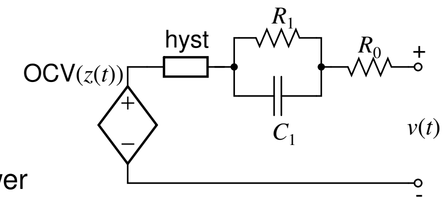
Applications of a cell model

- In this course, you have learned how to make equations that describe the operation of a lithium-ion battery cell
- You have seen how to use lab-test data to find static and dynamic model parameter values
- You have also learned how to simulate voltage response of a cell to an input-current stimulus
- This week, we look at other model applications
  - Simulating constant voltage and constant power
  - Simulating battery packs comprising many cells



Cell voltage has fixed and instantaneous parts

- How do we simulate battery cell models with input equal to desired terminal voltage?
- Consider the ESC cell model,

$$\begin{aligned} x[k] &= A[k-1]x[k-1] + B[k-1]i[k-1] \\ v[k] &= \underbrace{\text{OCV}(x[k]) + \text{hysteresis}(x[k]) - \text{diffusion}(x[k])}_{\text{not a function of instantaneous current}} - R_0 i[k] \end{aligned}$$

- Note that $x[k]$ does not depend on $i[k]$—it depends on $i[k-1]$, $i[k-2]$ etc.
- So, cell voltage comprises a "fixed" part, which does not depend on the present cell current, and a "variable" part, $-R_0 i[k]$, which does depend on present cell current

Finding current to result in desired voltage

- If fixed part is $v_f[k]$, we have $v[k] = v_f[k] - R_0 i[k]$
- To simulate constant voltage, we calculate the input current that results in the desired output voltage

$$\begin{aligned} v[k] &= v_f[k] - R_0 i[k] \\ i[k] &= \frac{v_f[k] - v[k]}{R_0} \end{aligned}$$

- As an application, note that a common type of battery-cell charging profile is CC/CV
  - CC until a voltage limit is reached, then CV at that limit until current is negligible
- CC/CV is often used in laboratory tests of cells and is straightforward to simulate

Code to simulate CC/CV charge (1)

- Consider Octave/MATLAB script to simulate CC/CV charge

```
% ------------------------------------------------------------
% simCharge: Simulate CC/CV charging of a battery cell
% ------------------------------------------------------------
% creates variable "model" with E1 cell parameter values
clear; close all; clc; load E1model;

% Get ESC model parameters
maxtime = 3001; T = 25; % Simulation run time, temperature
q  = getParamESC('QParam',T,model);
rc = exp(-1./abs(getParamESC('RCParam',T,model)));
r  = (getParamESC('RParam',T,model));
m  = getParamESC('MParam',T,model);
m0 = getParamESC('M0Param',T,model);
g  = getParamESC('GParam',T,model);
r0 = getParamESC('R0Param',T,model);
maxV = 4.15; % maximum cell voltage of 4.15 V
```


Code to simulate CC/CV charge (2)

- Consider Octave/MATLAB script to simulate CC/CV charge

```
% Setup for simulation
storez = zeros([maxtime 1]);  % create storage for SOC
storev = zeros([maxtime 1]);  % create storage for voltage
storei = zeros([maxtime 1]);  % create storage for current
storep = zeros([maxtime 1]);  % create storage for power
z  = 0.5; irc = 0; h = -1; s = -1; % initialize to 50% SOC, resting
CC = 9;  % constant current of 9 A in CC/CV charge
```


Code to simulate CC/CV charge (3)

- Consider Octave/MATLAB script to simulate CC/CV charge

```
% Simulate CC/CV
for k = 1:maxtime,
  v = OCVfromSOCtemp(z,T,model) + m*h + m0*s - r*irc; % fixed voltage

  ik = (v - maxV)/r0;                % compute test ik to achieve maxV
  ik = max(-CC,ik);                  % but limit ik to no more than CC in mag.

  z = z - (1/3600)*ik/q;             % Update cell SOC
  irc = rc*irc + (1-rc)*ik;          % Update resistor currents
  fac = exp(-abs(g.*ik)./(3600*q));
  h = fac.*h + (fac-1).*sign(ik);    % Update hysteresis voltages
  if abs(ik)>1e-3, s = sign(ik); end % update current sign
  storez(k) = z;                     % Store SOC for later plotting
  storev(k) = v - ik*r0;
  storei(k) = ik;                    % store current for later plotting
  storep(k) = ik*storev(k);
end % for k
```

Code to simulate CC/CV charge (4)

- Consider Octave/MATLAB script to simulate CC/CV charge

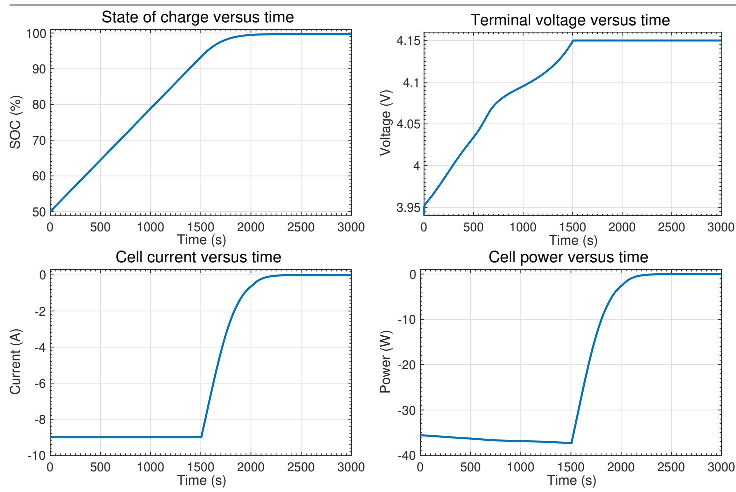
```
% Plot results
time = 0:maxtime - 1;
figure(1); plot(time,100*storez); title('State of charge versus time');
ylabel('SOC (%)'); ylim([49 101]); xlabel('Time (s)'); grid on

figure(2); plot(time,storev); title('Terminal voltage versus time');
ylabel('Voltage (V)'); ylim([3.94 4.16]); xlabel('Time (s)'); grid on

figure(3); plot(time,storei); title('Cell current versus time');
ylabel('Current (A)'); ylim([-10 0.3]); xlabel('Time (s)'); grid on

figure(4); plot(time,storep); title('Cell power versus time');
ylabel('Power (W)'); ylim([-40 1]); xlabel('Time (s)'); grid on
```


Simulation results



- Simulation results when charging a battery cell from 50 % SOC to max voltage using a CC/CV profile

Summary

- In this lesson, you have learned that our discrete-time model of cell voltage has a “fixed” portion and an “instantaneous” portion at every time step
  - This observation is critical for everything we study this week
- One application of this feature is an ability to simulate constant voltage
- You have learned how to simulate CC/CV charging, for example
- Next, we will exploit this feature to be able to simulate CP/CV charging