Unit - I
1.5 Batteries

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Syllabus

UNIT – I **10 Periods**

Introduction and Basic Concepts: Concept of Potential difference, voltage, current - Fundamental linear passive and active elements to their functional current-voltage relation - Terminology and symbols in order to describe electric networks - Concept of work, power, energy and conversion of energy- Principle of batteries and application.
Principles of Electrostatics: Electrostatic field - electric field intensity - electric field strength - absolute permittivity - relative permittivity - capacitor composite – dielectric capacitors - capacitors in series & parallel - energy stored in capacitors - charging and discharging of capacitors.

Lead-acid

Battery
- → Electrode → Solid-state battery
- → Electrolyte → ceramics

3.3V ~ 0.1V

Li-ion → ✓
- → Na-ion
- Fe-ion
- Metal-air

Outline

- Why is this important?
- Terminologies
- Brief history of batteries
- Basic chemistry
- Battery types and characteristics

Battery terminology

- **Cells** are the smallest individual electrochemical unit, and deliver a voltage that depends on the cell chemistry
  - There are primary (single use) and secondary (rechargeable) cells
  - A cell is different from a battery, but many people (including me at times!) use the term “battery” to describe any electrochemical energy source, even if it is a single cell, and this can lead to confusion

Battery terminology

- **Batteries** and battery packs are made up from groups of cells wired in series/parallel
  - These cells can be wired together in series, in parallel, or in some combination of both
  - Sometimes they are packaged in a single physical unit
  - For example, automotive 12 V lead-acid batteries comprise six 2 V cells in series
  - Other times, the connections are external to the cells

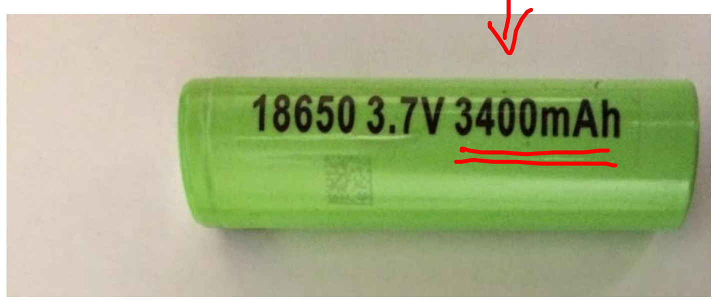
- **Cell (nominal) capacity** specifies the quantity of charge, in ampere hours (Ah) or milliampere hours (mAh), that the cell is rated to hold

↳ 3000 mAh → 3Ah ←

C rate

20Ah → 20A → 1C
→ 2A C/10
→ 200 → 10

- The **C rate** is a relative measure of cell electrical current → 1C
- It is the constant-current charge or discharge rate that the cell can sustain for one hour
- A 20 Ah cell should be able to deliver 20 A ("1C") for 1 h or 2 A ("C/10") for about 10h
- If the cell is discharged at a 10C rate, it will be completely discharged in about six minutes
- Example: The 1C rate of the example to the right is 3.4A

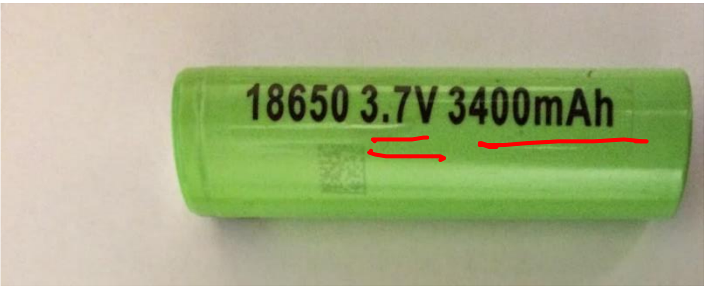


Energy and Power

- A cell stores energy in electrochemical form, which it can later release to do work

$V \times Ah$

- The total energy storage capacity of a cell is roughly its nominal voltage multiplied by its nominal capacity (mWh, Wh, or kWh)
- Example: The nominal energy storage capacity of the example is $3.7\ V \times 3.4\ Ah = 12.58\ Wh$



Mobile battery → Lifetime

→ 10,000 cycles

~~Charging~~

charging cycle → 1 charge + 1 discharge

10% – 90%

90% – 10%

10% – 14% → 11% – 9%

Cells connected in series

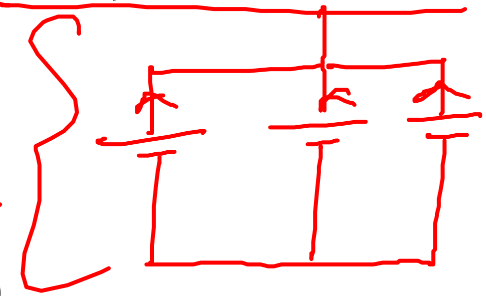
- When cells are connected in series, the battery voltage is the sum of the individual cell voltages
- However, battery capacity is equal to individual cell capacity since the same electrical current passes through all of the cells (charging and discharging all cells at the same rate)
- Example: A battery constructed from three 3 V, 20 Ah cells in series will have:
- A nominal voltage of $3 \times 3V = 9V$
- A nominal capacity of $1 \times 20\ Ah = 20\ Ah$
- A nominal energy capacity of $3 \times 3V \times 20\ Ah = 180\ Wh$

Cells connected in parallel

- When cells are connected in parallel, the battery voltage is equal to the cells' voltage
- However, battery capacity is the sum of the cells' capacities, since the battery current is the sum of all the cell currents

2V, 3V, 5V | 10V
10Ah 20Ah 30Ah → 10Ah

- Example: A battery constructed from three 3 V, 20 Ah cells in parallel will have:
- A nominal voltage of $3 \times 3V = 3V$
- A nominal capacity of $3 \times 20\ Ah = 60\ Ah$
- A nominal energy capacity of $3 \times 3V\ \times 20\ Ah = \boxed{180\ Wh}$



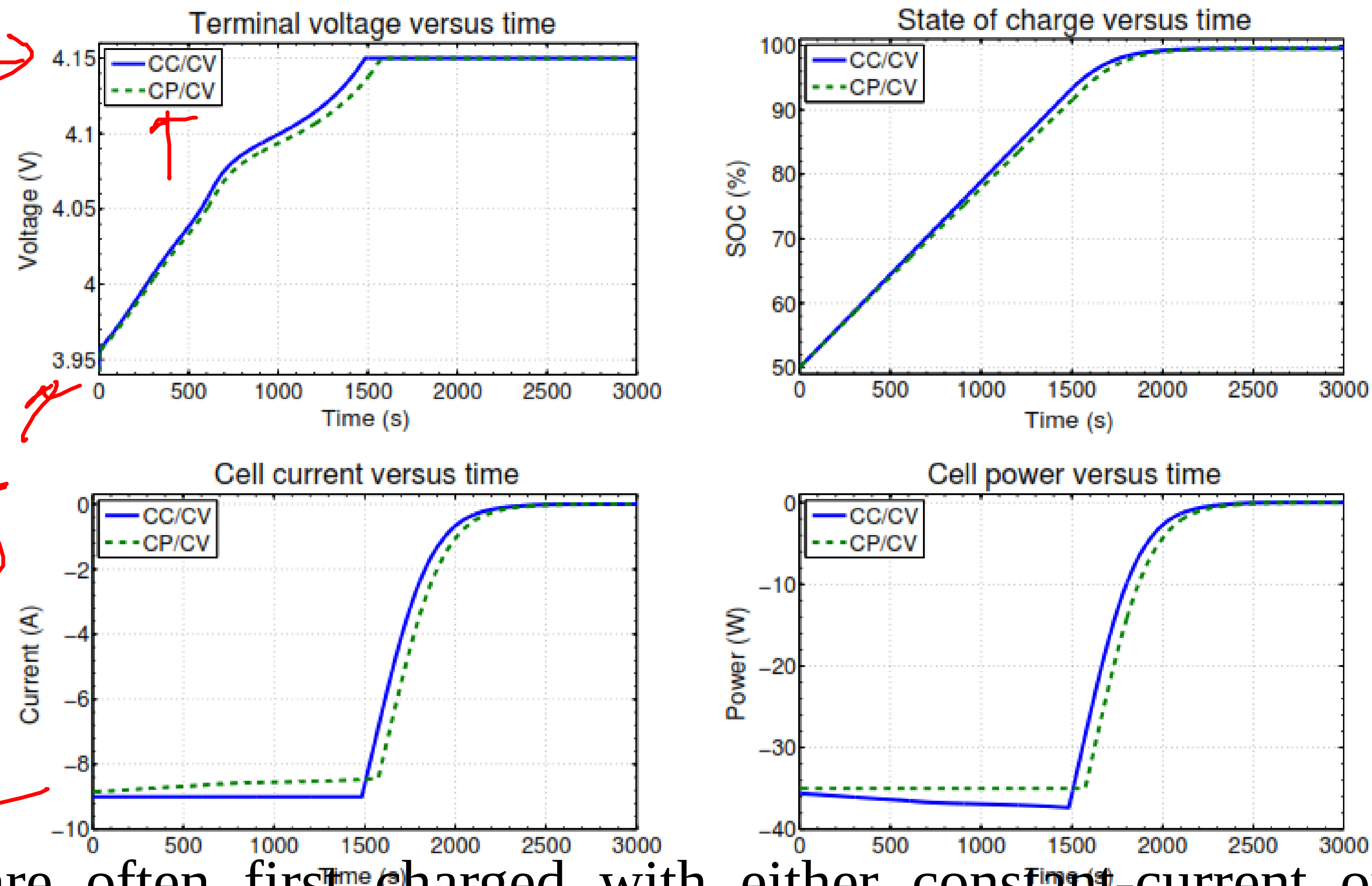
Battery Charging

CC

0% → 90%

CV

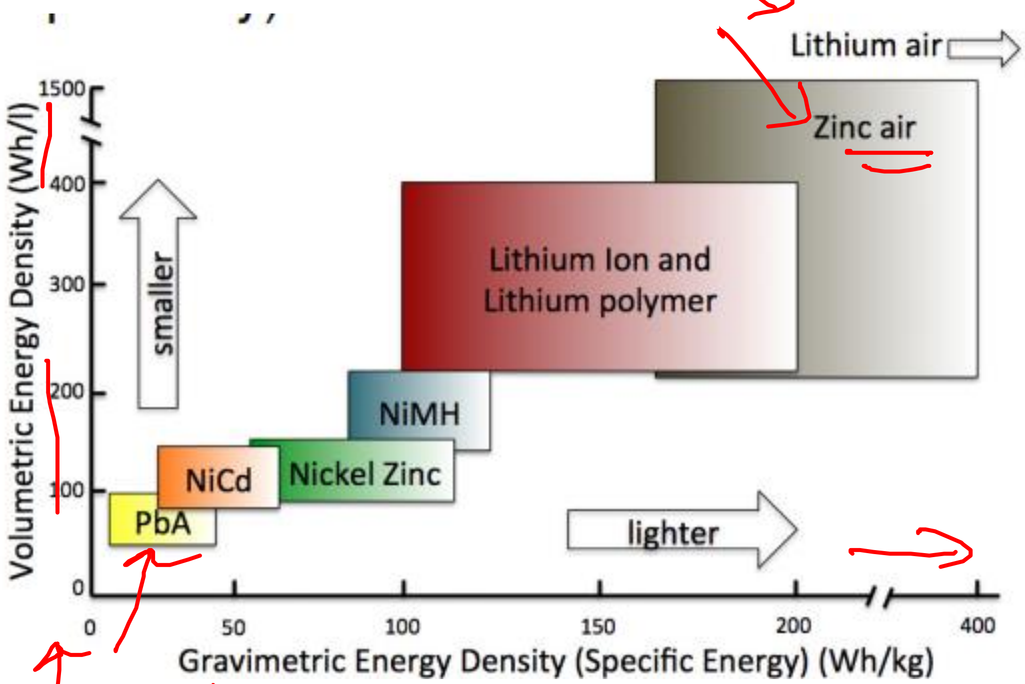
Trickle charging



- Cells are often first charged with either constant-current or constant-power
- When maximum permitted cell voltage is reached, the cell is held at that voltage until it is fully charged

Specific energy and energy density

- Specific energy and energy density measure the maximum stored energy per unit weight or volume (respectively)
- For a given weight, higher specific energy stores more energy
- For a given storage capacity, higher specific energy cells are lighter
- For a given volume, higher energy density stores more energy
- For a given storage capacity, higher energy density cells are smaller



Battery History

1800	Voltaic pile: silver zinc
1836	Daniell cell: copper zinc
1946	Neumann: sealed NiCd
1960s	Alkaline, rechargeable NiCd
1970s	Lithium, sealed lead acid
1991	Lithium ion → 1000 $ / kwh → 100 $ / kwh
1992	Rechargeable alkaline
1999	Lithium ion polymer

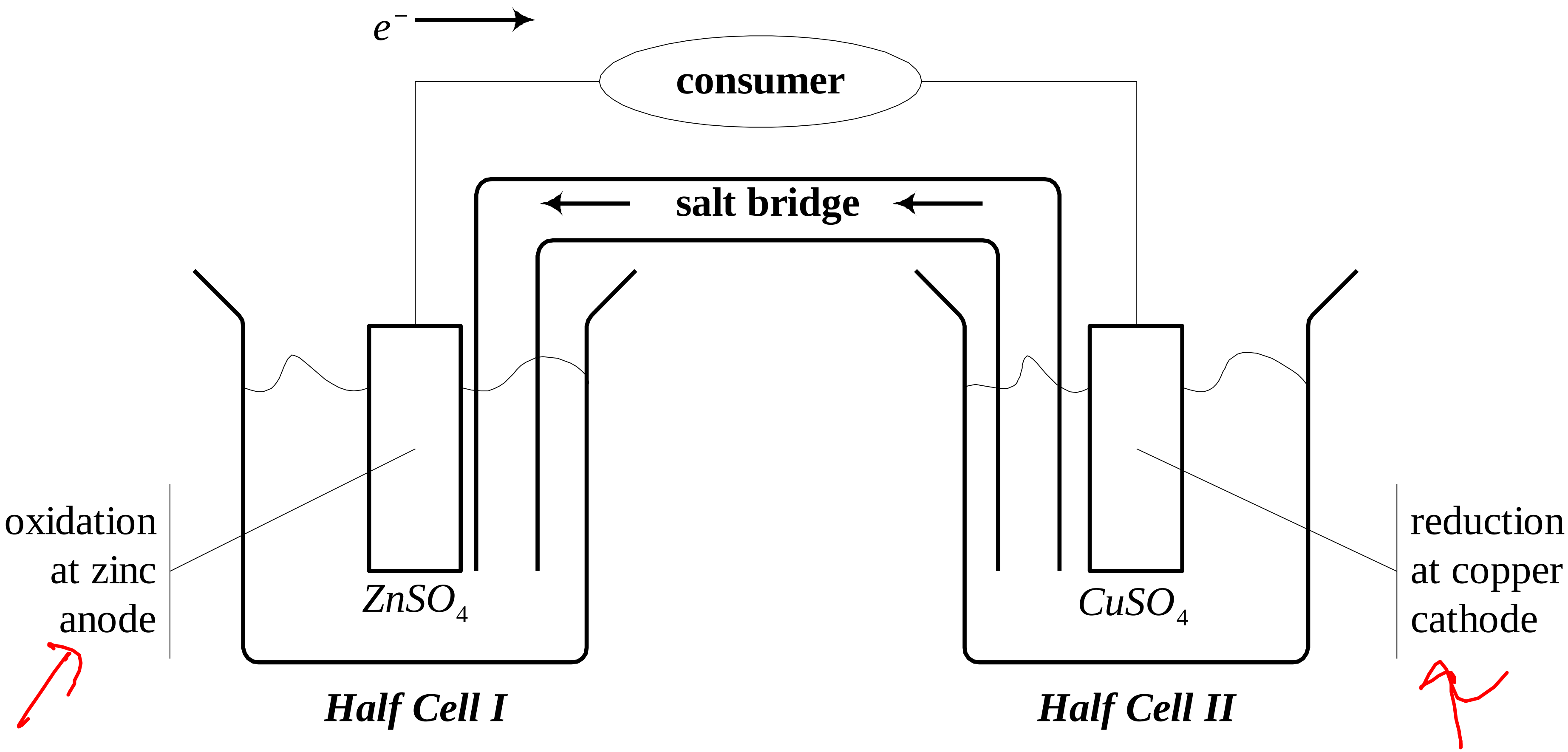
Battery Nomenclature

Duracell batteries — 9v battery — 6v dry cell

Two cells — **A real battery** — **Another battery**

More precisely

The Electrochemical Cell



The Electrochemical Series

Most wants to **R**educe (**RIG**) (**G**ain electrons)

- Gold
- Mercury
- Silver
- Copper
- Lead
- Nickel
- Cadmium

But, there's a reason it's a *sodium* drop

- Iron
- Zinc
- Aluminum
- Magnesium
- Sodium
- Potassium
- ***Lithium***

Most wants to **O**xidize (**L**ose electrons)(**OIL**)

Battery Characteristics

- Size
  - Physical: button, AAA, AA, C, D, ...
  - Energy density (watts per kg or cm^3)
- Longevity
  - Capacity (Ah, for drain of C/10 at 20°C)
  - Number of recharge cycles
- Discharge characteristics (voltage drop)

Primary (Disposable) Batteries

- Zinc carbon (flashlights, toys)
- Heavy duty zinc chloride (radios, recorders)
- Alkaline (all of the above)
- Lithium (photoflash)
- Silver, mercury oxide (hearing aid, watches)
- Zinc air

Secondary (Rechargeable) Batteries

- Nickel cadmium
- Nickel metal hydride
- Alkaline
- Lithium ion
- Lithium ion polymer
- Lead acid

Lead Acid Batteries

- Chemistry

  Lead

  Sulfuric acid electrolyte

- Features

  + Least expensive

  + Durable

  – Low energy density

  – Toxic

Lithium Ion Batteries

- Chemistry

  Graphite (-), cobalt or manganese (+)

  Nonaqueous electrolyte

- Features

  \+ 40% more capacity than NiCd

  \+ Flat discharge (like NiCd)

  \+ Self-discharge 50% less than NiCd

  – Expensive

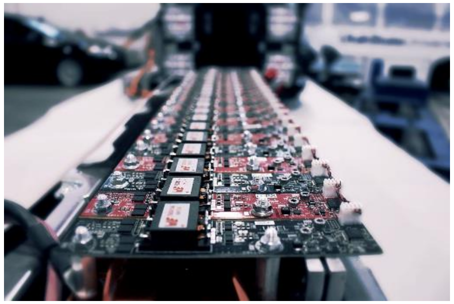
Lithium-ion Batteries in Gadgets

- Lithium: greatest electrochemical potential, lightest weight of all metals
  - But, Lithium metal is explosive
  - So, use Lithium-{cobalt, manganese, nickel} dioxide
- Overcharging would convert lithium-*x* dioxide to metallic lithium, with risk of explosion

Battery Types

Battery Management Systems

- Comprises purpose-built electronics plus custom designed algorithms (computer methods)



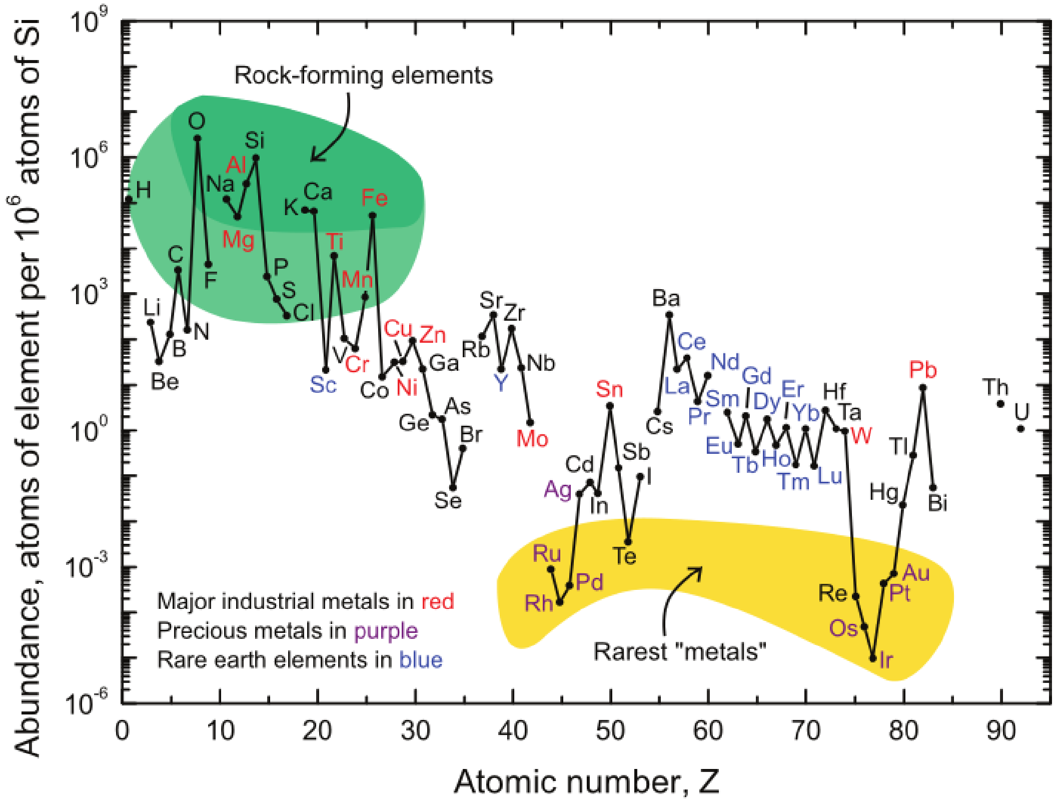
10%

0%

- Example: If a PbA battery is not maintained at a high state-of-charge, lead sulphate deposits on both electrodes will begin to form hard crystals, which cannot be reconverted by a standard fixed-voltage (13.6 V) battery charger.

Is lithium going to run out?

- Is there enough lithium for xEVs and other applications?
- Li is between 20 and 100 times more abundant than Pb and Ni



How much lithium is in a lithium-ion cell?

- The lithium content in a lithium-ion cell is actually quite small. Consider an LCO cell
- Lithium content in $LiCoO_2$ is only 7 % by weight
- Overall, total lithium content in high-energy cell ≤3 % by weight
- xEV cells weigh about $7kgkWh^{-1}$: 1 : Li content $\sim 0.2kgkWh^{-1}$
- 200-mile EV needs $\sim 60kWh$ battery: Li content $\sim 12kg\ /\ EV$
- 1 million EVs would consume ≤12000 tons of Li
  - Known available supply of Li is over 200 billion tons, including from seawater
  - Each human being presently alive could own more than 2000 EVs, without recycling!

Summary

Batteries

Terminologies

chemistry

- Batteries
  - Terminologies
  - Chemistry

References

- https://www.coursera.org/learn/battery-management-systems