✱ State of charge Estimation

what is state of charge?

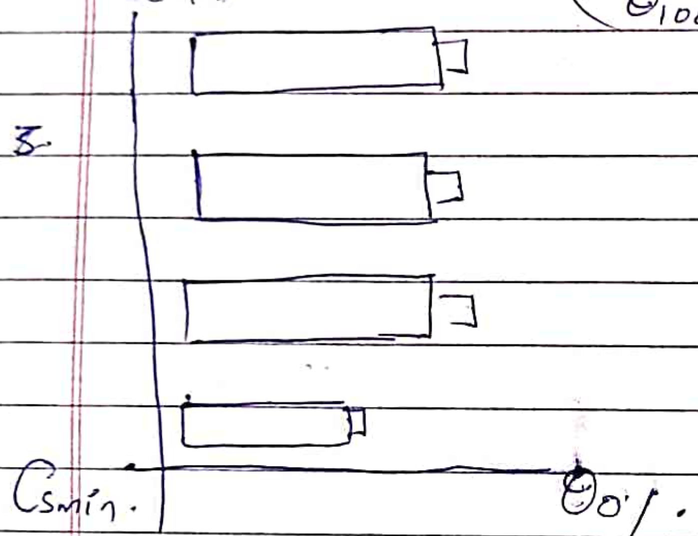
1. Charging & discharging is involved within moving the lithium ion b/w electrode.

2. Electrochemically, 1 cell state of charge is amount of Lithium ion concentration in negative electrode solid particle.

$$\theta = \frac{C_{s\,avg}}{C_{s\,max}}$$

$\theta_{100\%}$ $C_{s\,max}$. $\quad z_k = \left(\frac{\theta - \theta_0}{\theta_{100} - \theta_0}\right)$.

3.

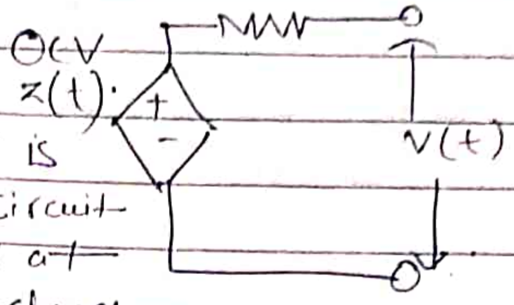


✱ Energy & Power Estimation :-)

(1) Cell Energy v/s Power

→ Energy is ability to do work & Power is rate of moving energy.

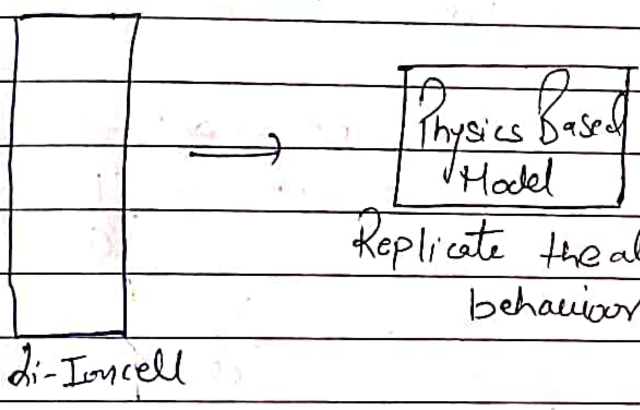
→ Discharging/charging at high rates leads to cells degradation.



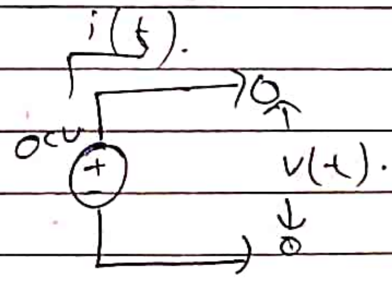
OCV is Open circuit voltage at 100% charge

Battery Pack Simulation - OCV & SOC of cell.

Equivalent circuit cell models :-



① Open Circuit Voltage (OCV).



ideal voltage source.

- Voltage is not a f(ckt).
- Voltage is not a f(past usage).
- Voltage is constant

OCV = V(t)

+ State of Charge (SoC) → $Z(t)$.

① when cell is 100% charged → OCV_{max} → max voltage.
2 when cell is 0% charged → OCV_{min} → min voltage.

State of charge $z(t)$ of a cell →.

$z = 100\%$ fully charged

$z = 0\%$. fully discharged.

Total capacity (Q).

Q → total charge withdrawn from

$z \to 100\% \to 0\%$.

SoC can be modeled using eqⁿ →

$$\dot{z}(t) = -\frac{i(t)}{Q}.$$

$$\boxed{\frac{dz}{dt} = -\frac{i(t)}{Q}}$$

$$Z(t) = Z(t_0) - \frac{1}{Q}\int_{t_0}^{t} i(t)\,dt)$$

$i(t)$ → +ve for discharging.

~~(+)~~ $i(t)$ → −ve for charging.

Discret the eqⁿ.

$$Z[k+1] = Z[k] - \frac{i[k]\,\Delta t}{Q}.$$

Page No.:
Date: / /

Efficiency factor → $\eta(t)$

Efficiency & discharge rate or current drawn.

$$SOC = \frac{\text{Current drawn} \times \text{efficiency}}{\text{Total charge}}$$

Linear Polarization :-

$$V(t) = OCV(z_t) - i(t)R_0$$

For charging $i(t) > 0$

For discharging $V(t) < 0$

Polarization :-

Departure of cells terminal voltage from OCV due to current passage.

$$\frac{d}{d(t)}\left(i_{R_1}(t)\right) = \frac{-1}{R_1C_1} i_{R_1}(t) + \frac{1}{R_1C_1} i(t)$$

Current with diffusion voltage.

$$V(t) = OCV(z(t)) - i(t)R_0 - i_{R_1}(t)R_1$$

ΔV_0 → Immediate Jump in voltage as cell is unloaded.

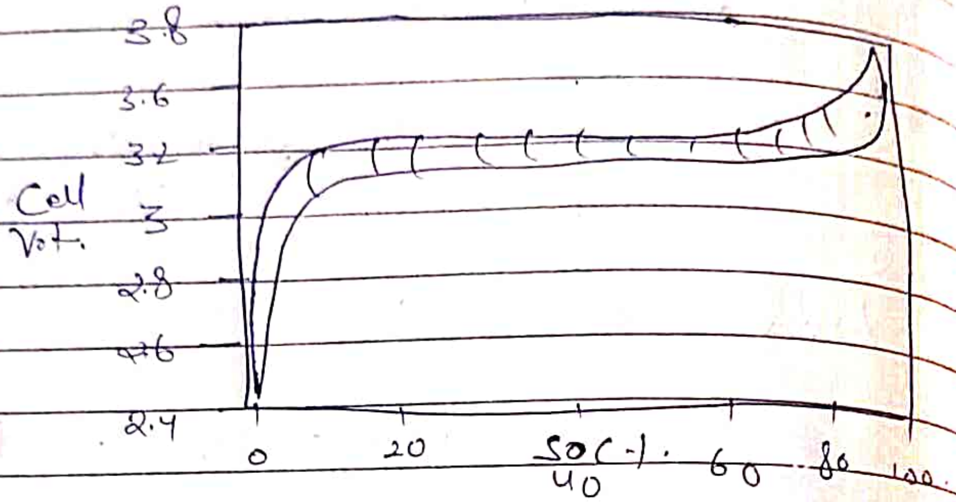
$$\Delta V_0 = R_0 \Delta i \qquad R_0 = \frac{\Delta V_0}{\Delta i}$$

ΔV_∞ = Steady state voltage change.

$$\Delta V_\infty = (R_0 + R_1)\Delta i.$$

$$R_1 = \frac{\Delta V_{ov}}{\Delta i} - R_0$$

+ Hysteresis Voltage.



(1) For a cell allowed to rest →
For long enough time.

Diffusion voltage → 0 V.

$$v(t) = OCV(z(t))$$

Realistic condition.

For a SOC → range of OCV.

discharge rate → C/30 (approx equilibrium state)

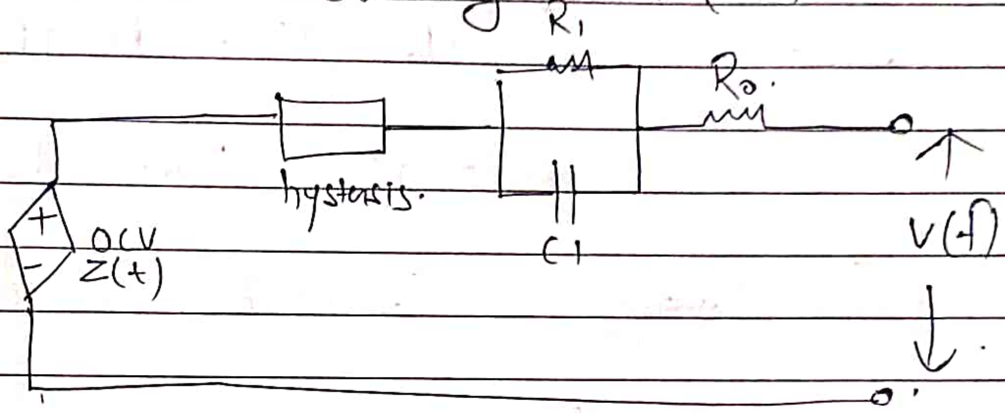
$$i(t) = Q/30$$

discharge rate → $C/30$

(approx equilibrium state).

$$i(t) = Q/30$$

The Enhanced Self Correcting model (ESC) - OCV Testing.



Enhanced :→ Includes a generic hysteresis element.

Self correcting :→ Converges to OCV + hysteresis → at rest

OCV + hysteresis − $i\Sigma R$ for constant current.

SoC → $$z[k+1] = z[k] - \frac{\eta[k]\Delta t\, i[k]}{Q}$$

i_R → $$i_R[k+1] = A_{RC}\, i_R[k] + B_{RC}\, i[k].$$

$$A_{RC} = \exp\left(\frac{-\Delta t}{R_1 C_1}\right) i_R[k]$$

$$B_{RC} = \left\{1 - \exp\left(\frac{-\Delta t}{R_1 C_1}\right)\right\} i_R[k]$$

Page No.:
Date: / /

Hysteresis → $h[k+1]$

$$h[k+1] = A_H[k]\,h[k] + [A_H[k] - 1]\,sgn(i(k))$$

$$A_H[k] = \exp\left(-\frac{h[k]\,i[k]\,\gamma\,\Delta t}{Q}\right)$$

Terminal Voltage : $V[k] = OCV(Z[k]\,T[k]) + M_0 Z[k] + M h[k] - R_1 i_{R_1}[k] - R_0 i[k]$.

+ Cell Testing & Coulombic Efficiency :→.

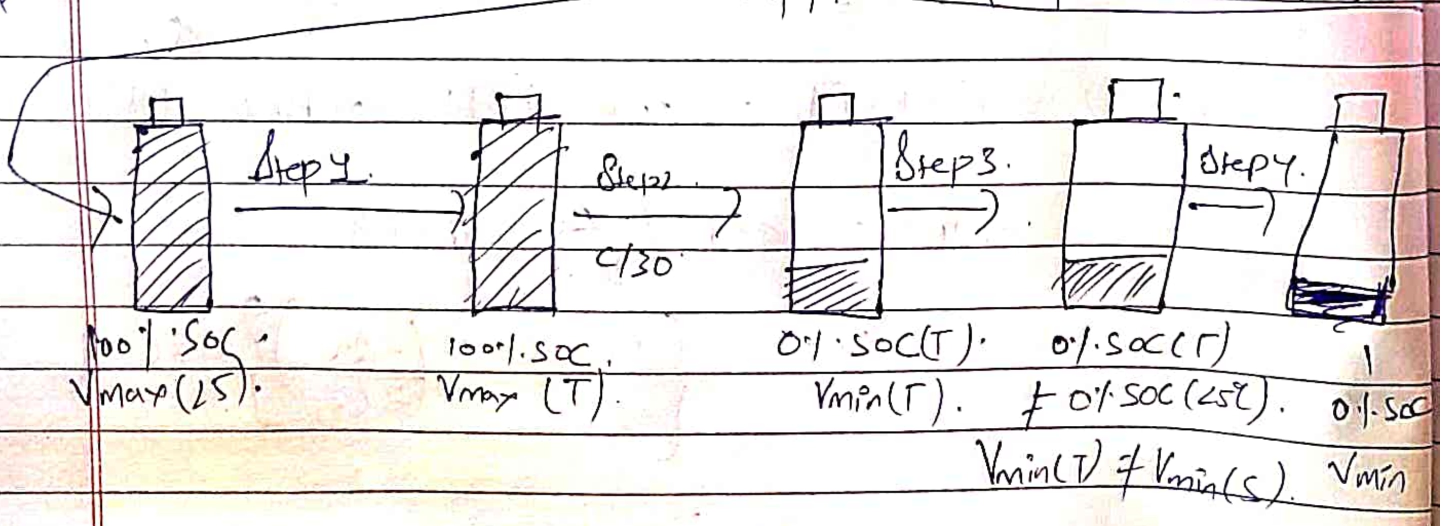
Cell Testing Procedure :→.

OCV → $f[Z(t), T(t)]$ → SoC & temp.

For experiment.

① Cell is charged & discharge at very slow rate.

+ Determine coulombic efficiency of the cell :→.



Total Ah discharged → Q.
Total Ah charged → Q.

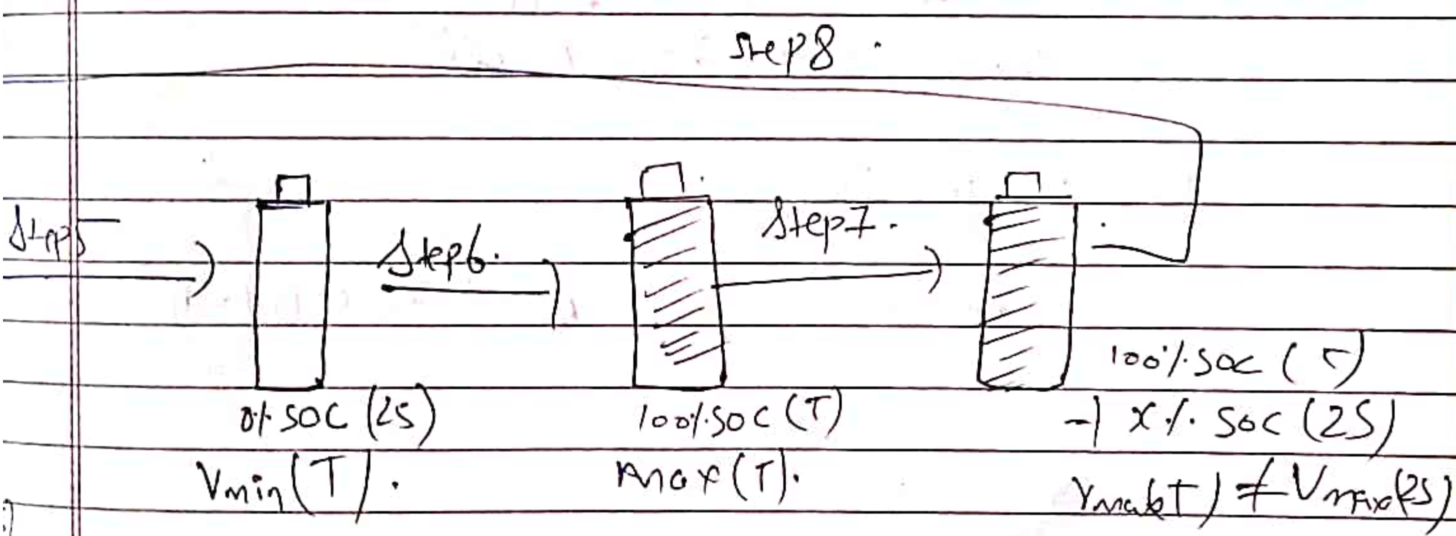
Case I   Temp — 25°C.

Stage 1 → Stage 2 → Stage 3 → Stage 4.
25°C discharg   25°C charge.
Q_{D1} Q_{D2} Q_{C1} Q_{C2}.

Total discharge → $Q_{D1} + Q_{D2}$.
total charge → $Q_{C1} + Q_{C2}$.

$$\eta(25) = \frac{\text{total discharge @ 25°C}}{\text{Total charge @ 25°C}}$$

$$= \frac{Q_{D1} + Q_{D2}}{Q_{C1} + Q_{C2}} = \frac{Q_D}{Q_C}.$$



Case II

Temp → T.

Stage 1 → Stage 2 → Stage 3 → Stg 4
Q_{DT} — Q_{D25} — Q_{CT} — Q_{C25}

$$\eta(T) = \frac{Q_{DT}}{Q_{CT}} - \eta(25)\frac{Q_{D25}}{Q_{C25}}$$

$$\eta(T) = \frac{\text{disc. at } T}{\text{Charge at } T} - \eta(25)\frac{\text{discharge at 25}}{\text{Charge at 25}}$$

\+ Temp & OCV :

Temp. Dependent OCV.

(1) OCV → $F(Z(t))$
$OCV(Z(t))$

DOD(t) → Depth of discharged →
how much charge has been extracted from cell
SoC → State of charge.
Charge left inside the cell.

$t_0 = 0s$ at Stage 1

$$DOD(t) = Q_D(t) - \eta(25)\, Q_{C25}(t) - \eta(T) Q_{CT}(t).$$

Page No.:
Date: / /

$$SoC = 1 - \frac{DoD(t)}{Q}$$

$$\boxed{Z(t) = 1 - \frac{DoD(t)}{Q}}$$