Progress in Management of Li-ion batteries

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Company Overview

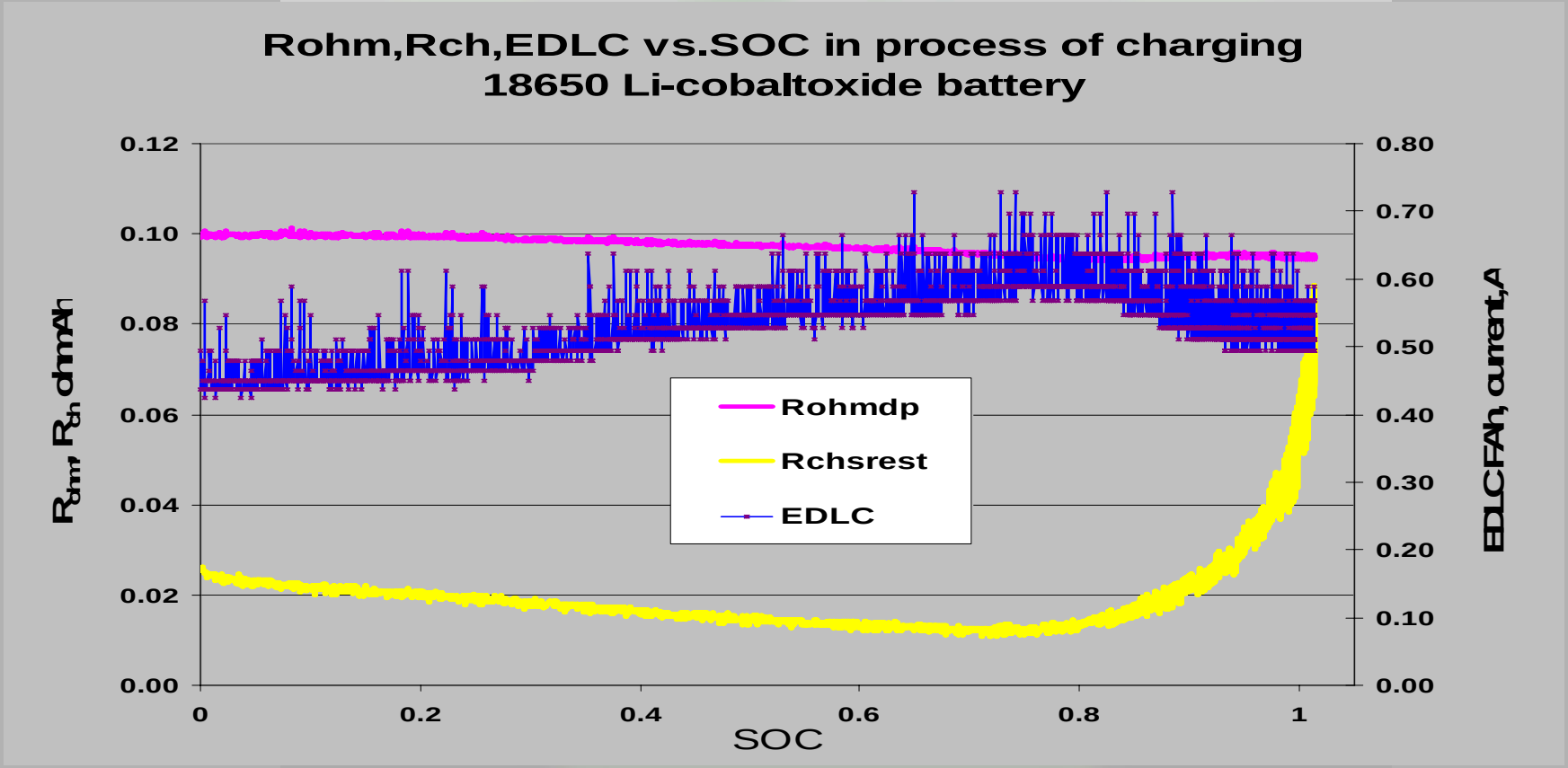
- *Located in Redlands, CA*
- *Intelligent Battery Management Technology Company*
- *Technical Consultant – Dr. Boris Tsenter*
- *Engineering Personnel*
  - *Electronics*
  - *Programming*

Matrix of battery parameters

- *Matrix of battery parameters (MoP) as key element of battery management*
- *MoP includes*
  - *Ohm resistance*
  - *Chemical resistance (polarization)*
  - *Electrical Double Layer Capacity (EDLC)*
  - *Instantaneous OCV*

Sampling Matrix of Battery Parameters(MoP)

MoP is sampled in process of battery pulse charging



Management components of Li-ion batteries

- *Battery over and undercharging protection*
- *Safety issues*
  - *Monitoring potential shunt*
  - *Monitoring potential Li electroplating*
  - *Cell equalization approach*

Management components (cont.)

- *SOC recognition via instantaneous OCV measurement*
- *SOH recognition as an assessment of battery's ability to sustain required energy and power for current cycle (diagnostic tool)*
- *SOH recognition as prediction of residual cycles prior to battery failure (prognostic tool)*

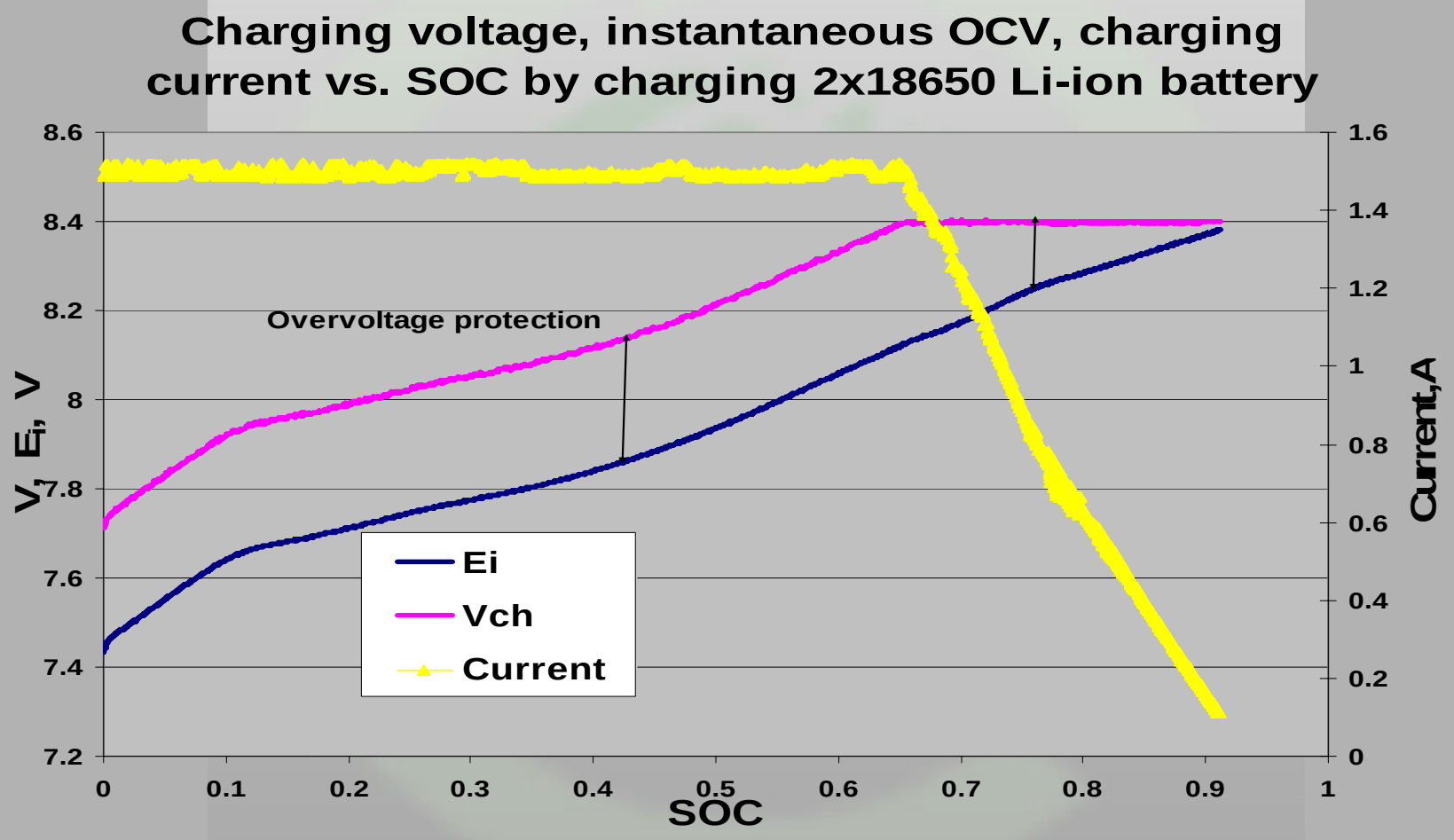
Over and undercharging protection

- *The product of charging current and battery ohm resistance is introduced as means of overvoltage protection*
- *Battery is charged under voltage balance*

  $V=E_i+ IxR_{ohm}\leq 4.2V$ *per individual cell*

  E_i *is instantaneous OCV,* IxR_{ohm} *is overvoltage protection*
- *Overvoltage protection drops as much as current drops at the end of charging*
- *Charging under constant voltage is provided up to certain overvoltage protection (i.e 10-30mV/cell), not up to minimum current*.

Ovevoltage protection (cont.)

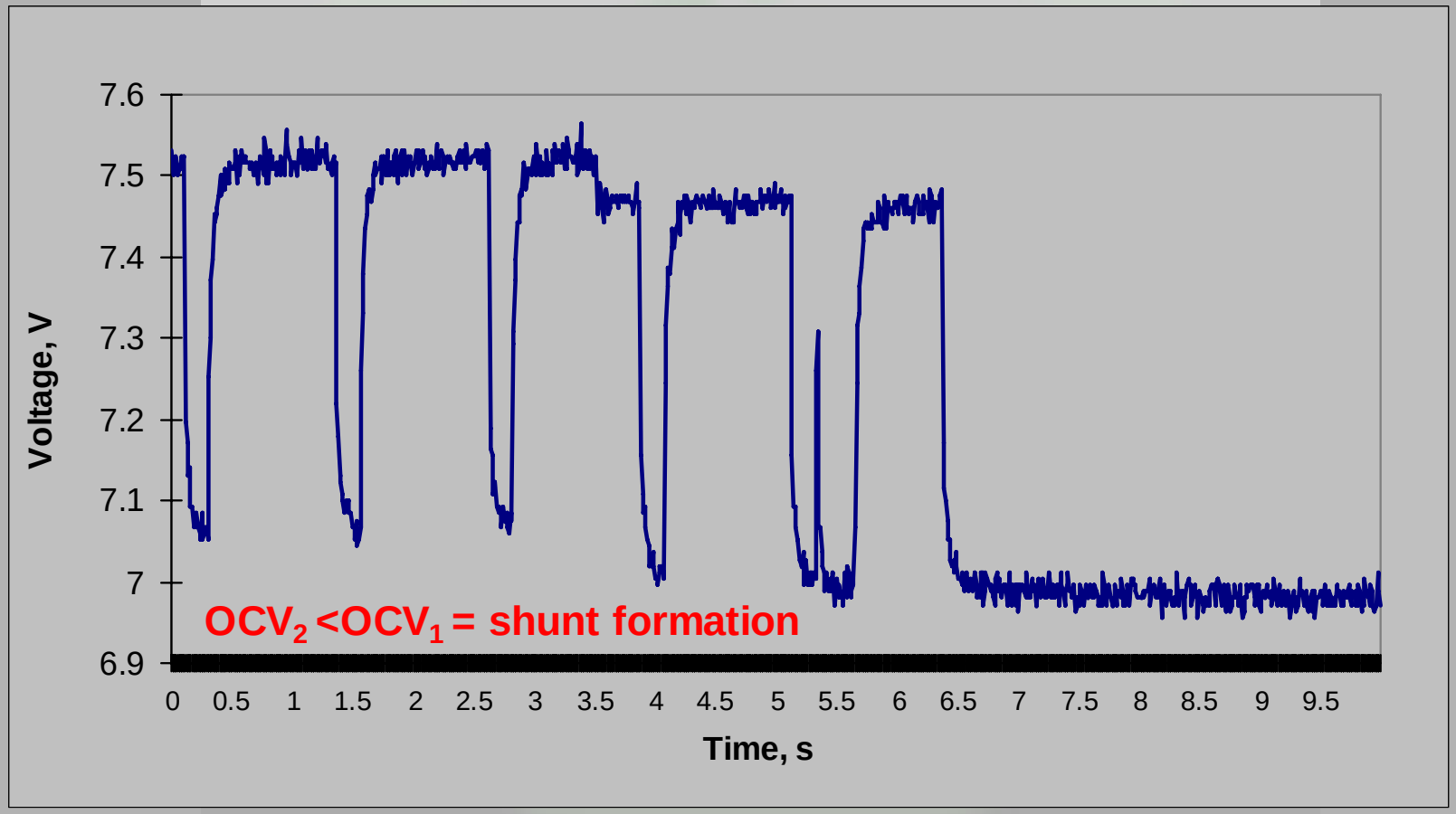


Safety Issues

- *Shunts detection*
  - *Monitoring:*
    - *negative value of dEi/dt for soft shunt*
    - *negative value of dV/dt for hard shunt*
    - *negative value of dVch/dt for chemical shunt*
- *Li electroplating detection*
  - *Monitoring:*
    - *arrest of discharging voltage*
    - *chemical polarization rise during charging*

Safety issues

Voltage and OCV changes during shunt formation (18650 cell)

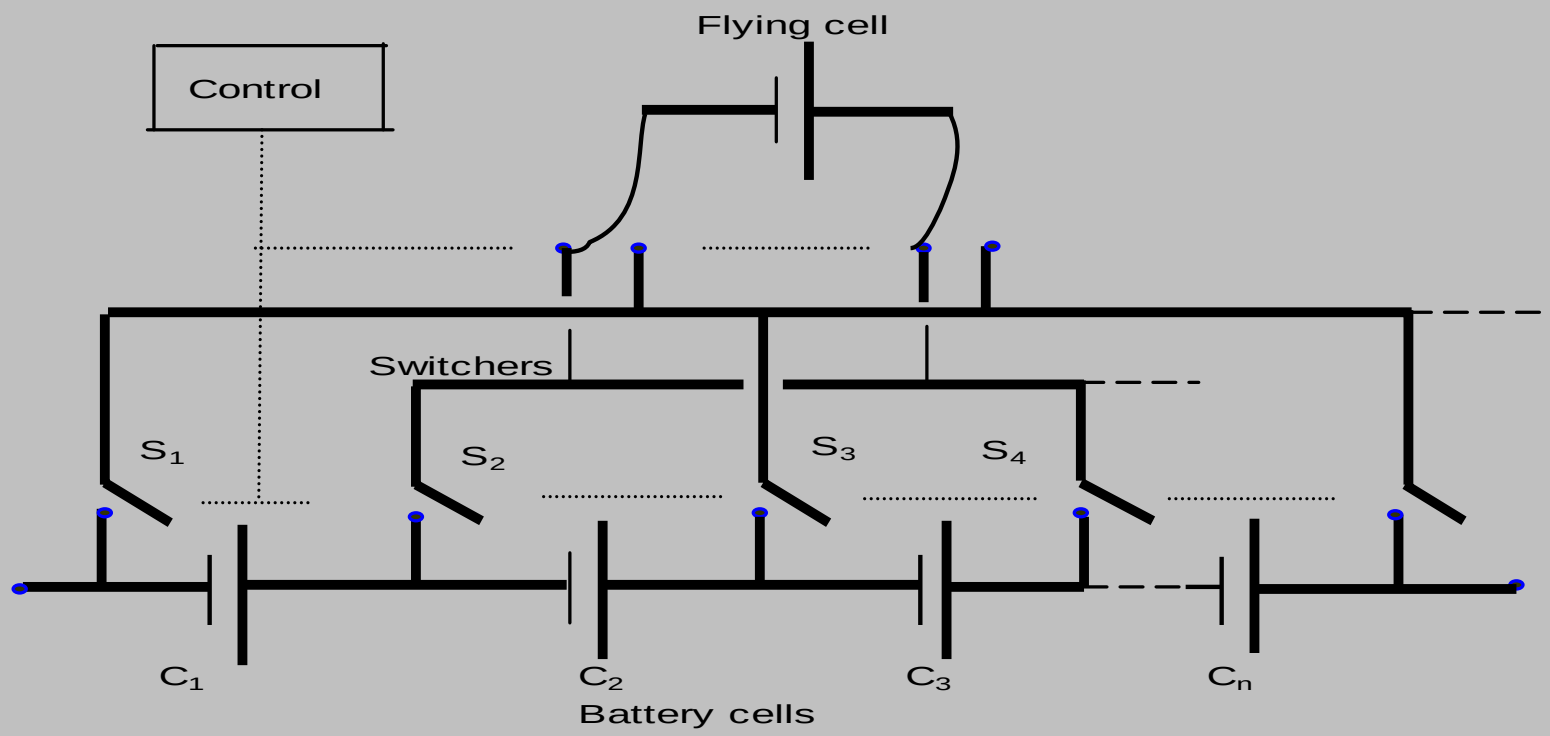


Safety issues: Cell equalization mechanism

- *Original method of cell equalization and redundancy:*
  - *Equalization is provided by monitoring voltage of individual cells during charging*
  - *Extra cell is periodically connected to battery cell with low voltage*
  - *Under discharging extra cell operates as capacity booster*

Safety issues: Cell equalization mechanisms

Electrical circuitry for battery cell equalization with extra Li cell

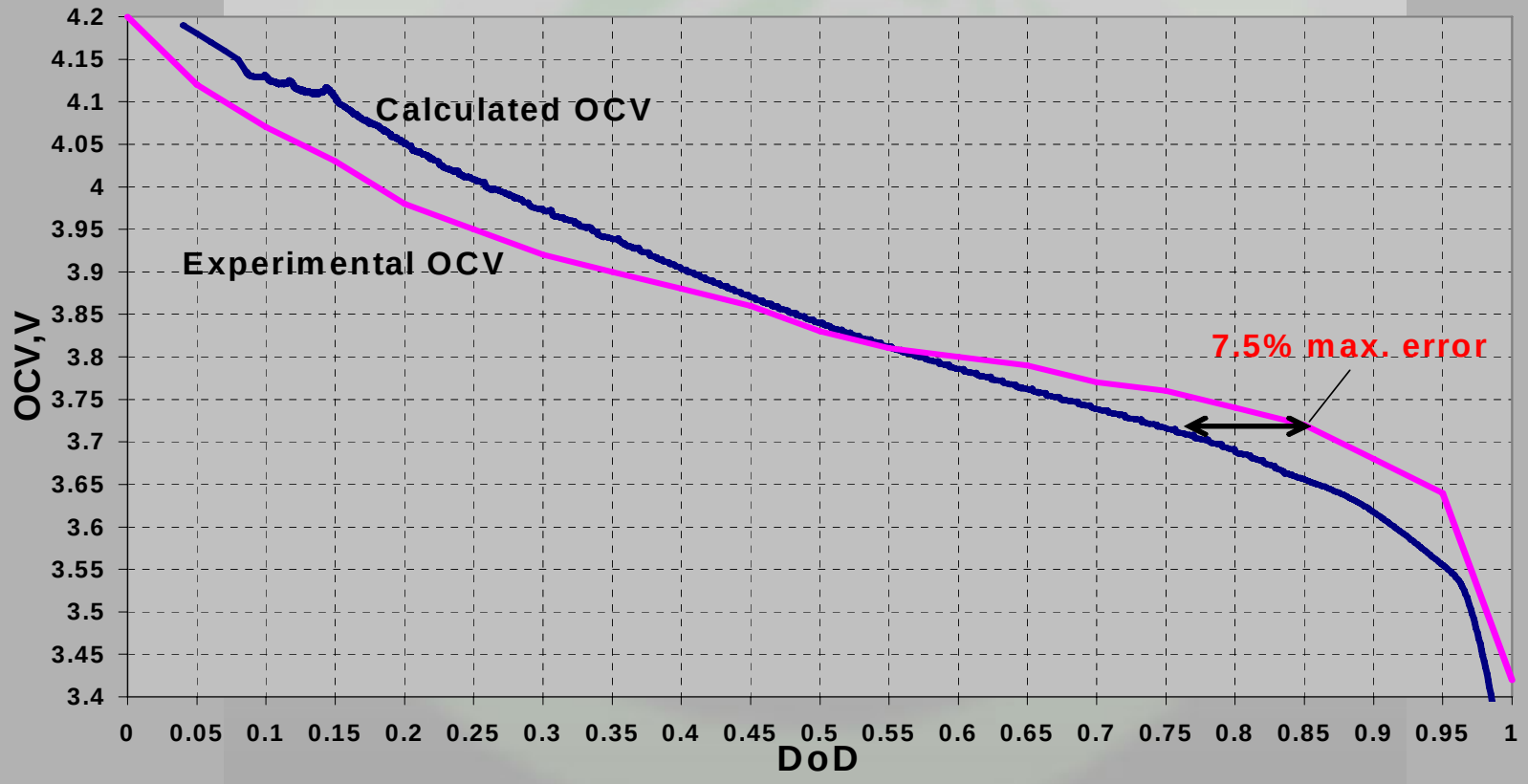


SOC recognition

- *SOC is measured using defined relationship between battery OCV and SOC*
- *While OCV in dynamic process is not accessible, instantaneous OCV sampled directly after current interruption can be used as an alternative to reversible OCV*
- *In process of battery discharging instantaneous OCV can be calculated by given ohm polarization value*

SOC recognition

Relationship between experimental OCV and calculated as OCV = E_i-$I_x R_{ch}$ vs. DoD for 18650 Li-ion battery



Power assessment (battery SOH)

- *Power assessment is achieved by analyzing components of battery electrodes polarization.*
- *Kinetic parameters (ohm and chemical polarization) of discharging process are found by applying unique analytical signal*
- *Tafel or linear parameters of overall reaction are recognized by treatment of this signal*

$$\Delta Vch = IRch \text{ – linear kinetic}$$

$$\Delta Vch = A + B|I| \text{ – Tafel kinetic}$$

- *Prediction of discharging voltage (V_{ds}) is based on subtracting ohm and chemical polarization from battery OCV*

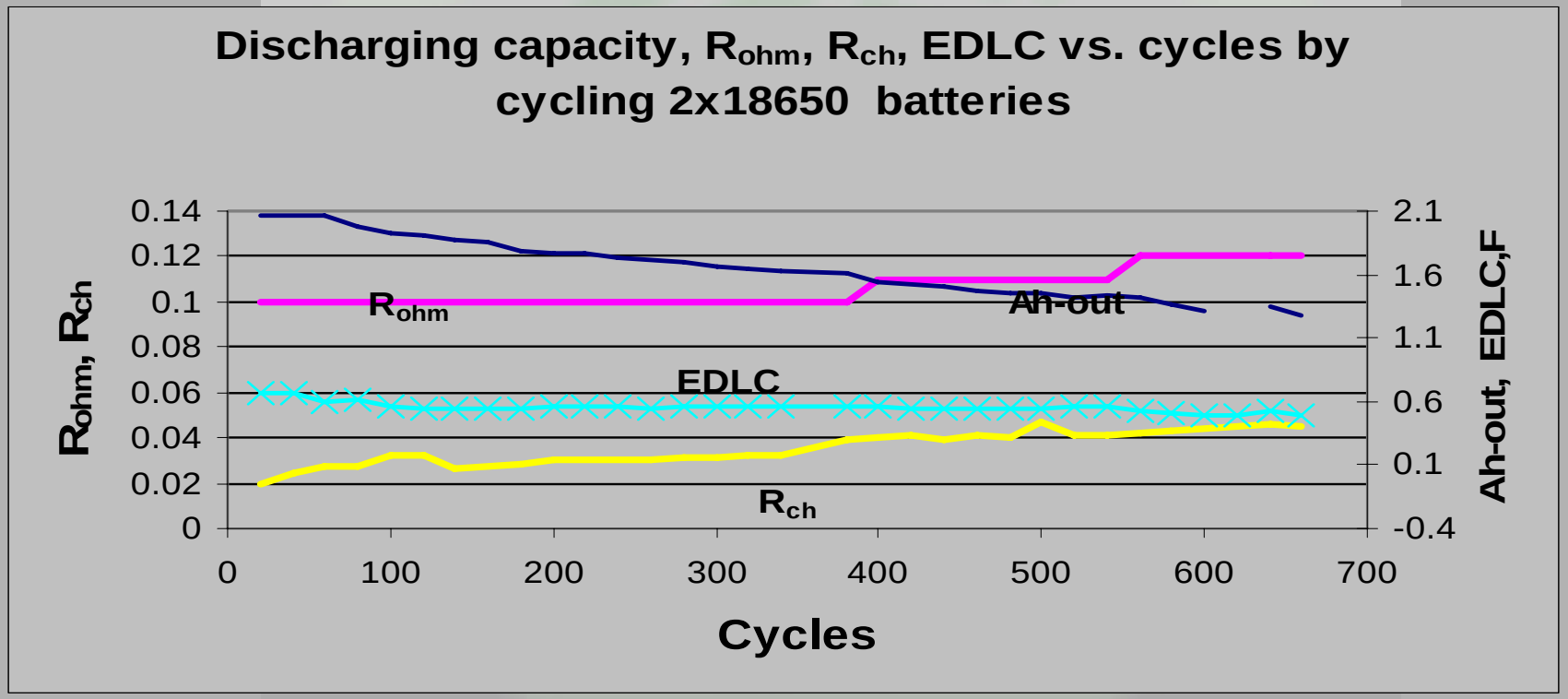
$$V_{ds} = OCV - IR_{ohm} - \Delta V_{ch}$$

Battery prognostic tool

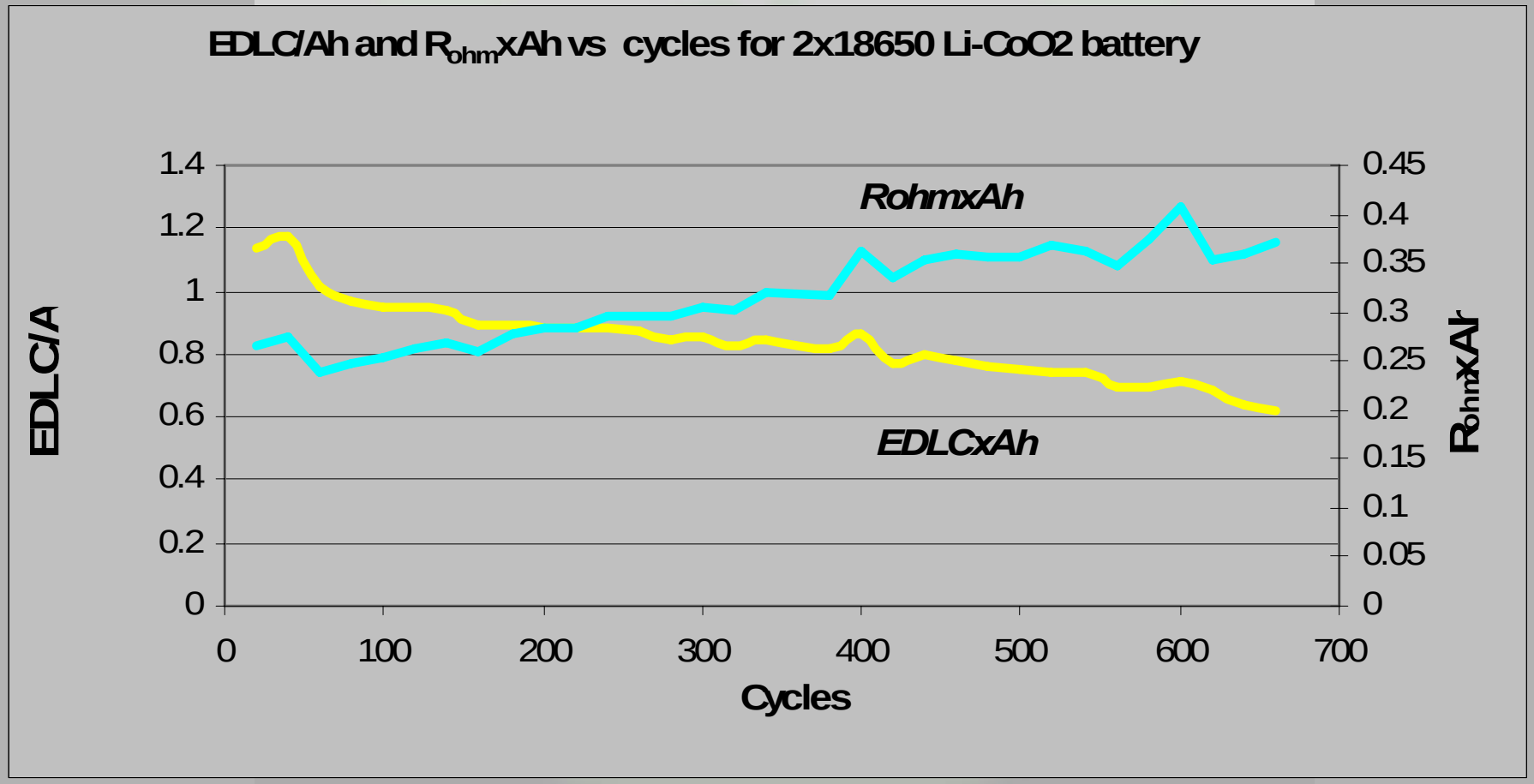
- *Battery prognostic tool is created by monitoring MoP evolution over battery cycling*
- *Change in ohm resistance may indicate problem with SEI*
- *EDLC transformation is associated with surface shrinking*
- *Rise in chemical polarization is indication of change in rate of Li^+ ion intercalation*

Battery prognostic tool: Li-cobaltoxide battery

A strong relationship exists between specific ohm resistance, EDLC and cycle number

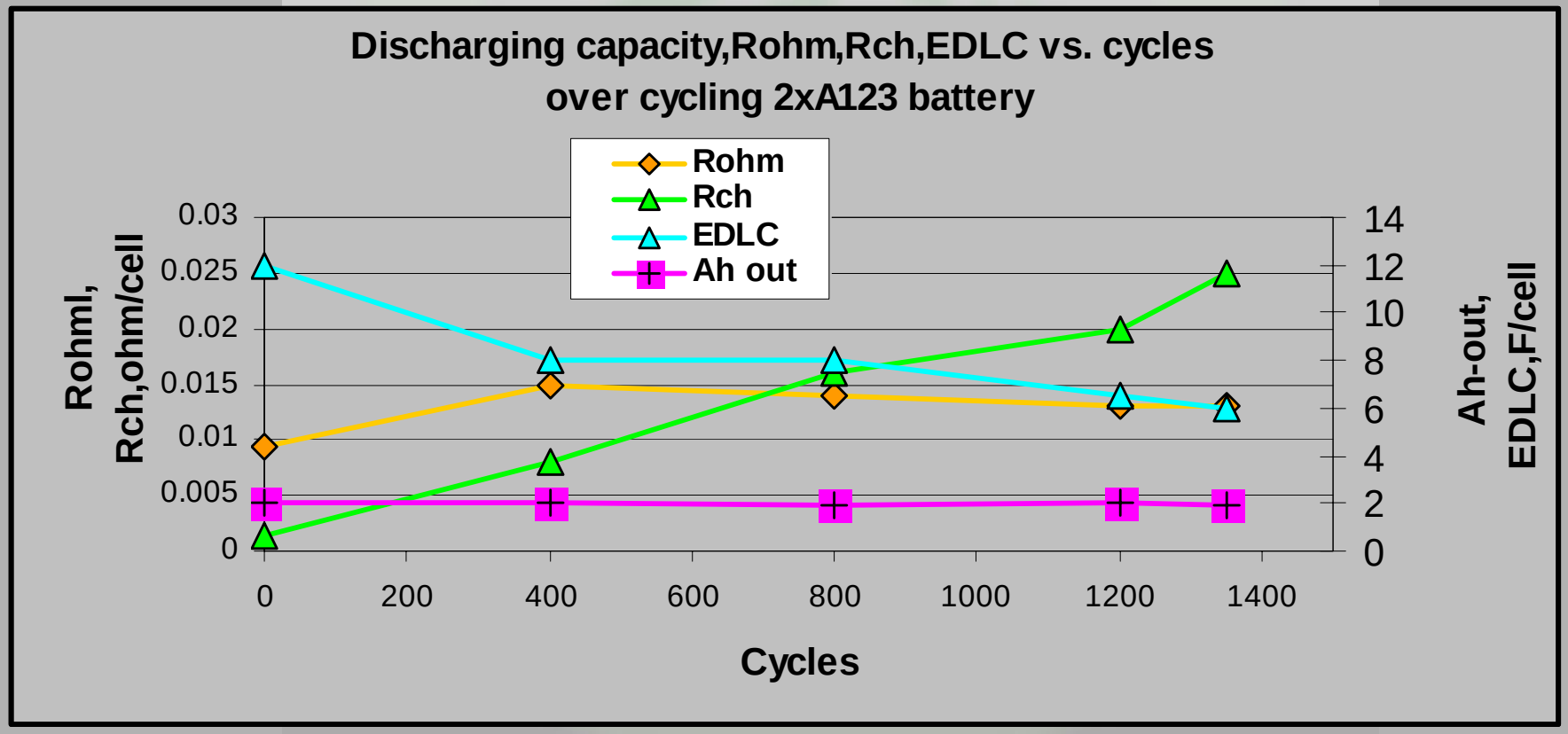


Battery prognostic tool: Li-cobaltoxide battery



Battery prognostic tool: Li-phosphate chemistry

A strong relationship exists between specific EDLC and cycle number



Battery prognostic tool: EDLC measurements

- *Advantage of EDLC as a prognostic parameter is that it is almost independent from temperature*
- *Ability to recognize degradation in one cell of multicell battery string.*
- *Terminal EDLC for N cells in a multicell battery is equal to:*

$$C=(C_1 x C_2 x \ldots\ldots x\ C_{n-1} x\ C_N) / \sum_{1}^{N} C_1 x C_2 x .. x C_{N-1}.$$

- *While EDLC of an individual cell is present in the expression as a factor, variation in EDLC of any cell will affect the terminal EDLC value.*

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