

Part 3: Electrical Power And Energy

3.1 Power

To recap, one volt is the energy needed to move one coulomb of charge around a circuit, thus volts are a measure of joules per coulomb, and:

$$\text{volts} = \frac{\text{joules}}{\text{coulomb}} \quad \text{and} \quad \text{joules} = \text{coulombs} \times \text{volts}$$

One ampere is the current flowing at a rate of one coulomb per second through the circuit, therefore:

$$\text{amperes} = \frac{\text{coulombs}}{\text{sec onds}} \quad \text{and} \quad \text{coulombs} = \text{amperes} \times \text{seconds}$$

Therefore: $\text{joules} = \text{amperes} \times \text{volts} \times \text{seconds}$

Or: $\mathbf{W = IUt}$

Power (P) is measured in watts and one watt is doing work at the rate of one joule per second, therefore:

$$P = \frac{\text{joules}}{\text{sec onds}} = \frac{IUt}{t}$$

$$\mathbf{P = IU}$$

We can use the equation: $U = IR$ to get two other equations for electrical power:

$$\mathbf{P = I^2 R} \quad \text{and} \quad \mathbf{P = \frac{U^2}{R}}$$

Note that these equations are not necessarily true for AC circuits (see parts 11 and 12).

Example

How much energy is supplied to a 100Ω resistor which is connected to a 150V supply for 1 hour.

$$P = \frac{U^2}{R} = \frac{150^2}{100} = 225\text{W}$$

$$W = Pt = 225 \times 1 \times 60 \times 60 (\text{in seconds}) = 810\,000\text{J} = 810\text{kJ}$$

Note that the number of joules supplied is a measure of the amount of electrical energy supplied. However, since in electrical terms the value is a small amount, kilojoules (kJ) are sometimes used although there are other common units of energy.

3.2 Kilowatt-Hours And Ampere-Hours

In domestic supplies the kilowatt-hour (kWh) is usually used. 1kWh is the energy used when a

power of 1kW is supplied for one hour (3600s). Notice that power = energy/time, therefore energy = power $\times$ time and since 1kWh is a power multiplied by a time, it is in fact a unit of energy (not power).

Example

A DC motor takes 15A from a 200V supply and is used for 40 mins. What will it cost to run if the tariff is 6p/kWh?

$$P = IU = 15 \times 200 = 3000\text{W} = 3\text{kW}$$

$$\text{Energy in kWh} = Pt = 3 \times 40/60 = 2\text{kWh}$$

$$\text{Cost} = 2 \times 6 = 12\text{p}$$

Batteries are often rated in the amount of ampere-hours (Ah) that they can supply. one ampere-hour is delivered when one ampere flows from the battery for 1 hour. Note that amperes = coulombs/time, therefore coulombs = amperes $\times$ time, so that the ampere-hour is a measure of the amount of charge that flows, because it is a current multiplied by time.

3.3 Converting Between Mechanical Power And Electrical Power

In the SI system there is no difference between electrical and mechanical quantities. Thus power and energy have the units of watts and joules respectively, regardless of whether we are considering mechanical or electrical quantities. In the imperial system the unit of mechanical power is *horse power* (hp) and these must be converted to watts when considering electrical power. In either case, when converting from mechanical to electrical power or visa versa, efficiencies must be taken into account.

Example

Calculate the power of a lift which can raise a mass of 800kg through a height of 50m in 98.1s.

$$\text{work done} = \text{force} \times \text{distance}$$

The motor must overcome the force due to the weight (not mass) of the lift. The weight of the lift equals its mass multiplied by the acceleration due to gravity (9.8m/s²).

$$\text{work done} = 800 \times 9.81 \times 50 \text{ J}$$

$$\text{power needed by lift} = \frac{\text{work done}}{\text{time}} = \frac{800 \times 9.81 \times 50}{98.1} = 4000\text{W} = 4\text{kW}$$

Calculate the output and input powers of a motor driving the lift if the lift gearing is 80% efficient and the motor is 90% efficient.

$$\text{efficiency} = \frac{\text{output}}{\text{input}}$$

The output from the motor must be enough to provide the lift with enough power once the losses in the gears have been taken into account.

$$\text{input to lift (including gears)} = \text{output of motor} = \text{output from gears} = 4 \times 100 = 5\text{kW}$$

The electrical power needed to drive the motor must be enough to provide 5kW of power from the motor after the losses incurred while converting electrical power into mechanical power.

$$\text{motor input} = \frac{\text{motor output}}{\text{efficiency}} = 5 \times \frac{100}{90} = 5.56\text{kW}$$