Chapter 6

Batteries

Types and Characteristics • Functions and Features • Specifications and Ratings

Overview

- Describing why batteries are used in PV systems.
- Identifying the basic components of battery construction.
- Defining battery terminology for battery specifications, ratings and operating parameters.
- Classifying common types of storage batteries and their performance characteristics.
- Understanding the NEC and OSHA requirements for battery installations and safety.

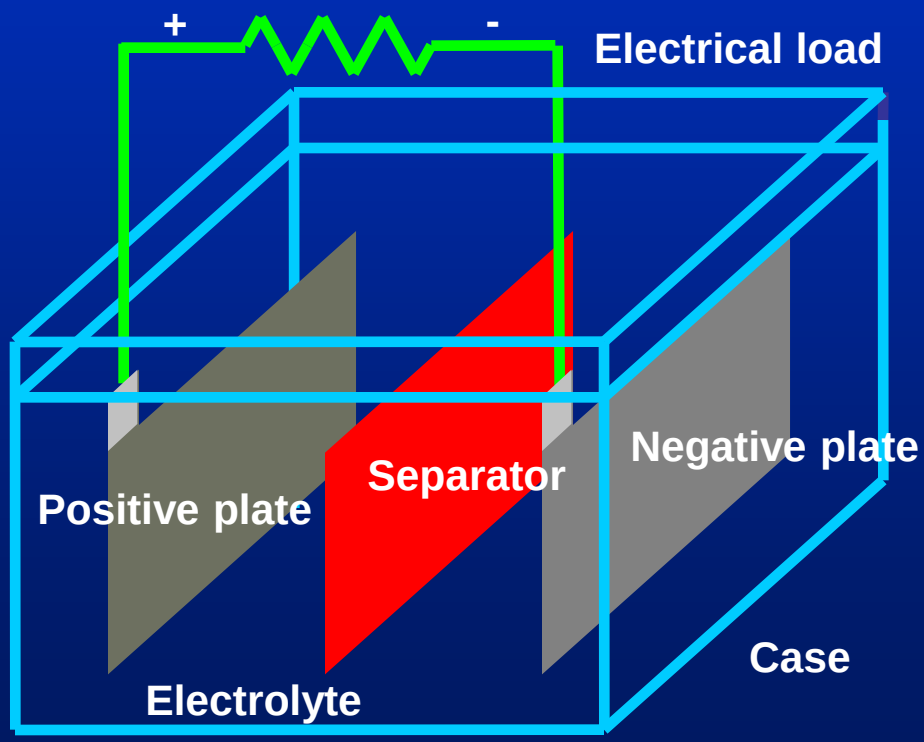
Battery Fundamentals

- **A battery is an electrochemical cell that stores energy in chemical bonds. Chemical energy is converted to DC electrical energy when a battery is connected to a load.**

- **Batteries are used in PV systems for the following purposes:**
  - To store energy produced by the PV array and supply it to electrical loads as needed.
  - To operate the PV array and electrical loads at stable voltages.
  - To supply surge currents to electrical loads or appliances.

Battery Cell Design

- A cell is the basic electrochemical unit in a battery.



Battery Components: Definitions

- **Plate: The positive or negative electrode in a battery cell, consisting of a grid and active material.**
- **Active Material: The reactant materials that comprise the positive and negative plates.**
- **Grid: A metal alloy framework that supports the active material on a battery plate.**
- **Separator: A porous, insulating divider between the positive and negative plates.**

Battery Components: Definitions (cont.)

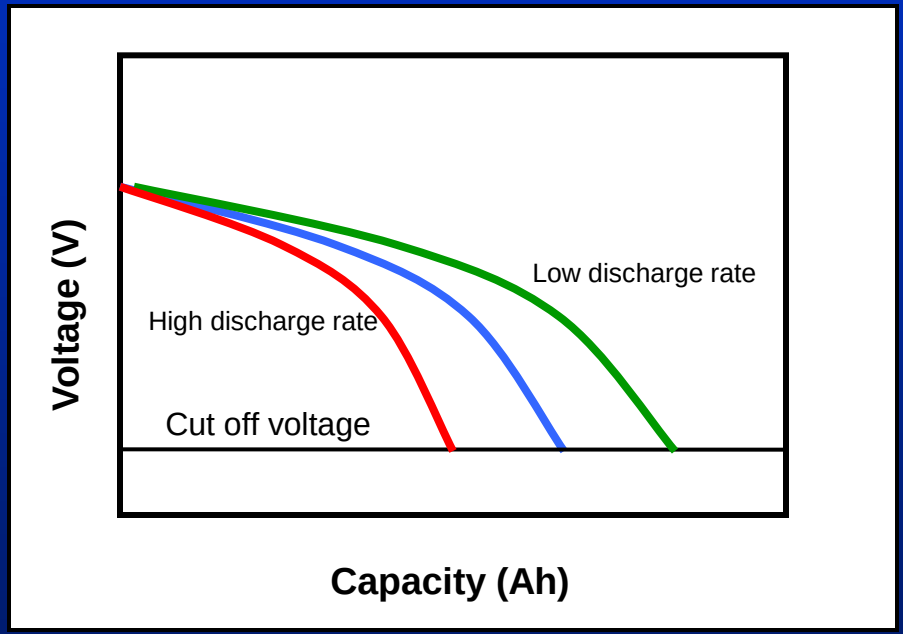
- **Electrolyte: A conducting medium which allows the flow of current via ionic transfer between the battery plates.**
- **Case: A container which encloses the plates, separators and electrolyte in a battery.**
- **Vent: a cap on flooded battery cells that also serves as a means to fill the battery. For sealed batteries, the vent is also a pressure regulating valve.**

Battery Construction

- The major components of battery construction are shown in this cut-away view.

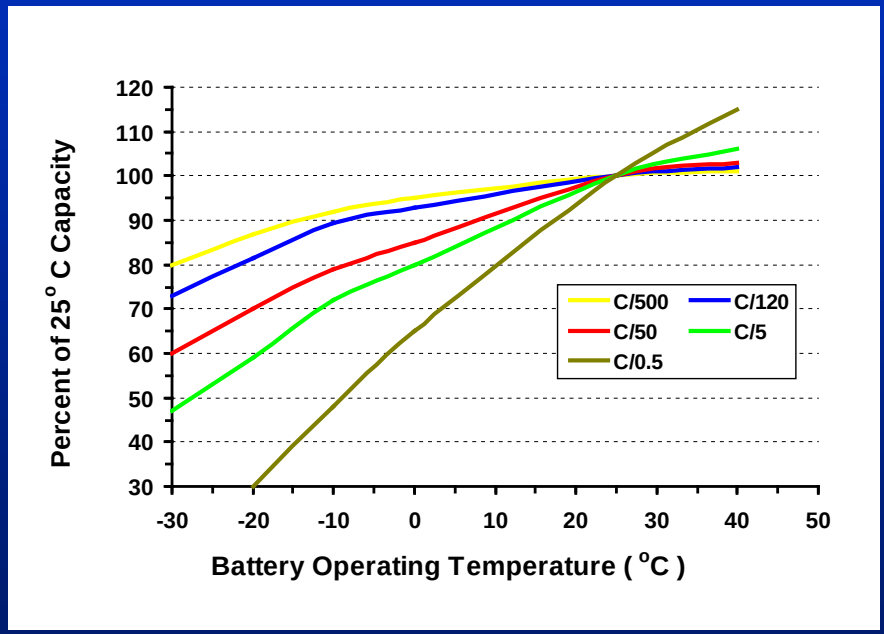
Battery Capacity

- Capacity is a measure of the stored electric charge or stored energy that a battery can deliver under specified conditions.
- An ampere-hour (Ah) is the common unit of battery energy storage capacity, equal to the transfer of one ampere for one hour.
- Capacity depends on the battery temperature, discharge rate and cut-off voltage.



Battery Discharging

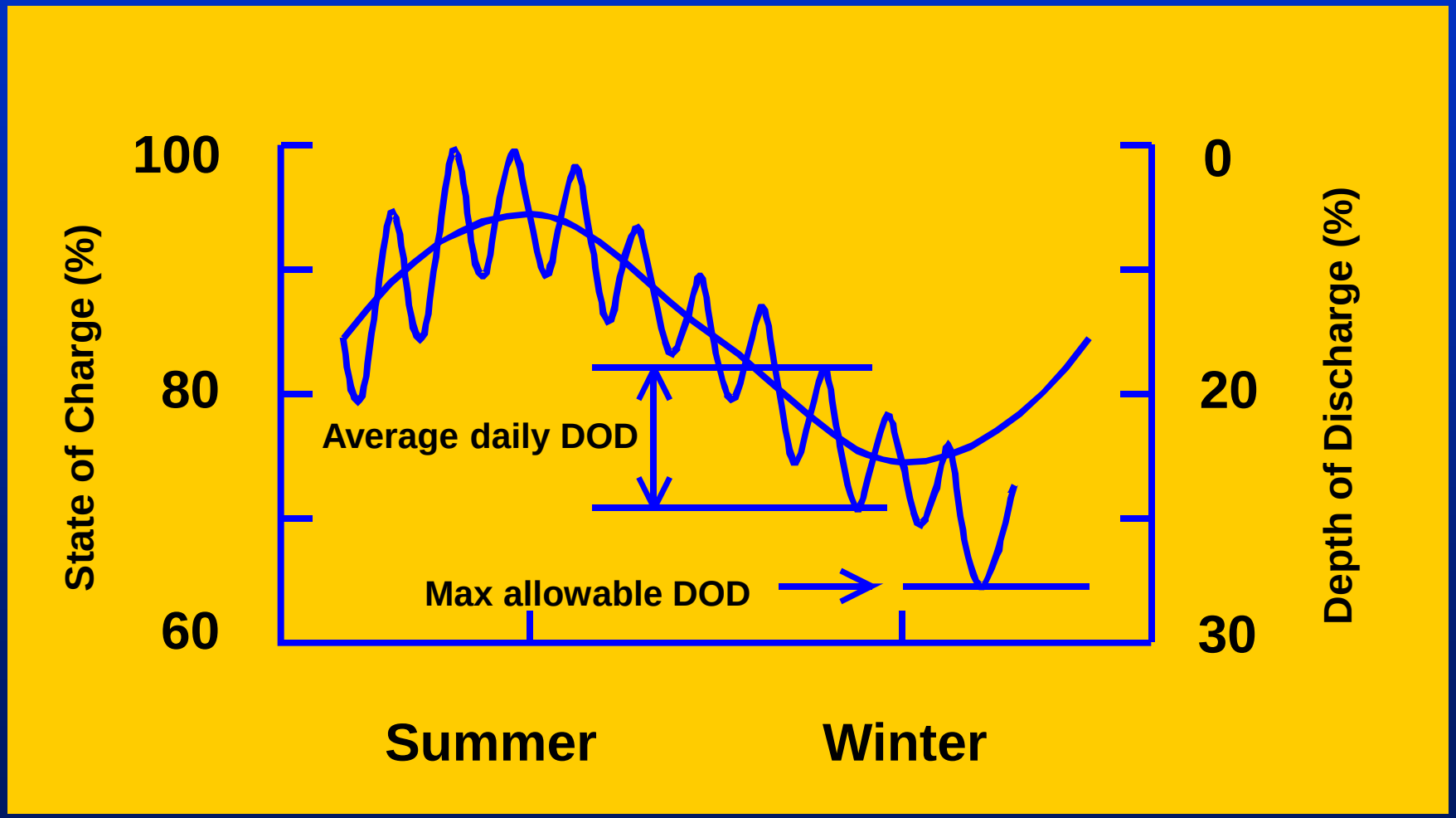
- Discharging is the process when a battery delivers current under the application of an electrical load.
- The discharge rate is the time in hours required to fully discharge a battery at a given current to a specified cutoff voltage.
- Lower temperatures and high discharge rates reduce available battery capacity.



Battery State-of-Charge

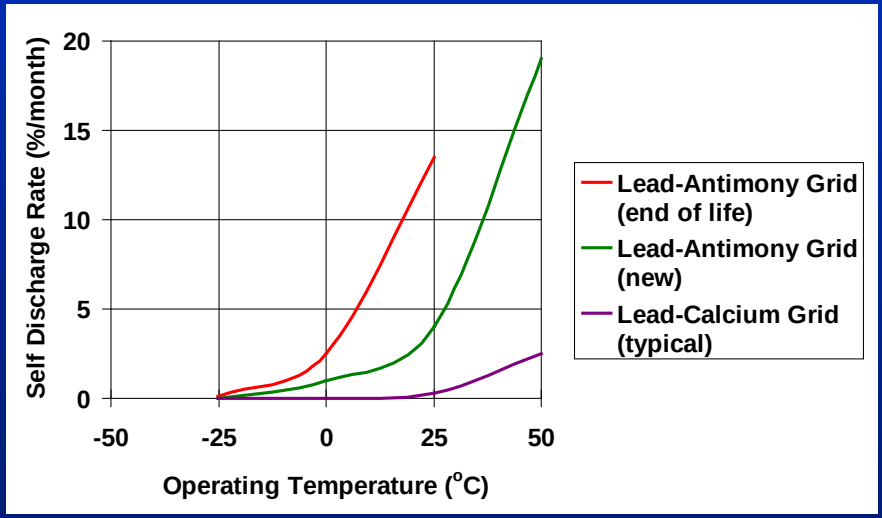
- **State-of-charge (SOC) is the percentage of energy stored in a battery compared to a fully charged condition.**
- **Depth-of-discharge (DOD) is the percentage of capacity that has been withdrawn from a battery compared to the total fully charged capacity:**
  - DOD = 100% - SOC
- **Allowable depth-of-discharge is the maximum limit of battery discharge in system operation.**
  - Cut-off voltage is the lowest voltage that a battery is allowed to operate and defined by the charge controller or equipment low voltage disconnect set point. The cut-off voltage defines the allowable depth-of-discharge and usable battery capacity at a specific discharge rate.

Battery State-of-Charge



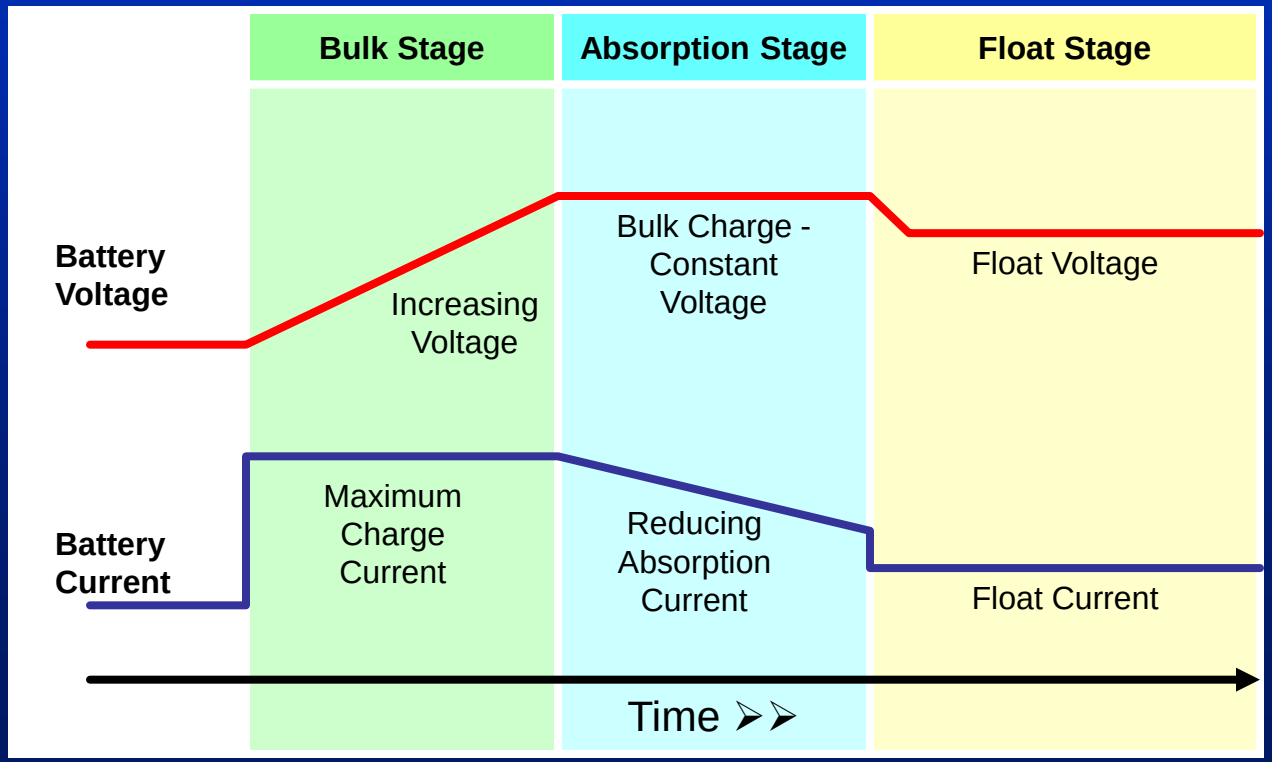
Self-Discharge Rate

- Self-discharge is due to internal losses within a battery that reduce state-of-charge over time.
- Higher temperatures result in higher self-discharge rates.
- Lead-antimony types and older batteries have higher self-discharge rates.

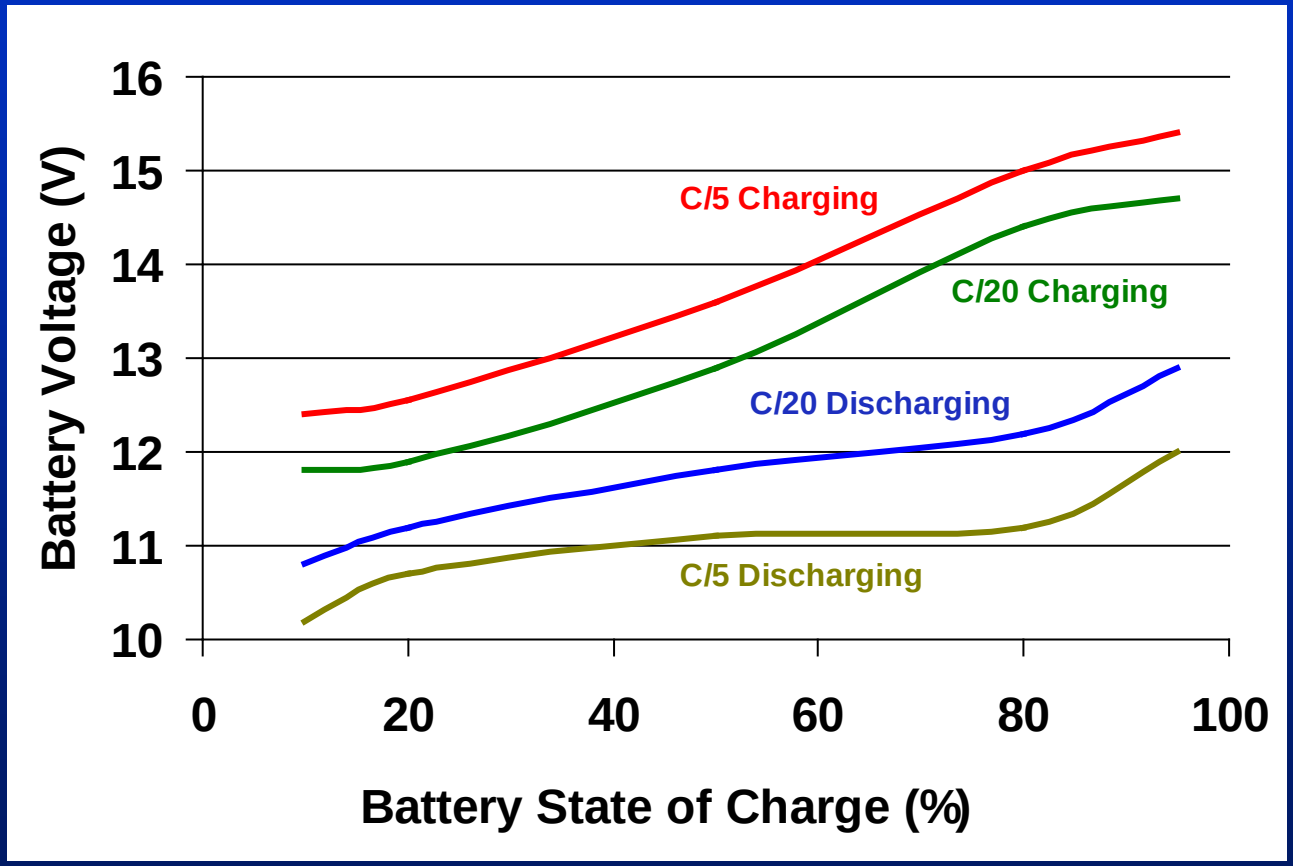


Battery Charging

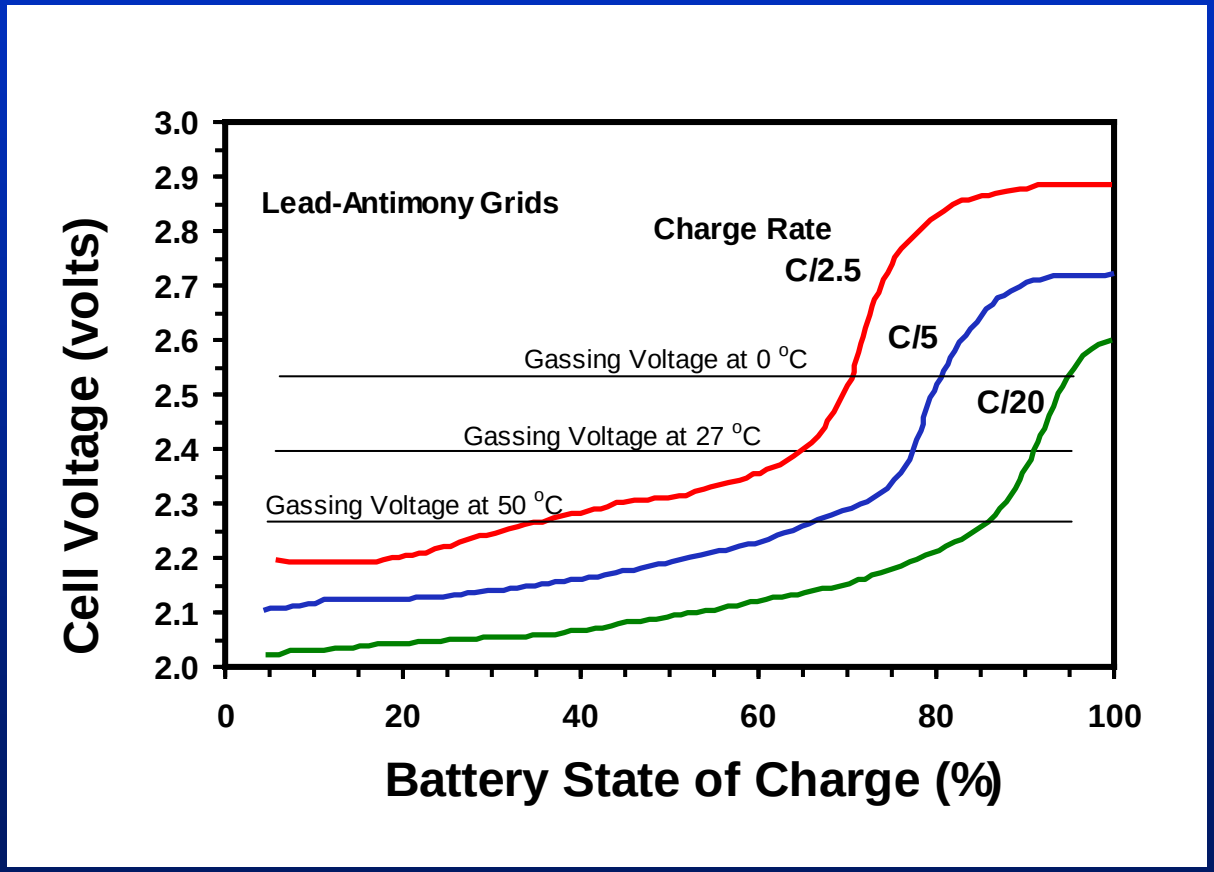
- Charging is the process when a battery receives or accepts current from a charging source, such as a PV array, and quantified by the charge current or rate.



Effects of Charge and Discharge Rates on Battery Voltage



Lead-Antimony Charging Voltage vs. Battery SOC



Chemical Reactions for the Lead-Acid Cell

At the positive plate or electrode:

$$PbO_2 + 4H^+ + 2e^- \Leftrightarrow Pb^{2+} + 2H_2O$$

$$Pb^{2+} + SO_4^{2-} \Leftrightarrow PbSO_4$$

At the negative plate or electrode:

$$Pb \Leftrightarrow Pb^{2+} + 2e^-$$

$$Pb^{2+} + SO_4^{2-} \Leftrightarrow PbSO_4$$

Overall lead-acid cell reaction:

$$PbO_2 + Pb + 2H_2SO_4 \Leftrightarrow 2PbSO_4 + 2H_2O$$

Sulfation and Stratification

- Sulfation is the process where lead-sulfate crystallizes on battery plates when left at partial state-of-charge, and reduces capacity.
- Stratification is a condition that can occur in taller batteries when electrolyte concentration varies vertically in the battery cell. Resulting higher concentrations at the bottom of the cell accelerate battery degradation and loss of capacity.
- Proper charging can minimize the effects of sulfation and stratification.

Battery Types

- **Primary batteries are not rechargeable.**
- **Secondary batteries are rechargeable.**

- **Lead-acid batteries are classified based in their design and intended service:**
  - Starting, Lighting and Ignition (SLI) – not typically used in PV systems
  - Motive Power or Traction
  - Standby or Stationary

- **Batteries are also classified as either flooded or sealed valve-regulated types.**

Flooded and Sealed Batteries

- **Flooded batteries have a liquid (fluid) electrolyte.**
  - Open-vent types have removable caps that permit electrolyte additions.
  - Sealed-vent types have non-removable caps and do not permit electrolyte additions.
- **Valve-regulated lead-acid batteries have an immobilized electrolyte and sealed pressure-relief vents.**
  - Gelled types immobilize the electrolyte by the incorporation of additives.
  - Absorbed glass mat (AGM) types immobilize the electrolyte in glass separator mats.

Types of Lead-Acid Batteries

Flooded Lead-Acid Batteries

Valve-Regulated Lead-Acid Batteries

Gelled

Absorbed Glass Mat

Flooded Nickel-Cadmium Batteries

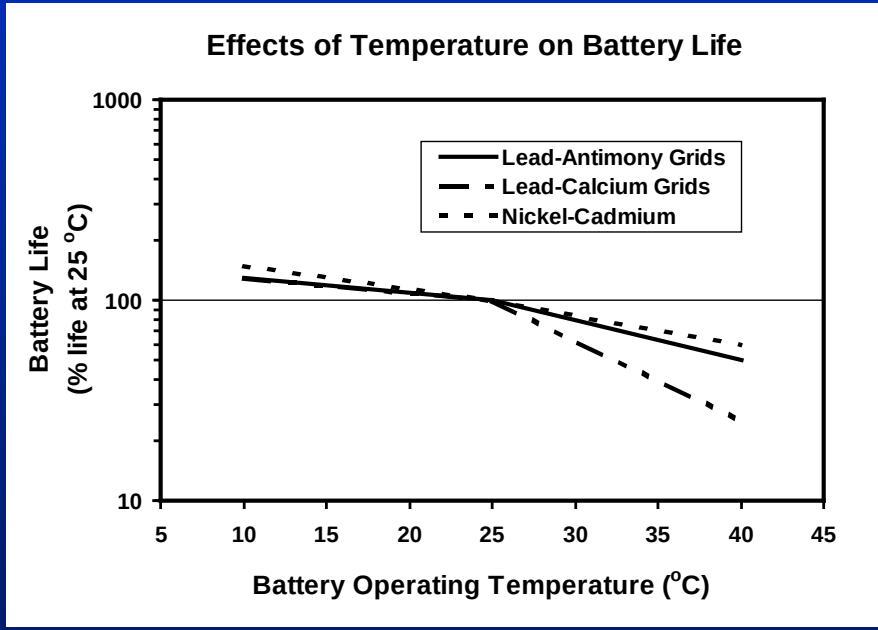
- Flooded pocket-plate nickel-cadmium batteries are used in some critical and low temperature PV applications.
- Advantages include long life and low maintenance, and excellent deep discharge and low temperature performance.
- Disadvantages include high cost and limited availability.
- Electrolyte is a flooded potassium-hydroxide solution.

Battery Characteristics

Battery Type	Advantages	Disadvantages
Flooded Lead-Acid		
Lead-Antimony	low cost, wide availability, good deep cycle and high temperature performance, can replenish electrolyte	high water loss and maintenance
Lead-Calcium Open-Vent	low cost, wide availability, low water loss, can replenish electrolyte	poor deep cycle performance, intolerant to high temperatures and overcharge
Lead-Calcium Sealed-Vent	low cost, wide availability, low water loss	poor deep cycle performance, intolerant to high temperatures and overcharge, can not replenish electrolyte
Lead-Antimony/Calcium Hybrid	medium cost, low water loss	limited availability, potential for stratification
Valve-Regulated Lead-Acid		
Gelled	medium cost, little or no maintenance, less susceptible to freezing, install in any orientation	fair deep cycle performance, intolerant to overcharge and high temperatures, limited availability
Absorbed Glass Mat	medium cost, little or no maintenance, less susceptible to freezing, install in any orientation	fair deep cycle performance, intolerant to overcharge and high temperatures, limited availability
Nickel-Cadmium		
Sealed Sintered-Plate	wide availability, excellent low and high temperature performance, maintenance free	only available in low capacities, high cost, suffer from ‘memory’ effect
Flooded Pocket-Plate	excellent deep cycle and low and high temperature performance, tolerance to overcharge	limited availability, high cost, water additions required

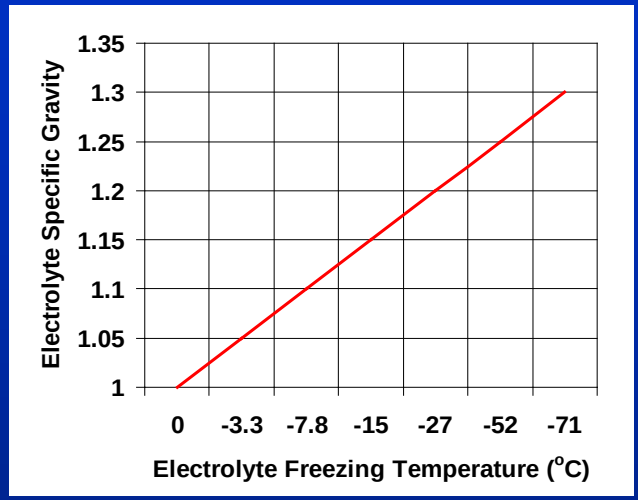
Effects of Temperature on Battery Life

- Lower operating temperatures reduce battery capacity but increase cycle life.
- For vented batteries, a 10°C increase in average operating temperature above 25˚C reduces battery life by 50%. This is worse for VRLA batteries.
- Higher temperatures accelerate corrosion of the grids and result in greater gassing and electrolyte loss.



Electrolyte Properties

- Electrolyte concentration is measured by its specific gravity, and related to battery state of charge.
- Batteries must be protected from freezing at low state-of-charge.



Specific Gravity	H_2SO_4 (Wt%)	H_2SO_4 (Vol%)	Freezing Point (°C)
1.000	0.0	0.0	0
1.050	7.3	4.2	-3.3
1.100	14.3	8.5	-7.8
1.150	20.9	13.0	-15
1.200	27.2	17.1	-27
1.250	33.4	22.6	-52
1.300	39.1	27.6	-71

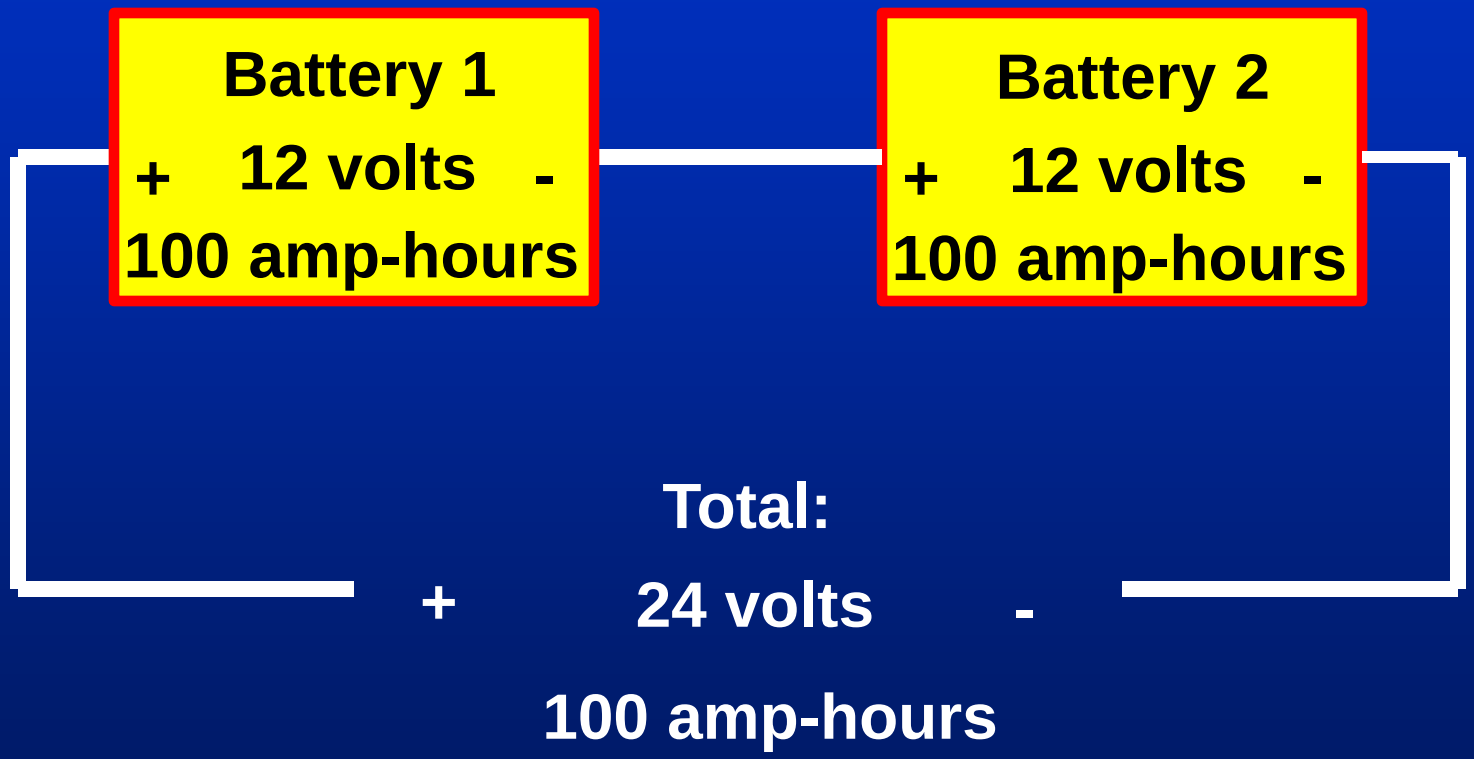
Battery Design and Selection Criteria

- **Electrical properties**
  - Voltage, capacity, charge/discharge rates
- **Performance**
  - Cycle life vs. DOD, system autonomy
- **Physical properties**
  - Size and weight
- **Maintenance requirements**
  - Flooded or VRLA
- **Installation**
  - Location, structural requirements, environmental conditions
- **Safety and auxiliary systems**
  - Racks, trays, fire protection, electrical BOS
- **Costs, warranty and availability**

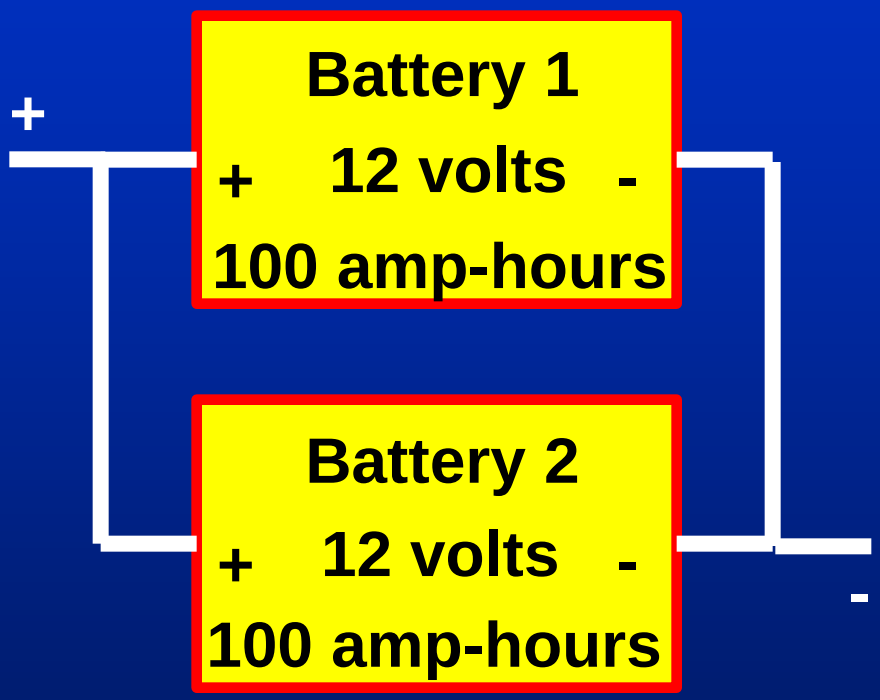
Battery Connections

- Batteries are first connected in series to achieve the desired DC system voltage for utilization equipment.
- Series connections of batteries are connected in parallel to increase energy storage capacity (amp-hours).

Series Battery Connections



Parallel Battery Connections



Total:

12 volts

200 amp-hours

OSHA Requirements for Battery Installations

- Unsealed batteries must be installed in ventilated enclosures to prevent fumes, gases, or electrolyte spray entering other areas, and to prevent the accumulation of an explosive mixture.
- Battery racks, trays and floors must be of sufficient strength and resistant to electrolyte.
- Face shields, aprons, and rubber gloves must be provided for workers handling acids or batteries, and facilities for quick drenching of the eyes and body must be provided within 25 feet of battery handling areas.
- Facilities must be provided for flushing and neutralizing spilled electrolyte and for fire protection.
- Battery charging installations are to be located in designated areas and protected from damage by trucks. Vent caps must be in place during battery charging and maintained in a functioning condition.

NEC Requirements for Battery Installations

- Battery installations in dwellings are limited to less than 50 volts, nominal unless live parts are not accessible during maintenance [690.71(B)].
- Live parts must be guarded for all battery systems in dwellings regardless of voltage [690.71(B)(2)].
- Live parts on any battery installations 50 volts and greater must be guarded [490.9, 110.27].
- Sufficient working spaces and clearances must be provided for any battery installations [110.26].

Battery Overcurrent Protection

- Battery circuit conductors must be protected from overcurrent in accordance with Art. 240 [690.9].
- Current-limiting overcurrent devices may be required for large battery banks with high fault currents [690.71(C)].
- Fuses energized from both directions must be able to be disconnected from all sources [690.16].

Battery Disconnects

- A disconnecting means must be provided for all ungrounded battery circuit conductors [690.15, 480.5].
- Disconnecting means must be provided for battery systems greater than 48 volts to isolate the battery system to sections no more than 48 volts for service and maintenance [690.71(E)].

Grounding Battery Systems

- **Battery systems are considered to be grounded when a current-carrying conductor of the connected PV source is grounded [690.71(A), 690.41].**

- **Battery systems over 48 volts are permitted without a grounded circuit conductor where all of the following apply:**
  - The PV and load circuits are grounded,
  - Both ungrounded battery circuit conductors have overcurrent protection and disconnecting means, and
  - A ground-fault indicator is required for the battery system [690.71(G), 690.35].

Battery Wiring Methods

- Flexible cables are permitted to facilitate battery connections [690.74, 400].
- Cables must be rated for hard service and moisture resistance. Welding cables are not allowed [690.74].
- Fine stranded cable must use lugs and terminals approved for such cables [690.74, 110.3].

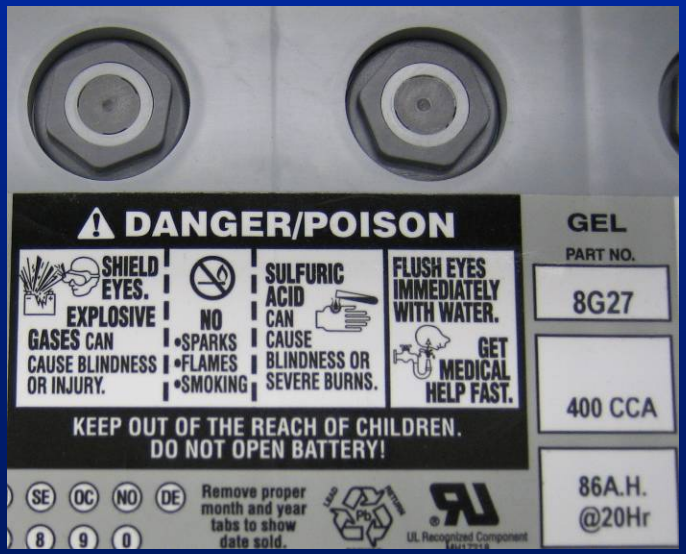
Battery Racks and Trays

- **Metal racks must be painted or otherwise treated to resist degradation from electrolyte and provide insulation between conducting members and the battery cells [480.9].**

- **Conductive racks are not permitted to be located within 150 mm (6 in.) of the tops of the nonconductive battery cases [690.71(D)].**
  - Does not apply to sealed batteries that are manufactured with conductive cases.
  - Conductive battery racks, cases or trays must also have proper equipment grounding.

Battery System Ventilation

- Ventilation of explosive battery gasses is required [480.9].
- Vented battery cells must incorporate a flame arrestor, and sealed batteries must have pressure relief vents [480.10].



Summary

- Batteries are used in stand-alone PV systems to store energy produced by the PV array for use by electrical loads as required.
- Batteries also establish the operating voltage for PV arrays and DC utilization equipment, such as charge controllers, inverters or DC loads.
- The types of batteries and their performance characteristics vary widely.
- Battery energy storage capacity is a function of temperature, discharge rate, cutoff voltage and age of the battery.
- Battery installation and safety requirements are covered in the National Electrical Code® and OSHA safety standards.

Questions and Discussion