Trade of Electrician

Standards Based Apprenticeship

Power and Energy

Phase 2

Module No. 2.1

Unit No. 2.1.6

COURSE NOTES

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Introduction

Welcome to this section of your course, which introduces you, the learner to the topics of **power** and **energy**. There is a subtle difference between **power** and **energy, which** must be understood.

Objectives

By the end of this unit you will be able to:

- Understand the terms work, power and energy
- Calculate the power dissipation of various circuits
- Calculate the energy consumption of various circuits
- Measure power using an ammeter and a voltmeter
- Decide rating of resistors by physical size or marking
- Calculate the power dissipated in a series circuit
- Calculate the power dissipated in a parallel circuit
- Calculate the power dissipated in a series-parallel circuit
- Calculate the energy consumed by a load in a given time
- Understand how energy consumption is measured
- Calculate the cost of energy consumed, given meter readings

Reasons

An electrician must be able to decide the power consumption of electrical equipment in order to be able to install it correctly and to successfully locate faults.

Work and Force

Whenever a **force** of any kind causes **motion**, ***work*** is said to be done. When a mechanical force, for instance, is used to lift a weight through a distance, work is done. The SI unit of force is the Newton (N) and the unit of distance or length is the metre (m).

Work

Work is measured in terms of distance moved by the object and the force, which caused the movement.

Work = Distance x Force

The unit is the **metre-newton** (mN), which is also known as the **joule** (J).

Example:

A force of 4000 Newtons is required to lift a bundle of steel conduit through a distance of 2.5 metres. How much work is done in lifting the conduit?

Solution:

Work = Distance x Force (metre-newtons)

Work = 2.5 x 4000

Work = **10,000 metre-newtons or joules**

Power

A **difference in potential**, between any two points in an electrical circuit, gives rise to a **voltage**. If there is a complete circuit this voltage causes current to flow. Here is an obvious case of a force causing motion, and so causing work to be done. Whenever a voltage causes electrons to move, **work** is done in moving them.

The **rate** at which this work is done is called electrical power.
It is represented by the symbol **P**.

The **energy consumed** in moving the electrons against the frictional resistance of the conductor, is **converted** into another form of energy - namely **heat**. This **rate of energy conversion** is what the word **power** really means.

The basic unit in which electrical power is measured is the **Watt (W)**.

The Watt can be defined as:

"The rate at which work is done when an EMF of one Volt causes a current of one Amp to flow".

Power = Voltage x Current

$$P = U \times I$$

or
$$U = \frac{P}{I}$$

or
$$I = \frac{P}{U}$$

The Power Triangle

This power triangle can be used in the same way as the Ohms Law Triangle.

Refer to Figure 1.

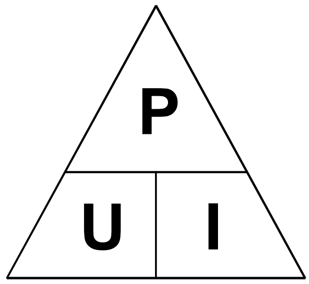

Figure 1.

Power Formulae

Other very useful formulae can be derived by combining the Ohms Law and Power Formulae.

$$\mathbf{P = U \times I}$$

From Ohm's Law $U = I \times R$ we can substitute $I \times R$ for U

$$P = I \times R \times I$$

$$\mathbf{P = I^2 \times R}$$

$$P = U \times I$$

From Ohm's Law $I = \frac{U}{R}$ we can substitute $\frac{U}{R}$ for I

$$P = U \times \frac{U}{R}$$

$$\mathbf{P = \frac{U^2}{R}}$$

List of Power Formulae

The three power formulae from the previous page are very important and can be transformed to give a total of nine power formulae as follows.

$$\mathbf{P} = \mathbf{U} \times \mathbf{I} \qquad U = \frac{P}{I} \qquad I = \frac{P}{U}$$

$$\mathbf{P} = \mathbf{I}^2 \times \mathbf{R} \qquad R = \frac{P}{I^2} \qquad I = \sqrt{\frac{P}{R}}$$

$$\mathbf{P} = \frac{\mathbf{U}^2}{\mathbf{R}} \qquad R = \frac{U^2}{P} \qquad U = \sqrt{P \times R}$$

Examples

The power rating is marked on most electrical devices. For example a lamp might be marked 100 Watt, or a heater might be marked 1 kW. These power ratings indicate the rate at which electrical energy is changed into another form of energy such as light and heat. The 1 kW heater consumes ten times more electricity than the 100 Watt lamp.

Each device is designed to operate at a particular voltage level. This is equally as important and will also be marked on the device.

Given the values of 100 Watts, 230 Volts, other values can be calculated e.g. current and resistance.

$$\text{Current} = \frac{\text{Power}}{\text{Voltage}} = \frac{\text{Watts}}{\text{Volts}} = \frac{P}{U}$$

$$I = \frac{100}{230} = \underline{\textbf{0.43 Amps}}$$

$$R = \frac{U}{I} = \frac{230}{0.43} = \underline{\textbf{535 Ohms}}$$

What current will flow through the 1 kW 230 Volt heater and what is the resistance of the heater element?

$$\text{Amps} = \frac{\text{Watts}}{\text{Volts}} = \frac{1000}{230} = \underline{\textbf{4.3 Amps}}$$

$$R = \frac{U}{I} = \frac{230}{4.3} = \underline{\textbf{53.5 Ohms}}$$

Example

Calculate the Power used or dissipated by the resistor in the circuit below.

Refer to Figure 2.

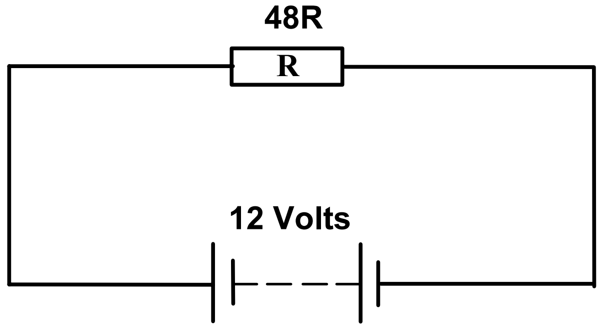

Figure 2

Solution:

From Ohm's law

$$I = \frac{U}{R} = \frac{12}{48} = \underline{\mathbf{0.25\ Amps}}$$

Therefore $P = U \times I = 12 \times 0.25$

$$P = \underline{\mathbf{3\ Watts}}$$

The previous solution could be done in one step by using the following formula:

$$P = \frac{U^2}{R} = \frac{12 \times 12}{48} = \frac{144}{48}$$

$$P = \underline{\mathbf{3\ Watts}}$$

Measuring Power

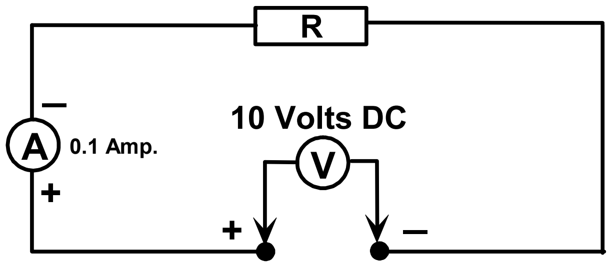

Figure 3

In the circuit above the supply voltage is 10 Volts and a current of 0.1 Amp is flowing. The power dissipated in the circuit can be obtained as follows.

Power	=	Volts x Amps
P	=	10 x 0.1
P	=	**1 Watt**

The resistor in the circuit above must have a **power rating** of at least **1 Watt**

Power Rating of Resistors

Manufacturers supply resistors with different power ratings. In the low power resistor range, these ratings are;
0.25 Watt, **0.5** Watt, **1** Watt and **2** Watt.

A resistor must have a power rating high enough to dissipate the heat produced by the current flowing through it (I^2R).

Some resistor types have the power rating marked on the body. In other cases it is the **physical size** of the resistor that determines its wattage. Carbon film resistor dimensions are illustrated below. Refer to Figure 4.

2W

1W

0.5W

0.25W

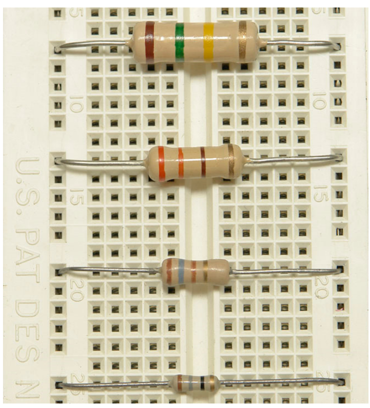

Figure 4

Power in a Series Circuit

The power dissipated by any resistor is given by, the voltage across that resistor multiplied by the current flowing through it.

Refer to Figure 5.

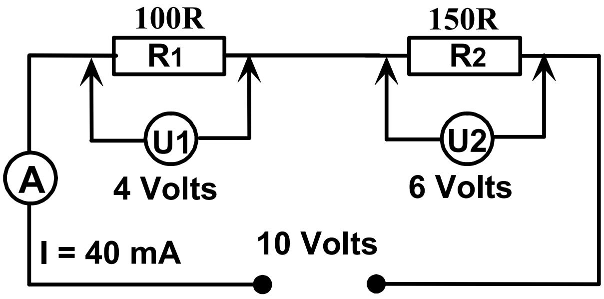

Figure 5

$P_1 = U_1 \times I$

$P_1 = 4 \times 0.04$

$P_1 =$ **0.16 Watts** (this is the power dissipated by R_1)

The power dissipated by R_2 could be different to that of R_1

$P_2 = U_2 \times I$

$P_2 = 6 \times 0.04$

$P_2 =$ **0.24 Watts**

The total power dissipated in the circuit is given by, the supply voltage (U_S) multiplied by the total current:

$P_T = U \times I$

$P_T = 10 \times 0.04$

$P_T =$ **0.4 Watts or 400 mW**

The total power dissipated in the circuit can also be calculated by adding P_1 and P_2.

$P_T = P_1 + P_2 = 0.16 + 0.24 =$ **0.4 Watts**

Power in a Parallel Circuit

The power dissipated by any resistor is given by, the voltage across that resistor multiplied by the current flowing through it.

Refer to Figure 6.

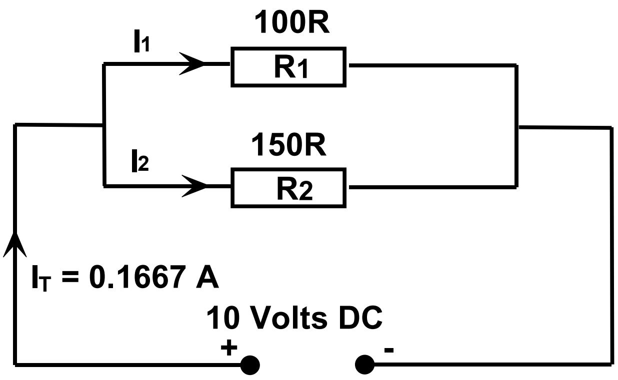

Figure 6

Find:

(a) Power dissipated by 100R.
(b) Power dissipated by 150R.
(c) Total power dissipated in the circuit.

(a) $P_1 = \frac{U^2}{R_1} = \frac{10 \times 10}{100} =$ **1 Watt**

(b) $P_2 = \frac{U^2}{R_2} = \frac{10 \times 10}{150} =$ **0.667 Watts**

(c) $P_T = P_1 + P_2 = 1 + 0.667 =$ **1.667 Watts**

or $P_T = U \times I_T$

$P_T = 10 \times 0.1667$

$P_T =$ **1.667 Watts**

Power in a Series / Parallel Circuit

Example

1. Find the total power dissipated in the circuit.

2. Find the power dissipated by:
   (a) R_1
   (b) R_2
   (c) R_3

Refer to Figure 7.

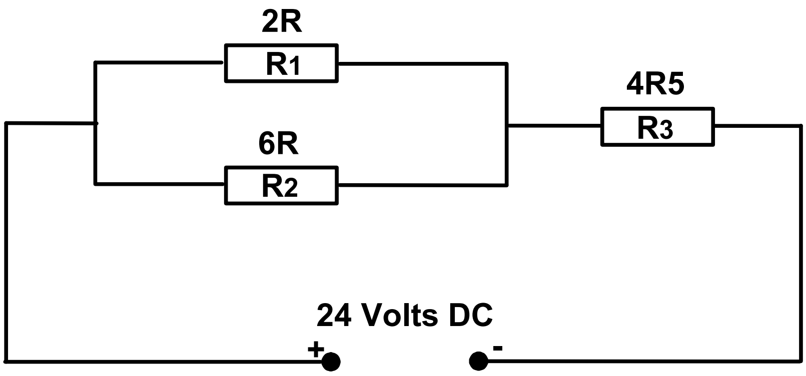

Figure 7

Solution

The total resistance, volt drops across the resistors and the circuit currents must first be calculated.

$$R_P = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{2 \times 6}{2 + 6} = \frac{12}{8} = 1R5$$

$$R_T = R_P + R_3 = 1.5 + 4.5 = 6R$$

1. $$P_T = \frac{U^2}{R_T} = \frac{24 \times 24}{6} = \underline{\textbf{96 Watts}}$$

The current I_T that will flow:

$$I_T = \frac{U}{R_T} = \frac{24}{6} = 4 \text{ Amps}$$

Volt drop across R_3

$$U_3 = I_T \times R_3 = 4 \times 4.5 = 18 \text{ Volts}$$

Volt drop across parallel resistors (R_1 and R_2)

$$U_P = I_T \times R_P = 4 \times 1.5 = 6 \text{ Volts}$$

2. Power dissipated in R_1, R_2 and R_3:

(a) $$P_1 = \frac{U_P^2}{R_1} = \frac{6 \times 6}{2} = \underline{\textbf{18 Watts}}$$

(b) $$P_2 = \frac{U_P^2}{R_2} = \frac{6 \times 6}{6} = \underline{\textbf{6 Watts}}$$

(c) $$P_3 = \frac{U_{R3}^2}{R_3} = \frac{18 \times 18}{4.5} = \underline{\textbf{72 Watts}}$$

The three individual powers added together gives the total power dissipated.

$$P_1 + P_2 + P_3 = P_T$$

$$18 + 6 + 72 = \underline{\textbf{96 Watts}}$$

The total power can be found as follows:

$$P_T = U_S \times I_T = 24 \times 4 = \underline{\textbf{96 Watts}}$$

Domestic Example

An electric shower element is drawing a current of 36 Amps. The voltage at its terminals is 228 Volts. What is the power dissipated by the shower element?

$$P = U \times I$$

$$P = 228 \times 36$$

$$P = \underline{\textbf{8,208 Watts}}$$

As this figure is quite large it would be better expressed in kilowatts:

$$P = 8.208 \text{ kilowatts}$$

$$P = \underline{\textbf{8.2 kW}} \quad (k = 1{,}000)$$

Question

The following loads are connected to a 230 V supply.

1. 9 kW electric shower
2. 3 kW immersion heater
3. 750 W food mixer
4. 1.5 kW electric fire
5. 10 X 75 W lamps

Find:

1. The current taken by each appliance.
2. The total current.
3. The total power.
4. The resistance of each appliance.
5. The approximate total resistance.

Energy

Energy is the ability to do work. If a 60 Watt and a 100 Watt electric lamp are compared, the 100 Watt lamp is brighter and therefore does more work.

The watt is the rate of doing work at one joule per second.

$$\textbf{1 Watt} = \frac{\textbf{1 Joule}}{\textbf{1 Second}}$$

Therefore 1 Joule = 1 Watt x 1 Second

Joules = U x I x t

The unit of electrical energy (**Symbol *W***) is the joule or 1 watt x 1 second.

Energy = U x I x t

***W* = U x I x t**

The joule or watt-second is too small a unit for commercial purposes. In considering domestic loads, the power is measured in kilowatts and the time in hours. A unit called the kilowatt-hour (kWh) is used

1 kWh = 1000 Watts x 1Hr

The kWh is the commercial unit of ENERGY

The kWh is the energy used when 1kW (1,000 Watts) of electric power is consumed for 1 hour or a 100 Watt lamp is on for 10 Hours.

The kWh is referred to as the **unit** of electricity and it is by this **commercial unit** that the Supply Authority charges for electrical energy.

Energy Formulae

(Energy) $W = U \times I \times t$ (Watts x t)

$$W = \frac{U \times I}{1000} \times t \text{ (kW x t)}$$

if **t** is in hours:

$$W = \frac{U \times I \times t}{1000} \text{ kWh}$$

if **t** is in minutes, divide by 60 to get hours:

$$W = \frac{U \times I \times t}{1000 \times 60} \text{ kWh}$$

if **t** is in seconds, divide by 60 to get minutes and 60 to get hours:

$$W = \frac{U \times I \times t}{1000 \times 60 \times 60} \text{ kWh}$$

Example

A 60 Watt lamp is on for 120 minutes. Calculate the amount of electrical energy consumed.

Solution

$$W = P \times t$$

$$W = \frac{60 \times 120}{60} \qquad \left(120 \text{ mins to hrs } = \frac{120}{60} \right)$$

$$W = \frac{60 \times 120}{60 \times 1000} = \frac{120}{1000} \text{ kWh}$$

$$W = \underline{\mathbf{0.12\ kWh}}$$

Example

An appliance draws a current of 13 Amps from the supply and has an element of resistance 17R5. How much energy is consumed after a period of 2.5 hours?

Solution

$$P = I^2 \times R$$

$$P = 13 \times 13 \times 17.5 = 2{,}957.5 \text{ Watts}$$

$$P = \underline{\mathbf{2.9575\ kW}} \quad (\text{ watts to kilowatts divide by } 1000\ )$$

$$W = P \times t$$

$$W = 2.9575 \times 2.5$$

$$W = \underline{\mathbf{7.39\ kWh}}$$

If the electricity supply company charges 11.5 cent per commercial unit of electrical energy:

$$\text{Cost} = \text{kWh} \times \text{Unit cost}$$

$$\text{Cost} = 7.39 \times 11.5$$

$$\text{Cost} = 85 \text{ cent}$$

This is the cost of running the element of the above appliance for 2.5 hours.

Measuring Power and Energy

A **wattmeter** is a combination of a **voltmeter** and an **ammeter**. It measures the **product** of **voltage and current**. Its **current coil** consists of a small number of turns of **large diameter wire**, as it must cater for the **load current.** Its **voltage coil** consists of a large number of turns of **small diameter wire**, as the current flow through it is very low. It has three terminals. It is connected as shown in Figure 8.

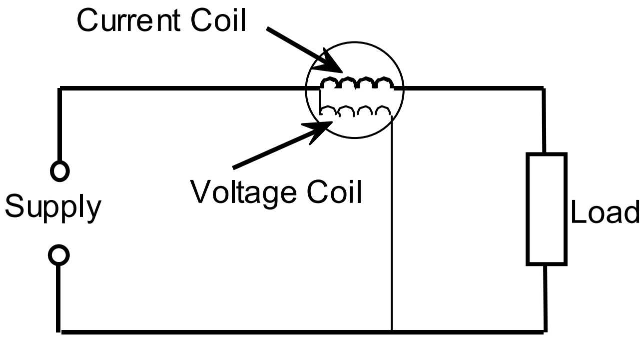

Figure 8

$$P = I \times U$$

An energy meter is similar to a wattmeter and its connections are the same. However, it is designed to show the number of kilowatt-hours of energy used.
See Figure 9.

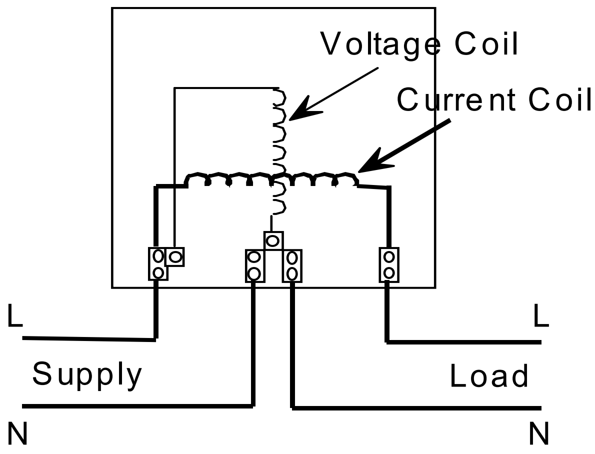

Figure 9

A kWh meter is familiar to most of us as our electricity meter. See Figure 10.

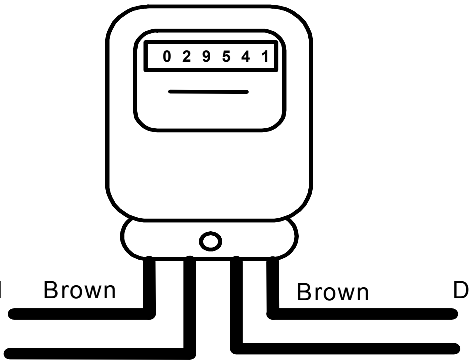

Figure 10

Cost of Electricity to Consumer

The kWh meter has a disc, which rotates at a speed, which is directly proportional to the power being consumed. After a given number of revolutions the scale will advance by one more unit. One **unit** of electricity is equivalent to one kilowatt of energy consumed in a period of one hour.

A representative of the Supply Authority will read the meter every two months and the consumer will receive a bill based on the energy consumed.

Example

Current meter reading	80014 kWh
Previous meter reading	79304 kWh
Units consumed	710 kWh

The customer's final bill would be based on this figure of 710 units of electricity.

Exercise

Examine a domestic consumer's electricity bill and determine how the account figures are calculated.