Electrical Fundamentals

BASICS & OHM'S LAW · AC CIRCUITS · DC CIRCUITS · CONDUCTORS & CONDUIT · DISTRIBUTION · VOLTAGE TYPES · PROTECTION & METERING STUDY & REVIEW

01 MUST KNOW

if you remember five things, remember these

01 **Ohm's law and Watt's law: resistance** opposes current and is measured in ohms. Ohm's law: current = voltage ÷ resistance (`I = E ÷ R`), so `E = I × R`. **Power** is the rate of doing work, in watts; Watt's law: `P = E × I`. **Energy** is power over time (`energy = W × h`), which is why utilities bill in **kilowatt-hours (kWh)**.

02 **AC distributes, DC lives at the rack: AC** reverses polarity and direction over time and is easy to transform and distribute; **DC** holds constant polarity and direction. A data center takes in AC, a **rectifier** converts AC→DC to charge the UPS batteries, an **inverter** converts DC→AC back toward the servers, and each server's power supply converts AC→DC again for its electronics.

03 **Three kinds of AC power: true power** P (watts, resistive work), **reactive power** Q (VAR, stored and returned by inductors and capacitors), and **apparent power** S (VA, the vector sum). **Power factor = P ÷ S**; unity (1) is ideal. Data centers are metered and built on **apparent power**, so the goal is to correct PF toward 1 by cutting reactive load.

04 **Reactance and phase:** in a **resistor**, voltage and current stay in phase. A **capacitor** opposes voltage change (current *leads* by 90°, reactance XC); an **inductor** opposes current change (voltage *leads* by 90°, reactance XL). **Impedance** Z combines resistance and net reactance, where `XT = XL − XC`.

05 **Higher voltage travels farther:** line loss is $P = I^2 \times R$, so utilities transmit at **high voltage** to shrink current and loss, then **transformers step down** through MV to LV. IEC classes: **LV** ≤ 1,000 V · **MV** 1,000 V–33 kV · **HV** 33–230 kV. Data-center IT gear runs at **100–240 V**.

02 KEY TERMS

TERM	DEFINITION
EMF (electromotive force)	The force that drives electrons in one direction through a conductor; measured in volts as the potential difference between two points
Current (I)	The flow of electric charge (electrons) through a region; measured in amperes (A)
Resistance (R)	The opposition a circuit offers to current flow; measured in ohms (Ω)
Conductance	A material's ability to allow electron flow; inversely related to resistance
Power factor (PF)	Ratio of true power to apparent power (P ÷ S); unitless; the cosine of the phase angle; 1 = unity, the most efficient use of power
Impedance (Z)	Total opposition in an AC circuit — the combination of resistance and reactance
Reactance	Opposition from reactive components: capacitive XC and inductive XL; total reactance XT = XL – XC
Rectifier	Converts AC to DC using one or more semiconductor diodes
Inverter	Converts DC back to AC — used in the UPS path that feeds the servers
Ampacity	The maximum current a conductor can safely carry without overheating; set by size, material, and insulation
AWG (American Wire Gauge)	The standard for wire diameter; the higher the gauge number, the smaller the wire
Transformer	Steps voltage up or down; the turns ratio equals the voltage ratio, and input power equals output power

03 ELECTRICAL QUANTITIES, UNITS & CORE LAWS

the vocabulary and math behind every circuit

QUANTITY	SYMBOL	UNIT	KEY RELATIONSHIP
Voltage (EMF)	E / V	volt (V)	$E = I \times R$ (Ohm's law)
Current	I	ampere (A)	$I = E \div R$
Resistance	R	ohm (Ω)	opposition to current flow
Power (true)	P	watt (W)	$P = E \times I$ and $P = I^2 \times R$
Energy	—	watt-hour (Wh)	energy = power × time
Capacitance	C	farad (F)	stores charge; opposes ΔV
Inductance	L	henry (H)	opposes ΔI

04 AC VS DC VOLTAGE

the two voltage types in a data center

AC — ALTERNATING CURRENT

generate, transform, distribute

— Polarity and direction **reverse** over time (a sine wave)
— **Easy to transform**; a transformer is required
— Most common source; dominant in data centers
— Symbol: a circle with a wavy line

DC — DIRECT CURRENT

store energy, run the electronics

— Polarity and direction stay **constant**; no transformer
— **Easy to amplify**; cheaper, strong over distance
— Natural source: UPS **batteries**, rectifiers, solar
— Server electronics — CPUs, fans, drives — run on DC

05 THE POWER TRIANGLE — THREE KINDS OF POWER

power factor = P ÷ S; unity (1) is ideal

POWER	SYMBOL	UNIT	WHAT IT IS
Apparent	S	volt-amp (VA)	Vector sum; what the utility meter reads and what data centers are built on
True (real)	P	watt (W)	Actual work done by resistive loads
Reactive	Q	VAR	Stored and returned by inductors and capacitors; does no useful work

06 POWER PATH THROUGH THE DATA CENTER

AC in, DC at the batteries, AC to the rack, DC in the server

01 Utility grid (MV/HV AC) → 02 **Transformer** steps voltage down → 03 **ATS** + switchgear (transfer to generator on outage) → 04 **UPS** — rectifier charges DC batteries → 05 **Inverter** back to AC → PDP → RPP → 06 Rack PDU → server power supply (AC→DC)

07 EXAM TRAPS

where the knowledge check gets you

- × "Electrons zip through the wire at light speed." — Individual electrons **drift** very slowly (about 0.02 cm/s in 12-gauge copper at 10 A); the wire is already full of them, so pushing one in nudges the whole line and the *effect* travels near light speed — the light turns on instantly.
- × "Conventional current is the true direction of electron flow." — Franklin guessed wrong: **electrons flow from negative to positive**. Conventional current (positive→negative) is only a historical convention we still use.
- × "A higher AWG gauge number means a bigger wire." — Backwards. The **higher** the gauge number, the **smaller** the wire — 2-gauge is larger than 10-gauge.
- × "A low, lagging power factor is fine." — A lagging PF (from inductive load) forces higher **apparent power**, wastes energy, and costs money on the utility meter; data centers correct PF toward **1** by cutting reactive load (kVAR).
- × "Reactive power does useful work." — Only **true power** (watts, resistive) does work. Reactive power (VAR) is merely stored and returned by capacitors and inductors each cycle — it loads the system without producing output.
- × "Utilities use high voltage to push more power." — They transmit at HV to **cut line loss**: loss is $P = I^2 \times R$, so raising voltage lowers current for the same power, shrinking both the loss and the cable size.
- × "In a capacitor, voltage leads current." — In a **capacitor**, *current* leads voltage by 90°; in an **inductor**, *voltage* leads current by 90°. Only a resistor keeps the two in phase.
- × "Semiconductors are just weak conductors." — A semiconductor (silicon, germanium, carbon; four valence electrons) acts as an insulator *or* a conductor depending on doping — boron makes **p-type**, antimony makes **n-type**, and joined they form the PN junctions inside transistors.

08 SELF-QUIZ

answers are upside-down below

Q1 State Ohm's law as an equation relating current, voltage, and resistance.

Q2 In which direction do electrons actually flow, and which flow direction do we still describe by convention?

Q3 Which device converts AC to DC to charge the UPS batteries, and which converts DC back to AC toward the servers?

Q4 Name the three sides of the power triangle and the unit of each.

Q5 How is power factor defined, and what value is called 'unity'?

Q6 In a purely capacitive AC circuit, what is the phase relationship between current and voltage?

Q7 Give the IEC voltage ranges for LV, MV, and HV.

Q8 Why do utilities transmit power at high voltage?

Q9 In a series DC circuit, how do you find total resistance, and what quantity is the same at every component?

Q10 What does ampacity measure, and how does American Wire Gauge relate to a wire's size?

ANSWER KEY (rotate the page)

Q1 current = voltage ÷ resistance (I = E ÷ R) **Q2** electrons flow negative → positive; conventional current is described positive → negative **Q3** a rectifier (AC→DC); an inverter (DC→AC) **Q4** apparent power S (VA), true power P (W), reactive power Q (VAR) **Q5** true power ÷ apparent power (P ÷ S); unity = 1 **Q6** current leads voltage by 90 degrees **Q7** LV ≤ 1,000 V; MV 1,000 V–33 kV; HV 33–230 kV **Q8** to reduce line loss ($P = I^2 \times R$) by lowering current for a given power, which also minimizes cable size **Q9** total resistance = R1+R2+R3 (they add); current is the same through all components **Q10** the maximum current a conductor can safely carry; higher AWG number = smaller wire