Alternating Currents

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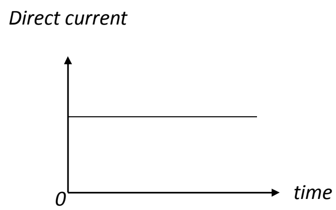
Describe Alternating Current

- In developed countries, mains electricity is a supply of alternating current (a.c.) rather than direct current (d.c.)
- Nowadays, the standard voltages in mains electricity supply is of 110/120 V or 230/240 V, and frequencies of 50 or 60 Hz.
- In this chapter, we will look at some of the reasons why a.c. has been chosen as a standard.
- First, we must take a look at the nature of alternating current.

Direct Current

- When a battery is connected to a circuit, ***current flows steadily in one direction***
- Let us consider a lamp with is supply by a D.C.
- An electric current is the flow of charge carriers through a conductor under the influence of an electric field.
- For the case of direct current, example due to battery, the electron flow in one direction only.
- In a lamp, emission of energy is due to collisions between the moving electrons and atoms of the filament.
- Graphical form of a direct current.

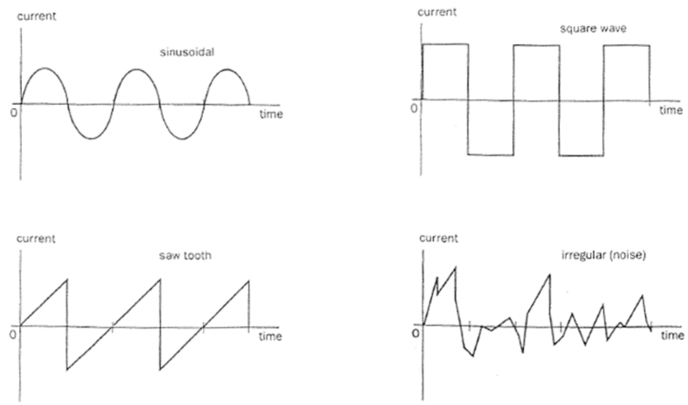


Alternating Current

- For the case of alternating current, the p.d. reverses its polarity regularly, which has the effect of causing the electrons to reverse their direction of motion with the same frequency as the source.
- At any instant, electrons are only flowing in one way. The flow of electrons through the filament releases energy as before, but there are instants, while the direction reverses, the electrons are stationary, so the lamp flashes on and off.
- However, at frequencies greater than about 20 Hz, the human eye and brain will interpret this as continuous illumination.
- In short, alternating current is a current that varies in **magnitude** and **direction** periodically with time.

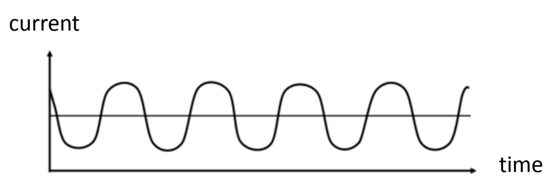
Alternating Current

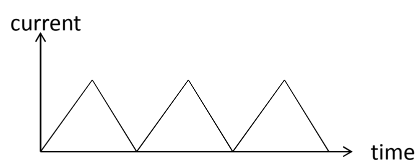
- Some examples of alternating current / voltage in graphical forms:

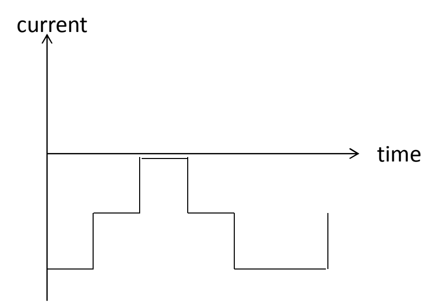


Alternating Current

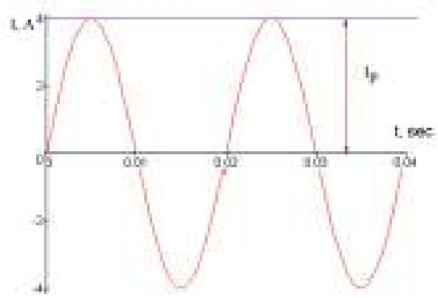
- Below are examples of current that are **NOT** alternating.!







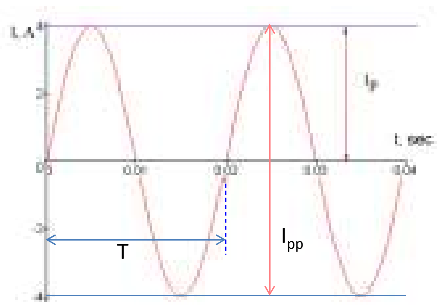
Sinusoidal Alternating Current



- A common alternating current has a sinusoidal waveform. (current varies like a sine wave)
- This current of sinusoidal waveform varies cyclically.
- During half of the cycle , the current is positive, and the other half it is negative.
- This means that the current flows alternately one way and then the other in the wires in which it is travelling.

- Whenever you use a mains appliance, current flows back and forth in the wires between you and the power station where it is being generated.
- At any instant of time, the current has a particular magnitude and direction given by the graph.
- This graph has the same shape as graphs used to represent simple harmonic motion, therefore it can be interpret the same way.
- In principle, any current whose direction changes between positive and negative can be described as alternating, but we will only be concerned with those which has a regular, sinusoidal pattern.

Sinusoidal Alternating Current



- We can write an equation to represent a.c.
- This equation tells us the value of the current, I at any time, t.

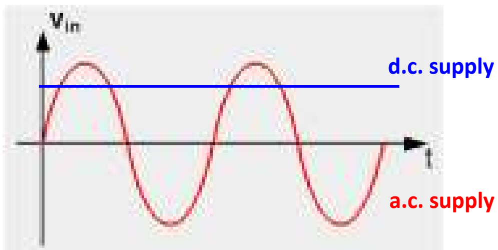
  $I = I_0 \sin \omega t$
- where ω is the angular frequency (rads^{-1})
- I is the a.c. at time t.
- I_0 is the peak value of the a.c. found from the highest point on the graph. (the amplitude of the varying current)

- Period, T, is the time for one complete cycle of the waveform.
- Frequency, f, is the number of complete cycles per second.
- Peak to peak value, I_{pp} is twice the peak value, I_0.
- To produce alternating current, the emf, V also has to varies sinusoidally. So we can write an equation to represent it which has the same form as the a.c.:

  $V = V_0 \sin \omega t$

Comparing A.C. & D.C.

- Since power supplied by an a.c. is varying at all time, we need to have some way of describing the average power which is being supplied.
- To do this, we compare an a.c. and d.c. , and find the d.c. that supplies the same average power as the a.c.
- We can placed 2 lamps side by side. One is connected to a.c. , another to d.c.
- In order for the 2 supplies to provide energy at the same average rate, the a.c. supply is adjusted so that the lamp brightness is equal to that of the d.c.
- The output voltages are then compared on the CRO.

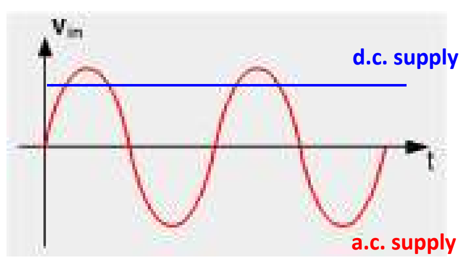


Comparing A.C. & D.C.

- From the trace shown below, we can deduce that the a.c. trace sometimes rise above the steady d.c. trace, and sometimes falls below it.
- In term of power delivery, it tells us that sometimes the a.c. is delivering more power than the d.c., and sometimes less, but the average power is the same for both, that's why we obtain similar brightness for both lamps.
- Studies showed that there is a mathematical relationship between the d.c. voltage and the peak value, V_0 of the a.c. voltage.
- To obtain equal brightness of lamps, the d.c. voltage is about 70% of V_0 (0.7071 V_0)
- This steady d.c. voltage is known as the root mean square value of the a.c. voltage.

In the same way, we can think of the rms value of the a.c. , I_{rms} :

The root mean square value of an alternating current, I_{rms} is that steady current which delivers the same average power as the a.c. to a resistive load.

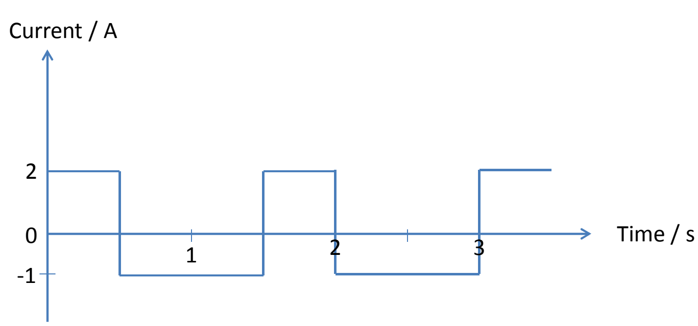


Root Mean Square Value

- To obtain the rms values, the following steps are taken:
  1.) **Square all** the values, I^2 or V^2 .
  2.) Find the **area within one period** under the I^2-t graph or V^2-t graph.
  3.) Find the **mean** of these squared values, $\langle I^2 \rangle$ or $\langle V^2 \rangle$, by dividing the area with the value of one period.
  4.) Find the I_{rms} by taking the **square root** of the mean squared value. $\sqrt{\langle I^2 \rangle}$ or $\sqrt{\langle V^2 \rangle}$

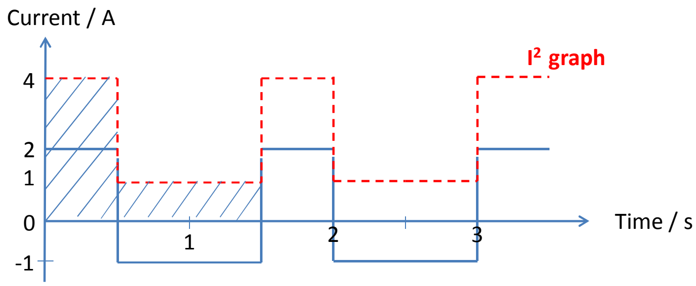
Example: Square wave

- Find the root mean square value of the alternating current.



Example: Square wave

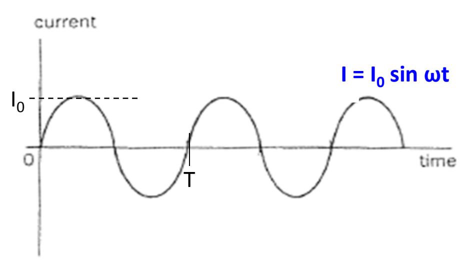
- Find the root mean square value of the alternating current.



- Step 1: Square of values: $(2)^2$ = **$4A^2$** & $(-1)^2$ = **$1\ A^2$**
- Step 2: Area within one period: (4 x 0.5) + (1 x 1) = **$3\ A^2s$**
- Step 3: Mean of square of value: (area within one period) / (one period) = 3 / 1.5 = **$2\ A^2$**
- Step 4: Root of the mean of square of value: I_{rms} = √2 = **1.41 A**

Example: Sinusoidal wave

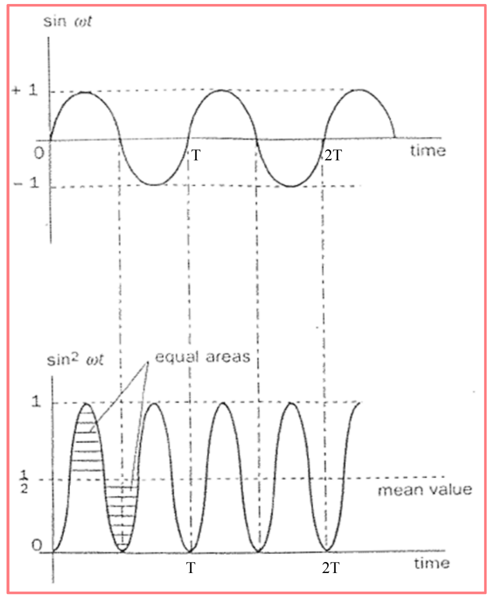
- Find the root mean square value of the alternating current.



Example: Sinusoidal wave

- Step 1:
  Square of values: $I^2 = I_0^2 \sin^2 wt$
- Step 2:
  Area within a period: $\int_0^T I_0^2 \sin^2 wt \, dt$
- Step 3:
  $< I^2 > = \frac{\int_0^T I_0^2 \sin^2 wt \, dt}{T}$
  $< I^2 > = \frac{I_0^2}{2}$

  *cos 2A = 1 – 2 sin² A
- Step 4:
  $I_{rms} = \sqrt{< I^2 >} = \sqrt{(\frac{I_0^2}{2})}$
  $I_{rms} = \frac{I_0}{\sqrt{2}} = 0.7071\, I_0$



Calculating Mean Power for A.C on a resistive load

- The importance of rms values is that they allow us to apply equation from our study of direct current to situation where current is alternating.
- We know that the equation for power is given by $P = VI = I^2R = V^2/R$
- Since the alternating current has particular magnitude at every instant of time, thus the power delivered to the load is also varying with time.
- Thus in order to apply to the common equation of power as above, we need to substitute the rms value of current, I_{rms} or V_{rms} ,hence the power calculated is always the average power.

- Average power / mean power, **$<P> = I_{rms}^2 R$**

- Or since **$I_{rms} = I_0 / \sqrt{2}$** , thus, $<P> = (I_0 / \sqrt{2})^2 R$
  $<P> = (I_0^{\ 2} R) / 2$; where $P_0 = I_0^{\ 2} R$
  $<P> = P_0 / 2$; P_0 is the maximum power.

Example 1

- An electric heater is marked “240 V , 2000 W”. Find

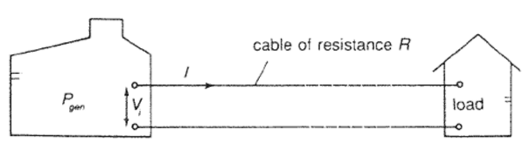
  a.) the rms current when the heater is connected to a 240 V supply.

  b.) the peak current.

  c.) the peak power produced by the heater.

Why use A.C for electricity supply?

- One of the problems in the transmission and distribution of electrical energy from the power station to the consuming loads (households & factories) is the **power loss (I^2R) in the grid cables.**
- This loss should be minimised for efficiency and economy.
- One solution to it is to **use very thick cables so that resistance can be lowered.** Thus power lost as heat in the cables will be a minimum.
- However, the thicker the cable used, higher the material cost, as well as heavier is the weight to be supported and hence the higher the construction cost.
- Another solution is to reduced the current transferred. A.C can be transformed to high voltages by using transformers, so that the current flowing is reduced, thus leading to lower power losses in the transmission lines.
- This is in fact the main reason why a.c. is preferred for national electricity supply system.



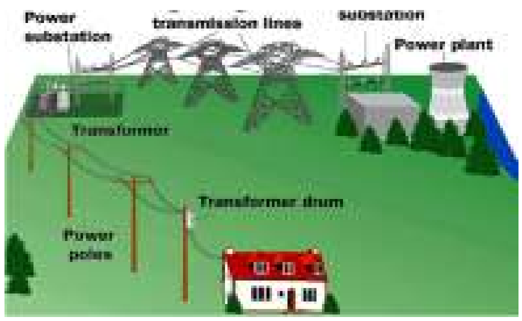
$P_{gen} = V_i \times I$

$P_{loss} = I^2 \times R$

$P_{loss} = (P_{gen} / V_i)^2 \times R$

Why use A.C for electricity supply?

- Yet there are also disadvantages of high voltage transmission, which are:
  1.) the transmission lines must be suspended high above the ground between pylons.
  2.) high quality insulators are required to prevent current passing form cables to the pylons.
  3.) danger of electrical discharges through the air.
  4.) necessity to build many sub-stations to step down the high voltage.

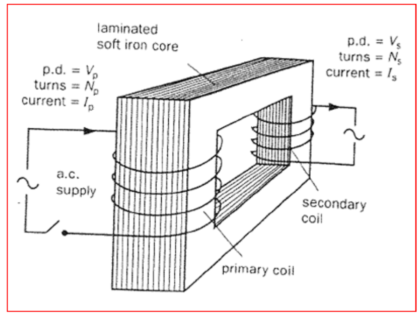


Example 2

- A power station generates electrical power at a rate of 10 MW. This power is to be transmitted along cables whose total resistance is 10 Ω. Calculate the power losses in the cable if the power is transmitted at 50 KV and 250 kV

Transformer

- Figure beside shows a simple transformer, which consists of 2 separate coils of insulated wire wound on a laminated core made from sheets of soft iron separated by an insulating varnish.
- The sheets are glued together so that they are electrically insulated from each other.
- The 2 coils are not linked electrically, only connection between then being any magnetic field in the core.



- One of the coils is referred to as primary coil, the other secondary coil.
- The number of turn on each coil is usually different. (N_p & N_s)
- It can be observed that a change in current in primary coil induces emf in the secondary coil.
- An alternating current in the primary will therefore create alternating magnetic field in the core, which links with the turns of the secondary coil.
- This alternating magnetic field therefore induces emf in the secondary, alternating with the same frequency as that in the primary.
- This emf will cause an alternating current to flow in any external circuit connect to it.

Transformer

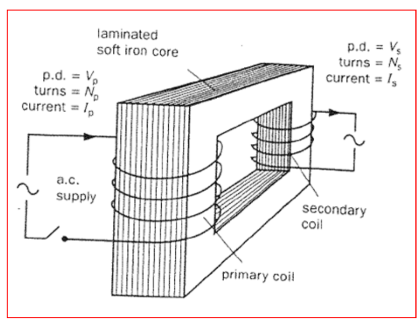
- Assuming 100% efficiency,

  $V_p=N_p\frac{d\Phi}{dt}$ & $V_s=N_s\frac{d\Phi}{dt}$

- Dividing these 2 equations will give:

  $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

- Step-up transformer if $N_s > N_p$ then $V_s > V_p$
- Step-downtransformer if $N_s < N_p$ then $V_s < V_p$



- Again assuming 100% efficiency, power in primary =power in secondary.

  $\mathbf{V_p I_p = V_s I_s}$

- Thus, the relationship between induced emf, induced current, and number of turns can be written as:

$$\boxed{\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}}$$

Example 3

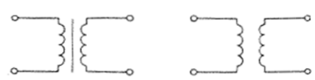
- A radio requires a 6.0 V supply but has to be operated from a 230 V mains supply. It is fitted with a transformer to reduce the mains voltage.

  a.) Calculate the turns ratio for this transformer.

  b.)If the primary coil have 5000 turns, how many turns must the secondary have?

Transformer

- Symbol for transformer:



a. Soft iron-core transformer b. Air-core transformer

- **Energy Losses in Transformer**

1. Heat lost through coil resistance in the copper coils.
   Heat loss can be reduced by using thick / high conductivity copper wires.

2. Heat is lost due to eddy currents induced by the alternating magnetic field in the iron core.
   Heat loss is reduced by laminating the core.

3. Energy is lost through magnetic flux leakage as some of the changing magnetic flux in the primary may not actually link to the secondary coil.
   This can be reduced by designing the transformer such that the primary and secondary coils are overlapping, for optimum flux linkage.

4. Energy is used to reverse the magnetization of the iron core; in a process known as hysterisis. Hysterisis in this case is the name given to the reluctance of a material to undergo changes in magnetisation. During each cycle of a.c., the core reverses polarity of its magnetisation, which required energy.
   Energy loss is reduced through careful choice of materials.

Rectification

- The major advantage of a.c. is the ease with which its voltage can be changed using transformers.
- The current obtained from our power points in homes, factories, and workplaces are a.c.
- However, many electronic apparatus require d.c. Thus it is necessary to convert a.c. to d.c.
- **Rectification** is the process of converting the a.c. to d.c. using a **rectifier.**

- Properties of a **rectifier**:

  a.) It is a conductor, which is mainly directional. (Conducts in one direction only)

  b.) It has low resistance in one direction. In the forward direction / forward biased, conduction occurs.

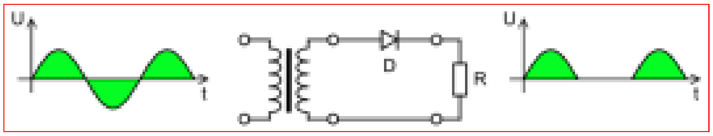
  c.) In the reverse direction, it has high resistance. No conduction occurs and the rectifier is reverse biased.

- A simple component that can act as a rectifier is the diode.

- 2 types of rectification are known as the **half wave rectification** and **full wave rectification.**

Half wave rectification

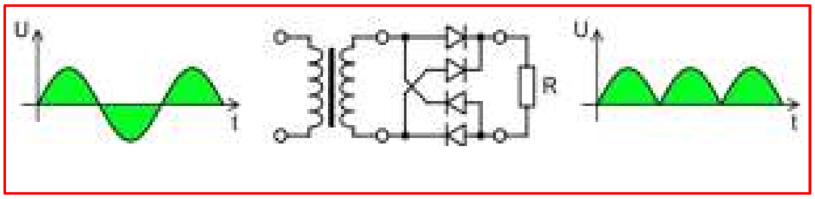
- **Half wave rectification** means that only one half of a cycle passes through the rectifier, either the positive or negative half of the AC wave is passed, while the other half is blocked.

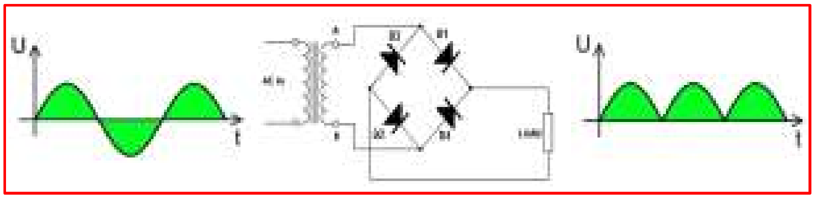


- First half cycle – During this half cycle the diode is forward biased and offers low resistance such that a pulse of current flows through the circuit. There is negligible p.d. across the diode. The p.d. across R is almost equal to the applied p.d.
- Next half cycle – The diode is now reversed biased and has very high resistance such that a very small currents flow through it. The p.d. across the diode is almost equal to the applied p.d. The p.d. across R is almost zero.
- An alternating voltage is thus rectified to gives a direct voltage, which eventually gives a direct current since its direction does not alter, but the magnitude shows considerable variation, and for half the time, there is no current.
- This mean that the power available from the half wave rectified supply is reduced.
- To overcome this problem of reduced power, a full wave rectifier is used.

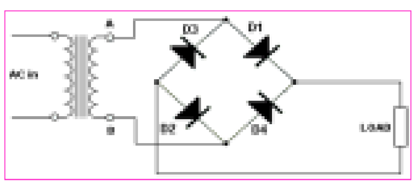
Full wave rectification

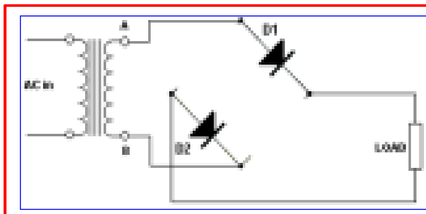
- **Full wave rectification** allows both halves of each cycle to pass through.
- A bridge rectifier consists of four diode performs full wave rectification.



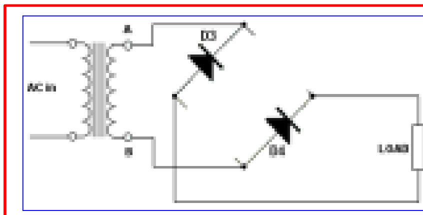


Full wave rectification





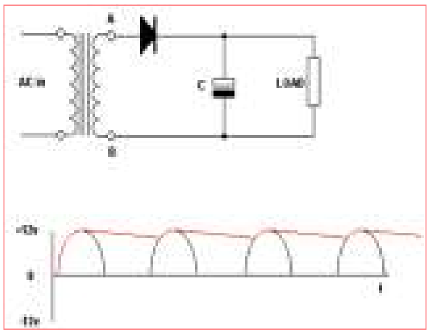
- **First half cycle** – When A is positive, diode 1 & 2 are forward biased and conduct. The current takes the path across diode 1 & 2.
- Diode 3 & 4 are reversed biased, hence does not conduct.



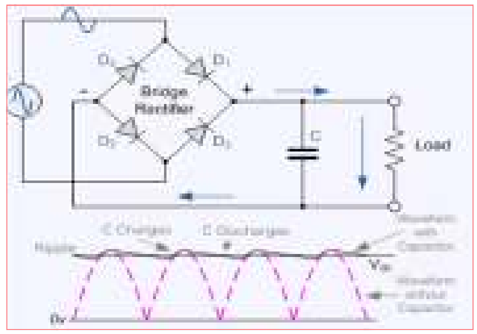
- **Next half cycle** – When B is positive, diode 3 & 4 are forward biased and conduct. The current takes the path across diode 3 & 4.
- Diode 1 & 2 are reversed biased, hence does not conduct.

Smoothing Capacitor

- The output obtained from the rectifiers are unidirectional but varying.
- In order to produce a steady d.c. than a "bumpy" d.c. that results from rectification, a smoothing capacitor must be incorporated in the circuit, in parallel with the load resistor.
- The idea is that the capacitor charges up (by the pulses) and maintains the voltage at high level. (The capacitor stores this pulses of voltage).
- When the rectified voltage drops, the resistive load will then used this stored power in the capacitor causing the capacitor discharges gradually, but the voltage soon rises again and the capacitor charges up again. This process is being repeated.
- The result is an output voltage with "ripple".



Smoothing capacitor in a half wave rectification



Smoothing capacitor in a full wave rectification

Smoothing Capacitor

- Initially the rising supply p.d. sends a current through R, and causes the p.d across the capacitor to increase to the peak value.
- As the supply p.d. decreases from its peak, the capacitor cannot discharge through the supply (due to direction of the diodes), but only through R. The capacitor p.d. will fall slowly.
- Meanwhile the supply p.d. has fallen to zero and started to increase again.
- When supply p.d. becomes greater than the p.d. across the capacitor, the capacitor starts to recharge up o the peak p.d.
- This process repeats giving rise to an almost steady p.d. with only a ripple of small amplitude.

- The amplitude of ripple can be controlled by careful choice of values of C and R.
- The smoothing action of the capacitor is due to the large time constant, given by C x R so that the output p.d. cannot fall as rapidly as the input p.d.
- Generally, if R is large value, time constant will be large, thus smoother the waveform / less pronounced ripples.
- Similarly, a large capacitor discharges more slowly than a small capacitor, so giving less pronounced ripples.
- Yet if the capacitor is too large, the initial uncharged capacitor may cause a sudden surge of current through the circuit and damage the rectifier. (diodes)