كلية التربية- الفرقة الثانية

تعليم اساسى برنامج اللغة الانجليزية

# English Programme

# Alternating Current

## By

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# Chapter one

# Fundamental of Alternating Current

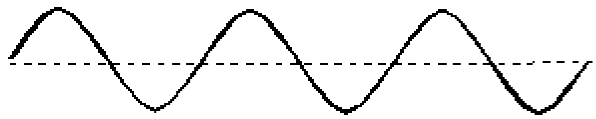
## Introduction

Electric current can be direct current (DC) or alternating current (AC). Direct current such as the power from dry cells and it is characterized by a uniform direction of flow and amount (voltage) of electricity.

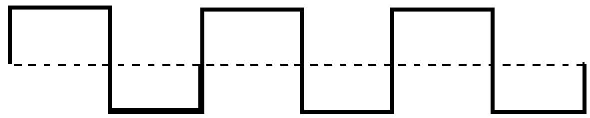
Alternating current is characterized by direction of flow and amount of electricity that changes cyclically over time.

All the houses and most of the electrical devices are used AC.  The solar cells are producing a constant electric current.  so that we can operate electrical devices that operate with an electric current, we must convert the current from DC to AC by a device called inverter  If we want to convert AC to DC power, we use a device called Rectifier
The wave of AC takes different shape sine, square, triangle and saw tooth wave

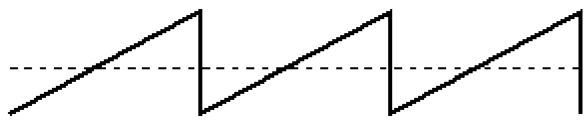
1. The sine wave is a common type of alternating current (AC) and alternating voltage
2. The square waves use in digital electronics and transformer electronics to test their work.
3. The triangle AC wave is used in sound synthesis, and is also useful in linear electronics testing
4. Sawtooth AC wave
5. ramp waves



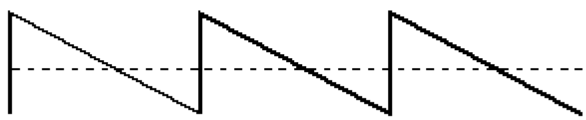
sine



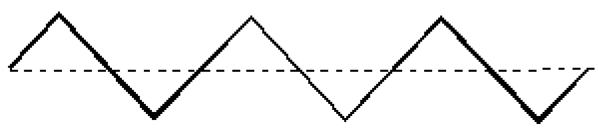
square



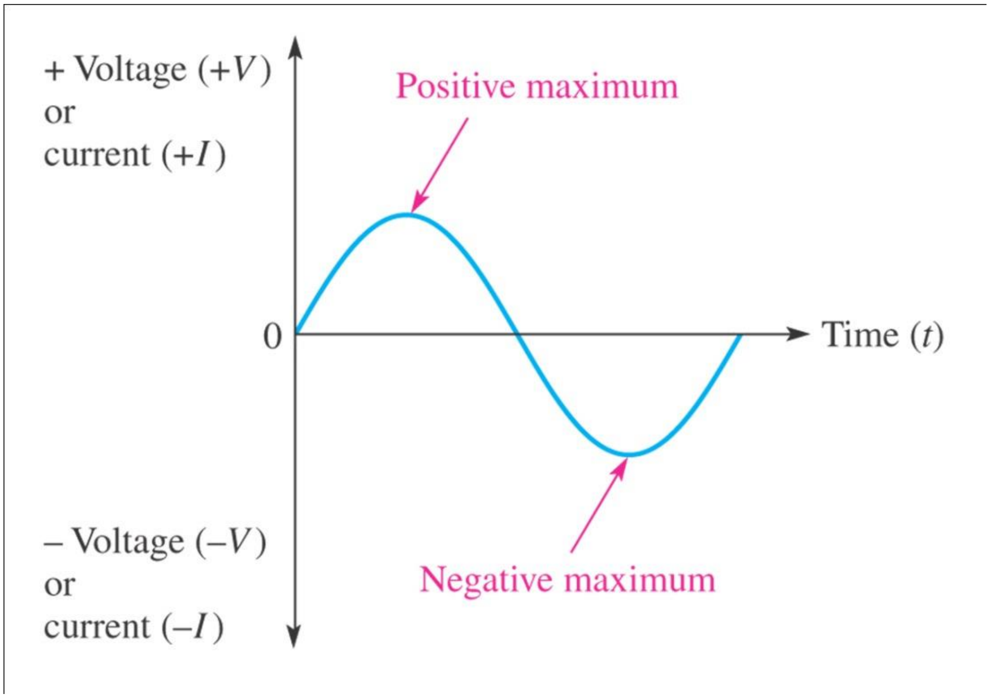
ramp



sawtooth

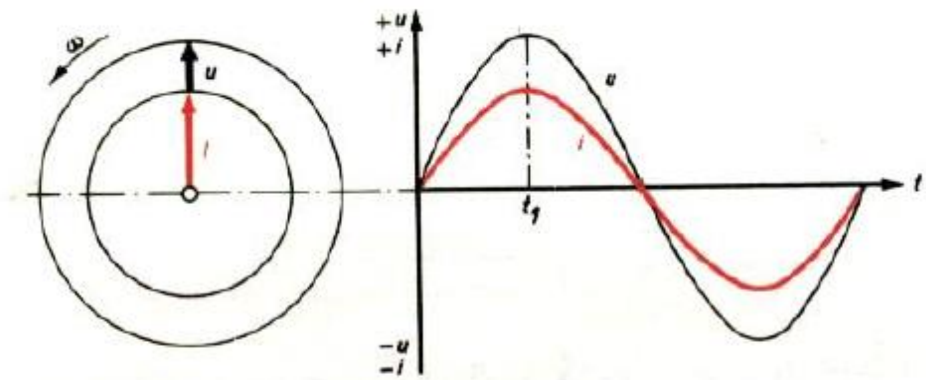


triangular

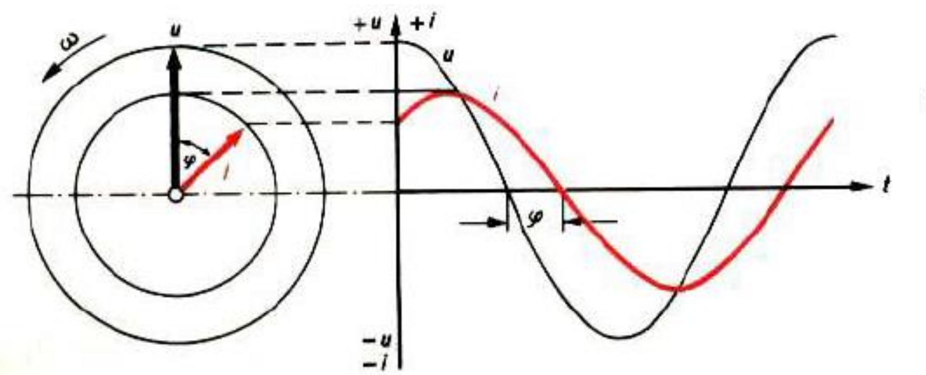



- The wave is the path drawn by the voltage or the current in terms of time

Two waves are in consistent in phase, if they reach the maximum and minimum value in same time




Two waves: The angle between them is Q (displacement angle). It is said that the current wave was delayed from the voltage wave at an angle of Q as the following shape




- Period of sine wave is the time required to complete a complete cycle and is denoted by T
- Frequency: is the number of oscillations generated by current or voltage per second and is denoted by **f** and measured by Hz

**The angular frequency** is the value of angle per second and is given by

$$w = 2\pi f$$

In addition, it measures by rad/second

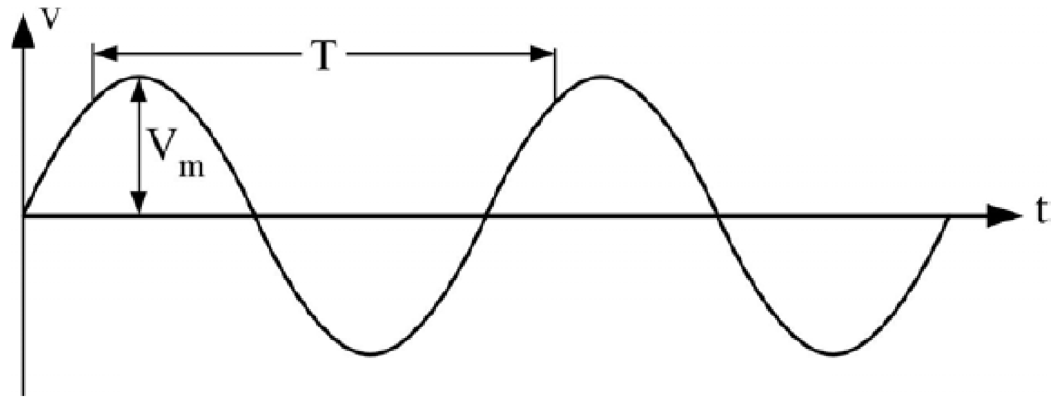
- The $V_t$ instantaneous value : is the amount of voltage at any given time and is given by

$$V_t = V_m \sin wt$$

- The effective value of the AC( $V_{eff}$ or $V_{rms}$ ) is the DC current that generates the same thermal energy generated by the AC during the same time period in the same resistance and is given from ;

$$I_{rms} = \frac{I_{\max}}{\sqrt{2}}$$

$$V_{rms} = \frac{V_{\max}}{\sqrt{2}}$$

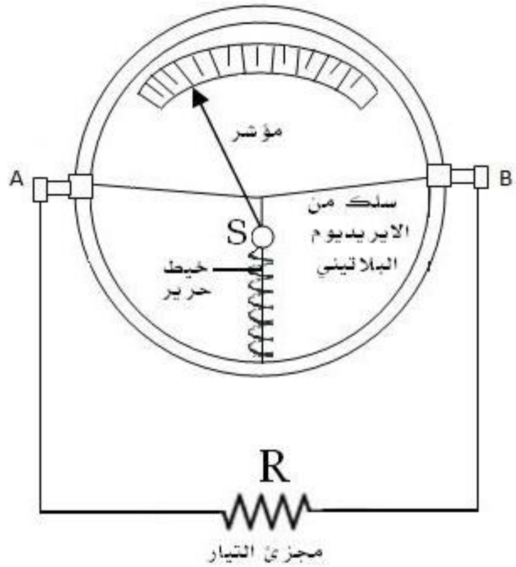



**AC properties;**

1. The electrical current can be increased or reduced using electrical transformers.
2. It can be transported long distances without much loss of electrical energy.
3. it can be converted to DC
4. 4. It can be used in lighting, heating processes, not use in electrolysis, and electroplating.
5. It has thermal effect

**Measuring AC**

AC current is measuring using the hot-coil Ammeter Its idea depends on the thermal effect of the current




Thermal Ammeter consist of:

1. A thin wire of iridium alloy and platinum is tight between the two screws A, B.
2. The wire is connected from the middle of a silk thread wrapped around a roll S
3. The silk is tightened by a spring fixed in the wall and is always tight.
4. A pointer is supported on the roller and it moves in front of an irregular gradient to measure current intensity
5. The wire is connected in parallel to the R resistance
6. The thermal Ammeter gives the effective value of AC

- When the current passes in the wire, then its temperature and expand are raising and relax to the bottom.
- The silk thread tightens the wire and turns the pulley ,the indicator moves on scale
- Reading is taken when the indicator is stable (equilibrium)
- The (irregular) scale indicates the effective value of AC
- When the AC is cut, the wire cools and shrinks

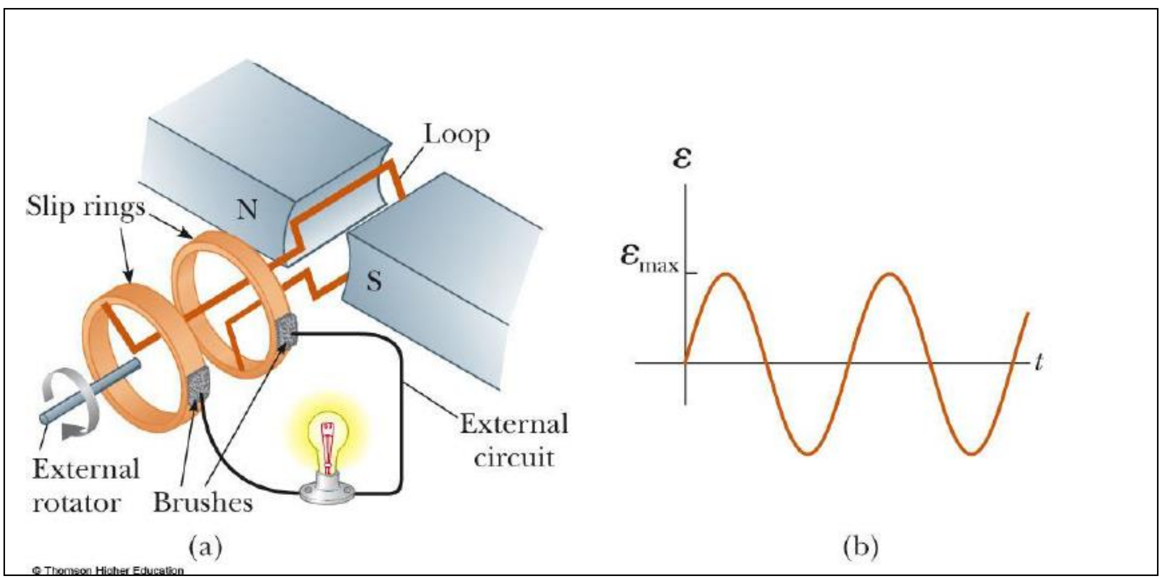
**Disadvantages of AC Ammeter**

- The indicator moves slowly when measured and returns to zero slowly after the measurement is finished.
- There is a zero error (effect of ambient temperature)

**Generating AC**

The electric generator or dynamo converts mechanical energy into electrical energy for transmission and distribution through power lines for use in industry and commerce. The dynamo is also used to produce the electric energy needed for the movement of cars, ships, planes and trains. This is done by falling waterfalls or burning oil or nuclear energy.

The electric generator consists of a coil of copper rotates by an external force between the magnet. The following figure shows the electric generator magnetic



**Ex1**

**1- Calculate the time period( T ) of a AC wave, its frequency**

A. 50 Hz

B. 60 Hertz

Sol

A- $T = \frac{1}{f}$ =1/50 =0.02 second

B - $T = \frac{1}{f}$ =1/60 = 0.01667 second

**2- If the equation of the voltage wave is**

$$V = 100\sin\left(377t + \frac{\pi}{6}\right)V$$

Calculate the following:

1. **Maximum value of voltage**
2. **Phase angle at the beginning of time**
3. **Phase angle at time 0.025 second**
4. **Instantaneous value at the time 0.025 second**

## Solution

$$V_m = 100 \text{ V}$$

$$\theta_v = \frac{\pi}{6} \text{ rad} = 30^\circ$$

$$\alpha = 377 \times 0.025 + \frac{\pi}{6} = 9.95 \text{rad} = \frac{9.95 \times 180}{\pi} \text{deg} = 570^\circ$$

$$v = 100 \times \sin 570^\circ = -50 \text{ V}$$

# Chapter Two

## Alternating-Current Circuits

### 1- Purely Resistive load

Consider a purely resistive circuit with a resistor connected to an AC generator, as shown in Figure 1 (As we shall see, a purely resistive circuit corresponds to infinite capacitance C = ∞ and zero inductance L = 0 .)

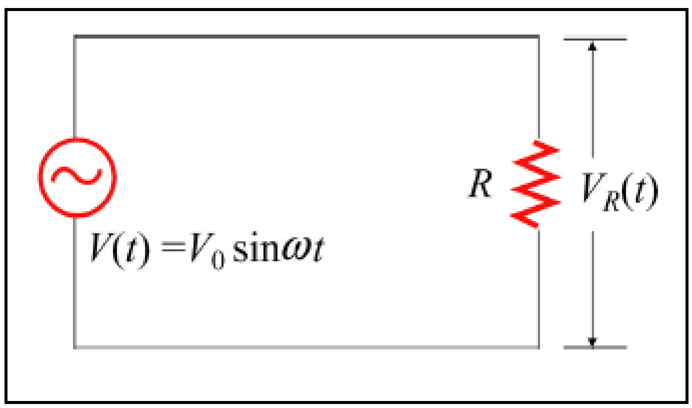



Fig 1; - Purely Resistive load

Applying Kirchhoff's loop rule yields

$$V_t - V_R = V_t - I_R R = 0$$

The instantaneous voltage drop across the resistor. The instantaneous current in the resistor is given by

$$I_R = \frac{V_R}{R} = \frac{V_m \sin wt}{R} = I_m \sin wt$$

$$I_m = \frac{V_m}{R}$$

It is clear that both current and voltage are in phase with each other, meaning that they reach their maximum or minimum values at the same time. The time dependence of the current and the voltage across the resistor is depicted in Fig. 2.

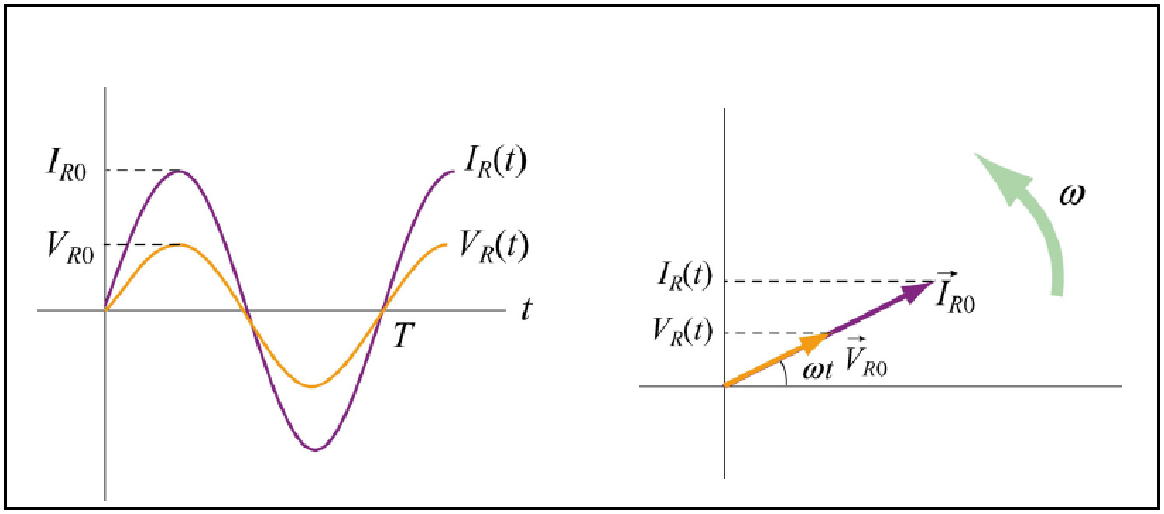



**Fig. 2 -**Phase diagram for the resistive circuit

## 2- Purely Inductive Load

Consider now a purely inductive circuit with an inductor connected to an AC generator, as shown in Figure.3.

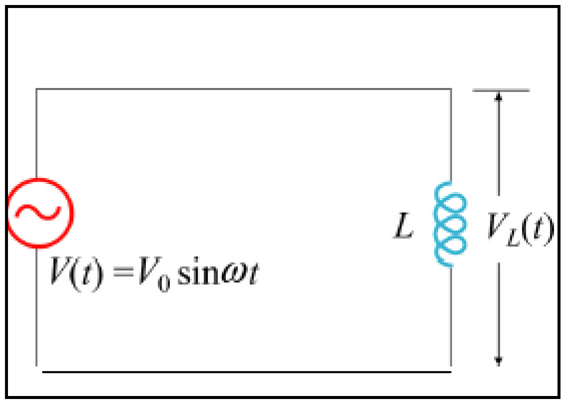



Figure 3- A purely inductive circuit

As we shall see below, a purely inductive circuit corresponds to infinite capacitance (C) and zero resistance (R). Applying the modified Kirchhoff's rule for inductors, the circuit equation reads

$$V_t - V_L = V_t - L\frac{dI}{dt} = 0$$

$$V_t = L\frac{dI}{dt}$$

$$\frac{V_m}{L}\sin wt.dt = dI$$

$$\frac{V_m}{L}\int \sin wt.dt = \int dI$$

$$-\frac{V_m}{L.w}.\cos wt = I$$

$$\cos wt = -\sin\left(wt - \frac{\pi}{2}\right)$$

$$I = \frac{V_m}{L.w}.\sin\left(wt - \frac{\pi}{2}\right)$$

$$I = I_m \sin\left(wt - \frac{\pi}{2}\right)$$

Rewriting the last expression. , we see that the amplitude of the current through the inductor is

$$I_m = \frac{V_m}{wL}$$

$$\frac{V_m}{I_m} = wL$$

$$X_L = 2\pi f L$$

$X_L$ is called the *inductive reactance*. It has SI units of ohms (Ω), just like resistance. However, unlike resistance, $X_L$ depends linearly on the angular frequency *w*. Thus, the resistance to current flow increases with frequency. This is because at higher frequencies the current changes more rapidly than it does at lower frequencies. On the other hand, the inductive reactance vanishes as *w* approaches zero.

The current and voltage plots and the corresponding phase diagram are shown below.

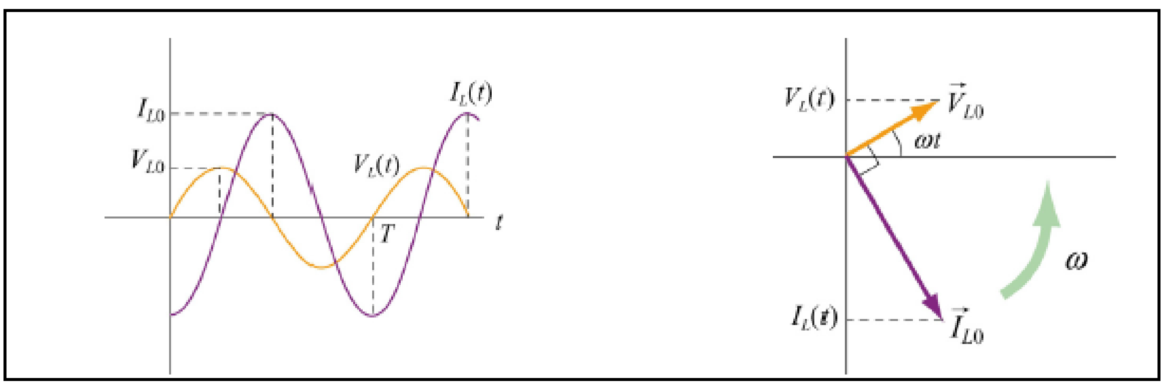



Figure 4 Phase diagram for the inductive circuit.

As can be seen from the figures, the current is out of phase with voltage by angle equals $\pi/2$. It reaches its maximum value after does by one quarter of a cycle. Thus, we say that:

**The current lags (delays) voltage by π / 2 in a purely inductive circuit**

**Example**

Consider a purely inductive circuit with an inductor, its self inductance equals 2 Henery, connected to an AC generator (V=12 volts and its frequency equals 50Hz) . Calculate the following:

- Current intensity
- The current intensity when self inductance changes to 6 Henery

**Solution**

$$X_L = 2\pi f L = 2\times 3.14\times 50\times 2$$

$$X_L = 628\ \Omega$$

$$I = \frac{V}{X_L} = \frac{12}{628} = 19\,\text{mA}$$

$$X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 6$$
$$X_L = 1884\ \Omega$$

$$I = \frac{V}{X_L} = \frac{12}{1884} = 6\,\text{mA}$$

**4-Purely Capacitive Load**

In the purely capacitive case, both resistance *R* and inductance *L* are zero. The circuit diagram is shown below:

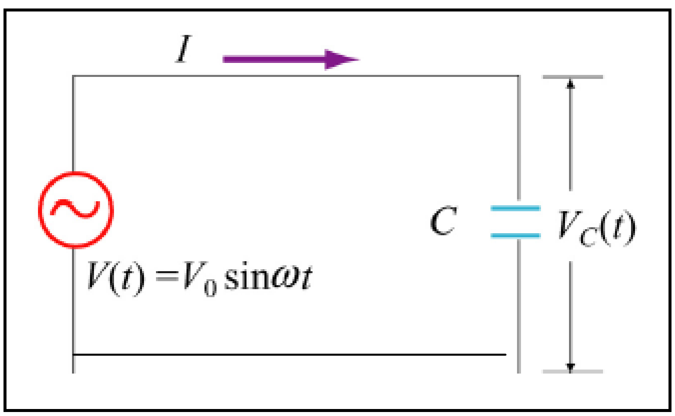



**Figure 5** A purely capacitive circuit

In addition, Kirchhoff's voltage rule implies:

$$V_t - V_c = 0$$
$$V_t - \frac{Q}{C} = 0$$

We know that

$$Q = CV = CV_c = CV_m \sin wt$$

$$I = \frac{dQ}{dt} = \frac{d(CV_m \sin wt)}{dt}$$

$$I = CwV_m \cos wt$$

$$I = CwV_m \sin\left(wt + \frac{\pi}{2}\right)$$

$$I = I_m \sin(wt + 90)$$

$$I_m = CwV_m$$

$$\frac{V_m}{I_m} = \frac{1}{wC} = X_C$$

$$X_C = \frac{1}{2\pi fC}$$

$X_C$ is called the ***capacitance reactance***. It also has SI units of ohms and represents the effective resistance for a purely capacitive circuit. Note that $X_C$ is inversely proportional to both $C$ and ω , and it diverges as ω approaches zero. The current and voltage plots and the corresponding phase diagram are shown in the Figure below :

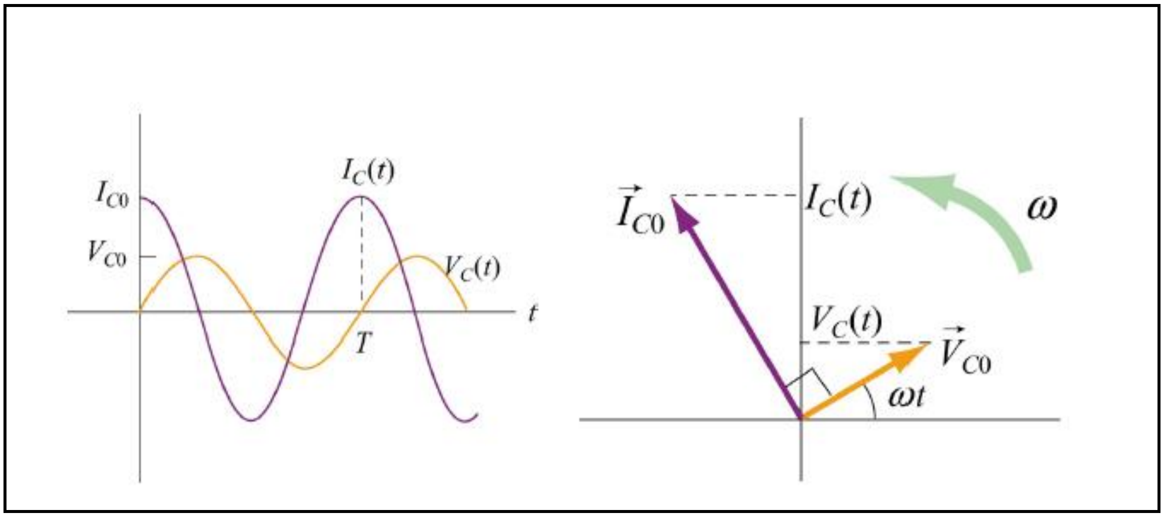



Figure 6 : Phase diagram for the capacitive circuit.

Notice that at, the voltage across the capacitor is zero while the current in the circuit is at a maximum. In fact that current reaches its maximum before by one quarter of a cycle ( $\pi/2$ ) voltage. Thus, we say that

**The current leads the voltage by $\pi/2$ in capacitive circuit**

**Example:**

Capacitor C, its capacity 1 micro Farad, has been used in radio circuit with frequency equals 1000Hz and $I_{r.m.s}$ equals 2 mA .Calculate the voltage across capacitor and what is current when $V_{r.m.s}$ equals 20 volts and frequency equals 50Hz.

Solution

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\times3.14\times1000\times10^{-6}} = 159 \text{ ohom}$$

$$V = IX_c = \frac{2}{1000}\times159 = 0.32\,\text{volt}$$

For f= 50 Hz and voltage =20 volts , then the capacitance reactance $X_C$

$$X_c = \frac{1}{2\pi fC} = \frac{1}{2\times3.14\times50\times10^{-6}} = 3180 \text{ ohom}$$

$$\text{I} = \frac{V}{X_c} = \frac{20}{3180} = 6.3\times10^{-3}\,Ampere$$

A summary for the above case in AC circuit

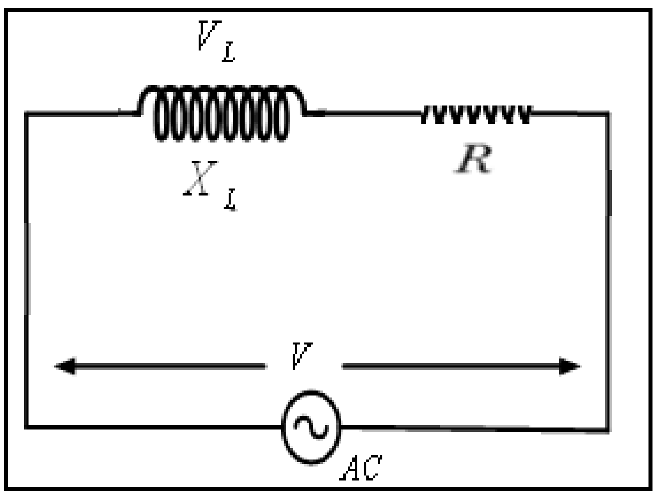
| Simple Circuit | $R$ | $L$ | $C$ | $X_L = \omega L$ | $X_C = \frac{1}{\omega C}$ | $\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$ | $Z = \sqrt{R^2 + (X_L - X_C)^2}$ |
|---|---|---|---|---|---|---|---|
| purely resistive | $R$ | 0 | $\infty$ | 0 | 0 | 0 | $R$ |
| purely inductive | 0 | $L$ | $\infty$ | $X_L$ | 0 | $\pi / 2$ | $X_L$ |
| purely capacitive | 0 | 0 | $C$ | 0 | $X_C$ | $-\pi / 2$ | $X_C$ |

# Chapter Three

# Alternating Series circuit

## 1-L R Alternating Series Circuit

Figure 1 represents a one of the Alternating Series Circuit have a resistance R and inductance L




- In the resistance, the voltage and current are in the same phase.
- In the inductance, the voltages (leads) precedes the current by π / 2

The voltage is calculated by

$$V = \sqrt{V_R^2 + V_L^2}$$

$$V = Z\,I \qquad V_R = I\,R \qquad V_L = I\,X_L$$

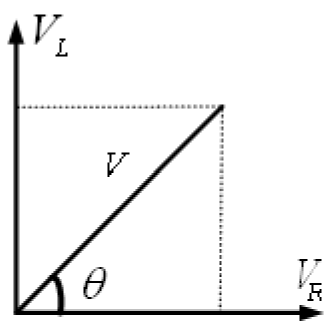
By substituting

$$IZ = I\sqrt{R^2 + {X_L}^2}$$

Therefore, the total impedance is

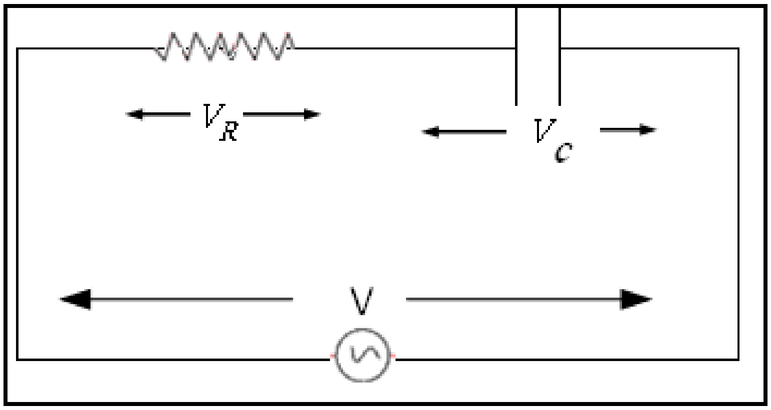
$$Z = \sqrt{R^2 + {X_L}^2}$$

The angle phase




$$\tan\theta = \frac{V_L}{V_R} = \frac{X_L}{R}$$

## 2-R C Alternating series circuit

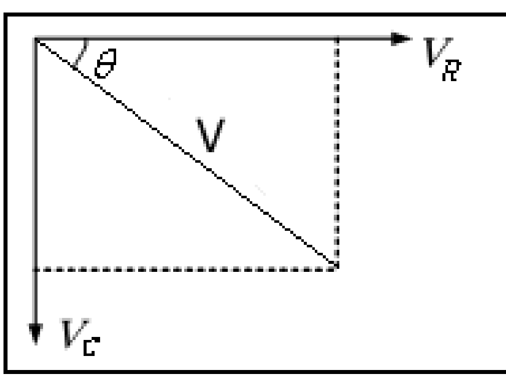



The figure represents AC Source and capacitor ( C )connect in series with ohomic resistance (R)

As we know before:

- In the resistance, the voltage and current are in the same phase
- In capacitor, the voltage delays current by π / 2

The total voltage is




$$V = \sqrt{V_R^2 + V_C^2}$$

$$V_C = I\ X_C \quad V_R = IR \quad \text{and} \quad V = IZ$$

By substituting

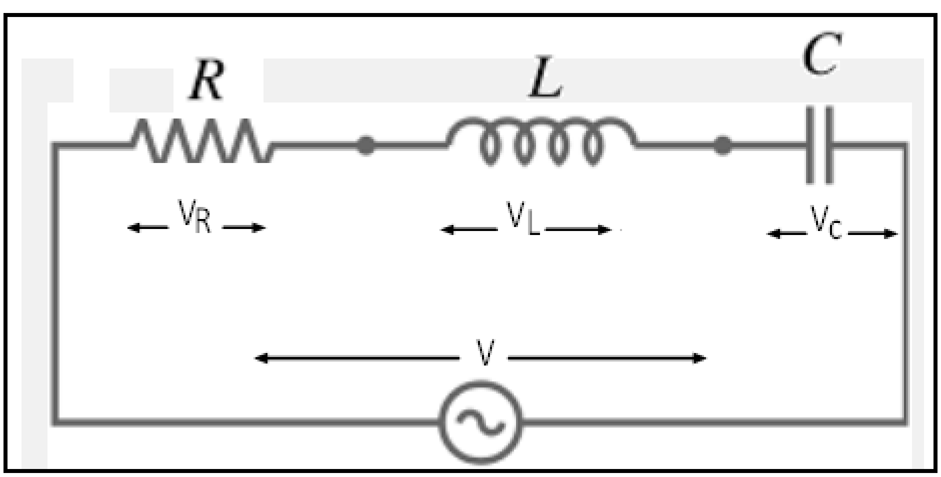
$$IZ = I\sqrt{R^2 + X_C^2}$$

$$Z = \sqrt{R^2 + X_C^2}$$

The angle phase is the angle between the voltages obtained with current

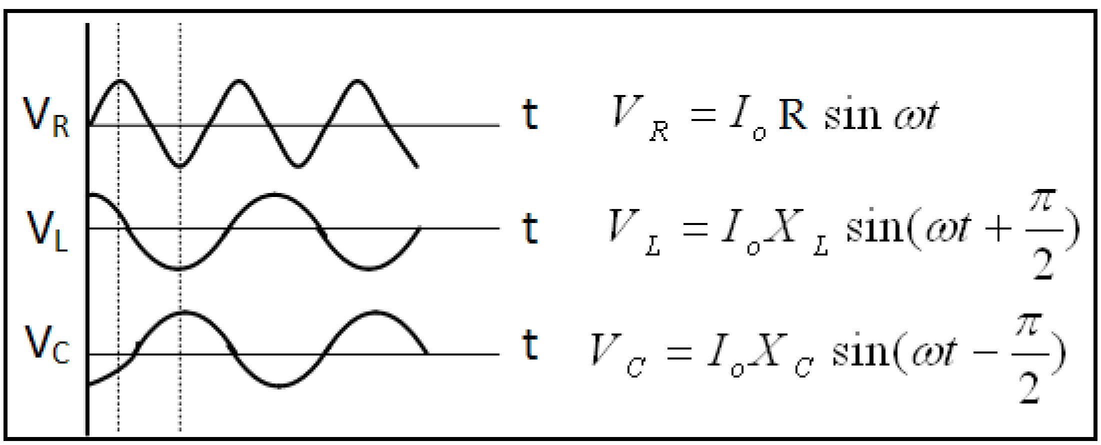
$$\tan\Phi = \frac{-V_c}{V_R} = \frac{-IX_C}{IR} = \frac{-X_C}{R}$$

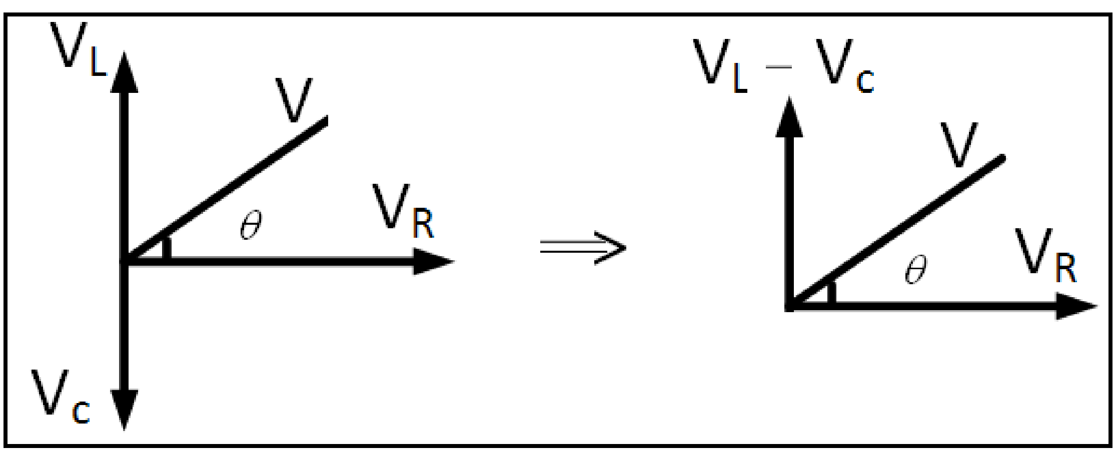
**3- RLC alternating series circuit**



The above circuit consists of Capacitor (C), Inductance (L) and Resistance (R) is connecting in series with AC power. As we mentioned before:

- In the resistance, the voltage and current are in the same phase
- In capacitor, the voltage delays current by π / 2



From the above figure (vector pattern), we can calculate the impedance as follow

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$V_L = IX_L \quad V_C = IX_C \quad V_R = IR \quad V = IZ$$

By substituting to calculate the impedance Z

$$IZ = I\sqrt{R^2 + \left[(X_L - X_C)^2\right]}$$

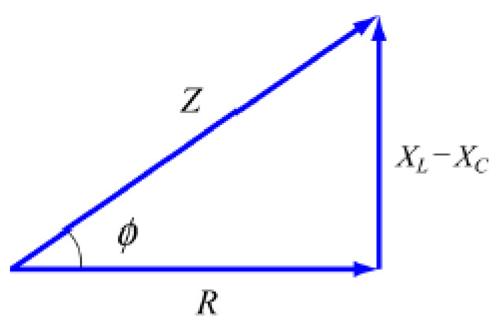
We have already seen that the inductive reactance and capacitance reactance play the role of an effective resistance in the purely inductive and capacitive circuits, respectively. In the series *RLC* circuit, the effective resistance is the *impedance*, defined as

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

To calculate the phase angle, find the angle tangent between the obtained voltage and current

$$\tan\Phi = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R}$$

The relationship between $Z$, $X_L$ and $X_C$ can be represented by the diagram shown in below




The impedance also has SI units of ohms. In terms of $Z$, the current may be rewritten as

Notice that the impedance $Z$ also depends on the angular frequency ω, as do $X_L$ and $X_C$.

The above equation in RLC circuit indicates that the amplitude of the current reaches a maximum when *Z* is at a minimum. This occurs when $X_L=X_C$

$$wL = \frac{1}{wC}$$

$$w_0 = \frac{1}{\sqrt{LC}}$$

The phenomenon at which $I_0$reaches a maximum is called a resonance, and the frequency $\omega_0$ is called the resonant frequency. At resonance, the impedance becomes *Z*=*R*, the amplitude of the current is

$$I_0 = \frac{V_0}{R}$$

In addition, phase angle is

$$\phi = 0$$

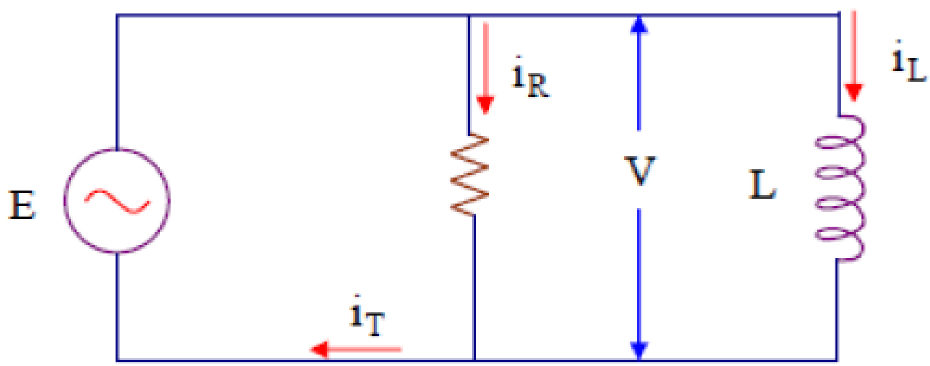
**When resonance occurs in serial RLC circuit**

1. Inductive reactance = capacitive reactance

2. The resistance in the circuit is equal to the ohmic resistance only.
3. The total voltage is equal to the voltage difference between the two ends of the ohmic resistance.
4. The phase difference between current and voltage is zero.
5. Consistent current and total voltage in phase.
6. The circuit has less resistance.
7. Passing in the circuit maximum current intensity

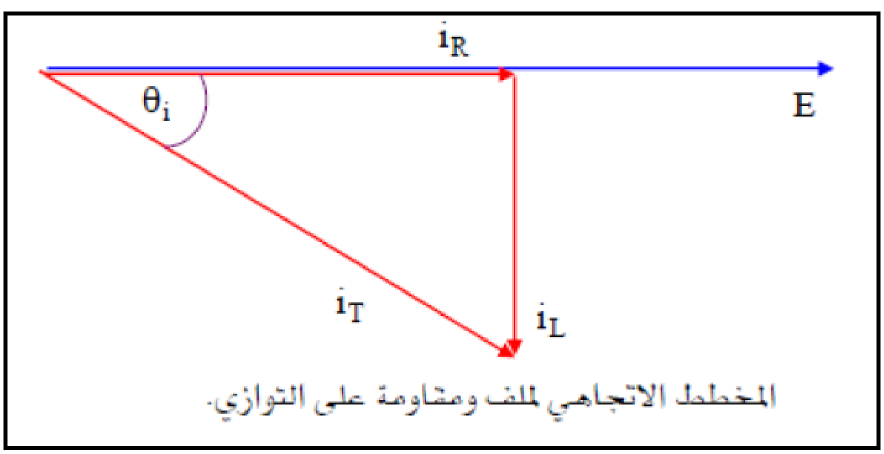
## Alternating parallel circuit

1- A circuit containing resistance R connected with inductive L in parallel with an AC source




مقاومة وملف على التوازي

The previous figure represents an AC circuit containing only two elements, R and L are connected in parallel.




المخطط الاتجاهي لملف ومقاومة على التوازي.

It is known before that the $I_L$ current is delayed from the $I_R$ current because the $I_R$ current in the same phase with voltage V, and the induction current $I_L$ delayed with 90 degrees from voltage then

$$I_t^2 = I_R^2 + I_L^2$$

$$= \left(\frac{V}{R}\right)^2 + \left(\frac{V}{X_L}\right)^2$$

$$I_t = V\sqrt{\frac{1}{R^2} + \frac{1}{{X_L}^2}}$$

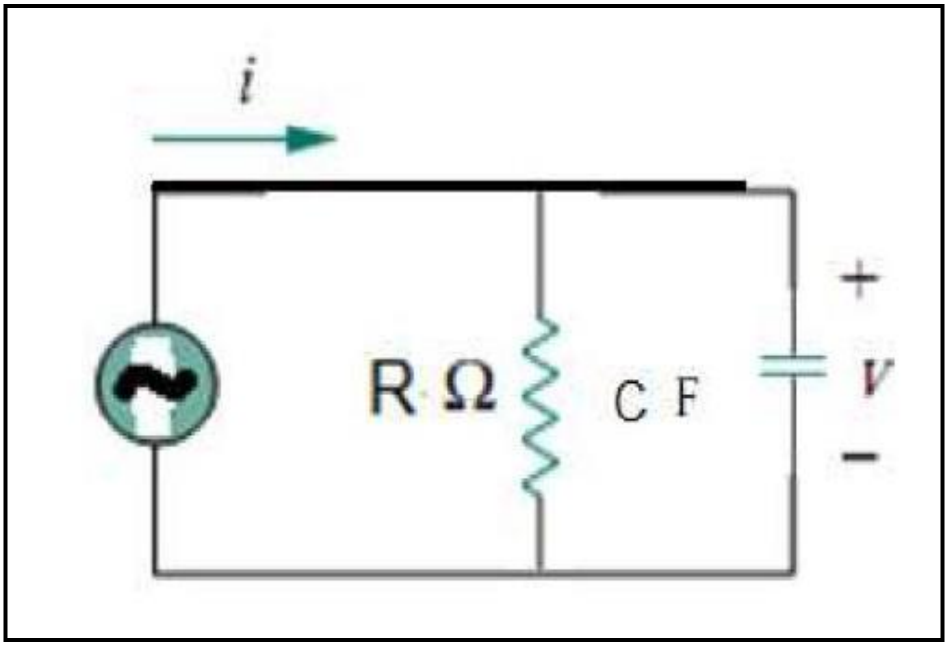
The impedance in this case

$$Z = \frac{V}{I_t} = \frac{1}{\sqrt{\frac{1}{R^2} + \frac{1}{{X_L}^2}}}$$

The total current delayed with total voltage by angel

$$\tan \Phi_i = \frac{I_L}{I_R} = \frac{R}{X_L}$$

2- A circuit containing capactance C connected with resistance R in parallel with an AC source




in this case the current of the capacitor leads to the current of the resistance with 90 degree because the resistance current is in the same phase with the voltage.

$$I_t^2 = I_R^2 + I_c^2$$

$$= \left(\frac{V}{R}\right)^2 + \left(\frac{V}{X_C}\right)^2$$

$$I_t = V\sqrt{\frac{1}{R^2} + \frac{1}{X_C{}^2}}$$

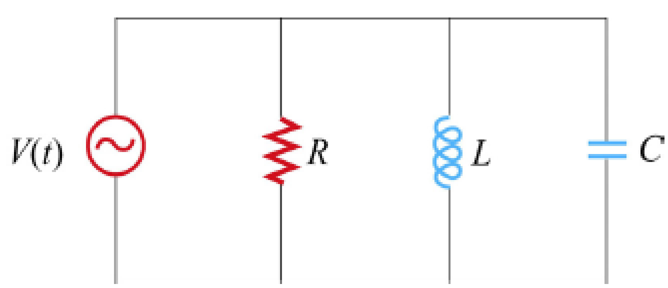
$$\frac{V}{I_t} = \frac{1}{\sqrt{\frac{1}{R^2} + \frac{1}{X_C{}^2}}} = Z$$

$$\tan\Phi_i = \frac{I_C}{I_R} = \frac{R}{X_C}$$

**3- Parallel *RLC* Circuit**

Consider the parallel *RLC* circuit illustrated in the following Figure 12.6.1. The AC voltage source is

$$V = V_0 \sin wt$$



Unlike the series RLC circuit, the instantaneous voltages across all three-circuit elements R, L, and C are the same, and each voltage is in phase with the current through the resistor. However, the currents through each element will be different.

In analyzing this circuit,. The current in the resistor is

$$I_R = \frac{V}{R} = \frac{V_0}{R}\sin wt$$
$$= I_{R0}\sin wt$$

The voltage across the inductor is

$$I_L = I_{L0}\sin\left(wt - \frac{\pi}{2}\right)$$

Similarly, the voltage across the capacitor is

$$I_C = I_{C0}\sin\left(wt + \frac{\pi}{2}\right)$$

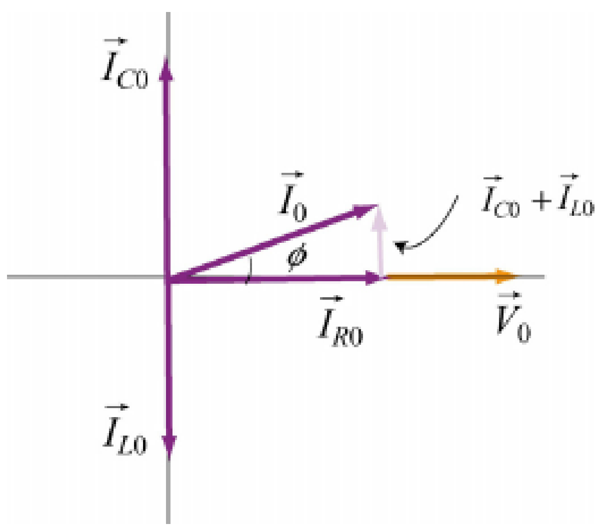
Using Kirchhoff’s junction rule, the total current in the circuit is simply the sum of all three currents.

$$I = I_R + I_L + I_C$$

$$= I_{R0} \sin \omega t + I_{L0} \sin\left( \omega t - \frac{\pi}{2} \right) + I_{C0} \sin\left( \omega t + \frac{\pi}{2} \right)$$

The currents can be represented with the phasor diagram shown in Figure. $I_0$, can be obtained as

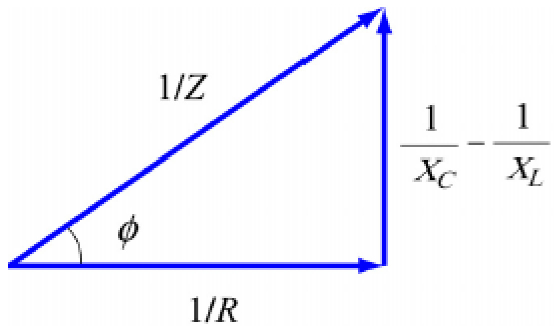
$$I_0 = |\vec{I}_0| = |\vec{I}_{R0} + \vec{I}_{L0} + \vec{I}_{C0}| = \sqrt{I_{R0}^2 + (I_{C0} - I_{L0})^2}$$
$$= V_0 \sqrt{\frac{1}{R^2} + \left( \omega C - \frac{1}{\omega L} \right)^2} = V_0 \sqrt{\frac{1}{R^2} + \left( \frac{1}{X_C} - \frac{1}{X_L} \right)^2}$$




With $I_0 = V_0 / Z$ the (inverse) impedance of the circuit is given by

$$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \left(\omega C - \frac{1}{\omega L}\right)^2} = \sqrt{\frac{1}{R^2} + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^2}$$

The relationship between *Z*, *R*, and *L* is shown in below Figure




From the figure or the phasor diagram shown in below Figure, we see that the phase can be obtained as

The resonance condition for the parallel *RLC* circuit is given by φ=0, which implies

$$\frac{1}{X_C} = \frac{1}{X_L}$$

The resonant frequency is

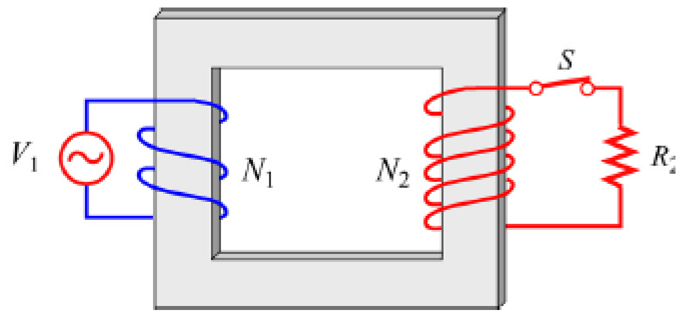
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

which is the same as for the series *RLC* circuit., we readily see that $1/Z$ is minimum (or $Z$ is maximum) at resonance. The current in the inductor exactly cancels out the current in the capacitor, so that the total current in the circuit reaches a minimum, and is equal to the current in the resistor:

$$I_0 = \frac{V_0}{R}$$

## Transformer

A transformer is a device used to increase or decrease the AC voltage in a circuit. A typical device consists of two coils of wire, a primary and a secondary, wound around an iron core, as illustrated in down Figure. The primary coil, with $N_1$ turns, is connected to alternating voltage source $V_t$ . The secondary coil has $N_2$ turns and is connected to a “load resistance” $R_2$. The way transformers operate is based on the principle that an alternating current in the primary coil will induce an alternating emf on the secondary coil due to their mutual inductance




In the primary circuit, neglecting the small resistance in the coil, Faraday's law of induction implies

$$V_1 = -N_1 \frac{d\Phi_B}{dt}$$

where $\Phi_B$ is the magnetic flux through one turn of the primary coil. The iron core, which extends from the primary to the secondary coils, serves to increase the magnetic field produced by the current in the primary coil and ensure that nearly all the magnetic flux through the primary coil also passes through each turn of the secondary coil. Thus, the voltage (or induced emf) across the secondary coil is

$$V_2 = -N_2 \frac{d\Phi_B}{dt}$$

In the case of an ideal transformer, power loss due to Joule heating can be ignored, so that the power supplied by the primary coil is completely transferred to the secondary coil:

$$I_1 V_1 = I_2 V_2$$

In addition, no magnetic flux leaks out from the iron core, and the flux $\Phi_B$ through each turn is the same in both the primary and the secondary coils. Combining the two expressions, we are lead to the transformer equation

$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1}}$$

By combining the two equations above, the transformation of currents in the two coils may be obtained as:

$$I_1 = \left( \frac{V_2}{V_1} \right) I_2 = \left( \frac{N_2}{N_1} \right) I_2$$

Thus, we see that the ratio of the output voltage to the input voltage is determined by the *turn ratio* $N_2/N_1$ if $N_2>N_1$ then $V_2>V_1$ which means that output voltage in the second coil is greater than the input voltage in the primary coil. A transformer with $N_2>N_1$ is called a *step-up* transformer. On other hand if $N_2<N_1$ then $V_2<V_1$ and the transformer is called step down transformer

**Summary**

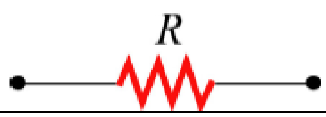
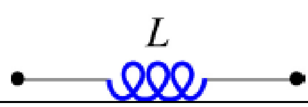
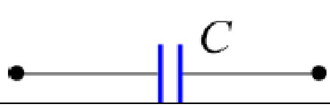
In an AC circuit with a sinusoidal voltage source

$$V = V_0 \sin wt$$

the current is given by

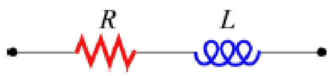
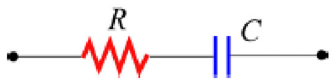
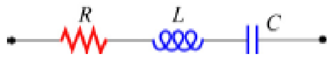
$$I = I_0 \sin(wt - \phi)$$

Where , $I_0$ is the amplitude and $\phi$ is the phase constant. For simple circuit with only one element (a resistor, a capacitor or an inductor) connected to the voltage source, the results are as follows:

| Circuit Elements | Resistance /Reactance | Current Amplitude | Phase angle $\phi$ |
|---|---|---|---|
|   | $R$ | $I_{R0} = \frac{V_0}{R}$ | 0 |
|   | $X_L = \omega L$ | $I_{L0} = \frac{V_0}{X_L}$ | $\pi/2$ current lags voltage by $90°$ |
|   | $X_C = \frac{1}{\omega C}$ | $I_{C0} = \frac{V_0}{X_C}$ | $-\pi/2$ current leads voltage by $90°$ |

where $X_L$ is the **inductive reactance** and $X_C$ is the **capacitive reactance**

For circuits which have more than one circuit element connected in series, the results are

| Circuit Elements | Impedance $Z$ | Current Amplitude | Phase angle $\phi$ |
| --- | --- | --- | --- |
|   | $\sqrt{R^2+X_L^2}$ | $I_0=\frac{V_0}{\sqrt{R^2+X_L^2}}$ | $0<\phi<\frac{\pi}{2}$ |
|   | $\sqrt{R^2+X_C^2}$ | $I_0=\frac{V_0}{\sqrt{R^2+X_C^2}}$ | $-\frac{\pi}{2}<\phi<0$ |
|   | $\sqrt{R^2+(X_L-X_C)^2}$ | $I_0=\frac{V_0}{\sqrt{R^2+(X_L-X_C)^2}}$ | $\phi>0$ if $X_L>X_C$<br>$\phi<0$ if $X_L<X_C$ |

where $Z$ is the **impedance** $Z$ of the circuit. For a series *RLC* circuit, we have

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

The phase angle between the voltage and the current in an AC circuit is

$$\phi=\tan^{-1}\left(\frac{X_L-X_C}{R}\right)$$

- In the parallel *RLC* circuit, the impedance is given by

$$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \left( \omega C - \frac{1}{\omega L} \right)^2} = \sqrt{\frac{1}{R^2} + \left( \frac{1}{X_C} - \frac{1}{X_L} \right)^2}$$

and the phase is

$$\phi = \tan^{-1}\left[ R\left( \frac{1}{X_C} - \frac{1}{X_L} \right) \right] = \tan^{-1}\left[ R\left( \omega C - \frac{1}{\omega L} \right) \right]$$

- The **rms** (root mean square) voltage and current in an AC circuit are given by

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}, \qquad I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

The **resonant frequency**

At **resonance**, the current in the series *RLC* circuit reaches the maximum, but the current in the parallel *RLC* circuit is at a minimum.

- The **transformer equation** is

$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1}}$$

where $V_1$ is the voltage source in the primary coil with $N_1$ turns, and $V_2$ is the output voltage in the secondary coil with $N_2$ turns. A transformer with $N_2>N_1$ is called a *step-up* transformer, and a transformer with $N_2<N_1$ is called a *step-down* transformer.

- Keep in mind the phase relationships for simple circuits

(1) For a resistor, the voltage and the phase are always in phase.

(2) For an inductor, the current lags the voltage by. 90°

(3) For a capacitor, the current leads to voltage by . 90°

When circuit elements are connected in *series*, the instantaneous current is the same for all elements, and the instantaneous voltages across the elements are out of phase. On the other hand, when circuit elements are connected in *parallel*, the instantaneous voltage is the same for all elements, and the instantaneous currents across the elements are out of phase.

Ex1.

A series *RLC* circuit with L=160 mH and C=100 $\mu$F and R = 40 Ω is connected to a sinusoidal voltage V=40 sin wt

With w =200 rad/s

1. What is the impedance of the circuit

2. What is the phase φ

The impedance of a series *RLC* circuit is given by

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

$$X_L = \omega L$$

$$X_C = \frac{1}{\omega C}$$

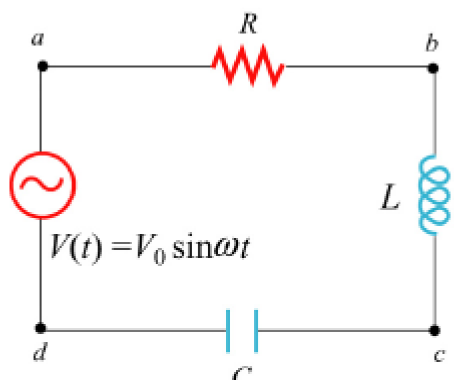
$$Z = \sqrt{(40.0\ \Omega)^2 + \left((200\ \text{rad/s})(0.160\ \text{H}) - \frac{1}{(200\ \text{rad/s})(100\times10^{-6}\ \text{F})}\right)^2}$$
$$= 43.9\,\Omega$$

The phase between the current and the voltage is determined by

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) = \tan^{-1}\left(\frac{\omega L - \dfrac{1}{\omega C}}{R}\right)$$

$$= \tan^{-1}\left(\frac{(200\ \text{rad/s})(0.160\ \text{H}) - \dfrac{1}{(200\ \text{rad/s})(100\times10^{-6}\ \text{F})}}{40.0\ \Omega}\right) = -24.2^\circ$$

Ex2



Suppose an AC generator with V=150 sin 100t is connected to a series *RLC* circuit with R=40 ohm , L=80 mH and C=50 $\mu$F

Calculate $V_{R0}$, $V_{L0}$ and $V_{C0}$ the maximum of the voltage drops across each circuit element

The inductive reactance, capacitive reactance and the impedance of the circuit are given by

$$X_C = \frac{1}{\omega C} = \frac{1}{(100 \text{ rad/s})(50.0\times10^{-6} \text{ F})} = 200\ \Omega$$

$$X_L = \omega L = (100 \text{ rad/s})(80.0\times10^{-3} \text{ H}) = 8.00\ \Omega$$

**Mark (√) to the True sentence and (×) to False one.**

1. AC current is a constant current
2. Solar cells are a source of AC
3. Inverter is used to convert DC to AC
4. AC is using in lighting and operation of electrical tools

5. AC power is using in metal coating
6. AC is passing through the capacitors while not passing the DC through capacitors
7. The hot-coil Ammeter is used in DC measurement
8. Frequency: is the number of oscillations generated by current or voltage per second
9. The electrical current (AC) can be increased or reduced using electrical transformers
10. For the resistive circuit, both current and voltage are reaching their maximum or minimum values at the same time.
11. The inductive reactance $X_L$. has units of ohms (Ω),
12. $X_L$ depends linearly on the angular frequency *w*.
13. The inductive reactance, $X_{L,}$ vanishes as *w* approaches maximum value
14. The current lags (delays) voltage by π / 2 in a purely inductive circuit.
15. In purely inductive circuit the inductive reactance is $X_L = 2fL$

16. The capacitance reactance ,$X_{C,}$ is direct proportional to both Capacitor (C) and angular frequency( $w$ )

17. ,$X_C$ diverges as ω approaches zero.

18. In capacitive circuit, the current delays the voltage by $\pi/2$ in capacitive circuit

19. The capacitance reactance in capacitive circuit is calculated from $X_C = \dfrac{1}{2\pi fC}$

20. Capacitance is the amount of electrical charge required to raise the voltage difference between the two panels by one volt

21. Resonance occurs in the case of an RLC circuit connected in serial with a voltage source when $X_C = X_L$.

22. In resonance RLC case, the phase difference between current and voltage is 90 degrees

23.

**Choose the Correct answer**

**The voltage in AC is expressed by :**

A. Vsin ω
B. sin t
C. $V_o$ sin ωt
D. V=IR

**The Current intensity in AC is expressed by :**

A. Isin ω
B. sin t
C. $V_o$ sin ωt
D. V=IR

**The current and voltage of the AC current have two corresponding phases if they are:**

A. They reach to their maximum and minimum at same time.
B. The  current delayed to the voltage with angle
C. The current precedes the voltage at an angle
D. The minimum value of the voltage equals the maximum value of the current

**The electric generator or dynamo converts mechanical energy into:**

A. Electrical energy
B. Solar energy
C. Kinetic energy
D. DC current

The generated power in resistance is calculated from

A. $P=I_{max} V_{max}/2$
B. $P=V_{max}/2$
C. $P=I_{max}/2$
D. $P=V_{rms}/2$

The maximum value of AC current produces a heat equal three times the produced heat from 2 Ampere DC

A. 3.3 Ampere
B. 2.9 Ampere
C. 4.94 Ampere
D. 5.8 Ampere

The maximum value of AC current produces a heat equal three times the produced heat from 2 Ampere DC

E. 3.3 Ampere
F. 2.9 Ampere
G. 4.94 Ampere
H. 5.8 Ampere

AC volts its value equal 4 is connected with 100 ohm of pure resistance. it was found that the current in mA is

A. 20 mA
B. 30.3 mA a
C. 28 mA
D. 22 mA

AC volts its value equal 4 is connected with 100 ohm of pure resistance . it was found that the power in mW is

A. 105 mW
B. 22.8 mW
C. 78 mW
D. 13.6 mW

In AC circuit has a capacitor , the $X_C$ is -A

B- $X_c = \frac{1}{2\pi f C}$

C- $X_c = \frac{1}{\pi f C}$

D- $X_c = \frac{1}{f C}$

E- $X_c = \frac{1}{f}$

In a AC circuit with a capacitor its capacity equals 1 microfarad, if the frequency is 1000 Hz and the current in the circuit is equal to 2 mA. It was found that voltage through the capacitor is

A. 21.2 volts
B. 33.2 volts

C. 0.32 volts
D. 0.56 volts

In a AC circuit with a capacitor its capacity equals 1 microfarad if the frequency of the current 50 Hz, then $X_C$ is

A. $X_C$ =2500 Ohm
B. $X_C$ =1702 Ohm
C. $X_C$ =3180 Ohm
D. $X_C$ =2652 Ohm

The inductance $X_L$ for AC circuit has a conductance L is

A. $X_L = \pi f L$
B. $X_L = wL$
C. $X_L = fL$
D. $X_L = 2L$

The generated power in resistance is calculated from

E. $P=I_{max} V_{max}/2$
F. $P=V_{max}/2$
G. $P=I_{max}/2$
H. $P=V_{rms}/2$

The maximum value of current produces a heat equal three times the produced heat from DC its value 2 Ampere

I. 3.3 Ampere
J. 2.9 Ampere
K. 4.94 Ampere
L. 5.8 Ampere

AC volts its value equal 4 is connected with 100 ohm of pure resistance . it was found that the current in mA is

E. 20 mA
F. 30.3 mA a
G. 28 mA
H. 22 mA

The inductance $X_L$ for AC circuit has a conductance is

E. $X_L = \pi f L$

F. $X_L = wL$

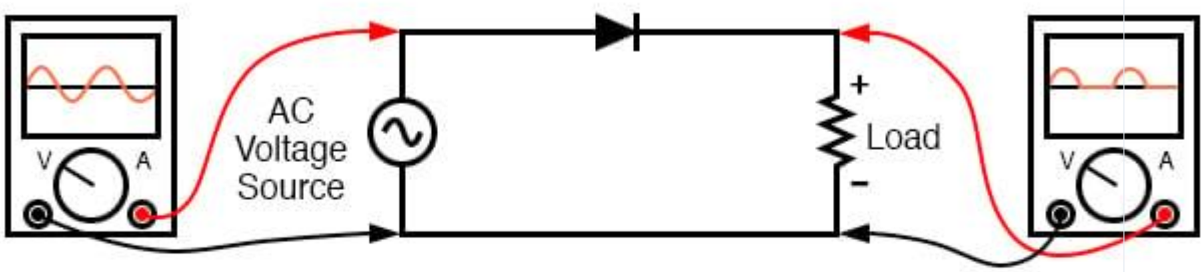
G. $X_L = fL$

# Fourth Chapter

## AC Rectification

DEFINITION: rectification is the conversion of alternating current (AC) to direct current (DC). This involves a device that only allows one-way flow of electrons. This is exactly what a semiconductor diode does. The simplest kind of rectifier circuit is the half-wave rectifier. It only allows one half of an AC waveform to pass through to the load. (Figure below). The type of supply available from a half-wave rectifier is not satisfactory for general power supply.This type of supply can be satisfactory for some particular purposes such as battery charging.

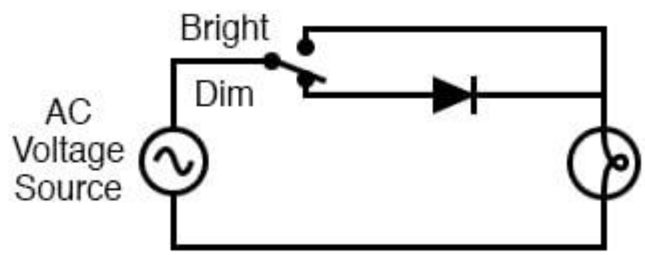
Now we come to the most popular application of the diode: *rectification*. Simply defined, rectification is the conversion of alternating current (AC) to direct current (DC). This involves a device that only allows one-way flow of electric charge. As we have seen, this is exactly what a semiconductor diode does. The simplest kind of rectifier circuit is the *half-wave* rectifier. It only allows one half of an AC waveform to pass through to the load. (Figure below)




Half-wave rectifier circuit.

## Half-Wave Rectification

For most power applications, half-wave rectification is insufficient for the task. The harmonic content of the rectifier's output waveform is very large and consequently difficult to filter. Furthermore, the AC power source only supplies power to the load one half every full cycle, meaning that half of its capacity is unused. Half-wave rectification is, however, a very simple way to reduce power to a resistive load. Some two-position lamp dimmer switches apply full AC power to the lamp filament for "full" brightness and then half-wave rectify it for a lesser light output. (figure below)



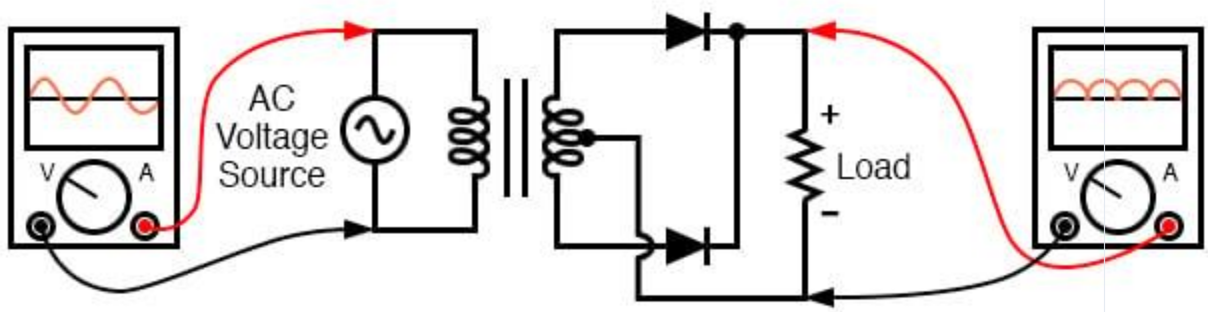

**Half-wave rectifier application: Two level lamp dimmer.**

In the "Dim" switch position, the incandescent lamp receives approximately one-half the power it would normally receive operating on full-wave AC. Because the half-wave rectified power pulses far more rapidly than the filament has time to heat up and cool down, the lamp does not blink. Instead, its filament merely operates at a lesser temperature than normal, providing less light output.

This principle of "pulsing" power rapidly to a slow-responding load device to control the electrical power sent to it is common in the world of industrial electronics. Since the controlling device (the diode, in this case) is either fully conducting or fully nonconducting at any given time, it dissipates little heat energy while controlling load power, making this method of power control very energy-efficient. This circuit is perhaps the crudest possible method of pulsing power to a load, but it suffices as a proof-of-concept application.

## Full-Wave Rectifiers

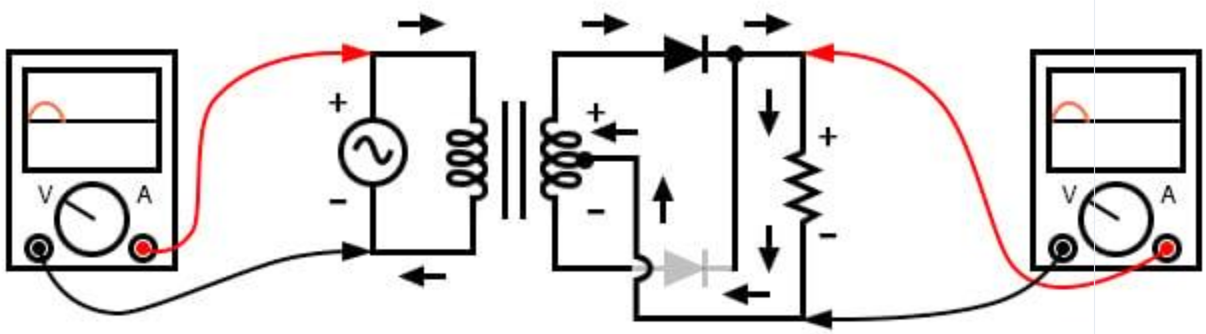
If we need to rectify AC power to obtain the full use of *both* half-cycles of the sine wave, a different rectifier circuit configuration must be used. Such a circuit is called a *full-wave* rectifier. One kind of full-wave rectifier, called the *center-tap* design, uses a transformer with a center-tapped secondary winding and two diodes, as in the figure below.




**Full-wave rectifier, center-tapped design.**

## Positive Half-Cycle

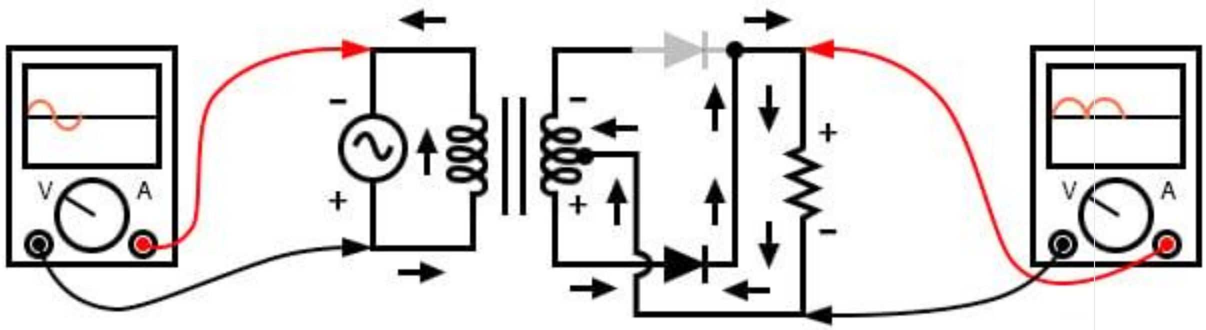
This circuit's operation is easily understood one half-cycle at a time. Consider the first half-cycle, when the source voltage polarity is positive (+) on top and negative (-) on bottom. At this time, only the top diode is conducting; the bottom diode is blocking current, and the load "sees" the first half of the sine wave, positive on top and negative on bottom. Only the top half of the transformer's secondary winding carries current during this half-cycle as in the figure below.




Full-wave center-tap rectifier: Top half of secondary winding conducts during positive half-cycle of input, delivering positive half-cycle to load.

## Negative Half-Cycle

During the next half-cycle, the AC polarity reverses. Now, the other diode and the other half of the transformer's secondary winding carry current while the portions of the circuit formerly carrying current during the last half-cycle sit idle. The load still "sees" half of a sine wave, of the same polarity as before: positive on top and negative on bottom. (Figure below)



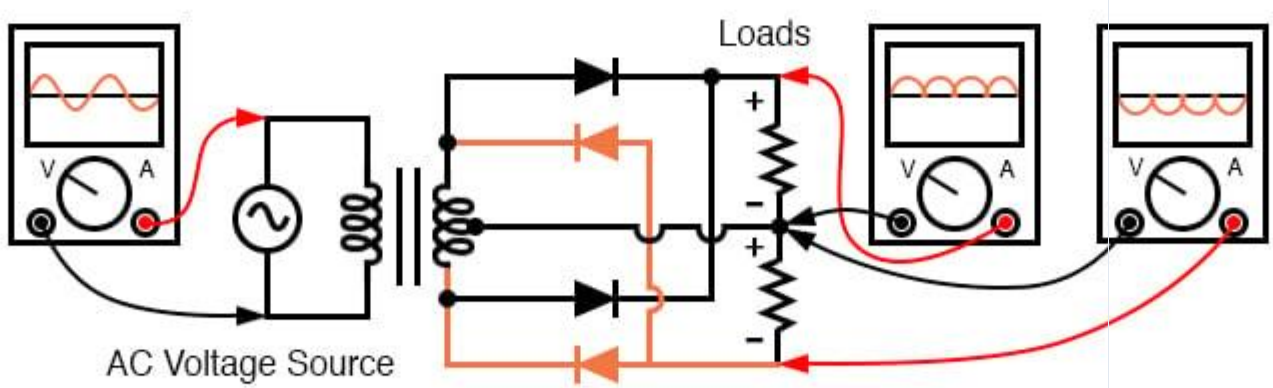

Full-wave center-tap rectifier: During negative input half-cycle, bottom half of secondary winding conducts, delivering a positive half-cycle to the load.

## Disadvantages of Full-wave rectifier Design

One disadvantage of this full-wave rectifier design is the necessity of a transformer with a center-tapped secondary winding. If the circuit in question is one of high power, the size and expense of a suitable transformer is significant. Consequently, the center-tap rectifier design is only seen in low-power applications.

# Other Configurations

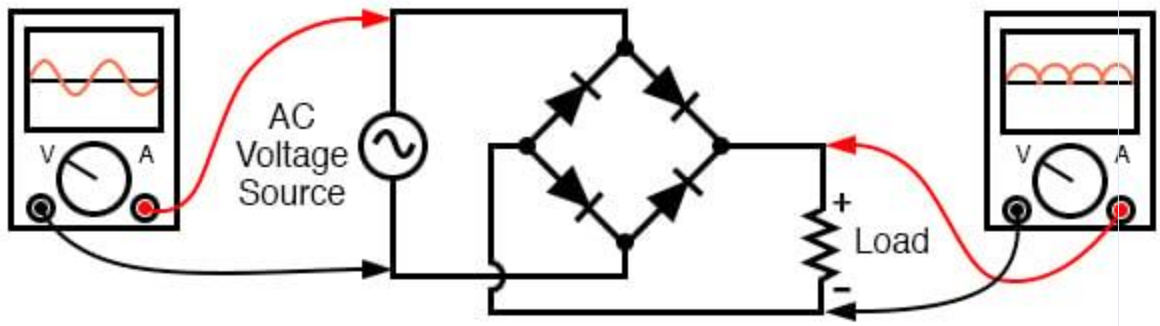
The full-wave center-tapped rectifier polarity at the load may be reversed by changing the direction of the diodes. Furthermore, the reversed diodes can be paralleled with an existing positive-output rectifier. The result is dual-polarity full-wave center-tapped rectifier in the figure below. Note that the connectivity of the diodes themselves is the same configuration as a bridge.




Dual polarity full-wave center tap rectifier

# Full-Wave Bridge Rectifiers

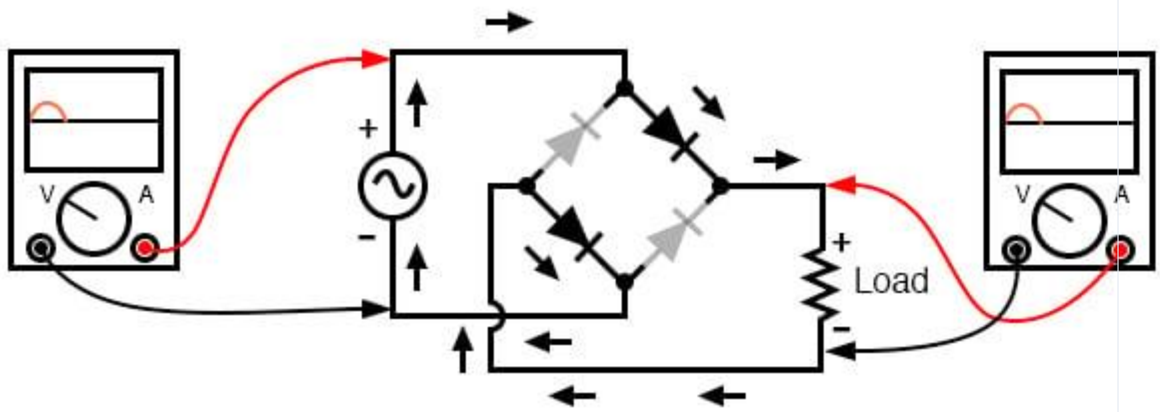
Another, more popular full-wave rectifier design exists, and it is built around a four-diode bridge configuration. For obvious reasons, this design is called a *full-wave bridge*. (Figure below)



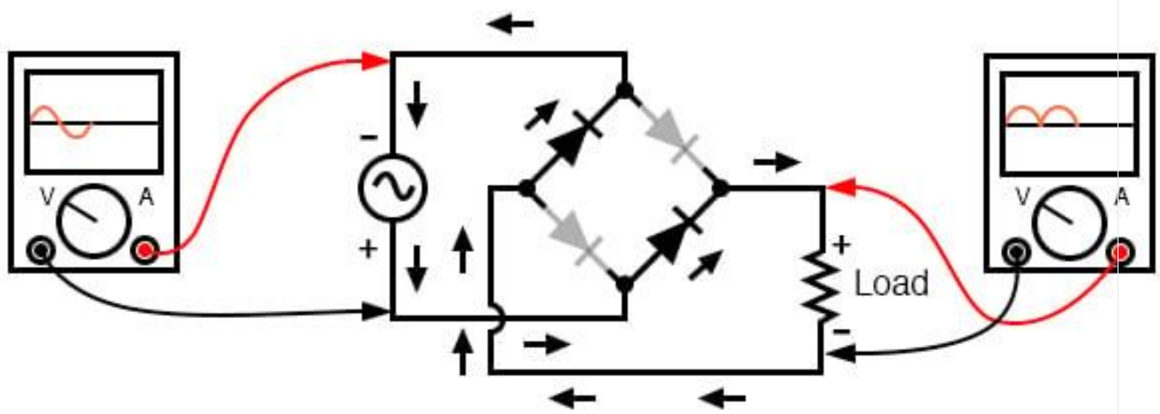

**Full-wave bridge rectifier.**

Current directions for the full-wave bridge rectifier circuit are as shown in the figure below for positive half-cycle and the figure below for negative half-cycles of the AC source waveform. Note that regardless of the polarity of the input, the current flows in the same direction through the load. That is, the negative half-cycle of source is a positive half-cycle at the load.

The current flow is through two diodes in series for both polarities. Thus, two diode drops of the source voltage are lost (0.7·2=1.4 V for Si) in the diodes. This is a disadvantage compared with a full-wave center-tap design. This disadvantage is only a problem in very low voltage power supplies.



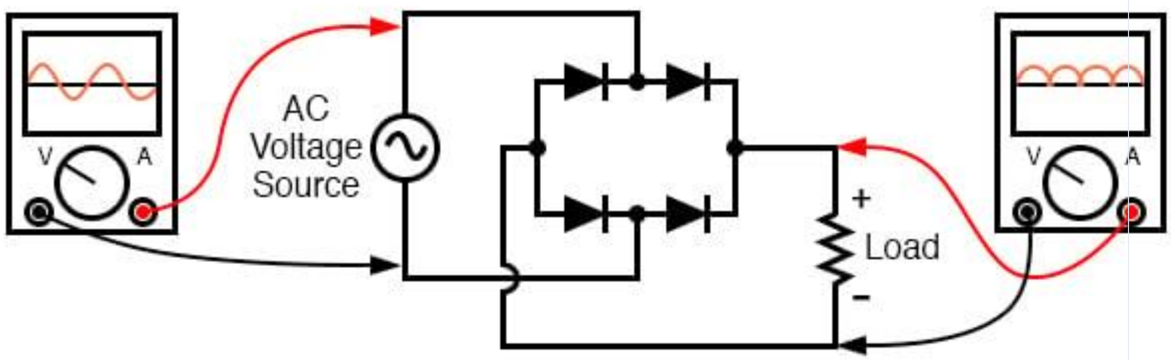

**Full-wave bridge rectifier: Current flow for positive half-cycles.**




**Full-wave bridge rectifier: Current flow for negative half-cycles.**

# Alternative Full-wave Bridge Rectifier Circuit Diagram

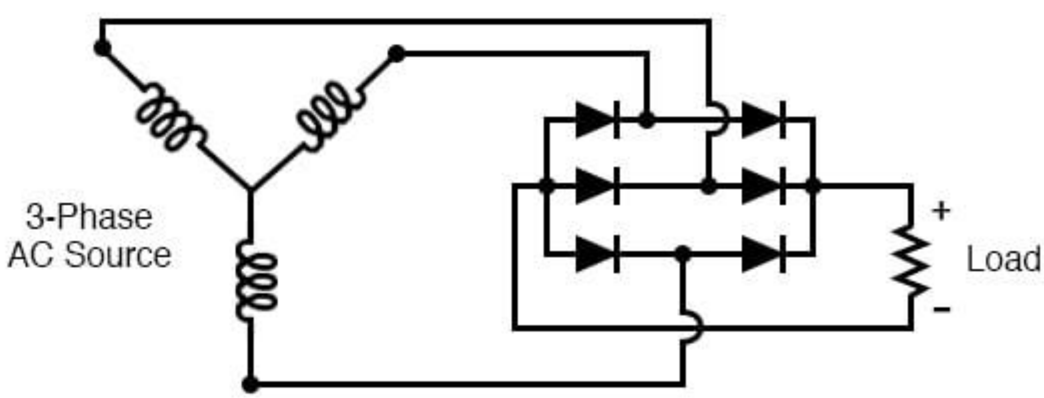
Remembering the proper layout of diodes in a full-wave bridge rectifier circuit can often be frustrating to the new student of electronics. I've found that an alternative representation of this circuit is easier both to remember and to comprehend. It's the exact same circuit, except all diodes are drawn in a horizontal attitude, all “pointing” the same direction. (Figure below)




Alternative layout style for Full-wave bridge rectifier.

**Polyphase Version using Alternative Layout**

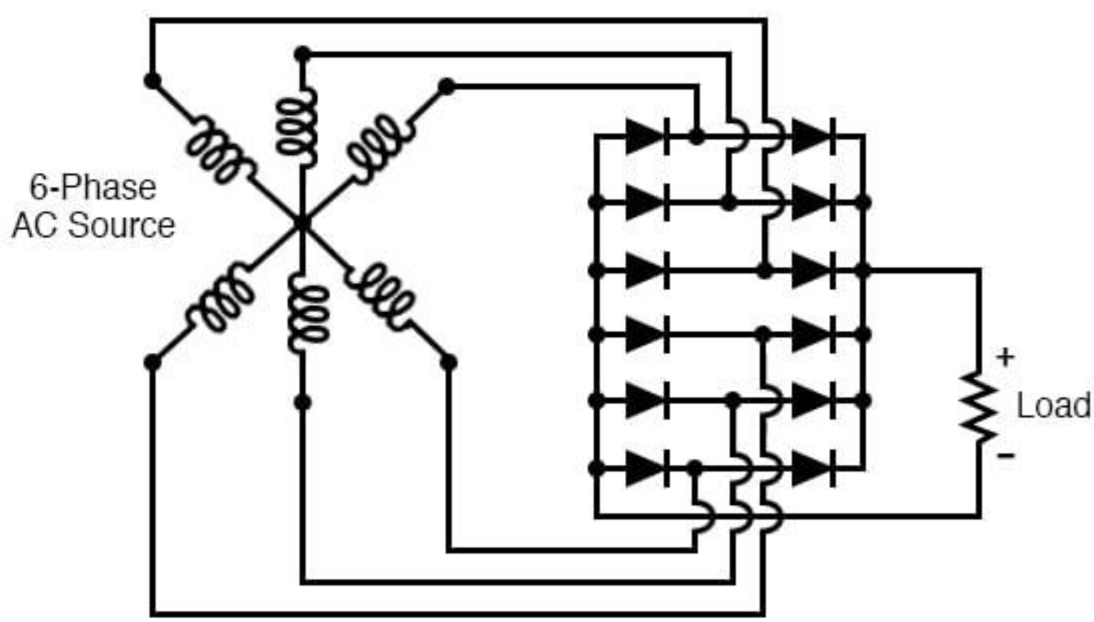
One advantage of remembering this layout for a bridge rectifier circuit is that it expands easily into a polyphase version in Figure below.




*Three-phase full-wave bridge rectifier circuit.*

Each three-phase line connects between a pair of diodes: one to route power to the positive (+) side of the load, and the other to route power to the negative (-) side of the load.

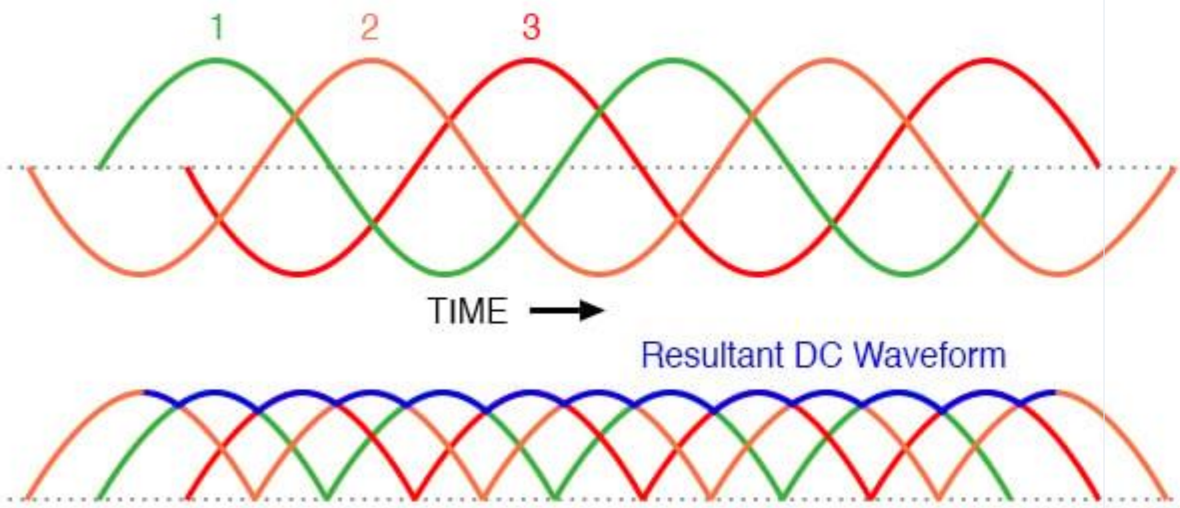
Polyphase systems with more than three phases are easily accommodated into a bridge rectifier scheme. Take for instance the six-phase bridge rectifier circuit in the figure below.




Six-phase full-wave bridge rectifier circuit.

When polyphaser AC is rectified, the phase-shifted pulses overlap each other to produce a DC output that is much “smoother” (has less AC content) than that produced by the rectification of single-phase AC. This is a decided advantage in high-power rectifier circuits, where the sheer physical size of filtering components would be prohibitive but low-noise DC power must be obtained.

The diagram in the figure below shows the full-wave rectification of three-phase AC.




***Three-phase AC and 3-phase full-wave rectifier output.***

# Ripple Voltage

In any case of rectification—single-phase or polyphase—the amount of AC voltage mixed with the rectifier's DC output is called *ripple voltage*. In most cases, since "pure" DC is the desired goal, ripple voltage is undesirable. If the power levels are not too great, filtering networks may be employed to reduce the amount of ripple in the output voltage.

### 1-Pulse, 2-Pulse, and 6-Pulse Units

Sometimes, the method of rectification is referred to by counting the number of DC "pulses" output for every $360^{o}$ of electrical "rotation." A single-phase, half-wave rectifier circuit, then, would be called a *1-pulse* rectifier, because it produces a single pulse during the time of one complete cycle (360$^o$) of the AC waveform. A single-phase, full-wave rectifier (regardless of design, center-tap or bridge) would be called a *2-pulse* rectifier because it outputs two pulses of DC during one AC cycle's worth of time. A three-phase full-wave rectifier would be called a *6-pulse* unit.

## Rectifier Circuit Phases

Modern electrical engineering convention further describes the function of a rectifier circuit by using a three-field notation of *phases*, *ways*, and number of *pulses*. A single-phase, half-wave rectifier circuit is given the somewhat cryptic designation of 1Ph1W1P (1 phase, 1 way, 1 pulse), meaning that the AC supply voltage is single-phase, that current on each phase of the AC supply lines moves in only one direction (way), and that there is a single pulse of DC produced for every 360$^o$ of electrical rotation.

## Is it Possible to Obtain More Pulses Than Twice the Number of Phases in a Rectifier Circuit?

The answer to this question is yes:, especially in polyphase circuits. Through the creative use of transformers, sets of full-wave rectifiers may be paralleled in such a way that more than six pulses of DC are produced for three phases of AC. A 30$^o$ phase shift is introduced from primary to secondary of a three-phase transformer when the winding configurations are not of the same type.

In other words, a transformer connected either Y-Δ or Δ-Y will exhibit this $30^{o}$ phase shift, while a transformer connected Y-Y or Δ-Δ will not. This phenomenon may be exploited by having one transformer connected Y-Y feed a bridge rectifier, and have another transformer connected Y-Δ feed a second bridge rectifier, then parallel the DC outputs of both rectifiers. (Figure below)

Since the ripple voltage waveforms of the two rectifiers' outputs are phase-shifted $30^{o}$ from one another, their superposition results in less ripple than either rectifier output considered separately: 12 pulses per $360^{o}$ instead of just six:

Polyphase rectifier circuit: 3-phase 2-way 12-pulse (3Ph2W12P)

**REVIEW:**

- *Rectification* is the conversion of alternating current (AC) to direct current (DC).
- A *half-wave* rectifier is a circuit that allows only one half-cycle of the AC voltage waveform to be applied to

the load, resulting in one non-alternating polarity across it. The resulting DC delivered to the load "pulsates" significantly.

- A *full-wave* rectifier is a circuit that converts both half-cycles of the AC voltage waveform to an unbroken series of voltage pulses of the same polarity. The resulting DC delivered to the load doesn't "pulsate" as much.
- Polyphase alternating current, when rectified, gives a much "smoother" DC waveform (less *ripple* voltage) than rectified single-phase AC.