MODULE 6 · STUDY NOTES

Data Center Battery Overview

How batteries support a data center's power supply, the three UPS battery chemistries, and the IEEE standards and IFC/NFPA fire codes that govern large stationary batteries

A data center only stays online while its equipment keeps receiving clean, uninterrupted power — and the battery is what makes that promise hold during the seconds when the grid drops and the generator has not yet spun up. This module first traces the whole power path (grid, transformer, generator, main distribution board, and the UPS) to show exactly where the battery fits and why it matters, then works through the three UPS battery chemistries — lead-acid with its valve-regulated and open-vented subtypes, nickel-cadmium, and lithium-ion — weighing the advantages and disadvantages of each. Because batteries store energy, contain inflammable electrolytes, and vent explosive hydrogen, the second half turns to governance: the difference between a voluntary standard and a legally imposed code, the IEEE standards that guide how large batteries are selected, installed, tested, and maintained, and the IFC and NFPA fire codes that dictate how they are stored, ventilated, and contained.

LEARNING OBJECTIVES

- Recognize the role of a battery in supplying power in a data center
- Identify the types of uninterruptible power supply (UPS) batteries used in a data center
- Identify the standards and codes associated with UPS battery systems

6.1 Sources of power supply in a data center

A data center requires several components working together to ensure a smooth, uninterrupted power supply. The **primary sources of power** are the **power grid**, the **transformer**, the **generator**, and the **main distribution board (MDB)**. The power grid is the main source — it supplies ample electricity for the power needs of the data center equipment. Before that electricity enters the facility, a **transformer** ensures the right voltage and type of current are supplied. Power is then directed to the MDB, which transfers it to the UPS, and the UPS passes the received power on to the equipment.

A **generator** is an on-premises electricity-generation device installed as a *secondary* source of power to be used during an outage. The catch is that a generator **takes time to start**. The **MDB** has two power sources — the grid and the generator — and when there is a problem with the grid supply, the MDB automatically switches to generator power. During the interval before the generator is ready, the **UPS supplies power to the equipment from its stored energy**; once the generator is up, the MDB transfers the load from the generator to the equipment through the UPS.

TABLE 6.1 The data-center power sources and where the battery fits

COMPONENT	ROLE IN THE POWER PATH
Power grid	The main source of supply — provides ample electricity for the data center's equipment
Transformer	Ensures the right voltage and type of current enter the data center before power reaches the MDB
Generator	On-premises generation used as the secondary source during an outage; reliable but takes time to start
Main distribution board (MDB)	Routes power from the grid or generator to the equipment through the UPS; automatically switches to generator power when the grid fails
UPS + battery	Stores grid power in batteries when utility power is available and supplies the critical load during an outage; the battery is its most important component

WHAT THE UPS DOES

- **Comes into play during a grid outage** — it is the source of power when the primary supply fails.
- **Supplies the critical load** while ensuring a consistent voltage.
- **Filters damaging power variations** such as high voltage, fluctuations, and sags — acting as a protection shield for the equipment.
- **Stabilizes the power supply and boosts uptime**, storing power in batteries when utility power is available and drawing on it during an outage.
- The **battery is the UPS's most important component** — it stores the power used during an outage.

WORKED EXAMPLE – THE OUTAGE SEQUENCE, STEP BY STEP

The grid drops. The MDB detects the loss of grid supply and begins switching over to the generator — but the generator cannot deliver power instantly; it needs time to start. In that gap, the UPS immediately supplies the critical load from the energy already stored in its batteries, holding voltage steady so servers, storage, and network gear never see the interruption. When the generator reaches full output, the MDB transfers the load to generator power, still routed through the UPS. When grid power returns, the flow reverts to the grid and the UPS recharges its batteries — ready for the next event. The battery, in other words, is what turns a hard outage into a seamless handoff.

A short module video, *Working of a Battery*, explains the underlying principle: a battery **creates power through a chemical reaction**, converting chemical energy into electrical energy. That chemistry — the electrodes and electrolyte a battery uses — is exactly what distinguishes the UPS battery types covered next.

COMMON PITFALL

The generator is not an instantaneous backup, and the UPS is not a generator. The generator needs time to start, and the UPS does not create electricity — it *stores* grid power in batteries and *discharges* it during the gap. Remove the battery and there is nothing to carry the critical load in the seconds before the generator is online.

6.2 Types of UPS batteries

There are **three types of UPS batteries — lead-acid, nickel-cadmium, and lithium-ion** — and they differ in the electrodes and electrolyte they use to turn chemical energy into electrical energy. **Lead-acid batteries** use sponge lead and lead peroxide as electrodes and water acidified with sulfuric acid as an electrolyte. They are very reliable for UPS systems, cost-effective, and low-maintenance, with minimal **self-discharge** — the tendency of a battery to lose its charge through chemical leakage or aging. Their disadvantages: the lead makes them not environmentally friendly; they **cannot be left in a discharged state** because that causes sulfation, after which the battery cannot be recharged; and, with limited discharge cycles, they are favorable mainly for **standby applications**.

Lead-acid batteries come in two subtypes. **Valve-regulated (VRLA)** batteries are sealed in a case and have vents in the valve to release pressure if it rises beyond a certain limit; they require no maintenance, can be placed horizontally or vertically because they are sealed, and use one of two electrolyte compositions — **absorbed glass mat (AGM)**, where the electrolyte is held in a porous glass separator, or **gel**, a mixture of silica and sulfuric acid. **Open-vented** batteries — also called *flooded* or *wet cell* because the plates are flooded with electrolyte — have a long life but are not sealed, so hydrogen is released directly into the environment; they must be maintained manually by adding water to the top, and because they carry risks they are **not preferred for use in data centers**.

VALVE-REGULATED (VRLA)	OPEN-VENTED (FLOODED / WET CELL)
sealed — preferred in data centers ▪ Sealed case; valve vents relieve pressure ▪ Maintenance-free; mount in any orientation ▪ AGM or gel electrolyte	*risky — not preferred* ▪ Flooded plates; long battery life ▪ Unsealed — vents hydrogen to the air ▪ Manual watering; risky, not preferred

Nickel-cadmium (Ni-Cd) batteries are rechargeable batteries that use nickel oxide and metallic cadmium as electrodes and water acidified with sulfuric acid as an electrolyte; the positive plate is composed of nickel hydroxide and the negative plate of cadmium hydroxide. Their advantages are substantial: a long life; high durability under large-current discharge, overcharge, and overdischarge; the ability to be stored in a discharged state; ultra-fast charging with little stress; and availability in a wide range of sizes and performance options. Their disadvantages: they are more expensive than valve-regulated lead-acid batteries; disposal is also expensive because nickel and cadmium are toxic; a low cell voltage of **1.20 V** means many cells are needed to reach a high voltage; and they have a **high self-discharge**, making them unsuitable for equipment that operates long-term at low power consumption.

Lithium-ion batteries, as the name suggests, use lithium ions moving from the negative electrode to the positive electrode to generate electrical energy. Rechargeable and long used in smartphones and electronics, they are increasingly used in UPS systems. Their advantages: a **built-in monitoring and management system** that checks the cells' performance; small size thanks to high power density; low maintenance; low self-discharge; and little need for cooling. Their disadvantages: they are costly compared with the other two types; they degrade at high temperature and when stored at high voltage; **rapid charging is not possible at freezing temperatures** (below 0 °C / 32 °F); they require transportation regulations when shipped in larger quantities; and they require a **protection circuit** to stay safe.

TABLE 6.2 The three UPS battery chemistries compared

CHEMISTRY	COMPOSITION	ADVANTAGES	DISADVANTAGES
Lead-acid	Sponge lead and lead peroxide electrodes; sulfuric-acid electrolyte	Reliable; cost-effective; low maintenance; minimal self-discharge	Not eco-friendly (lead); cannot be stored discharged; suited mainly to standby duty
Nickel-cadmium	Nickel-oxide and metallic-cadmium electrodes; sulfuric-acid electrolyte	Long life; endures overcharge/overdischarge; stores discharged; ultra-fast charge; wide size range	Costlier than VRLA; toxic disposal; low 1.20 V cells need many cells; high self-discharge
Lithium-ion	Lithium ions shuttle from the negative to the positive electrode	Built-in monitoring; small (high power density); low maintenance; low self-discharge; little cooling	Costly; degrades at high temperature/voltage; no rapid charge below freezing; needs a protection circuit

COMMON PITFALL

Do not confuse the self-discharge behaviors. Lead-acid and lithium-ion are the *low* self-discharge chemistries; **nickel-cadmium is high self-discharge**, which is exactly why it is a poor fit for long-term, low-draw equipment. And lithium-ion's low cooling needs do not mean it tolerates cold charging — it cannot be rapid-charged below freezing.

6.3 Standards and codes for UPS battery systems

UPS battery systems are governed by both **standards** and **codes**, and the distinction matters. A **standard** is a guideline issued by a designated authority that lists the best way of completing a task; it must be followed even though it is **voluntary**. (The International Organization for Standardization's ISO 9000, for example, gives guidelines for building quality systems.) The **Institute of Electrical and Electronics Engineers (IEEE) —** the world's largest technical professional organization **—** classifies standards by their degree of application into three levels: a **guide**, a **recommended practice**, and a **standard**.

KEY TERMS

Guide
The lowest level — basic informative material or a tutorial that enforces no rule and uses words such as 'may' or 'might'

Recommended practice
The middle level — encourages the user to do something and uses the word 'should'

Standard
The highest level, carrying the strongest degree of application

Code
A regulation imposed by law and enforced by government authorities; it may be modified to suit an area's needs, and negligence can lead to penalties or citations

A **code**, by contrast, is a regulation imposed by the law to be put into practice; government authorities implement and enforce it, and it may be modified according to the area and its needs. Non-compliance can lead to penalties. For example, if a safety code is not followed and an accident such as a fire outbreak or an injured worker occurs as a result, the owner or employer of the organization is susceptible to **fines or imprisonment**.

STANDARDS	CODES
voluntary — but should be followed	*legally imposed — enforced*
▪ Guidelines from a designated authority on the best way to do a task ▪ IEEE grades them: guide → recommended practice → standard ▪ Guide the selection, installation, testing, and maintenance of batteries ▪ Bodies include IEEE (most widely accepted), plus Cenelec and IEC	▪ Regulations imposed by law and enforced by government authorities ▪ May be modified to suit an area and its needs ▪ Non-compliance can bring penalties, fines, or imprisonment ▪ Fire safety codes come from the IFC and the NFPA

Why do these systems need such governance? UPS batteries are very important in a data center because they **limit the risk of downtime**, and modern batteries add enhanced features such as advanced charging and software management. But batteries provide constant support and yet **can fail**, and they raise other issues — lead-acid batteries, for instance, produce harmful **hydrogen gas that is both reactive and explosive**, so special ventilation and spill-containment systems must be used when installing them. Standards and codes have been created to provide **safety, compatibility, reliability, and environmental deference** when using UPS battery systems in a data center.

> **COMMON PITFALL**
>
> Standards are not laws, and the IEEE's three tiers are not interchangeable. A standard is voluntary (it *should* be followed); only a **code** is legally enforced. Within IEEE standards, a **guide** ('may'/'might') enforces nothing, a **recommended practice** ('should') is stronger, and a **standard** is stronger still — they differ in their degree of application.

6.4 IEEE standards for large batteries

Battery manufacturers produce batteries specifically for use in UPS systems to ensure the safety and quality of the systems used in a data center, and in doing so they follow prescribed standards; data centers, in turn, must follow installation standards. Although several standards organizations exist — such as **Cenelec** and the **IEC** — the standards defined by the **IEEE** are the most widely accepted for **selecting, installing, testing, and maintaining** battery systems. It is judicious to understand the basic requirements and prepare a list of questions before visiting a manufacturer.

TABLE 6.3 Key IEEE standards for large stationary batteries

IEEE STD.	WHAT IT COVERS
450	Recommended maintenance schedule, test time, and testing process to improve the lifetime and performance of installed, vented lead-acid (VLA) storage batteries in static mode; also guides battery replacement
485	Defines the direct current (DC) load, the sizing of a lead-acid battery, and the supply requirement of that load for static battery applications
1184	Guide for choosing the installation design, maintenance, and testing of VRLA, VLA, and Ni-Cd static standby batteries in UPS systems; also explains UPS battery charging and other converter components
1187	Rules for the design process, storage, placement, assembly, ventilation, instrumentation, and charging of VRLA batteries, including the necessary safety procedures
1188	Testing and maintenance procedures, with schedules for enhanced battery performance and life, and a battery-replacement procedure
1189	Guide to selecting the most relevant type of VRLA battery for static float applications, raising awareness of VRLA battery issues for better decisions
1375	Rules for the electrical protection process of static battery systems
1491	Operational specifications for battery-monitoring equipment in static applications, and the parameter values required under monitoring
1578	Electrolyte spill containment and management for electrolytes in VLA, VRLA, and Ni-Cd fixed batteries
1635 / ASHRAE 21	Ventilation and thermal management of stationary battery systems as applied to VLA, VRLA, and Ni-Cd batteries
1657	Information required to install and maintain stationary batteries, with corresponding systems to identify safety and reliability
1881	An informative reference for the stationary-battery industry, providing definitions used throughout the IEEE stationary-battery standards

THE THEMES THE IEEE STANDARDS COVER

- **Selection and sizing** — 485 (DC load and sizing), 1189 (choosing a VRLA type for float applications).
- **Installation and maintenance** — 1184, 1187, 1188, 450, 1657.
- **Protection and monitoring** — 1375 (electrical protection), 1491 (monitoring equipment).
- **Safety and environment** — 1578 (spill containment), 1635 / ASHRAE 21 (ventilation and thermal management).
- **Common vocabulary** — 1881 provides the definitions used across the stationary-battery standards.

6.5 Fire codes: the IFC and Section 608

Because batteries contain electrolytes that are highly inflammable, fire safety must be ensured during the installation and maintenance of UPS battery systems. Codes are the regulations that must be implemented to ensure human safety, health, and welfare, and two major councils define the fire safety codes for large stationary batteries that data centers must follow: the **International Fire Code (IFC)** and the **National Fire Protection Association (NFPA)**. The **International Code Council (ICC)** is a membership association responsible for ensuring building safety and fire prevention; it governs the international codes used to construct residential and commercial buildings. The **IFC is a member of the ICC —** it outlines the minimum requirements for fire safety and fire protection systems and is continuously revised to keep pace with new advancements and equipment.

Section 608 of the IFC deals with battery storage systems. It applies to stationary battery storage systems with capacities exceeding **70 kWh for lead-acid and Ni-Cd** batteries, **20 kWh for lithium, sodium, and flow** batteries, and **10 kWh for all others**. The section is organized into six subsections.

TABLE 6.4 IFC Section 608 subsections

SUBSECTION	TITLE	WHAT IT COVERS
608.1	Scope	Permits, construction documents, seismic and structural design, combustible-storage requirements, and the testing, maintenance, and repair of batteries and equipment
608.2	Location and Construction	Rules for the location of UPS battery systems, stationary battery arrays, and outdoor installations
608.3	Maximum Allowable Quantities	Unlimited for lead-acid and Ni-Cd; 600 kWh for lithium, sodium, and flow; 200 kWh for others
608.4	Storage Batteries and Equipment	Design and installation of storage batteries and associated equipment (chargers, inverters, safety caps, thermal-runaway protection)
608.5	Suppression and Detection System	Fire suppression, smoke detection, ventilation, gas detection, and spill control
608.6	Specific Battery Requirements	Requirements specific to lead-acid, Ni-Cd, lithium, sodium, and other battery types

COMMON PITFALL

Watch the two sets of Section 608 numbers — they are different questions. The **70 / 20 / 10 kWh** figures are the *applicability thresholds* that decide whether Section 608 governs a system at all. The **unlimited / 600 kWh / 200 kWh** figures under **608.3** are the *maximum allowable quantities* once it does apply.

6.6 NFPA codes

The **NFPA** is an international organization that promotes safety standards, education, and training on fire- and electrical-related hazards. **NFPA 1** is the fire code that provides an integrated approach to fire code regulation and hazard management to ensure fire and life safety for the public. Its **Chapter 52** applies to stationary battery storage systems with an electrolyte capacity higher than **1,000 pounds for lithium-ion** batteries, **100 gallons in a sprinkled building**, and **50 gallons in a non-sprinkled building** for lead-acid, Ni-Cd, and VRLA batteries.

NFPA 1, 52.3.6 — VENTILATION FOR BATTERY ROOMS AND CABINETS

- Applies to flooded lead-acid, flooded Ni-Cd, and VRLA batteries: rooms and cabinets must be designed for proper ventilation in accordance with the **International Mechanical Code (IMC)**.
- In addition, **one** of the following design considerations must be applied:
- The ventilation system must allow a **maximum of 1% hydrogen concentration** with reference to the volume of the room, **or**
- **Continuous ventilation** must occur at a rate no less than **1 cfm per square foot** of the total floor area of the battery room or cabinet.

Leveraging these standards and codes according to a data center's requirements should be treated as the most important parameter for the smooth functioning of large storage battery systems. It is often observed that when all or some of these standards and codes are not adhered to, data centers suffer serious damage and increased downtime — the very outcome the battery system exists to prevent.

Module summary

- Utility power flows grid → transformer → MDB → UPS → critical load; the grid is the main source, the transformer sets the right voltage and current, and the generator is the on-premises backup that feeds the MDB during an outage.
- A generator takes time to start, so the UPS discharges its batteries to carry the critical load until the generator is ready; the MDB then transfers the load to generator power. The battery is the UPS's most important component and makes power through a chemical reaction.
- Beyond backup, the UPS supplies the critical load with consistent voltage, filters damaging variations (high voltage, fluctuations, sags), stabilizes the supply, and boosts uptime.
- Three chemistries: lead-acid (reliable, cost-effective, low maintenance, minimal self-discharge, but heavy with lead and standby-only), nickel-cadmium (long life, durable, stores discharged, ultra-fast charge, but expensive, toxic, 1.20 V cells, high self-discharge), and lithium-ion (built-in monitoring, small/high-density, low self-discharge, little cooling, but costly, heat-sensitive, no sub-freezing rapid charge, needs a protection circuit).
- Lead-acid has two subtypes: valve-regulated (VRLA) — sealed, AGM or gel electrolyte, maintenance-free, mountable in any orientation, and preferred in data centers — and open-vented (flooded/wet cell) — long-lived but hydrogen-venting, needs watering, risky, and not preferred.
- A standard is a voluntary guideline from a designated authority (the IEEE grades them guide → recommended practice → standard); a code is a legally imposed regulation whose violation can bring fines or imprisonment.
- Standards and codes exist because batteries can fail and lead-acid emits reactive, explosive hydrogen — so ventilation and spill containment are required for safety, compatibility, reliability, and environmental deference.
- IEEE standards (450, 485, 1184, 1187–1189, 1375, 1491, 1578, 1635/ASHRAE 21, 1657, 1881) are the most widely accepted for selecting, installing, testing, and maintaining large stationary batteries.
- The IFC (a member of the ICC) governs fire safety; Section 608 applies above 70/20/10 kWh thresholds and covers scope, location, maximum quantities (unlimited/600/200 kWh), equipment, suppression and detection, and battery-specific requirements across six subsections.
- NFPA 1 Chapter 52 governs large battery storage; 52.3.6 requires battery-room ventilation (per the IMC) to hold hydrogen to at most 1% of room volume or provide continuous ventilation of at least 1 cfm per square foot.

Review questions

1. **Trace the data-center power path from the grid to the equipment, and say where the generator and battery fit.**

   Answer: Grid → transformer (right voltage/current) → MDB → UPS → equipment. The generator is the on-premises backup that feeds the MDB when the grid fails; because it takes time to start, the UPS battery discharges to carry the critical load in the interim, then the MDB transfers the load to generator power through the UPS.

2. **What does the UPS do beyond providing backup power?**

   Answer: It supplies the critical load with consistent voltage, filters damaging power variations (high voltage, fluctuations, sags), stabilizes the supply, and boosts uptime — acting as a protection shield for the equipment. It stores grid power in batteries when utility power is available and draws on it during an outage.

3. **Compare the two lead-acid subtypes and say which data centers prefer.**

   Answer: Valve-regulated (VRLA) are sealed with pressure-relief vents, maintenance-free, mountable in any orientation, and use AGM or gel electrolyte. Open-vented (flooded/wet cell) are unsealed, vent hydrogen into the environment, need manual watering, and are long-lived but risky. Data centers prefer VRLA; open-vented is not preferred.

4. **Give one standout advantage and one disadvantage of each battery chemistry.**

   Answer: Lead-acid: cost-effective / not environmentally friendly and standby-only. Nickel-cadmium: long life and high durability / expensive with high self-discharge. Lithium-ion: built-in monitoring and small size / costly and cannot be rapid-charged below freezing.

5. **How does a standard differ from a code, and how does the IEEE grade its standards?**

   Answer: A standard is a voluntary guideline that should be followed; a code is a legally imposed regulation whose violation can bring penalties, fines, or imprisonment. The IEEE grades standards as a guide (lowest, 'may'/'might'), a recommended practice (middle, 'should'), or a standard (highest).

6. **Why are fire codes necessary for battery rooms, and which two councils set them?**

   Answer: Battery electrolytes are highly inflammable and lead-acid batteries emit reactive, explosive hydrogen, so ventilation and spill containment are required for human safety. The International Fire Code (IFC, a member of the ICC) and the National Fire Protection Association (NFPA) set the fire safety codes for large stationary batteries.

7. **What capacity thresholds trigger IFC Section 608, and what maximum allowable quantities does it set?**

   Answer: It applies above 70 kWh for lead-acid and Ni-Cd, 20 kWh for lithium/sodium/flow, and 10 kWh for all others. Its 608.3 maximum allowable quantities are unlimited for lead-acid and Ni-Cd, 600 kWh for lithium/sodium/flow, and 200 kWh for others.

8. **What does NFPA 1, 52.3.6 require for battery-room ventilation?**

   Answer: For flooded lead-acid, flooded Ni-Cd, and VRLA batteries, rooms and cabinets must be ventilated per the International Mechanical Code, and one of two options must apply: hold hydrogen to a maximum of 1% of the room volume, or provide continuous ventilation of at least 1 cfm per square foot of floor area.