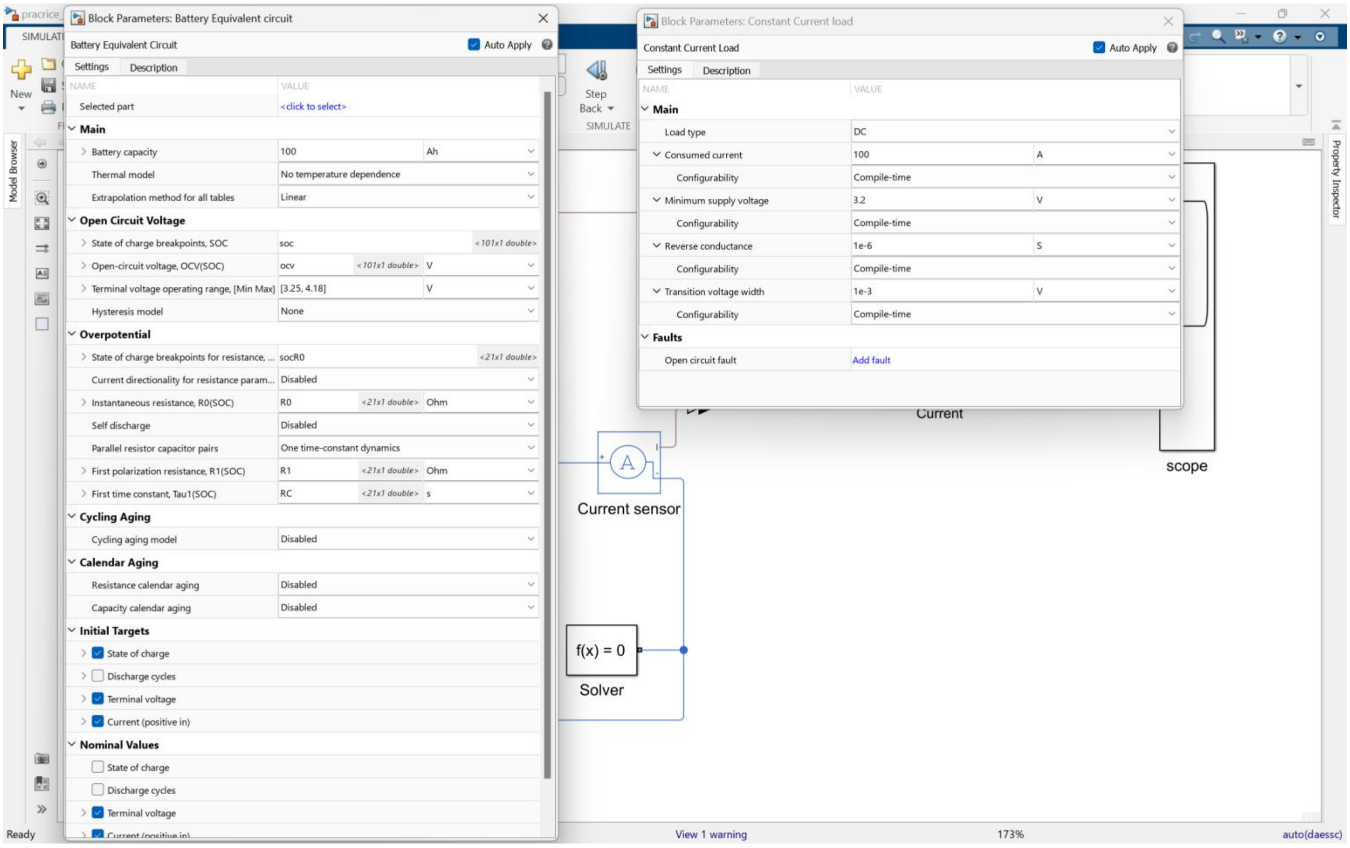

Figure 6: Cell and Constant Current Load Configurations

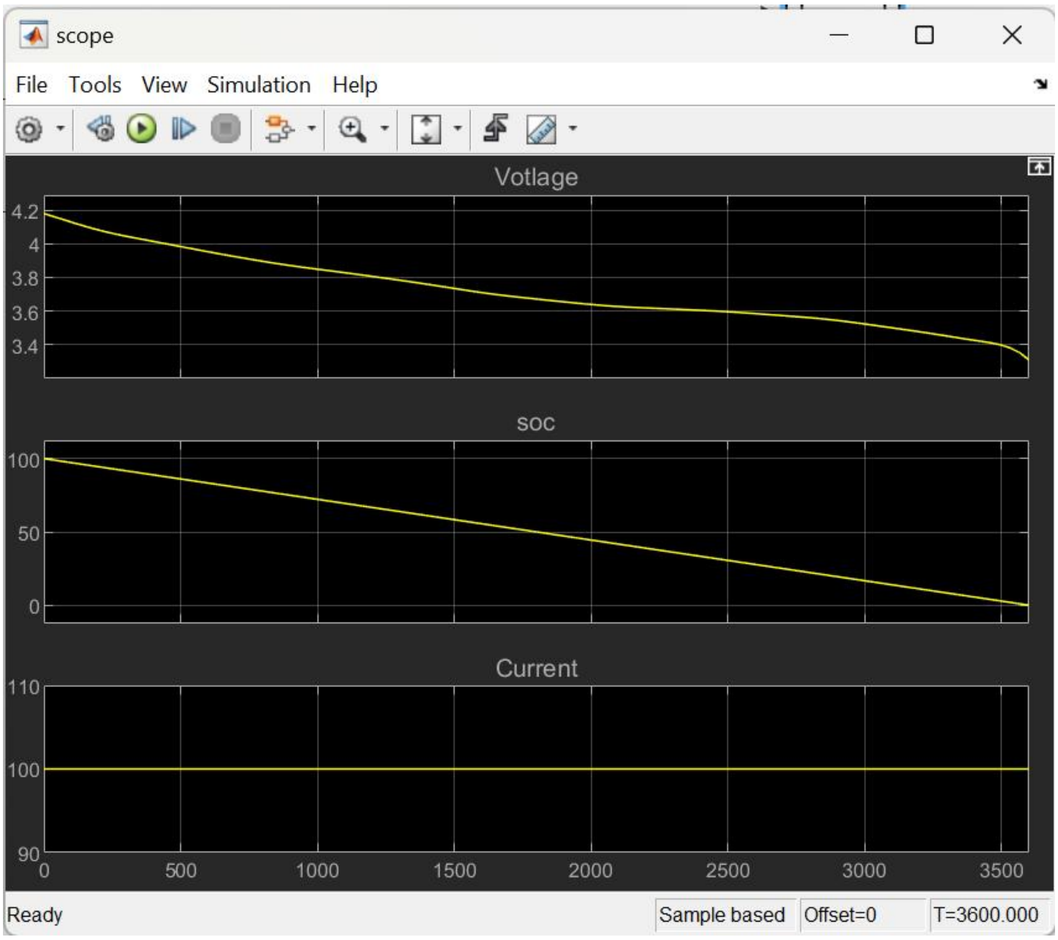

Figure 7: Output Plot at 100A (1C) of Discharge Current

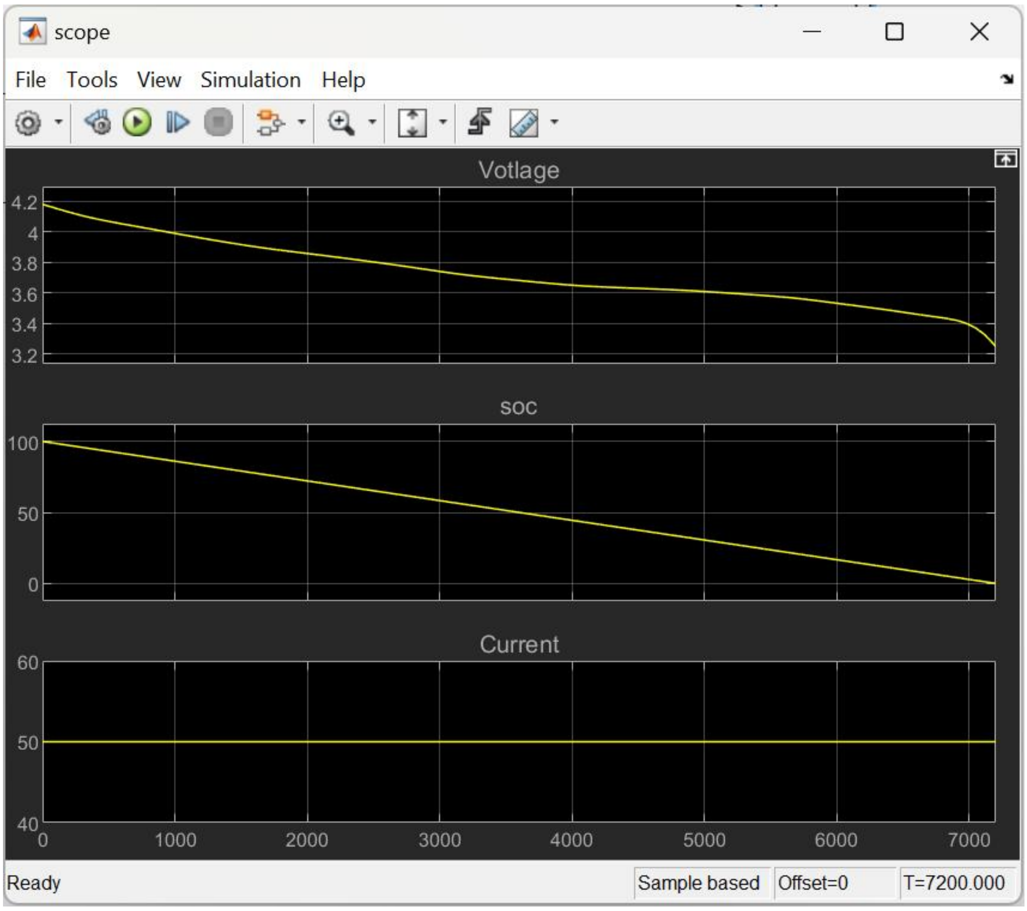

Figure 8: Output plot at 50A (0.5 C) of Discharge Current

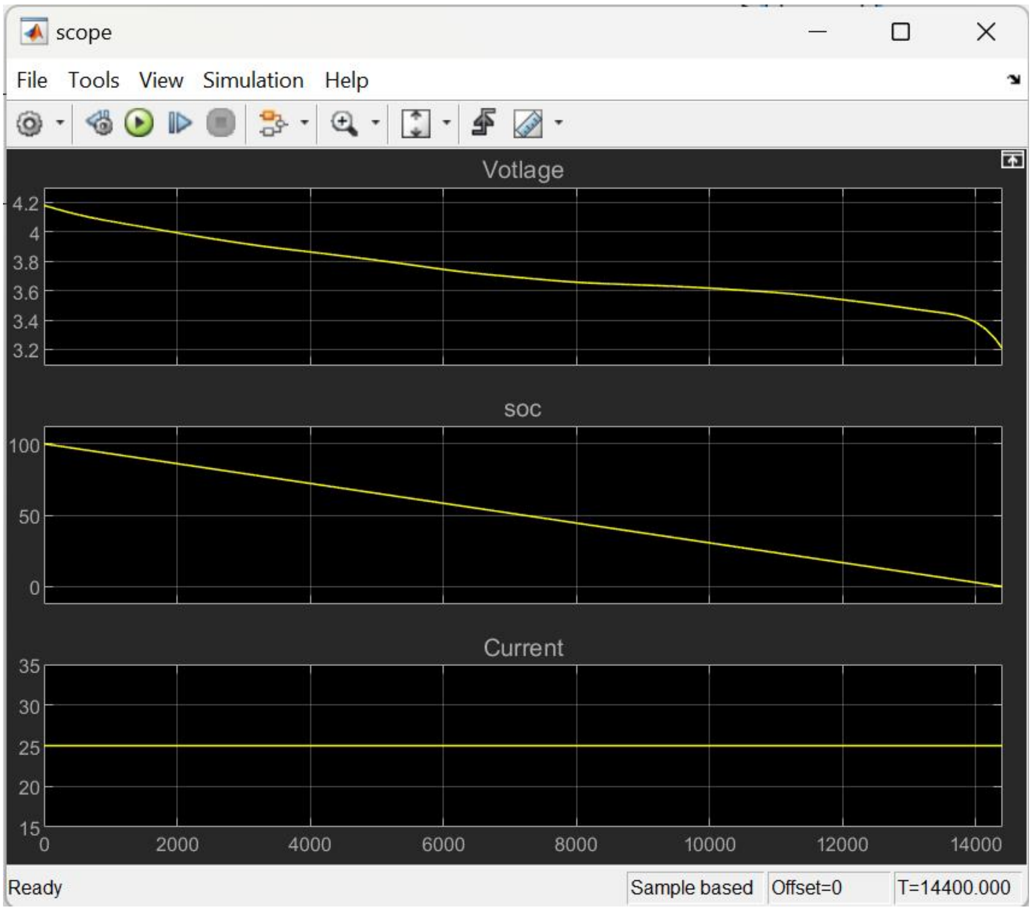

Figure 9: Output plot at 25A (0.25 C) of Discharge Current

❖ Result 1

- **Voltage response:** Sluggishness decreased with lower discharge current (100A > 50A > 25A), becoming nearly linear at 25A.

- **Discharge time:** Directly related to current (double at 100A vs 50A, quadruple at 25A vs 50A).

- **Internal resistance:** Observed discharge times shorter than theoretical C-rates, suggesting an unmodeled internal resistance not captured by the Thevenin 2-RC model.

- **State of Charge (SOC):** Independent of discharge current, showing no significant change across tested rates.