# Chapter 2

# Electrical basics

## 2.1 Physical quantities

Table 2.1 summarises key electrical quantities.

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

**Table 2.1:** Key electrical quanities

Note that voltage is a difference between *two* points. Often measured in any system with respect to a common earth / ground.

## 2.2 Laws

There are two key laws that relate basic electrical quantities, Ohm's Law and the Power Relation.

### 2.2.1 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.

$$V = R \cdot I \tag{2.1}$$

$$\Rightarrow I = \frac{V}{R} \tag{2.2}$$

$$\Rightarrow R = \frac{V}{I} \tag{2.3}$$

**Example 1** (Ohm's law)**.** A 7 Ω resistance carries a current of 2 A. Determine the voltage across the component.

$$V = 7 \times 2 \tag{2.4}$$

$$= 14\,\mathrm{V} \tag{2.5}$$

**Example 2** (Ohm's law with rearrangement)**.** When an electrical component is connected across a battery nominally supplying 12 V a current of 3 A flows. Calculate the resistance of the component.

$$V = R \cdot I \tag{2.6}$$

$$\Rightarrow R = \frac{V}{I} \tag{2.7}$$

$$= \frac{12}{3} \tag{2.8}$$

$$= 4\,\Omega \tag{2.9}$$

### 2.2.2 Power relation

Power quantifies how much energy is converted from one form to another per unit time. Measured in Joule per second $\mathrm{J\,s^{-1}}$, more commonly the Watt W. Just as with Ohm's law, the power relation, Equation 2.10, can be rearranged to give $V$ or $I$:

$$P = V \cdot I \tag{2.10}$$

$$\Rightarrow V = \frac{P}{I} \tag{2.11}$$

$$\Rightarrow I = \frac{P}{V} \tag{2.12}$$

**Example 3** (Power calculation)**.** A graphics card is supplied from the 12 V power supply in a computer. The current flowing is measured at 5 A. Determine the power consumed by the graphics card.

$$P = 12 \times 5 \tag{2.13}$$

$$= 60\,\mathrm{W} \tag{2.14}$$

**Example 4** (Power calculation with rearrangement)**.** A computer power supply delivers 6 W to a hard disk drive on the 12 V line. Determine the current flowing in the cable.

$$I = \frac{P}{V} = \frac{6}{12} \tag{2.15}$$

$$= 0.5\,\mathrm{A} \tag{2.16}$$

### 2.2.3 Combining

Ohm's law and the power relation can be combined by substituting one quantity for another.

## 2.3 Alternating current (AC)

Mains electricity is supplied in most parts of the world as alternating current (AC). In Ireland and most of the EU, mains electricity is supplied at a *nominal* voltage of 230 V and frequency 50 Hz. This means that the instantaneous voltage $v(t)$ varies sinusoidally with respect to time.

$$v(t) = V_{\text{max}} \sin(2\pi f t) \tag{2.17}$$

A single cycle of a generic AC waveform is shown in Figure 2.1

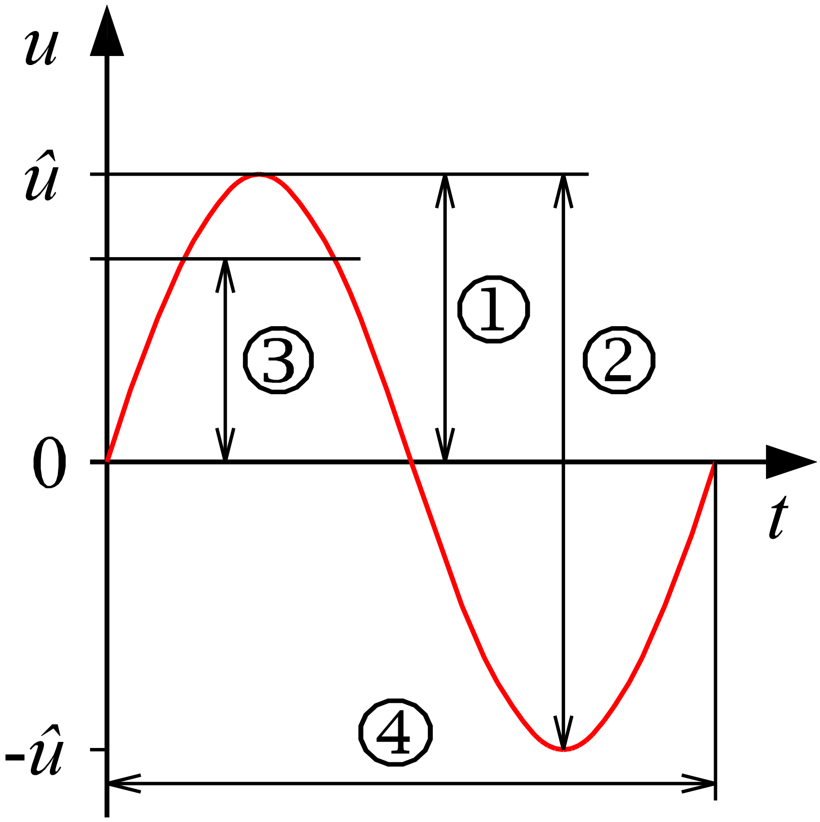


**Figure 2.1:** AC waveform properties

### 2.3.1 Amplitude

The **maximum voltage** $V_{max}$ of a sinusoid is the amplitude of the sine wave in both directions. The most positive value is $V_{max}$ whilst the most negative value is $-V_{max}$.

### 2.3.2 Peak-to-peak voltage

We can thus define the **peak-to-peak** amplitude as the difference between these two values:

$$V_{\text{PK-PK}} = V_{max} - (-V_{max}) \tag{2.18}$$
$$= 2V_{max} \tag{2.19}$$

**Example 5** (Peak-to-peak to amplitude)**.** Calculate the amplitude of an AC waveform with a 650 V peak-to-peak amplitude.

$$V_{max} = \frac{V_{\text{PK-PK}}}{2} \tag{2.20}$$
$$= \frac{650}{2} \tag{2.21}$$
$$= 325\,\text{V} \tag{2.22}$$

### 2.3.3 RMS Voltage

The voltage in western Europe is a nominal 230 V RMS. This is a root mean square value, which is equivalent to the heating power that the same DC voltage would deliver.

$$V_{\text{max}} = \sqrt{2}V_{\text{RMS}} \tag{2.23}$$

$$\Rightarrow V_{\text{RMS}} = \frac{V_{\text{max}}}{\sqrt{2}} \tag{2.24}$$

**Example 6** (RMS to peak voltage)**.** Calculate the amplitude of a 230 V RMS AC supply.

$$V_{\text{max}} = \sqrt{2}V_{\text{RMS}} \tag{2.25}$$

$$= \sqrt{2} \times 230 \tag{2.26}$$

$$= 325\,\text{V} \tag{2.27}$$

**Example 7** (Peak to RMS voltage)**.** Calculate the RMS voltage of an AC supply with an amplitude of 100 V.

$$V_{\text{RMS}} = \frac{V_{\text{max}}}{\sqrt{2}} \tag{2.28}$$

$$= \frac{100}{\sqrt{2}} \tag{2.29}$$

$$= 70.7\,\text{V} \tag{2.30}$$

### 2.3.4 Frequency / Period

A single cycle lasts for a period of time, $T$. The period is directly related to the frequency:

$$T = \frac{1}{f} \tag{2.31}$$

$$\Rightarrow f = \frac{1}{T} \tag{2.32}$$

**Example 8** (Frequency to period)**.** Calculate the period of a signal that repeats at 20 Hz.

$$T = \frac{1}{20} \tag{2.33}$$

$$= 0.05\,\text{s} \tag{2.34}$$

**Example 9** (Period to frequency)**.** Determine the frequency of a signal with a period of 40 ms.

$$f = \frac{1}{40 \times 10^{-3}} \tag{2.35}$$

$$= 25\,\text{Hz} \tag{2.36}$$

## 2.4 Mains electricity

Mains wiring in Ireland generally involves three conductors:

**Live** carries a 230 V RMS AC voltage.

**Neutral** provides the return path for current on the live conductor, and under normal conditions:

1. It will carry the same current in reverse as the live conductor.
2. It's voltage (measured with respect to earth) will be zero.

**Earth** is connected to earth and bonded to metal casings.

### 2.4.1 Circuit protection

**Fuses:** a piece of thin wire encased in a holder that is deliberatly designed to melt if the current exceeds the fuse rating.

**Circuit Breakers (MCB):** electromechanical devices that will trip when the current exceeds the circuit breaker's rating.

**Residual current device (RCD):** protect from electric shock by detecting any leakage of current to earth by comparing live and neutral currents. Trips if these differ by more than a set amount $\Delta I$, normally 30 mA. Other names: GFI, ELCB.

**Residual Current Breaker Overload (RCBO):** combined MCB and RCD functionality in one device.

## 2.5 Computer power supplies

Power Supply Units (PSUs) are used to convert the mains-supplied power into a form suitable for use in computers.

### 2.5.1 Computer power requirements

Computers require a variety of DC voltages, the most common being:

**3.3 V** (orange)

**5 V** (red)

**12 V** (yellow).

These are normally supplied relative to a common ground (black).

**Negative −12 V** (blue) is often available.

A PSU also permanently supplies 5 V (purple) and will turn on when the green terminal is shorted to ground.

### 2.5.2 Power supply tasks

A computer's power supply unit (PSU) has two key jobs:

**Rectify** the mains-supplied AC to a steady DC supply.

**Step down** the voltage (230 V) to the required level(s).

The precise methods and order that these tasks are performed in will vary, and are outside the scope of our discussion.

### 2.5.3 Capacity

A power supply will usually have a rated capacity:

- This will either be given in terms of power (watts) or in current (amps).
- On a supply providing multiple voltages, there will usually be a limit on each rail as well as possibly an overall limit.

## 2.6 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.

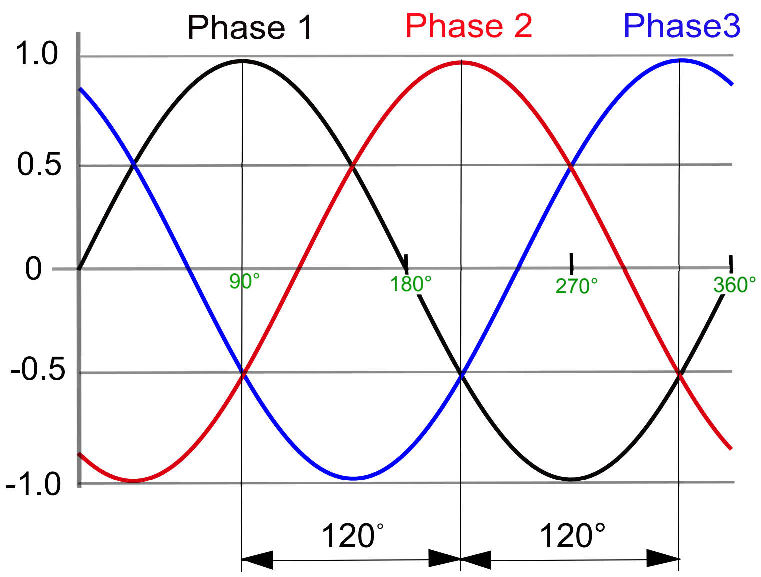


**Figure 2.2:** 3-phase waveform (Wikipedia)

Let $v_n(t)$ be the voltage in phase $n$ of a three-phase supply. We can use Equation 2.17 for the first phase. Phase 2 must lags phase 1 by 120 degrees. Similarly, phase 3 leads phase 1 by 120 degrees.

$$v_1(t) = V_{\text{max}} \sin(2\pi f t) \tag{2.37}$$

$$v_2(t) = V_{\text{max}} \sin\left(2\pi f t - \frac{2\pi}{3}\right) \tag{2.38}$$

$$v_3(t) = V_{\text{max}} \sin\left(2\pi f t + \frac{2\pi}{3}\right) \tag{2.39}$$

### 2.6.1 Line and phase voltages

When dealing with three-phase power, we actually have two voltages to consider:

**Phase voltage** is the voltage between *any* phase and neutral.

**Line voltage** is the voltage measured between *any* two phases.

The line and phase voltages are related mathematically by $\sqrt{3}$:

$$V_{\text{line}} = \sqrt{3} \times V_{\text{phase}} \tag{2.40}$$

$$\Rightarrow V_{\text{phase}} = \frac{V_{\text{line}}}{\sqrt{3}} \tag{2.41}$$

**Example 10** (Line to phase voltage)**.** A three phase power supply has a phase voltage of 220 V. Calculate the line voltage.

$$V_{\text{line}} = \sqrt{3} \times V_{\text{phase}} \tag{2.42}$$

$$= \sqrt{3} \times 220 \tag{2.43}$$

$$= 381\,\text{V} \tag{2.44}$$

**Example 11** (Phase to line voltage)**.** A three phase power supply has a line voltage of 400 V. Calculate the phase voltage.

$$V_{\text{phase}} = \frac{V_{\text{line}}}{\sqrt{3}} \tag{2.45}$$

$$= \frac{400}{\sqrt{3}} \tag{2.46}$$

$$= 231\,\text{V} \tag{2.47}$$