TSTE26 Powergrid and technology for renewable production

Lecture 9
Energy storage

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Outline

- Stand-alone systems
- Battery technology and conditions
- Converter setup
- Application examples

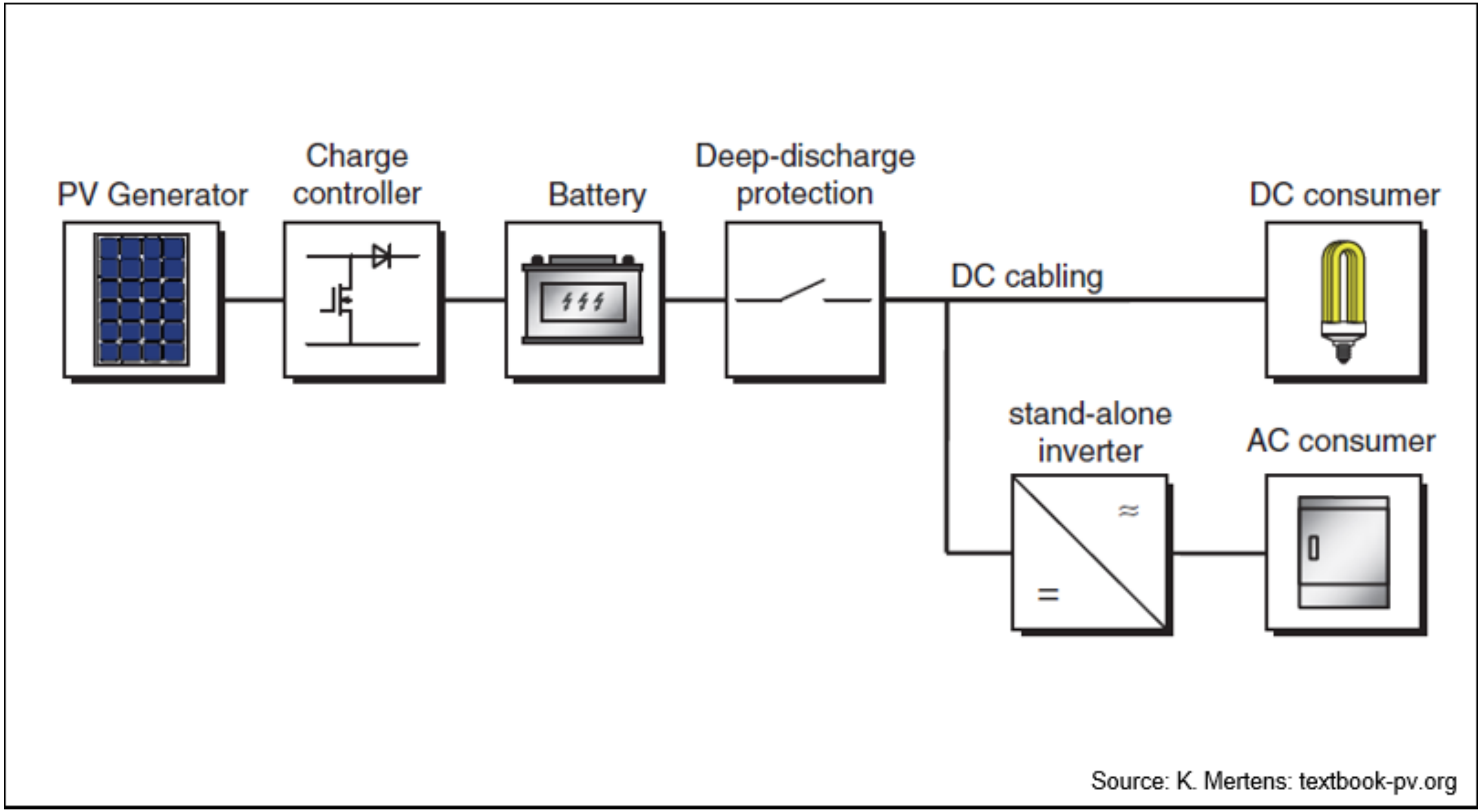
Photovoltaics: Fundamentals, Technology and Practice, Mertens, Konrad, Hanser, Karl Friedrich, Wiley 2013 (Available as eBook at Liu library)

- Chapter 7.3 Stand-Alone Systems

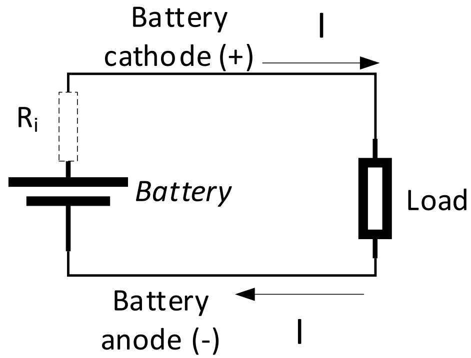
POTESTAS ET SCIENTIA SINCE 2003 BATTERY UNIVERSITY

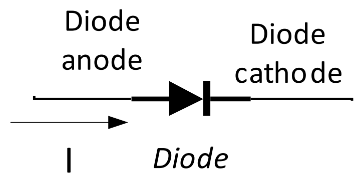
https://batteryuniversity.com

Standalone/Off-Grid system



Battery terminology 1





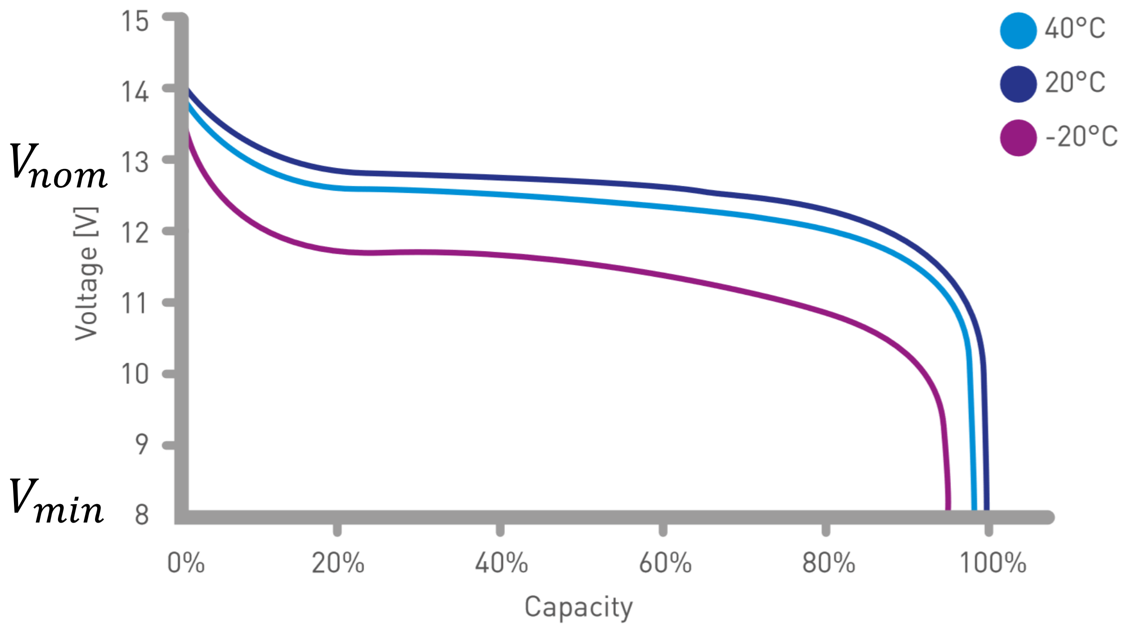
- **Cathode** – positive terminal, current exit on discharge
- **Anode** – negative terminal, current entry on discharge
- **Electrolyte** – Electrically conductive substance between the anode and cathode
- **Voltage** – V_{oc}, open circuit
- **Internal resistance, R_i** -
- **Capacity** [Ah] – Total stored charge

Battery terminology 2

- **Capacity, C** [Ah] – Total stored charge. Discharge current over time

$$C = \int_{t(V_{nom})}^{t(V_{min})} I dt$$

$$E_{nom} = C \cdot V_{nom}$$



- **Energy capacity, E_{nom} [J, Wh, kWh]**

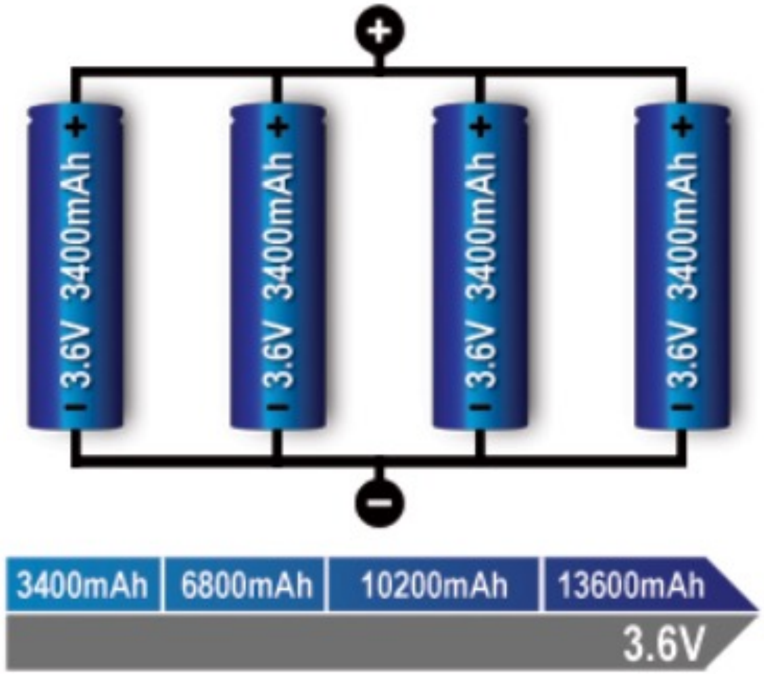
Battery cells in series & parallel

Series

Voltage increase at constant current capacity

Parallel

Increasing current capacity at constant voltage



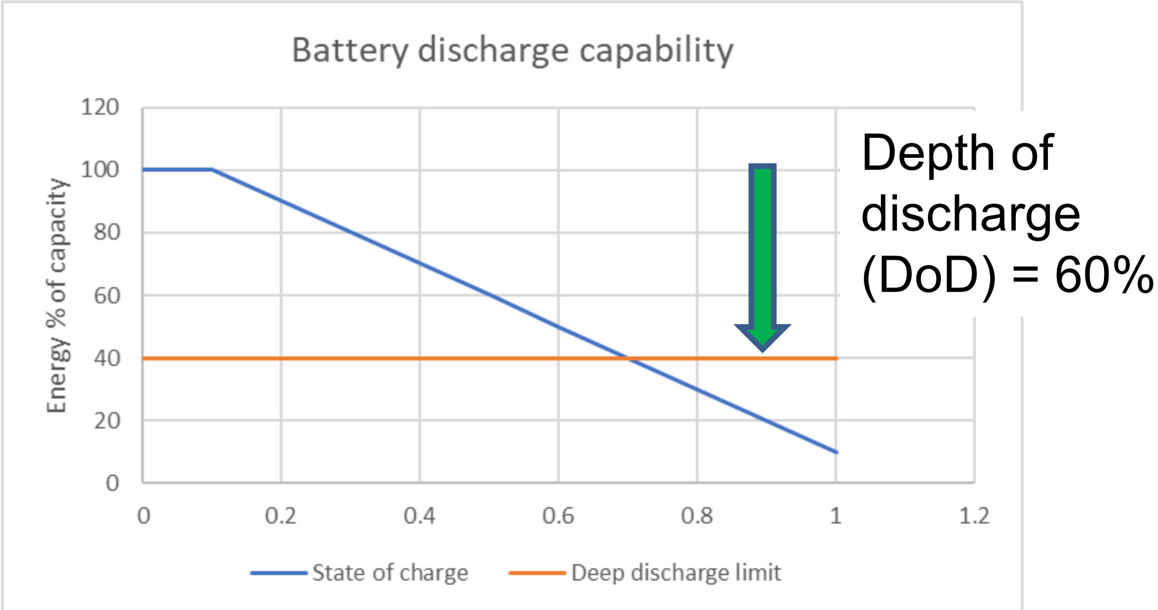
Battery terminology 3

- **C-rate** – Normalized discharge/Charge current
- $C - rate = \frac{Current\ [A]}{Capacity\ [Ah]}$
- 1C - Current in A = Capacity
- Example: Capacity 100 Ah

C-rate	Current	Time
2C	200 A	0.5 h
1C	100 A	1 h
0.5C	50 A	2 h
0.2C	20 A	5 h

State-of-Charge & Depth-of-discharge

$$DoD = SoC_{max} - SoC_{min}$$



State of charge, SoC – Battery charge level

Max stored charge of a battery : SoC_{max} = 100%

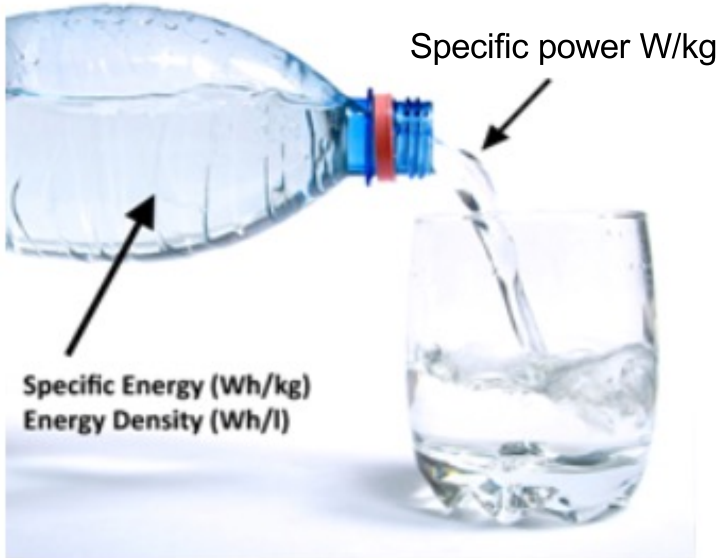
Lowest discharge level without reduced lifetime:

Lead-Acid example: SoC_{min} = 40%

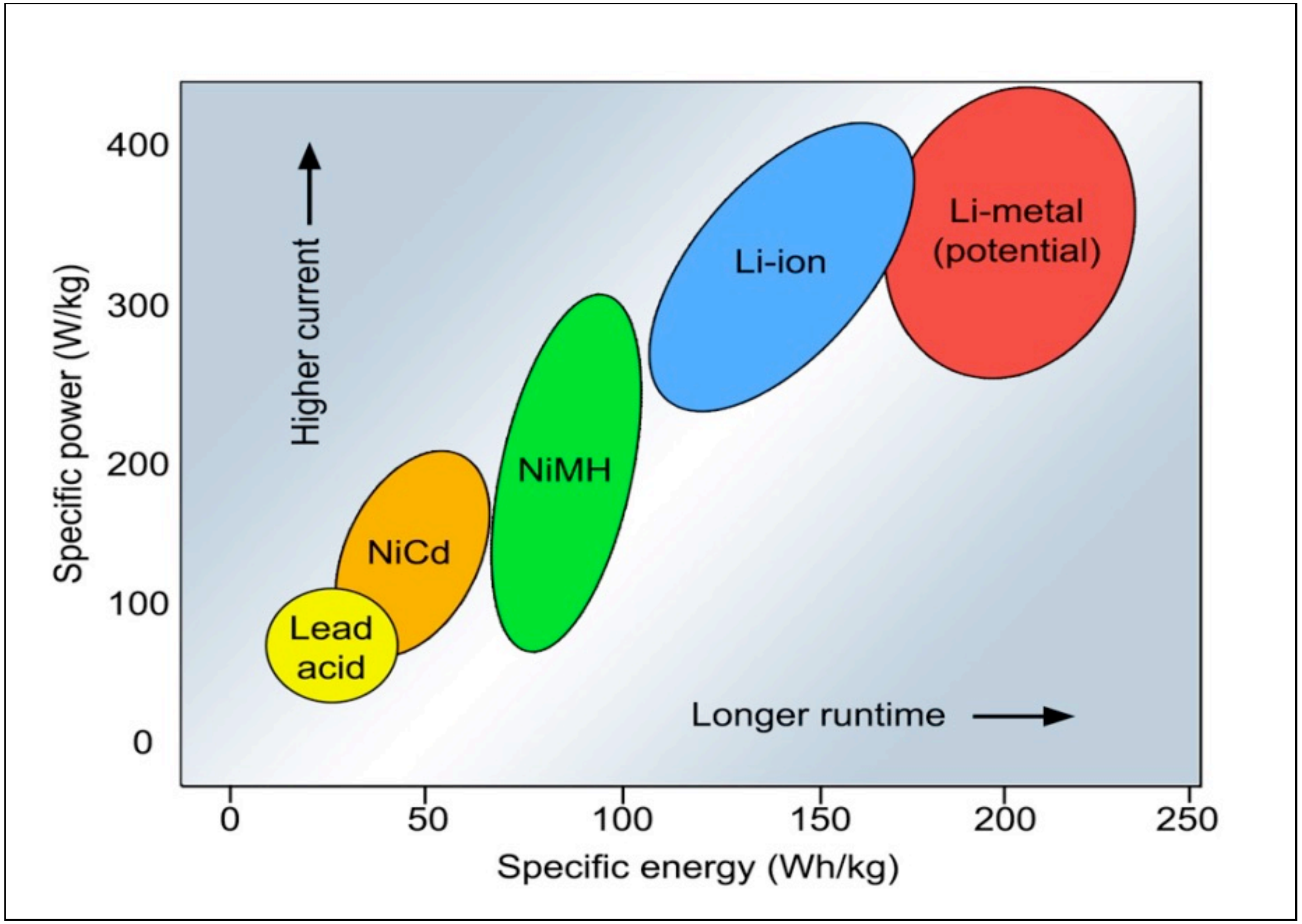
Depth of discharge: DoD = SoC_{max} - SoC_{min} = 60%

Battery terminology 4

- **Specific Energy** [Wh/kg] – Energy capacity per weight
- **Energy density** [Wh/l] – Energy capacity per volume
- **Specific power** [W/kg] – Loading capability



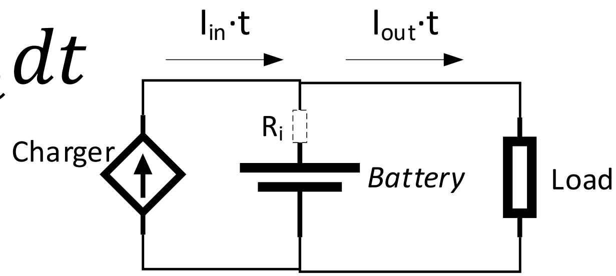
Battery capabilities: Power and Energy



Battery terminology 5

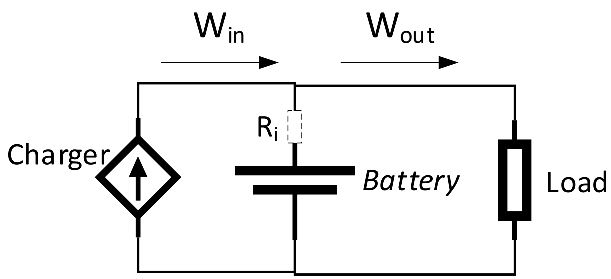
- **Coulombic efficiency** (Faradaic efficiency) (>99%)

$$\frac{Charge\ out}{Charge\ in} = {\int I_{out}dt} \Big/ {\int I_{in}dt}$$



- **Energy efficiency** (90-95%)

$$\frac{Energy\ out}{Energy\ in} = W_{out} / W_{in}$$

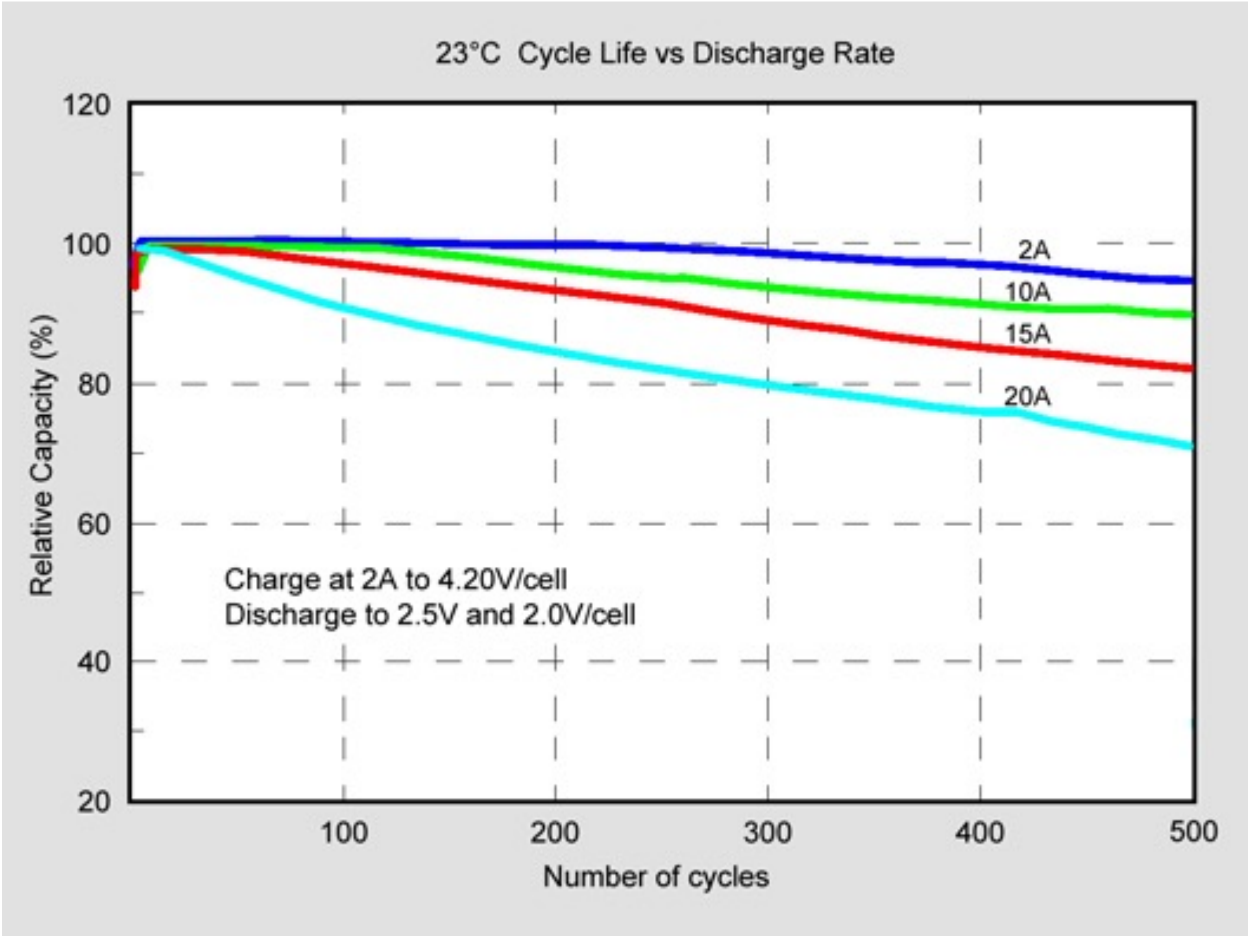


Cycle life, State-of-health SoH

- Capacity, the ability to store energy
  - Capacity reduction over time/cycles
- Internal resistance, the capability to deliver power
- Internal resistance increase over time/cycles and at low temperature
- Self-discharge, internal leakage

Battery type	Self-discharge per month
Lead-Acid	4% to 6%
NiCd	15% to 30%
NiMH	30%
Lithium	2% to 3%

Lithium-Ion cycle life



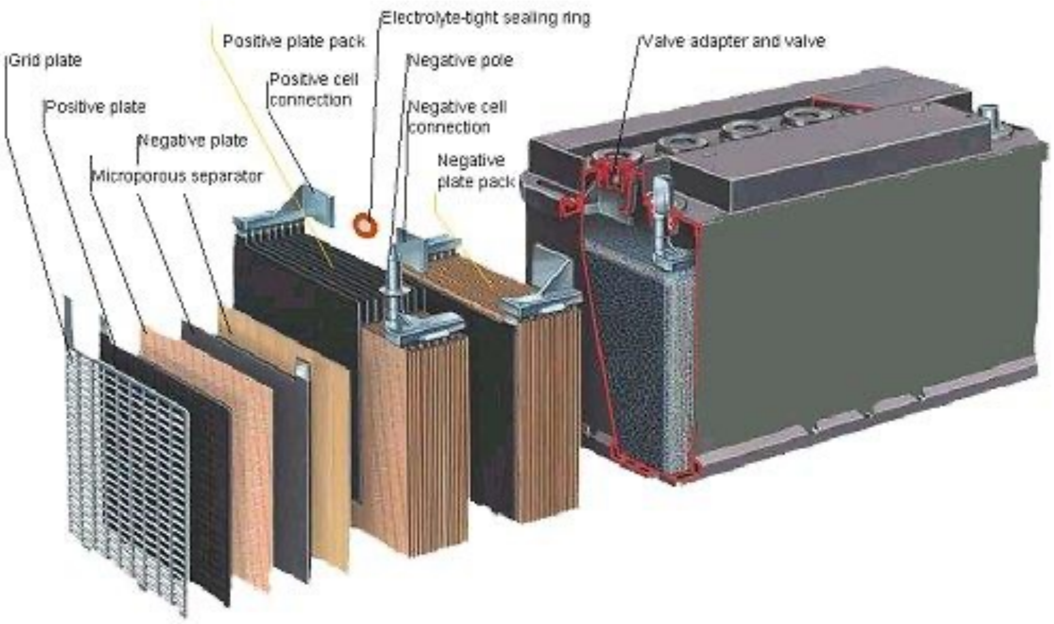
SoH = Relative capacity

Lead-Acid Battery

- One of the oldest rechargeable batteries
- Rugged, forgiving if abused, safe, low price
- Usable over a large temperature range

- Has low specific energy
- Limited cycle life, does not like full discharges
- Must be stored with sufficient charge
- Produces gases,
  needs ventilation

Vehicles, boats, UPS, golf cars, forklift, wheelchairs,



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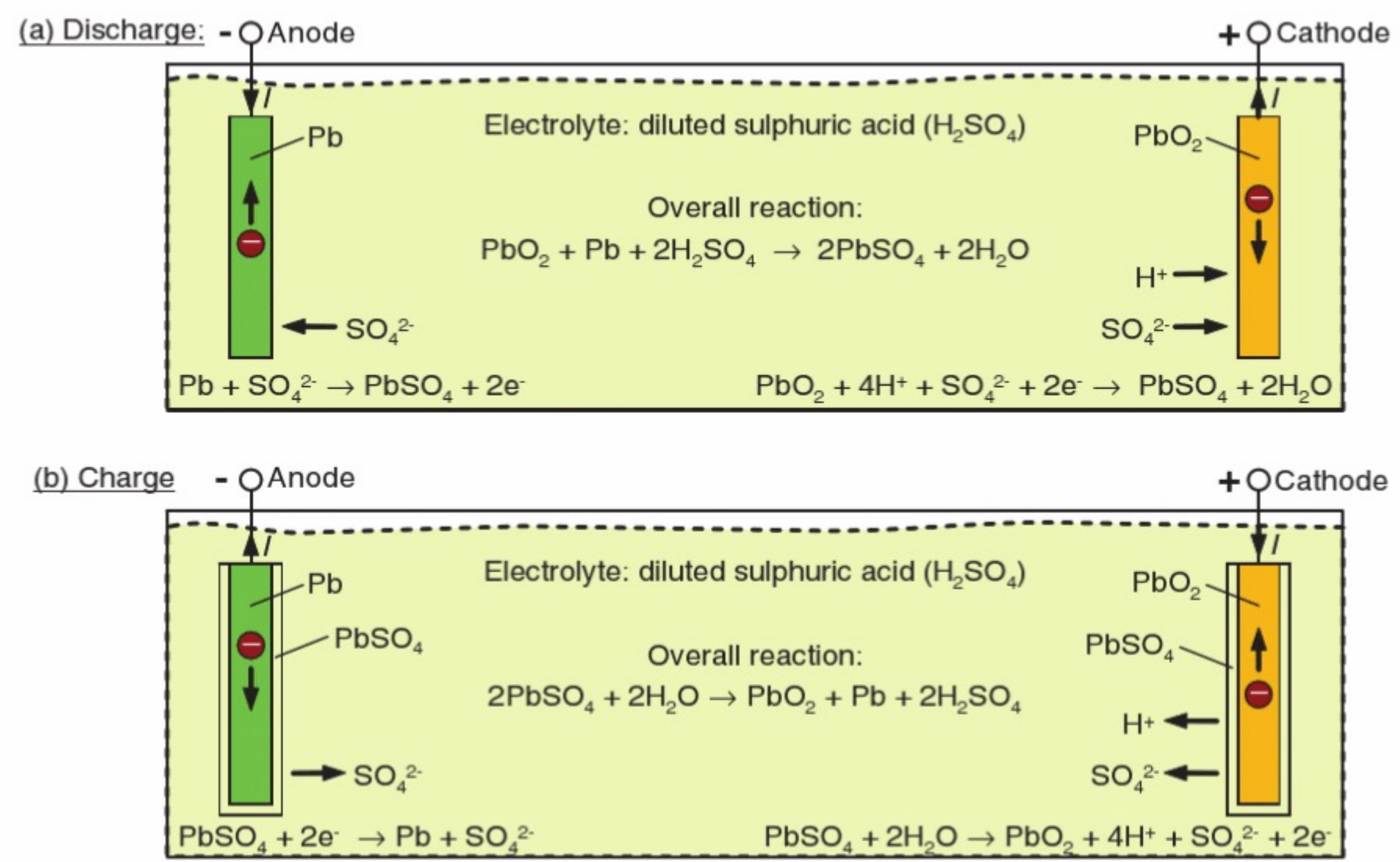
Chemical process in Lead-Acid



Types of Lead Acid Batteries

- **Flooded** (liquid electrolyte, needs water)
- **Gel** (electrolyte in gelled, maintenance free)
- **AGM** (absorbent glass mat, maintenance free)

Depth of discharge	Starter battery	Deep-cycle battery
100%	12 – 15 cycles	150 – 200 cycles
50%	100 – 120 cycles	400 – 500 cycles
30%	130 – 150 cycles	1,000 and more

Battery types

Nickel-cadmium (NiCd)

- Rugged, durable, good cold temperature performance
- Cadmium is toxic, prohibited in consumer products

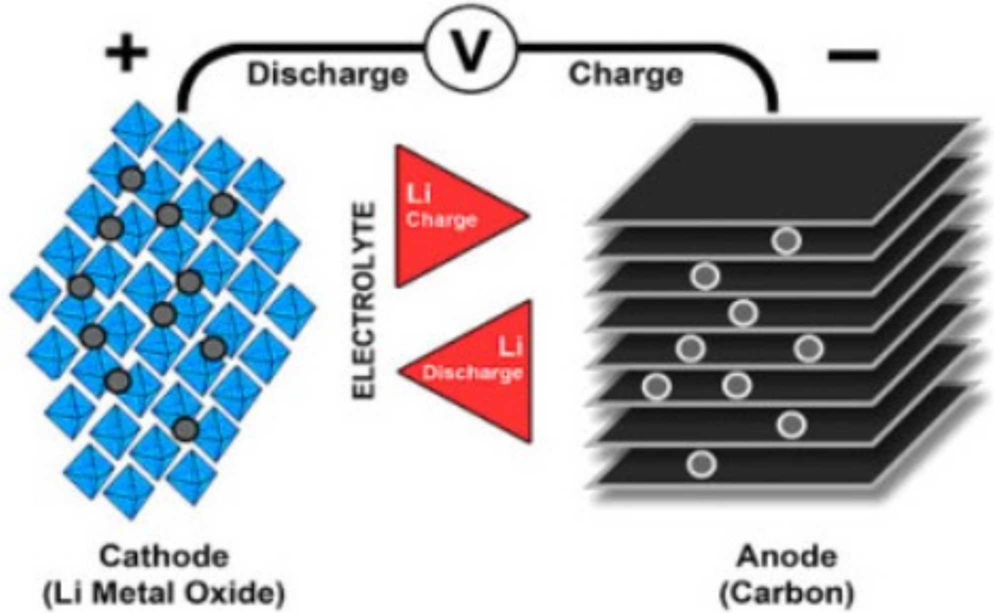
Aircraft main battery, UPS in cold environments, vessels, vehicles needing high cycle life, power tools (not in consumer products)

Nickel-metal-hydride (NiMH)

- 40% higher specific energy than NiCd, mild toxicity
- Not as rugged as NiCd, more difficult to charge

Consumer products, hybrid vehicles; being replaced with Li-ion
Also available in AA and AAA cells

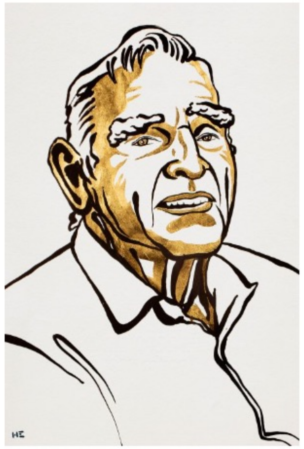
Lithium-Ion battery



Intercalation: Insertion of ions into material with layered structure

- Charging: Li^+ ions move from cathode to anode
- Discharging: Li^+ ions move from anode to cathode

Nobel prize in chemistry 2019



Ill. Niklas Elmehed. © Nobel Media.
John B. Goodenough
Prize share: 1/3

Ill. Niklas Elmehed. © Nobel Media.
M. Stanley Whittingham
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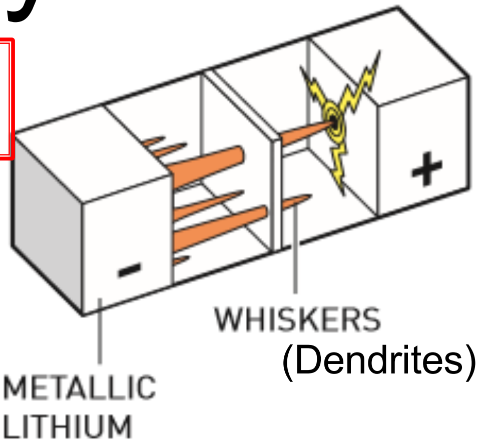
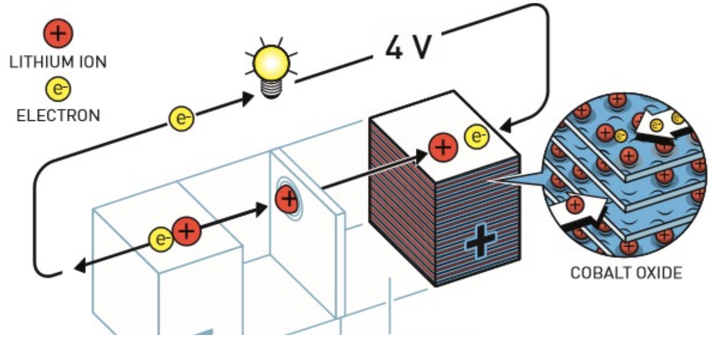
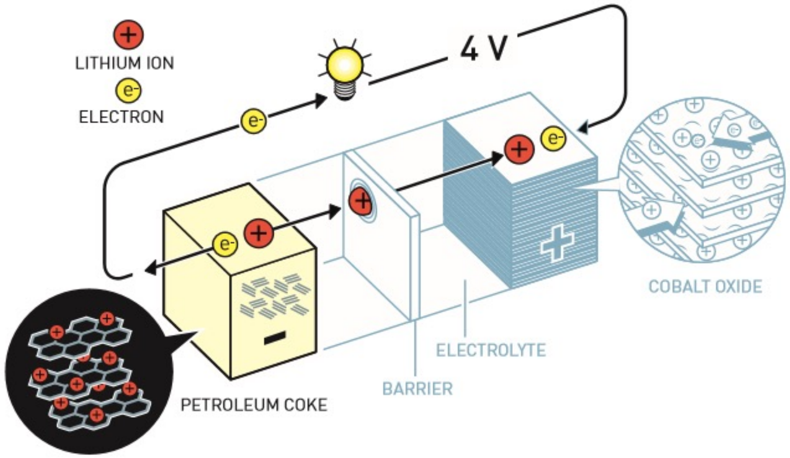
Original design







Whittingham: Intercalation
Goodenough: Li-cathode
Yoshino: Carbon anode

Lithium cell types: Cylindrical

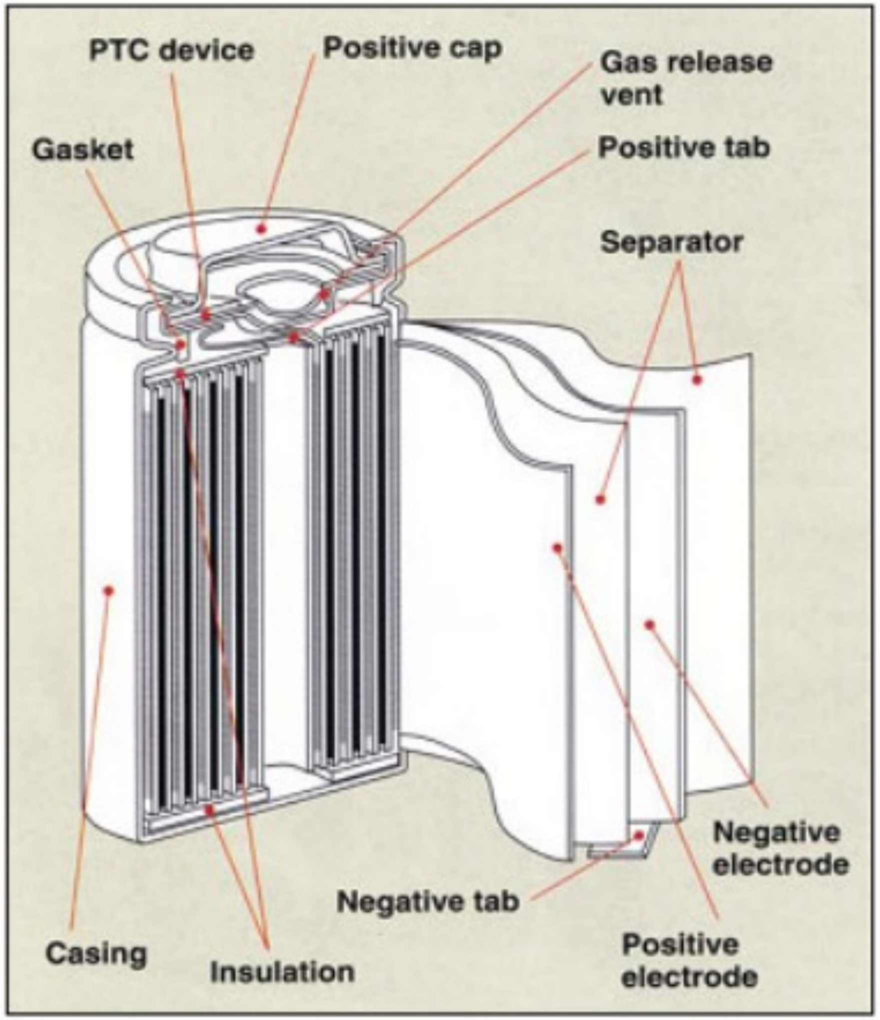


Figure 2: Cross section of a lithium-ion cylindrical cell

The cylindrical cell design has good cycling ability, offers a long calendar life, is economical but is heavy and has low packaging density due to space cavities.

Courtesy of Sanyo

Lithium cell types: Prismatic

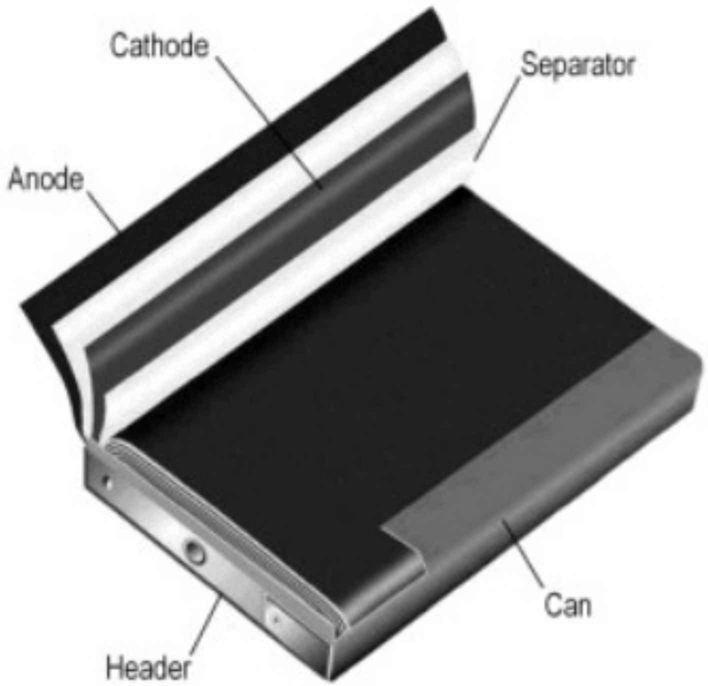


Figure 6: Cross section of a prismatic cell

The prismatic cell improves space utilization and allows flexible design but it can be more expensive to manufacture, less efficient in thermal management and have a shorter cycle life than the cylindrical design.

Courtesy of Polystor Corporation

Lithium cell types: Pouch

Figure 7: The pouch cell

The pouch cell offers a simple, flexible and lightweight solution to battery design. Exposure to high humidity and hot temperature can shorten service life.

Courtesy of Cadex

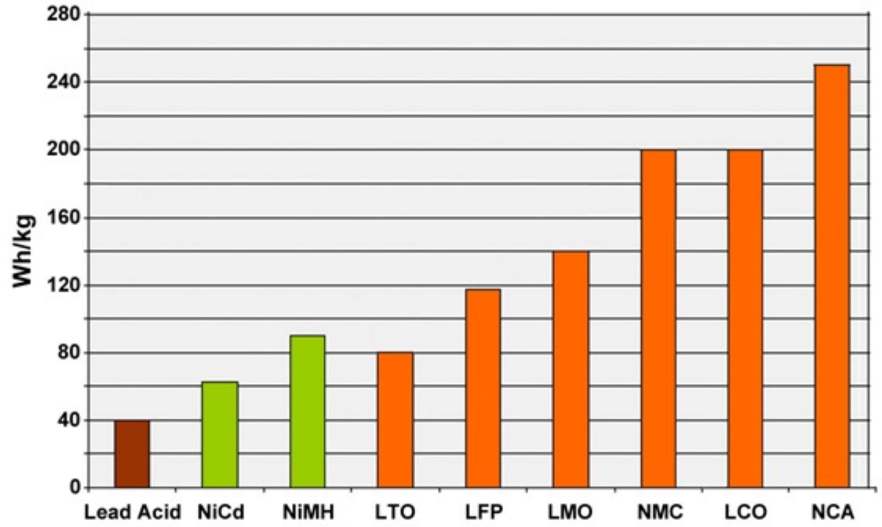
Cell voltages

Lead acid:	2 V/cell nominal
NiCd, NiMH:	1.20 V/cell
Li-ion:	3.6 V/cell
LiFePO4:	3.2 V/cell

Battery Chemistries and their Energy Densities

Battery chemistry

Chemical	Anode	Cathode	V	Wh/kg
Primary cells:				
Alkaline MnO_2	Zn	MnO_2	1.5	145
Li/FeS_2	Li	FeS_2(iron sulfide)	1.5	260
Secondary cells:				
Lead Acid	Pb	PbO_2	2	35-40
Nickel-cadmium	Cd	NiOOH	1.2	40-60
Nickel metal hydride	MH	NiOOH	1.2	60-120
Litium-ion (Li-ion)	Li_xC_6	$Li_{(1-x)}CoO_2$	3.6	100-265



MH - hydrogen-absorbent metal mixture

Lithium ion cell types

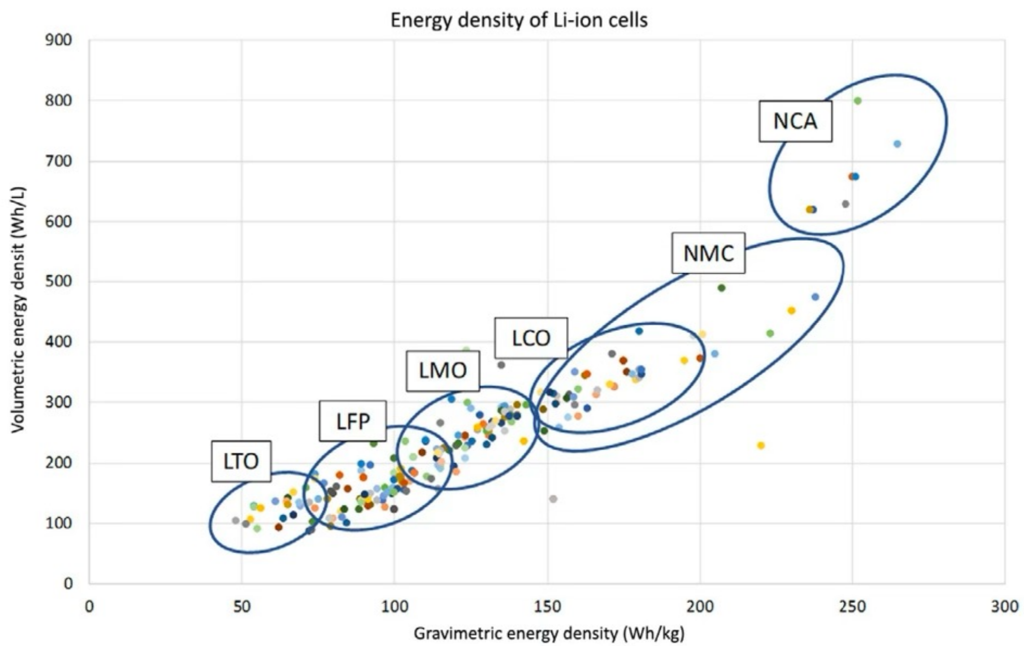


FIG. 48

Gravimetric and specific energy densities of lithium-ion cells.

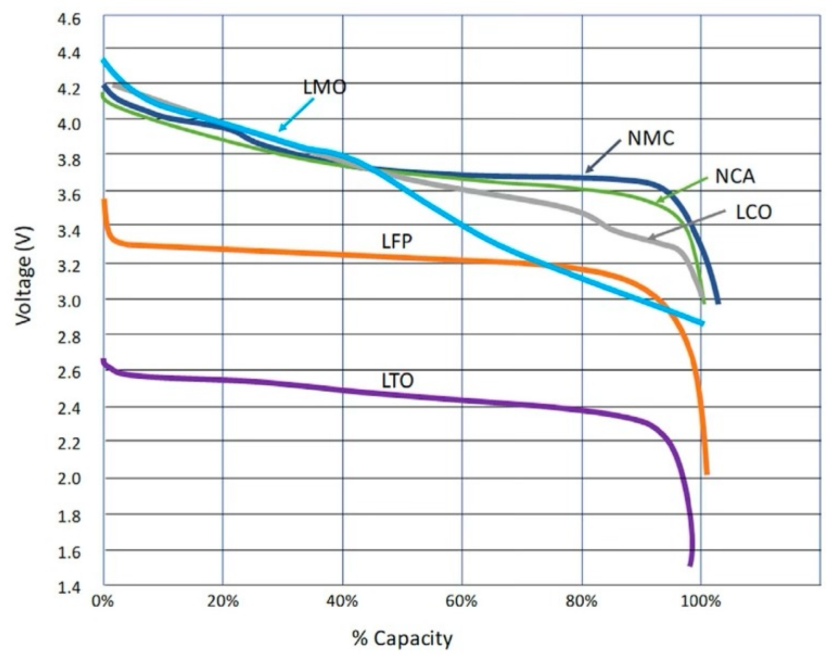


FIG. 44

Typical voltage discharge curves for different Li-ion chemistries.

Lithium Ion Cell Properties

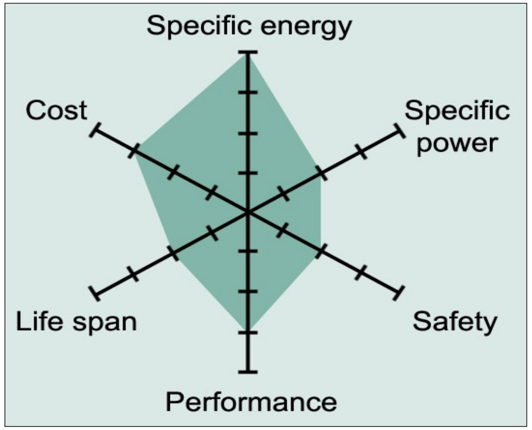
Table 3 Comparison of lithium-ion chemistries

	Lithium iron phosphate	**Lithium manganese oxide**	**Lithium titanium oxide**	**Lithium cobalt oxide**	**Lithium nickel cobalt aluminum**	**Lithium nickel manganese cobalt**
Chemistry descriptor	LFP	LMO	LTO	LCO	NCA	NMC
Specific energy (Wh/kg)	90–120	100–150	60–80	150–200	200–300	150–280
Energy density (Wh/L)	190–300	250–360	170–230	400–600	490–675	325
Specific power (W/kg)	4000	4000	1000	1000	1000	1000–4000
Power density (W/L)	10,000	10,000	2000	2000	2000	2000–10,000
Volts (per cell)	3.3 V	3.7 V	2.3 V	3.6 V	3.6 V	3.7 V
Cycle life	5000–6000	300–700	>15,000+	500–1000	500	3000–4000
Self-discharge (% per month)	<1%	5%	2–10%	1–5%	2–10%	1%
Operating temperature range	−20°C to +60°C	−20°C to +60°C	−30°C to +75°C	−20°C to +60°C	−20°C to +60° C	−20°C to +55°C

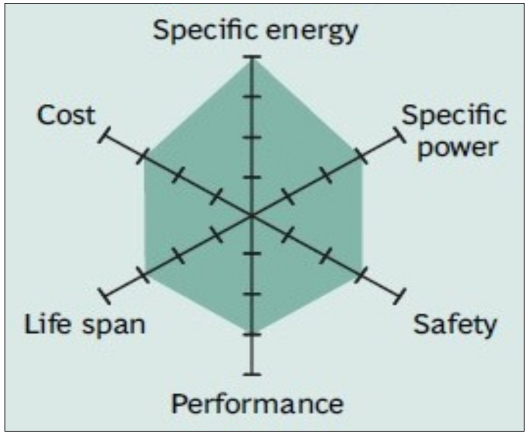
Based on Warner, J. T. (2015). The handbook of lithium-ion battery pack design: Chemistry, components, types and terminology. *Boston: Elsevier, p. 77.*

Lithium-Ion batteries

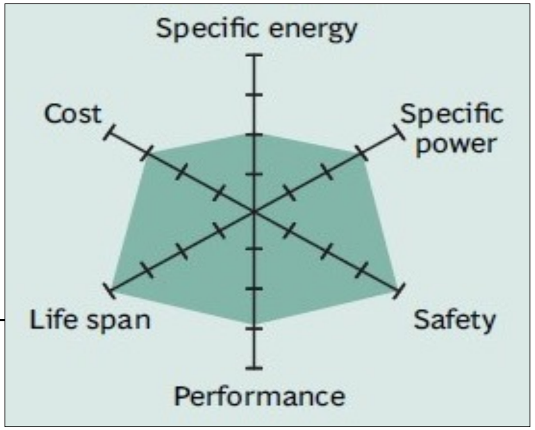
Li-cobalt (LiCoO2, LCO)
Available since 1991, replaces NiCd and NiMH. Lighter, longer runtimes.



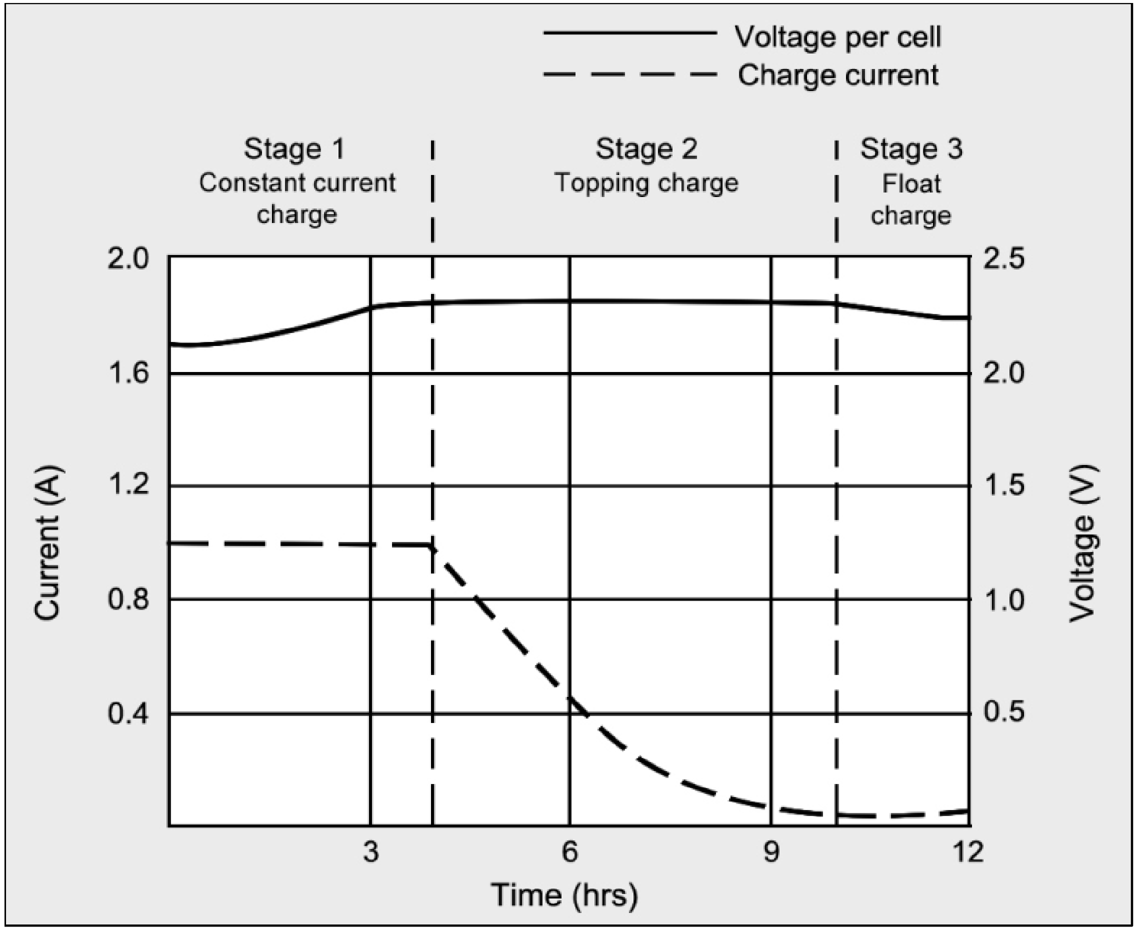
NMC (nickel-manganese-cobalt)
High specific energy. Power tools, medical instruments, e-bikes, EVs.



Li-phosphate (LiFePO4, LFP)
Long cycle life, enhanced safety but has lower specific energy. UPS, EVs

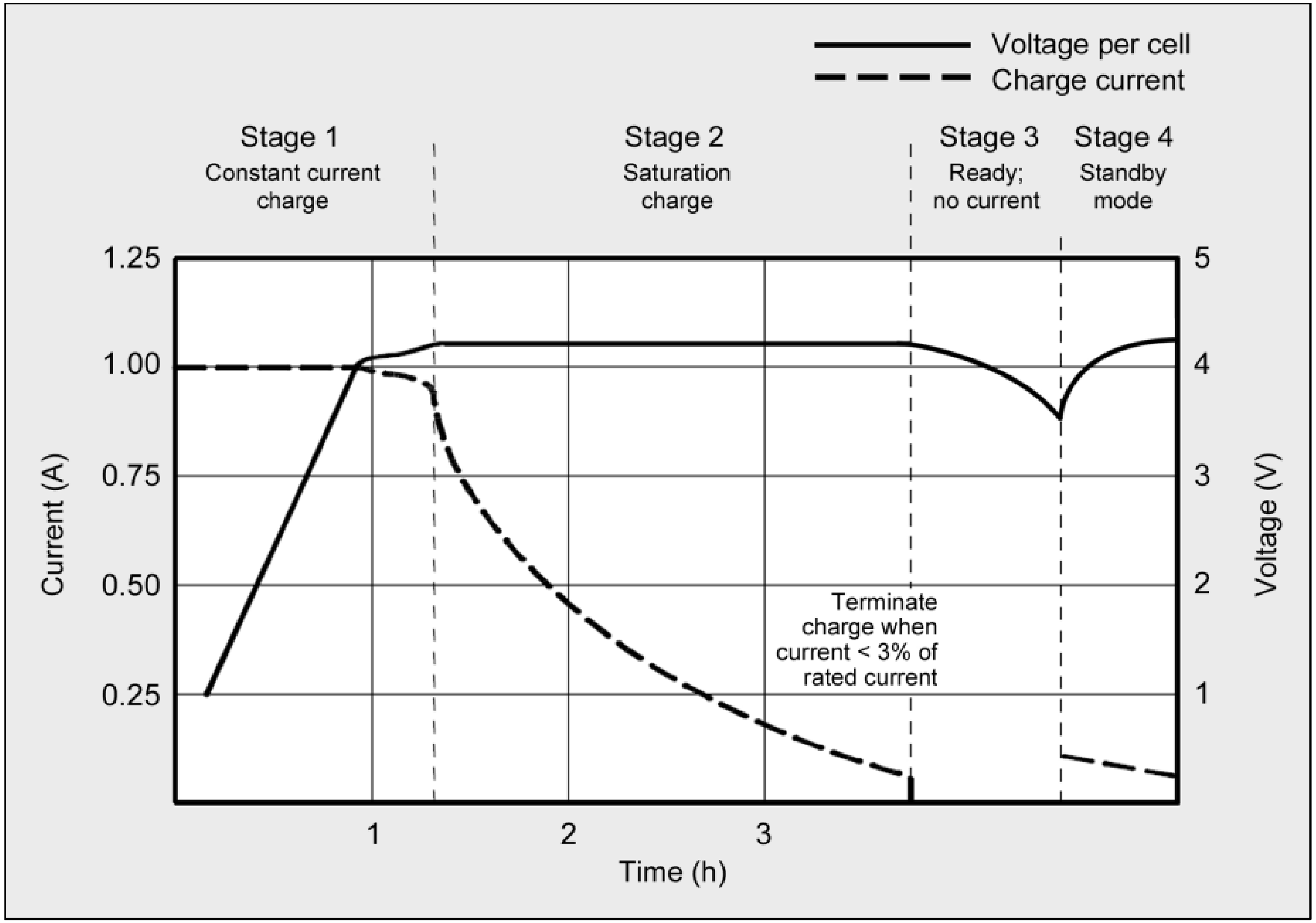


Lead-Acid battery charging



- Stage 1: Constant current until 2.40V/cell
- Stage 2: Topping charge, constant voltage of 2.4V/cell
- Stage 3: Constant voltage 2.25V/cell float charge (trickle-charge) compensates for self-discharge
- Over-charging causes corrosion, short life

Li-Ion battery charging



- Constant current charge to 4.20V/cell**(*)**
- Constant voltage until current < 3%
- Absolutely no trickle charge; cells must relax after charge
- Occasional topping charge allowed

(*) Max charge voltage dependent on cell type

Charge & Discharge vs temperature

Battery type	Charge temperature	Discharge temperature	Charge advisory
Lead acid	–20°C to 50°C (–4°F to 122°F)	–20°C to 50°C (–4°F to 122°F)	Charge at 0.3C or lessbelow freezing. Lower V-threshold by 3mV/°C when hot.
NiCd, NiMH	0°C to 45°C (32°F to 113°F)	–20°C to 65°C (–4°F to 149°F)	Charge at 0.1C between –18°C and 0°C. Charge at 0.3C between 0°C and 5°C. Charge acceptance at 45°C is 70%. Charge acceptance at 60°C is 45%.
Li-ion	0°C to 45°C (32°F to 113°F)	–20°C to 60°C (–4°F to 140°F)	No charge permitted below freezing. Good charge/discharge performance at higher temperature but shorter life.

Table 1: Permissible temperature limits for various batteries. Batteries can be discharged over a large temperature range, but the charge temperature is limited. For best results, charge between 10°C and 30°C (50°F and 86°F). Lower the charge current when cold.

Lithium cell capacity versus temperature

Internal resistance increase at low temperature

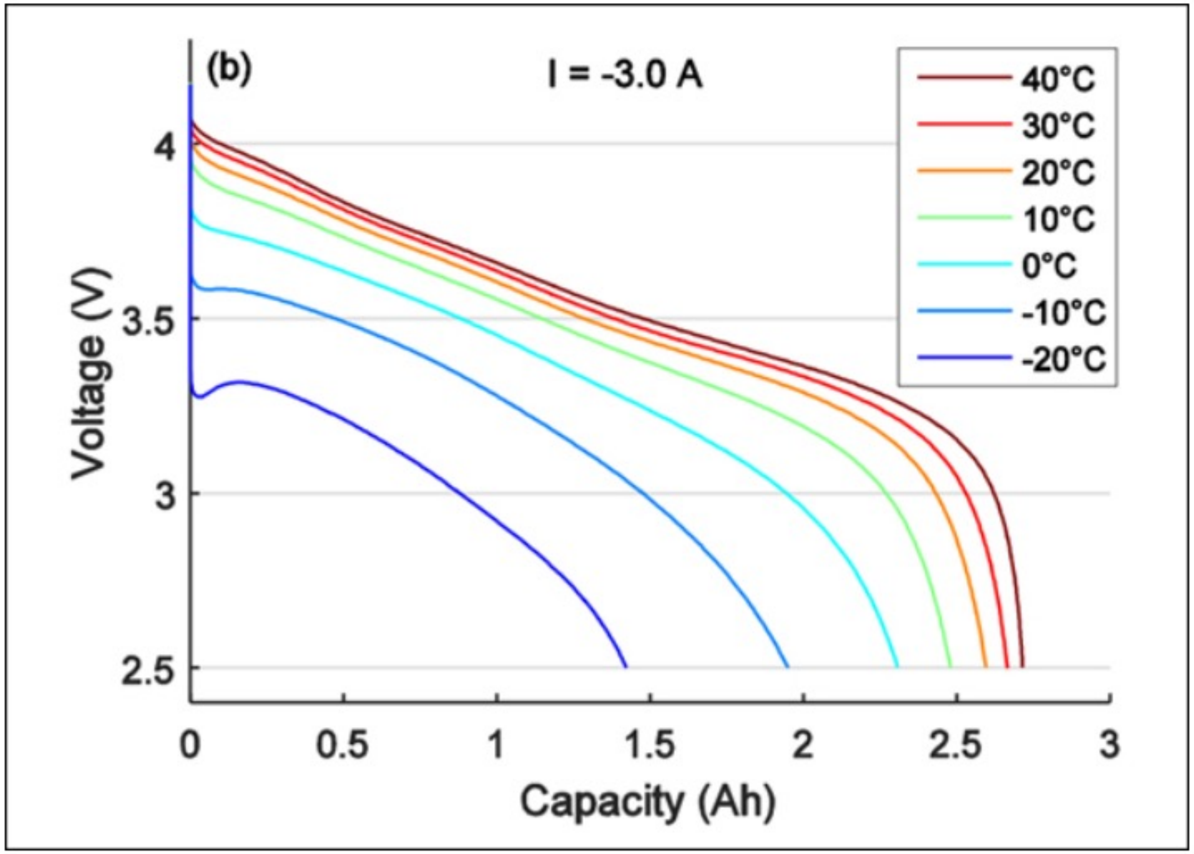


Figure 1: Discharge voltage of an 18650 Li-ion cell at 3A and various temperatures.
Cell type: Panasonic NRC18650PD, 2.8Ah nominal, LiNiCoAlO2 (NCA)
Source: Technische Universität München (TUM)

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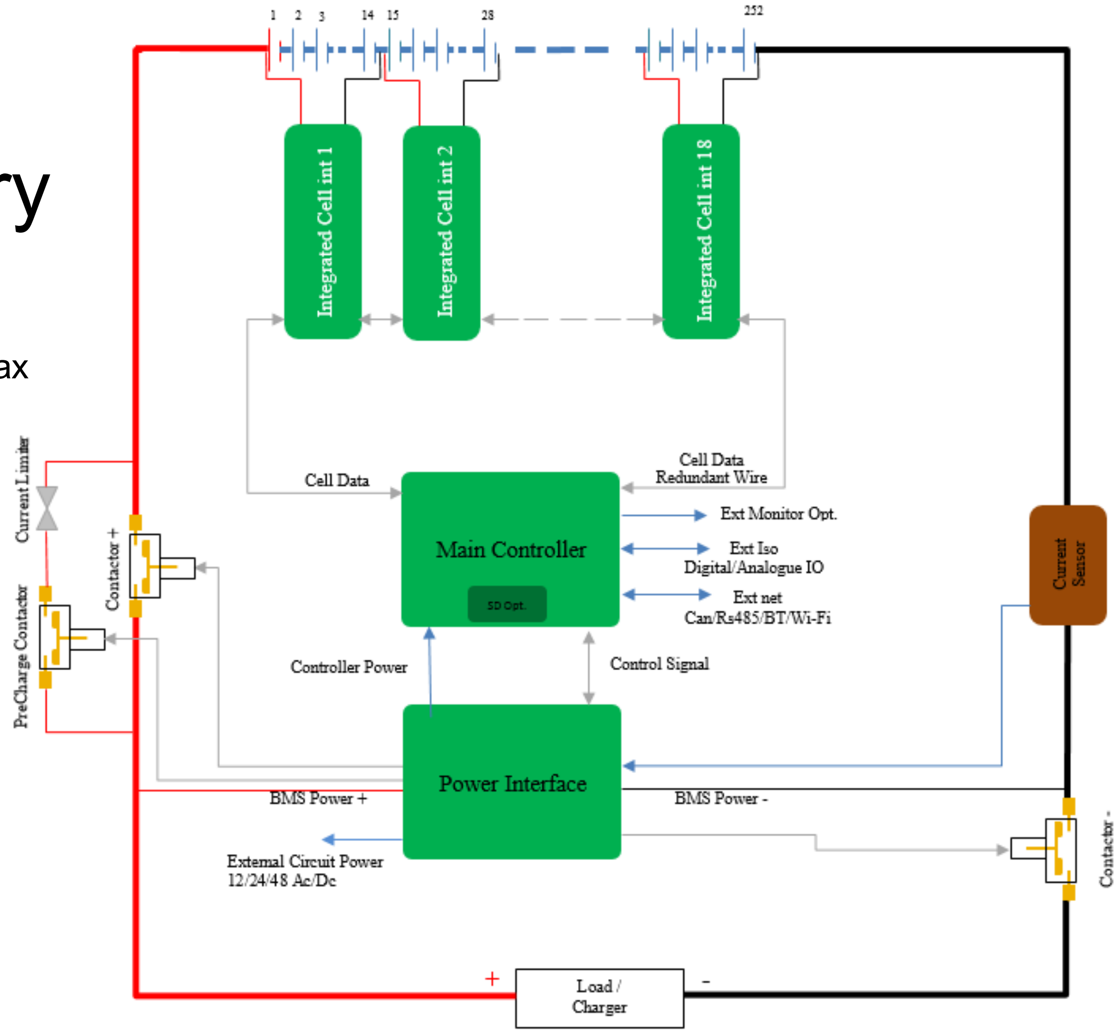
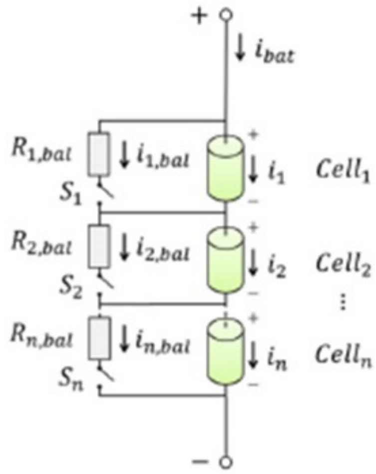
Battery Management System, BMS

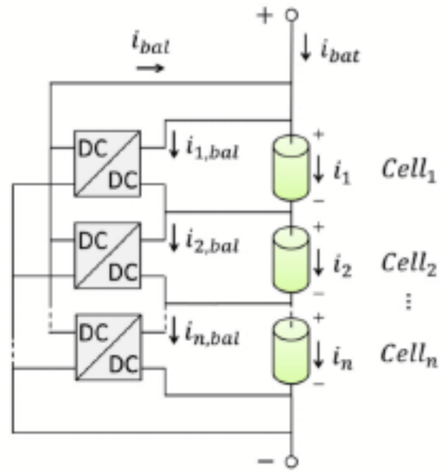
- Monitoring of battery status
  - U_{min} < Cell voltage < U_{max}
  - T_{min} < Cell temp < T_{max}
  - SoC (StateOfCharge)
  - SoH (StateOfHealth)
- Cell balancing
- Protection



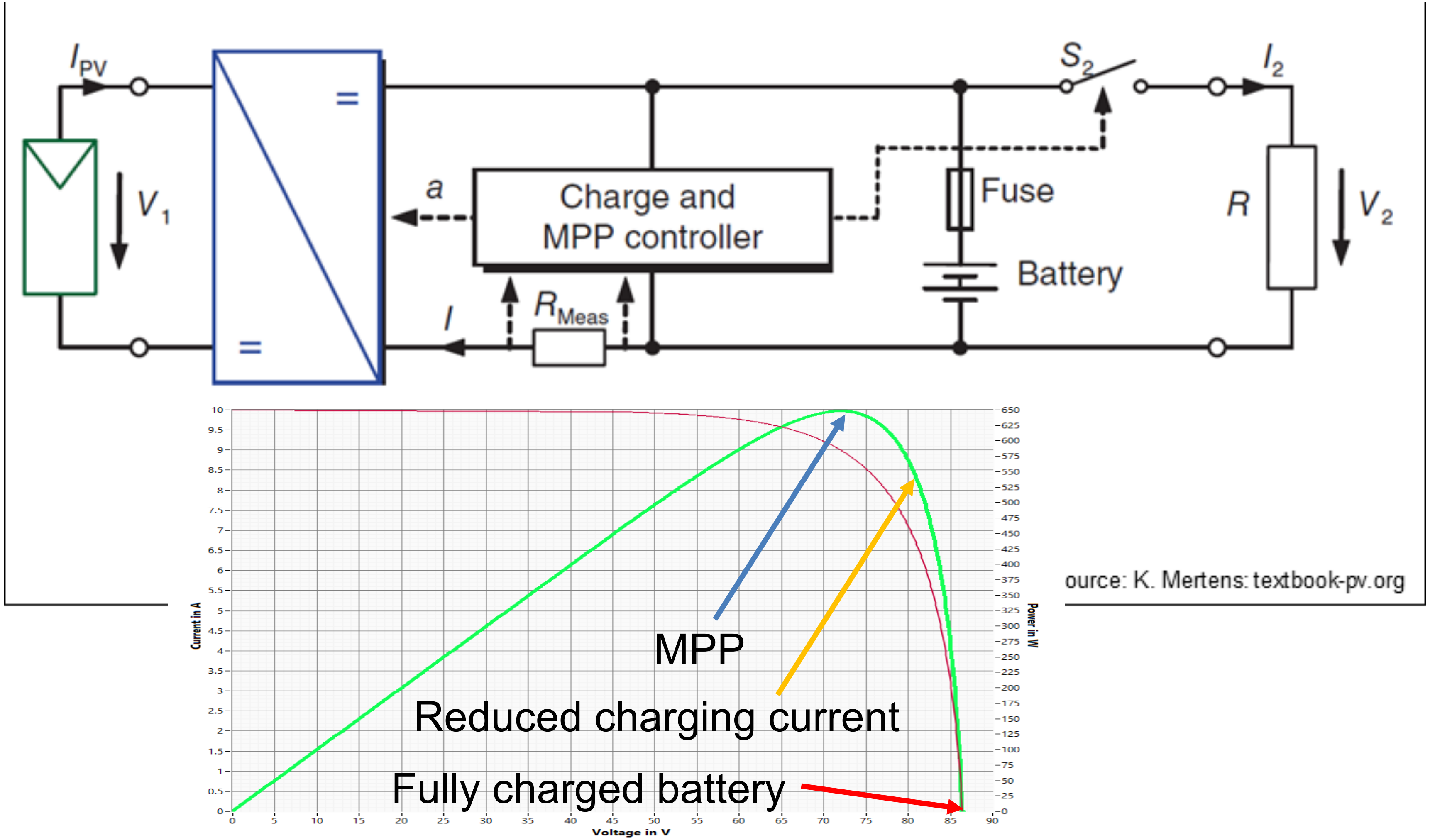
Cell balancing during charging

- **Target**: To ensure cell voltages are balanced
- Avoid single cells limiting overall capacity
- Passive balancing
  - Cells with high voltage is loaded by resistor to dissipate excess energy
- Active balancing
  - DC/DC converter to move energy from one cell to other cells

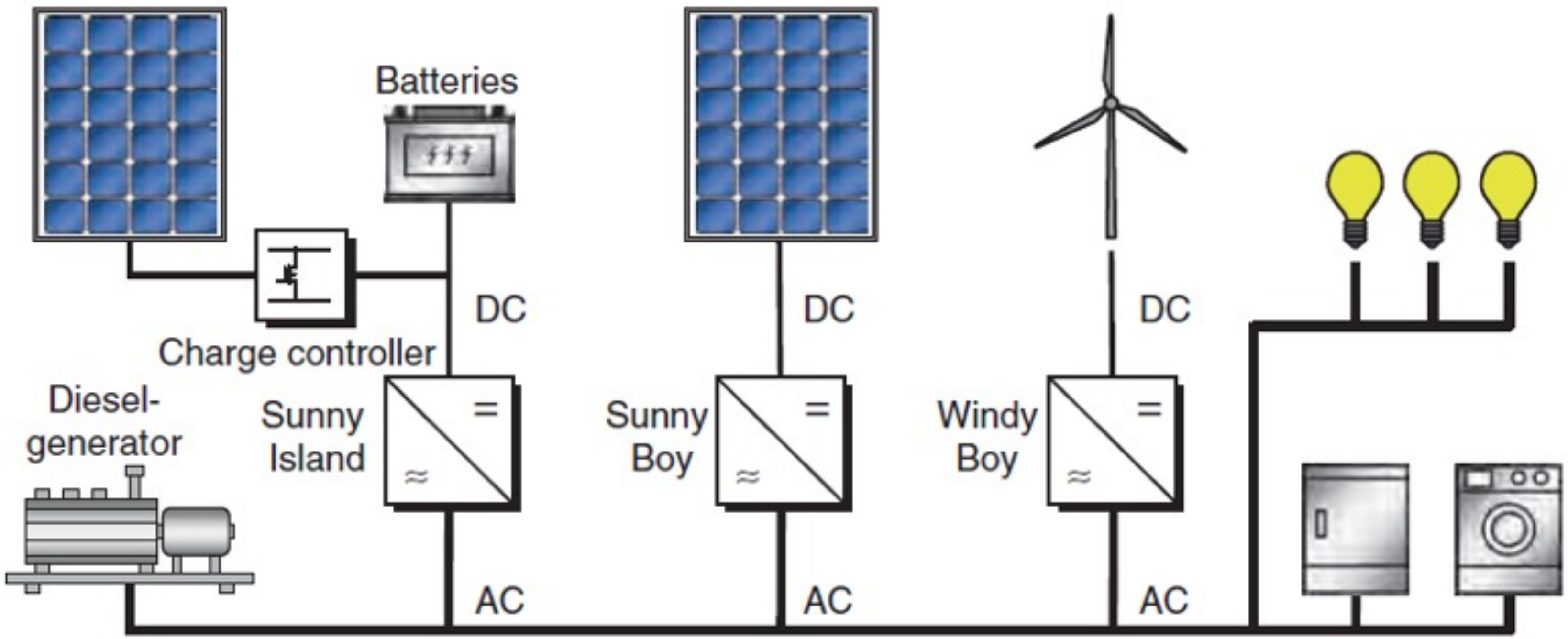




Standalone PV dc-system



Off-grid ac-based PV system



Source: K. Mertens: textbook-pv.org

Battery rating

$$C_N = \frac{W \cdot N_A}{DoD \cdot V_N}$$

- C_N: Battery capacity (Ah)
- W: Energy consumption (Wh/day)
- N_A: Autonomy days, days to serve load without PV-input
- DoD: Depth-of-Discharge. Useful capacity avoiding deep-discharge
- V_N: Battery nominal voltage

PV rating requirements

$$P_{pv} = \frac{W}{N_{sun} \cdot C_{slant} \cdot C_{temp} \cdot \eta_{line} \cdot \eta_{conv} \cdot \eta_{adapt}}$$

- W: required energy production (Wh/day)
- P_{pv}: required PV power rating (at STC: 1000 W/m^2)
- N_{sun}: No of full-load (STC) sun hours horizontal (1 kW/m^2)
- C_{slant}: Correction factor relative horizontal orientation
- C_{temp}: Correction for temperature versus STC (T_{cell}=25C)
- η_{line}: Electrical circuit efficiency (0.94)
- η_{conv}: Battery energy efficiency (0.9)
- η_{adapt}: Energy loss if not MPPT (0.9)

Standalone PV example

PV-modules in south orientation at 30 deg inclination
Summer: 3.5 autonomy days for battery rating
Winter: 5.5 autonomy days
Battery: 12V, DoD=70%
η_{line}: 0.94, η_{conv}: 0.9, η_{adapt}: 0.9

Table 7.4 Consumption balance of a small holiday cottage

Consumer	Nom. power P_N in W	Daily operating time t in h		Daily consumption W in Wh	
		Summer	Winter	Summer	Winter
3 lamps in living room	$3 \times 12 = 36$	1	3	36	108
2 reading lamps in bedroom	$2 \times 7 = 14$	1	2	14	28
1 outside lamp with motion detector	10	0,1	0,5	1	5
1 TV	50	2	3	100	150
1 refrigerator	50	Unknown	Switched off	200	Switched off
Total	160			351	291

Solar radiation on a horizontal level

Table 2.2: Total radiation per day (H_d) on a horizontal surface for various places over the year in **kWh/(m² d)**

Place		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Glasgow	H_{Direct}	0.06	0.23	0.49	1.18	1.66	1.60	1.38	1.03	0.60	0.25	0.10	0.03	0.71
55.7?°N	$H_{Diffuse}$	0.39	0.81	1.45	2.23	2.83	3.11	2.97	2.46	1.73	1.00	0.51	0.29	1.65
4.5?°W	H	**0.45**	**1.04**	**1.94**	**3.41**	**4.49**	**4.71**	**4.35**	**3.49**	**2.33**	**1.25**	**0.61**	**0.32**	**2.36**
Hamburg	H_{Direct}	0.13	0.37	0.74	1.49	2.18	2.32	2.01	1.82	1.10	0.52	0.18	0.10	1.08
53.6?°N	$H_{Diffuse}$	0.40	0.78	1.35	2.04	2.55	2.79	2.67	2.26	1.63	0.99	0.51	0.31	1.52
10.0?°E	H	**0.53**	**1.15**	**2.09**	**3.53**	**4.73**	**5.11**	**4.68**	**4.08**	**2.73**	**1.51**	**0.69**	**0.41**	**2.60**
London	H_{Direct}	0.17	0.36	0.82	1.36	1.88	2.08	1.91	1.72	1.24	0.61	0.26	0.12	1.04
51.6?°N	$H_{Diffuse}$	0.48	0.84	1.43	2.06	2.56	2.79	2.68	2.28	1.70	1.08	0.61	0.38	1.57
0.0?°W	H	**0.65**	**1.20**	**2.25**	**3.42**	**4.44**	**4.87**	**4.59**	**4.00**	**2.94**	**1.69**	**0.87**	**0.50**	**2.61**
Munich	H_{Direct}	0.36	0.75	1.28	1.83	2.43	2.62	2.69	2.26	1.71	0.89	0.38	0.24	1.45
48.4?°N	$H_{Diffuse}$	0.67	1.05	1.60	2.18	2.61	2.81	2.71	2.35	1.82	1.24	0.75	0.55	1.70
11.7?°E	H	**1.03**	**1.80**	**2.88**	**4.01**	**5.04**	**5.43**	**5.40**	**4.61**	**3.53**	**2.13**	**1.13**	**0.79**	**3.15**

$$N_{sun}(\text{per day}) = H_d / P_{STC}$$

Photovoltaics: Fundamentals, Technology, and Practice, Second Edition
By: Konrad Mertens

PV correction factor relative horizontal orientation, C_{slant}

Table 8.5: Correction factor, C_{Slant}, for deviations from the horizontal in Germany and other sites [22, 40]

Site	**Direction**	**Slant angle**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Germany	South	30°	1.67	1.54	1.31	1.16	1.07	1.01	1.02	1.1	1.25	1.38	1.58	1.68
		45°	1.88	1.7	1.37	1.15	1.02	0.95	0.96	1.08	1.28	1.46	1.76	1.93
		60°	2.02	1.77	1.36	1.09	0.93	0.84	0.86	1	1.25	1.48	1.85	2.07
	Southwest	30°	1.55	1.36	1.21	1.08	1.02	0.97	0.96	1.05	1.16	1.29	1.42	1.48
		45°	1.73	1.46	1.24	1.06	0.98	0.91	0.9	1.02	1.17	1.35	1.54	1.61
		60°	1.83	1.49	1.22	0.99	0.89	0.82	0.81	0.94	1.13	1.34	1.56	1.68
	West	30°	1.1	0.98	0.98	0.93	0.92	0.9	0.88	0.93	0.96	1.02	1.01	0.95
		45°	1.12	0.97	0.95	0.87	0.86	0.83	0.81	0.87	0.92	1	0.99	0.93
		60°	1.1	0.93	0.9	0.8	0.78	0.76	0.74	0.79	0.86	0.95	0.96	0.91
	Southeast	30°	1.35	1.36	1.19	1.12	1.05	1.02	1.05	1.08	1.16	1.2	1.35	1.45
		45°	1.43	1.46	1.21	1.11	1.01	0.97	1.01	1.05	1.17	1.22	1.45	1.61
		60°	1.47	1.48	1.18	1.05	0.93	0.89	0.94	0.98	1.12	1.18	1.46	1.68
	East	30°	0.87	0.98	0.95	0.97	0.96	0.98	1	0.96	0.95	0.9	0.94	0.95
		45°	0.83	0.98	0.91	0.93	0.9	0.93	0.96	0.91	0.91	0.86	0.92	0.93
		60°	0.8	0.94	0.85	0.86	0.83	0.85	0.9	0.84	0.84	0.8	0.86	0.89

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PV correction relative STC conditions, C_{temp}

Table 8.6: Correction factor, C_{Temp}, for various sites in case of on-roof installations [40]

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Berlin	1.06	1.05	1.02	0.98	0.94	0.93	0.92	0.93	0.96	1	1.04	1.06
Marseille	0.98	0.98	0.95	0.93	0.91	0.89	0.87	0.88	0.91	0.93	0.97	0.98
Cairo	0.93	0.92	0.9	0.88	0.86	0.84	0.84	0.84	0.86	0.87	0.9	0.93

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Standalone PV example

- Summer, south orientation at 30 deg inclination, 3.5 autonomy days

$$P_{PV} = \frac{351\ \text{Wh}}{3.53\ \text{h} \cdot 1.25 \cdot 0.96 \cdot 0.94 \cdot 0.9 \cdot 0.9} = 108.8\ \text{Wp}$$

$$C_N = \frac{351\ \text{Wh} \cdot 3.5}{0.7 \cdot 12\ \text{V}} = 146.3\ \text{Ah}$$

- Winter, south orientation at 30 deg inclination, 5.5 autonomy days

$$P_{PV} = \frac{291\ \text{Wh}}{0.79\ \text{h} \cdot 1.68 \cdot 1.06 \cdot 0.94 \cdot 0.9 \cdot 0.9} = 271.7\ \text{Wp}$$

$$C_N = \frac{291\ \text{Wh} \cdot 5.5}{0.7 \cdot 12\ \text{V}} = 190.5\ \text{Ah}$$

Stationary battery storage

Alexander och Philip (2020): **Battery Sizing and Placement in the Low Voltage Grid including Photovoltaics**

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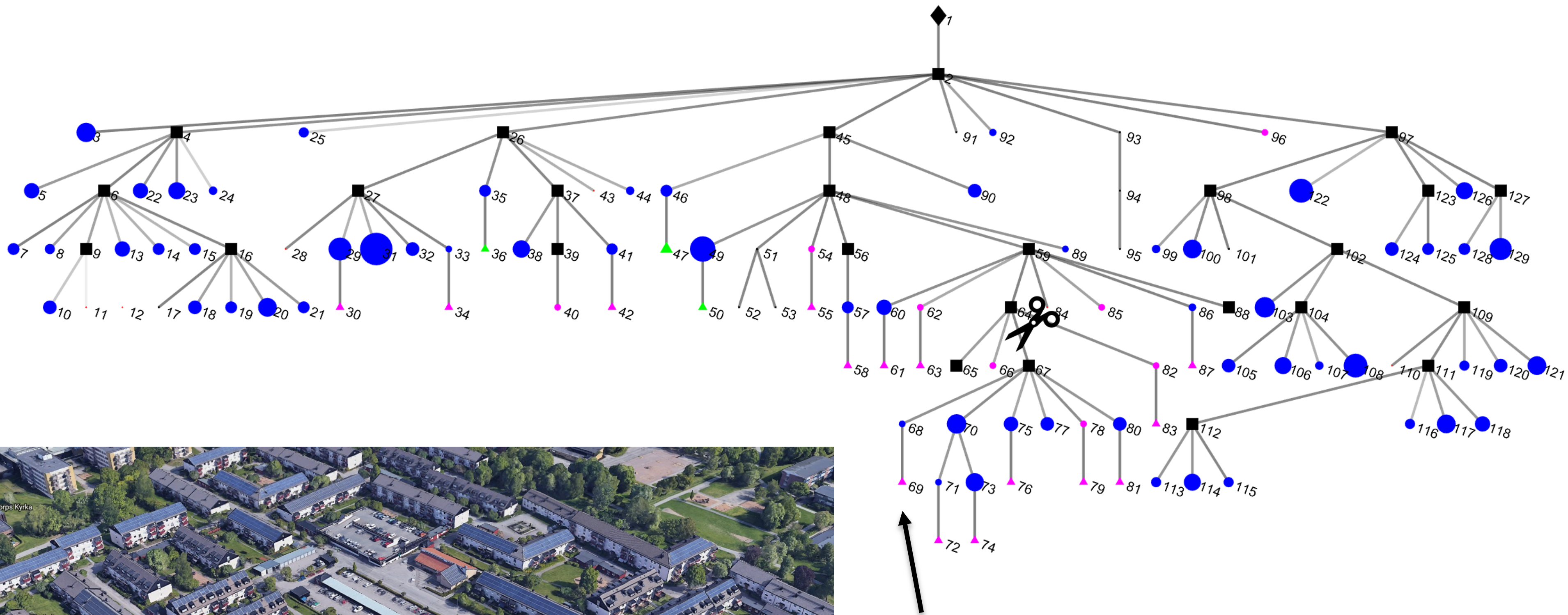
Tekniska verken

RI. SE

Limitations in a grid – a real case

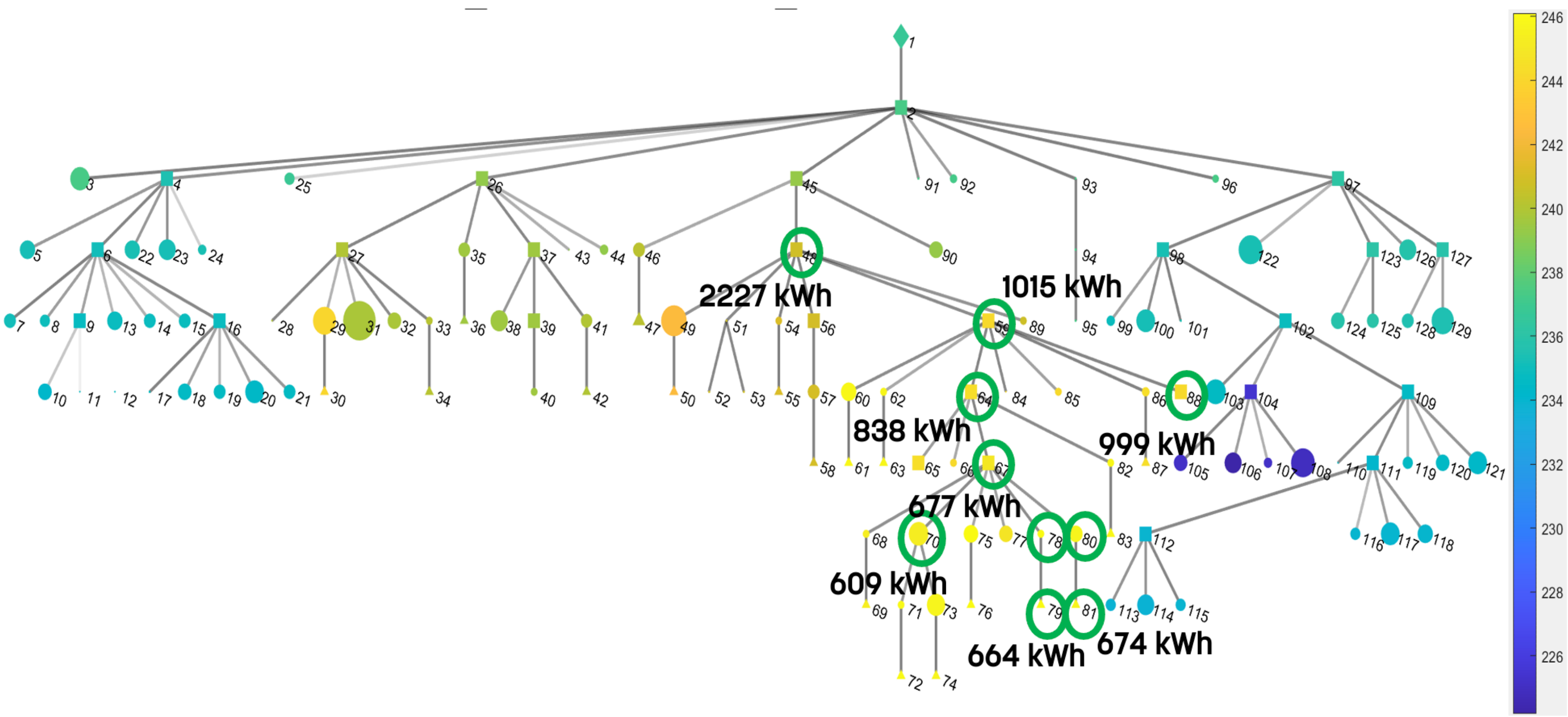
One consumer got problems with over voltage (voltage more than 260V).

Grid reinforcement vs battery stoarge



High voltage!

Grid reinforcement vs battery stoarge



Electric vehicles in the grid

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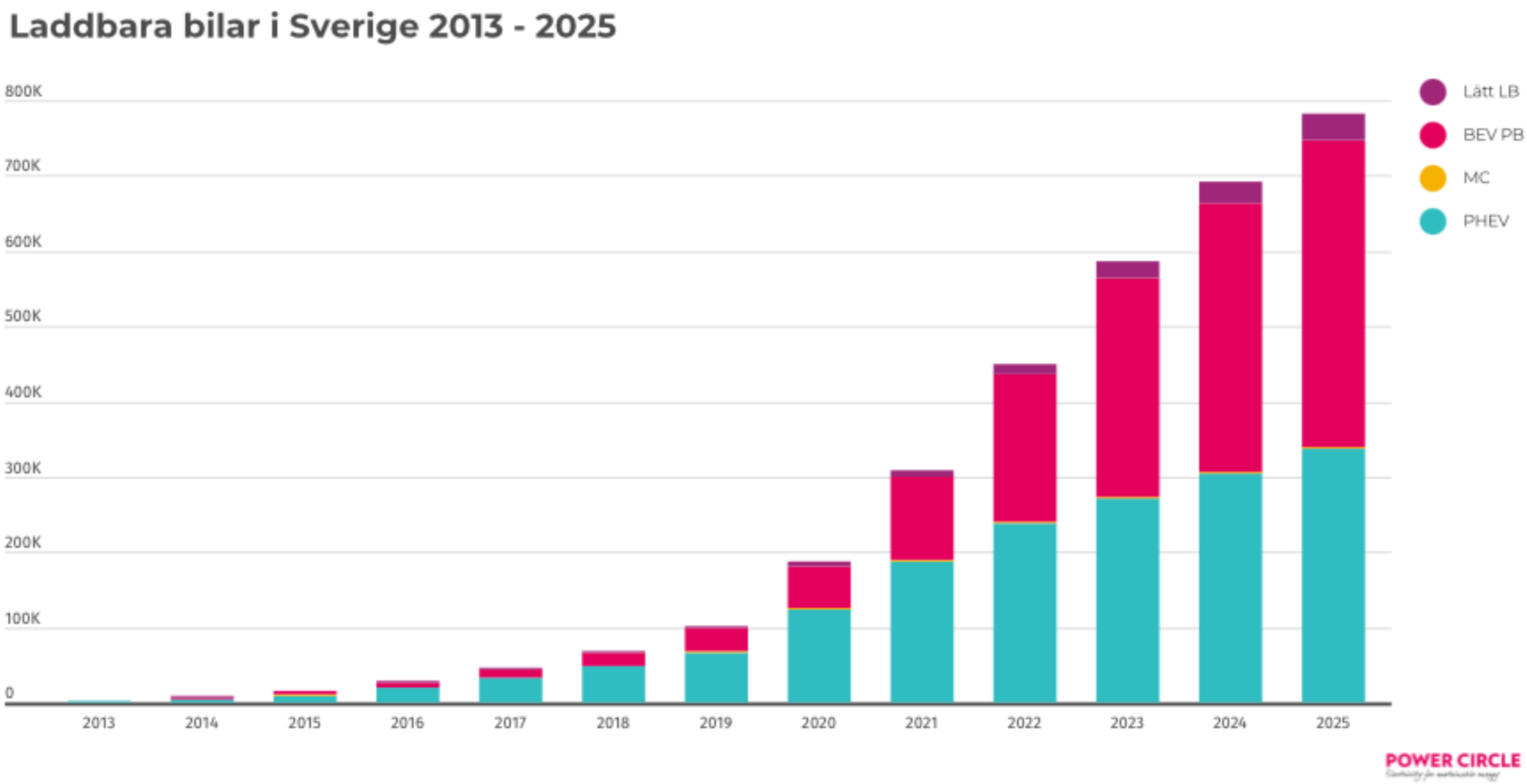
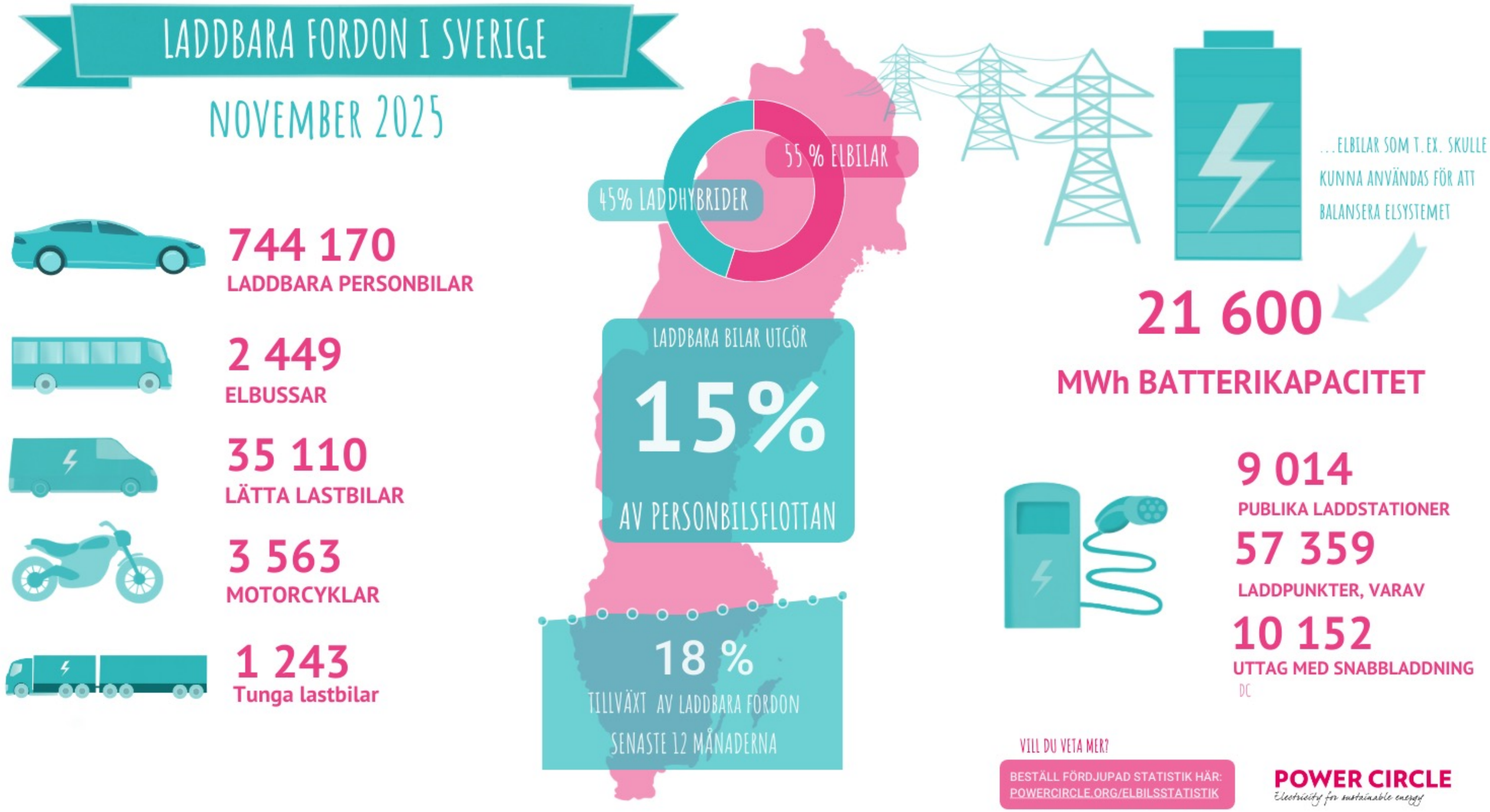
Chargeable vehicles in Sweden



Rapid increase in chargeable vehicles that can be used to stabilize the grid (or de-stabilize….).

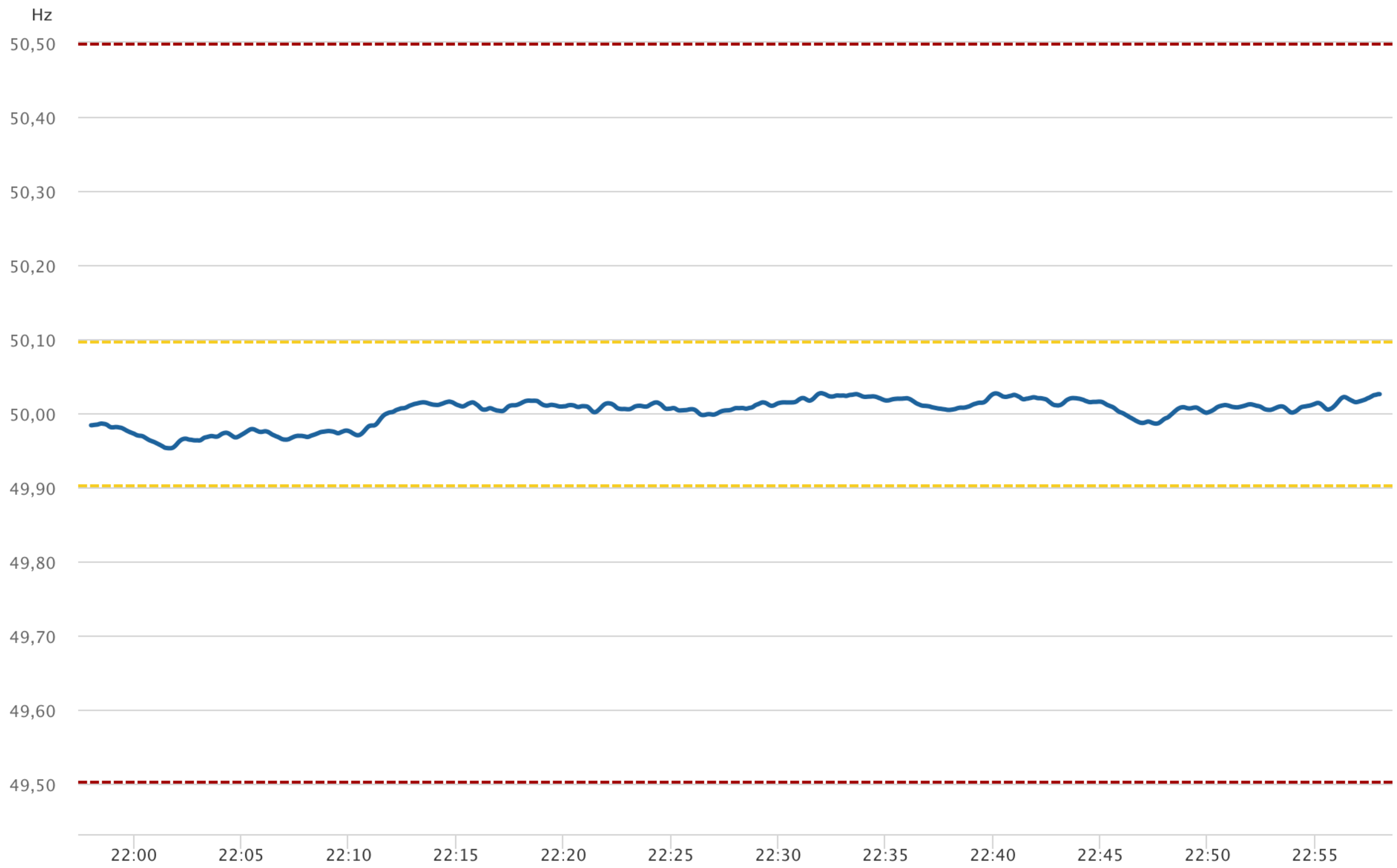
Charging

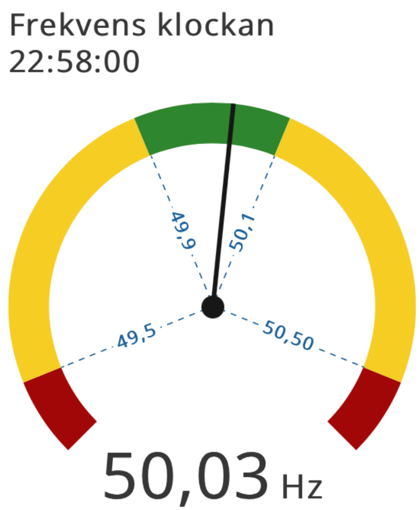


Electric peak power in Sweden ~25GW (coldest day of the year). If one milion vehicle charged at 11kW pluged in -> total power 11GW. High possibility for controlled charging on different time scales (seconds to hours/days).

Frequency

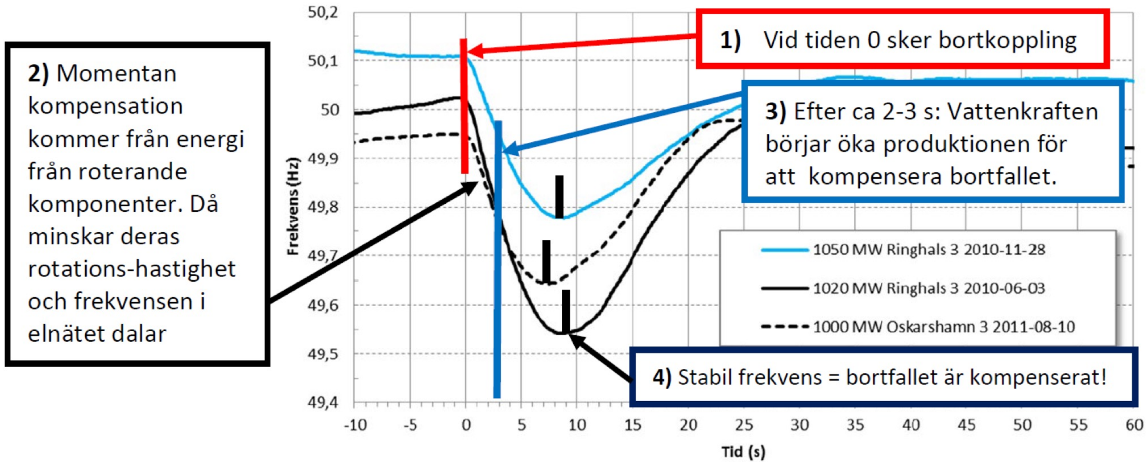
Varies between 49.9Hz and 50.1Hz under normal operation in Sweden.





Frequence stability - Rotating mass

Rotating inertia in (primarily) directly connected synchronous machines contribute with inertia that stabilizes the grid.



"Input power"+change in rotating energy=consuption

Wind power can contribute by adjusting turbine speed when grid frequence diviate from reference value.

SVK frequency reserve

Översiktlig kravbild för reserver

Uppdaterad 11 oktober 2023

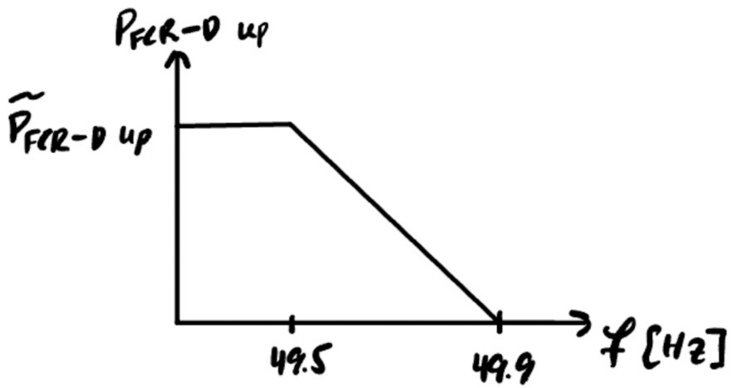
Avhjälpande åtgärd	Frekvenshållningsreserver			Frekvensåterställningsreserver	
FFR	**FCR-D upp**	**FCR-D ned**	**FCR-N**	**aFRR**	**mFRR**
Snabb frekvensreserv (Fast Frequency Reserve)	Frekvenshållningsreserv -Störning uppreglering (Upward Frequency Contain-ment Reserve - Disturbance)	Frekvenshållningsreserv -Störning nedreglering (Downward Frequency Containment Reserve - Disturbance)	Frekvenshållningsreserv -Normaldrift (Frequency Containment Reserve - Normal)	Automatisk Frekvens-återställningsreserv (Automatic Frequency Restoration Reserve)	Manuell Frekvens-återställningsreserv (Manual Frequency Restoration Reserve)
Uppreglering	Uppreglering	Nedreglering	Symmetrisk upp- och nedreglering	Upp- och/eller nedreglering	Upp- och/eller nedreglering
Minsta budstorlek 0,1 MW	**Minsta budstorlek** 0,1 MW	**Minsta budstorlek** 0,1 MW	**Minsta budstorlek** 0,1 MW	**Minsta budstorlek** 1 MW	**Minsta budstorlek** Kapacitetsmarknad: 1 MW** Energiaktiveringsmarknad: 5MW
Aktivering Automatiskt vid frekvensförändringar vid låg nivå av rotationsenergi	**Aktivering** Automatisk linjär aktivering inom frekvensintervallet 49,90-49,50 Hz	**Aktivering** Automatisk linjär aktivering inom frekvensintervallet 50,10-50,5 Hz	**Aktivering** Automatisk linjär aktivering inom frekvensintervallet 49,90-50,10 Hz	**Aktivering** Automatiskt vid frekvensavvikelse från 50,00 Hz	**Aktivering** Manuellt på begäran av Svenska kraftnät
Aktiveringstid Tre alternativ för 100 %: - 0,7 sek (vid 49,50 Hz) - 1,0 sek (vid 49,60 Hz) - 1,3 sek (vid 49,70 Hz)	**Aktiveringstid** Aktiveringstid för FCR-D upp redovisas i dokumentet med tekniska krav för frekvens-hållningsreserver (FCR) Se krav 2 på sida 18	**Aktiveringstid** Aktiveringstid för FCR-D ned redovisas i dokumentet med tekniska krav för frekvens-hållningsreserver (FCR) Se krav 2 på sida 18	**Aktiveringstid** Aktiveringstid för FCR-N redovisas i dokumentet med tekniska krav för frekvens-hållningsreserver (FCR) Se krav 1 på sida 14 samt krav 9 på sida 28	**Aktiveringstid** 100 % inom 5 minuter	**Aktiveringstid** 100 % inom 15 min
Volymkrav för Sverige Upp till ca 100 MW	**Volymkrav för Sverige** Upp till 558 MW	**Volymkrav för Sverige** Upp till 538 MW*	**Volymkrav för Sverige** 231 MW	**Volymkrav för Sverige** Upp till 111 MW	**Volymkrav för Sverige** Kapacitetsmarknad: Upp till 200 MW Energiaktiveringsmarknad: Inga volymkrav
Uthållighet - Uthållighet: 30 sek alternativt 5 sek - Repeterbarhet: Redo för aktivering inom 15 minuter	**Uthållighet** Uthållighet: Minst 20 min	**Uthållighet** Uthållighet: Minst 20 min	**Uthållighet** Uthållighet: 1 h	**Uthållighet** Uthållighet: 1 h	**Uthållighet** Uthållighet: 1 h

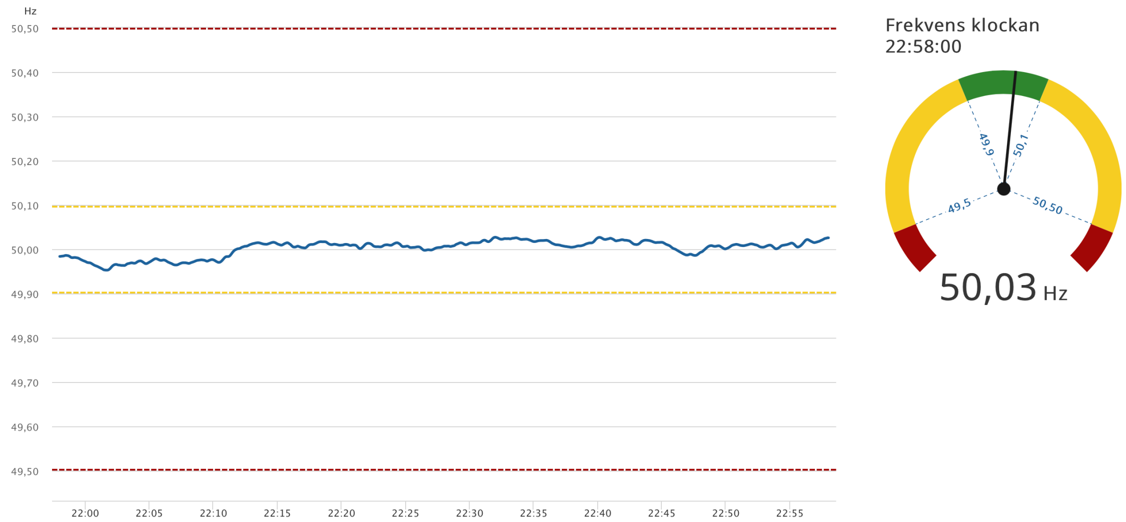
* Aktuell upphandlingsplan är lägre än volymkravet då FCR-D ned är en ny produkt sedan januari 2022. Upphandlingsplanen uppdateras kvartalsvis.
Mer information finns på Svenska kraftnäts webbplats: www.svk.se/aktorsportalen/bidra-med-reserver/behov-av-reserver-nu-och-i-framtiden/

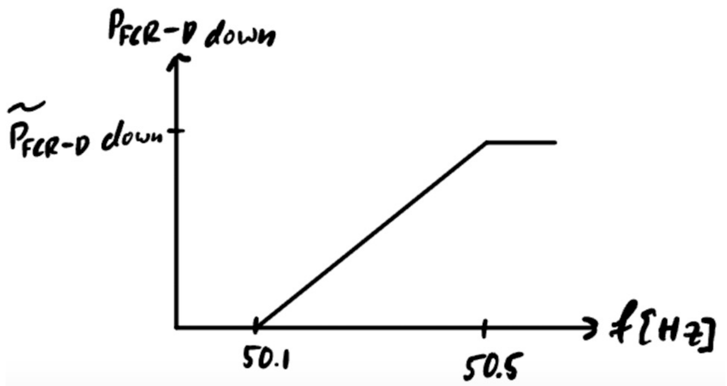
** Ett avropat bud på kapacitetsmarknaden innebär ett åtagande om att lämna bud på energiaktiveringsmarknaden.
För mer utförlig information om kraven, se Balansansvarsavtal och tillhörande regeldokument. De finns för nedladdning på Svenska kraftnäts webbplats: www.svk.se/aktorsportalen/balansansvarig/balansansvarsavtalet/

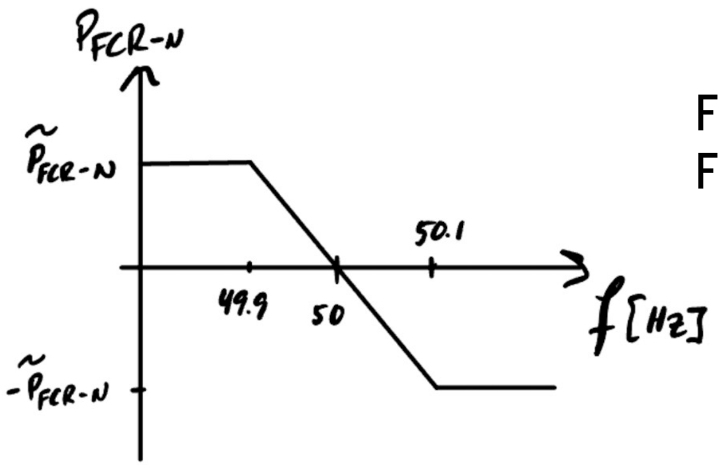
Possibility for both producers and consumers to be active.

FCR markets



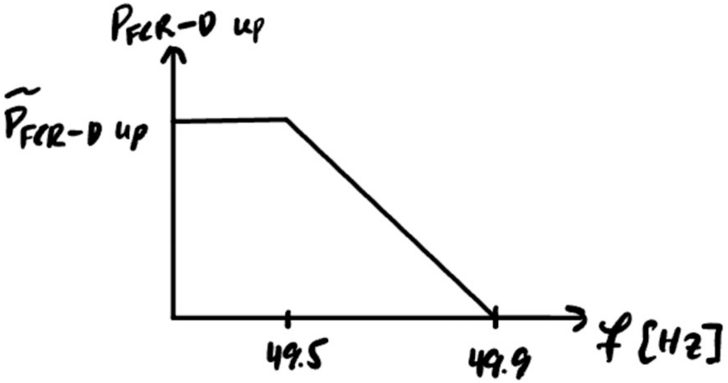


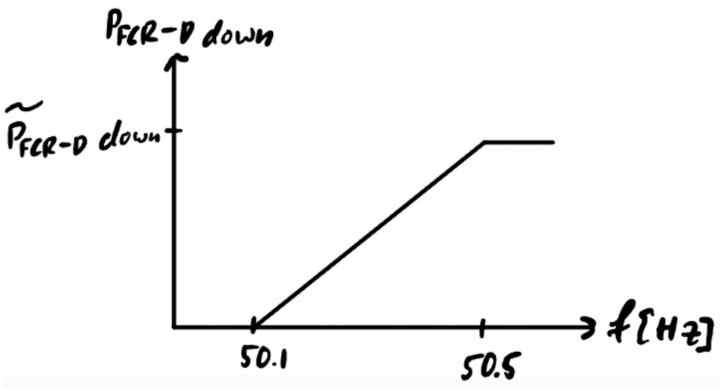


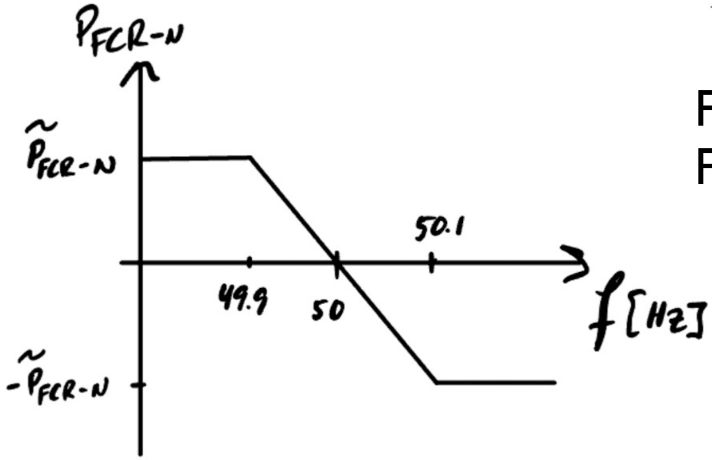


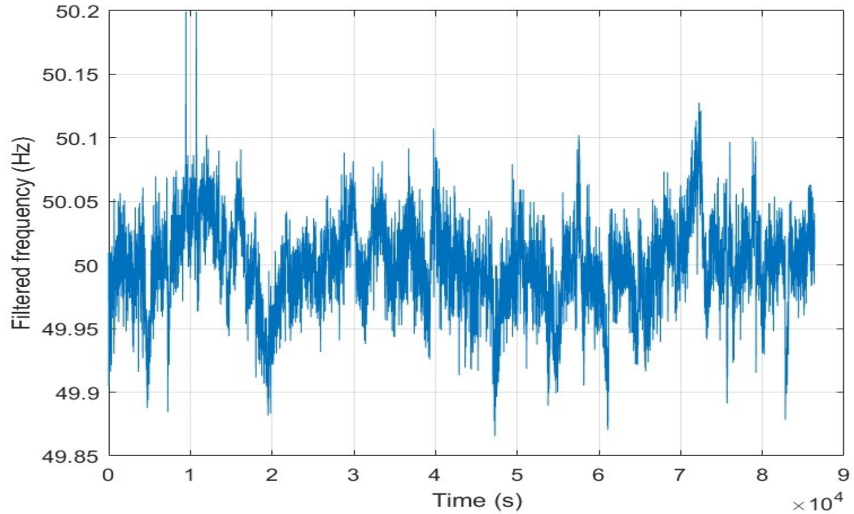
FCR-N active all the time.
FCR-D not much at all.

FCR markets









FCR-N active all the time.
FCR-D not much at all.

Power sources for different markets

Total volym av förkvalificerade enheter och grupper per produkt per 1 oktober 2024 (avrundat till närmaste 10-tal)

Kraftslag	FFR (MW)	FCR-N (MW)	FCR-D upp (MW)	FCR-D ned (MW)	aFRR upp (MW)	aFRR ned (MW)	mFRR upp (MW)	mFRR ned (MW)
Energilager	300	90	520	470	0	0	80	80
Flexibel förbrukning	100	<10	410	40	0	0	490	260
Kombination vattenkraft + energilager	10	20	20	20	0	0	0	0
Kärnkraft	0	0	0	0	0	0	0	200
Solkraft	0	0	<10	30	0	0	0	0
Vindkraft	0	0	0	240	0	50	240	1 260
Vattenkraft	0	1 790	2 710	1 590	2 340	2 350	12 960	13 000
Värmekraft	0	50	50	50	0	0	300	260

FFR = Fast Frequency Reserve
100% after ~ 1 second.

FCR = Frequency Containment Reserve
100% after ~5 seconds

FRR = Frequency Restauration Reserve
aFRR (automatic): 100% after 5 minutes
mFRR (manual): 100% after 15 minutes

TSTE26/Christofer Sundström

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