TITLE:- GENERATION OF ALTERNATING CURRENT

LECTURER:-

DATE:-

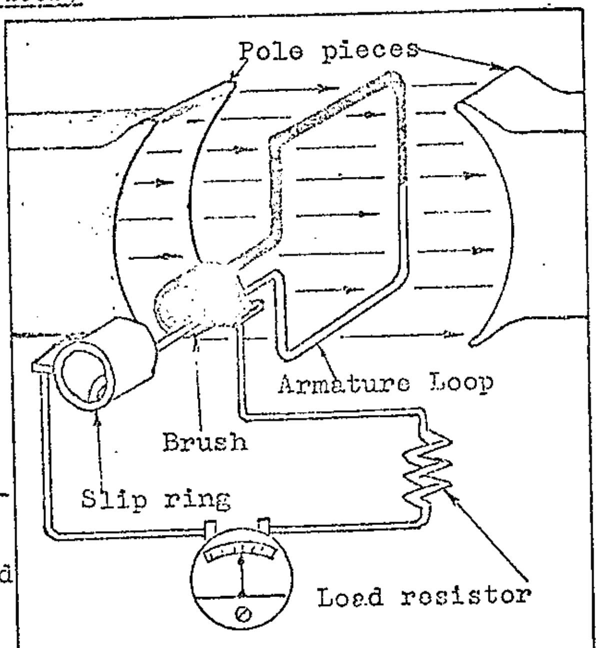
EQUIPMENT:-

If a piece of wire is connected across a very sensitive meter, and a magnet moved past the wire, the meter needle will deflect. This deflection indicates that electricity is produced in the wire.
If the magnet is placed near the wire and held still, no deflection results, however if the magnet is once again moved, being kept near the wire, the needle again deflects.

This demonstrates that magnetic flux and conductors are not enough on their own to generate an e.m.f. and since, if the wire is moved past the magnet the effect is the same, then it can be said that relative motion between the two is the third necessary factor.
For a continuous source of electricity a continuous motion has to be maintained by either the wire or the magnetic field. The most practical way to do this is to rotate the wire in a circle through the magnetic field.

Elementary A.C. Generator (Alternator)

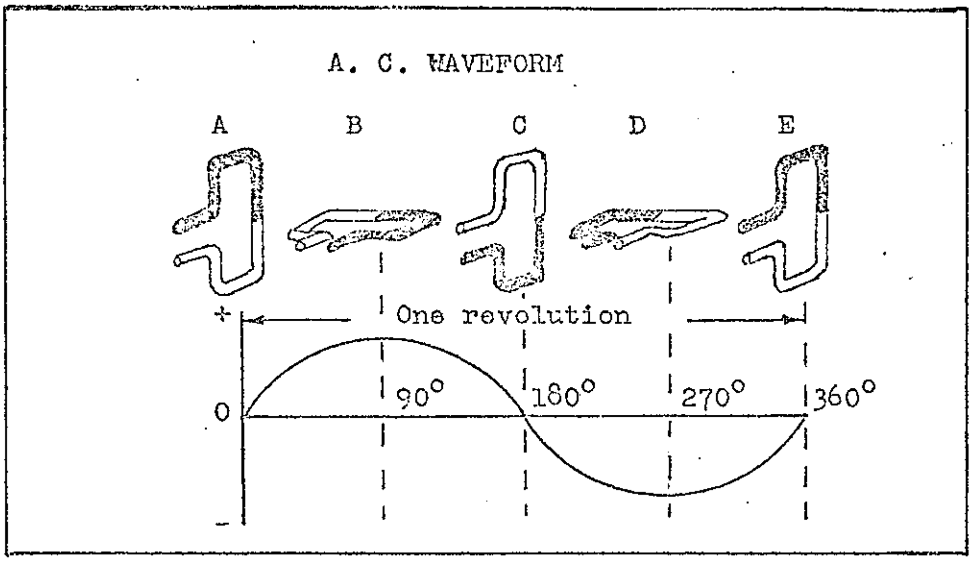
An elementary generator consists of a loop of wire placed so that it can be rotated in a uniform magnetic field to produce electricity in the loop. The ends of this "armature" loop are connected to rings called "slip rings". These rings, mounted on the shaft in a practical generator are insulated from the shaft and from each other. Current collectors called "brushes" ride on the slip rings to carry the electricity to the external circuit.



ELEMENTARY GENERATOR

Operation

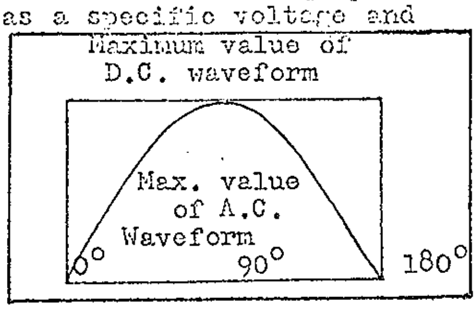
Assume loop is rotating in a clockwise direction and its initial position is A (Fig. 2). In position A, the loop is perpendicular to the magnetic field and the black and white conductors are moving parallel to the magnetic field. No lines of force are cut therefore no e.m.f. is generated. As the loop rotates from A to B, the conductors are cutting through more and more lines of force, until at 90 degrees (position B) they are cutting through a maximum number of lines of force. In other words between 0 degrees and 90 degrees, the e.m.f. generated in the conductors builds up from zero to a maximum. At this time, the black conductor is moving down through the field and the white conductor up through the field. The e.m.f.'s in both conductors are in series, therefore the resultant voltage across the two brushes will be the sum of the two e.m.f.'s.
The current will vary as the e.m.f. varies.
As the loop continues rotating from position B (90 degrees) to position C (180 degrees), the conductors which are cutting through a maximum number of lines of force at position B cut through fewer lines, until at position C they are moving parallel to the magnetic field and no longer cut any lines of force.
The generated e.m.f. therefore will decrease whilst the loop moves from position B to position C in the same manner as it increased from zero to 90 degrees.



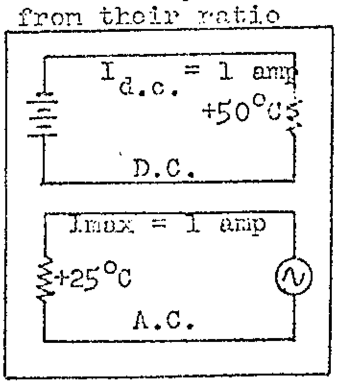
From zero to 180 degrees, the conductors of the loop have been moving in a given direction through the magnetic field: therefore the polarity of the generated e.m.f. has remained the same. But beyond 180 degrees, the direction of the cutting action of the conductors through the magnetic field reverses.
In consequence, polarity of the e.m.f. and the current flow will reverse. While the loop is rotating from C to D and back to A, the current flow will be in the opposite direction to that in which it was flowing when the loop was rotating from A to C.
The rise and fall of generator terminal voltage will be the same as it was from A to C except for its reversed polarity. The alternator has now completed an output of one <u>cycle</u> of alternating current.
The shape of the graph of the generated e.m.f. and current is known as a sine wave.
Since one complete cycle of voltage and current is generated for one revolution of the elementary generator, if the loop is rotated at 50 revolutions per second, the generated e.m.f. will complete <u>50 cycles per second (50 HZ)</u> and this will be said to be its <u>frequency</u>.
A.C. frequency is important since most a.c. electrical equipment requires a specific frequency as well as a specific voltage and current, for proper operation.

<u>Effective value of A.C.</u>

It will be clear that if an A.C. waveform with a certain maximum value is compared to a D.C. waveform with the same maximum value, the D.C. value is greater than the A.C. at all points except the point at which the A.C. sine wave passes through its peak.



The A.C. value therefore will have an <u>effective</u> value that is less than the D.C. value. A convenient way of finding the effective value is to compare the heating effect in a resistor of a given value when D.C. is passed through it for a given period of time, and when A.C. of an equal maximum value is passed through it for the same period of time. The two temperature increases are then compared with each other: and from their ratio the effective value of the A.C. is calculated.
Consider the two circuits alongside, both of which have a resistor R of the same resistance. In the D.C. circuit, a current of 1 amp raises the temperature of the resistor by (say) 50 degrees C. In the A.C. circuit, the current at its maximum value is 1, and the resistor is only raised by 25 degrees C.



The power loss, or energy consumed in a resistor is measured by the formula $P = I^2 R$.
The power loss in the D.C. circuit (I^2d.c.R) raised the temp. by 50 degrees C., while in the A.C. circuit, the power loss(I^2EFF x R) caused by I max. of 1, caused only half the D.C. loss.

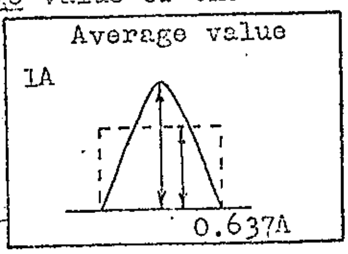
$$\text{It follows that } I^2_{EFF} \times R = \tfrac{1}{2} I^2_{d.c.} \times R = \tfrac{1}{2} I^2_{Max.} \times R$$

$$\text{Simplifying} \quad I^2_{EFF} \times \tfrac{1}{2} I^2 \text{ Max.}$$

$$I_{EFF} = \frac{1}{\sqrt{2}} I_{max.} \quad \text{or} \quad 0.707 \text{ I max.}$$

In other words, the effective current is only 0.707 of I maximum, therefore in the A.C. circuit, I maximum will have to be increased to IEFF x 2 (1.414) before it will produce the same heating effect as 1 amp of D.C.
The effective value of voltage or current is referred to as the R.M.S. (root mean square) values of voltage and current.
R.M.S. values are so called because of the method used to determine them:-
(a) A specific number of instantaneous values are taken from a complete cycle of the sine curve.
(b) Squaring these instantaneous values and finding the average of all the squared values - remember the heating effect of a current is proportional to the average value of the square of the current.
(c) Finding the square root of the average of the squared values - this is the 'root mean square' or r.m.s. value of the current or voltage.
When an A.C. current or voltage is specified, it is always the r.m.s value that is means unless otherwise stated.
All A.C. meters are graduated in R.M.S. values unless marked to the contrary.

Average values of waveforms
If an A.C. current is passed through a d.c. meter movement, the pointer would turn in one direction for a half cycle then, as the current reversed direction, the pointer would move in the opposite direction.
If the frequency of the A.C. was 50 c.p.s. the pointer would be unable to follow the reversal of current fast enough, and the pointer would vibrate back and forth at zero, the average value of a sine wave.
N.B. This vibration will soon damage a d.c. meter.
By using a rectifier in series with the d.c. meter, current flows only for half of each cycle, i.e. current flows in pulses which are all in the same direction. Each pulse causes a deflection of the pointer, which cannot move fast enough to return to zero between pulses and so continuously indicates the average value of the current pulses.
In a sine wave, the average value of a half cycle is 0.637 of the maximum or peak value. This value is obtained by averaging all the instantaneous values of the sine wave for a half cycle.
Although the deflection of the meter pointer depends on the half cycle average value of current, it is usual for meters to be calibrated to read R.M.S. values directly.



Phasor Diagrams
These are used to represent variable quantities such as current and voltages since they are much less laborious and time consuming to draw than sine waves.

With this method, all values are represented by straight lines which are drawn to scale. The time relationships are shown by the directions of these lines, which are considered to rotate in an anti-clockwise direction about a fixed point, with the 360 mechanical degrees representing 360 electrical degrees. Thus a 240 volt source with a current of 5 amps lagging by 30 degrees would be represented by the phasor diagram of fig. 1. It can be seen from the diagram that the voltage is represented by a line with an open arrowhead, whereas the current phasor has a closed arrowhead. This rule should be followed to avoid confusion. Another rule to observe is that whichever quantity is to be used as the reference, should be drawn horizontal, in this case the current.

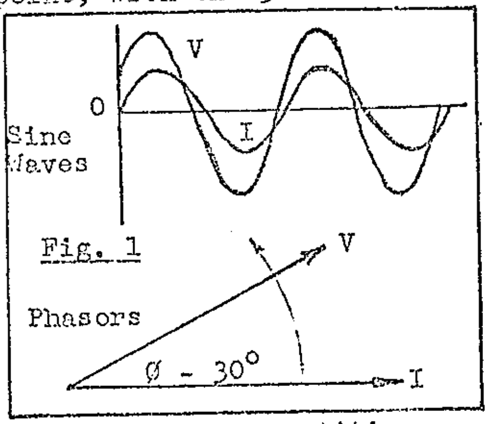


Fig. 1

Sometimes it is required to find the resultant of two quantities which are out of phase with each other, and this can easily be done with phasors.
If the reference and the individual quantities, (e.g. voltages) are drawn in, it will be found that if the two component voltages (Exc, ExL) are taken to be two sides of a parralelogram, the completed parallelogram would have phasor E as its diagonal (Fig. 2) i.e. The resultant e.m.f. would be represented in magnitude and phase by the diagonal of a parallelogram of which the two components formed the sides.

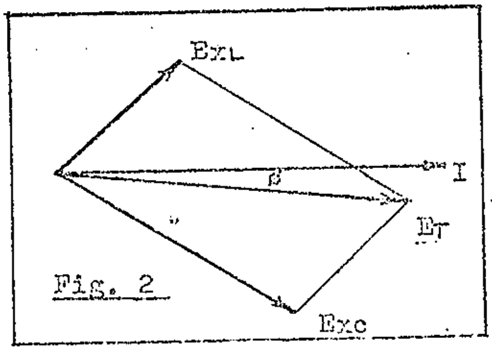


Fig. 2

To subtract one phasor from another when they are out of phase with each other, the phasor to be subtracted is rotated through 180 degrees, i.e. made negative, and then the resultant is found using the parallelogram method, e.g. if in Fig. 3, Exc is subtracted from ExL , the phasor diagram would take the form of Fig.3 with E_T the resultant.

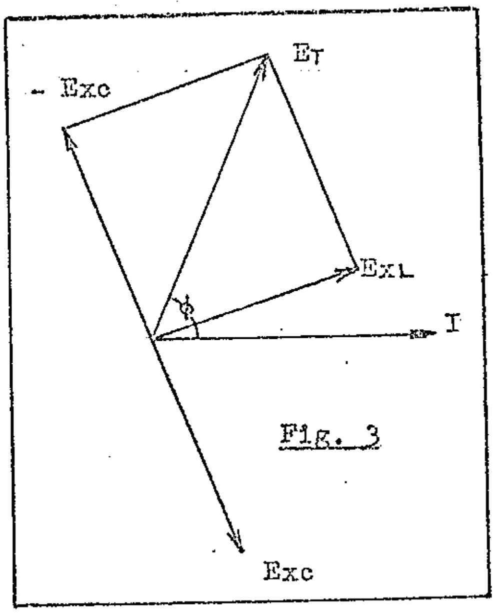
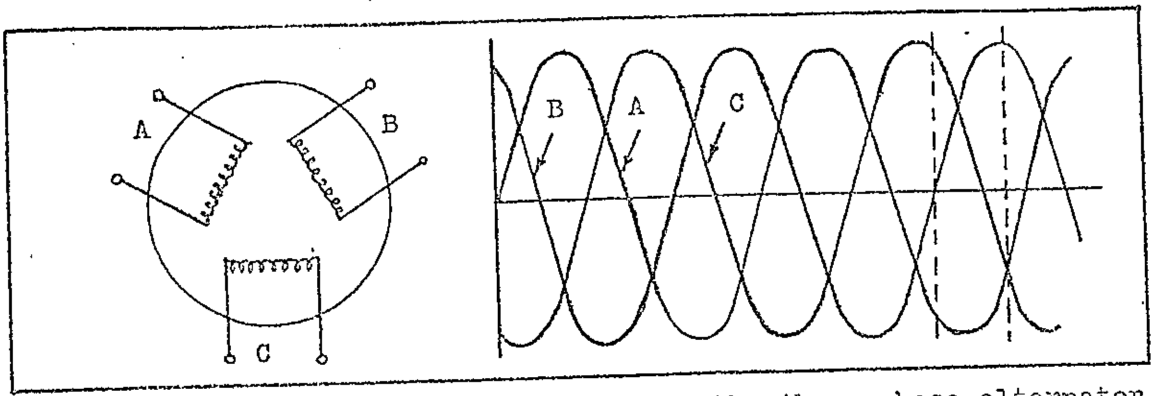


Fig. 3

Generation of 3 phase E.M.F.

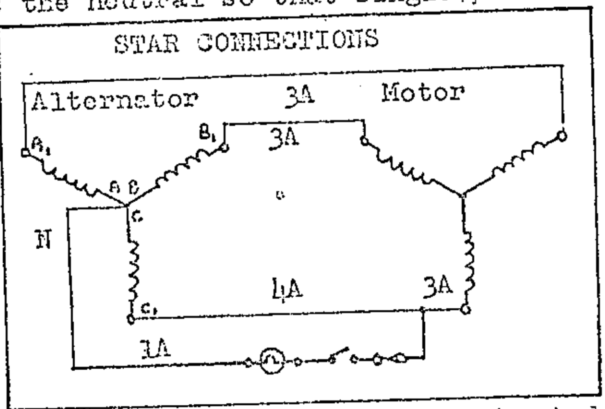
The three phase alternator, as the name implies, has three single phase windings so spaced that the voltage induced in any one is phase displaced by 120 degrees from each of the other two. A schematic diagram of a three phase stator showing all the coils becomes complex, and it is difficult to see what is actually happening, so the simplified schematic illustrated shows the windings of each single phase lumped together as one winding.
The voltage waveforms generated across each phase are drawn on a graph, phase displaced 120 degrees from each other.



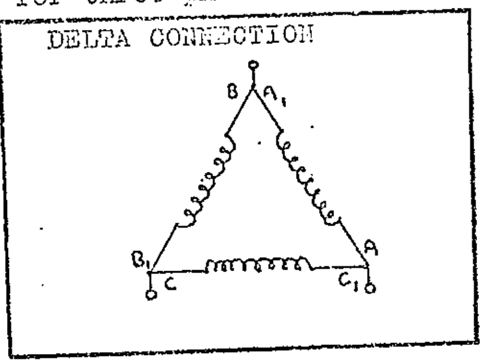
Instead of having six leads coming out of the three phase alternator from three separate phases, either of two special connections can be used so that only three leads are brought out from the alternator. Using these connections, power can be fed out to a three phase load through the leads as each in turn becomes positive, the lead(s) which at that moment are negative being used to complete the circuit. Thus in a 3 phase balanced system, no neutral is needed.

Star Connection In this system, the like ends are connected together to form a star point. (i.e. the three starts or the three finishes). This star point forms the neutral so that single phase loads can be connected with this system, the neutral wire returning the single phase current to the alternator.
The voltage from any of the line leads to the neutral is called the phase voltage. The voltage across any two of the line leads is the line voltage and is 1.73 times the phase voltage.

Line currents and phase currents in the windings are equal in a star connection.



Delta Connection With this connection the unlike ends are connected together (i.e. start to finish). In a delta system the line voltage and the phase voltage are equal, line current is 1.73 times the phase current. No neutral is available with a delta connection. Both star and delta connections are used for three phase alternators and motors.



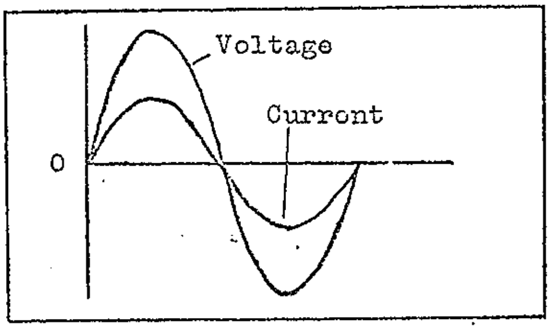
TITLE:- EFFECTS OF RESISTANCE, INDUCTANCE AND CAPACITANCE ON A.C.

LECTURER:-

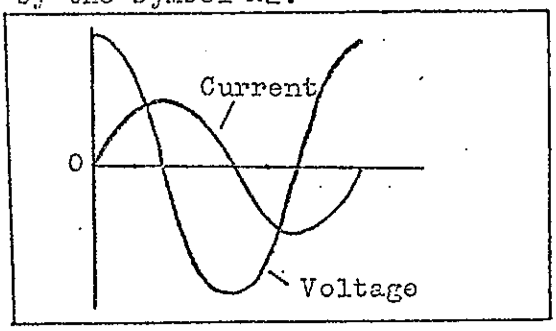
DATE:-

EQUIPMENT:-

Many A.C. circuits consist of "pure resistance" only, and for such circuits the same rules and laws apply as for D.C. circuits. These circuits contain devices which have no inductance or capacitance such as resistors, lamps and heating elements. When an A.C. circuit contains only such devices as these, Ohm's law, Kirchoff's laws, and the circuit rules for voltage, current and power can be used exactly as in d.c. circuits.
When an A.C. voltage is applied across a resistor, voltage increases to maximum in the +Ve direction, decreases to zero, increases to maximum in the -Ve direction and again decreases to zero to complete a cycle of voltage. The current flow follows the voltage: as voltage increases, current increases and current falls to zero along with the voltage i.e. voltage and current are "in phase".
Voltage and current are in "in phase" when they are the same frequency and pass through zero simultaneously, both going in the same direction.



Inductance in an A.C. circuit When a current flows in a conductor, a magnetic field is set up around that conductor, the magnitude of the field varying with the current. If the current is alternating, then the flux will also be alternating. This will induce an alternating e.m.f. in the conductor, the magnitude of which will at any instant be proportional to the rate of change of flux at that instant. This e.m.f. is called the e.m.f. of Self Induction.
By Lenz Law:- The direction of an induced current is such that the electromagnetic effects of the current oppose the change producing it. i.e. The induced e.m.f. is in opposition to the applied e.m.f. and is called a "back e.m.f.".
The back e.m.f. produces a choking effects on the current which is called inductive reactance, denoted by the symbol X_L.
If an A.C. circuit contains only pure inductance, the current is not in phase with the voltage. Instead, it rises to a maximum a quarter of a cycle later than does the voltage; and it remains a quarter of a cycle behind at all points in the cycle i.e. current lags voltage by 90°. Since all practical circuits contain resistance, however, the current never lags the voltage by as much as 90° but at a lesser angle depending upon the amounts of resistance and reactance in the circuit.



The formula used for finding the reactance in a circuit is:-

$$X_L = 2\pi fL \qquad \text{where } f = \text{frequency}$$
$$L = \text{inductance in henrys}$$

e.g. Find the current which will flow through a coil of negligible resistance and an inductance of 0.04 henry when connected to a 200 volt, 50 Hz supply.

$$X_L = 2\pi FL = 2\pi 50 \frac{4}{100} = 4\pi \text{ ohms}$$

$$I = \frac{V}{X_L} = \frac{200}{4\pi} = \frac{50}{\pi}$$

$$\underline{I = 15.92 \text{ Amperes}}$$

The back e.m.f. can also be calculated:-

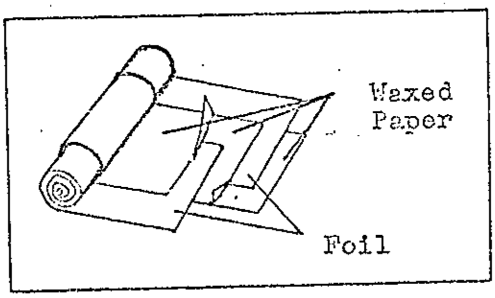
e.g. A 240 volt coil whose resistance is 8 Ω draws 3A when energised. Find the back e.m.f.

$$Eb = 240 - (3 \times 8) = 240 - 24$$

$$\underline{Eb = 216 \text{ volts}}$$

Capacitance in an A.C. circuit

Capacitance is the property of a circuit which opposes any change in circuit voltage. It exists in an electric circuit because certain parts of the circuit are able to store electric charges. Devices used to add capacitance to a circuit are called capacitors, sometimes called condensers. Basically, capacitors consist of two plates which can be charged - separated by an insulating material called the "dielectric". Most capacitors use metal foil for the plates. Common dielectric materials include air, mica, and waxed paper.



Three basic factors effect the capacitance of a capacitor:-

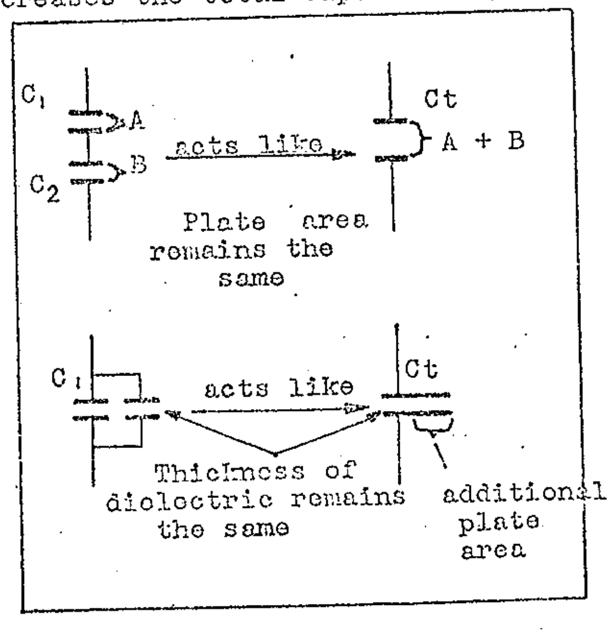
(1). Plate area - the larger the plates, the larger the capacitance.

(2) Distance between plates - the smaller the distance, the greater the capacitance.

(3) Dielectric material - the effect of different materials is measured against an air dielectric and will multiply the capacitance by an amount known as the "dielectric constant" e.g. a certain oiled paper has a dielectric constant of three; and if this is placed between the plates, the capacitance will be three times greater than if the dielectric was air.

When capacitors are connected in series or parallel, the effect on the total capacitance is opposite that for similarly connected resistor.

Connecting capacitors in series decreases the total capacitance, because it effectively increases the spacing between the plates. To find the total capacitance of series connected capacitors, a formula is used similar to the formula for parallel resistances. When capacitors are connected in parallel, the total capacitance increases because the plate area receiving the charge increases. The total capacitance for parallel connected capacitors is found by adding the values of the various capacitors connected in parallel.



Series Capacitance formula

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Parallel capacitance formula

$$C_T = C_1 + C_2 + C_3$$

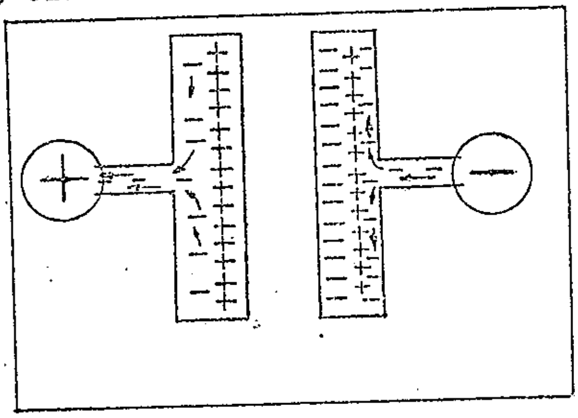
Units of Capacitance

The basic unit of capacitance is the farad. A capacitor has a capacitance of one farad when a charging current of one ampere flowing for one second causes a change of one volt in the potential between its plates.

The farad is much too great to use as the unit of capacitance for practical electrical circuits. Because of this, the units normally used are the microfarad (μF), equal to one millionth of a farad, and the picofarad (pF) equal to one million-millionth of a farad. Since electrical formulae use capacitance stated in farads, it is important to be able to change various units of capacitance to other units.

In order to charge a capacitor, an electrical force is required. Extra electrons forced onto one plate from a negative charge will charge the plate negatively. As these extra electrons build up on the plate, they repel or oppose the electrons trying to follow them. This slows the charging rate. When the repelling force equals the charging force, no more electrons flow.

Similarly, with the positive plate, electrons are removed by the attraction of a positive charge. The first electrons leave easily, but as the plate builds up a positive charge, it becomes increasingly difficult to pull electrons away. When the positive attracting force equals the plate's positive charge, no more electrons leave the plate. On discharge, the electrons move in the opposite direction.

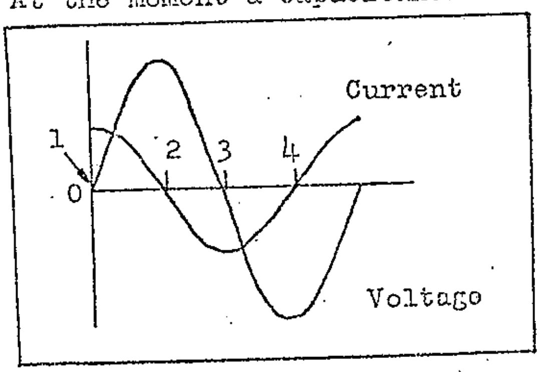


The action of the plates in opposing the movement of electrons is called "capacitance reactance" and is denoted by Xc.

Using the formula $X_c = \dfrac{1}{2\pi FC}$ where (F = frequency) (C = capacitance), capacitance reactance can be found.

If an A.C. voltage is applied to a capacitor, an ammeter in series with the capacitor will give a reading due to the electron movement, even although no electrical connection exists between the two plates.

If the capacitor is charged and the source removed, it will retain its charge. In a theoretical circuit of pure capacitance and no resistance, the voltage across the capacitor exists only after current flows to charge the plates. At the moment a capacitance starts to charge, the voltage across its plates is zero and the current flow is maximum (Point 1). When the capacitance reaches full charge, the current is zero and the voltage is maximum (Point 2). In discharging, the current rises to a maximum in the opposite direction while the voltage falls from maximum to zero (Point 3). Therefore it can be seen that in a purely capacitive circuit, the current leads the voltage by 90 degrees. In practice it will be less than 90 degrees because some resistance is always present.



Types of capacitor

Many different types of capacitors are used in electrical and electronic circuits, both fixed and variable.

Some of these types are as follows:-

(1) One type of variable capacitor uses air as a dielectric. One set of plates is mounted on a spindle so that the plates can be

moved in and out of the spaces between another fixed set of plates. The plate area, and hence, the capacity can be varied by turning the spindle.

(2) Another type, the variable mica capacitor, consists of two plates with a sheet of mica between them. A screw adjustment is used to force the plates together, and adjustment of this screw varies the capacitance of the capacitor. Several layers of mica and plates are used in larger capacitors of this type.

(3) Fixed mica capacitors consist of thin metal foil plates separated by sheet mica and moulded into a plastic cover. These capacitors are made in a capacity range between 10 pF and 0.01 μF.

(4) Paper capacitors use strips of metal foil as plates, separated by strips of waxed paper. Paper capacitors range in value from 250 μF to 1 μF, for most uses although larger paper capacitors are made for special applications.

Can be encased in either a cardboard cylinder or for wider temperature ranges, hard plastic or metal.

Paper capacitors used for high voltages (over 600 Volts) are impregnated with oil and oil filled.

Ceramic capacitors - extremely small type of capacitor - fixed or variable - use ceramic as dielectric and a film deposit of silver for the plates. They usually range in value from 1pF to 0.01 μF. The dielectric will insulate against voltages higher than 10,000 volts.

Electrolytic For value greater than 1 μF, the physical size of paper or mica capacitors becomes excessive and electrolytic capacitors are used for values of 1 μF to 1000 μF.

This type of capacitor is polarised, and if connected wrongly will break down and act as a short circuit ∴ it is important to make sure of correct connections.

A "reversible" or non polarised type is sometimes used in A.C. circuits e.g. for motor starting.

TITLE:- SERIES AND PARALLEL IMPEDANCE AND RESONANCE

LECTURER:-

DATE:-

EQUIPMENT:-

SERIES

As has been previously explained, an alternating quantity can be represented in magnitude and phase relationship to other components by a straight line called a phasor.

If it was desired to find the voltage applied to two series connected resistors whose voltage drops were 10 volts and 25 volts respectively, they could be added numerically or drawn as phasors and added as in Fig. 1. All alternating quantities are not in phase however as numerical addition can not always be used.

If one of the above resistors (V1) was replaced with a pure inductance (X1), the phasor diagram would have to be redrawn as in Fig. 2. because in a purely inductive circuit the current lags the voltage by 90 degrees.

The applied voltage (VA) would now no longer equal the numerical sum of V1 + V2 but would equal their phasor sum which could be obtained by completing the parallelogram and measuring the diagonal O - VA (Fig. 3). This would be found to be larger than either V1 or V2 but always less than their numerical sum. If Fig. 3 is studied it will be noticed that the dotted line V2-VA is equal and parallel to O-V1 therefore a triangle could be drawn to represent these voltages (Fig. 4) and since this is a right angled triangle, Pythagoras theorem could be used to find VA. Thus $VA = \sqrt{V1^2 + V2^2}$.

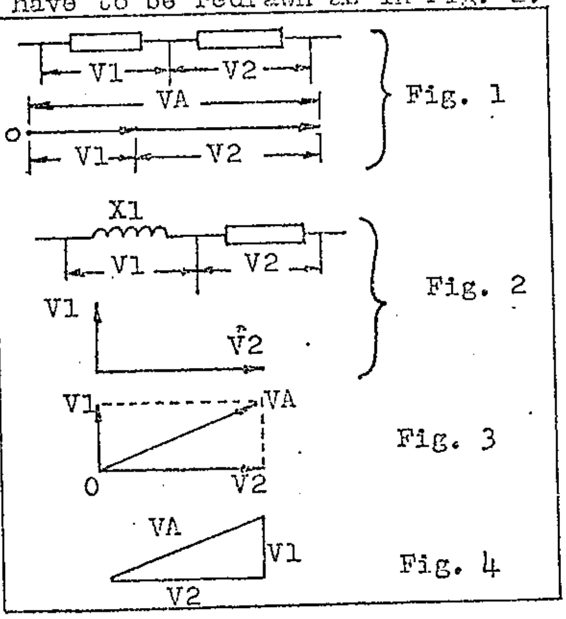


Fig. 1

Fig. 2

Fig. 3

Fig. 4

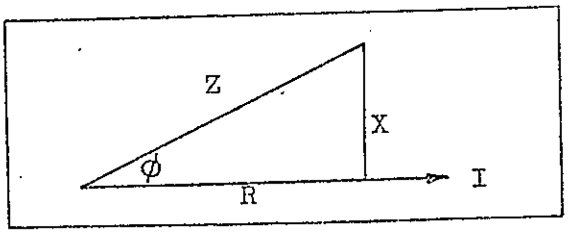
Hence, in an A.C. series circuit, the numerical sum of voltage drops may be much greater than the applied voltage, the exception being when current and voltage are in phase, when numerical and phasor sums will be equal.

This voltage triangle can be used to obtain the total effective circuit resistance. The side V1 = IxX and the side V2 = I x R(Resistance) and the side VA = I times the effective resistance of the series circuit.

Because the current I is the same in all parts of a series circuit, the resistance valves must have the same relationship as the voltage values.

Therefore values of resistance can be substituted for voltages V1, V2, and VA (Fig. 5).

Therefore $Z = \sqrt{R^2 + X^2}$.



The name given to the total effective circuit resistance, which is a combination of resistance and reactance is IMPEDANCE.

The triangle of Fig. 5 is known as an impedance triangle.

The angle Ø is important since this is the angle by which the current lags the applied voltage. (VA leads VR by Ø in Fig. 4. VR is in phase with the current).

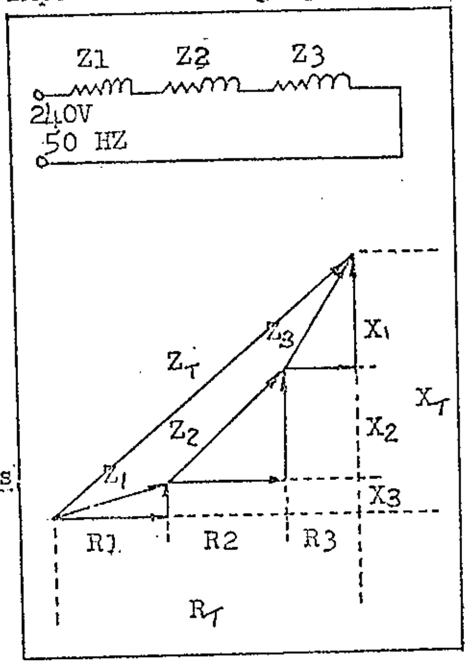
An impedance triangle can only be used to show the relationship between R, X, and Z in a series circuit. Other methods are used for parallel circuits.

IMPEDANCES IN SERIES

It is not possible to combine impedances to obtain a total impedance. To find the total impedance of a circuit it is necessary to add all the resistance components together and add them vectorially to the sum of all the reactance components.

Thus Z Total = $\sqrt{\text{sum of resistances}^2 + \text{sum of reactances}^2}$

The reason will be best seen if a set of impedances are graphically combined.



Example

Find the current flowing in the circuit opposite.

Where Z1 = 75 ohms resistance = R1
5 ohms reactance = X1

Z2 = 20 ohms resistance = R2
20 ohms reactance = X2

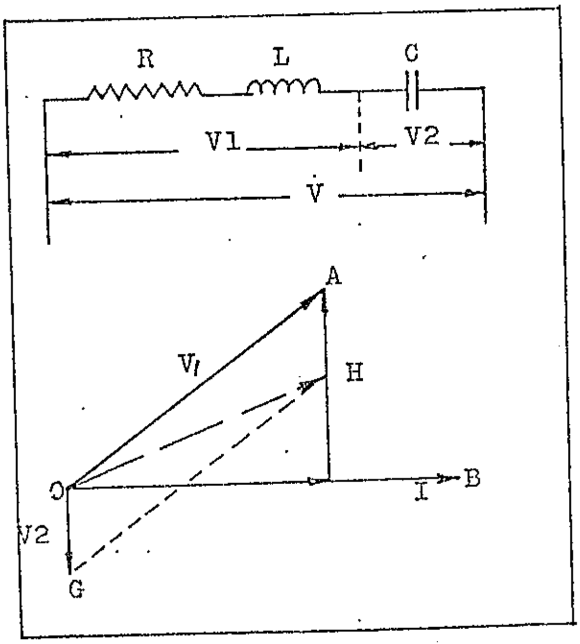
Z3 = 5 ohms resistance = R3
75 ohms reactance = X3

Answer from Phasors:- ______ Ohms

Using formula $ZT = \sqrt{RT^2 + XT^2}$ = ______ Ohms

The only time the impedances can be added is when all the phase angles are equal.

SERIES CIRCUIT CONTAINING RESISTANCE, INDUCTANCE AND CAPACITANCE.



In diagram: V1 = Voltage across L and R
V2 = Voltage across C

Then V is the phasor sum of V1 and V2.
Since current is common to all parts of a series circuit, it is used as the reference. In the phasor diagram let OB represent the current phasor.
V1 represented by OA is obtained as previously explained.
V2, the voltage acrsss the capacitor, is represented by OG drawn 90° behind the current vector since the capacitor has a leading current.
Complete the parallelogram OGHA. Join OH. Then OH represents the applied voltage.

$$OH^2 = OC^2 + CH^2$$

$$\begin{aligned} OC &= IR \\ CH &= CA - AH \\ &= IX_L - IXc \\ &= I\ (X_L - Xc) \end{aligned}$$

$$\therefore \quad E^2 = I^2R^2 + I^2\ (X_L - Xc)^2$$

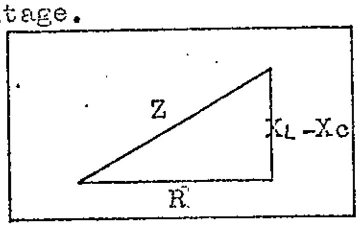
$$E = I\sqrt{R^2 + (X_L - Xc)2}$$

$$I = \frac{V}{\sqrt{R^2 + (X_L - Xc)^2}} \qquad \text{or} \qquad I = \frac{V}{Z} \qquad \text{since}$$

$R^2 + (X \quad - Xc)^2$ is the impedance of the circuit, denoted Z.
The angle of lag $\emptyset$ is such that $\tan \emptyset = \frac{HC}{OC} = \frac{(X_L - Xc)}{R}$

If Xc is greater than X_L, then OH falls on the other side of OB and the current is then leading the applied voltage.

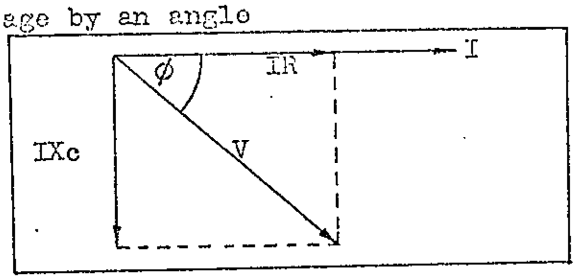
The impedance triangle is obtained by dividing each side of voltage triangle by I.



A circuit containing resistance and capacitance only, is really only one in which X is zero.

Current is then given by $I = \frac{V}{\sqrt{R^2 + Xc^2}}$

The current leads the applied voltage by an angle $\emptyset$ such that $\tan \emptyset = \frac{Xc}{R}$



IMPEDANCES IN SERIES

$$Z_T = \sqrt{R_T^2 + X_T^2}$$

$$\text{Where } R_T = R1 + R2 + R3$$

$$X_T = 2\pi FL - \frac{1}{2\pi FC_T}$$

$$L_T = L1 + L2 + L3$$

$$\frac{1}{C_T} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

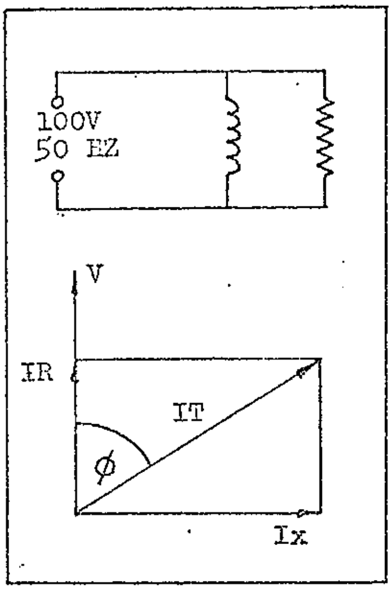
CIRCUITS CONTAINING RESISTANCE AND REACTANCE IN PARALLEL

The rules used to solve series circuits can be used to solve each individual branch of a parallel network.
However, the currents in each branch will not be in phase with each other and can not be added numerically to obtain total circuit current, therefore they must be added vectorially.
Considering the simple case of a pure inductance and a resistance connected in parallel.

Reactance of L = $2\pi fL = 6.28 \times 50 \times .05 =$ 15.71 ohms

Current through L = $\frac{V}{X} = \frac{100}{15.71} = 6.37$ amps

Current through R = $\frac{V}{R} = \frac{100}{12} = 8.33$ amps



The phasor of the diagram can now be drawn. Voltage is used as the reference when solving parallel circuits since it is the same in both branches.
From the phasor diagram it can be seen that

$$I = \sqrt{I^2 + Ix^2}$$

$$= \sqrt{8.33^2 + 6.37^2}$$

$$= \underline{\underline{10.5 \text{ Amps}}}$$

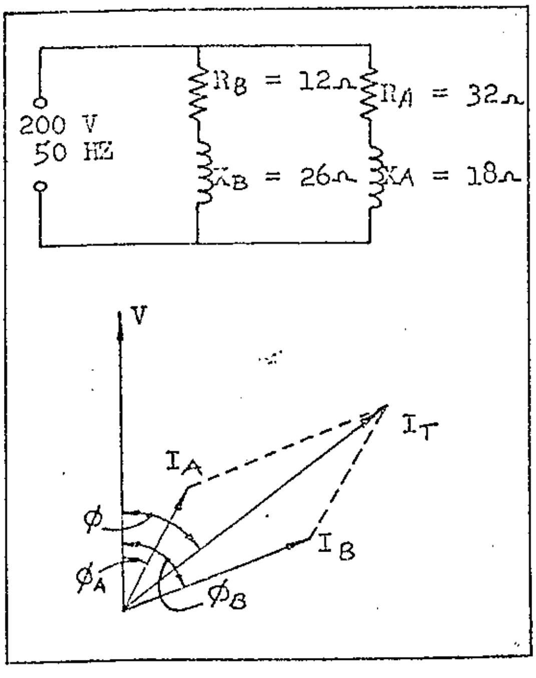
Knowing the total current and voltage, the impedance can be found

$$Z = \frac{V}{I} = \frac{100}{10.5} = \underline{9.52 \text{ ohms}}$$

Note The impedance is less than either the resistance or the reactance.
From phasor:- $\tan \phi = \frac{I_X}{I_R} = \frac{6.37}{8.33} = 0.7467$

$$\phi = 37.4^\circ$$

When each branch contains both resistance and reactance the current in each branch is found separately and the phasor sum of these currents equals the total current drawn from the mains.
Consider the circuit opposite.



In Branch A
the impedance $Z_A = \sqrt{R_A^2 + X_A^2}$

$$= \sqrt{32^2 + 18^2}$$

$$= \underline{36.7 \text{ ohms}}$$

and branch current

$$= \frac{V}{Z_A} = \frac{200}{36.7} = \underline{5.45 \text{ amps}}$$

The phase angle between applied voltage and branch current

$$= \tan \phi_A = \frac{X}{R} = \frac{18}{32} = .5625$$

therefore $\phi_A = \underline{29.4^\circ}$

In Branch B
the impedance $Z = \sqrt{R_B^2 + X_B^2}$

$$= \sqrt{12^2 + 26^2}$$

$$= \underline{28.6 \text{ ohms}}$$

and branch current

$$= \frac{V}{Z_b} = \frac{200}{28.6} = \underline{6.99 \text{ amps}}$$

The phase angle between applied voltage and branch current =

$$\tan \phi_B = \frac{X}{R} = \frac{26}{12} = 2.167$$

therefore $\phi_B = \underline{65.2^\circ}$

The phasor diagram is opposite.
When the graphical method is not suitable the resultant current I_T

can be calculated as follows:-

Determine the power component of I_A and I_B and add them numerically.

Do the same with the reactive components.

Thus:- $I_A \cos \emptyset_A = 5.45 \cos 29.4$ degrees

and $I_B \cos \emptyset_B = 6.99 \cos 65.2$ degrees

$= (5.45 \times 0.8712) + (6.99 \times 0.4195)$

$I = \underline{7.68 \text{ amps}}$ (In Phase)

$I_A \sin \emptyset_A = 5.45 \sin 29.4$ degrees

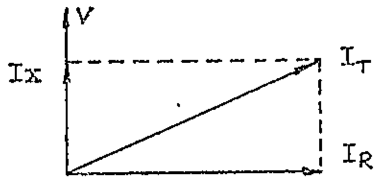
and $I_B \sin \emptyset_B = 6.99 \sin 65.2$ degrees

$= (5.45 \times 0.4909) + (6.99 \times 0.9078)$

$I_X = \underline{9.02 \text{ amps}}$ (Lagging 90 degrees)

The phasor diagram can now be drawn to scale to give the total current or by Pythagoras theorem

$$I_T = \sqrt{I_R^2 + I_X^2}$$
$$= \sqrt{7.68^2 + 9.02^2}$$
$$= \underline{11.85 \text{ amps}}$$



When solving parallel circuits the following procedure should be used.

1. Draw circuit layout.
2. Treating each branch as a separate series circuit, determine the impedance, current and phase angle of each branch.
3. Determine the power and reactive components of each branch current.
4. Add all the branch current power components.
5. Add all the branch current reactive components.
6. Add, by using phasors the total power and reactive currents to obtain the total current in the network.

<u>Series or Voltage Resonance</u>

Consider the circuit opposite which contains Resistance, Inductance and Capacitance in series.

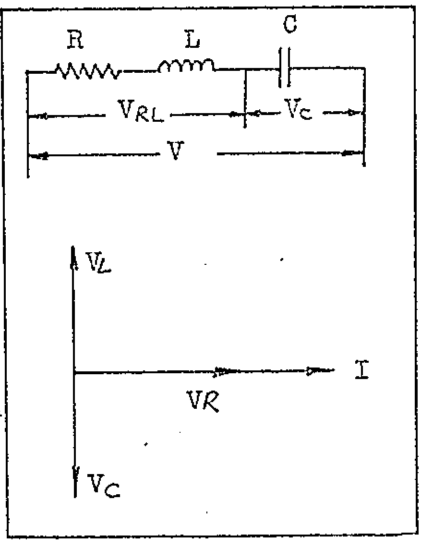
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

If $X_L = X_C$ the Z becomes equal to R and the current is given by $I = \frac{V}{R}$.

The circuit is now said to be in Series or Voltage resonance.

For a given circuit, this condition rises only at one particular frequency called the Resonant Frequency. The current is maximum and is in phase with the applied voltage as the phasor shows.

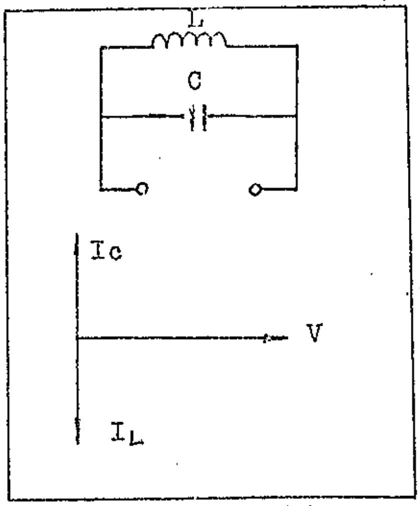
A circuit may be brought into resonance by altering the frequency until $X_L = X_C$ i.e.



$$2\pi f L = \frac{1}{2\pi f C}$$

$$\text{or } (2\pi f)^2 = \frac{1}{LC} \quad \therefore \quad 2\pi f = \frac{1}{\sqrt{LC}}$$

$$\text{Resonant frequency} \quad f = \frac{1}{2\pi\sqrt{LC}}$$



Parallel Resonance

Consider a pure inductor L in parallel with a capacitor C connected to a supply voltage V.

Current taken by inductor, $I_L = \frac{V}{X_L}$ lagging V by 90 degrees.
Current taken by capacitor, $I_c = \frac{V}{X_c}$ leading by 90 degrees.
The current I_T taken from the supply is equal to the difference between I_L and I_c.
If the frequency be gradually raised from zero, I_L will decrease from infinity and I_c will increase from zero. At a certain frequency I_L becomes equal to I_c and then I_T becomes zero. This condition is known as Parallel Resonance. Once again the frequency for this condition is known as resonant frequency.
An oscillating current which may assume large proportions is set up in the local circuit. Energy will surge between the capacitor and the inductor, electromagnetic energy becoming electrostatic energy and vice versa: no energy will be taken from the supply.
In practice, however, some resistance is always present hence these oscillations cannot be maintained without some energy being taken from the supply.

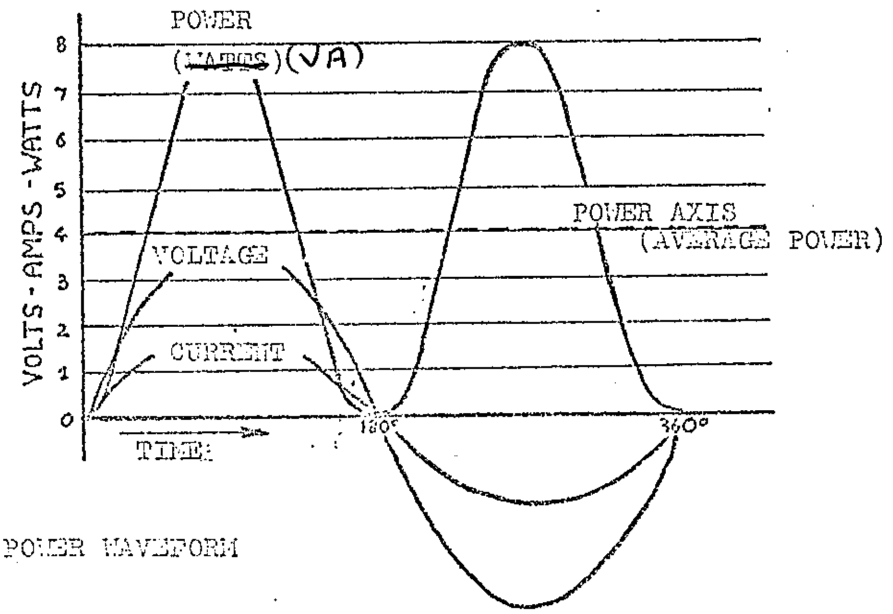
TITLE:- POWER IN A.C. CIRCUITS

LECTURER:

DATE:-

EQUIPMENT:-

The power used in an A.C. circuit is the average of all the instantaneous values of power or heating effect in a complete cycle. Instantaneous values of voltage and current are multiplied together to find the instantaneous values of power, which are then plotted to form a power curve. The average of this curve is the actual power used in the circuit.



A.C. POWER WAVEFORM

For "In phase" current and voltage waves the entire power curve is above the zero axis, (Fig. 1) even when current and voltage are negative since when two negatives are multiplied, the result is always positive. It should also be noted that when the power axis is drawn in, it can be seen that the power wave frequency is twice that of the voltage and current waves.

The power axis represents the average value of power in a resistive circuit, since the areas above the axis are exactly equal in area to those below it. Average power is the actual power used in any A.C. circuit.

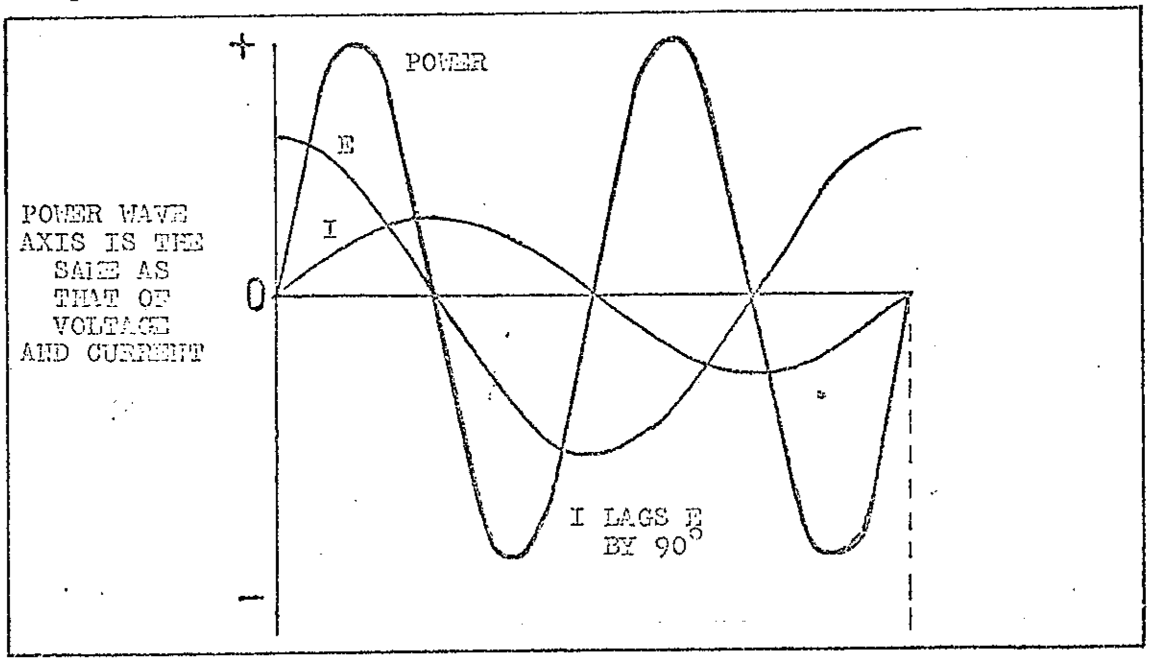
Since all values of power are positive for A.C. circuits consisting only of resistance, the average power for such circuits is equal to exactly one half the maximum, positive instantaneous power value. This value can also be found by multiplying the R.M.S. values of V and I together.
N.B. This rule only applies to A.C. circuits containing all resistance.

The R.M.S. values of V and I are:- $\frac{V_{max}}{\sqrt{2}}$ and $\frac{I_{max}}{\sqrt{2}}$

$$\text{average power} = \frac{E_{max}}{\sqrt{2}} \times \frac{I_{max}}{\sqrt{2}} = \frac{E_{max} \times I_{max}}{2}$$

$$= \frac{\text{Maximum power}}{2}$$

Power in inductive circuits
In a theoretical circuit containing only pure inductance, the current lags the voltage by 90 degrees. The power curve is found in the same way as for the purely resistive circuit, using instantaneous values of voltage and currents.
As was shown, the power curve for "in phase" voltages and currents is entirely above the zero axis since all the multiplications of instantaneous values gave positive answers. When a negative number is multiplied by a positive number, however, the result is a negative number. Thus, in calculating instantaneous values of power when the current and voltage are 90 degrees out of phase with each other, half the instantaneous values of power are positive and half are negative, as shown in Fig. 2. In such a circuit, the voltage and current axis is also the power wave axis, and the frequency of the power wave is twice that of the current and voltage waves.



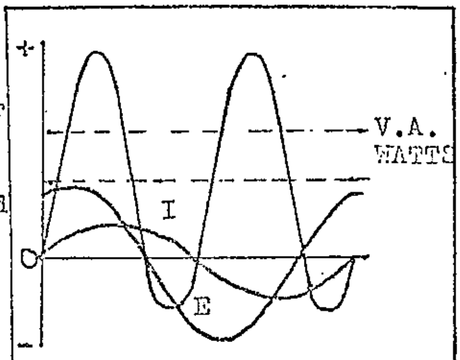
That portion of a power wave which is above the zero axis is called "positive power" and that which is below the axis is called "negative power".
In the case of a pure inductive circuit, the positive power furnished to the circuit causes a field to build up. When this collapses, it returns an equal amount of negative power to the power source. Since no power is used for heat or light in a circuit containing pure inductance (if such a circuit was possible) no actual power will be used even though the current flow is large.

Power Factor
When current and voltage are in phase, the product of their R.M.S. values is power in watts, as in D.C. circuits. If current and voltage are not in phase, the produce of their R.M.S. values is known as "volt-amps". The true power in watts then becomes I^2R or $\frac{E^2}{R}$, i.e. Power used in the resistive part of the circuit.

N.B. It is quite possible for a source to be producing many volt-amps while the true power dissipation of the circuit in watts, remains quite small. The ratio of true power to volt-amps of a circuit is called power factor.
In a pure resistive circuit, power in watts is equal to the product of the R.M.S. values of voltage and current so the power factor is unity (one).
When the power factor is less than unity it is expressed as a decimal. Any practical inductive circuit contains resistance and the phase angle is always less than 90 degrees. For phase angles of

less than 90 degrees, the amount of positive power always exceeds the amount of negative power, the difference between the two representing the actual power used in overcoming the circuit resistance. For example, if the circuit contains equal amounts of inductive reactance and resistance, the phase angle is 45 degrees and the positive power exceeds the negative power as shown in Fig. 3.

When apparent power is divided into true power, the resultant decimal is the Power factor i.e. P.F. = $\frac{I^2R}{\text{Volt-amps}}$.



VA - APPARENT POWER (EXI)

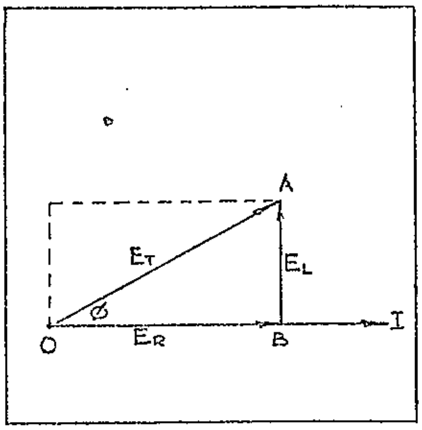
WATTS - TRUE POWER (I^2R)

The difference between apparent power and true power is sometimes called "wattless power" since it does not produce heat or light but does require a current flow in a circuit.

It can be seen that the current lags the voltage in an inductive circuit from the waveform diagrams, therefore inductive circuits are said to have a lagging power factor.

Consider the phasor diagram for the voltages in an R and L, A.C. series circuit.

It can be seen from Fig. 4 that E_R is the component of Et which is in phase with the current, and E_L is the component of Et which is 90 degrees out of phase with the current.



From the definitions of true power and apparent power: True power = $E_R I$

Apparent power = EtI

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{E_R I}{Et\ I}$$

If top and bottom are both now divided by I

$$\text{Power Factor} = \frac{E_R}{E_T}$$

This ratio is the cosine of angle A.O.B. which is the phase angle.

So power factor = Cos Ø

Then true power (P) = Apparent power x Power factor

$$P = EI\cos\text{Ø}$$

And since the voltage phasor has its sides in proportion to an impedance triangle for the same circuit, cos Ø also equals $\frac{R}{Z}$.

Consider the following example:

A 40 watt fluorescent tube in conjunction with its inductive ballast is connected to a 240V 50 HZ supply, the current being 0.4 amps and a wattmeter indicating 48 watts. Determine the Power Factor.

$$\text{Power Factor} = \cos\text{Ø} = \frac{\text{Watts}}{\text{Volt Amps}} = \frac{48}{240 \times 0.4} = \underline{0.5}$$

This power factor is low and it should be noted that the 48 watts could have been produced by 0.2 amps if the current had been in phase with the voltage.

To improve poor power factor is a vital requirement in the application of electricity to industry throughout the world.

It can be considered as a measure of calculating that portion of the current which is converted into useful work or power by a particular machine. The nearer the power factor approaches unity, the greater does this proportion become.

Apart from the loss of useful power which accompanies a low power factor, there are many other serious disadvantages among which are:-

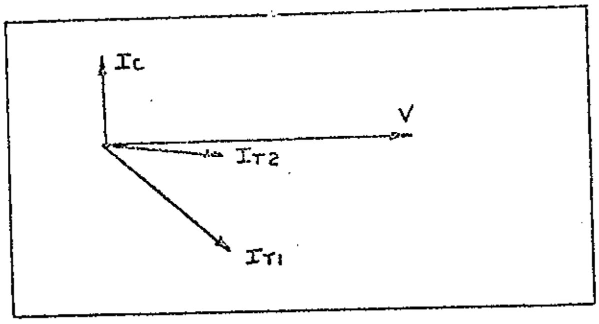
1. Increased power losses in the transmission system due to heavier currents.
2. Larger cables necessary to deal with heavier current without exceeding permissable voltage drop.
3. Control equipment etc. must be able to handle heavier current.
4. Increased size of generating plant necessary.
5. Extra fuel required in generating station because of increased losses.

Low power factor can be directly attributed to certain types of apparatus, among which are:-

(a) Induction motors
(b) Transformers
(c) A.C. welders
(d) Induction furnaces
(e) Vapour lighting.

In all these cases, a portion of the current is necessary to create a magnetic field and thus is not converted to useful power.

<u>Power Factor Correction</u>:- To counteract the large amount of "watt-less power" present when power factor is low, capacitors are placed in parallel with the individual loads. The current leads by 90 degrees in a purely capacitive circuit and with careful choice, the capacitor can bring the current close to unity power factor. In Fig. 5. the current I_{T1} lags by approx. 45° before insertion of capacitor in the circuit. With the capacitor in circuit however, the resultant I_{T2} shows a marked improvement in power factor is achieved.



Another method, usually used on a much larger scale, is to connect lightly loaded synchronous motors in parallel with suitable sections of the load. This has a similar effect to the capacitor but has the advantage that with this system it is possible to maintain the power factor at any required value within normal limits for all load conditions by adjusting the value of D.C. excitation.

<u>Power in 3 phase circuits</u>

Let I. be the current in the line
V. be the voltage between each pair of conductors
i,e, be the current and voltage respectively of each individual branch load.

First consider a non-inductive load.

The power given to each branch load circuit is i,e watts. Since there are three such branch circuits, the total power transmitted by the line to the branch circuits is 3 i.e. watts.

In the star connection $i = I$ and $e = \frac{E}{\sqrt{3}}$, hence in this case total

power $= 3i.e. = 3I\frac{E}{\sqrt{3}} = \underline{\sqrt{3}IE}$

In the delta connected system $i = \frac{I}{\sqrt{3}}$ and $E = e$, consequently

power of system $= 3i.e. = 3\frac{I}{\sqrt{3}}E = \underline{\sqrt{3}IE}$

Thus in either case the power is the same and equal to 3IE watts.

If the load is partly inductive the phase current and voltage will not be in phase with each other. In this case the power in each branch circuit will be e.i. cos Ø instead of i.e. watts. If the angle of lag in all the branch circuits is the same, the expression for the power in the line becomes

$$\text{Power} = 3\ \text{i.e.}\cos\phi \quad \text{or} \quad 3IE\cos\phi$$

which is the general expression for the power transmitted by a 3 phase line with equal loading on all phases i.e. a balanced load.

It is most important to remember that Ø is the phase angle between current and voltage in the branch circuits, and not between line current and line voltage. Also, the power factor of a 3 phase balanced circuit is the power factor of the three loads supplied.

TITLE:- RECTIFICATION

LECTURER:-

DATE:-

EQUIPMENT:-

Rectification means changing alternating current to direct current. Some equipment, both electrical and electronic, require D.C. for their operation, and since most power is supplied as an A.C. it has to be rectified before being fed to such equipment.
Rectifiers are devices which allow current to flow through them in one direction only, i.e. they act as an insulator against current flow in the other direction. Consequently, the current flow in a simple rectifier circuit is pulsating d.c. derived from the positive half cycles of A.C. rather than a steady d.c. current flow.

RECTIFIER TYPES

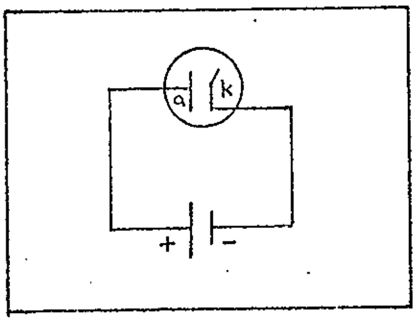
(1) Metal Rectifiers:- Largely replaced by more modern types, these can still, however, be found in use. They are generally made in the form of washers which are assembled on a mounting bolt in any desired series or parallel combination to form a rectifier unit. They are constructed by pressing certain metallic materials together to form a junction.
The combinations most often used are (1) copper and copper oxide and (2) cadmium alloy (or tin) and selenium.
Copper oxide rectifiers consist of discs of copper, coated on one side with a layer of copper oxide; and selenium rectifiers are constructed of discs made of metal (nickel, iron or aluminium) coated on one side with selenium, on top of which has been deposited a surface electrode in the form of a layer of cadmium alloy or tin. No metal rectifier will stand more than a few volts across its terminals but by stacking in series, the voltage rating can be increased.
Similarly, no element can pass more than a limited amount of current. When greater current is required, several stacks are connected in parallel.

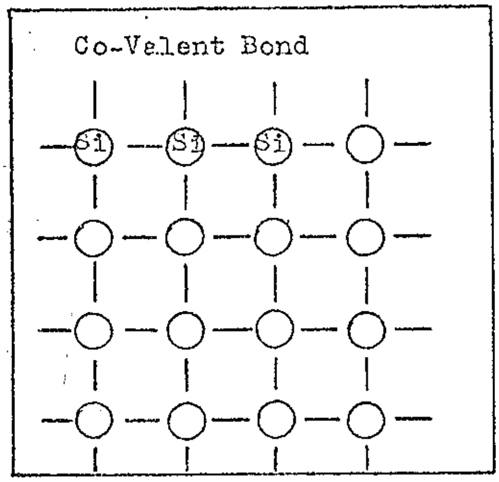
(2) Diode valves:- A diode valve is a glass tube, in which is placed two electrodes (anode and cathode) and a heating element, then the air is evacuated, leaving a partial vacuum.
Cathode - made of nickel with an oxide coating, to emit electrons freely.
Anode - the anode surrounds the cathode and is made of nickel plated steel.

OPERATION

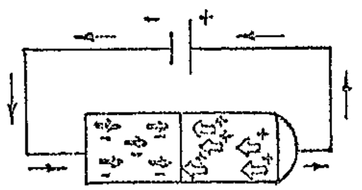
When the cathode is heated sufficiently, its electrons become excited and their velocity increases until they leave the parent body. Increased heat will form an electron "cloud", if a battery is now connected between anode and cathode with anode negative, the electrons are repelled back to the cathode. Reversal of polarity, will now encourage electrons to flow from the cathode to anode, while other electrons flow from battery to cathode.

Diode When silicon is "doped" with other materials which are either tri-valent or penta-valent, it forms either a positive (P) type material or an negative (N) type material respectively. The P type material is capable of accepting electrons and the N type material is capable of giving electrons up.

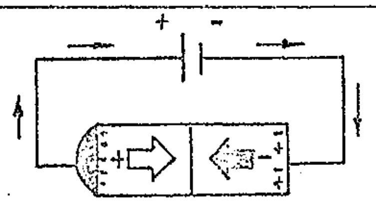




If a junction is formed of these two materials and a voltage applied to it with the N type material connected to +Ve and the P type material connected to -Ve, no current will flow due to the attraction - repulsion effect set up when a P.D is applied to a P.N junction. If, however, the P.D is reversed, current flows since the charged particles will attract and combine in the P.N junction. A diode, therefore, only allows current flow in one direction.



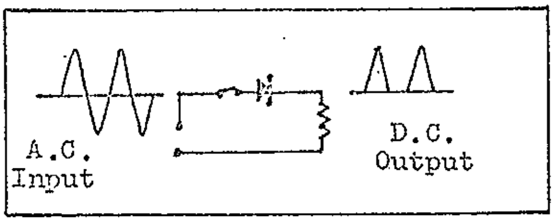
Forward Bias



Reverse Bias

Symbol. Since rectifiers were being made before the electron theory was used to determine the direction of current flow, the arrow points in the direction of conventional current flow (+Ve to -Ve), this is in the opposite direction to electron flow. Thus the arrow points in the opposite direction to that of the current flow used in electronics:

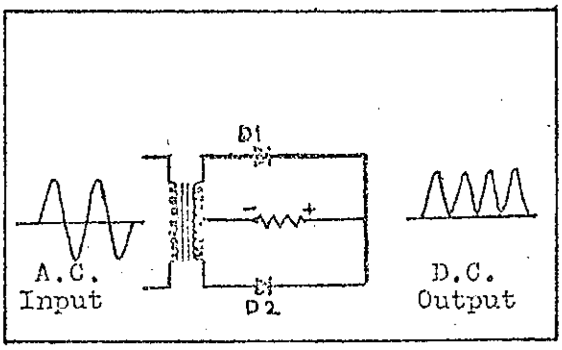
RECTIFIER CIRCUITS: The simplest form of rectifier circuit is called half wave. When the top half of the transformer becomes positive, the diode will conduct and current will flow for half a cycle through the load. When the polarity changes, (next half cycle), the diode blocks and no current flows.



Advantages (1) Cheap - uses only one diode.
(2) Does not require a centre tapped transformer.

Disadvantages (1) Not very good D.C. produced.
(2) Not very efficient - half wave not used.
(3) Diode has full supply voltage in both directions.

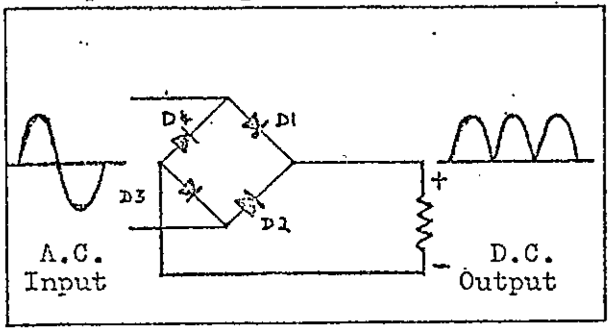
To overcome most disadvantages, the full wave rectifier is used. When the top side of the transformer is positive D1 conducts and current flows through the load as shown. When the next half cycle occurs, the polarities reverse and D2 conducts, and D1 blocks. Current flows again in same direction through load.



<u>Advantages</u> (1) Purer D.C. produced.
(2) No wasted power (both half cycles used).

<u>Disadvantages</u> (1) Centred tapped transformer needed, so twice supply voltage at terminals needed.
(2) Uses two diodes.

<u>Full wave bridge</u> - This commonly used type eliminates the need for a centre tapped transformer, yet still produces good D.C.

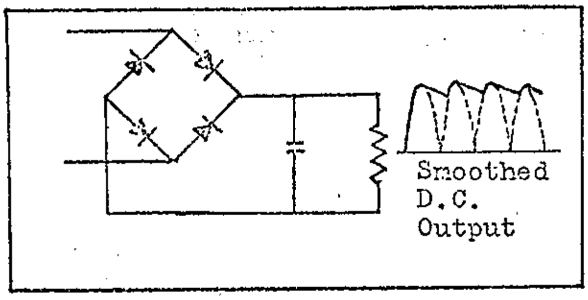


When the top of the transformer is positive, D1 conducts and D4 blocks, as does D2, so current flows through the load to the junction of D4 and D3, it flows through D3, because if it went through D4, it would be going back to the same potential. It will not flow through D2 for the same reason. When polarities are reversed, current flows through D2, while D3 and D1 block. Current then flows through the load in the same direction, until it reaches junction of D4 and D3. Current will flow through D4 because it is at a higher potential, then back through the transformer.

<u>Advantages</u> (1) No centre tapped transformer needed.
(2) Good D.C. produced.
(3) Efficient - all of cycle used.
(4) Diodes in series can be half rated supply voltage.

<u>Disadvantage</u> Cost - uses four diodes.

<u>Filtering (Smoothing)</u> The output from the rectifiers mentioned is a pulsating D.C. This is undesirable, especially in some electronic circuits. The filtering circuit smoothes out the ripples to give a steadier D.C. output.
The simplest way to give a smoothing effect is to connect a capacitor across the output.



<u>Operation</u> As the output voltage is rising, and current flowing through the load, the capacitor is being charged. After the peak is reached and the voltage starts falling away, the capacitor discharges across the load so that the voltage across the load does not fall to zero. As the capacitor is discharging, the next half cycle of voltage rises again and once again starts charging the capacitor as well as supplying the load.

TITLE: ELECTROMAGNETISM - PRODUCTION OF A MAGNETIC FIELD

LECTURER: SHANE / ALAN

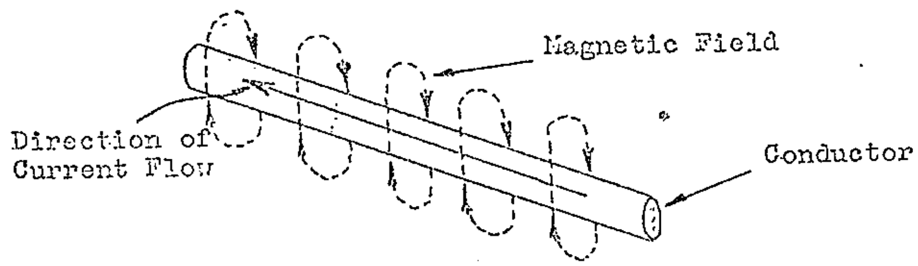
DATE: 13/7/81

EQUIPMENT:

Introduction - from previous study on Electron Theory, it is known that electric current is due to the movement of electrons in a conductor and that this current is always accompanied by a magnetic field, due to "electron spins" (similar to the Earth orbiting about the Sun and spinning on its own axis). It is reasonable to assume then, that any electron in motion will create a magnetic field, due to its motion. Thus, all matter possesses magnetic forces to some degree, because all matter is made up of atoms, which have one or more electrons in motion around their nucleus.

Magnetic Field due to Current Carrying Conductor.

A conductor carrying current is surrounded all along its length by a magnetic field, the lines of magnetic flux being concentric circles in planes at right angles to the conductor. (Magnetic lines of force are imaginary and cannot be seen.)



MAGNETIC FIELD - CURRENT CARRYING CONDUCTORS

The direction of the magnetic field can be found from either of the following 2 rules:-

(1) Right Hand Rule - place the outstretched right thumb along the conductor in the direction of the current flow, with the fingers wrapped around the conductor. The fingers point in the direction in which the magnetic field is acting round the conductor.

(2) Corkscrew Rule - the direction of the magnetic field is the direction of rotation of a corkscrew turned so as to advance along the wire in the direction of the current.

By experimentation, the following facts can be verified:-

(a) No magnetic effect is produced by two conductors laid side by side and carrying the same current in opposite directions;

(b) The magnetic effect produced by two conductors laid side by side and carrying the same current in the same direction is twice the magnetic effect due to one such conductor alone;