



DC fundamentals EE3103
Student workbook 2019
Power and energy theory
and calculation exercises



Student name

“Power and Energy”

Introduction

In this unit we will look at the relationship between energy and power, the equivalence of mechanical energy/power to electrical energy/power and the attending losses to efficiency.

We will see how power relates to ohms law, measure and calculate values for power and energy, and explore where technological advances changed mechanical power to electrical power.

We will calculate how much money will be needed to buy the energy to heat our hot water cylinder and how the power rating of the element relates to how long it takes to reheat the water back up.

Electrical power

Power is the rate of expending energy and it follows that electrical power is the rate of expending electrical energy.

If we know the current flowing and the voltage supplying that current we are able to calculate the power dissipated by the formula,

$$P = V \times I \quad (\text{where } P = \text{Power})$$

And as we know $V = I \times R$ (from ohms law)

Then we can substitute $I \times R$ into $P = V \times I$

And arrive at $P = I \times R \times I$

$$\text{Or } P = I^2 R$$

And finally substituting $\frac{V}{R}$ for I into $P = V \times I$

$$\text{We can write } P = \frac{V^2}{R}$$

These are the 3 formulae that you need to remember to calculate power in a circuit.

Electrical energy

Energy is the ability to do work, where power is the rate of doing work.

With more energy, more work can be done.

le more charge in a battery or more fuel in a petrol tank.

With more power, the work or task can be completed faster.

le A bigger electric motor or a larger truck, to carry more in one load.

Units of measurement.

Energy is primarily measured in joules. This can be seen on any nutritional information panel on packaged food that we eat.

Power is measured in watts as shown on appliance rating plates.

We can define the relationship between power and energy as,

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} \quad \text{And by transposition}$$

$$\text{Energy} = \text{Power} \times \text{time}$$

And as electrical power is measured in watts and time in seconds then,

Electrical energy = watts x seconds or watt-seconds and as energy is also measures in joules then **1 watt-second = 1 joule**

A joule is a very small unit of energy so the electrical industry measures electrical energy in units of **Kilowatt – hours**, this is known as the tariff unit, usually shortened to the unit.

As there are 3600 seconds in an hour, and 1000 watts in a kilowatt, it follows that there are 3,600,000 watt-seconds or joules in a kilowatt-hour.

$$\text{1 kilowatt-hour} = 3.6 \text{ Megajoules} = \text{1 unit (tariff unit)}$$

The energy from our sun is absorbed into our food chain, which in turn is consumed by us and fuels our physical output. We could then manually rotate a hand generator causing a flow of electricity to illuminate a light bulb or charge up a battery.

This illustrates that **Mechanical energy = Electrical energy**

Mechanical power

therefore it follows that dividing both sides by time that

$$\text{Mechanical power} = \text{Electrical power}$$

We have all heard of the term horsepower associated with how powerful a car is, and now also expressed as the kilowatt output rating. (kW)

Older electric motors were rated in horsepower (hp)
Horsepower is measured at the output shaft as **mechanical output power**.

Kilowatts or watts could be either **input electric power** or **mechanical output power**, so care is needed with the interpretation of the rating plates

The relationship between these two measurement systems is,

$$1 \text{ hp} = 746 \text{ watts}$$

Derivation of "The Horsepower"

James Watt, descendant of the inventor of the steam engine, wanted to sell steam engines to Scottish mine owners.

He needed to persuade tight fisted mine owners that the savings from using new technology would offset the costs of buying it.

James needed to be able to measure these savings, and to do that he needed to quantify the work the horses were doing dragging carts and driving pumps.

He found a horse could keep working all day dragging a 500LB weight, and if the replacement steam engine could do the same measure of work, then the cost of running the steam engine and its purchase could be compared to the cost of a horse and its feed.

With the change to the metric system, the horsepower measure has been replaced with the watt.

The equivalent measure of 1 horsepower is 746 watts.

Note: Mechanical power in horsepower equates to electrical power in watts.

Efficiency

Power loss is any power that does not do useful work.

An incandescent lamp is rated at 100 watts. This is the rate at which it is consuming electrical energy when it is connected to the supply. It produces around 6 watts of visible light and 94 watts of heat and invisible light.

A 1-kilowatt motor will typically use 140 watts in heat and sound from 4 main factors.

1. Frictional heat in bearings
2. Wind friction in cooling fans
3. Copper losses or heat loss due to resistance in the windings.
4. Iron losses or heat loss due to the changing magnetic flux in the magnetic fields

The ratio of useful power used to total power supplied is called the efficiency ratio.

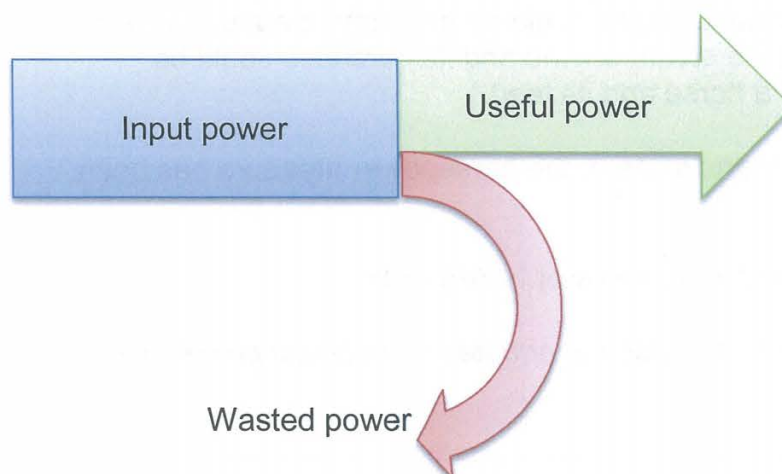
$$\text{Efficiency} = \frac{\text{useful power}}{\text{Total power}} \quad \text{or} \quad \text{Efficiency} = \frac{\text{output power}}{\text{input power}}$$

And must always be **less** than 100%

This formula above can be transposed in the same manner as ohm's law

The input power is all transferred to the output power, and as the output power is made up of useful power and wastage or losses then we can say

$$\text{Input power} = \text{output power} + \text{losses}$$



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Value Variations

When values are calculated from a theoretical circuit we are assuming all the values used are absolute.

ie The supply voltage of 230 volts is 230.000000000000000000v

The resistor value of 25 ohms is going to be 25.000000000000....Ω as shown in the diagram.

We would work out with our calculator that the current flowing in this circuit would be

$$I = \frac{V}{R}$$
$$I = 230 \div 25 = 9.2000000000000000000000000000A$$

This is all theoretical but in the real world that we operate in

The supply voltage could easily be between 220v to 240v AND changing up or down by the second, by the time we take the measurement to include in our calculation the voltage could move by 10v

1 This is called supply variation.

The 25 ohm resistor will probably at best be 2% so it's value could be anywhere between 24.5 and 25.5 ohms

2 This is called component tolerance

When we come to measure the values with a meter we need to realise that the value displayed on the meter is only an approximate value and could vary by 2% up or down for an average meter compared to an expensive laboratory calibrated meter.

3 This is called instrument error

And of course whenever people are involved taking the measurements errors can creep in through:

Poor eye sight

Wrong range settings.

Not allowing for lead resistance.

Moving coil meter not laying flat

4 These types of variations are called measurement error

25070 Water heating calculations worksheet 7

(merit level for advanced students)

Knowing how to carry out these calculations will allow an electrician to be able to advise a customer what size element to use to heat a required amount of water. How long it will take to heat or reheat, how much it will cost, what size cable is required for the element size.

You can always get the boss to do it or you can impress him with your skills.

What we need to know

It requires 4190 joules of energy to heat one kilogram of water one degree Celsius. Other liquids require different quantities of energy to heat up.

$$Q = m \times \Delta t \times C$$

Energy in joules at 100% efficiency equals the mass in kilograms times the change in temperature times 4190 joules to heat each of those kg's each degree of temperature change

It follows that if 200 kg of water is heated from 18 degrees to 42 degrees then the energy needed would be

$$Q = 200 \times (42 - 18) \times 4190$$

$$Q = 20,112,000 \text{ joules or } 20.112 \text{ MJ}$$

Other formula that you will need are

$$1\text{kWh} = 3.6\text{MJ} = 1 \text{ tariff unit}$$

$$\text{Efficiency} = \text{output} \div \text{input}$$

$$1\text{m}^3 = 1000 \text{ litres of water} = 1000\text{kg}$$

$$1 \text{ litre water} = 1 \text{ kg}$$

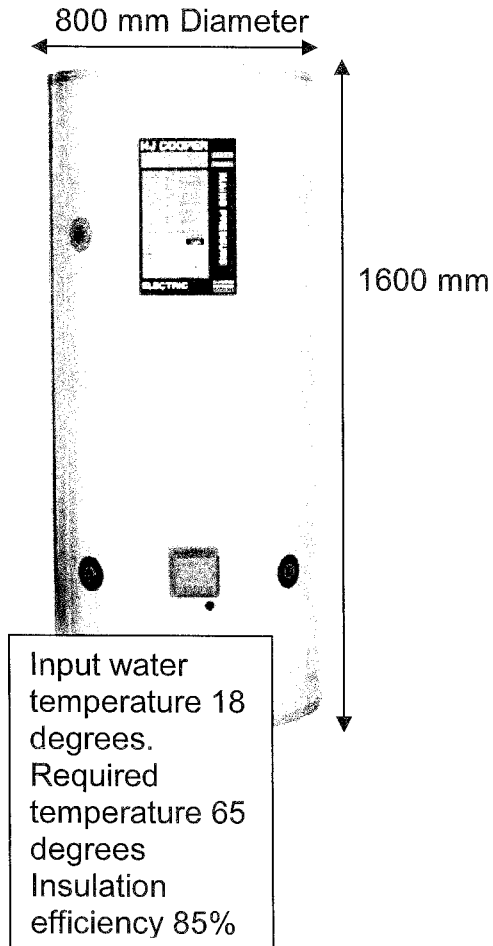
$$\text{Power} = \text{energy} / \text{time}$$

$$\text{Energy} = \text{power} \times \text{time}$$

$$\text{Time to heat (hours)} = \text{kWh energy} / \text{element size in kW}$$

$$\text{Volume of a cylinder} = \pi \times r^2 \times h$$

Example



- a) Firstly determine how much water is in the tank

$$\text{Volume of a cylinder} = \pi \times r^2 \times h$$

$$3.142 \times 0.4^2 \times 1.6 = 0.804 \text{ m}^3$$

- b) Determine how much energy it would take to heat the water

$$Q = m \Delta t C$$

$$Q = 804 \times (65 - 18) \times 4190$$

$$Q = 158,331,720 \text{ joules}$$

$$Q = 158.3 \text{ MJ}$$

This is the energy needed to get the job done with no losses

- c) To cover the losses

$$\text{energy needed} = \frac{158.3 \text{ MJ}}{0.85}$$

$$\text{Energy needed} = 186.3 \text{ MJ}$$

- d) and as $3.6 \text{ MJ} = 1 \text{ kWh}$

$$\frac{186.3 \text{ MJ}}{3.6} = 51.75 \text{ kWh}$$

- e) If the tank had a 4 kW element then

$$\frac{51.75 \text{ kWh}}{4 \text{ kW}} = 12.94 \text{ hours to carry out the job}$$

- f) If the electricity cost 27 cents per unit then

$$51.75 \text{ kWh} \times \$0.27 = \$13.97 \text{ to heat that water}$$

Question 1

Calculate the time taken to heat the water in a hot water cylinder that is 2m tall and has a diameter of 750mm.

The cylinder has a 10kW element fitted and insulated to 85%.

Initial water temperature is 15°C and required temperature is 65°C

