Introduction to Electrics

A brief introduction into basic electrics, aimed for Mechatronic students without Electric engineering background

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1 Symbols

Table 1. Symbols used in this text

Term	Description	Unit
V	Voltage	Volt (V)
I	Current	Ampere (A)
R	Resistance	Ohm (Ω)
P	Power	Watt (W)
X_C	Capacitive reactance	Ohm (Ω)
C	Capacitance	Farad (F)
X_L	Inductive reactance	Ohm (Ω)
L	Inductance	Henry (H)
f	Frequency	Hertz (Hz)
Z	Impedance	Ohm (Ω)

2 DC circuits

DC (Direct Current) circuits have one-directional current from higher to lower potential. Potential difference is measured in voltage. Power (P) of a DC circuit is determined as the potential difference over the component and the current going through it.

$$P = VI \tag{1}$$

2.1 Ohm's Law

Ohm's law represents the relationship between voltage (V), current (I) and resistance (R) of a circuit. By knowing 2 of these values in a circuit, the unknown term can be calculated.

$$V = RI \tag{2}$$

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

$$R = \frac{V}{I} \tag{4}$$

Voltage represents a difference in electric potential between 2 points. Current flows from higher potential to lower potential. Resistors reduce current flow and dissipates the electric energy into heat.

In the example (Figure 1) the voltage and the current are known, and the resistance needs to be determined. By using Ohm's law (Equation 4.), we know that the relationship between voltage and current produces resistance. → $\frac{12V}{6A} = 2\Omega$

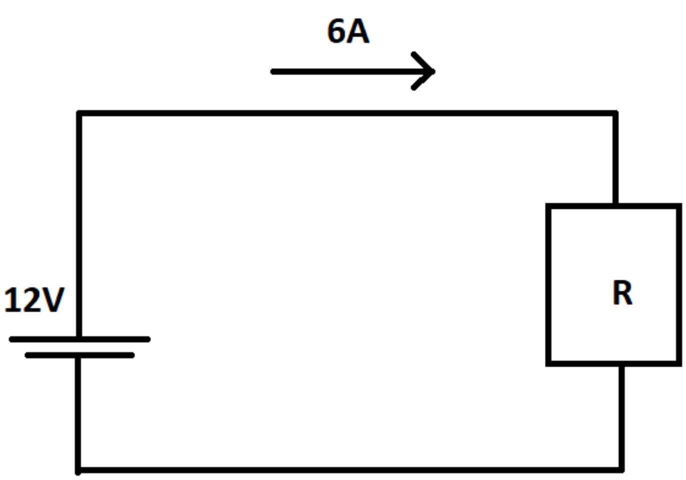


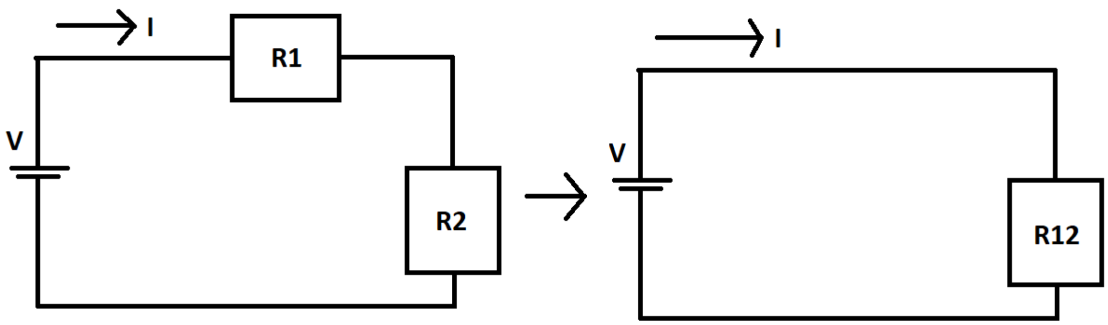
Figure 1. DC circuit with unknown resistance.

2.2 Series and parallel circuits

When dealing with multiple resistances in a circuit, the sum of resistances can be simplified to one term. The two ways of simplifying the resistance are series (Figure 2) or parallel (Figure 3) coupling. In series the total resistance of 2 different resistors can be represented as:

$$R_{12} = R_1 + R_2 \tag{5}$$

Figure 2. DC circuit with resistors in series.



Parallel resistors can be represented as one resistor.

$$R_{12} = \frac{R_1 R_2}{R_1 + R_2} \tag{6}$$

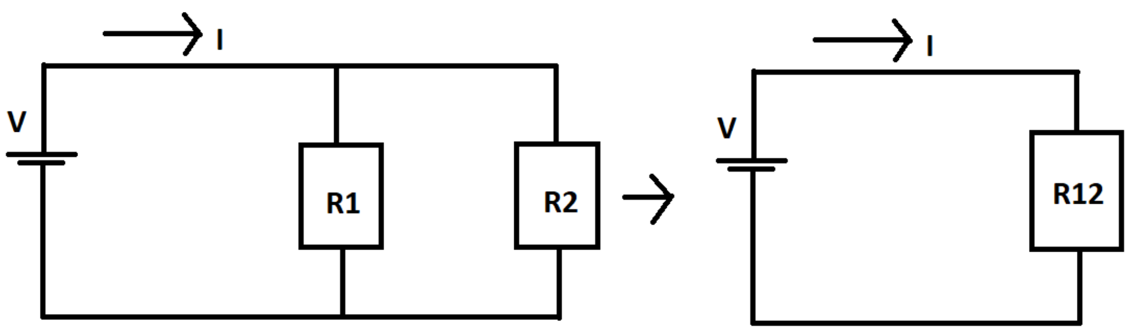


Figure 3. DC circuit with parallel resistors.

2.3 Kirchhoff's circuit laws

2.3.1 Kirchhoff's junction rule

According to Kirchhoff's junction rule, the sum of currents flowing into a junction must be equal to the currents flowing out of the junction.

$$\sum I_{in} = \sum I_{out} \tag{7}$$

In Figure 4, the sum of currents at node A would be written as:

$$I_1 = I_2 + I_3 \tag{8}$$

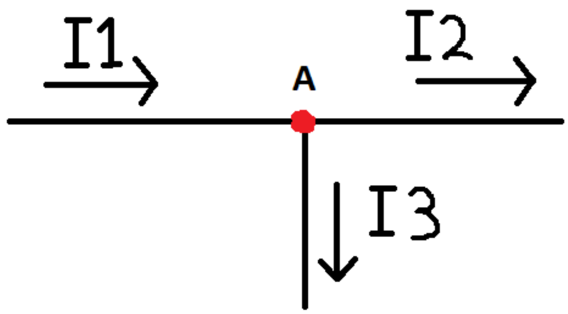


Figure 4. Currents in node A.

2.3.2 Kirchhoff's voltage law

According to Kirchhoff's voltage law (The loop rule), the sum of voltages in a circuit must be equal to 0.

$$\sum V_n = 0 \tag{9}$$

In the case of Figure 5, equation 9 would be:

$$V_b - V_1 - V_2 = 0$$

The voltage terms are positive when going from lower voltage to higher voltage, and negative when going from higher voltage towards lower voltage. The voltage drops in the direction of the current when moving over a resistor. The voltages V_1 and V_2 can be determined by knowing the current and resistance with Ohm's law ($V_1 = \frac{I}{R_1}$).

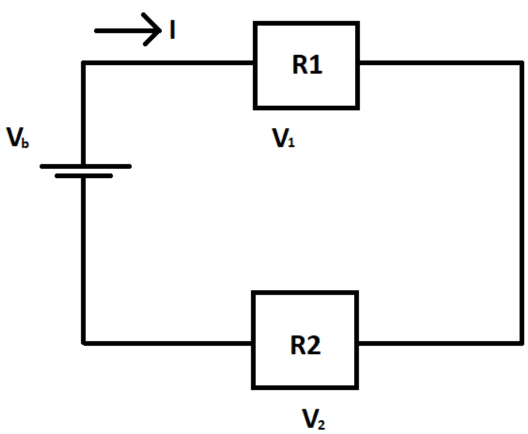


Figure 5. DC circuit with voltage terms.

3 AC circuits

AC (Alternating current) circuits have a changing direction and magnitude of its current. The voltage and current are represented as RMS values (root mean square) since the values are not constant. The connection between maximum and RMS values is:

$$V_{max} = \sqrt{2}V_{rms} \tag{10}$$

3.1 Capacitor

Capacitors store electric energy in an electric field. In AC circuit the electric current is determined from capacitive reactance (X_C), which can be determined from frequency (f) of the current and capacitance (C) of the capacitor.

$$X_C = \frac{1}{2\pi f C} \tag{11}$$

After solving capacitive reactance, the current can be determined with voltage of the alternating current. This requires a circuit with only a capacitor.

$$V_{rms} = X_C I_{rms} \tag{12}$$

3.2 Inductor

Inductors store electric energy in a form of an electromagnetic field. In an AC circuit, the amount of current flowing through needs to be determined with inductive reactance (X_L). The inductive reactance is determined from frequency of the alternating current, and the inductance (L) of the inductor.

$$X_L = 2\pi f L \tag{13}$$

After solving inductive reactance, the current can be determined with voltage of the alternating current. This requires a circuit with only an inductor.

$$V_{rms} = X_L I_{rms} \tag{14}$$

3.3 Resistor

Resistors work in AC circuits the same way as in DC circuits, but the heat dissipation rate is not constant since the current oscillates.

3.4 RLC-circuit

RLC-circuit is a circuit consisting of a capacitor, inductor and a resistor. In the simplest case, the components would be in series (Figure 6). The RMS flow of current is determined with impedance (Z), which can be determined from resistance, inductive reactance and capacitive reactance of the circuit.

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \tag{15}$$

$$I_{rms} = \frac{V_{rms}}{Z} \tag{16}$$

In a case of an RC or RL circuit, the impedance drops out the reactance term corresponding to the component. This would make the impedance in RC circuit:

$$Z = \sqrt{R^2 + (0 - X^c)^2}$$

And the impedance for RL circuit:

$$Z = \sqrt{R^2 + (X_L - 0)^2}$$

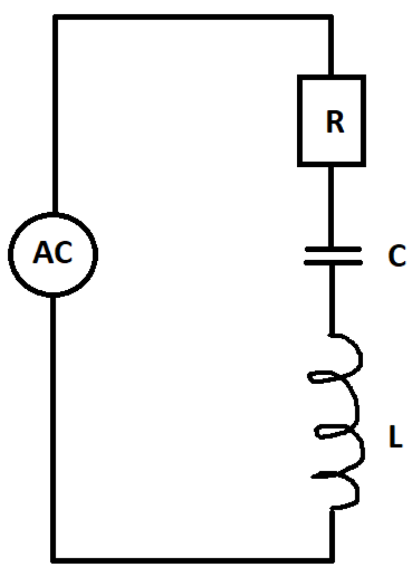


Figure 6. RLC-circuit in series.