Power

Dr Peadar Grant

Data Centre Infrastructure

Electrical quantities

Quantity	Symbol	Unit	
Voltage	V	Volt	V
Current	I	Ampere	A
Resistance	R	Ohm	Ω
Power	P	Watt	W

Table: Key electrical quanities

Voltage is difference between *two* points.
One point often common earth / ground.

Ohm's law

Voltage, current and resistance are related by Ohm's law, which can be written in terms of V, I or R. Re-arrange to calculate required quantity.

$$V = R \cdot I \tag{1}$$

$$\Rightarrow I = \frac{V}{R} \tag{2}$$

$$\Rightarrow R = \frac{V}{I} \tag{3}$$

Power

Power quantifies how much energy is converted from one form to another per unit time. Units: $\mathrm{J\,s^{-1}} = \mathrm{W}$.

$$P = V \cdot I \tag{4}$$

$$\Rightarrow V = \frac{P}{I} \tag{5}$$

$$\Rightarrow I = \frac{P}{V} \tag{6}$$

Mains electricity

Nominal mains in Ireland is 230 V 50 Hz.
Three conductors:

Live (or hot, or phase) carries a 230 V RMS AC voltage.

Neutral provides the return path for current on the live conductor, and under normal conditions will be the negative of that.

Earth is connected to earth and bonded to metal casings.

Circuit protection

Fuses: thin wire

Melts if $I > I_{\text{rated}}$.

Circuit Breakers (MCB):

trips when $I > I_{\text{rated}}$.

Residual current device (RCD):

protects against electric shock

Trips if $\left|I_{\text{L}} - I_{\text{N}}\right| > \Delta I$

Normally $\Delta_I = 30\,\text{mA}$.

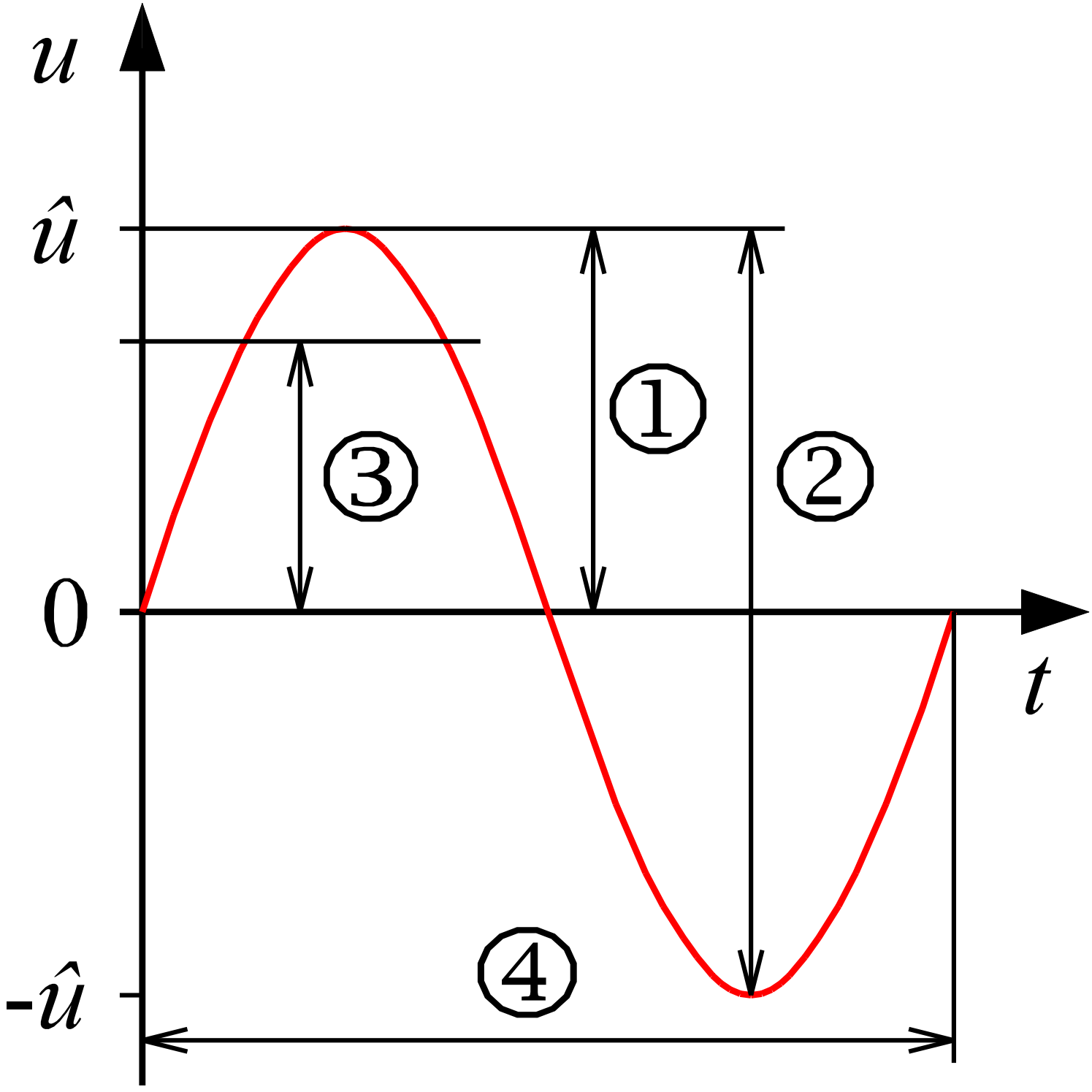
Residual Current Breaker Overload (RCBO):

MCB and RCD in single device

Alternating current (AC)

Mains in most parts of world is **alternating current (AC)**. This means that the instantaneous voltage $v(t)$ varies sinusoidally with respect to time.

$$v(t) = V_{\text{max}} \sin(2\pi f t) \tag{7}$$


u
û
0
-û
t
①
②
③
④

AC waveform properties

Amplitude V_{max}

Peak-to-peak amplitude from $-V_{\text{max}}$ to V_{max}.

$$V_{\text{PK-PK}} = V_{\text{max}} - (-V_{\text{max}}) \tag{8}$$

$$= 2V_{\text{max}} \tag{9}$$

Root Mean Square (RMS)

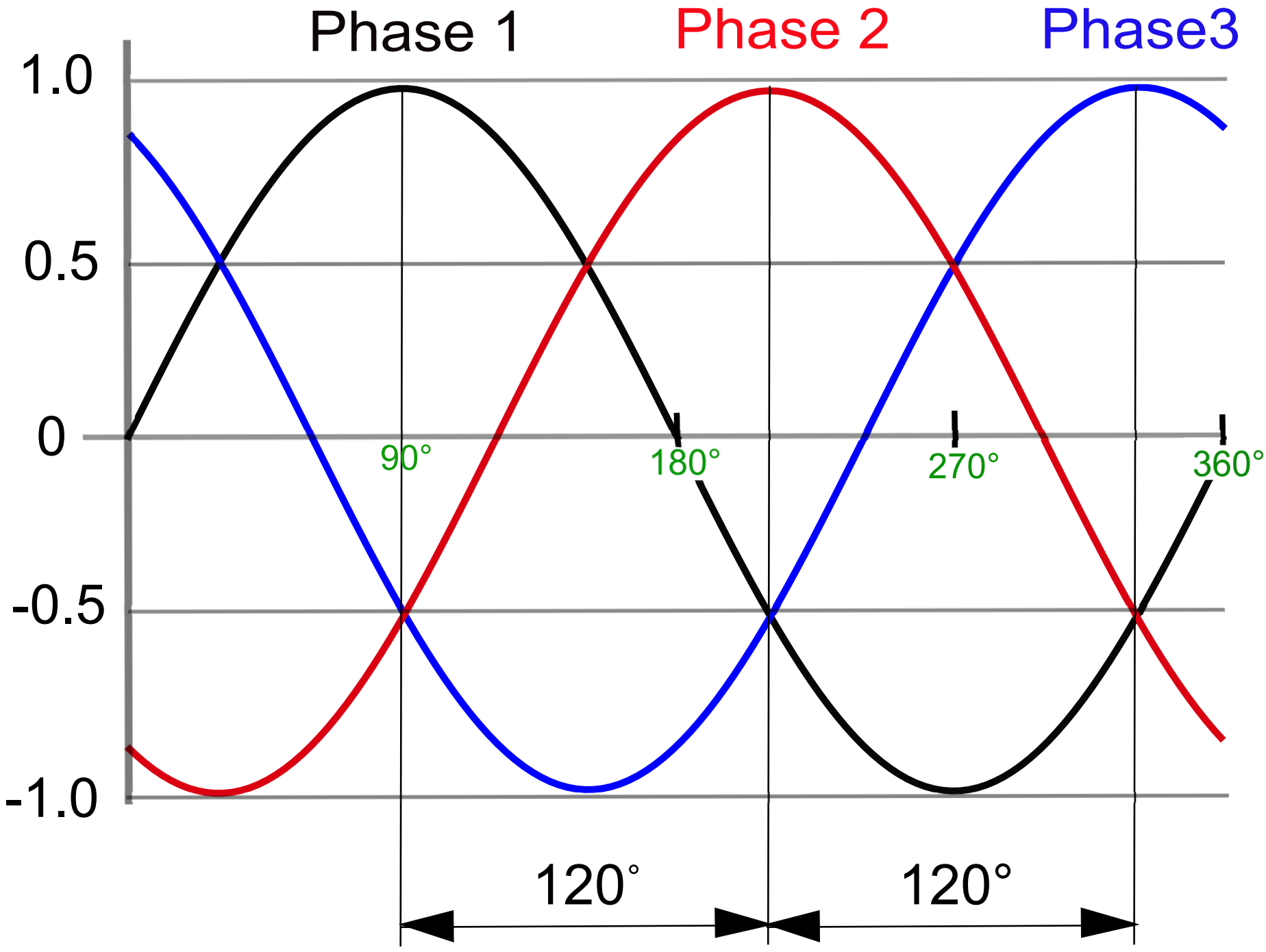
$$V_{\text{max}} = \sqrt{2}V_{\text{RMS}} \tag{10}$$

Period T related to Frequency f

$$T = \frac{1}{f} \tag{11}$$

Three-phase supply

Mains power is generated and distributed in three-phase form, with 3 live conductors and one neutral conductor. The sine wave is shifted by 120 degrees, or $\frac{2\pi}{3}$ radians in any phase relative to one of the two other phases.


Phase 1
Phase 2
Phase3
1.0
0.5
0
-0.5
-1.0
90°
180°
270°
360°
120°
120°

Let $v_n(t)$ be the voltage in phase n of a three-phase supply. Phase 1 same as any AC waveform:

$$v_1(t) = V_{\text{max}} \sin(2\pi ft) \tag{12}$$

Phase 2 lags phase 1 by 120 degrees.

$$v_2(t) = V_{\text{max}} \sin\left(2\pi ft - \frac{2\pi}{3}\right) \tag{13}$$

Similarly, phase 3 leads phase 1 by 120 degrees.

$$v_3(t) = V_{\text{max}} \sin\left(2\pi ft + \frac{2\pi}{3}\right) \tag{14}$$

Line and phase voltages

Three-phase power := two voltages to consider:

Phase voltage between *any* phase and neutral.

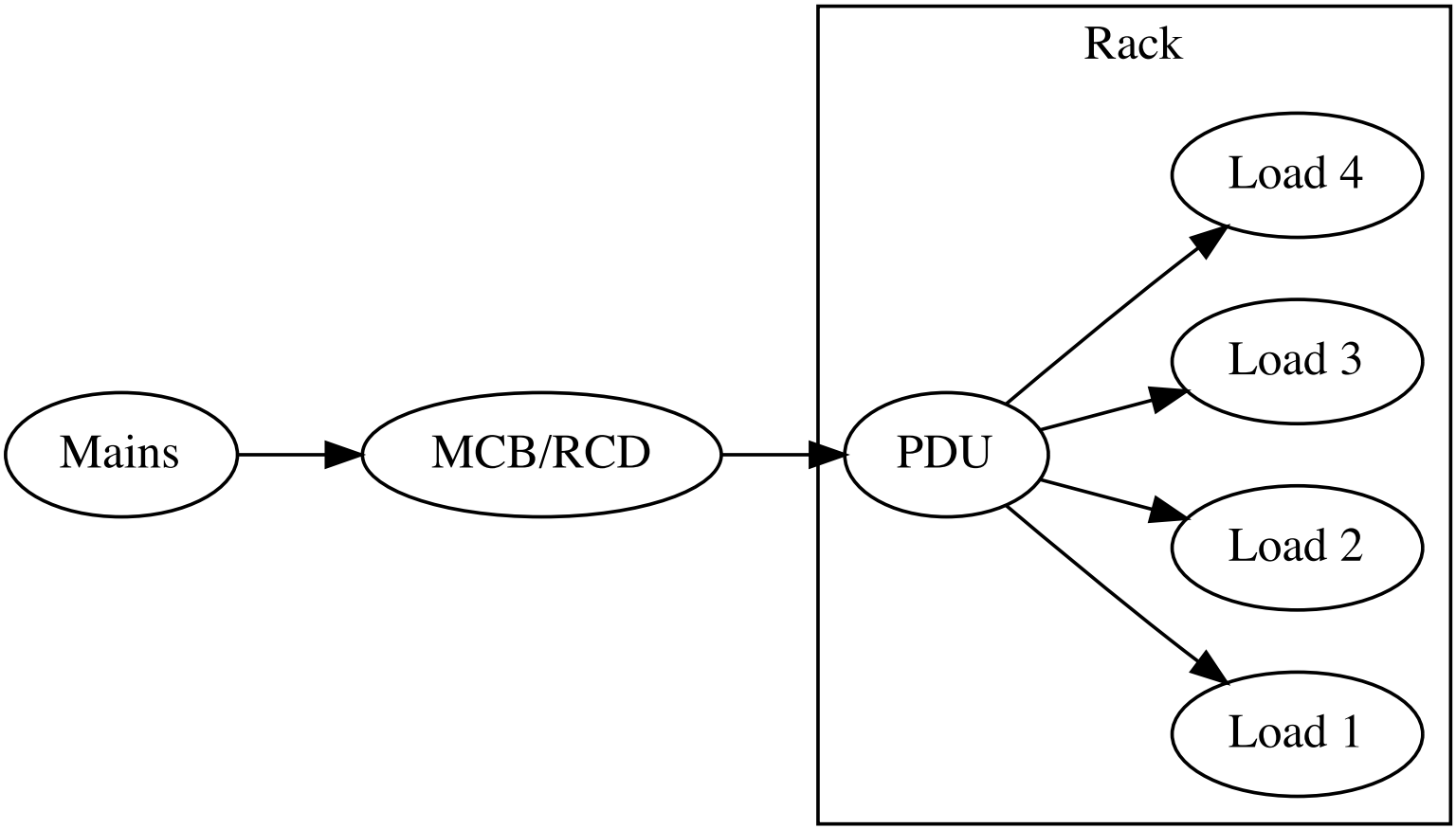
Line voltage between *any* two phases.

Related by $\sqrt{3}$:

$$V_{\text{line}} = \sqrt{3} \times V_{\text{phase}} \tag{15}$$

$$\Rightarrow V_{\text{phase}} = \frac{V_{\text{line}}}{\sqrt{3}} \tag{16}$$

Distribution path



Power distribution unit (PDU)

Each rack has PDU, like multiplug adapter:

- PDU mounted:
  - vertically in the back of rack, or
  - in a rack space (facing in or out)
- May include surge protection.
- Maximum current depends on connector type on input to PDU.
- "Smart" PDUs: remote measurement and on/off sockets.

Common connectors

Type	I_{max}	Male	Female
BS 1363	13 A		
IEC C13/14	10 A	C14	C13
IEC C19/20	16 A	C20	C19
IEC 60309	16 A		

Table: Common connector types

Disturbance types

Blackout: total power loss.

Surge/sag: **short-term** (0.5 of a cycle up to 1 minute) voltage variations:

- **Surge or spike** high-voltage $> 110\,\%$
- **Sag** low-voltage

Over and under-voltage persisting minutes to days:

- **Over-voltage**
- **Under-voltage** (Formerly: brownout)

Frequency fluctuations where $f \neq 50\,\mathrm{Hz}$

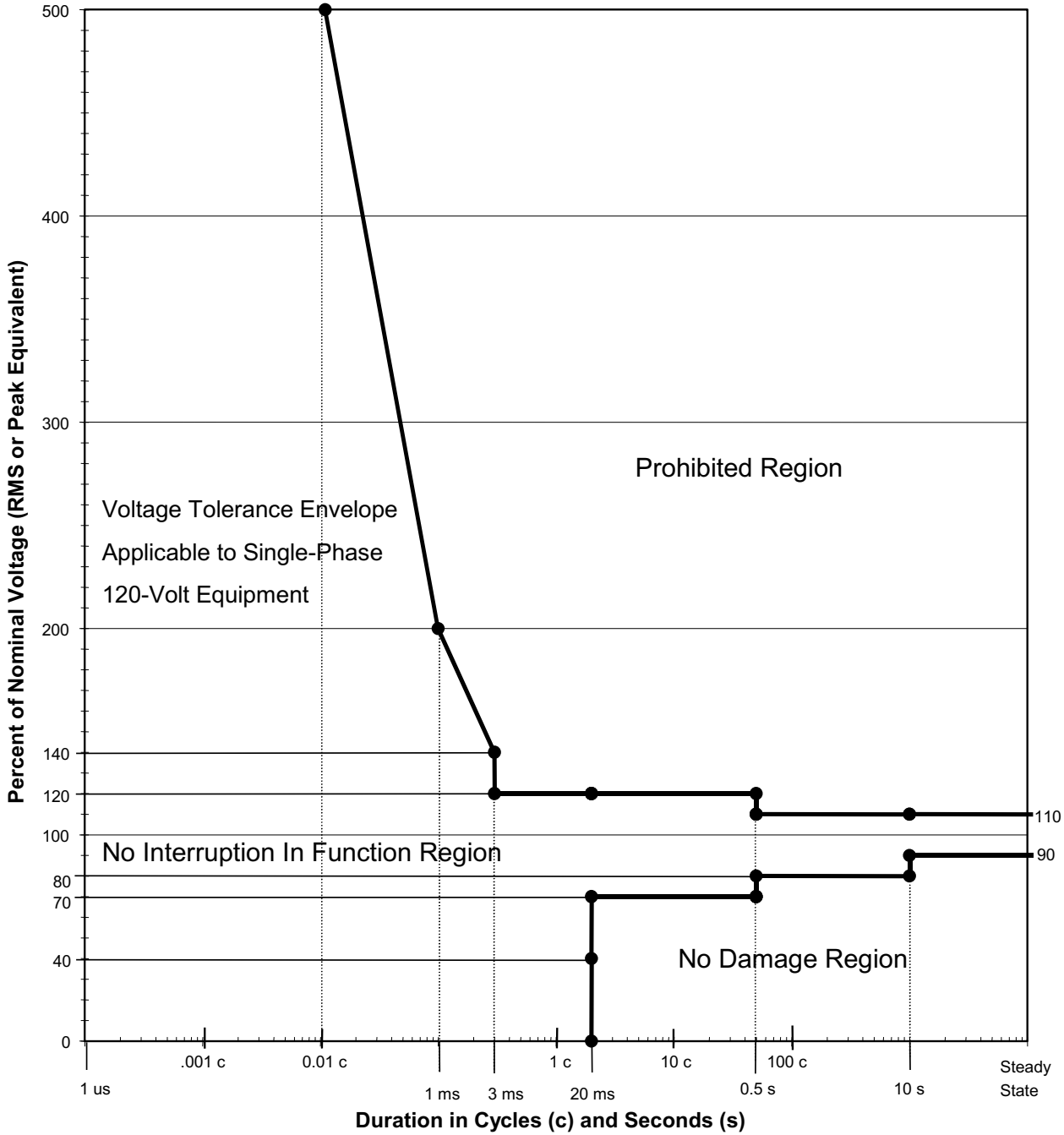
Waveform distortion: no longer is a sinusoid.

CBEMA curve

Undesirable conditions are generally less disruptive the shorter that they persist for:

- This includes disturbances in the power supply.
- The Computer Business Equipment Manufacturers Association (CBEMA) in the 1970s generated a curve that partitioned voltage events and times into acceptable and unacceptable region.

ITI (CBEMA) Curve
(Revised 2000)



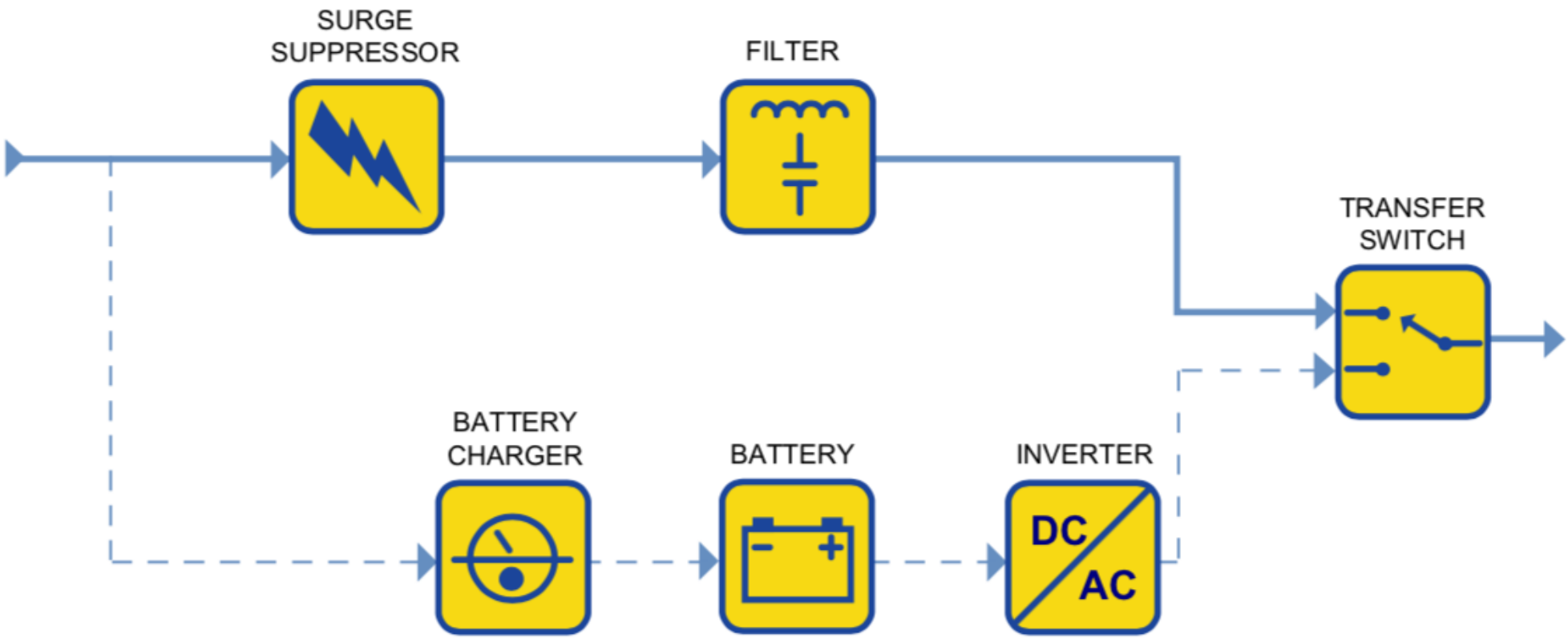
Form factors

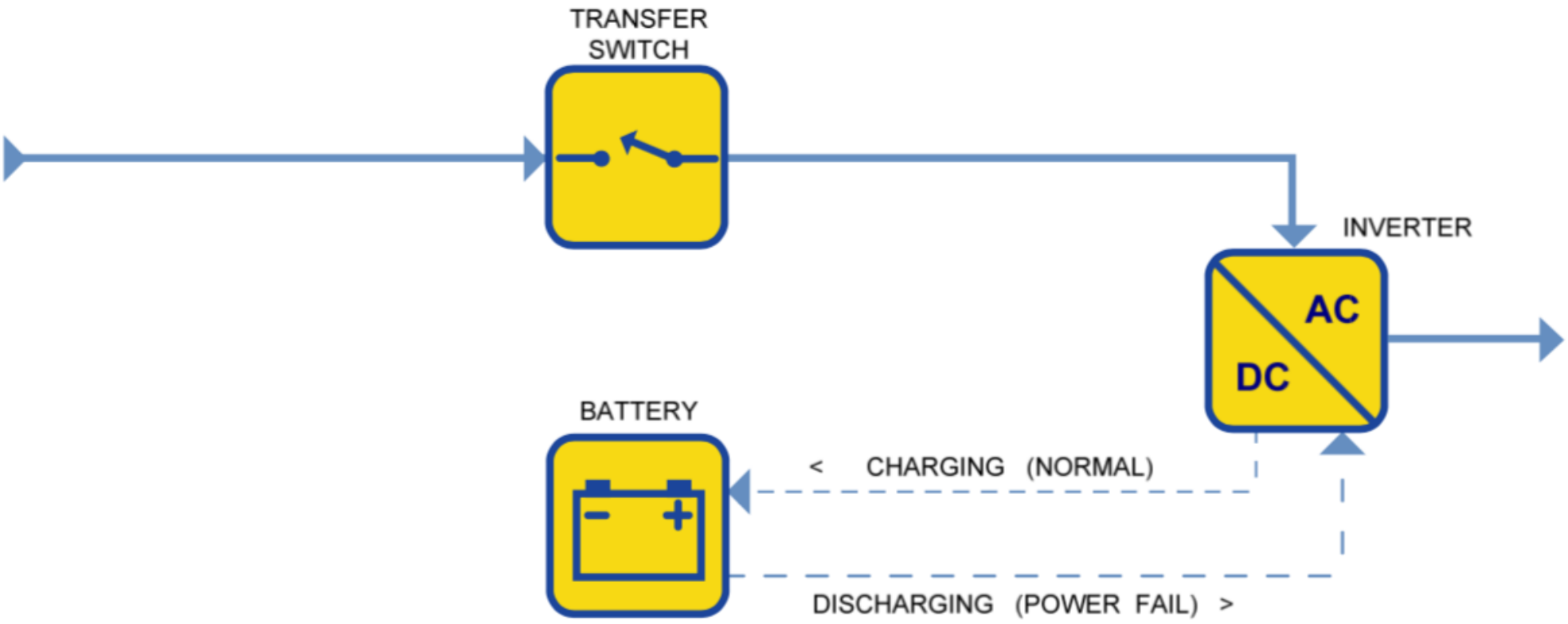
UPS units are available in various form factors:

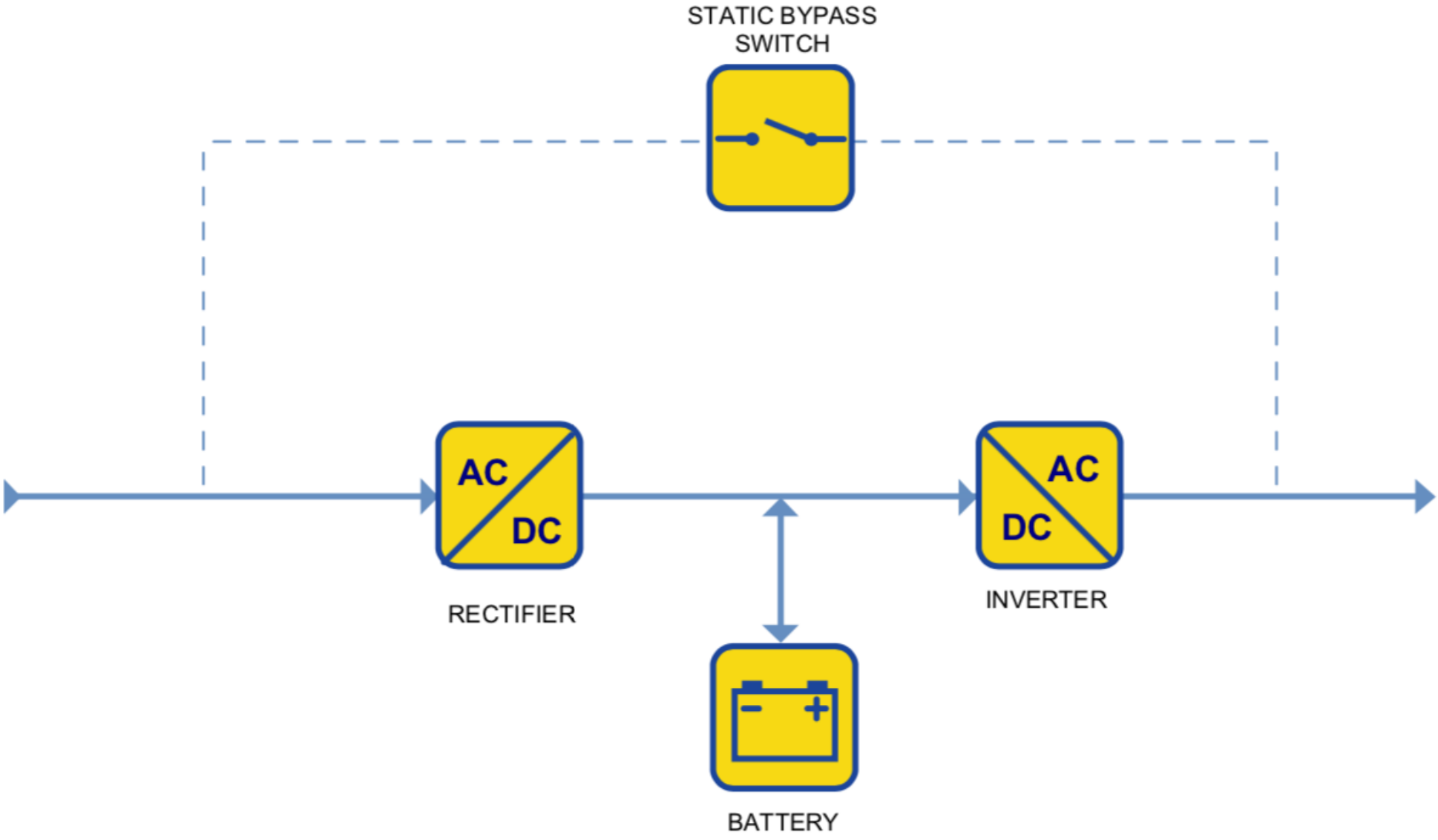
Freestanding / tower similar to PC powering a single device or multiple devices via a PDU. Usually located adjacent to the IT equipment.

Rackmount powering a single device or multiple devices via a PDU. Usually co-located inside the same rack as the IT equipment.

Floor-standing UPS devices located within the IT environment itself or in another part of the facility. These normally supply multiple IT loads and are often managed by facilities rather than IT personnel.


SURGE
SUPPRESSOR
FILTER
TRANSFER
SWITCH
BATTERY
CHARGER
BATTERY
INVERTER
DC
AC


TRANSFER
SWITCH
INVERTER
AC
DC
BATTERY
< CHARGING (NORMAL)
DISCHARGING (POWER FAIL) >


STATIC BYPASS
SWITCH
AC
DC
RECTIFIER
AC
DC
INVERTER
BATTERY