Data Center Physical Infrastructure - Power

01 MUST KNOW

if you remember five things, remember these

01 **The power path: utility feed (480 V–21 kV, higher at scale) → transformer → switchgear → UPS/generator backup → PDU → wireway/busway → rPDU → IT equipment.** A *transformer* lowers voltage; a *switchgear* protects and transfers it (and acts as an ATS to the generator); a *wireway* carries it to the racks; an *rPDU* — a power strip with extras — feeds the rack components.

02 **Transformers step voltage down:** a single transformer per lineup typically converts utility voltage to **480 V** (phase-to-phase) or **277 V** (phase-to-neutral) for the building and HVAC, then a second step-down to **208 V** or **120 V** feeds the PDUs and racks. Transformers are *static* devices — energy transfers by **electromagnetic induction**, so there are no moving parts, only a small energy loss, and input ≈ output power (watts) at a constant frequency.

03 **Generator + UPS partnership: generators are the primary backup but take ~20 to 30 seconds to start and pick up the load.** The **UPS** bridges that gap with stored battery power the instant utility fails, until the generator is online — so the two must be *synchronized* for a seamless transfer. Data centers target **100 percent uptime**.

04 **Three UPS types: standby** (offline until the main supply drops, no surge protection, common on desktops) · **line-interactive** (active while utility is connected, protects against surges) · **double-conversion** (AC→DC→AC, highest protection — keeps electricity from flowing straight to the server).

05 **Safety is regulated: OSHA** (federal-law work practices) and the **NFPA** (300+ consensus codes) govern data center electrical safety. The four essential regulations: `OSHA 29 CFR 1910`, `NFPA 70` (safe design/installation), `NFPA 70E` (safe work practices + PPE), `IEEE 1584` (arc flash calculations). An **arc flash** can reach **35,000 °F**.

02 KEY TERMS

TERM	DEFINITION
Transformer	Static device that transfers energy between circuits by electromagnetic induction to step voltage (and current) up or down; nearly equal input and output power at constant frequency
Switchgear	Assembly of disconnect switches, fuses, and circuit breakers that controls, protects, and isolates equipment, safely transfers utility power, and acts as an ATS to a generator
Wireway	Modular track of wires that distributes power from the main supply to the racks; connects racks to PDUs (directly or through an RPP)
Busway	Modular track placed above or below the racks — a wireway that can distribute three-phase power
Three-phase power	AC supply system using three power lines so that current is always available from any two of the lines
PDU	Power distribution unit — a floor-mounted panel of a transformer and breakers that distributes power to racks; it cannot generate power, only deliver AC
rPDU	Rack power distribution unit — a power strip with added functionality, mounted in the rack (horizontal or vertical) to feed the IT equipment inside it
RPP	Remote power panel — a freestanding distribution system without a transformer that extends a PDU's circuit capacity without adding PDUs
UPS	Uninterruptible power supply — supplies stored battery power to bridge the gap between a power failure and generator startup; stays on standby when utility power is available
ATS	Automatic transfer switch — switches the load to the generator when utility power fails and switches back (shutting the generator off) when it is restored

TERM	DEFINITION
PUE	Power usage effectiveness = total facility power ÷ IT equipment power; measures how effectively power is consumed (DCiE is its inverse)
Arc flash	Energy release when the insulation between energized conductors fails and current arcs through the air; can reach 35,000 °F, and its explosion is an arc blast

03 THE DATA CENTER POWER PATH

high voltage in, low voltage to the rack

01 **Utility feed** — 480 V to 21 kV (higher at scale) → 02 **Transformer** — steps down to 480/277 V, then 208/120 V → 03 **Switchgear** — protects, isolates, transfers (ATS) → 04 **Backup** — UPS bridges, generator takes the load → 05 **PDU** — floor-mounted transformer + breakers → wireway/busway → 06 **rPDU** — in-rack strip feeds the IT equipment

04 UPS SYSTEM TYPES

know surge protection and standby behavior

TYPE	SURGE PROTECTION	HOW IT OPERATES
Standby	None	Offline / on standby until the main supply is disconnected; widely used for desktops
Line-interactive	Protects against surges	Active even when the main power supply is connected
Double-conversion	Highest level	Converts AC→DC, sends some DC to charge the battery, reconverts the rest to AC; blocks electricity flowing straight to the server

05 COMMON PDU TYPES

basic just distributes; intelligent PDUs meter and control

PDU TYPE	CAPABILITY
Basic	Reliable power distribution to multiple devices
Metered	Network-grade; locally monitors load level to avoid potential overloads
Monitored	Network-grade; remotely monitors single- or three-phase voltage, frequency, and load in real time over a built-in network connection
Switched	Network-grade; adds remote outlet control — switch power on/off, shut down remotely, assign power efficiently
Floor-mounted (MDU)	Large unit (300 kVA and higher) bridging building power to many equipment racks
rPDU	Rack-mounted, horizontal or vertical; feeds IT equipment inside the rack; some are remotely accessible

06 STEP-UP VS STEP-DOWN TRANSFORMER

power stays constant, so V and I trade off

STEP-UP TRANSFORMER

increases voltage, decreases current

- Primary winding has *fewer* turns than the secondary
- Secondary voltage is higher than the primary
- Current falls from high to low (power = V × I stays constant)
- Example: secondary 100 turns / primary 50 turns → double the voltage, half the current

STEP-DOWN TRANSFORMER

decreases voltage, increases current

- Primary winding has *more* turns than the secondary
- Secondary voltage is lower than the primary
- Current rises from low to high
- Steps utility voltage down for data center equipment — the common case
- Example: primary 100 turns / secondary 50 turns → half the voltage

07 EXAM TRAPS

where the knowledge check gets you

- × "A PDU can generate power." — A PDU **cannot generate power**; it only *delivers* AC power sourced from a power supply, UPS, utility, or generator, converting one or several inputs into multiple outputs.
- × "Any PDU tracks power consumption." — Only **metered** (and higher) PDUs track consumption using meters; a **basic** PDU simply distributes power.
- × "Generators carry the load the instant utility fails." — A generator takes about **20 to 30 seconds** to start and pick up the load; the **UPS** supplies battery power across that gap, which is why the two must be synchronized.
- × "PUE and DCiE are the same metric." — **DCiE is the inverse of PUE.** `PUE = total facility power ÷ IT equipment power`; `DCiE = IT equipment power ÷ total facility power`.
- × "A step-up transformer has more turns on the primary." — Backwards: a **step-up** transformer has *fewer* turns on the primary than the secondary; a **step-down** transformer has *more* turns on the primary.
- × "NFPA 70 and NFPA 70E are interchangeable." — **NFPA 70** is the benchmark for safe electrical *design, installation, and inspection*; **NFPA 70E** covers safe *work practices*, maintenance, and PPE selection. IEEE 1584 is the arc flash *calculation* guide; OSHA 29 CFR 1910 is federal work-practice law.
- × "Natural gas generators need on-site fuel storage." — Only **diesel** generators store fuel on site (and often keep extra backup fuel). **Natural gas** arrives by pipeline, so no fuel storage is required unless the utility itself fails.
- × "One amperage limit fits all rPDUs." — Keep rPDUs **≤ 40 A for single-phase** but **≤ 32 A for three-phase** to avoid overloads; ≤ 20 A units add reliability because they need no circuit breaker.

08 SELF-QUIZ

answers are upside-down below

Q1 What is the primary role of a transformer in the data center power system?

Q2 Which component protects and safely transfers power from the utility and can act as an automatic transfer switch to a generator?

Q3 During a power failure, what bridges the gap until the generator starts supplying power?

Q4 About how long does a generator take to start and pick up the electrical load during an outage?

Q5 Name the three common UPS system types.

Q6 A rack power distribution unit (rPDU) is essentially what everyday device with added functionality?

Q7 To avoid overloads, what is the recommended maximum amperage for an rPDU in single-phase applications (and in three-phase)?

Q8 Write the equation for power usage effectiveness (PUE).

Q9 Which two organizations govern the standards and regulations for data center electrical safety?

Q10 What phenomenon occurs when insulation between energized conductors fails and current arcs through the air, reaching up to 35,000 °F?

ANSWER KEY (rotate the page)

Q1 to lower (step down) the utility voltage to levels the data center equipment can use **Q2** the switchgear **Q3** the UPS, using its stored battery power **Q4** 20 to 30 seconds (roughly 30 seconds) **Q5** standby, line-interactive, and double-conversion **Q6** a power strip **Q7** ≤ 40 A single-phase; ≤ 32 A three-phase **Q8** PUE = total facility power ÷ IT equipment power **Q9** OSHA and the NFPA **Q10** an arc flash (its explosion is an arc blast)