

ELECTROTECHNICH LAB.

PART 3

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MEASUREMENT OF CURRENT, VOLTAGE AND POWER IN ALTERNATING CURRENT (AC)

8.1 INTRODUCTION

As we know, direction and the magnitude of the Alternative current change during the time it works. The devices which measure alternative current do not have poles. The connection of the Ampermeter and the Voltmeter is shown in figure 3.1

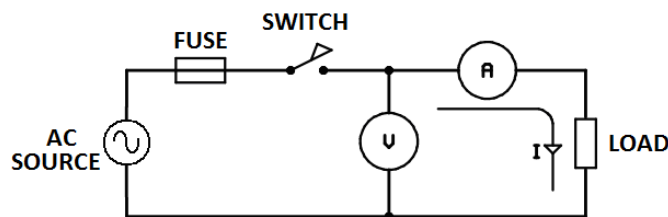


Figure 3.1

8.2 MEASUREMENT OF POWER IN AC CURRENTS

In the AC currents which the frequency is low (**up to 500Hz**), "**Wattmeter**" is used for power measurement if the active power will be measured. Wattmeters and Varmeters are connected between AC supply and the load.

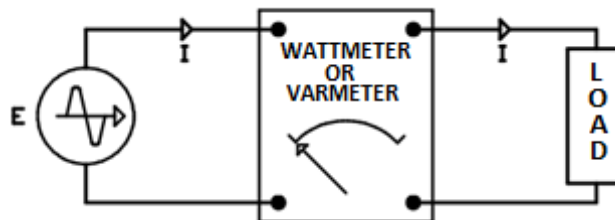


Figure 3.2

The connection of Wattmeter or Varmeter to the circuit is shown in figure 3.2. These two devices generally have three types.

- 1- Electrodynamic
- 2- Induction
- 3- Static

Electrodynamic types of Wattmeter or Varmeter are used in practice. The structures of both devices are approximately the same. The only difference is that the Wattmeter show the value of power in cosines (Φ) terms while the Varmeter shows in sinus terms (Φ)

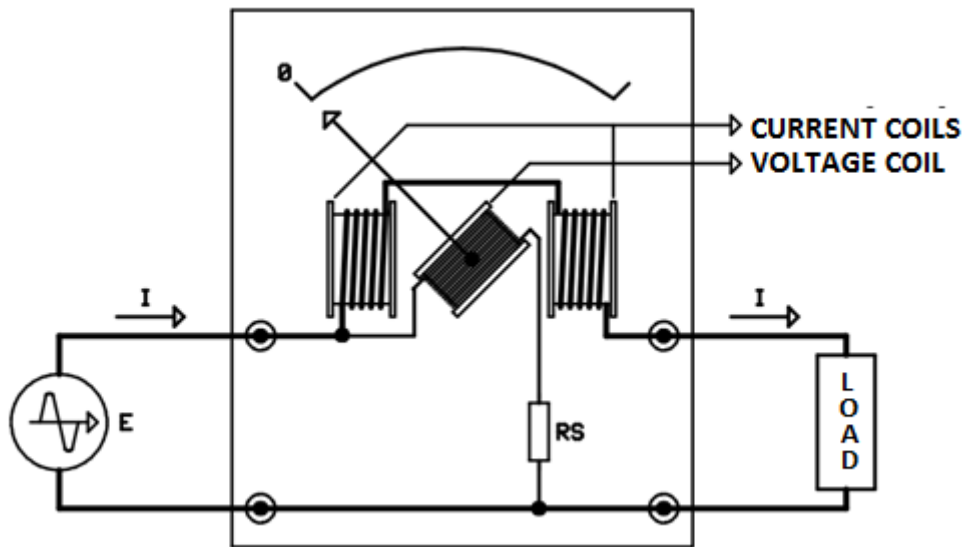


Figure 3.3

As shown in figure 3.3 there are two types of coil in the dynamic type of Wattmeters or Varmeters. First is the current coils consisting of two parts serially connected to each other and the second is the voltage coil.

Current coils has small resistances and they are wrapped with thick conductors. Current conductors are serially connected to the circuit. Voltage coils has big resistances and wrapped with thin conductors. They are parallely connected to the circuit. Structurally, current coils are assembled as fixed, voltage coils are assembled as capable of moving between the current coils. Pointer (needle) of the device is assembled to the carcasse of voltage coil. While the measurement is performed, load current passes through the current coils and it creates a magnetic field around the current coils. At the same time, current also passes through the voltage coils and there appears a second magnetic field. The electromagnetic field which came into being at the voltage coils is controlled by the **RS** resistance value. With the result of two magnetic field affecting each other voltage coil rotates because the current coil is fixed. The pointer which is assembled on the voltage coil also rotates and shows a value over the scale which is divided into values of watt or var. The deviation angle of the pointer is directly proportionate with the voltage applied and the current passing. Measurement fields of the wattmeter or Varmeters can be set gradually by changing the RS resistance.

The maximum power values that wattmeter or Varmeter can measure is written on them. Measurement activity over these levels must not be done.

Voltmeter-ampere meter and cosine Φ meter can be used for active power measurement when the wattmeter does not exist. Cosine Φ meters are connected to the circuit just like the Wattmeter. In this method, mathematical operation is carried out by using the values shown by three devices.

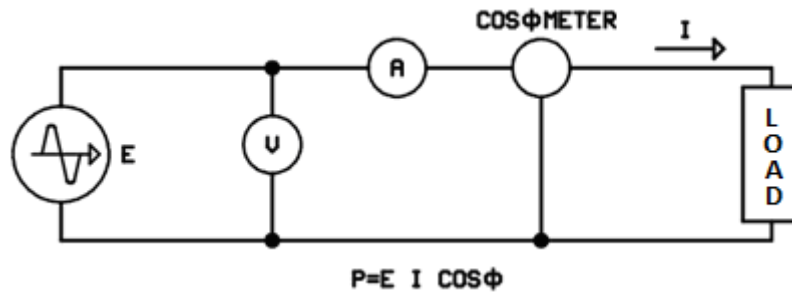


Figure 3.4

Using the methods we examined, power measurement can not be done correctly in the AC currents which have frequency over 500Hz. Especially over the 100 KHz frequency, correct power measurement is very difficult to do. There are four (4) methods for power measurement in high frequencies:

- | | |
|--------------------------------|--------------------------------|
| 1 -Robinson Lamp Method | 2 -Calori-metric Method |
| 3 -Wattmeter | 4 -Oscilloscop Method |

Robinson Lamp method is the most reliable of these methods. Sound amplifiers that work up to 40 KHz, transmitters of sound and picture communication which work at up to GigaHertz's of frequency are the electronical devices that generate energy in high frequencies. There are certain levels of resistances of the loads for those devices. Robinson Lamp is a resistance in a glass tube that is isolated from environmental effects. Robinson Lamp is produced as appropriate for the loads of the high frequency devices. Power measurement with Robinson Lamp Method is shown in Figure 3.5

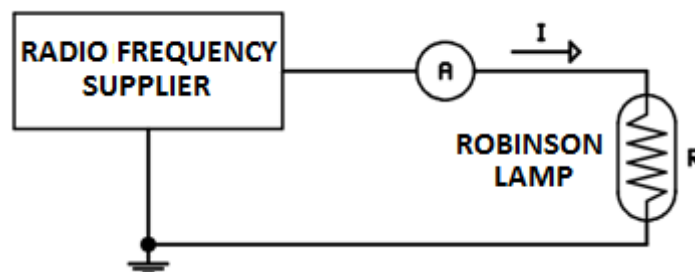


Figure 3.5

The Ampermeter used in Robinson Lamp Method must be able to do power measurement in high frequencies. The result of the measurement can be calculated by a mathematical operation using the value of the resistance of Robinson Lamp and the value of current which Ampermeter shows.

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

In Formula;

P= Active Power (**Watt**)

I= Current (**Amper**)

R= Resistance of Robinson Lamp (**ohm**)

In practice, the most widely used method is Wattmeter although its faults. The Wattcmeters used in high frequencies are connected to the place of load for measurement.

8.3 EXAMINATION OF SINE WAVE

The alternating current (**AC**) that we use in daily is in the form of sine wave. Sine wave should be examined better in order to understand the alternating current.

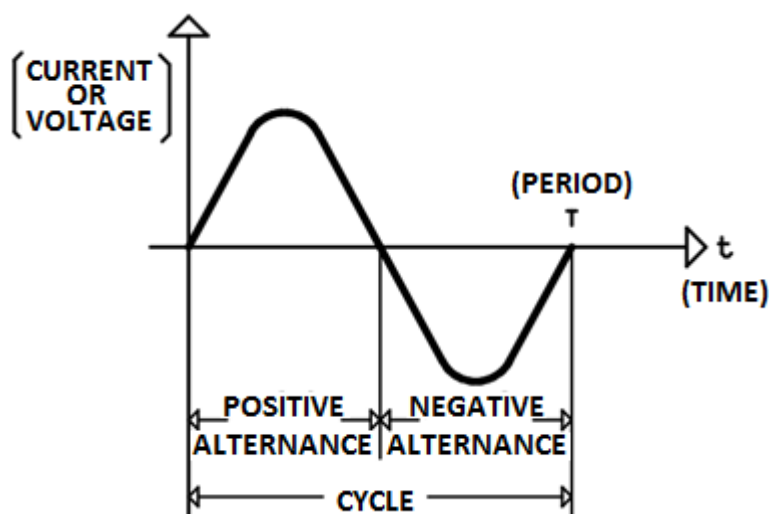


Figure 7.5

Cycle: The sum of the values of sine wave takes while it starts from point zero, generates positive wave then the negative way and returns to starting position.

Alternation: positive or negative wave of cycle is called "**alternation**". So, a cycle consists of two successive alternations', positive and negative.

Period: The time required for the completion of a cycle is called the "**period**".

Frequency: The number of cycles in a second is called "**Frequency**". It is the most important variable of alternating current calculations. Unit of frequency is cycle/second or "**Hertz**"

$$F = \frac{1}{T} \text{ dir.}$$

In Formula;

F : Frequency (**Hertz**)

T : Period (**Second**)

The values for sine wave that we refer are shown in figure 5.14. The frequency of the alternating current that is produced in centrals and used in industry is 50 Hertz. Hertz is a very small unit to define the frequencies that we use in electric circuits. Because of that multiples of Hertz are used.

These are **Kilohertz (KHz)**, **Megahertz (MHz)** and **Gigahertz (GHz)**.

1KHz : 10^3 Hz

1MHz : 10^6 Hz

1GHz : 10^9 Hz

8.4 ALTERNATING CURRENT VALUES

Sine wave is generated by complete tour of generator coil in the magnetic field. The form of current or voltage in any point of time (**t**) is shown in figure 7.6

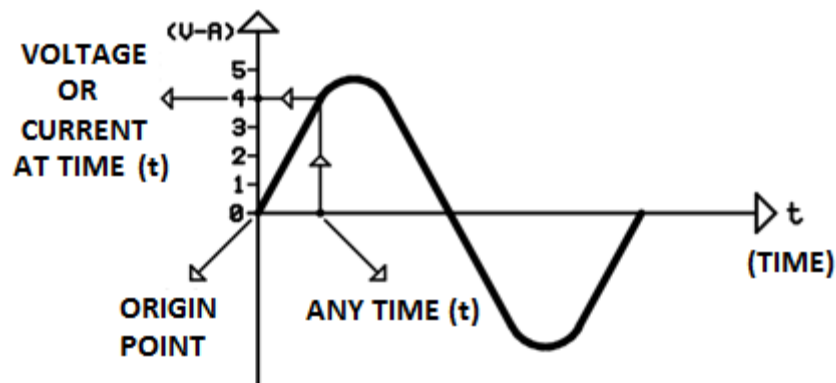


Figure 7.6

A perpendicular line is drawn from the relevant point of time (**t**) to the field where the sine wave is. From the point where that line intersects the sine wave, a parallel line is drawn towards EMF axis. The distance between the origin and the point where the parallel line intersects is the value of current or voltage at that specific moment. In figure 7.6, this value is 4 Volt or 4 Amper. It is observable that value of EMF is different at every point of time. Any point of this line of value is called "**instantaneous value**". Instantaneous value is symbolized by "**e**" for voltage and by "**i**" for current

"**Vectorial Quantities**" should be known in order to calculate instantaneous values mathematically. The quantities that we use daily are scalar quantities and they can be expressed by a single number. Yet, in some situations scalar quantities are incapable for defining magnitudes. For example, a value that has both weight and direction can not be defined by scalar quantities. The quantities that have more than one aspect are called "**Vectorial quantities**". Vectorial quantities can only be defined by using a vector.

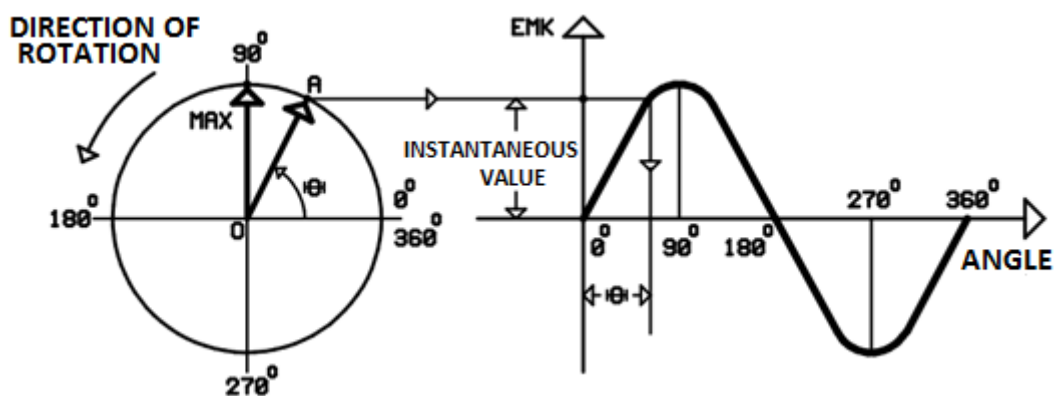


Figure 7.7

In figure 7.7, "OA" radius vector turns counter clockwise. Let's calculate the instantaneous value when the radius vector turns with an angle of " θ " (**Teta**). On the sine curve, it is schematically shown where the " θ " angle is and the value of instantaneous value. The point which the instantaneous value is at maximum is the point where the radius vector is perpendicular to horizontal axis or $\theta=90^{\circ}$. The value at that moment is called "**maximum value**". Maximum value is shown by "**Emax**" for voltage and by "**Imax**" for current. As seen in the figure, the length of the radius vector is always the maximum value. Trigonometric correlations are used for mathematical calculation of instantaneous value.

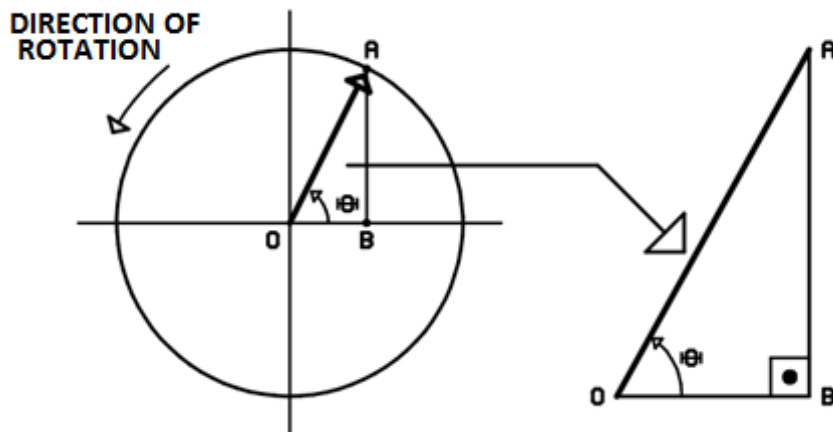


Figure 7.8

When the radius vector turns with an angle of " θ ", if a perpendicular line is drawn from the point "A" to the horizontal axis, there will be a OAB right triangle. Let's assume that we know the value of the angle " θ " and the length of radius vector. At that moment, the instantaneous value equals the length of "AB". The length of "AB" is calculated by "**Law of Sines**"

Law of Sines: "In a right triangle, sine of an acute angle equals to the proportion of the leg (opposite to that angle) to the hypotenuse"

If it is applied to the "OAB" triangle;

$$\sin\theta = \frac{AB}{OA} \text{ And } AB = OA \cdot \sin\theta$$

In formula, length of "AB" equals instantaneous value. Length of "OA" (Hypotenuse) equals to the maximum value. So the instantaneous voltage and current value:

$$e: E_{\max} \cdot \sin\theta$$

$$i: I_{\max} \cdot \sin\theta$$

Example: A generator has a maximum voltage of 400Volt and maximum current of 160 Amper. Find the instantaneous voltage and current when there is angle of 25° between the generator coil and the horizontal axis.

Solution: $\theta = 25^\circ$. First, we should look at the value of 25° from the trigonometric scale

$$\sin\theta = \sin 25^\circ = 0,4226$$

$$e: E_{\max} \cdot \sin\theta$$

$$e: 400 \cdot 0,4226$$

$$e: 169 \text{ Volt}$$

$$i: I_{\max} \cdot \sin\theta$$

$$i: 160 \cdot 0,4226$$

$$i: 67.6 \text{ Amper}$$

Practically, it is impossible to find the angle (θ) between the coil and horizontal axis. For this reason, the questions will be in the form of "find the instantaneous value after a given amount of time". If the coil did not make a complete tour in the given amount of time, the angle between the coil and horizontal can be calculated by the following method. Because of the fact that perigon equals 360°

$$A\grave{c}i = \frac{360^\circ}{T} \text{ olur.}$$

In formula, "T" is the amount of time in one cycle, shortly it is the "period". The result of the operation is degree/second. This value is called "angular speed". It is symbolized by "W" (Omega). To write the angular speed as frequency:

$$f = \frac{1}{T}$$

$$W = \frac{360^\circ}{T} = \frac{360^\circ}{\frac{1}{f}} = \frac{360^\circ \cdot f}{1}$$

$$W = 360^\circ \cdot f$$

The " θ " angle between the coil and the axis in a given period of time (t) is:

$$\theta = \omega t = 360^\circ \cdot f \cdot t$$

If this equation is inserted into the formula of instantaneous values:

e: $E_{\max} \cdot 360^\circ \cdot f \cdot t$

i: $I_{\max} \cdot 360^\circ \cdot f \cdot t$

In mathematical calculations of electric and electronics, angular speed is not expressed in degrees. Instead of degree, another unit "**Radian**" is used, it will help us to make mathematical calculations in our future topics.

One radian is the angle subtended at the center of a circle by an arc of circumference that is equal in length to the radius of the circle. It is symbolized by "**R**". The mathematical relation between Radian and degree is as follows:

$$\text{Perigon } (360^\circ) = 2\pi = 6.28R$$

$$1R = \frac{360^\circ}{2\pi} = \frac{360^\circ}{6,28} = 57,3^\circ$$

The " θ " angle between the coil and the axis in a given period of time (t) in Radian is:

$$\theta = \omega t = 2 \pi f t$$

If we put this equation in the formula of instantaneous values:

e: $E_{\max} \cdot \sin \omega t$

i: $I_{\max} \cdot \sin \omega t$

This equation is called "**alternating current and voltage equation**".

Only the values of acute angles (**between 0° - 90°**) are given in trigonometric scales. In problem solutions the angle " θ " will appear as wide angle. In order to convert the " θ " angle to acute angle the value of " ωt " is divided by $2\pi=6,28$. Integer part (before the coma) of the number will be the number of complete turns that the generator coil has made. If the part of the number after the coma is multiplied by 2π , radian value of the " θ " angle in the moment of " t " is found. This value of angle is converted to degree by multiplying it with "**57,3**". If the result is an acute angle, it is chosen for the mathematical operation. If it is not, then it is converted to acute angle by the following basic mathematical operation.

θ	SIGN	WORK TO DO
BETWEEN 0°-90°	POSITIVE	—————
BETWEEN 90°-180°	POSITIVE	$180^\circ - \theta$
BETWEEN 180°-270°	NEGATIVE	$\theta - 180^\circ$
BETWEEN 270°-360°	NEGATIVE	$360^\circ - \theta$

Figure 7.9

Example: A generator has a maximum voltage of 600 Volt, maximum current of 300 Amper and 50Hz of frequency. Find the instantaneous voltage and current at the time of 1.237 seconds.

Solution:

$$e: E_{\max} \cdot \sin \omega t$$

$$e: E_{\max} \cdot \sin 2 \pi f t$$

$$e: 600 \cdot \sin 2 \cdot 3,14 \cdot 50 \cdot 1,237$$

$$e: 600 \cdot \sin 388,418^{\text{R}}$$

To convert 388,418 radian to degrees:

$$388,418 / 6,28 = 61,85$$

The number "**61.85**" indicates that the generator coil has completed "**61**" turns, and the number "**0.85**" indicates that it completed %85 of the **62nd** turn. Value of %85 in radian:

$$\theta = 0,85 \cdot 6,28 = 5,338^{\text{R}}$$

This value in degrees:

$$\theta = 5,338 \cdot 57,3 = 305,8^{\circ}$$

At that moment the values are negative. $305,8^{\circ}$ is a wide angle. To convert it to acute angle;

$$\theta = 360^{\circ} - 305,8^{\circ} = 54,2^{\circ}$$

In trigonometric scale;

$$\sin 54,2^{\circ} = 0,81$$

$$e: 600 \cdot \sin 54,2^{\circ}$$

$$e: 600 \cdot 0,81$$

$$e: 486 \text{ Volt}$$

Instantaneous current at that moment:

$$i: I_{\max} \cdot \sin 54,2^{\circ}$$

$$i: 300 \cdot 0,81$$

$$i: 243 \text{ Amper}$$

8.5 EFFECTIVE VALUE

“Effective value” is the value of alternating voltage or current that will have the same effect on a resistance as a comparable value of direct voltage or current will have on the same resistance. Effective value is used in almost all alternating circuits. For this reason, the word “effective” is not used in daily life. Effective voltage is symbolized by **“E”** and effective current is symbolized by **“I”**.

$$E = \sqrt{\frac{e_1^2 + e_2^2 + \dots + e_n^2}{n}}$$

$$I = \sqrt{\frac{i_1^2 + i_2^2 + \dots + i_n^2}{n}} \text{ 'dir.}$$

In formulas, the higher the values of instantaneous value of voltage and current taken, the more accurate will be the result. Positivity or negativity of instantaneous value is irrelevant in calculating the effective value. The reason of this is the fact that squares of the negative numbers are also positive. Numerical effective value derived from the formulas is **“0.707”** unit of sine wave of which the maximum value is **“1”**.

Formula of the effective value of alternating voltage or current of which the maximum value is known;

$$\mathbf{E} = E_{\max} \cdot 0,707$$

$$\mathbf{I} = I_{\max} \cdot 0.707$$

Effective value equals the instantaneous value at the moment when the radius vector is at $\theta = 45^\circ$.

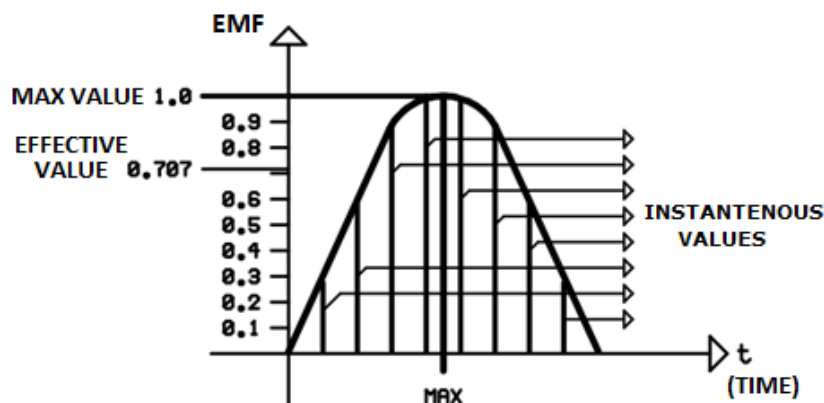


Figure 7.10

The position of effective value in the EMF axis is shown in figure 7.10. Alternating voltage or current measurement devices measure effective value unless they are produced for a special purpose.

Effective value is also called **“RMS”** (**R**oot **M**ean **S**quare).

8.6 AVERAGE VALUE

“Average Value” of an alternating current or voltage is the average of all the instantaneous values during one alternation. Average voltage is symbolized by **“ E_{avg} ”** and average current is symbolized by **“ I_{avg} ”**. Average value in formula;

$$E_{or} = \frac{e1 + e2 + \dots + en}{n}$$

$$I_{or} = \frac{i1 + i2 + \dots + in}{n}$$

In formulas, the higher the values of instantaneous value of voltage and current taken, the more accurate will be the result. To put it basically, average value is the average height of an alternation. If we assume that the maximum value of the sine wave is **“1”** unit, average height of an alternation is **“0,637”**. For this reason, average voltage and current in formula:

$$E_{avg} = E_{max} \cdot 0,637$$

$$I_{avg} = I_{max} \cdot 0,637$$

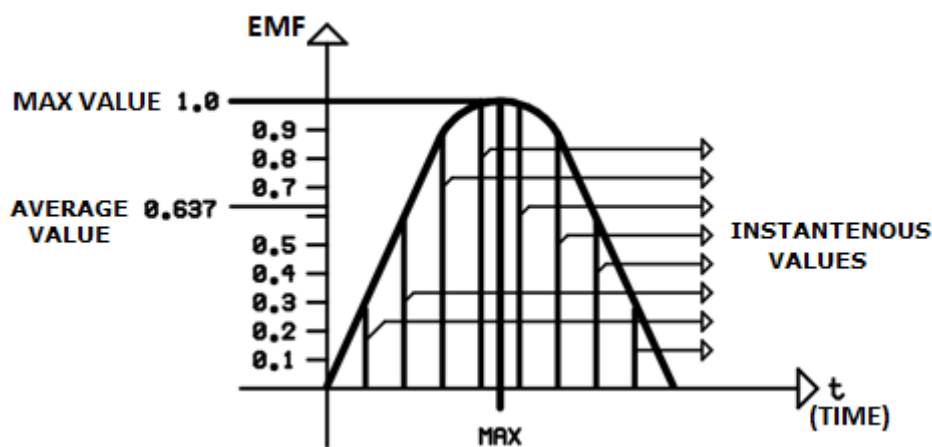


Figure 7.11

Average value is not used in alternating current circuits. It is used in the direct current circuits which has varying magnitudes during the working time. Examples of these circuits are the accumulator charging devices. Effective value of the current or voltage is calculated by the following formula if their average value is known:

$$E = E_{or} \cdot \frac{0,707}{0,637}$$

$$I = I_{or} \cdot \frac{0,707}{0,637}$$

In formula, the ratio of factor of effective value to the factor of average value is called "**form factor**". Form factor as numerical value is:

$$\frac{0,707}{0,637}$$

Example: Find the average voltage and current of a generator which has a maximum current of 300 Amper and a maximum voltage of 600Volt.

Solution:

$$E_{avg} = E_{max} \cdot 0,637$$

$$E_{avg} = 600 \cdot 0,637$$

$$E_{avg} = 382,2 \text{ Volt}$$

$$I_{avg} = I_{max} \cdot 0,637$$

$$I_{avg} = 300 \cdot 0,637$$

$$I_{avg} = 191,1 \text{ Amper}$$

8.7 PEAK TO PEAK VALUE

In voltage and current measurements that are made with oscilloscope, effective value can be obtained by mathematical operations. For this reason, "**peak to peak value**" is used instead of effective value because it is easily readable from the display of the oscilloscope. Peak to peak value is the sum of mathematical absolute values of positive and negative maximum values. In other words, it is the double of maximum value. For voltage peak to peak is symbolized by "**E_{pp}**" and for current it is symbolized by "**I_{pp}**"

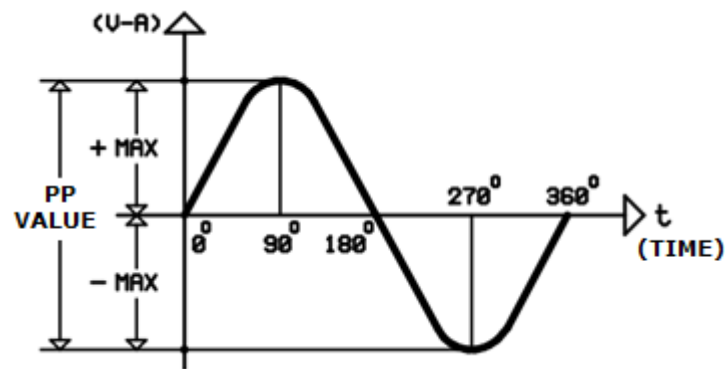


Figure 7.11

Peak to peak value in the sine wave is shown in figure 7.11

Example: Find the peak to peak voltage and current of a generator which has a maximum current of 300 Amper and a maximum voltage of 600Volt.

Solution:

$$\mathbf{E_{pp}} = E_{max} \cdot 2$$

$$\mathbf{E_{pp}} = 600 \cdot 2$$

$$\mathbf{E_{pp}} = 1200 \text{ Volt}$$

$$\mathbf{I_{pp}} = I_{max} \cdot 2$$

$$\mathbf{I_{pp}} = 300 \cdot 2$$

$$\mathbf{I_{pp}} = 600 \text{ Amper}$$

EXAMINATION OF PHASE AND PHASE DIFFERENCE

9.1 VECTOR DIAGRAM

Initial moment of the sine wave is called "**phase**". It is the EMF that enables electric current to pass through a load. We can also call EMF, shortly, as "**voltage**". If a load is assembled to the terminals of a generator, the voltage generated by generator can be seen on the load terminals. Current begins to pass through the load. If the phases of voltage and current on the load are examined, it will be observed that there are three different phase relations related to the properties of load. If the voltage and current starts from zero at the same moment and reach the maximum and zero at the same time during the working time, this type of phase relation is called "**monophase circuit**". Some loads resist current and cause it to fall behind voltage. Some loads resist voltage and cause it to fall behind the current. These type of phase relations are called "**polyphase circuits**". Sine waves of voltage and current for monophase and polyphase circuits are shown in figure 8.1. Illustration of phase relation of this type is called "**vector diagram**".

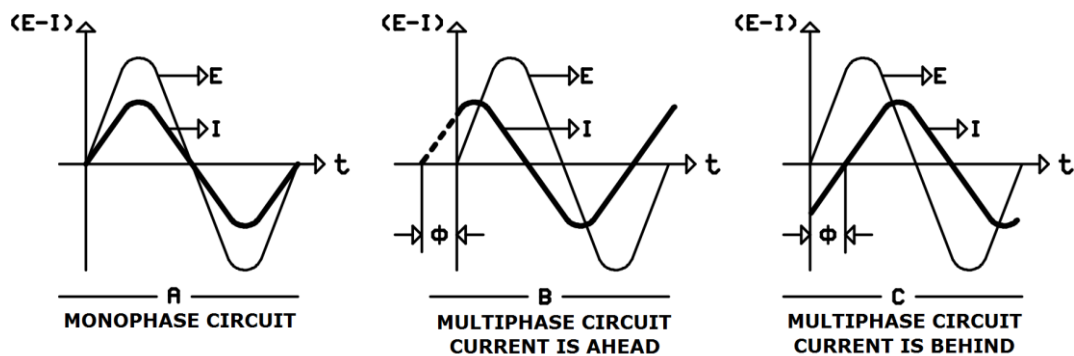


Figure 8.1

In figure 8.1A, voltage and current starts from zero (0) and reach maximum and zero at the same time. Then, they reach maximum and zero at the same time in opposite direction. So the diagram in 8.1A is the vector diagram of monophase circuit. In figure 8.1B, voltage and current do not reach maximum and zero at the same time. So the diagram in 8.1A is the vector diagram of polyphase circuits. One of the variables is taken as reference in polyphase vector diagrams. The reference variable is assumed to be the origin (intersection of x and y axis). In figure 8.1B and 8.1C, voltage is taken as reference. The position of the other variable is defined in terms of the reference. So, the current is ahead from the voltage as much as " Φ " angle in figure 8.1B. The reason why we use the term ahead is that current is in the positive field while voltage is at origin. In figure 8.1C, the current is behind the voltage as much as " Φ " angle. The reason why we use the term behind is that the current is in the negative field while the voltage is at origin.

Reference variable should be chosen as to help the solution of the alternating current circuits. Current is taken as reference in serial connected circuits because the same current passes through all the components.

Voltage is taken as reference variable in parallel connected circuits because the voltage is same at the terminals of all the components. Vector diagrams are not sufficient in the solutions of alternating current circuits. For this reason "**phasor diagrams**" are used because variables can be shown with physical forces in phasor diagrams. When explaining the phase relation in phasor diagrams, direction of rotation is always counter clock wise. Length of the physical vector is compatible with the magnitude of the variable. Phasor diagrams of vector diagrams in figure 8.1, are shown in figure 8.2

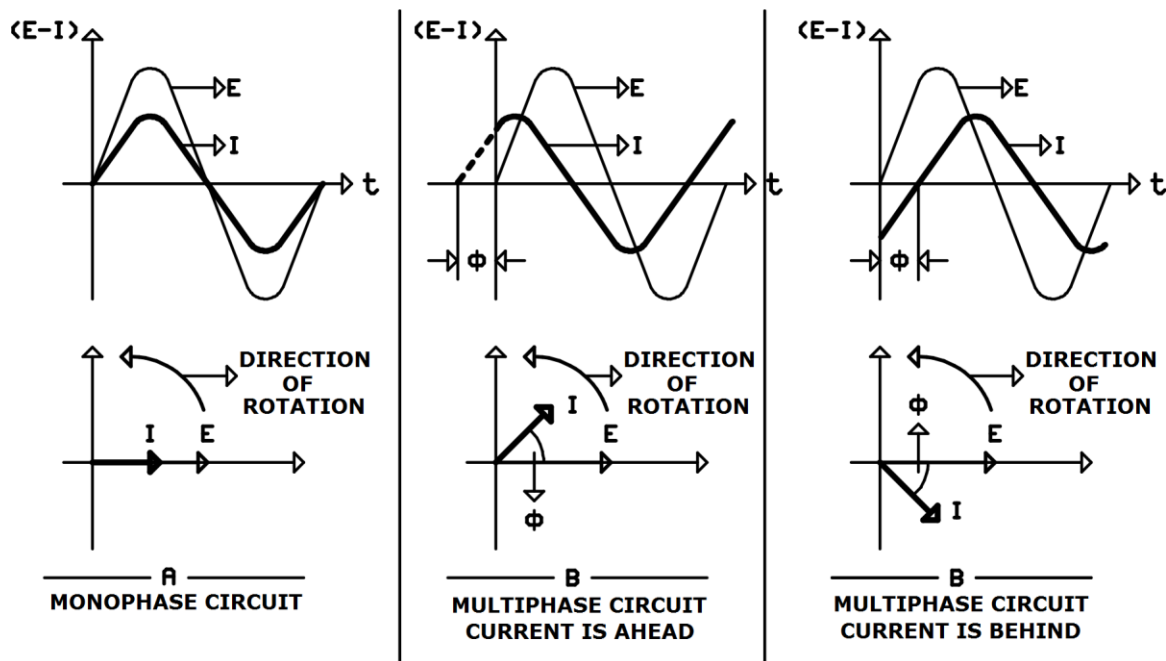


Figure 8.2

To write the equations of instantaneous current and voltage values for the diagrams in figure 8.2A;

$$\mathbf{e} = E_{\max} \cdot \sin \omega t$$

$$\mathbf{i} = I_{\max} \cdot \sin \omega t$$

When writing the equations of instantaneous current and voltage values for the diagrams in figure 8.2B, equations are the same because the voltage is the reference. " Φ " angle is added to the angle of voltage because the current is ahead from voltage as much as " Φ " angle.

$$\mathbf{e} = E_{\max} \cdot \sin \omega t$$

$$\mathbf{i} = I_{\max} \cdot \sin (\omega t + \Phi)$$

When writing the equations of instantaneous current and voltage values for the diagrams in figure 8.2B, equations are the same because the voltage is the reference again. " Φ " angle is deducted from the angle of voltage because the current is ahead from voltage as much as " Φ " angle.

$$e = E_{\max} \sin \omega t$$

$$i = I_{\max} \sin (\omega t - \Phi)$$

A generator has a maximum voltage of 600 Volt and a maximum current of 300 Amper. A load is assembled to the terminals of generator and the current passing through the load is 30° from the voltage. Find the instantaneous values for voltage and current when the voltage is at 20° .

Solution:

$$e = E_{\max} \sin \Phi$$

$$e = 600 \sin 20^\circ$$

$$e = 600 \cdot 0,342$$

$$e = 205,2 \text{ Volt}$$

$$i = I_{\max} \sin (\mathbf{0} + \mathbf{30}^\circ)$$

$$i = 300 \sin (\mathbf{20}^\circ + \mathbf{30}^\circ)$$

$$i = 300 \sin 50^\circ$$

$$i = 300 \cdot 0,766$$

$$i = 229,8 \text{ Amper}$$

9.2 VECTORIAL ALGEBRA

The rules that we use in DC circuits can not be used in the same way for the solution of AC circuits because most loads presents opposition to DC and AC in different levels. For example, if a coil is connected to the terminals of a DC supply, the opposition to the passing current is the one that we read at the display of resistance measurement devices. If the same coil is connected to the AC circuit, because of the fact that the current passing through the AC is variable a counter EMF will be generated on the pins of the coil as we know from the Lenz's Law. The counter EMF presents opposition to the current. This opposition is added to the opposition that coil makes to the DC.

The opposition of the circuit or circuit components presented to the AC is called "**impedance**". It is symbolized by "**Z**". The most effective factor on impedance is frequency.

If a circuit or load presents the same opposition to the AC and DC, this opposition is called "**Ohmic resistance**". Impedance and resistance of these type of circuits are equal. These circuits are called "**Ohmic Circuits**". If Ohmic circuits are connected to the AC generators, voltage and current are in the same phase during the work time. Because of this, the rules in DC circuits also apply to the Ohmic circuits. In polyphase circuits, current attempts to flow towards the supply when the voltage and current are at opposite fields (**positive-negative fields**) of the cycle. For this reason, the impedance of the circuit increases and current decreases. In polyphase circuits, the impedance is greater than the resistance.

In such circuits, solution is made through applying trigonometric relations and "**Pythagorean theorem**" to the vectors in phasor diagrams. These operations are called "**Vectorial algebra**". In serial connected AC circuits Kirchoff's Voltage Law is used while in parallel connected AC circuits the current law is used. To apply Ohm's Law in AC circuits, it is enough to use impedance instead of resistance.

9.3 SUMMING THE ELEMENTS WITH THE SAME PHASE

The fixed property of serial connected circuits is that the same current passes through all the components of that circuit. If there is no phase difference of voltage or current on the circuit components, DC rules are applicable. Thus, the voltage is divided on the circuit components.

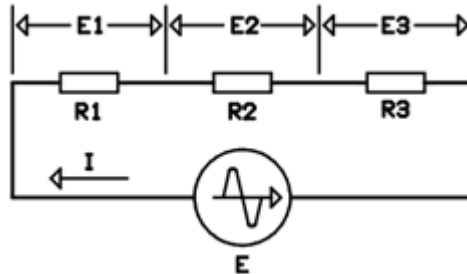


Figure 8.3

According to the Kirchoff's Voltage Law;

$$E = E_1 + E_2 + E_3$$

Vector diagram of the circuit is as in the following.

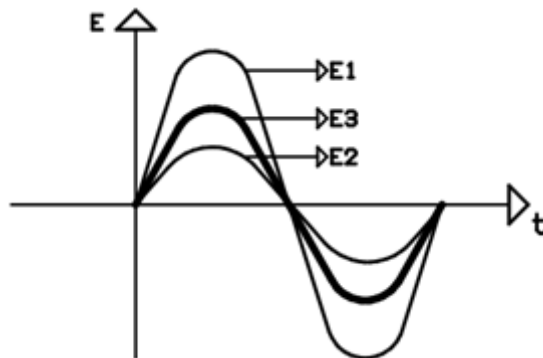


Figure 8.4

To draw the phasor diagram of the circuit, the variable that will be taken as reference is the current because this is a serially connected circuit. Because this is a monophasic circuit, I-E1-E2-E3 is drawn starting from the origin and towards the direction which the rotation starts (**right side of the horizontal axis**). They are drawn proportional to their respective magnitudes. Phasor diagram of the circuit is shown in figure 8.5

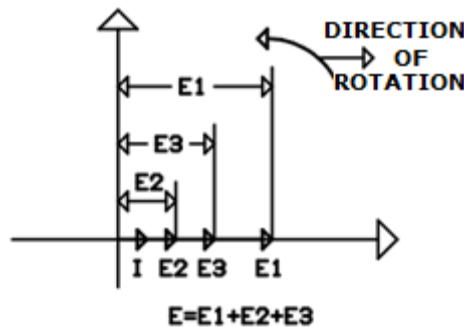


Figure 8.5

9.4 SUMMING THE ELEMENTS WITH THE PHASE DIFFERENCE 90°

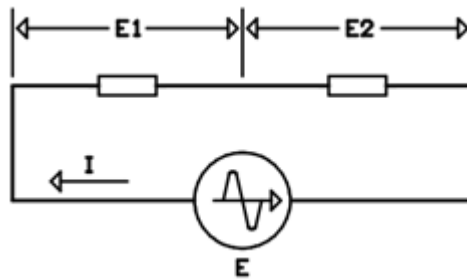


Figure 8.6

Assume that "**E1**" voltage is 90° ahead from the "**E2**" voltage in figure 8.6. Vector diagram of the circuit will be as following:

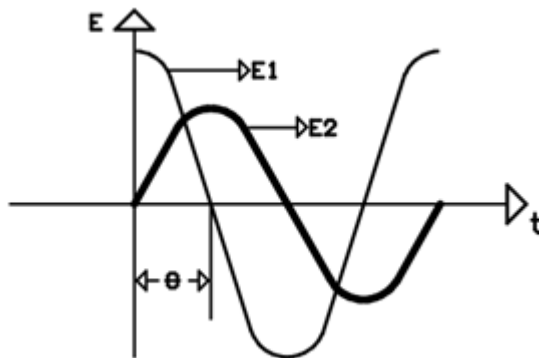


Figure 8.7

Phasor diagram of the circuit will be drawn taking voltage as reference because the circuit is serially connected. Because the phase of "**E2**" voltage is zero at the vector diagram, it will be drawn starting from origin and towards the right side of the horizontal axis. In that situation, "**E1**" will be at the upper side of the vertical axis because it is 90° ahead.

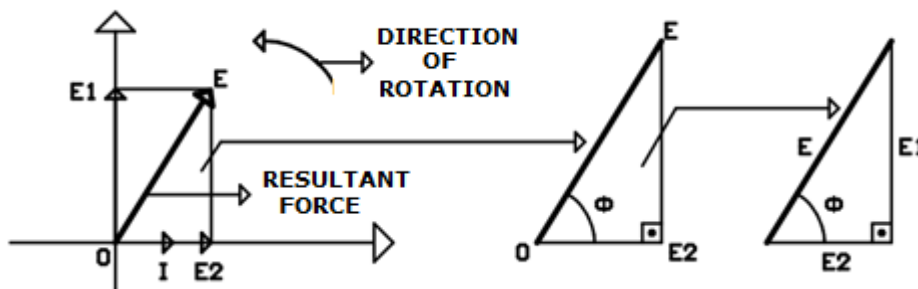


Figure 8.8

As we see from the phasor diagram, directions of "**E1**" and "**E2**" voltages are different. Circuit voltage is the resultant of two voltages. Mathematical solution is made through Pythagorean Theorem.

“Pythagorean theorem: The sum of the squares of the lengths of the legs of a right triangle is equal to the square of the length of the hypotenuse.”

0, E, E₂ triangle is a right triangle. “E₂” is a right angle. The triangle on the right side is the same but its legs are written as voltage. Resultant force is the hypotenuse or the circuit voltage. Using Pythagorean Theorem in circuit voltage;

$$E = \sqrt{E_1^2 + E_2^2}$$

“Φ” angle in the triangles we see is the angle between circuit voltage and current. This is called “circuit phase angle”. As we know, circuit current is taken as reference and it is on the horizontal axis. This angle is essential for calculating power in AC circuits. After finding the circuit voltage using Pythagorean Theorem, we know length of all the legs. In such a triangle, “Φ” angle can be calculated trigonometrically by “**law of cosines**”, “**tangent theorem**” or “**law of sines**” which we saw earlier.

Law of Cosines states given any right triangle with side lengths a, b and c (right angle) and opposing angles A, B and C (hypotenuse), Cosine of angle “a” equals the ratio of leg “B” to leg “C” (hypotenuse), so;

$$\cos\phi = \frac{E_2}{E}$$

“Law of tangents states that in any given right triangle, tangent of an acute angle equals the ratio of opposing right leg to the other right leg” so;

$$\tan\phi = \frac{E_1}{E_2}$$

The values obtained are converted using the trigonometric scale.

Example. In the following circuit, **E₁**=50Volt and **E₂**=30Volt. E₁ voltage is in the same phase with circuit current and E₂ voltage is 90⁰ ahead.

A-Draw the phasor diagram of the circuit.

B-Find the circuit voltage.

C-Find the phase angle.

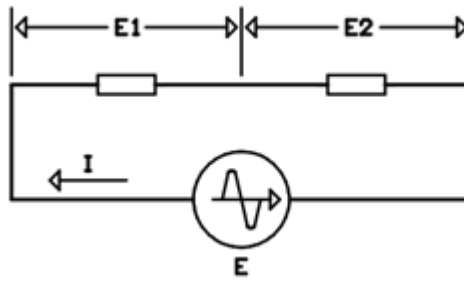


Figure 8.9

Solution:

A-

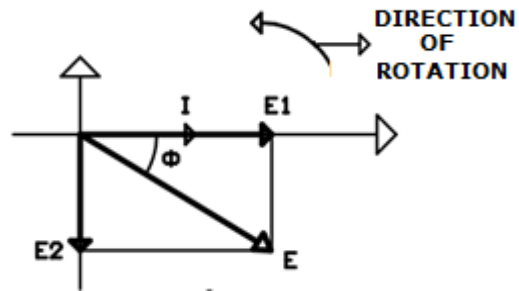


Figure 8.10

B-

$$E = \sqrt{E1^2 + E2^2}$$

$$E = \sqrt{50^2 + 30^2}$$

$$E = \sqrt{2500 + 900}$$

$$E = \sqrt{3600}$$

$$E = 60\text{Volt}$$

C-

$$\cos\phi = \frac{E1}{E}$$

$$\cos\phi = \frac{50}{60}$$

$$\cos\phi = 0,833$$

$$\phi = 33^{\circ}\text{ dir.}$$

9.5 SUMMING THE ELEMENTS WITH THE PHASE DIFFERENCE θ^0

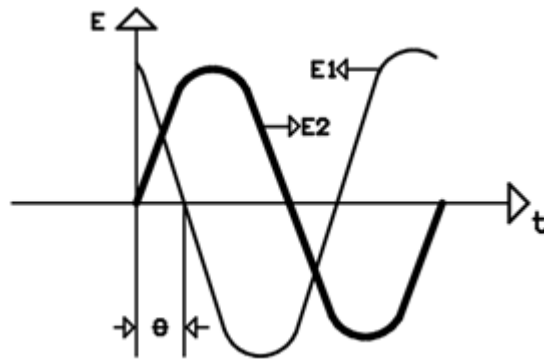


Figure 8.11

Vector diagram of a serially connected circuit is shown in figure 8.11. E2 voltage is in the same phase with circuit current and E1 voltage is ahead from E2 as much as " θ " angle. Phasor diagram will be drawn in order to find the circuit voltage. Parallel legs method is used for phasor diagram.

This process is made through drawing parallel lines from the edge of E1 to E2 and from E2 to E1.

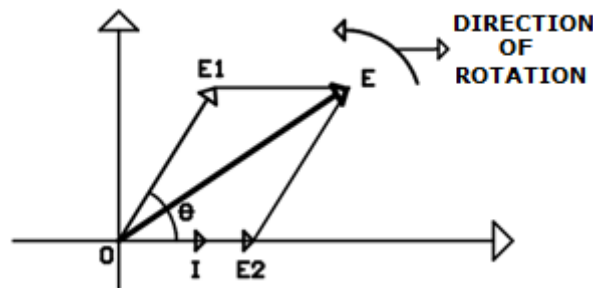


Figure 8.12

In figure 8.12, there is a parallelogram of 0, E1, E, E2. Circuit voltage is the "**OE**" diagonal of that parallelogram. Mathematical solution of such a phasor diagram could be achieved by using trigonometric relations. For this reason, right triangles shall be formed by drawing perpendicular lines to horizontal axis from the edge of circuit voltage (point E).

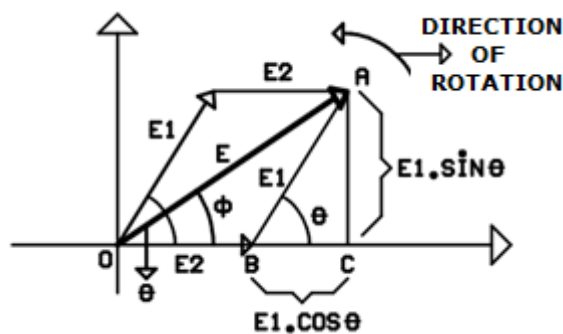


Figure 8.13

In "ABC" triangle, leg "AB" is the hypotenuse and equals the "E1" voltage. "B" angle is the phase angle between two voltages. Since we know the "E1" voltage and "B=θ" angle, the lengths of the right legs of ABC triangle can be calculated by using Law of Sines and Law of Cosines.

$$\sin\phi = \frac{AC}{E1} \text{ 'dir.}$$

$$AC = E1.\sin\theta \text{ olur.}$$

$$\cos\theta = \frac{BC}{E1} \text{ 'dir.}$$

$$BC = E1.\cos\theta \text{ olur.}$$

The right legs of "OAC" triangle;

$$\mathbf{AC} = E1.\sin\theta$$

$$\mathbf{OC} = E2 + E1.\cos\theta$$

Pythagorean Theorem is used to find circuit voltage.

$$E = \sqrt{(E1.\sin\theta)^2 + (E2 + E1.\cos\theta)^2}$$

$$E = \sqrt{(E1^2.\sin^2\theta) + (E2^2 + 2.E2.E1.\cos\theta + E1^2.\cos^2\theta)}$$

$$E = \sqrt{E1^2.\sin^2\theta + E2^2 + 2.E2.E1.\cos\theta + E1^2.\cos^2\theta}$$

$$E = \sqrt{E1^2(\sin^2\theta + \cos^2\theta) + E2^2 + 2.E2.E1.\cos\theta}$$

$$\sin^2\theta + \cos^2\theta = 1 \text{ 'dir.}$$

$$E = \sqrt{E1^2 + E2^2 + 2.E1.E2.\cos\theta} \text{ olur.}$$

Circuit phase angle is "φ" in phasor diagram. This angle can be found by law of sines in OAC triangle.

$$\sin\phi = \frac{E1.\sin\theta}{E}$$

Example: In the following circuit, **E1**=90Volt and **E2**=60Volt. E1 voltage is in the same phase with circuit current and E2 voltage is 60° ahead.

A-Draw the phasor diagram of the circuit.

B-Find the circuit voltage.

C-Find the phase angle.

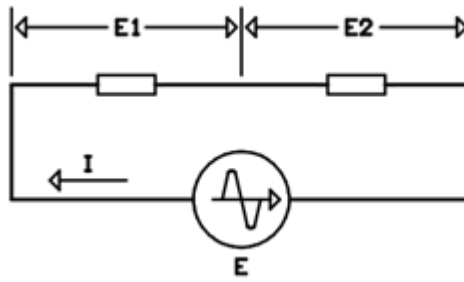


Figure 8.14

Solution:

A-

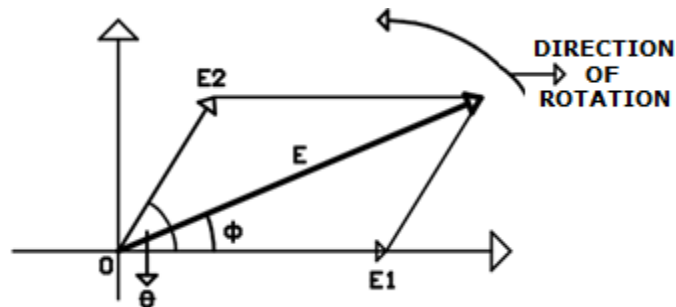


Figure 8.15

B-

$$E = \sqrt{E_1^2 + E_2^2 + 2.E_1.E_2.Cos\theta}$$

$$Cos\theta = Cos60^\circ = 0,5$$

$$E = \sqrt{90^2 + 60^2 + 2.90.60.0,5}$$

$$E = \sqrt{8100 + 3600 + 5400}$$

$$E = \sqrt{17100}$$

$$E = 130,7\text{Volt}$$

C-

$$Sin\phi = \frac{E_1.Cos\theta}{E}$$

$$Sin\phi = \frac{90.0,5}{130,7}$$

$$Sin\phi = 0,344$$

$$\phi = 20^\circ$$

When examining the phase and phase difference, we take the current as reference because the circuit is serial. If it was a parallel circuit, voltage would be the reference. The reason for this is the fact that there is the same voltage on the terminals of every component of the circuit. In phasor diagrams of such circuits, first the voltage is drawn to the horizontal axis and then currents take their position according to the voltage.

POWER IN AC CIRCUITS

10.1 POWER IN ELECTRICITY

Power in direct current (**DC**) is the multiplication of current and voltage. It is symbolized by "**P**" and its unit is "**Watt**". Watt is symbolized by "**W**"

$$P = E.I$$

In Formula;

P= Power (**Watt**)

E= Voltage (**Volt**)

I= Current (**Amper**)

As we know, DC is the electric current of which direction does not change during the work time. Whereas in AC, current direction and magnitude varies constantly. For this reason, power calculation in DC does not always apply to AC. "**Instantaneous power**" is the multiplication of instantaneous current and voltage values in any "**t**" moment of AC. It is symbolized by "**p**" and the unit is again "**Watt**". In monophased circuits, formula of instantaneous power;

$$p = e.i$$

$$e = E \max . \sin wt$$

$$i = I \max . \sin wt$$

$$p = (E \max . \sin wt) . (I \max . \sin wt)'dir.$$

Let's write the instantaneous power formula for polyphased circuits.

$$p = e.i$$

If we assume that current is behind voltage as much as "**Φ**" angle;

$$e = E \max . \sin wt$$

$$i = I \max . (\sin wt - \phi)$$

$$p = (E \max . \sin wt) . [I \max . (\sin wt - \phi)]'olur.$$

Regardless of AC circuit is monophased or polyphased, multiplication of effective values for voltage and current is called "**apparent power**". It is symbolized by "**S**" and its unit is "**Volt-Amper**". Volt-Amper is symbolized by "**VA**"

Apparent power in formula;

$$S = E.I$$

In Formula;

S= Apparent Power (**VA**)

E= Effective value of Voltage (**Volt**)

I = Effective value of Current (**Amper**)

Practically in AC circuits, instantaneous power and apparent power are not used singly. The used power values are obtained by the conversion of these two power values which will be explained accordingly.

10.2 POWER IN MONOPHASED AC CIRCUITS

In monophased AC circuits, power calculation is performed as in the DC circuits. Effective values of current and voltage is taken in mathematical calculations. In AC, this power is called "**Active power**" or "**average power**". Effective power is symbolized by "**P**" or "**P_{av}**". The unit is again the "**Watt**". Effective power in formula:

$$P = E.I$$

In Formula;

P= Active Power (**Watt**)

E= effective value for voltage (**Volt**)

I= effective value for current (**Amper**)

In monophase AC circuits, apparent power and active power are equal. Regardless of AC is monophased or polyphased, instantaneous power varies in the form of sine wave as we can see from its formula. Active power is also called average power because it is the average of the instantaneous values in any unit of time.

Examples of monophased circuits are filament bulbs that we use in enlightening and, heaters made of chrome-nickel mixture. Power vector diagram of monophased AC circuit is shown in figure 9.1

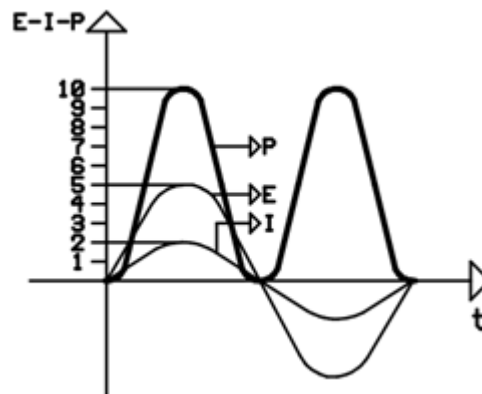


Figure 9.1

In figure 9.1, power slope is naturally in the opposite field when the voltage and current are at the negative alternation because the multiplication of two negative numbers is also positive.

Example: 220V/50Hz AC is applied to the terminals of filament bulb and it is observed that 2.25A of current passes through the circuit. Find the active power that the bulb uses?

$$P = E.I$$

$$P = 220 \cdot 2.25$$

$$P = 495 \text{Watt}$$

10.3 POWER IN MULTIPHASE AC CIRCUITS

We know that the instantaneous power is the multiplication of instantaneous voltage and instantaneous current; active power varies in the form of a sine wave in all AC circuits. In polyphase circuits, phase difference is also effective over the slope of power. Let's explain this effect mathematically. Power is the multiplication of instantaneous voltage and instantaneous current. If one of the multipliers is zero then the multiplication will be zero, too. So, power will be zero in any moment when the current or voltage is zero. At other points, power slope will be the algebraic multiplication of instantaneous voltage and instantaneous current. In other words, if one of the voltage or current is on the negative and the other is on the positive, the power will be on the negative field. If both voltage and current are at the negative or positive, the power will be in positive field. In figure 9.2, power slope of the AC circuit is shown; current is behind from voltage as much as " Φ " angle.

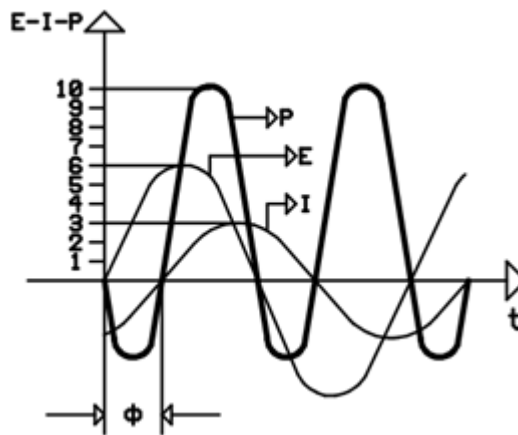


Figure 9.2

As shown in figure 9.2, power makes two alternations in one alternation of voltage and current. **Angular Speed (ω)** in the formula of instantaneous voltage and current will be 2ω in instantaneous power formula.

Effect of phase angle to the power can be explained mathematically with a system like in the following:

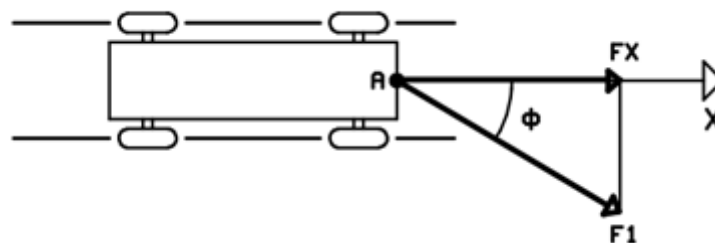


Figure 9.3

In figure 9.3, a trailer on the rails is pulled by an "F1" force applied to the point "A". The trailer can only move linear. "F1" force is not in the same direction with rails. "FX" is the force that affects trailer. To calculate the "FX" using the trigonometric relations;

In A,F1,FX triangle

$$\cos\phi = \frac{FX}{F1}$$

$$FX = F1.\cos\phi'olur.$$

F1 force can be assumed as the multiplication of voltage and current. So, the formula of active power in polyphased AC circuits;

$$P = E.I.\cos\phi' dir.$$

In Formula;

P= Active Power (**Watt**)

E= effective value for voltage (**Volt**)

I= effective value for current (**Amper**)

Φ= phase angle (**Degree**)

Correctness of this formula can be proved by applying to the monophased AC circuits. In monophased circuits the phase angle is 0 (**zero**). Because the cosine of 0 (**zero**) is 1 (**one**), it is not shown in the mathematical operations. As we know, 1 (**one**) is the neutral element in the multiplication.

"**Cos Φ**" multiplier of the phase angle is called "**power coefficient**". In AC circuits, phase angle varies between 0⁰-90⁰. Power coefficient of these values of angles varies between 0-1.

As a general formula in AC, Power is;

$$P = E.I.\cos(2wt - \phi)'olur.$$

In Formula;

P= Active Power (**Watt**)

E= Effective value for voltage (**Volt**)

I= Effective value for current (**Amper**)

Φ= Phase angle (**Degree**)

W= Angular Speed (**2πf**)

t = Time (**Second**)

In the AC circuits in which the phase angle is greater (**Φ angle near 90⁰**), active power will be too small at the points where the current and voltage are too big. In such circuits, sine of the phase angle is used. That force is called "**reactive power**" and symbolized by "**Q**". Its unit is "**volt-ampere-reactive**" or shortly "**VAr**"

Reactive power in formula;

$$Q = E.I.\sin\phi' du.$$

In the formulation;

Q= Reactive Power (**VAr**)

P= Active Power (**Watt**)

E= Effective value for voltage (**Volt**)

I= Effective value for current (**Amper**)

Φ= Phase angle (**Degree**)

Example. A load draws a current from an AC source that has a 220V voltage. The current drawn is 30° ahead phased and has a value of 8Amper.

A-Find the apparent power of load.

B-Find the active power of load

C-Find the reactive power of load

Solution:

A)

$$S = E.I$$

$$S = 220.8$$

$$S = 1760VA$$

B)

$$P = E.I.\cos\phi$$

$$P = 220.8.\cos 30^\circ$$

$$P = 220.8.0,866$$

$$P = 1524Watt$$

C)

$$Q = E.I.\sin\phi$$

$$Q = 220.8.\sin 30^\circ$$

$$Q = 220.8.0,5$$

$$Q = 880VAr$$

RESISTANCES

11.1 INTRODUCTION

Resistances are components that resist on electric current. Despite they are composed of conductor materials they resist on electric current. Even their heights and cross-sections are the same, materials resist differently because of their materials. The materials that are called good conductors also resist on electric current. "**Resistivity**" is the level of resistance of the materials on which the electric current passes. Resistivity is the resistance value of a material which has 1cm height and 1cm^2 cross sectional area. Carbon and copper are examples of two materials with different sensitivities. The resistivity of carbon is 2500 times larger than copper. Resistances are mostly produced by using carbon and crom-nickel alloys. While in the low current circuits carbon resistances are used, in the high current circuits crom-nickel alloy resistances are used. Resistances made of crom-nickel alloy are also called as "**wire resistances**". Resistances both resist AC and DC electric current in the same intensity.

Resistances are shown as the letter "**R**" in electrics and electronics. The unit of resistance is "**Ohm**". Ohm is shown whether using " **Ω** " (**Omega**) or the letter "**R**". One ohm is the resistance when the voltage is 1 volt and the current is 1 ampere. Ohm is relatively small for electronic circuit applications because of this usually higher multipliers of ohm are used.

Lower multipliers of ohm are not used commonly. In figure 10.1 the higher and lower multipliers of ohm are shown.

HIGHER MULTIPLIERS	(M) MEGA OHM	1M=1000 000 R
	(K) KILO OHM	1K=1000 R
UNIT	(R) OHM	
LOWER MULTIPLIERS	(m) MILI OHM	1000 m = 1R
	(μ) MICRO OHM	1000 000 μ = 1R

Figure 10.1

Resistances are used to limit the current in circuits; they keep the current in the desired value. There are there types of resistances which are constant resistances, one time adjustable "**trim pots**" and adjustable "**potentiometers**". Constant resistances have two pins. Trim pots and potentiometers have three pins. Two vertexes have constant resistance and midpoint has variable resistance. Figure 10.2 shows the symbols of the resistances.

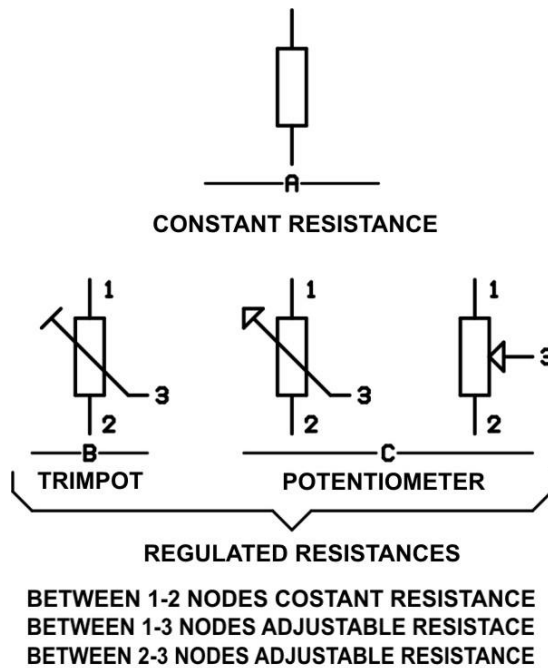


Figure 10.2

The resistances of trim pots and potentiometers are adjusted with 270° circular rotation of a shaft. There exist trim pots and potentiometers with multiple rotations in order to use for sensitive circuits. These trim pots and potentiometers can be adjusted with 10 rotations.

The electronic equipments of nowadays technology are very small in surface. The resistances for these equipments can be surface-mounted which is plastered in electronic boards. There also exist multiple resistances in a cover or integrated resistances.

11.2 RESISTANCE CONNECTIONS

In some cases, some needed resistance or power values may not be found while designing circuits. In these cases the needed resistance value may be obtained using a combination of resistances. This can be achieved in three ways.

- 1-** Serial connection
- 2-** Parallel connection
- 3-** combined connection

These connection types will be examined sequentially. No matter what type of connection exists, the power that supply gives is equal to the power dissipated in resistances.

1. **Serial Connection:** If there is not a single resistance with high enough value, one may obtain desired high values with the serial connection of resistances. In serial connection resistances could be connected infinitely. The figure 10.4 shows the serial connection of three resistances.

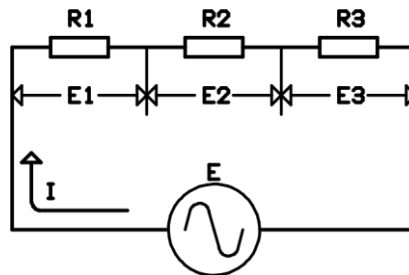


Figure 10.4

In serial connection, same current passes through the all resistances. Voltage of the resistances will be determined according to the kirschhof voltage law i.e. the sum of voltages in resistances is equal to the voltage of the circuit.

$$E = E1 + E2 + E3$$

The voltage of the resistances is found by ohm's law.

$$E1 = I.R1 \quad , \quad E2 = I.R2 \quad , \quad E3 = I.R3$$

Let the total resistance of the circuit be "**RT**" and the voltage of the circuit is written using ohm's law.

$$E = I.RT$$

If we combine the two equations, we get:

$$E = E1 + E2 + E3$$

$$I.RT = I.R1 + I.R2 + I.R3$$

If we divide equation by "**I**", we get the equation of total resistance of serially connected resistances.

$$RT = R1 + R2 + R3$$

Example: In a circuit, there are two resistances serially connected with values $R1=30R$, $R2=90R$ and the voltage of the circuit is $240V$ AC.

- A-** Find the total resistance of the circuit?
- B-** Find the current of the circuit?
- C-** Find the voltage of each resistance?

SOLUTION:

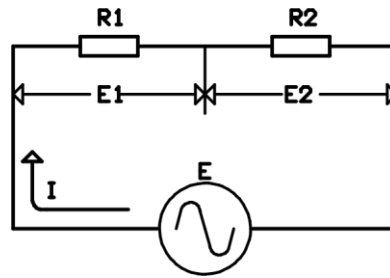


Figure 10.5

A-

$$RT = R1 + R2$$

$$RT = 30 + 90$$

$$RT = 120R$$

B-

$$I = \frac{E}{RT} = \frac{240}{120} = 2A$$

C-

$$E1 = I.R1$$

$$E1 = 2.30$$

$$E1 = 60V$$

$$E2 = I.R2$$

$$E2 = 2.90$$

$$E2 = 180V$$

The validation test:

$$E = E1 + E2$$

$$240 = 60 + 180$$

$$240 = 240$$

2. Parallel connection: If a single resistance does not have enough power, the problem is solved by parallel connection of the resistances. In parallel connection, one pin of the each resistance is connected to one node and the other pin of each resistance is connected to another node. Figure 10.6 shows the parallel connection of three resistances.

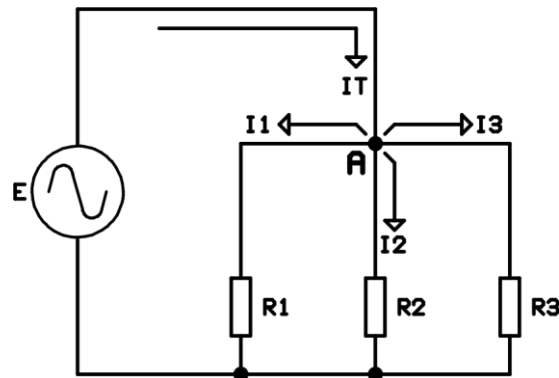


Figure 10.6

In parallel connection all the resistances have supply voltage in their pins. Circuit voltage can be found by Kirschof current law. According to Kirschof current law, the sum of incoming currents to a node is equal to the sum of outgoing currents. Thus, the current equality at node "A" is;

$$I = I_1 + I_2 + I_3$$

The current of each resistance by Ohm's law is:

$$I_1 = \frac{E}{R_1} \quad , \quad I_2 = \frac{E}{R_2} \quad , \quad I_3 = \frac{E}{R_3}$$

Let the total resistance of the circuit be "**RT**" and by Ohm's law the equality of circuit current is:

$$I = \frac{E}{R_T}$$

Combining the two equalities:

$$I = I_1 + I_2 + I_3.$$

$$\frac{E}{R_T} = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3}$$

If we divide equation by "E", we get the equation of total resistance of parallel connected resistances.

$$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

If two resistances are parallel connected:

$$RT = \frac{R1.R2}{R1 + R2}$$

Example: In a circuit, there are two resistances parallel connected with values $R1=30R$, $R2=90R$ and the voltage of the circuit is $240V$ AC.

- A-** Find the total resistance of the circuit?
- B-** Find the current of the circuit?
- C-** Find the current of each resistance?

SOLUTION:

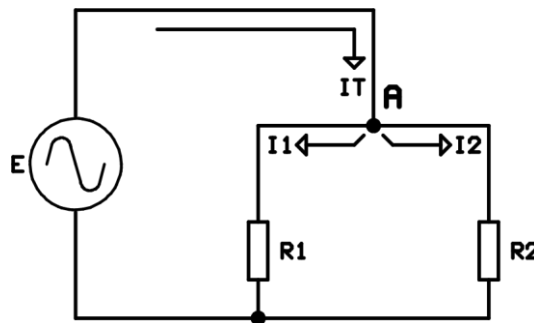


Figure 10.7

A-

$$\frac{1}{RT} = \frac{1}{R1} + \frac{1}{R2} = \frac{1}{30} + \frac{1}{60} = \frac{2}{60} + \frac{1}{60} = \frac{3}{60}$$

(2) (1)

$$RT = \frac{60}{3} = 20R$$

Or

$$RT = \frac{R1.R2}{R1 + R2} = \frac{30.60}{30 + 60} = \frac{1800}{90} = 20R$$

B-

$$I1 = \frac{E}{RT} = \frac{240}{20} = 12A$$

C-

$$I_1 = \frac{E}{R_1} = \frac{240}{30} = 8A$$

$$I_1 = \frac{E}{R_2} = \frac{240}{60} = 4A$$

The validation test:

$$I = I_1 + I_2$$

$$12 = 8 + 4$$

$$12 = 12$$

3. Combined connection: In a circuit, there may be parallel and serial connections. This is called as combined connection. Figure 10.8 shows a combined connection.

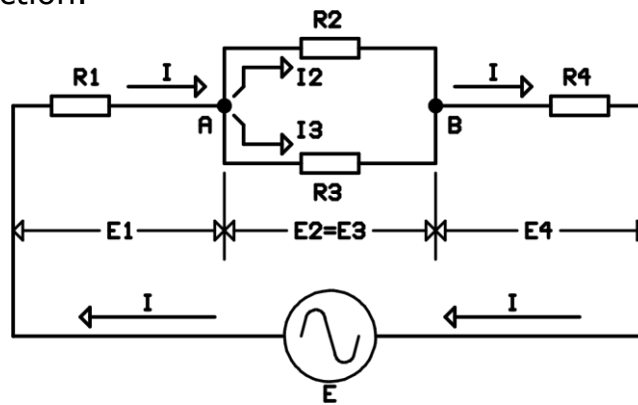


Figure 10.8

In figure "R2" and "R3" are connected parallel and "R1" and "R4" are connected serially to these resistances. While working these kinds of circuits, Kirchhoff's law and Ohm's law are used. First of all circuit is solved like serially connected circuit and voltages are found using Kirchhoff's voltage law.

$$E = E_1 + E_2 + E_4 \quad \text{Or} \quad E = E_1 + E_3 + E_4$$

And the circuit's current is;

$$I = I_1 = I_2 + I_3 = I_4$$

After that by the help of Ohm's law, voltages and currents can be found.

Example: Find the voltages and current of all the resistances in figure 10.9?

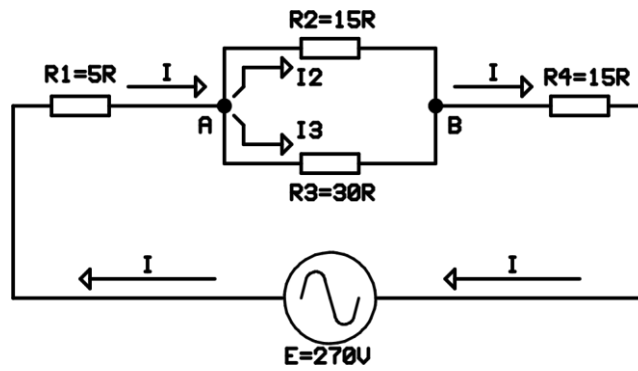


Figure 10.9

First of all let's find the total resistance of parallel connected "R2" and "R3" resistances and call it "RA".

$$R_A = \frac{R_2 \cdot R_3}{R_2 + R_3} = \frac{15 \cdot 30}{15 + 30} = \frac{450}{45} = 10R$$

Then the circuit becomes.

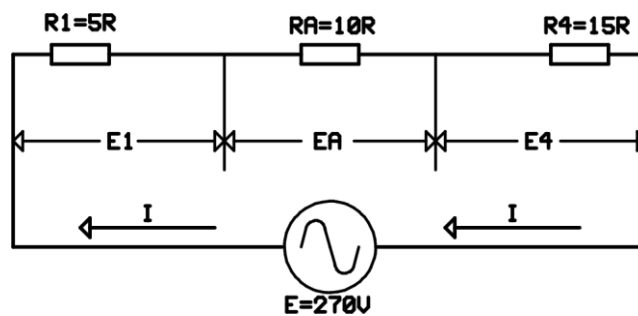


Figure 10.10

The total resistance of the circuit is;

$$R_T = R_1 + R_A + R_4$$

$$R_T = 5 + 10 + 15$$

$$R_T = 30R$$

And the circuit current is;

$$I = \frac{E}{R_T} = \frac{270}{30} = 9A$$

The voltages of the resistances by the Ohm's law are;

$$E_1 = I \cdot R_1 = 9 \cdot 5 = 45V$$

$$E_A = E_2 = E_3 = I \cdot R_A = 9 \cdot 10 = 90V$$

$$E_4 = I \cdot R_4 = 9 \cdot 15 = 135V$$

The validation test;

$$E = E1 + EA + E4$$
$$270 = 45 + 90 + 135$$
$$270 = 270$$

The circuit current passes through "R1" and "R4".

$$I1 = I4 = 9A$$

The voltage of "R2" and "R3" are "EA=90V". The current of these resistances are;

$$I2 = \frac{EA}{R2} = \frac{90}{15} = 6A$$
$$I3 = \frac{EA}{R3} = \frac{90}{30} = 3A .$$

11.3 RELATIONSHIP BETWEEN RESISTANCE AND HEAT

All the materials, which electric current passes through, use some electric energy as heat energy. This heat energy is useless and reduces the output of system. With the increasing working time, the dissipated energy increases.

If the temperature of the system increases, the dissipated energy also increases. Thus the system output can be increased by reducing the temperature of the system. Computers, power supplies, sound amplifiers have fans inside in order to reduce the temperature i.e. these fans increase the system output.

In general, the resistances of metals increase with the increasing temperature. This change is formulated as;

$$R_t = R_o (1+at)$$

R_t = resistance in t⁰C (**Ohm**)

R_o = resistance in 0⁰C (**Ohm**)

a = resistance temperature constant

t = temperature (**centigrade**)

The "a" constant in the equation is the increase of resistance value from 0⁰C to 1⁰C for a conductor of 1cm in length and 1cm² in cross sectional area. This constant can be found in user's manual of the conductor. There exist materials with negative resistance temperature constant. Carbon is an example of this kind of materials i.e. the resistance of carbon is inversely proportional with the temperature.

By the combination of materials with positive and negative valued resistance temperature constant, materials with little resistance-temperature change can be formed.

11.4 RESISTANCE OF CONDUCTORS

In an electric circuit all the power wanted to be consumed on the load. The conductors on the circuit consume power even it is small. The power that is lost on the conductor resistance is seen as heat and voltage drop on the load. Especially in high current circuits the power loss of the conductor can not be ignored. In the transmission of the electric energy conductor resistance is not desirable. Today there are researches to produce zero resistance super conductors.

There are three main factors that affect the conductor resistance. The power loss can be minimized if the conductors are chosen according to these factors.

1- Conductor's length: conductor's length is the path that electrons travel through. Conductor's resistance is directly proportional to the length of it. Electric current is the flow of electrons. The magnitude of electric current is directly proportional to the number of free electrons and the velocity of the electrons. When electrons travel through the conductors, they collide with each other and the molecules inside the conductor i.e. the conductor's length is directly proportional to the number of collisions. Thus conductor gets hot and the electric current passes through it increases.

2- Conductor's cross sectional area: The area that is perpendicular to the electron flow is called as cross sectional area of the conductor i.e. it is the path's width. If the width of the conductor increases, the collisions decrease. Thus, the conductors with larger width get less hot when the electric current passes through and they have the ability to conduct more current. Cross sectional area of the conductor is inversely proportional to the resistance of the conductor i.e. if the cross sectional area of the conductor is larger, it has less resistance.

3-Type of the conductor: Different materials resist in a different way to the electron flow. As we all know, conductors have different resistances even they have same length and cross sectional area. This is known as '**resistivity**'. Resistivity is the resistance of a conductor which has 1 meter length and 1mm cross sectional area at 20⁰C. Resistivity is shown with the letter "**ρ**" (**Ro**) and its unit is (**ohm.m**). The inverse of the resistivity is '**conductivity**'.

Conductivity is shown with the letter '**G**' and its unit is '**Mho.m⁻¹**' the conductivity equation is:

$$G = \frac{1}{\rho} \text{dur.}$$

Conductors are usually made with metals. Conductors dissipate some of the electrical energy as heat energy while current passes through them. While current passes through the conductors, they get hotter.

This causes the electron flow to slow down and the electric current to reduce i.e. the resistance of the conductor increases while current passes through them. It is important in sensitive circuits.

While doing calculations, room temperature is usually taken as 18°C - 20°C. The resistance equation is:

$$R = \rho \cdot \frac{L}{A}$$

In this equation:

R: resistance (ohm)

ρ : Resistivity (ohm)

L: length of the conductor (cm)

A: cross sectional area of the conductor (cm²).

The conductors' resistivity is found at the specification sheet of it.

We deal with the resistances in direct current (DC) circuits. The resistances of the conductors in dc circuits are not so important and can be negligible. Resistances in alternating current (AC) circuits are important.

Conductors resist ac current in a different way than they resist dc current. In ac current the total resistance is called '**effective resistance**' or '**AC resistance**'. Effective resistance is determined by four factors.

1- Skin effect: While direct current passes through, electron density is same all over the cross sectional area of the conductor. In AC current electron density is lower at the center of the conductor. Because of this, the center usage of the conductor is low and this causes the usage of the cross sectional area be lower and when the cross sectional area is lower, the resistance gets higher.

2- Eddy current loss: While passage of AC current, the magnetic difference in the conductor inducts current in near conductors. This current is called 'Foucault current'. This reduces the electric energy of the conductor. This loss energy is modeled by another resistance i.e. the resistance of the conductor increases.

3- Dielectric loss: The instantaneous change in AC current effects the insulator part of the conductor and heat energy occurs in the insulator part. The heat energy causes the loss of electric energy. This loss energy is modeled by another resistance i.e. the resistance of the conductor increases. The resistance caused by dielectric is small.

4- Hysteresis loss: The change of the direction of the AC current causes a change in the direction of the magnetic field. This causes the magnetic materials nearby behave like magnet. The poles of this magnet change in every alternation. This fast pole change is the direction change of millions of electrons and molecules.

This crowded motion causes the collision and friction of electrons and molecules with each other. Thus conductors get hotter. The heat energy is the loss of effective energy. This loss energy is modeled by another resistance i.e. the resistance of the conductor increases. Hysteresis loss can be reduced by using some special materials like silica.

Figure 10.11 shows the effective resistance.

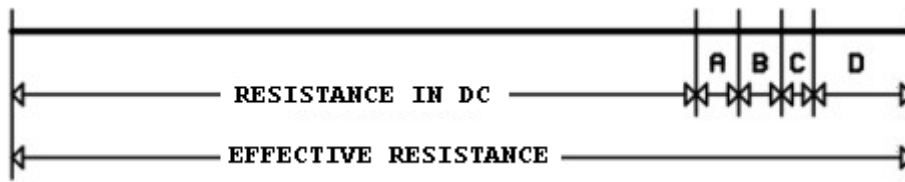


Figure 10.11

In figure

- A-** The resistance of the skin effect
- B-** The resistance eddy currents
- C-** The resistance of dielectric loss
- D-** The resistance of the hysteresis loss.

EXAMINATION OF RESISTANCES IN ALTERNATING CURRENT

12.1 INTRODUCTION

In AC current resistances that we deal with are components which works with electric energy and resist both AD and DC current in the same way i.e. components that uses electric enegy in single phase. incandescent lamps, electric heaters are the examples of this kind.

Incandescent lamps are made of tungsten replaced in an airless tube. When electric current passes through tungsten, it gets hotter and passes to the incandescent phase then it starts to emit light. Incandescent lamps dissipate electric energy as heat energy and light energy. Since the heat energy is greater than light energy, the efficiency of them is smaller.

Electric heaters are made of chromium nickel. If electric current passes through chromium nickel, they get hotter and start to heat up nearby.

As you can remember, the electric circuits with mono phase are also called as ohmic circuits. Figure 11.1 shows the vector and phase diagrams of the mono phase circuits.

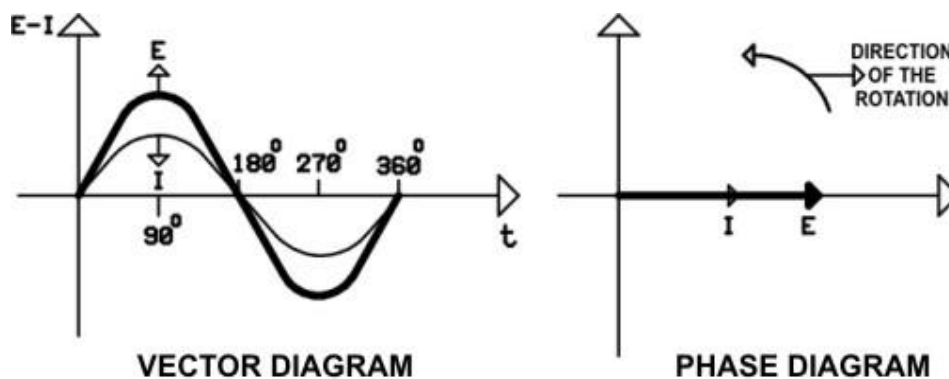


Figure 11.1

In mono phase AC circuits, mathematical calculations are made as if they are DC circuits by using Ohm's law and Kirchoff's law.

12.2 DİRENÇLİ AC DEVRELERİNDE GÜÇ

While electric current passes through electrical components, they dissipate power. In DC and mono phase AC circuits, the dissipated power is found by the equation below.

$$P=I.E$$

In this equation;

P: power (**Watt**)

E: voltage (**Volt**)

I: current (**Ampere**).

In mathematical applications, power is usually found by using current and resistance. Combining Ohm's law and power equation;

$$P=I.E$$

$$P=I.I.R$$

$$P=I^2.R$$

Electrical components are usually identified by their electric power. Power is the energy dissipated by the component in one hour. The actual unit of the power is '**watt. hour**' but shortly, it is called as '**watt**'. Watt is a small value for electrical devices.

Because of this, "**Kilowatt**" and "**Megawatt**" are usually used in order to talk about higher power values. The mathematical equation is below.

$$1 \text{ Megawatt} = 1.000 \text{ Kilowatt} = 1.000.000 \text{ Watt}$$

In mono phase AC circuits instantaneous power is the multiply of instantaneous voltage and instantaneous current. Figure 11.2 shows the vector diagram of this kind circuit. Vertical axis is shown with '**A**'. Amplitude is simply shown as '**A**' in electric circuits.

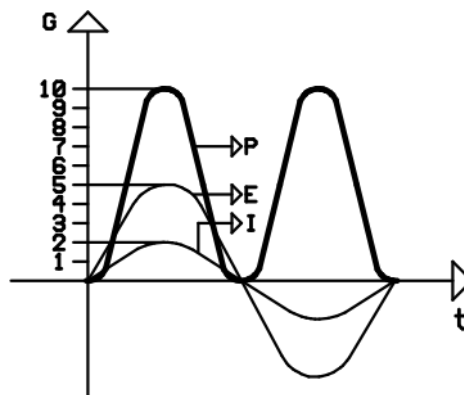


Figure 11.2

As seen in figure 11.2 power is always positive. A device has a capacity before overheating. While using resistances after checking the resistance values, power values also must be checked. In electric circuits, there are lots of resistances and they are so close to each other. Also usually there is no air flow in these devices. Because of this usually resistances with higher power values are used. Mathematical calculations are not so reliable. In computers, power supplies have air fans in order to cool them.

12.3 MEASUREMENT OF PHASE DIFFERENCE IN AC CIRCUITS

In electrics and electronics, signals are measured by using oscilloscopes. They are palely connected to the circuit like voltmeters. Because of this measuring voltage is easy. Since oscilloscopes cannot be connected serially, it is difficult to measure current. In order to measure the current, a small valued resistance is connected to the circuit. By using the voltage value of this resistance, current value can be calculated. Figure 11.3 shows the voltage and current measurement in AC circuits by using oscilloscope.

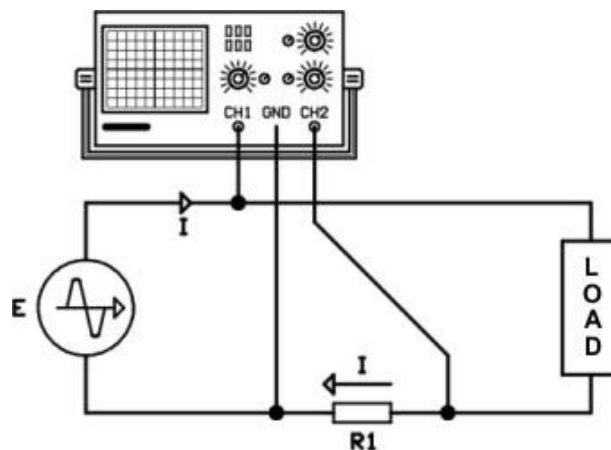


Figure 11.3

In figure 11.3, the '**CH1**' channel of the oscilloscope is parallel connected to the power supply and it measures the voltage. If the resistance '**R**' is ignored, this voltage is the voltage of the load. The '**CH2**' channel of the oscilloscope is parallel connected to the resistance '**R**'. By using the voltage of the small resistance, current can be calculated.

COILS

13.1 INTRODUCTION

Coils are the elements which resist AC and DC current in different ways. They are usually used in AC circuits in order to manage AC and differ AC from DC. Also, when electric current passes through coils, they form magnetic field. Because of this, they are widely used in electrical machines (**motors, transformers, etc.**). Coils are also widely used in electrical devices based on electromagnets like relays, bells, contactors and cranes, etc.

When DC current passes through coils, coil highly resist to the current only at the very beginning. After that current reaches its normal value and there will be no change on the current during the operation time. The only resistance is wire's resistance.

When AC current passes through the same coil, it induces negative electromotive force (**EMF**) on the coil during the operation time. Figure 12.1 shows the negative EMF from the beginning of alternans to the point where it reaches its maximum.

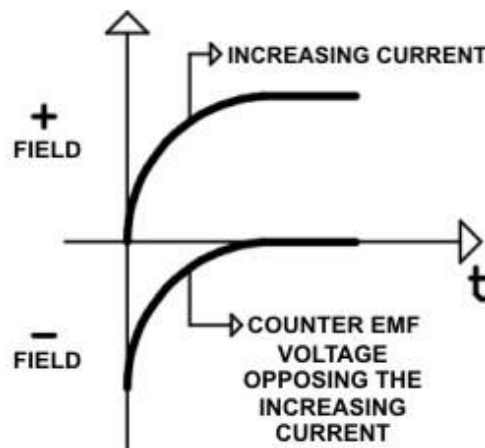


Figure 12.1

Negative EMF resist AC current. Because of this, coils' resistance is greater while working in AC than working in DC.

After the maximum point of alternans (while coil current decreases to zero), the negative EMF in the coil tries to maintain the current.

Figure 12.2 shows the effect of negative EMF.

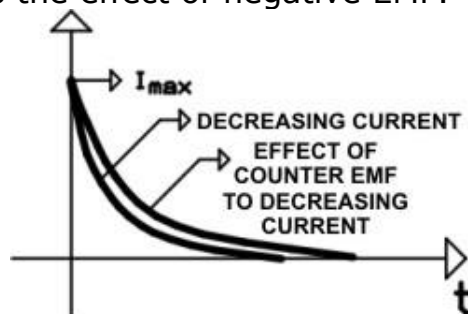


Figure 12.2

It is clear that, coils are elements which can store electric energy in electromagnetic field.

The ability of coil to store electric energy and to resist the current is related with its coil value. Coils are shown with letter 'L' and their unit is 'Henry'. Henry is shortly shown with letter 'H'.

"Henry is the coil value when one volt voltage is induced in a coil in a change of one ampere of current in one second."

Coil values are also called as "inductance". The inductance is large in high frequency circuits.

Because of this the lower multipliers are mostly used in electronics. In figure 12.3, the lower multipliers and their mathematical conversion can be seen.

UPPER MULTIPLES	LACKING	
MAIN UNIT	(L) HENRY	
LOWER MULTIPLES	(m H) MILI HENRY	1 000mH = 1H
	(μ H) MICRO HENRY	1 000μH = 1mH

Figure 12.3

Generally, coils with high inductance are used in electrics and coils with low inductance are used in electronics. In lower frequencies (up to 20 KHz) and in DC, the inductances of coils are larger. Higher inductance coils have larger turns and their kernel have larger conductivity. Kernels increase coils inductance directly proportional with their conductivities. There exist carcass and air between coil and its kernel. Conductivity in this subject is ratio of magnitude of the force vector between poles of a magnet when there is that material and air. It is also called as permeability. It is shown with the letter "μ" (mü). "μ" (mü) is generally small. Metals have low resistivity.

Materials with high permeability are done by experiments.

For example; Ferro- ferrite (**Fe₃ O₄**), cupper-Ferro- ferrite (**Cu Fe₂O₄**), lead-Ferro-Ferrite (**Pb Fe₂O₄**) and iron combinations have resistivities nearly 10⁸R and magnetic permeabilities are between 100-200. These cores are called "ferrous" cores. Ferrite is a nonmetal with high conductivity. Ferrite cores have conductivities between 10 and 200.

The cores in coils must have low eddy current loss. For example, if iron is used as a core in a coil, eddy current occur in iron and this causes eddy current loss. Eddy current loss heats the core and this causes loss of electric energy. Eddy current losses can be reduced by using a combination of silisium and iron. The conductivity of core can be made zero by using insulators like dope and this reduces the eddy current loss. In lower frequency circuits, this structure is used and mechanical robustness and lower costs are achieved in ac machines (**motors, transformers etc.**)

In high frequency circuits (**larger than 20 KHz**), silisium iron combination is not used since they have higher loss, ferrite core coils are used instead.

In too high frequency or a certain frequency band circuits, adjustable core coils are used. In these kinds of coils, core is moved in coil and inductance is adjusted. In lower inductance coils, cores which have lower conductance than air are used. Brass is an example of this kind of material. It reduces the coil inductance.

Coils with different cores have different symbols. These symbols are shown in figure 12.4.



Figure 12.4

Coils with higher inductance can be achieved by using a structure that will capture magnetic forces inside and outside the coil.

Figure 12.5 shows two different coil structures.

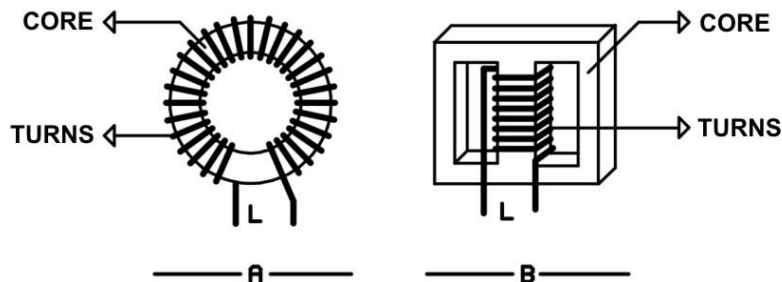


Figure 12.5

The coil in figure 12.5A is called as "**trio coil**" trio coils are used in SMPS (**Switch Mode Power Supply**) circuits. The coil in figure 12.5A is called as "**transformer type**" coil. These coils are used in transformer and filter circuits.

13.2 MEASUREMENT AND INDICATION OF COIL VALUES

Coil values are indicated in two different methods. Both methods use the unit micro Henry (**μH**). In first method, numbers formed by three digits are used. The first and the second digits form the number, the third digit is the multiplier. For example, if the number 124 is in a coil. The inductance of this coil is:

$$L = 120000\mu H = 120mH.$$

The second method is same as the four band resistance color code. For example the colors in a coil are yellow, violet, red and gold then this coil has an inductance of:

$$L=4700\mu\text{H} \text{ the tolerance is } \%5.$$

Some coils have high inductances like 100H. This inductance are shown directly writing the value and unit.

The inductance is measured by inductance meter. Inductance meters give a 1 KHz small current to the coil and measure the inductance with the help of this current. Coil inductances must be measured off the circuit. The ohmic resistance of the coil is measured by ohmmeter.

Besides their inductances, the current and the frequency is also important for coils. In electric circuits, usually current is high and frequency is low. The wire of the coil must be thick enough for the high current. In electronic circuits, usually current is low and frequency is high. In these circuits, cores must be chosen convenient for the frequency.

13.3 COIL CONNECTIONS

Coils are sometimes used in serially or parallel connected in electric and electronic circuits. Since coils inductances are AC current resistances, they are mathematically calculated like resistances.

1. Serial connection: By serial connection, the inductance values are increased. Figure 12.6 shows the serial connection of three coils.

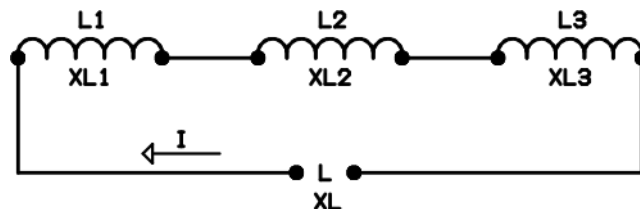


Figure 12.6

In serial connection, total inductance is the sum of all coil inductances.

$$L=L1+L2+L3$$

In serial connection total inductive reactance is the sum of all inductive reactance.

$$XL=XL1+XL2+XL3$$

Circuit current is found by Ohm's law.

$$I = \frac{E}{XL}$$

In serially connected coil circuit, the maximum circuit current is the current passing through the coil with minimum current.

Circuit voltage is divided directly proportional to the inductive reactance of the coils.

$$E_1 = I \cdot X_{L1}, \quad E_2 = I \cdot X_{L2}, \quad E_3 = I \cdot X_{L3}$$

$$E = E_1 + E_2 + E_3$$

Example: Two coils one with inductance of 2H and max current of 2A and the other with inductance 3H and current 0,5A are serially connected to a AC voltage source with 220V and 50Hz.

A- Find the total inductance?

B- Find the total inductive reactance?

C- Find the circuit current?

D- Find the coil voltages?

E- Find the maximum current passing through the circuit?

Solution:

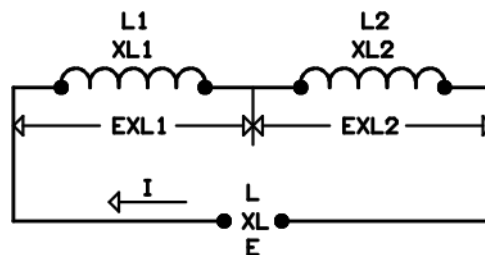


Figure 12.7

A)

$$L = L_1 + L_2$$

$$L = 2 + 3$$

$$L = 5 \text{ H}$$

B)

$$X_{L1} = 2\pi f L_1$$

$$X_{L1} = 6,28 \cdot 50 \cdot 2$$

$$X_{L1} = 628 \text{ R}$$

$$X_{L2} = 2\pi f L_2$$

$$X_{L2} = 6,28 \cdot 50 \cdot 3$$

$$X_{L2} = 942 \text{ R}$$

$$X_L = X_{L1} + X_{L2}$$

$$X_L = 628 + 942$$

$$X_L = 1570 \text{ R}$$

C)

$$I = \frac{E}{X_L} = \frac{220}{1570} = 0,14 \text{ A}$$

D)

$$E_{L1} = I \cdot X_{L1}$$

$$E_{L1} = 0,14 \cdot 628$$

$$E_{L1} = 87,9V$$

$$E_{L2} = I \cdot X_{L2}$$

$$E_{L2} = 0,14 \cdot 942$$

$$E_{L2} = 131,9V$$

$$E = E_{L1} + E_{L2}$$

$$E = 87,9 + 131,9$$

$$E = 219,82$$

Circuit voltage is 220V. Mathematical difference is because of calculation error.

E) Since the maximum current is equal to the current of the coil with the minimum current;

$$I = 0,5A \text{ dir.}$$

2. Paralel connection: Parallel connection is used in order to increase the current capacity of the circuit. Figure 12.8 shows the parallel connection of three coils.

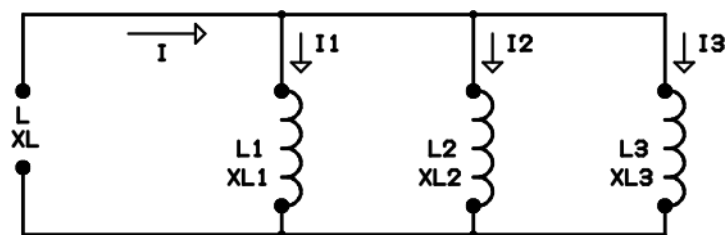


Figure 12.8

In parallel connection, total inductance is found by the equation below. Total inductance is smaller than the inductance of the coil with the smallest inductance.

$$\frac{1}{L} = \frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3}$$

In parallel connected circuits, total inductance is found by the equation below.

$$\frac{1}{X_L} = \frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}}$$

Circuit current is calculated by Ohm's law.

$$I = \frac{E}{XL}$$

The current of the each coil is calculated by;

$$I_1 = \frac{E}{XL_1} , \quad I_2 = \frac{E}{XL_2} , \quad I_3 = \frac{E}{XL_3} \text{ 'tir.}$$

The circuit current is the sum of all currents.

$$I = I_1 + I_2 + I_3$$

Example: Two coils one with inductance of 3H and max current of 2A and the other with inductance 6H and current 5A are parallel connected to an AC voltage source with 220V and 50Hz.

- A-** Find the total inductance?
- B-** Find the total inductive reactance?
- C-** Find the circuit current?
- D-** Find the coil currents?
- E-** Find the maximum current passing through the circuit?

Solution:

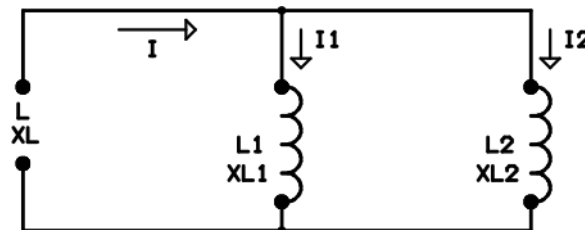


Figure 12.9

A)

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$

$$\frac{1}{L} = \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{L} = \frac{3}{6}$$

$$L = \frac{6}{3}$$

$$\mathbf{L = 2 H}$$

B)

$$XL1 = 2\pi fL$$

$$XL1 = 6,28 \cdot 50 \cdot 3$$

$$XL1 = 942R$$

$$XL2 = 2\pi fL$$

$$XL2 = 6,28 \cdot 50 \cdot 6$$

$$XL2 = 1884$$

$$\frac{1}{XL} = \frac{1}{XL1} + \frac{1}{XL2}$$

$$\frac{1}{XL} = \frac{1}{942} + \frac{1}{1884}$$

$$\frac{1}{XL} = \frac{3}{1884}$$

$$XL = \frac{1884}{3}$$

$$XL = 628R$$

C)

$$I = \frac{E}{XL} = \frac{220}{628} = 0,35A$$

D)

$$I1 = \frac{E}{XL1} = \frac{220}{942} = 0,23A$$

$$I2 = \frac{E}{XL2} = \frac{220}{1884} = 0,12A$$

The validation of equations is;

$$I = I1 + I2$$

$$0,35 = 0,23 + 0,12$$

$$0,35 = 0,35$$

E)

$$I = 2 + 5 = 7A$$

EXAMINATION OF COILS IN ALTERNATING CURRENT

14.1 INTRODUCTION

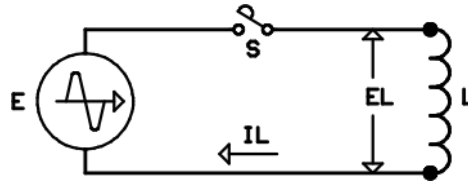


Figure 13.1

In figure 13.1 when the S switch is closed, voltage is applied to the coil. Coil inductance gradually increases and reaches to its normal value. If we examine the vector diagram of this kind circuit we notice that current lags the voltage 90° .

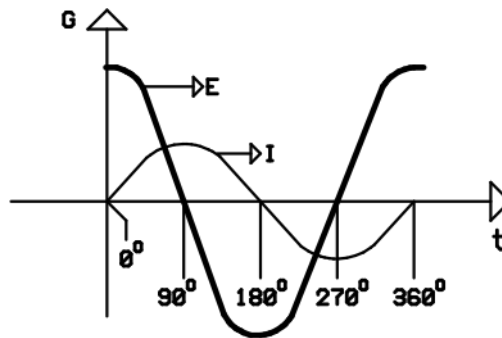


Figure 13.2

0° is the time when the switch is closed. At this moment voltage is maximum level and current is zero.

Between 0° - 90° while instantaneous voltage decreases, instantaneous current increases in positive direction. At 90° voltage is zero and current is maximum.

Between 90° - 180° while instantaneous voltage increases in negative direction, instantaneous current decreases to zero. At 180° voltage is maximum level at negative and current is zero.

Between 180° - 270° while instantaneous voltage increases to zero, instantaneous current increases to maximum value in negative direction. At 270° voltage is zero and current is maximum in negative direction.

Between 270° - 360° while instantaneous voltage increases in positive direction, instantaneous current decreases to zero.

Figure 13.3 shows the phase diagram of this kind circuit.

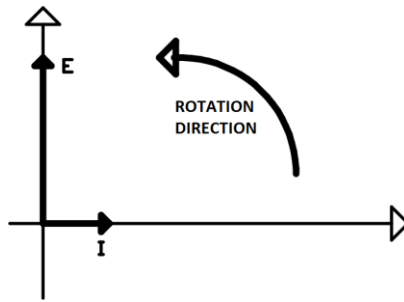


Figure 13.3

If voltage leads current, the circuit is called as “**inductive circuit**” .The examples are electric motors, transformer and electromagnets.

For an AC circuit includes only a coil voltage leads current 90° or $\pi/2$ radians. In these circuits, the instantaneous voltage and current equations are given below. If the current is reference;

$$i = I_{max} \cdot \sin \omega t$$

$$e = E_{max} \cdot \sin(\omega t + \pi/2)$$

If the voltage is reference;

$$e = E_{max} \cdot \sin \omega t$$

$$i = I_{max} \cdot \sin(\omega t - \pi/2) .$$

In the previous discussion, the ohmic resistance of the coil is ignored but this is not the case. The ohmic resistance of the coils are called as internal resistance. Internal resistance is modeled as a serially connected resistance. Internal resistance decreases the coil current. This loss is called as copper loss. Besides the copper loss there exist eddy current loss, dielectric loss and hysteresis loss. These are modeled as a parallel connected resistance.

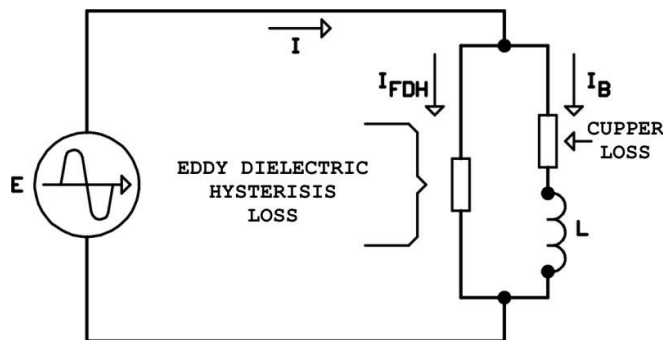


Figure 13.4

Figure 13.4 shows the losses in a coil. Eddy, dielectric and hysteresis losses cause some current loss in the circuit. The current loss is generally small. Copper loss decreases the current passing through coil. Copper loss is big enough and it cannot be ignored. If we examine the circuit in the view of the source, eddy, dielectric and hysteresis losses increases the current and copper loss decreases the current. Copper loss is the most significant loss. Because of this, the measured current is smaller than the calculated current.

14.2 INDUCTIVE REACTANCE

The resistance of an AC circuit is called as impedance. If this is composed of only ohmic resistances the impedance of the circuit is equal to the DC resistance. If a coil is connected to an AC source there is another resistance, the negative EMF, other than the ohmic resistance. The resistance of the coil in AC is called as "**inductive reactance**". The unit of inductive reactance is also ohm. Inductive reactance is directly proportional with the coil inductance and the frequency of the circuit. The equation of inductive reactance is:

$$X_L = 2\pi fL$$

In this equation;

X_L = inductive reactance (**Ohm**)

F = frequency (**Hertz**)

L = coil inductance (**Henri**)

2π = constant (**6,28**).

Example: A coil with 1500mH inductance is connected to an AC source with 220V 50Hz. Find inductive reactance and circuit current?

Solution:

$$X_L = 2\pi fL$$

$$X_L = 6,28 \cdot 50 \cdot 1,5 = 471R.$$

$$I = \frac{E}{X_L} = \frac{220}{471} = 0,46A$$

Coil impedance is the vector sum of inductive reactance and ohmic resistance of the coil. In AC circuits, ohmic resistance and inductive reactance are shown as serially connected. In low frequency circuits ohmic resistance cannot be ignored.

14.3 QUALITY FACTOR

The ohmic resistances of the coils decrease the efficiency especially in low frequency AC circuits. The quality factor is a degree of efficiency in coils. It is shown with the letter "**Q**". Its equation is:

$$Q = \frac{X_L}{R}$$

In this equation;

Q = Quality factor

X_L = inductive reactance (**Ohm**)

R = ohmic resistance (**Ohm**).

The ohmic resistance of a coil is a DC resistance. It is fixed for a coil. Inductive reactance increases with the increasing frequency. If the quality factor is high, the inductance value is higher than ohmic resistance. Quality factor is directly proportional with the frequency.

Example: Find the coil's quality factor with 100R Ohmic resistance and 2H inductance in a 500 Hz frequency circuit?

Solution:

$$XL = 2\pi fL$$

$$XL = 2.3, 14.500.2$$

$$XL = 6280R$$

$$Q = \frac{XL}{R}$$

$$Q = \frac{6280}{100} = 62,8' dir.$$

In high frequency circuits, the inductance of the coils are usually small. Because of this they have less turns. The ohmic resistance is ignored in this kind of coils. In AC circuits if the ohmic resistance is ignored, the Ohm's law is applied using inductive reactance instead of resistances.

$$I = \frac{E}{XL} , \quad E = I.XL , \quad XL = \frac{E}{I}$$

14.4 POWER IN AC CIRCUITS WITH COILS

For a coil circuit current lags the voltage 90° . Then the power factor (**Cos Φ**) is zero since the cosine of 90° is zero. Then the active power of the circuit is zero.

$$P = E.I.Cos \Phi$$

$$\Phi = 90^{\circ}$$

$$Cos90^{\circ} = 0$$

$$P = 0$$

The current meters measure the real power. Theoretically, loads consist of only coils consume no power. It is bad for electric suppliers. Because of this power factor is made "1" by using additional components. The power of these kind circuits is calculated as reactive power (**Q**).

$$Q = E.I.Sin \Phi$$

$$\Phi = 90^{\circ}$$

$$Sin90^{\circ} = 1$$

$$Q = E.I VAR.$$

Figure 13.5 shows the vector diagram of a circuit consist of only coils.

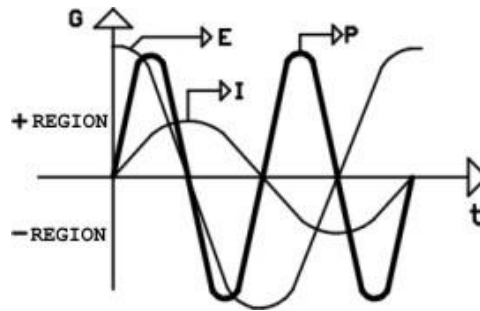


Figure 13.5

Coils can store the electric energy. Let's try to explain the current direction in the power curve. When both current and voltage is in either positive or negative region i.e. they have the same signs, electric energy is stored in the magnetic field of the coil. When voltage and current have different signs, the stored energy is given to the AC source.

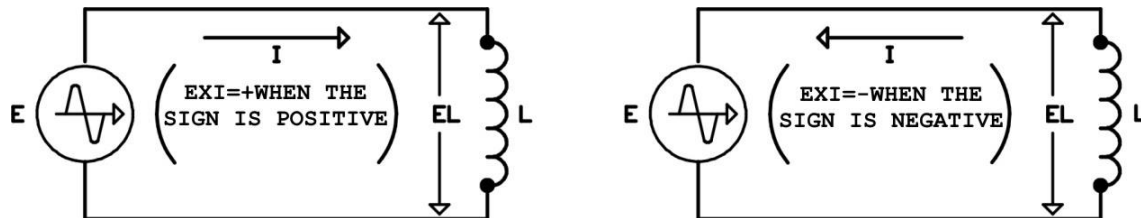


Figure 13.6

Figure 13.6 shows the direction of current in AC circuits. If the alternans of the power curve is positive, this instantaneous power is positive. If the alternans of the power curve is negative, this instantaneous power is negative. In an AC circuit if the area under the curve is zero, the total power is zero.

Coils have an internal resistance. Because of this they also consume real power. If there is a coil in an AC circuit, coils' internal resistance resist as if it is a real resistance. This makes the circuit consist of a coil and a resistance not only an ideal coil and the phase difference between voltage and current is lower than 90° .

In the experiment about coils in AC circuits, the internal resistance of the coil is ignored.

CAPACITORS

15.1 INTRODUCTION

Capacitor is a passive element that can store direct current (**DC**) electrical energy. Capacitors are made by putting an insulator between a pair of conductors. These conductors are called plates, and the insulator between the plates is called "**dielectric**"

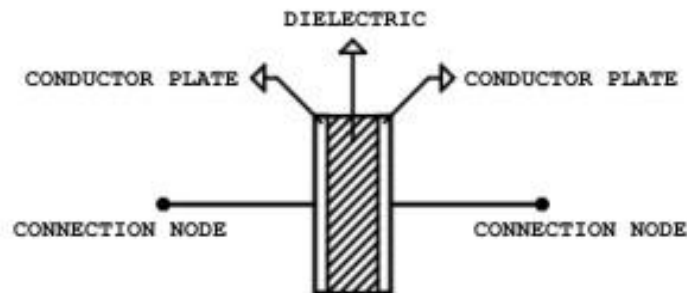


Figure 14.1

In figure 14-1 the structure of the capacitor is shown. In the conductors there are a lot of valence electrons. In conductors valence electrons can easily leave the nucleus of the atom. In insulators electrons are attached to their atoms with a big force. In ordinary situations the electrons that are in the plates are spinning around their atoms.

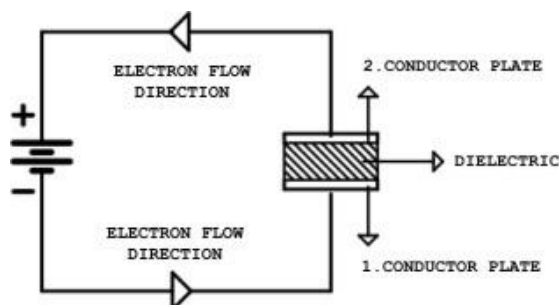


Figure 14.2

In figure 14-2 capacitor is attached to a direct current source. The electrons that are separated from the negative pole of the direct current source move towards the positive pole of the source. This situation goes on until the voltage difference between the two plates is equal to the direct current voltage. In the first plate there will be excess of electrons, and in the second plateThe voltage difference between the two plates disrupts the orbit of the electrons of the dielectric material atoms and put it into a shape of elliptic.

This situation is shown in figure 14-3.

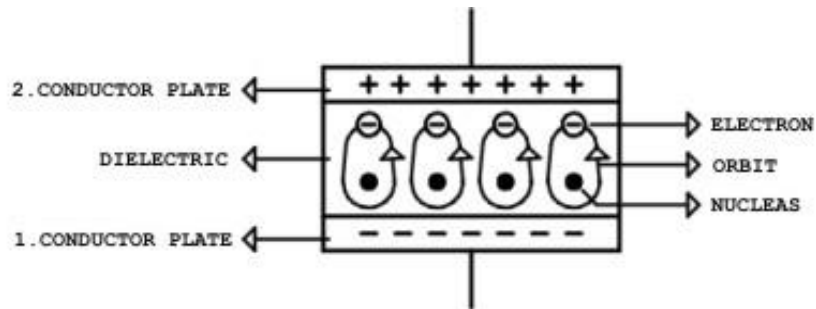


Figure 14.3

In figure 14-3 four atoms are shown. Actually, the number of atoms in a dielectric material is so many that is uncountable. At this moment if the direct current supply is taken out from the circuit the electric charge on the capacitor does not change. This situation is called the charging of the capacitor. A charged capacitor is direct current supply.

If a capacitor is connected to a high-voltage supply the electrons in the dielectric break off the atoms they are attached. At this moment the insulator property of the dielectric goes off and the electric charge disappears. A dielectric which exposed to this situation can not be recovered. If a dielectric of a capacitor breaks down, capacitor can not be used again.

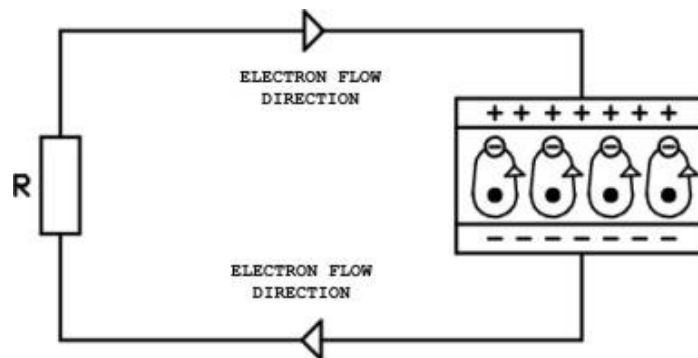


Figure 14.4

In figure 14-4 a resistance is connected to a charged capacitor. In this situation electrons that come from the plate that has excess of electrons move through the resistance to the plate that has low number of electrons. Electron flow will go on until the plates have the same electric charge. This situation is called discharging of a capacitor. Discharged capacitors have zero electric charge.

The electrons of dielectric material of a discharged capacitor have a normal circle orbit.

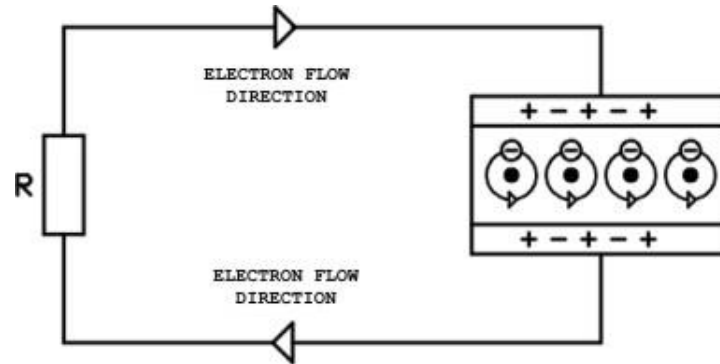


Figure 14.5

In figure 14-5 the charges of the plates of a capacitor and the structure of an atom in the dielectric is shown.

The electric energy storage capacity of a capacitor is directly proportional to the area of the plates and inversely proportional of the distance between the plates. The type of the dielectric material also affects the energy storage capacity. In DC circuits capacitors are used as an energy storage device whereas in the **AC/DC** converters they are used as filters.

In **AC** current circuits capacitors behaves like a conductor. Because of this property in alternating current they are usually used as coupling (**conductor**); and shuttling (**short circuit**) elements. The conductance of the capacitance is directly proportional to the frequency of the alternating current (**AC**) circuit.

The main unit of the capacitance is **farad**. Farad is shown by the letter **F**. The capacitance of a capacitor whose plates have a one coulomb electric charge and which has a voltage of one volt has 1 Farad capacitance. Farad is a big value. In electric circuits lower multiples of Farad are used.

In Figure 14-6 lower multiples of Farad and the relationship between them is shown.

UNIT	<F> FARAD	
LOWER MULTIPLIERS	<mF> MILIFARAD	$10^3 \text{ mF} = 1\text{F}$
	< μ F> MICRO FARAD	$10^6 \mu\text{F} = 1\text{F}$
	<nF> NANO FARAD	$10^9 \text{ nF} = 1\text{F}$
	<pF> PIKO FARAD	$10^{12} \text{ pF} = 1\text{F}$

Figure 14.6

Usually the capacitance values of the capacitors are written on the capacitors by the producers. Earlier some capacitors were produced whose capacitance values are specified by colors like resistors. Some producers specify the tolerance values of the capacitors by a letter written after the capacitance value.

The tolerance letters of the capacitors and their mathematical meaning is shown below.

F- %F 1	B- %F 0,10
G- %F 2	A- %F 0,05
D- %F 0;5	J - %F 5
C- %F 0,25	K- %F 10

When buying capacitors, capacitance value and the voltage must be specified. The maximum voltage value that a capacitor can work is written on it.

If a voltage higher than maximum voltage is applied to capacitor it will blow up and it could harm the user and the environment. Because of this reason the working voltage of the capacitor is so important.

In capacitors metals with high conductors are used as plates. Aluminum is the mostly used material for capacitor manufacturing. This is because of aluminum is cheap and resistive to humidity. Dielectric material varies so much.

According to dielectric material capacitors can be categorized as follows:

1.AIR	5.MIKA
2.PAPER	6.CERAMIC
3.PLASTIC	7.GLASS
4.POLYSTER	8.ELECTROLITIC

In electronics capacitors behave differently according to their dielectric materials.

- 1.** Paper-plastic-polyester capacitors
- 2.** Ceramic-mica capacitors
- 3.** Electrolytic capacitors

1. Paper-plastic-polyester capacitors: They are used in sound frequency (**20Hz-40 KHz**) and radio frequency (**150 KHz-110MHz**) circuits. In paper dielectric circuits, dielectric material is obtained by injecting paraffin into the paper. They are capacitors without a pole. Their capacitances are usually under $1\mu\text{F}$ (**microfarad**)

2. Mica-ceramic capacitors: They are used in high frequency (**10^4MHz**) circuits. Their power loss is small. They are also capacitors without poles. Their capacitances are usually under $1\mu\text{F}$ (**microfarad**)

3. Electrolytic capacitors: Their dielectrics are usually acid boric. They are usually used in sound frequency (**20Hz-40KHz**) and radio frequency (**150 KHz-110MHz**) circuits. Their capacitances are between $1\mu\text{F}$ and $10^4\mu\text{F}$.

Electrolytic capacitors have poles. When connecting to the circuit poles must be checked. If it is connected in the reverse direction it could harm the user and the environment.

In electrolytic capacitors aluminum or tantalum are used as plates. The capacitors with tantalum plates are called "**Tantalum Capacitors**". Their power loss is very small.

Electrolytic capacitors are produced either taking out the nodes from the left or right (axial type) or taking out the nodes from the same direction (**radial type**)

Capacitors are manufactured three types according to their work. They are constant capacitors, trimmer which is once adjusted in the set up of the circuit, and the variable which can be adjusted at any time.

In figure 14-7 symbols of the capacitors are shown.

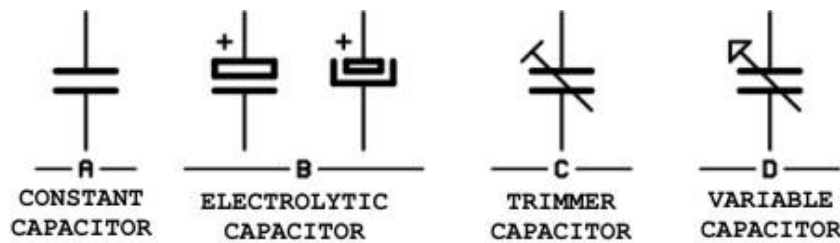


Figure 14.7

15.2 ENERGY STORED IN THE CAPACITORS

One plate of the capacitor is loaded with (+) positive charges and the other plate is loaded with (-) negative charges. This is called charging of the capacitor. After charging, if these plates are connected to each other, electron flow occurs. This heats the capacitor.

The stored energy in a capacitor is found by the formula;

$$W = \frac{1}{2} CE^2$$

In the formulation;

W=stored energy

C=capacitance (**Farad**)

E=voltage (**volt**).

15.3 CONNECTIONS OF THE CAPACITOR

In electronic circuit applications sometimes the exact capacitance or voltage value can not be obtained. In these situations by connecting capacitors parallel, serial or mixed the desired value can be obtained.

1. Serial Connection: In figure 14-8 serial connected three capacitors are shown.

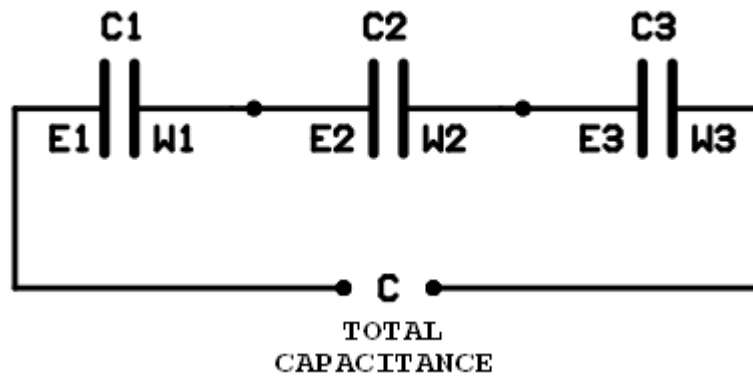


Figure 14.8

If the serial connected capacitors have poles (**electrolytic**) positive pole of a conductor is connected to the negative pole of another capacitor. If the capacitors are connected serially their total capacitance decreases.

By formulation;

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} .$$

The energy that can be stored is the total energy of the three capacitors as in the parallel connection.

$$\mathbf{W=W1+W2+W3}$$

The voltage value of the new capacitor is the sum of the voltages of the three capacitors.

$$\mathbf{E=E1+E2+E3.}$$

Example;

$$\mathbf{C1=60\mu F / 50V}$$

$$\mathbf{C2=30\mu F / 25V}$$

$$\mathbf{C3=20\mu F / 25V}$$

Three capacitors are connected serially.

A- Calculate the total capacitance.

B- Calculate the maximum work voltage for the new capacitance group.

Solution:

A-Total capacitance;

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

$$\frac{1}{C} = \frac{1}{60} + \frac{1}{30} + \frac{1}{20}$$

Equate the dominators (**take it 120**)

$$\frac{1}{C} = \frac{2}{120} + \frac{4}{120} + \frac{6}{120}$$

$$\frac{1}{C} = \frac{12}{120} \Rightarrow 12C = 120$$

$$C = \frac{120}{12} = 10\mu F .$$

B-The maximum work voltage for the capacitance group;

$$E = E_1 + E_2 + E_3$$

$$E = 50 + 25 + 25$$

$$E = 100 \text{ Volts.}$$

1. Parallel Connection: In Figure 14-9 parallel connection of three capacitors are shown.

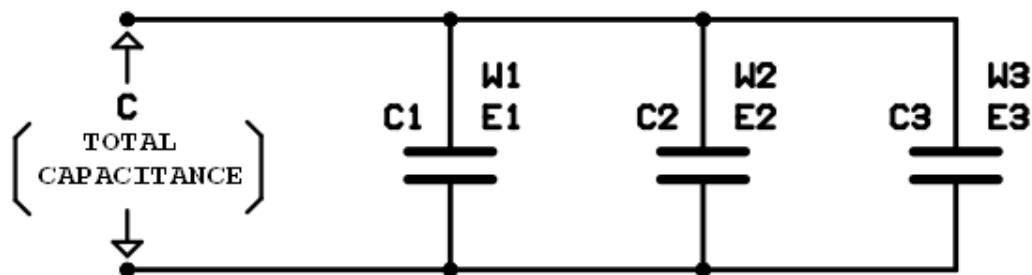


Figure 14.9

If the structure of the capacitance is remembered it can be seen that the area of the capacitance plates increases.

$$C = C_1 + C_2 + C_3$$

The stored energy is sum of the energy of the three capacitors.

$$W = W_1 + W_2 + W_3.$$

The voltage of the new capacitance group is equal to the lowest voltage value of the capacitors. This structure is used when the voltage value of the capacitors is enough but the capacitance value is not enough.

Example;

$$C_1 = 100 \text{ MF}/50\text{V}$$

$$C_2 = 33 \text{ MF}/50\text{V}$$

$$C_3 = 22 \text{ MF}/25\text{V}$$

Three capacitors are connected parallel.

A- Calculate the total capacitance?

B- Calculate the maximum work voltage for the new capacitance.

Solution:

A- Total Capacitance;

$$C = C_1 + C_2 + C_3$$

$$C = 100 + 33 + 22$$

$$C = 155 \mu\text{F}.$$

B- Since the maximum voltage that the capacitors can work is the smallest of the maximum voltages of the capacitor;

$$E = 25\text{Volt}.$$

CAPACITORS IN ALTERNATING CURRENTS

16.1 INTRODUCTION

In alternating current circuits capacitors without pole (**bipolar**) are used. Dielectric material of the pole capacitors are break down since in AC circuits, alternation is changing periodically.

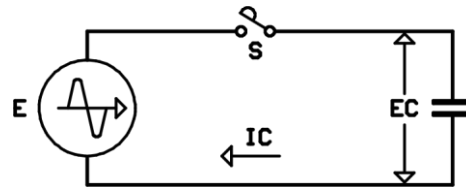


Figure 15.1

In figure 15-1 when the switch S turns on capacitor behaves like a short circuit so the current value gets its maximum value. After that capacitor begins to charge and after a time supply voltage is seen on the capacitor. This happens in one alternation of the AC. If the vector diagram of the circuit is checked it is seen that the voltage value on the capacitor is 90° behind the alternating current.

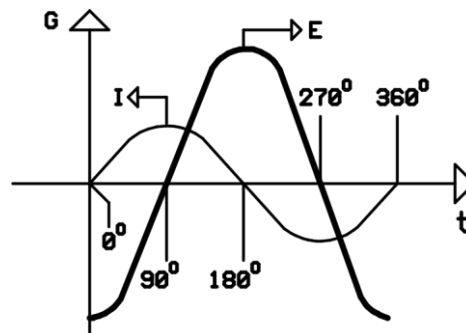


Figure 15.2

When switch is turned on it is 0° on the vector diagram. At this moment current is in the positive direction with the maximum value and the voltage is zero.

Between 0° - 90° while the current value decreases voltage value increase. At 90° current is zero voltage is maximum.

Between 90° - 180° the current value goes to its maximum in the negative direction while the voltage value goes to zero. At 180° current is maximum in the negative direction and the voltage value is zero.

Between 180° - 270° the current value goes to zero while the voltage value goes the its maximum in the negative direction. At 270° current is zero and the voltage is maximum in the negative direction.

Between 270° - 360° the current value goes to its maximum while the current value goes to zero. At 360° current is maximum and the voltage is zero. This point is the starting point. This cycle periodically happens.

The phase diagram of the circuit is shown in figure 15.3

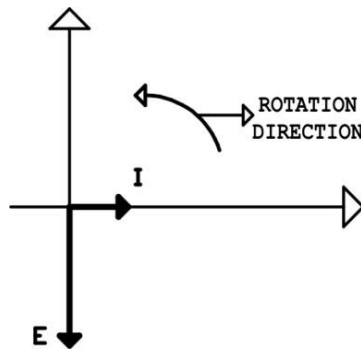


Figure 15.3

The circuit that has a current which is ahead of voltage value is called "**Capacitive Circuit**" without looking the phase angle.

During the work time, capacitor charges and discharges. Since the plates of the capacitor are separated by dielectric no current flows over the capacitor. But in ever cycle electron current exists from the supply in the positive or negative direction. Circuit current depends on the voltage on the capacitance. In the circuit current is formulated as:

$$i = c \cdot \frac{\Delta e}{\Delta t}$$

In the formulation;

i = Current (**Ampere**)

c = Capacitor Capacitance (**Farad**)

$\frac{\Delta e}{\Delta t}$ = The rate of the voltage change (**Volts/Seconds**).

If current is assumed with zero phase at any " t " time current and voltage at the vector diagram are formulated as:

$$i = I_{max} \cdot \sin \omega t$$

$$e = E_{max} \cdot \sin(\omega t - \pi / 2)$$

If voltage is assumed zero phase;

$$e = E_{max} \cdot \sin \omega t$$

$$i = I_{max} \cdot \sin(\omega t + \pi / 2) .$$

Dielectric material is like a resistance parallel to capacitor plates.

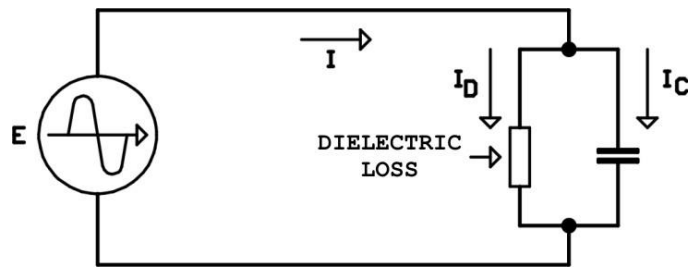


Figure 15.4

In figure 15.4, the effect of the dielectric material to the circuit is shown. A current passes through the dielectric material even it is small. This current is the loss of the dielectric. Dielectric loss increases the current of the circuit.

16.2 CAPACITIVE REACTANCE

We know that a capacitor that is connected to an alternating current source charges and discharges. The electrical change in the plates of the capacitor creates an electric field between the plates and an opposite EMF emerges. This opposite EMF means a resistance. The resistance of the capacitor to AC is called "**Capacitive Reactance**". The unit of the capacitive reactance is "Ohm" like in the resistances. Capacitive reactance is inversely proportional to capacitance value and the frequency of the circuit.

In formula capacitive reactance is;

$$X_c = \frac{I}{2\pi f c}$$

In the formulation;

X_c =Capacitive reactance (**Ohm**)

F =Frequency (**Hertz**)

C =Capacitance (**Farad**)

2Π = Coefficient (**6, 28**).

Example; A 10μF capacitor is connected to 50 Hz 220 Volts Ac supply. Calculate the capacitive reactance and the current.

Solution:

$$10\mu F = 10 \cdot 10^{-6} \text{ Farat}$$

$$X_c = \frac{I}{2\pi f c}$$

$$X_c = \frac{I}{6,28 \cdot 50 \cdot 10 \cdot 10^{-6}}$$

$$X_c = \frac{10^6}{6,28 \cdot 50 \cdot 10}$$

$$X_c = 318R.$$

$$I = \frac{E}{X_c} = \frac{220}{318} = 0.69 \text{ A.}$$

16.3 POWER IN THE AC CIRCUITS WITH CAPACITOR

We know that current is ahead of 90° voltage in a capacitor that is connected to AC supply. According to this in a circuit that is only made of capacitors power factor will be zero. This is because the cosine of 90° is zero. Mathematically the multipliers of zero is zero so the active power of the circuit will be zero.

$$\begin{aligned}P &= E.I.\cos \Phi \\ \Phi &= 90^\circ \\ \cos 90^\circ &= 0 \\ P &= 0\end{aligned}$$

In the houses and workplaces electricity meters measure the active power. Theoretically circuits that are purely capacitance do not consume any electrical energy. This is very bad for electricity suppliers. Because of this reason extra elements are used in order to make power factor "1". Power of these circuits is calculated using reactive power (Q).

$$\begin{aligned}Q &= E.I.\sin \Phi \\ \Phi &= 90^\circ \\ \sin 90^\circ &= 1 \\ Q &= E.I \text{ VAR}\end{aligned}$$

Capacitors have an internal resistance which can be low or high. So, capacitors consume some amount of active power. The vector diagram of a circuit that is made of only capacitors is shown in figure 15.5.

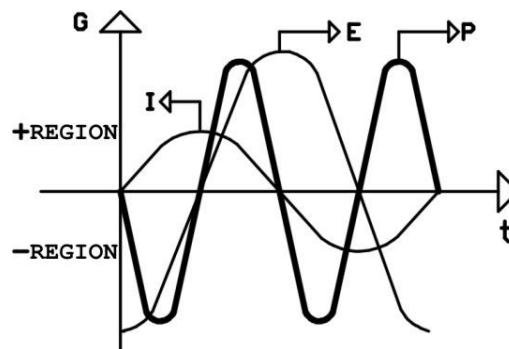


Figure 15.5

Capacitors can store electrical energy like coils. Let's explain direction of the electric current in the power curve in Figure 15.5. When both of the current and the voltage value have positive or negative signs i.e. their multiplication is positive electrical energy is stored in the capacitance. When the voltage is positive, current is negative or the voltage is negative, current is positive the current flows from the capacitor to the AC supply capacitor discharges.

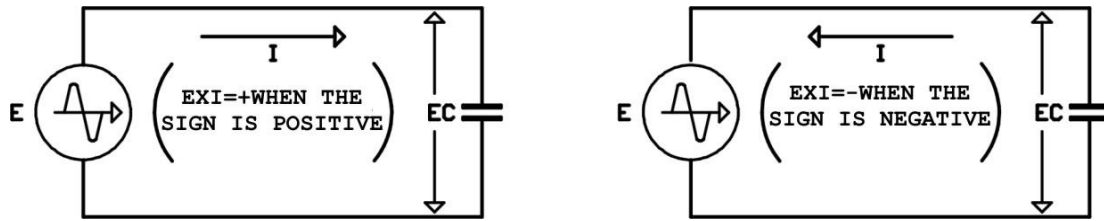


Figure 15.6

In figure 15.6 the directions of the AC current is shown. If the alternans of the power curve is positive, the power is positive. If the alternans of the power curve is negative, power is negative. The total area under the power curve is zero. Then total power is zero.

The power calculations for the circuits with the coil and capacitance are same.