Chapter 2

Voltage, Current and Power

Voltage Current and Power

- Electrical power source
  - Electricity grid (socket)
  - Batteries for small, portable devices (need to be replaced / recharged)

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

Quantity	Unity	Symbol
Voltage, potential diff.	Volt (V)	V
Current	Ampere (A)	I
Power	Watt (W)	P

Table 2.1: *Electrical quantities with their respective unities and symbols.*

Electrical Power vs. Electrical Energy

- Electrical energy is the power consumed during a period of time.

- Units: J (Joule) or Watt-hour (W h)
- 1 Joule = 1 Watt-sec = 0.000278 Watt-hour

*"We used *** electric power in this month" or*
*"We used *** electrical energy in this month"?*

A simple calculation:
How much electrical energy will a given light bulb use in hour?

Sources of electrical energy

Limited e.g. Batteries	⟷	**Unlimited** e.g. Laboratory power supplies, our grid …	→ **Energy**
Voltage Laboratory power supplies, our grid,batteries	⟷	**Current** Often embedded, part of a circuit	→ **Constant**
Direct (DC) I or V constant over time	⟷	**Alternating (AC)** I or V fluctuates over time in a fixed rhythm like our grid voltage	→ **Time**

Direct Current (DC)

Two types of electrical power sources:

- Batteries
- Electricity grid (socket)

• Direct Current (DC)
- Current always flows in the same direction.

• Alternating Current (AC)
- The direction of current alternates.

Direct Current (DC)

Features of an DC voltage source

- Constant voltages are supplied.
- An ideal DC voltage source:
  the voltage is independent of the magnitude and duration of the current.
- Batteries are not the only DC sources. Why?
- DC sources connected to the electricity grid behave more or less like ideal DC-sources.

Direct Current (DC)

! Note

When doing experiments which require a constant voltage, you can make use of a DC-power source. These sources have at least two connections: the mass (black) and the positive potential (red). The mass can be seen as the ground and we take its potential as 0 V. The potential difference between the black and red connection is the voltage supplied by the source. In Appendix D you can find more information about the most common sources you will be using at the university.

Figure 19.1: *A laboratory power supply.*

Alternating Current (AC)

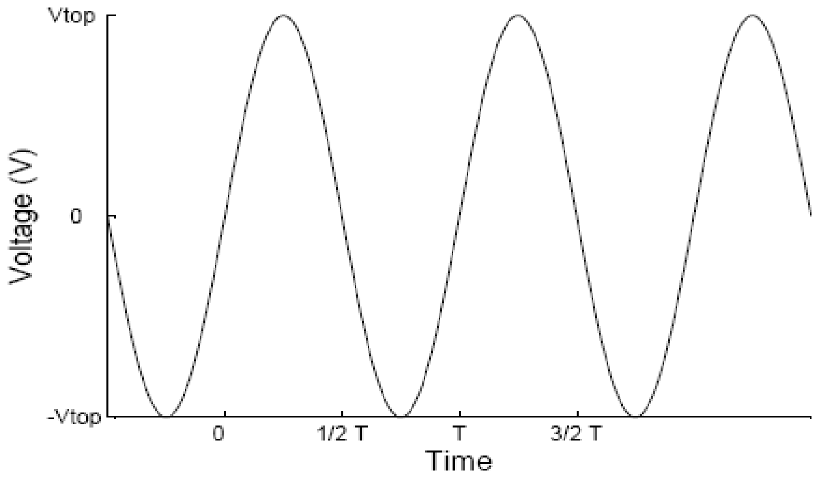


Figure 2.1: *Example of an AC sine waveform.*

- Potential difference between the two plugs of the contact alternates.
- If we put a resistance between the plugs, we could see that the current alternates.

Alternating Current (AC)

$$V(t) = V_{top} \cdot \sin(2\pi \cdot f \cdot t + \varphi)$$

f : frequency of the signal
V_{top} **:** the peak value or amplitude
t : time
T : the period of the sine wave (T=1/f)
ω : the frequency of rotation (ω = 2.π.f)
φ : phase, can be zero [equation (2.2)].

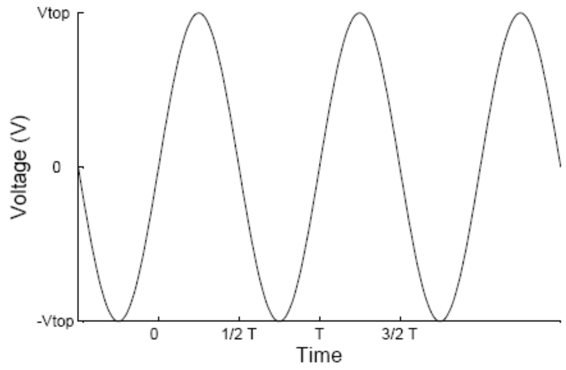


Figure 2.1: *Example of an AC sine waveform.*

- In the Netherlands, f = 50 Hz, V_{top} = 325 V (why not 230 V?)
- A lamp connected to the electricity grid goes on and off twice during one cycle.
- A combination/superposition of an AC voltage (V_{AC}) and a DC (V_{DC}) voltage
  - V_{DC} is called an offset voltage.
  - This will be illustrated later, when you start working with a function generator.

RMS Values

RMS: Root Mean Square

- Why RMS?
  - V_{top} is not a good measure of AC voltages.
  - AC voltage changes all the time.

- RMS value - The effective value of a varying voltage or current. It is the equivalent steady DC (constant) value which has the same heating potential.

- RMS is also called the effective DC value.

RMS Values

$$\frac{V_{RMS}^2}{R} = (\frac{V^2}{R})_{\text{mean of period}} \tag{2.3}$$

where V_{RMS} is the RMS value (DC equivalent) of $V(t)$. Since R is constant, we get:

$$V_{RMS}^2 = (V^2)_{\text{mean of period}} \tag{2.4}$$

Since V_{RMS} should be positive, this results in:

$$V_{RMS} = \sqrt{(V^2)_{\text{mean of period}}}\,. \tag{2.5}$$

The value of $(V^2)_{\text{mean of period}}$ can be calculated by summing up all the instantaneous values of $V^2(t)$ during one period, divided by the number of values $(\frac{1}{N}(V^2(t_1) + V^2(t_2) + ... + V^2(t_N)))$. This can be expressed as follows:

$$(V^2)_{\text{mean of period}} = \frac{1}{T}\int_0^T V(t)^2 dt. \tag{2.6}$$

RMS Values

!! For a true sine wave

$$V_{RMS} = 0.7 \cdot V_{peak}, \tag{2.7}$$

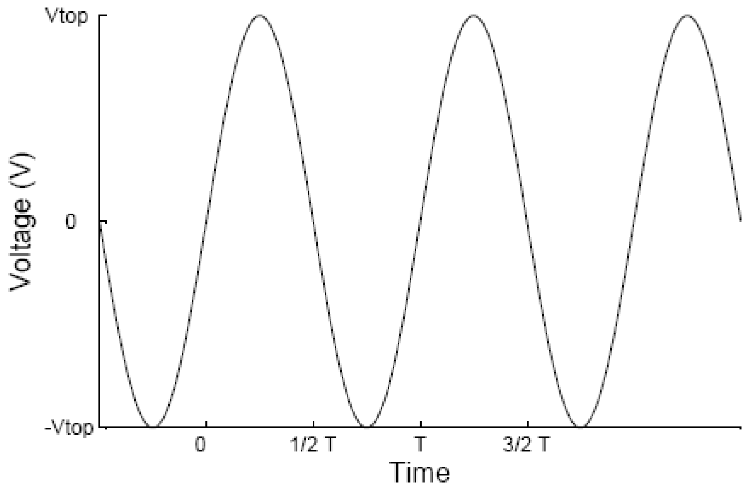
$$V_{peak} = 1.4 \cdot V_{RMS}. \tag{2.8}$$

RMS is not a simple average!

Sine Waves

- Sine waves are the most common type of AC.

- A dynamo on your bike is a small generator.
- A combination of mechanical and electromagnetic properties generates a sinusoidal signal.



$$V(t) = V_{top} \cdot \sin(2 \cdot \pi \cdot f \cdot t) \tag{2.2}$$

Figure 2.1: *Example of an AC sine waveform.*

Sine Waves

- The rotating field in the generator can be seen as a vector.
- The sine wave is a projection of this vector onto a certain axis.

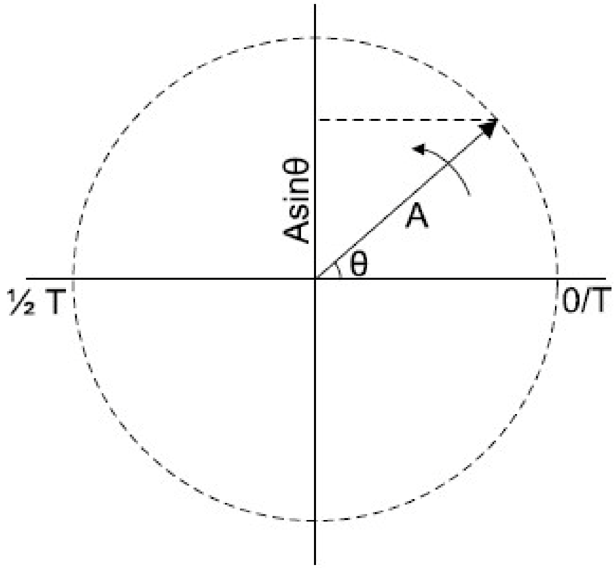


Figure 2.2: *The projection of a rotating vector on the y-axis results in a sine wave.*

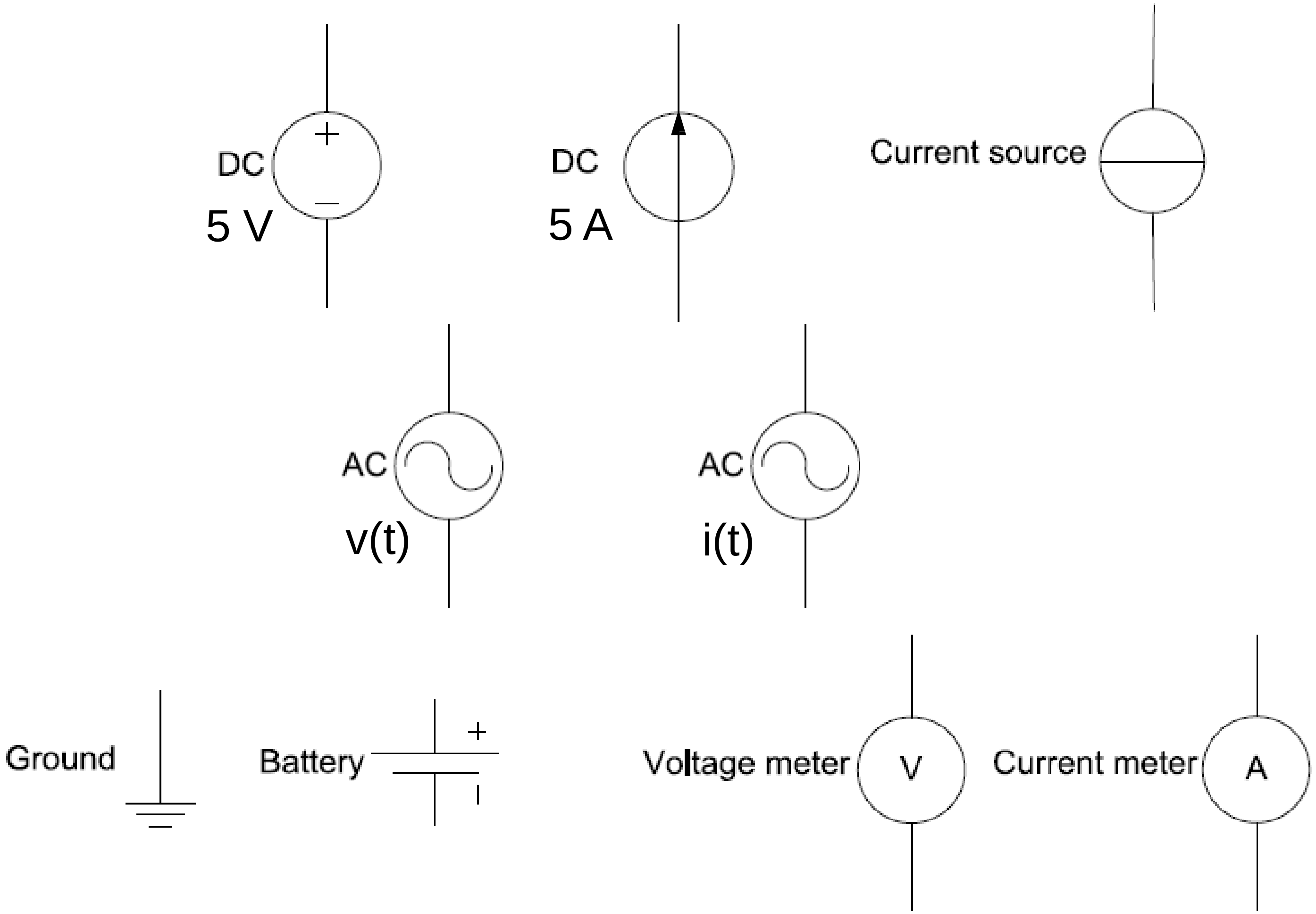
The change in over time is , which is related to the period time T by = 2 /T.

Energy vs. Information

- Voltages and currents are related to the electrical energy consumption of circuits.
- Voltages and currents are also used to transmit / receive information.

- Waveforms (sound wave)
- Digital bits (code)

Symbols of Sources and Meters



Exercise – RMS Calculation

For a sinusoidal signal,

$$V(t) = V_{top} \cdot \sin(2 \cdot \pi \cdot f \cdot t) \qquad (2.2)$$

Calculate its RMS by

$$V_{RMS}^2 = \frac{1}{T} \int_0^T V^2(t) dt$$

$$V_{RMS} = \sqrt{\frac{1}{T} \int_0^T V^2(t) dt}$$

Exercise – RMS Calculation

Exercise – RMS Calculation

$$V_{RMS}^2 = \frac{1}{T}\int_0^T V_{top}^2 \sin^2(2\pi f t)\,dt$$

$$= \frac{V_{top}^2}{T}\int_0^T \frac{1-\cos(4\pi f t)}{2}\,dt$$

← based on Trigonometric identities

$$= \frac{V_{top}^2}{2T}\left[\int_0^T 1\,dt - \int_0^T \cos(4\pi f t)\,dt\right]$$

$$= \frac{V_{top}^2}{2}$$

Therefore,

$$V_{RMS} = \frac{V_{top}}{\sqrt{2}} \approx 0.7V_{top}$$