MODULE 7 · STUDY NOTES

Data Center Generators

The three components of a standby generator, its operating modes, how it draws on utility resources, the fuels that power it, and the fuel system that keeps it running

A data center is expected to run non-stop, and the number that captures that promise is a `99.99%` annual availability target. Grid power cannot guarantee it — one of the biggest causes of downtime is a utility failure or an unstable main supply, and a sudden loss of power can corrupt sensitive data and damage IT equipment. The standby generator is the insurance policy: a properly sized backup that carries the critical IT load and its supporting infrastructure through an outage or a maintenance window. This module opens the generator up — first the three components that make backup power automatic and seamless (the emergency generator, the automatic transfer switch (ATS), and the uninterruptible power supply (UPS)) and the nine elements inside the emergency generator itself, then the two operating modes and how the ATS draws on two or three utility and self-generated power inputs. Next come the fuels that turn combustion into electricity — six common types, each with trade-offs — and finally the fuel system that keeps the generator fed: its requirements, safe handling and cooling, its four redundant component units, ongoing maintenance, and the NFPA codes that govern all of it.

LEARNING OBJECTIVES

- Describe the three main components of a standby generator
- Describe the two operating modes of a standby generator
- Describe the use of utility resources related to generator operation
- Identify the types of fuel used by generators
- Recognize the components of the fuel system used by generators in a data center

7.1 Standby generators and the three main components

A **standby generator** is an important component in achieving higher data center uptime. IT equipment may rarely need to fall back on backup power, but having a backup source on standby is essential: it **avoids unnecessary downtime**, helps achieve the annual availability target of `99.99%`, **ensures a consistent power supply** to the connected devices, and **switches to a backup source** if the primary source fails. Standby generators must be **properly designed and sized** to continuously supply power to the critical IT load and its associated supporting infrastructure, both during a power outage and during maintenance.

Many capacities and voltages are available on the market — for example *3 MVA at 415 V* or *2.4 MVA at 10 kV*. Low-voltage generators do not usually synchronize generators, whereas medium-voltage generators usually synchronize generators, as in power stations. A standby generator has **two or three power inputs** — a combination of utility lines and power generated by the generator itself — and switches to a backup source if the primary fails. That switch is managed by the **automatic transfer switch (ATS)**, which works in conjunction with the **uninterruptible power supply (UPS)** that supplies temporary power while the switch is being completed.

WHY A STANDBY GENERATOR MATTERS

- Avoids unnecessary downtime for equipment that may not use backup power regularly but cannot afford to lose it
- Helps achieve the annual availability target of `99.99%`
- Ensures a consistent power supply to every device connected to it
- Automatically switches to the backup power source if the primary (usually the utility) fails

TABLE 7.1 The three main components of a standby generator

COMPONENT	ROLE
Emergency generator	Generates backup power in case of failure of the primary power source (usually the utility)
Automatic transfer switch (ATS)	Governs the source of power output to the connected devices; manages the transition from one power source to another on failure
Uninterruptible power supply (UPS)	Provides temporary power as the ATS performs the power-source switch; a combination of a battery and a charger

COMMON PITFALL

The three components are easy to conflate. Keep the division of labor straight: the **emergency generator** makes the backup power, the **ATS** decides and executes which source feeds the load, and the **UPS** carries the load for the brief moment the ATS needs to complete the switch.

7.2 The emergency generator: nine elements

The **emergency generator** generates backup power when the primary power source fails. Most generators consist of nine elements working together to turn stored fuel into clean, regulated electricity. The **engine** is the main part that produces electricity — the more powerful the engine, the higher its electricity-production capacity. It converts fuel (commonly diesel, gasoline, natural gas, and several others) into mechanical energy and then into electrical energy; steam engines, turbines, and microturbines are also widely used to generate energy.

TABLE 7.2 Elements of the emergency generator

ELEMENT	WHAT IT DOES
Engine	Produces electricity by converting fuel into mechanical (then electrical) energy; capacity scales with engine power
Alternator	A fixed stator and a moving rotor create an electromagnetic field, converting mechanical energy into electrical energy
Fuel system tank	Stores the generator's fuel; tank capacity affects how much electricity the generator can produce, and vice versa
Voltage stabilizer	Regulates the electricity generated by the alternator; converts the AC supply to DC supply when required
Cooling & exhaust systems	A fan and coolant reduce thermal stress from continuous high-output operation; the exhaust system expels the hot air
Lubrication system	Keeps all parts oiled or lubricated to protect the mechanical parts from wear and tear due to friction
Battery charger	An automatic device that keeps the battery charged and stays on 24/7 standby to start the generator in an emergency
Control panel	The user interface for electric start/shutdown, engine and generator gauges, and other manual and automatic controls
Frame	The outer body of the generator

The **fuel system tank** is a space to store the generator's fuel, and its capacity impacts the amount of electricity the generator can produce. An **injector** forces fuel from the tank into the engine, where **combustion** is carried out to power the engine; the remaining fuel is then redirected back to the tank after proper filtration. The **alternator** consists of two parts — while the stator remains fixed, the rotor moves to create an electromagnetic field, thereby producing electricity — and effectively converts mechanical energy into electrical energy.

> **FOLLOW THE ENERGY: FUEL TO USABLE POWER**
>
> Trace one cycle through the elements. The tank stores fuel; an injector forces it into the **engine**, where combustion converts the fuel into mechanical energy. The engine drives the **alternator**, whose spinning rotor and fixed stator create an electromagnetic field that turns that mechanical energy into electrical energy. The **voltage stabilizer** then regulates that raw output and converts AC to DC where required. Meanwhile the **cooling and exhaust** systems shed heat, the **lubrication** system fights friction, and the **battery charger** stands ready to crank the engine the next time the generator is called on.

7.3 The automatic transfer switch (ATS)

The **ATS shifts the power source between the utility supply and generator-produced electricity**. In data centers, *low-voltage ATS* units are common; a low-voltage ATS can detect delays in as little as **one second** and initiate the appropriate power-source shift. An ATS can be either **manual** or **automatic**.

MANUAL ATS	AUTOMATIC ATS
operator-driven, for maintenance ▪ Switches the generator's operation mode from automatic to manual ▪ Used during preventative maintenance ▪ Enables safety and testing procedures	*senses and switches on its own* ▪ Identifies a change in the availability of power from the main source ▪ Automatically shifts to the alternate source when the main source fails ▪ Shifts back to the main source when available power is restored ▪ Operates in one of two transition modes: open or closed

TABLE 7.3 The automatic ATS's two transition modes

MODE	SWITCHING ORDER	CHARACTERISTIC
Open transition	First breaks the connection from the main source, then connects to the emergency source	Break-before-make; a momentary gap
Closed transition	First connects the emergency source, then disconnects from the main source	Make-before-break; brief overlap

COMMON PITFALL

Open versus closed transition turns entirely on **order of operations**. Open transition *disconnects the main first*; closed transition *connects the emergency first*. Exam distractors swap the two — anchor on which source is touched first.

7.4 The UPS and standby generator operating modes

The **UPS system works with the ATS and the emergency generator** to facilitate immediate switching during a power failure, providing power backup either as a standalone unit or coupled with other backup systems. A UPS runs on the main power supply and has a battery that is kept charged for emergencies. Under normal conditions, the main power flows *through* the UPS to the equipment, avoiding surge or fluctuation damage; in the case of a power surge, the UPS battery takes over immediately. In a data center, the UPS plays a vital role in providing backup during both a power outage and the maintenance process.

ADVANTAGES OF A UPS SYSTEM

- Keeps equipment safe during a power surge
- Provides smooth electrical flow without any surge or fluctuation, even if either occurs in the main supply
- Provides instant power-backup support and cost efficiency when coupled with an emergency generator

Standby generators have **two operating modes: normal and emergency**. In **normal mode**, power is flowing as expected from the main power source. **Emergency mode** activates when the ATS detects a failure in the *main* power supply and, along with the UPS, orchestrates a switch to the *backup* power supply.

NORMAL MODE	EMERGENCY MODE
business as usual ▪ Power is flowing as expected from the main power source ▪ The UPS conditions that power on its way to the equipment ▪ The generator waits on standby	*main source has failed* ▪ The ATS detects a failure in the main power supply ▪ The UPS carries the load momentarily ▪ The ATS orchestrates a switch to the backup (generator) supply

COMMON PITFALL

A common false statement claims emergency mode switches *to the main* supply (or that the ATS detects a failure in the *backup*). Both are reversed. Normal mode = main source healthy; emergency mode = main source **failed**, so the system switches **to the backup**.

7.5 How generators use utility resources

Generators are an **indispensable part of a data center**, boosting the uptime and life of IT equipment. A standby generator contains an **ATS that governs the distribution and output of power**. That ATS can have **two or three sources of power**, which it switches between as needed to maintain the supply. The **transitions between sources are triggered by monitoring the available voltage** from those sources. Generators use fuel as input to create power independently, and they also require input from utility resources to pass power forward to the connected devices.

FEATURES OF A STANDBY GENERATOR'S POWER HANDLING

- **ATS** — governs the distribution and output of power to connected devices
- **Transitions** — switches between sources, triggered by monitoring the available voltage
- **Fuel inputs** — fuel creates power independently; utility resources are also drawn on to feed the load
- The ATS is designed to receive **two or three** power inputs, in a variety of combinations, to keep the supply constant

In practice, the ATS receives power input from **at least two sources —** typically a combination of utility resource lines and power created by the generator itself. It monitors the voltage of the primary power source (typically the utility resource) and, if a failure is detected, switches between sources as needed to maintain the power supply to the connected devices.

7.6 Generator fuel types

Fuel is required for generators to create power, and the right fuel depends on the scenario. Some generators are even **bi-fuel**, meaning they can use gasoline or diesel.

TABLE 7.4 Common fuel types by generator scenario

SCENARIO	APPLICATION	FUEL TYPE
Scenario 1	Industries and other applications with heavy electricity requirements	Diesel
Scenario 2	Residential generator	Natural gas, propane
Scenario 3	Portable generator	Gasoline, diesel, propane

There are **six common generator fuel types**: diesel, emulsified diesel, biodiesel, gasoline, propane, and natural gas. Each carries its own trade-offs in flammability, shelf life, cleanliness, cost, and availability during an outage.

TABLE 7.5 The six common generator fuel types — advantages and disadvantages

FUEL	ADVANTAGES	DISADVANTAGES
Diesel	Least flammable; easily available and delivered; cost-effective	Shelf life up to 24 months; may cause pollution; supply may be impacted by a power outage
Emulsified diesel	Medium flammability; easily available and delivered; cost-effective	Shelf life up to 24 months; difficult to maintain the water/diesel ratio; supply may be impacted by outages
Biodiesel	Medium flammability; easily available; cleaner fuel; cost-effective; easy to store and use; fewer emissions	Shelf life up to 24 months; supply may be impacted by outages (made from vegetable oil)
Gasoline	Easily available	Extremely flammable; shelf life up to 12 months; storable only in limited quantities; expensive and inefficient
Propane	Cleaner fuel, no residue, fewer emissions; easy to store; available during outages; cost-effective	Highly flammable; complex and prone to failed operations; needs special plumbing that raises install cost; risky if pipes mishandled
Natural gas	Easily available and in bulk; cleaner fuel; available during outages; fewer emissions	Possibly unavailable during natural disasters; lower output than gasoline; needs special plumbing; risky if pipes mishandled

COMMON PITFALL

Diesel is a favorite exam target because it inverts an intuition: it is the **least flammable** of the six fuels and the **most common** data-center fuel, even though it can burn inefficiently, may cause pollution, and runs in noisy engines. Gasoline, by contrast, is **extremely flammable** with the shortest shelf life.

7.7 Fuel systems and fuel requirements

Every operational data center runs non-stop, every day, to meet constant global demand for data availability, so it must stay up without delay. One of the biggest reasons for downtime is **grid power failure or an unstable main supply —** a sudden power failure can lead to the loss of sensitive data and can damage IT equipment. A generator works as an **emergency power-backup system** to ensure zero or minimal downtime: it takes the main supply as input and distributes it to the data center load, and on a utility failure it immediately switches the load to generator-produced power (the emergency power supply). To keep that backup working, **extra fuel must be stocked**.

FUEL REQUIREMENTS

- Generator **capacity should match the load requirement** of the data center
- Generator operators must ensure the required fuel is **always available**
- The most optimal generator is the one that suits all of the data center's requirements **using fuel readily available in the area**

SIZING FUEL STORAGE – THE DAY TANK AND THE STORAGE TANK

Suppose a data center must store enough fuel for **30 hours**, but its **day tank** capacity only allows for **15 hours** of power. Because the day tank is short, another tank — a **storage tank** — is required to make up the difference, sized to the remaining `15 hours` and kept filled. The basic rule for finding the optimal fuel-storage capacity is **not** to evaluate the best-case scenario; instead, it is the *minimum amount of fuel that should always be available*. Different data centers have different loads served by different generators, and the optimal generator is the one that meets every requirement using fuel that is easily available in the vicinity.

7.8 Safe fuel systems and fuel cooling

Data center fuel systems cater to higher loads for a longer time, and fuel is a **combustible and flammable material** that demands care in storage and handling. Achieving safe operation depends on both having enough fuel and handling it correctly at every step.

ELEMENTS OF A SAFE FUEL SYSTEM

- Sufficient fuel must be available **both inside the fuel tank and in standby fuel storage**
- Storing, transporting, and transferring fuel must be done **with care** to avoid any accident
- Ensure proper fuel **delivery, storage, filtration, and combustion**
- As a general best practice, store bulk fuel **away from the generator and data center building** if possible

Fuel systems also heat up easily. In many cases, pumps continuously supply excess fuel to the engine, causing a bulk of overheated fuel to return to the day tank. If the generator must run for long hours while outside temperatures are high, the returning fuel gets hotter — possibly beyond the generator's limits — causing a **thermal shutdown**. These conditions create *thermal stress* on the generator, and it must be handled.

THE THERMAL-STRESS RULE OF THUMB

Every `10 °F` of temperature increase above `100 °F` causes the engine horsepower to decrease by almost `1%`. Thermal stress can be handled effectively in two ways: **redirect the hot fuel to an underground bulk fuel tank** instead of the day tank, and **integrate a fuel cooling system (a fuel cooler)** to immediately lower the impacts of fuel overheating.

7.9 Fuel system components and maintenance

A **fuel system consists of pumps, day tanks, automated and manual valves, bulk tanks, and control panels**. All of these components must be capable of **concurrent maintainability** and **fault tolerance**, which is why the fuel-system components of a data center must be **redundant**. The components can be categorized into four important units: the **fuel unit**, the **fuel polishing module**, the **fuel transferring pump**, and the **fire safety design**.

KEY TERMS

Concurrent maintainability
The ability to perform maintenance of data center equipment without affecting the operations of the data center

Fault tolerance
The ability of the systems to operate even if there is a failure

TABLE 7.6 The four fuel-system component units

UNIT	PURPOSE AND REDUNDANCY
Fuel unit	The fuel tanks (day tanks); ideally installed underground with ample space and fire protection. Capacity follows redundancy standards — if a 30-hour tank is needed, add another 30-hour tank
Fuel polishing module	Cleans the fuel and prevents contamination; the pump and filter assembly are its main equipment. Redundancy follows the `1+1` principle (1 running, 1 on standby)
Fuel transferring pump	Moves fuel with redundancy of `n+1` or `n+n`; covers the electrical panel, has a meter for fuel input, and provides for leak detection
Fire safety design	Tank isolated and fitted with a fire alarm and water sprinkler; a fire hydrant installed for the tank unit; electrical equipment is explosion-proof

Every system needs maintenance, and **fuel system maintenance must be performed regularly** so the data center keeps performing optimally. Fuel **degrades** because it is vulnerable to the growth of microbes and to dust and particle formation, and that degradation impacts the combustion process. Where fuel is consumed and refilled continuously, degradation is rare; where stored fuel is hardly used, degradation is common.

TACKLING FUEL DEGRADATION

- **Fuel testing** should be done regularly to identify and tackle degradation and contamination
- **Cleaning and filtration** is important for contaminated fuel
- **Fuel polishing** cleans the fuel by passing it through a series of filters and water separators
- **Biocides** can be injected into the fuel polishing process to keep the fuel uncontaminated longer

7.10 Fuel system codes

Because fuel is combustible and flammable, all equipment in the fuel system must comply with **fuel system codes** crafted to protect life and resources around a generator and its fuel storage. In the United States, the **National Fire Protection Association (NFPA)** is a key issuer of fuel-tank regulations; **CSA Group** requirements (formerly the Canadian Standards Association) or other applicable governing bodies may also apply depending on your geography. These codes do not imply that fuel tanks are mounted on top of the generators.

TABLE 7.7 Key NFPA codes for generator fuel systems

CODE	TITLE AND COVERAGE
NFPA 30	Flammable and Combustible Liquids Code — governs different types of fuel tanks under various standards, such as above-ground tanks built to American Petroleum Institute (API) standards
NFPA 37	Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines — Chapter 6 considers only liquid fuel systems (diesel and gasoline); diesel is the most popular and commonly used generator fuel
NFPA 110	Standard for Emergency and Standby Power Systems — states the basic requirements for an emergency power supply system to run smoothly

COMMON PITFALL

Keep the three codes distinct by scope: **NFPA 30** is about the *liquids and tanks*, **NFPA 37** is about the *engines and turbines* (liquid fuel only — diesel and gasoline), and **NFPA 110** is about the *emergency and standby power system* as a whole.

Module summary

- A standby generator is a properly sized backup that carries the critical IT load and its supporting infrastructure through an outage or maintenance, helping hit the `99.99%` availability target; its three main components are the emergency generator (makes backup power), the ATS (governs and executes which source feeds the load), and the UPS (a battery-and-charger that supplies temporary power while the ATS switches).
- The emergency generator has nine elements: engine, alternator, fuel system tank, voltage stabilizer, cooling & exhaust systems, lubrication system, battery charger, control panel, and frame — the engine converts fuel to mechanical energy and the alternator converts that to electrical energy.
- A data-center low-voltage ATS detects a delay in as little as one second; a manual ATS is used for maintenance, while an automatic ATS senses main-source loss and switches (open transition = break-before-make; closed transition = make-before-break).
- The two operating modes are normal (power flowing from the main source) and emergency (ATS detects a failure in the main supply and, with the UPS, switches to the backup supply); the ATS receives two or three power inputs — combinations of utility lines and generator-produced power — switching between them by monitoring available voltage.
- Six common fuels — diesel (least flammable, most common), emulsified diesel, biodiesel, gasoline (extremely flammable), propane, and natural gas — trade off flammability, shelf life, cleanliness, cost, and availability during outages.
- Fuel systems must store enough to match the load (a storage tank makes up a short day tank, sized to the minimum that must always be available), be handled safely (bulk fuel away from the building), and be cooled — thermal stress costs ~1% horsepower per 10 °F above 100 °F, managed with underground bulk tanks and fuel coolers.
- The fuel system delivers concurrent maintainability and fault tolerance through redundancy across four units — fuel unit, fuel polishing module (`1+1`), fuel transferring pump (`n+1` or `n+n`), and fire safety design — maintained by testing, filtration, fuel polishing, and biocides, and governed by NFPA 30 (liquids/tanks), NFPA 37 (engines/turbines, liquid fuel only), and NFPA 110 (emergency and standby power systems), plus CSA and API standards.

Review questions

1. **What are the three main components of a standby generator, and what does each one do?**

   Answer: The emergency generator generates backup power when the primary source (usually the utility) fails; the ATS governs which source feeds the connected devices and manages the transition on failure; the UPS (a battery-and-charger) provides temporary power while the ATS performs the switch.

2. **Trace how the emergency generator turns stored fuel into regulated electricity, naming the key elements.**

   Answer: The fuel tank stores fuel; an injector forces it into the engine, where combustion converts it to mechanical energy; the alternator (fixed stator + moving rotor) converts that mechanical energy to electrical energy; the voltage stabilizer regulates the output and converts AC to DC when required — while cooling/exhaust, lubrication, and the battery charger keep it running.

3. **How does a manual ATS differ from an automatic ATS, and what are the automatic ATS's two transition modes?**

   Answer: A manual ATS is switched to manual mode for maintenance, safety, and testing; an automatic ATS senses loss of the main source, shifts to the alternate source, and shifts back when power is restored. Its two modes are open transition (break from main first, then connect emergency) and closed transition (connect emergency first, then break from main).

4. **Describe what happens in normal mode versus emergency mode.**

   Answer: In normal mode, power flows as expected from the main source (conditioned by the UPS). In emergency mode, the ATS detects a failure in the main supply and, together with the UPS, orchestrates a switch to the backup (generator) supply.

5. **Name the six common generator fuel types, and identify which is least flammable and most common in data centers.**

   Answer: Diesel, emulsified diesel, biodiesel, gasoline, propane, and natural gas. Diesel is the least flammable and the most commonly used data-center fuel.

6. **A data center needs 30 hours of fuel but its day tank holds only 15 hours. What must be done, and what rule governs storage capacity?**

   Answer: Install and fill a storage tank to make up the shortfall (another 15 hours). The rule is to size storage to the minimum amount of fuel that should always be available, not to the best-case scenario — and the fuel unit follows redundancy standards (e.g., a second 30-hour tank).

7. **What are concurrent maintainability and fault tolerance, and what are the four component units of a fuel system?**

   Answer: Concurrent maintainability is performing maintenance without affecting operations; fault tolerance is continuing to operate even if a failure occurs. The four units are the fuel unit, the fuel polishing module, the fuel transferring pump, and the fire safety design — all made redundant to achieve both.

8. **Which three NFPA codes matter for generator fuel systems, and what does each cover?**

   Answer: NFPA 30 (Flammable and Combustible Liquids Code — fuel tanks, e.g., above-ground tanks to API standards); NFPA 37 (installation and use of stationary combustion engines and gas turbines, considering only liquid fuel — diesel and gasoline); and NFPA 110 (Standard for Emergency and Standby Power Systems).