How are fields used to move electrical energy?

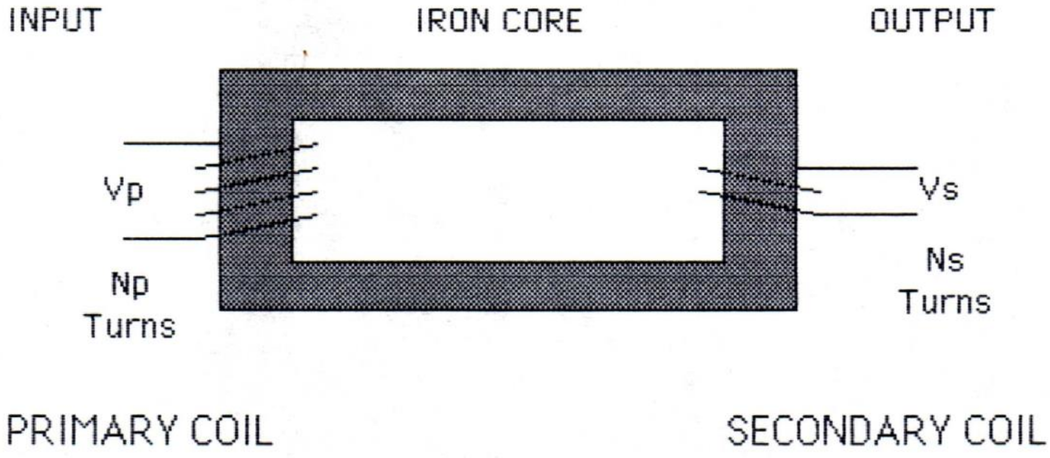
Reference: Heinemann Physics 12 4th Edition Chapter 4 Pages 132 – 145

Physics with Synno – Electrical Energy – Lesson 3

EP.4 **Transformers**

Video: Working of Transformer
Transformers - Experiments and Demos
https://www.youtube.com/watch?v=y0WrKT45ZZU

A transformer is used to change (transform) the voltage. A transformer is basically two coils of wire "coupled" by an iron loop.



If an alternating EMF is applied across the primary coil, the changing current will produce a changing magnetic field. This magnetic field is "channelled" via the iron core to the secondary coil. This will induce an EMF in the second coil.

It turns out that:

$$\frac{\textit{Voltage across primary Coil}}{\textit{Vottage across Secondary Coil}} = \frac{V_p}{V_s} = \frac{N_p}{N_s}$$

In a good transformer energy is conserved and:

Power In = Power Out

I.e. $V_p\, I_p = V_s\, I_s$

Thus we have $\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}$

Example

A transformer supplies a model train that operates on 12 V from the mains 240 V supply.

a If the number of turns in the secondary coil is 100, what will be the number of turns in the primary coil?

b If the train requires a current of up to 4 A, what will be the current and the power drawn from the mains?

Solution

a We know that the turns ratio $\frac{N_s}{N_p}$ is equal to the voltage ratio $\frac{V_s}{V_p}$.

Thus we can write:

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{240}{12} = 20$$

As there are 100 turns in the secondary there must be 2000 turns in the primary.

b The current ratio is the inverse of the turns and voltage ratio so that the current in the primary will be $\frac{1}{20}$ of the secondary current. Thus:

$I_p = 4 \div 20 = 0.2$ A

The power required by the train was 12 V × 4 A = 48 W. Alternatively, the input power was 240 V × 0.2 A = 48 W, which is of course the same, as we assumed that the transformer itself uses no power.

E.5.6 Power Transmission

The major problem with the transmission of power is that some of it is lost during transmission.

$$Power\ Loss = I^2R$$

The power loss is kept to a minimum by keeping both I and R as low as possible.

R is kept low by using thick wires.

In order to keep the current low and transmit large amounts of power, it is necessary to use high voltage. The highest voltage used for transmission in Australia is 500 kV.

To insulate the line from the supporting structure either glass or porcelain insulators are used.

Imagine that 400 MW of power was available to be transmitted along a transmission line of 4.0 Ω. How would the power losses due to the resistance of the transmission line vary with the voltage across the transmission line? The following table shows some typical values.

Transmission voltage	1000 kV	500 kV	220 kV	66 kV
Current $\left(I = \frac{P_{tot}}{V}\right)$	400 A	800 A	1800 A	6100 A
Power loss ($P_{loss} = I^2 R$)	640 kW	2.6 MW	13 MW	150 MW
Power loss (%)	0.2%	0.6%	3.3%	37%

Example

In a circuit, a 240 V AC supply of negligible resistance is connected by wires of total resistance 4.0 Ω to a motor of resistance 116 Ω. Calculate:

a) the current flowing through the wires
b) the power loss in the wires
c) the voltage drop across the wires
d) the voltage or potential difference across the motor
e) the power converted in the motor

Solution

a)

$V = I R$

$240 = I (4 + 116)$

$I = 2.0 \text{ A}$

b)

$P = I^2 R$

$P = (2.0)^2 \times 4$

$P = 16 \text{ W}$

c)

$V = I R$

$= 2.0 \times 4.0$

$= 8.0 \text{ V}$

d)

$V = I R$

$= 2.0 \times 116$

$= 232 \text{ V or } 2.3 \times 10^2 \text{ V}$

e)

$P = I^2 R$

$= (2.0)^2 \times 116$

$= 464 \text{ W or } 4.6 \times 10^2 \text{ W}$

E.5.6.1 Power Distribution

Video: Electrical Grid 101 _ All you need to know
Spacer Installation on 765,000 volt line
Wind Turbine Tour

In Victoria, electricity is generated at a variety of voltages. In Yallourn, the voltage is 20 000 V (20 kV). In Newport, the generating voltage is 24 000 V. From the various generators around Victoria, the voltage is stepped up to 500 kV to transmit the electrical energy over the long distances to Melbourne.

When the cables reach the outskirts of Melbourne, the high voltage is stepped down to 66 kV for distribution within the suburban area.

In each suburb, the voltage is then further stepped down to 11 kV, either for delivery to yet another step-down transformer or to a neighbourhood power pole.

There it is reduced to 240 V for connection to all the houses in the immediate neighbourhood.

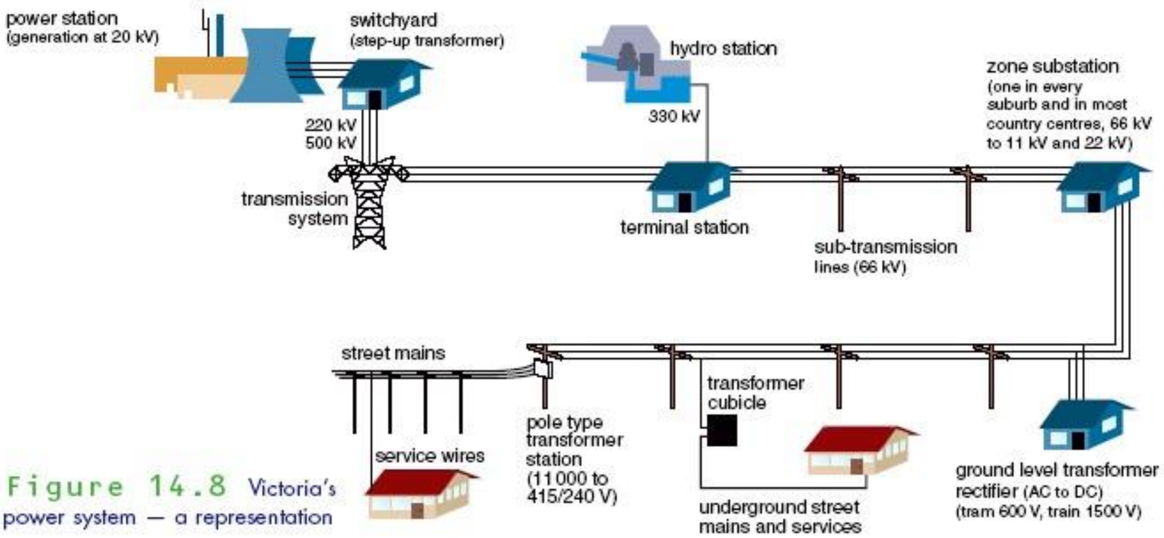
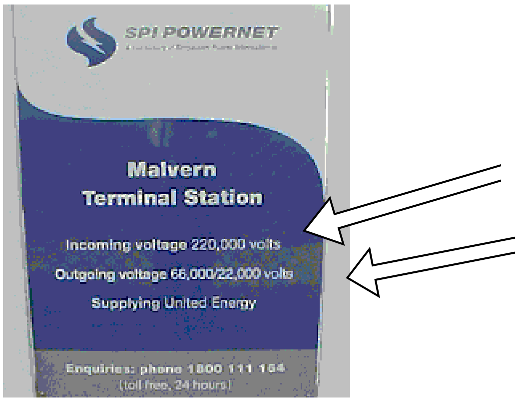


Figure 14.8 Victoria's power system — a representation



Typically, the power is sent from the generating station at voltages as high as 500/220 kV.

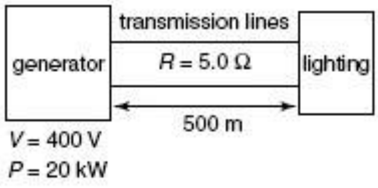
As it arrives at a terminal station it is stepped down to 66 kV and then down to 22 kV at a substation.

Pole transformers further step it down to 415 and 240 volts for domestic use.

At various stages, power is taken from the system and rectified into 600 V (trams) or 1500 V DC (trains) for public transport. Power is also transformed into other AC voltages for specific uses in industry.

Example

A 20 kW, 400 V diesel generator supplies power for the 400 V lights on a film set at an outside location. The 500 m transmission cables have a resistance of 5.0Ω.



(a) What is the current in the cables?

(b) What is the voltage drop across the transmission cables?

(c) What is the power loss in the cables as a percentage of the power supplied by the generator?

(d) What is the voltage supplied to the lighting?

Solution

(a) Current in the cables = Current coming from generator

For the generator: $P = 20\,000$ W, $V = 400$ V, $I = ?$

$P = VI$

$20\,000 \text{ W} = 400 \text{ V} \times I$

$I = 50$ A

Note: Using $V = IR$ with $V = 400$ V and $R = 5.0\ \Omega$ is incorrect because the 400 V is across both the cables *and* the load at the end.

(b) For cables: $I = 50$ A, $R = 5.0\ \Omega$, $V = ?$

$$\begin{aligned} V &= IR \\ &= 50 \text{ A} \times 5.0\ \Omega \\ &= 250 \text{ V} \end{aligned}$$

(c) For cables: $I = 50$ A, $R = 5.0\ \Omega$, $P_{\text{loss}} = ?$

$$\begin{aligned} P_{\text{loss}} &= I^2R \\ &= 50 \text{ A} \times 50 \text{ A} \times 5.0\ \Omega \\ &= 12\,500 \text{ W} \end{aligned}$$

$$\text{As a percentage, } \%P_{\text{loss}} = \frac{12\,500}{20\,000} \times \frac{100}{1}$$

$$= 62.5\%$$

(d) Generator voltage = sum of voltages in circuit

$V_{\text{gen}} = 400$ V, $V_{\text{cables}} = 250$ V, $V_{\text{load}} = ?$

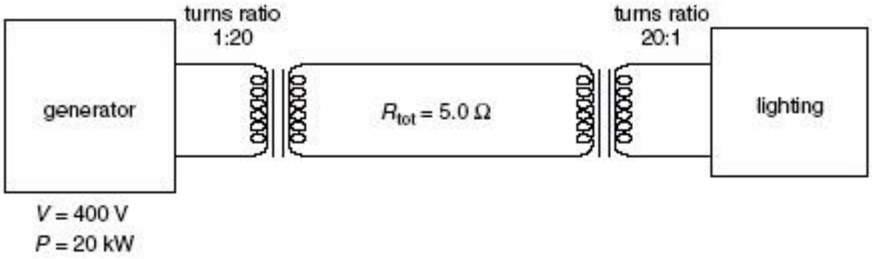
$400 \text{ V} = 250 \text{ V} + V_{\text{load}}$

$$\begin{aligned} V_{\text{load}} &= 400 \text{ V} - 250 \text{ V} \\ &= 150 \text{ V} \end{aligned}$$

At this distance the voltage drop across the cables is too much to leave sufficient voltage to operate the lights at their designated voltage. Given the noise of the generators, they cannot be moved closer. Therefore, step-up and step-down transformers with turns ratios of 20 are used to reduce the power loss in the cables and increase the voltage at the lights.

Example

Repeat the calculations in the previous sample problem, but this time increase the generator voltage by a factor of 20 and, prior to connection to the lights, reduce the voltage by a factor of 20.



(a) What is the current in the cables?

(b) What is the voltage drop across the transmission cables?

(c) What is the power loss in the cables as a percentage of the power supplied by the generator?

(d) What is the voltage supplied to the lighting?

Solution

(a) Current in cables = Current coming from step-up transformer

$V_{sec} = 20 \times 400$ V

$= 8000$ V

For an ideal transformer: $P_{prim} = 20\,000$ W, $I_{sec} = ?$

$P_{prim} = P_{sec} = V_{sec}\, I_{sec}$

$20\,000 \text{ W} = 8000 \text{ V} \times I_{sec}$

$I_{sec} = 2.5$ A

(b) For cables: $I = 2.5$ A, $R = 5.0\ \Omega$, $V = ?$

$V = IR$

$= 2.5 \text{ A} \times 5.0\ \Omega$

$= 12.5$ V

(c) For cables: $I = 2.5$ A, $R = 5.0\ \Omega$, $P_{loss} = ?$

$P_{loss} = I^2R$

$= 2.5 \text{ A} \times 2.5 \text{ A} \times 5.0\ \Omega$

$= 31.25$ W

As a percentage, $\%Ploss = \frac{31.25}{20\,000} \times \frac{100}{1}$

$= 0.16\%.$

(d) Voltage supplied to step-down transformer = 8000 V − 12.5 V = 7988 V

Voltage supplied to lighting:

$Vsec = 7988 \text{ V} \times \frac{1}{20}$

$= 400$ V

Text Questions: Page 139 Ex 4.4 All Questions