IDC102:Hands-on Electronics
Lecture - 3

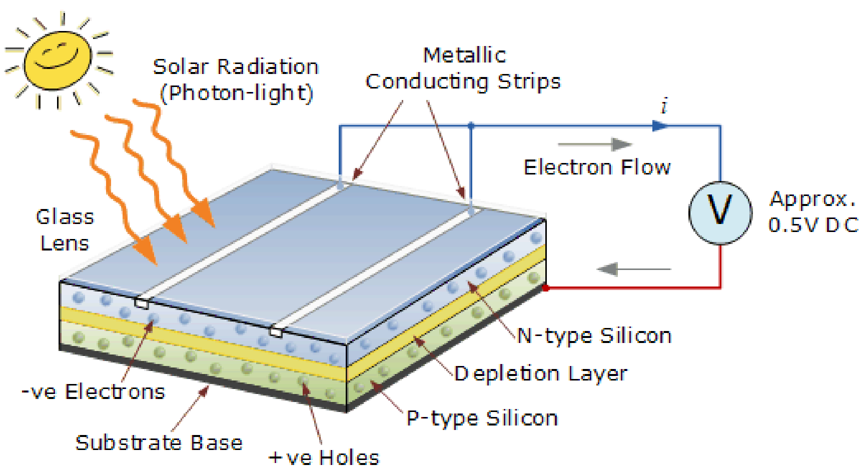
Basic - 3

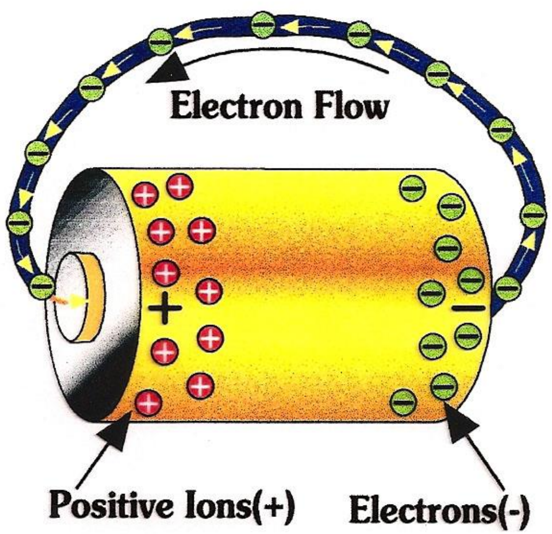
IISER

Satyajit Jena, 09/05/2022

DC electricity (Direct Current)

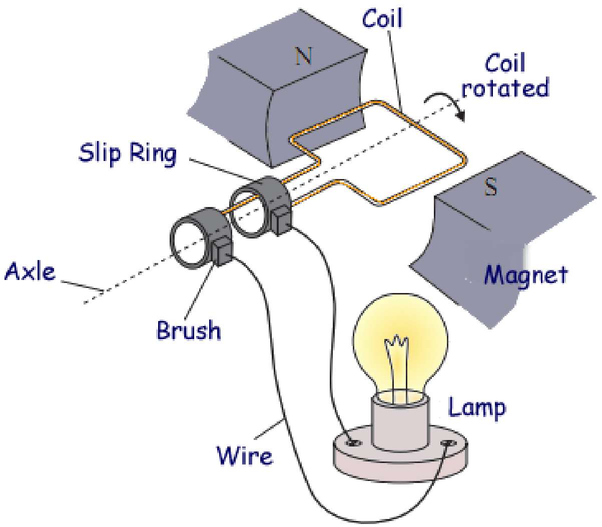
- The electrical energy we get from batteries and solar cells is transferred from where it is stored or produced to where it is required by a flow of charge in **one direction**
- We say that current is a flow of negative charge (electrons) that flows from negative to positive.



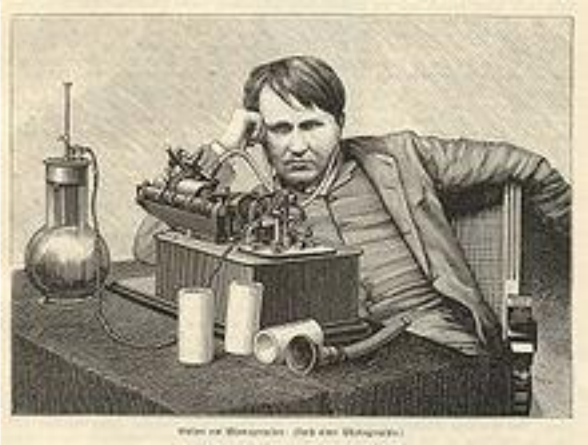


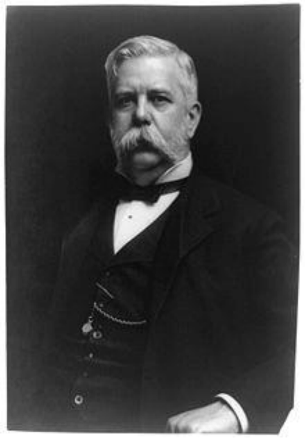
AC electricity (Alternating Current)

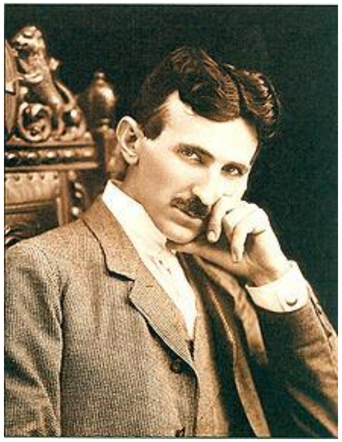
- AC electricity is produced by a "generator". This is a spinning magnet inside a stationary coil of wire.
- The electricity flows one way then the other. The frequency of this alternating current depends on the frequency of rotation of the generator.
- In the UK our electricity is produced using generators that spin 50 times a second (50Hz)
- This alternating current is pushed one way and than pulled back the other way. This means that the flow of charge is always changing!



The DC vs. AC Current Wars







Thomas Edison pushed for the development of a DC power network.

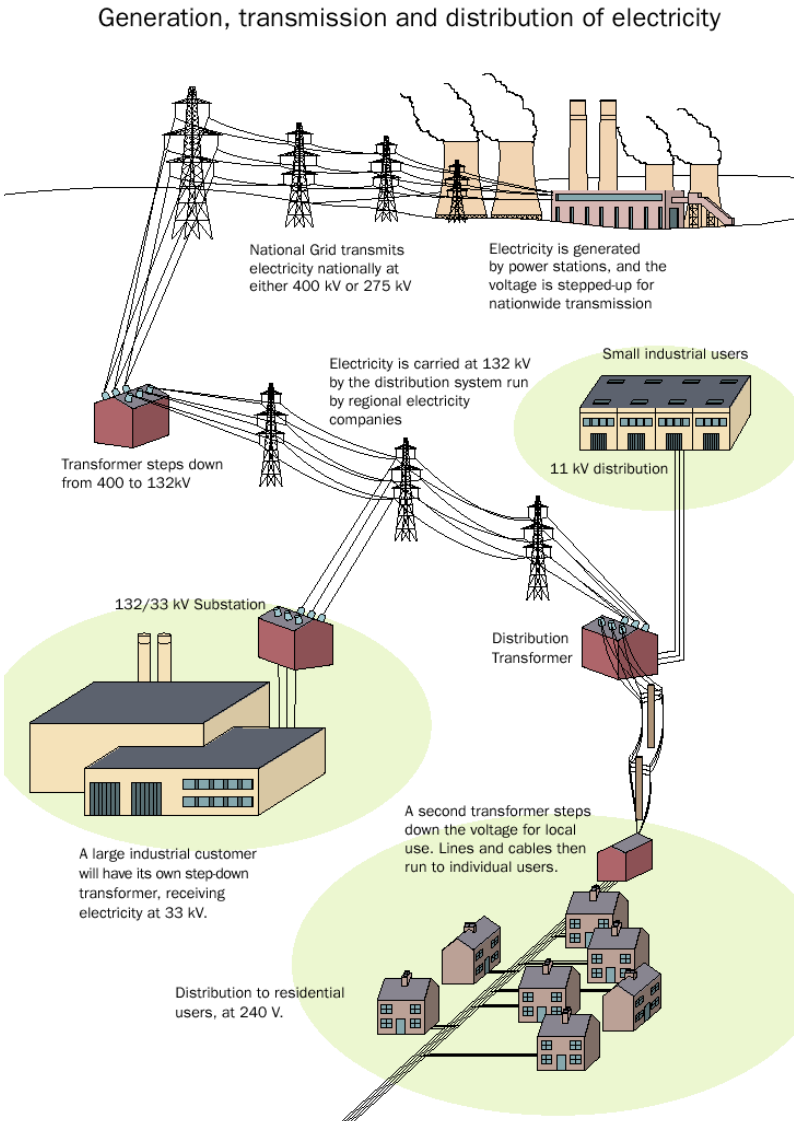
George Westinghouse backed Tesla's development of an AC power network.

Nikola Tesla was instrumental in developing AC networks.

Edison was a brute-force experimentalist but was no mathematician. AC cannot be properly understood or exploited without a substantial understanding of mathematics and mathematical physics, which Tesla possessed.

Edison tried all possible way to stop Tesla. He set out to convince the world that DC was superior for the transmission and distribution of power. He resorted to crazy demonstrations like killing large animals with AC in an attempt to prove its terrible dangers. For a time, he was successful, and most municipalities utilized local power plants with DC supply. However, getting power to less populated, rural communities all over the country with DC proved very inefficient, so Westinghouse ultimately won out and AC became the dominant power source.

AC Transmission Line



Transmission losses: $P_{loss} = RI^2$

Power = voltage x current

Increasing voltage twice reduces current twice and therefore reduces transmission losses 4 times

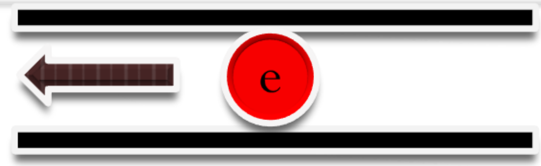
But increasing voltage level increases the cost of insulation

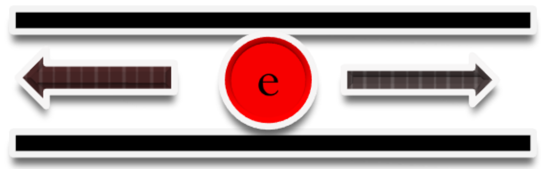
Transmission lines – longer distances, higher voltage (275 kV, 400 kV)

Distribution lines – shorter distances, lower voltage (132 kV, 33 kV, 11 kV)

AC vs DC

- Direct currents work by electrons moving one way from negative to positive. Whilst doing this they transfer energy or power
- Alternating currents work by moving electrons backwards and forwards. Whilst doing this they also transfer energy or power (but in a different way)
- If we think about it a direct current is a steady current with I the same all the time.
- If we think about an alternating current it changes all the time so we cannot do the same simple calculations.
- However, if we could convert the AC current to a DC current we could.....



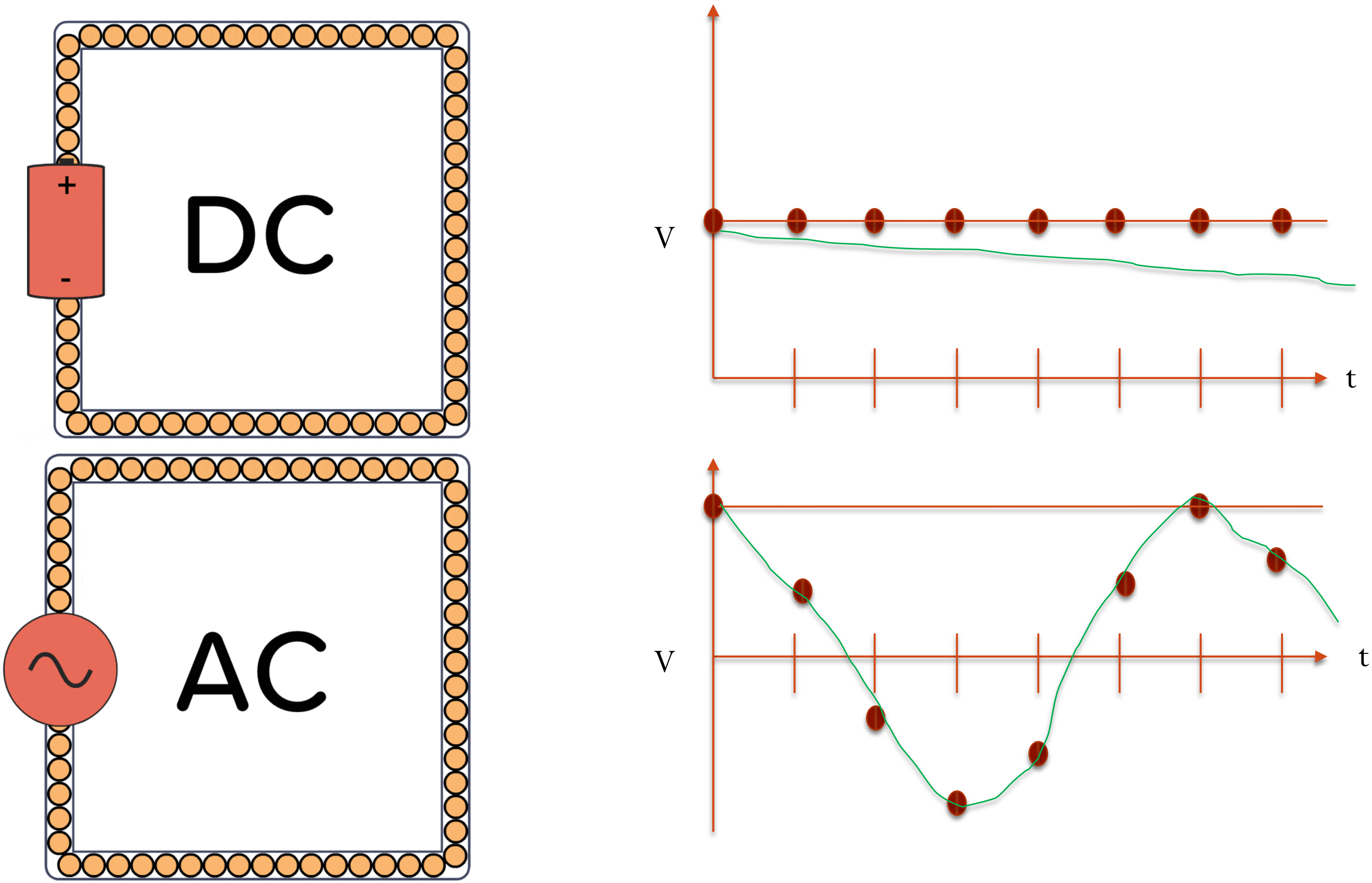


AC Constantly Changing current

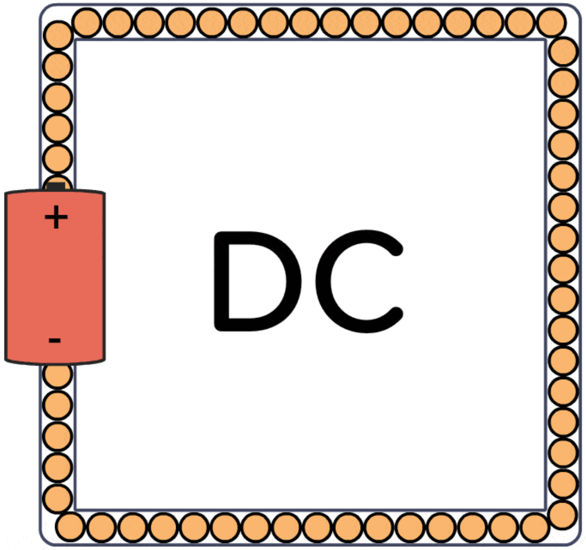
Convert it…

Steady DC Equivalent Current

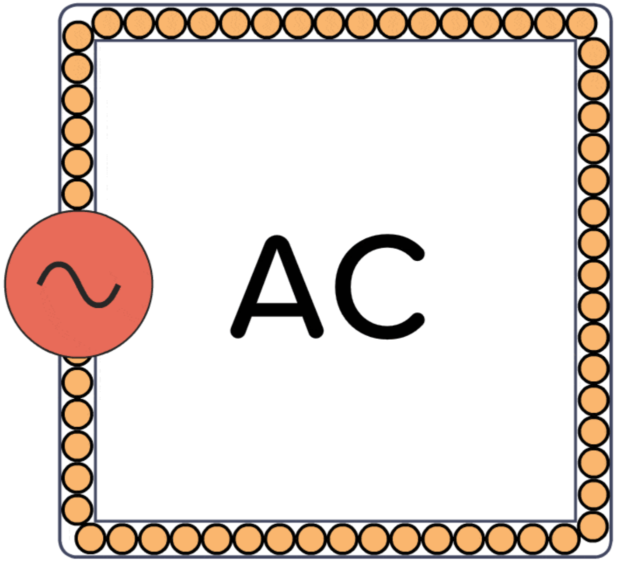
AC vs DC: Voltage



AC vs DC: Current



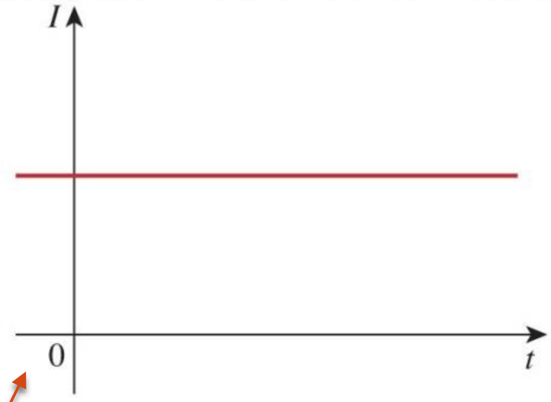
- **Direct Current (DC)** is a current that remains constant with time is called
- A common source of DC is a battery.



- A current that varies sinusoidally with time is called **Alternating Current (AC)**
- Mains power is an example of AC

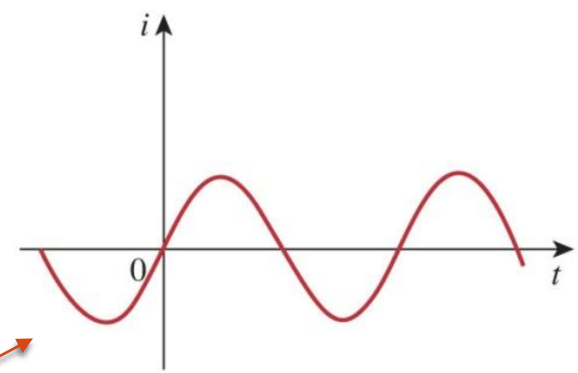
IDC102: Basics

- **Direct Current (DC)** is a current that remains constant with time is called
- A common source of DC is a battery.



(a)

- A current that varies sinusoidally with time is called **Alternating Current (AC)**
- Mains power is an example of AC

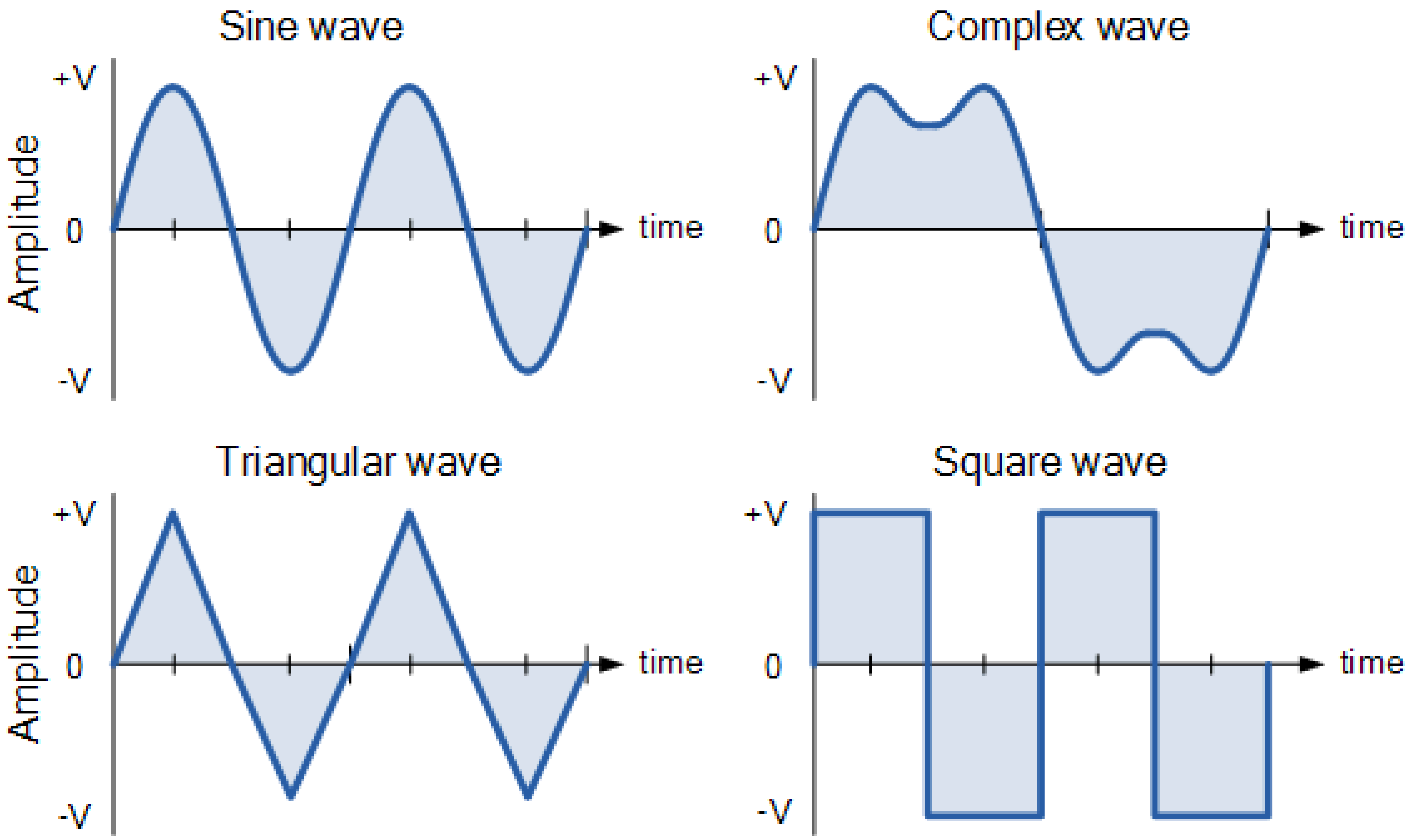


(b)

What are these?

These are called wave forms!

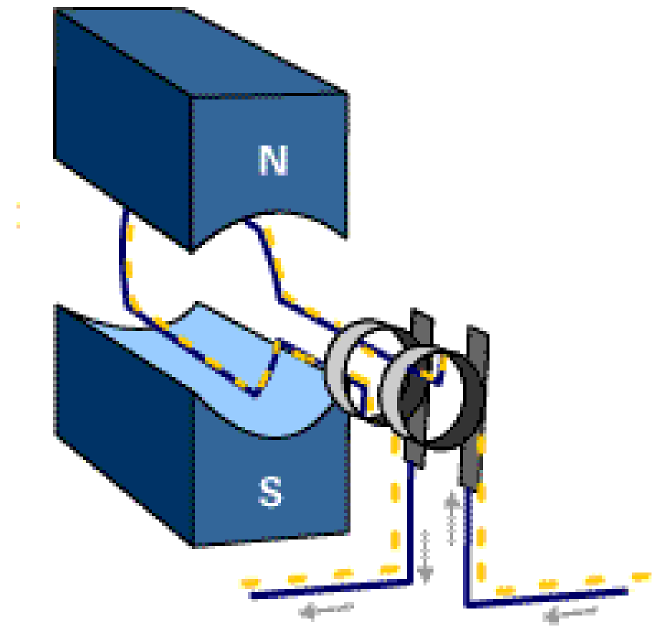
Waveforms

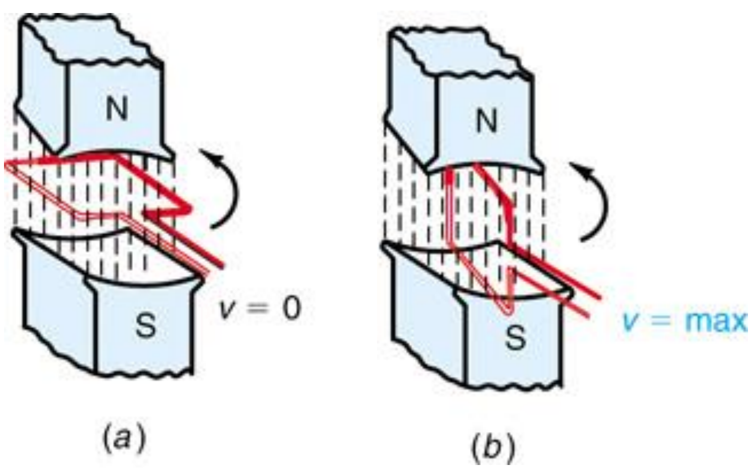


Waveforms are decided by the generators or power sources

Generator

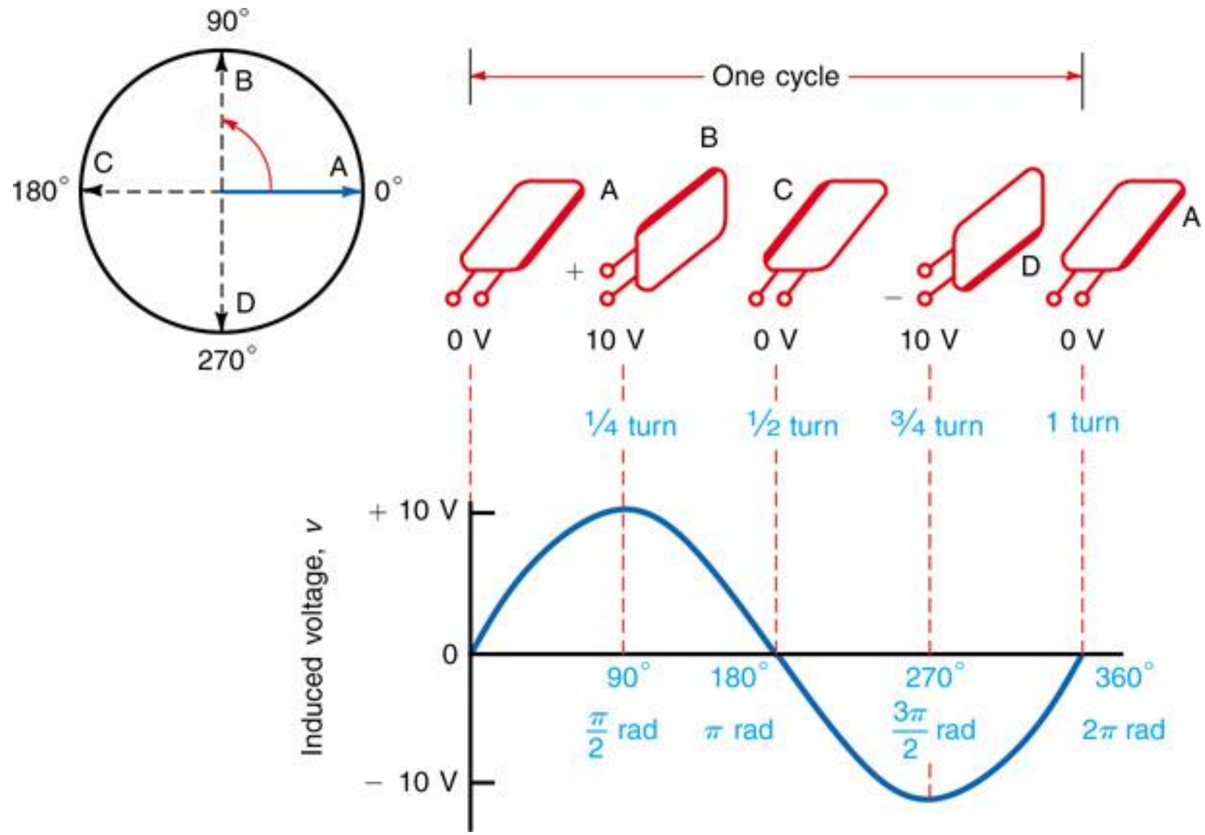
- This is a device that uses this basic principle to create a current that alternates (changes direction).
- As the coil rotates it cuts the lines of the magnetic field and a current is induced.
- If a wire is moved to cut across lines of magnetic flux a current will flow.





AC Generator

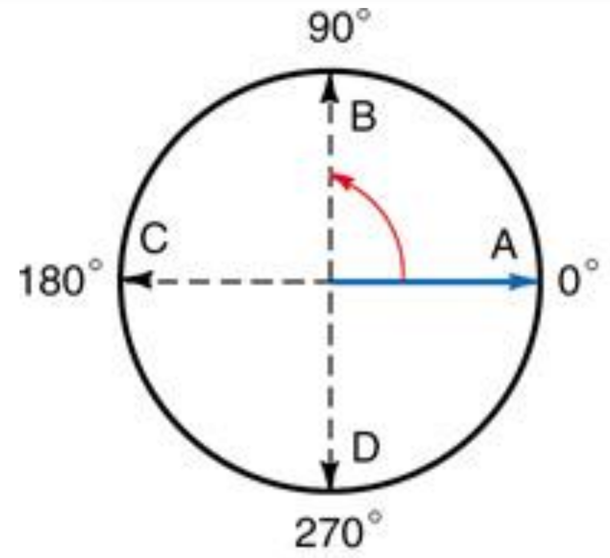
The voltage waveform shown is called a **sine** wave, **sinusoidal** wave , or **sinusoid** because the amount of induced voltage is proportional to the sine of the angle of rotation in the circular motion producing the voltage.

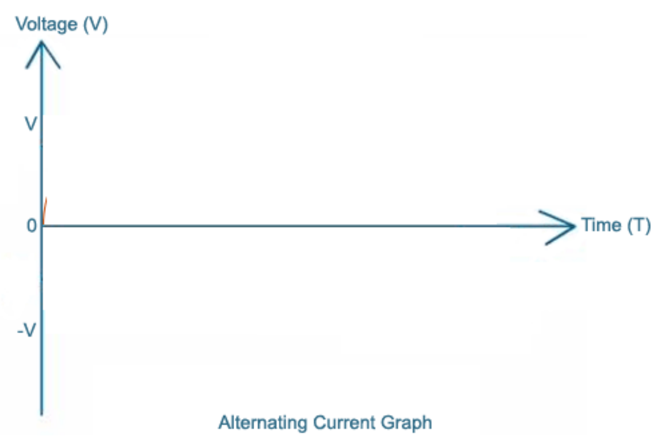


One cycle of alternating voltage generated by rotating loop. Magnetic field, not shown here, is directed from top to bottom

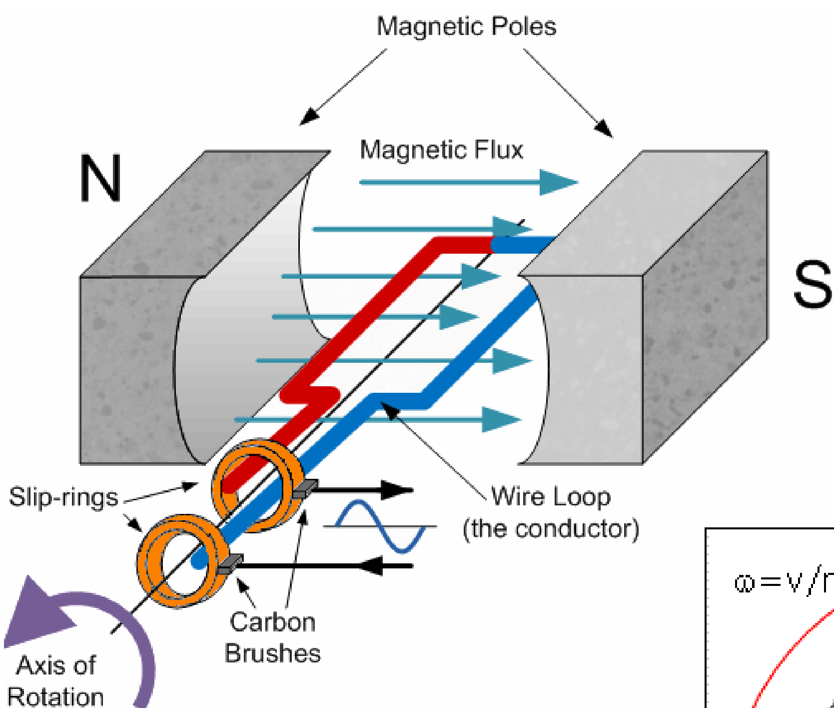
AC Angular Waveform

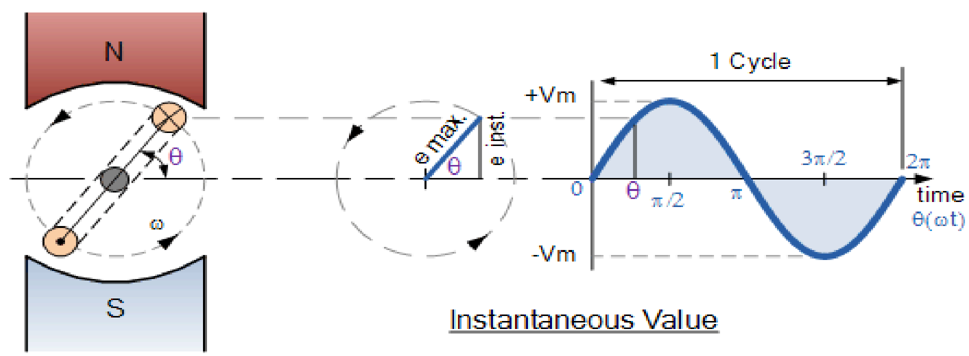
- Angular Measure and Radian Measure
  - The cycle of voltage corresponds to rotation of the loop around a circle, so parts of the cycle are described in angles.
  - The **radian** (rad) is an angle equivalent to 57.3°.
  - A radian is the angular part of the circle that includes an arc equal to the radius *r* of the circle.
  - A circle's circumference equals $2\pi r$, so one cycle equals 2π rad.



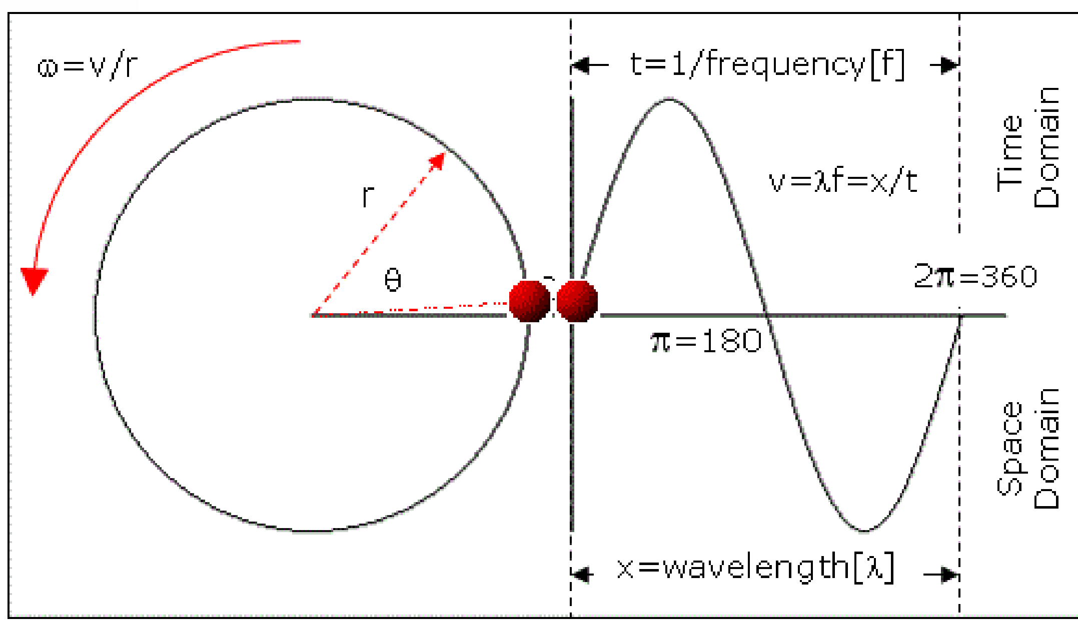


AC wave form



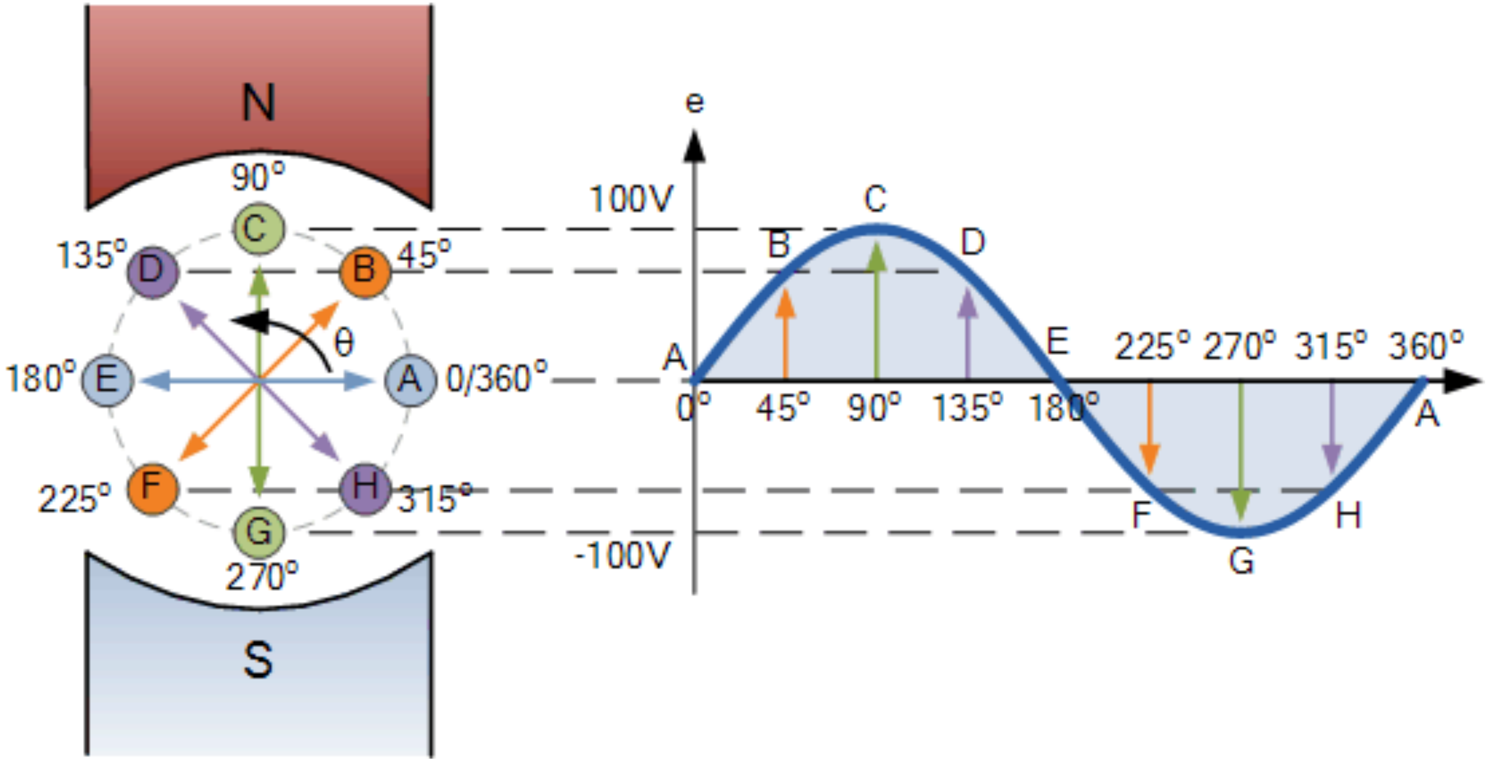


The rotation or angular frequencies of generators decide how fast this change would happen



Sinusoidal wave Construction

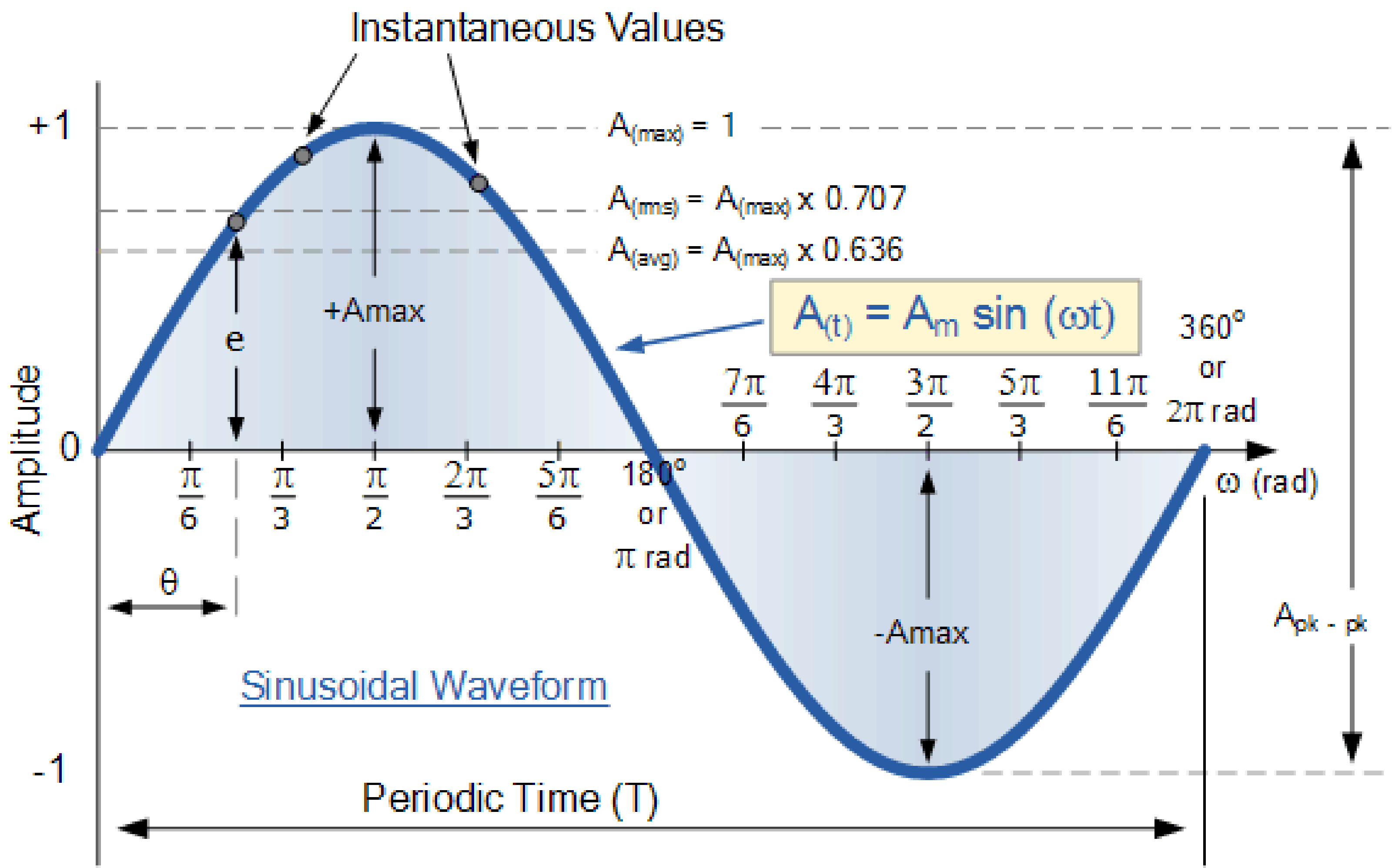
Coil Angle (θ)	0	45	90	135	180	225	270	315	360
e = Vmax.sinθ	0	70.71	100	70.71	0	-70.71	-100	-70.71	-0



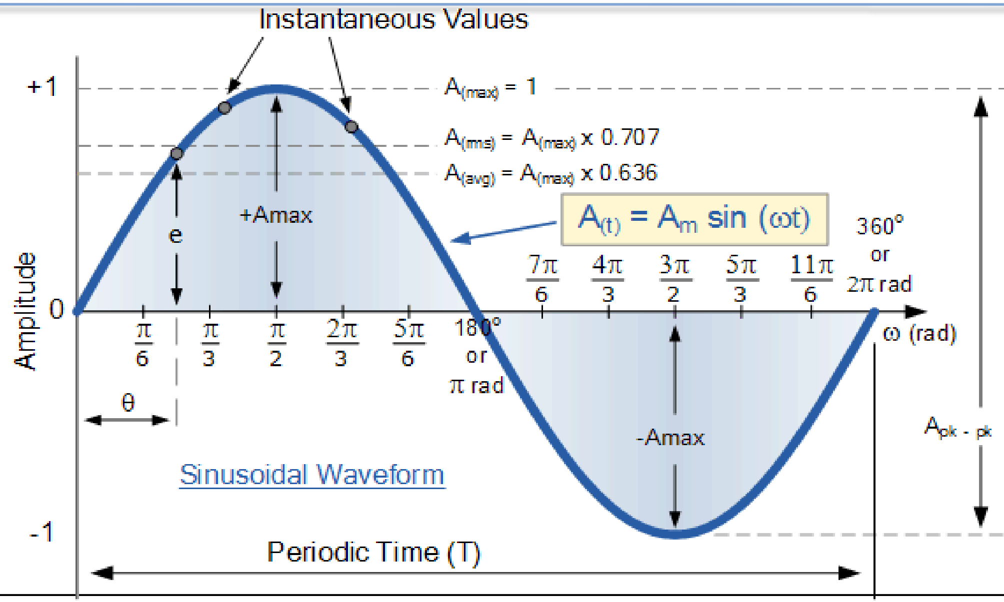
Degrees and Radians

Degrees	Radians	Degrees	Radians	Degrees	Radians
0^o	0	135^o	$\frac{3\pi}{4}$	270^o	$\frac{3\pi}{2}$
30^o	$\frac{\pi}{6}$	150^o	$\frac{5\pi}{6}$	300^o	$\frac{5\pi}{3}$
45^o	$\frac{\pi}{4}$	180^o	π	315^o	$\frac{7\pi}{4}$
60^o	$\frac{\pi}{3}$	210^o	$\frac{7\pi}{6}$	330^o	$\frac{11\pi}{6}$
90^o	$\frac{\pi}{2}$	225^o	$\frac{5\pi}{4}$	360^o	2π
120^o	$\frac{2\pi}{3}$	240^o	$\frac{4\pi}{3}$		

Sinusoidal Waveform



AC Waveform:

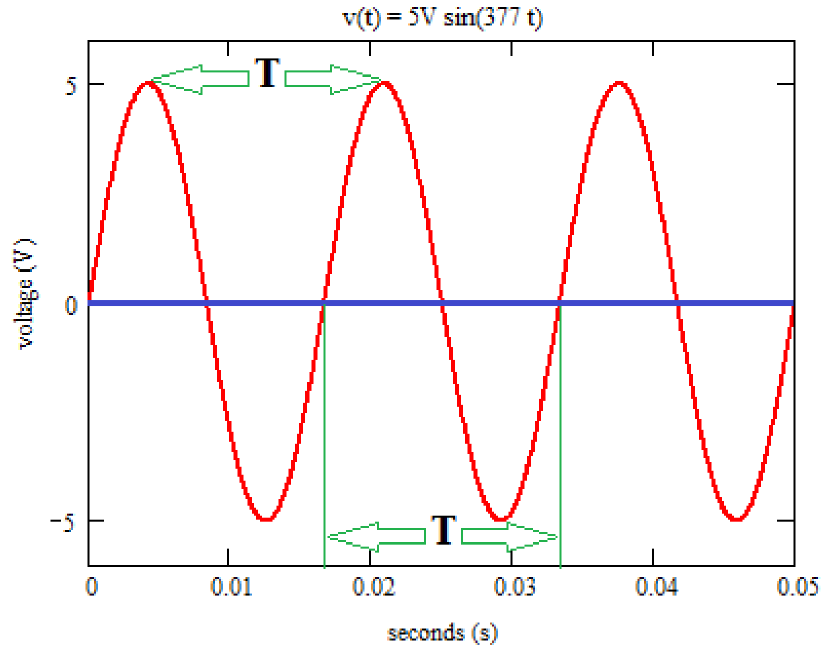


a. The Period, (T) is the length of time in seconds that the waveform takes to repeat itself from start to finish. This can also be called the *Periodic Time* of the waveform for sine waves, or the *Pulse Width* for square waves.

b. The Frequency, (f) is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ($f = 1/T$) with the unit of frequency being the *Hertz*, (Hz).

c. The Amplitude (A) is the magnitude or intensity of the signal waveform measured in volts or amps.

Time Period, T



The Period, (T) is the length of time in seconds that the waveform takes to repeat itself from start to finish. This can also be called the *Periodic Time* of the waveform for sine waves, or the *Pulse Width* for square waves.

For our power supply at home, the current changes 50-60 times per seconds, if it is 60 times per seconds then:

$$T = t_2 - t_1 = \frac{1}{60} s = 16.7 ms$$

Frequency: f

The Frequency, (f) is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ($f = 1/T$) with the unit of frequency being the *Hertz*, (Hz).

$$\text{Frequency}, (f) = \frac{1}{\text{Periodic Time}} = \frac{1}{T} \text{ Hertz}$$

or

$$\text{Periodic Time}, (T) = \frac{1}{\text{Frequency}} = \frac{1}{f} \text{ seconds}$$

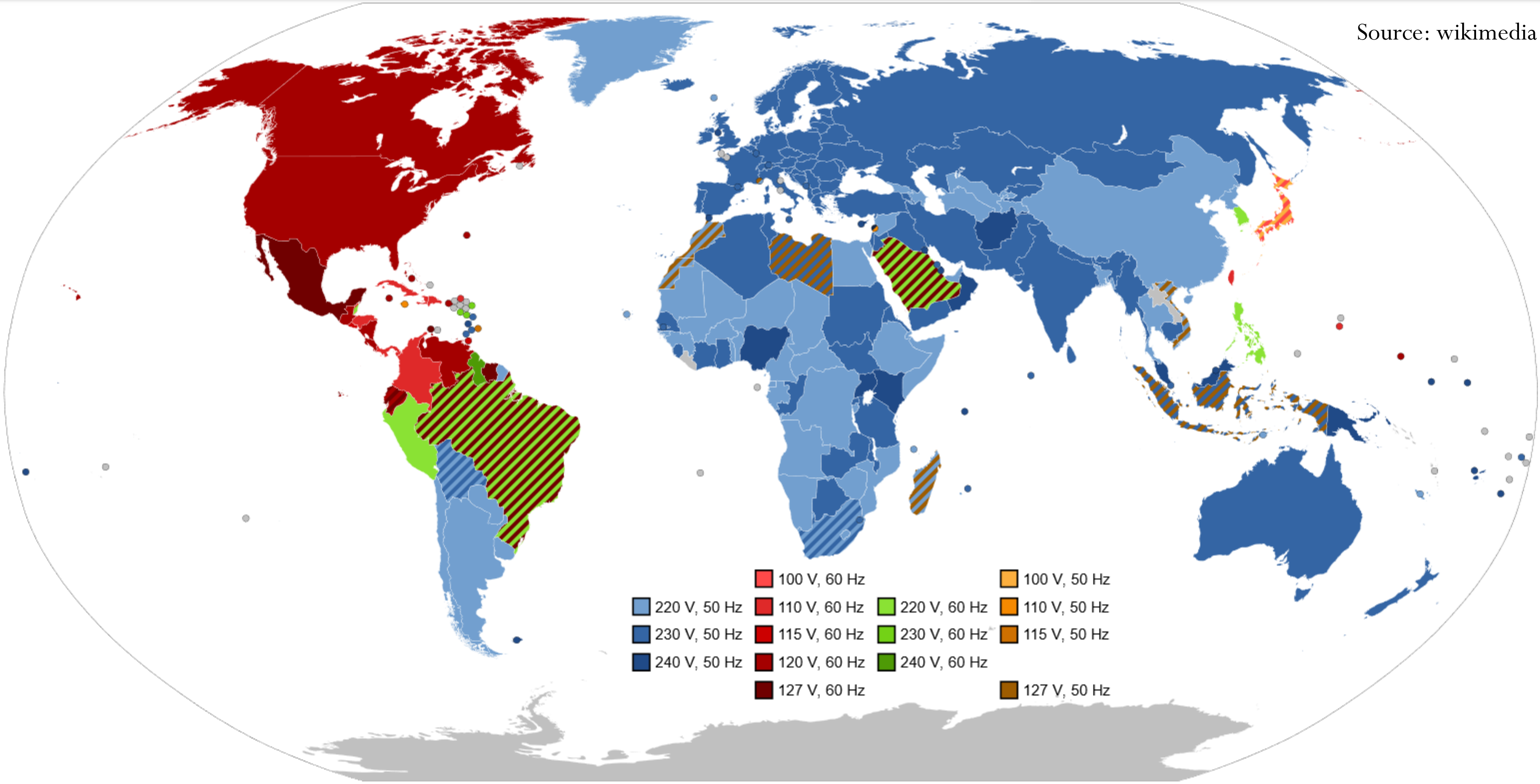
Prefix	Definition	Written as	Periodic Time
Kilo	Thousand	kHz	1ms
Mega	Million	MHz	1us
Giga	Billion	GHz	1ns
Terra	Trillion	THz	1ps

The longer the period, the lower the frequency is.

For supply at home:

$$f = \frac{1}{T} = \frac{1}{16.7ms} = 60Hz$$

World Map of Mains Voltages and Frequencies



If you really see most of the world uses 120 and 220 Volt; 60 Hertz (USA), 230 Volt; 50 Hertz (Europe & Asia) standard.

Question is why? Why the frequency is 50-60 Hz, not more or not less

Angular frequency

- Motors are used in the alternators in coal- and gas-powered electric generation stations. One full rotation of the motor shaft produces one complete cycle of the ac electricity produced.
- Position of the motor shaft is measured in radians (rad) or degrees (^{o}).
  - 1 rad = 57.3^o
  - 2p rad = 360^o

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$f = 60Hz \qquad \omega = 377 \text{ rad/s}$$

Why use 50Hz or 60Hz, rather than lower or higher frequency?

- The two factors are related as per the following formula: $P = 120 \times \frac{f}{N}$

Generator Frequency (f) =

Number of revolutions per minute of the engine (N) x $\frac{\text{Number of magnetic poles (P)}}{120}$

- As per the above formula, a 2-pole generator producing an output frequency of 60 Hz has an engine speed of 3,600 rpm.
- if the frequency is 100Hz, then the synchronous speed will be 6000rpm
- To change the output frequency to 50 Hz for the same generator configuration, the engine speed needs to be reduced to 3,000 rpm.
- Similarly, for a 4-pole generator, an engine speed of 1,800 rpm produces output of 60 Hz.
- Reducing the engine speed to 1,500 rpm yields an output of 50 Hz.

Why use 50Hz or 60Hz, rather than lower or higher frequency?

- In electrical system, frequency is a very important basic element, not arbitrarily determined. It looks like simply, but in fact, it is a much complex issue, involve with many aspects.

- From the principle, we should mention the classical electromagnetic theory found by Maxwell, Hertz added a critical point for Maxwell's theory, Faraday's law of electromagnetic induction and the world's first electromagnetic induction generator, the British engineer Ward King made the electromotor first, the French Pixie made generator, Siemens found the generator principle, the invent the power generation machine, which is the first case in practical application.

- The electric generator is made according to the basic principle of the rotating coil in the magnetic field to achieve the conversion from mechanical energy to electrical energy.

Why use 50Hz or 60Hz, rather than lower or higher frequency

- **Frequency value is related to the structures and materials of generator, motor and transformer.** Like 400Hz needs 24000rpm
  - High speed will bring a lot of troubles to manufacture the generators, especially the rotor surface speed is too fast which will limit the generator capacity greatly.
  - The high frequency will make the reactance increase, electromagnetic loss, and increase the reactive power => for example, the current will decrease greatly in a motor, the output power and torque will decrease evidently, which does not has any benefit.
  - if use a lower frequency such as 30Hz, transformer efficiency is too low, not benefit for AC power transformation and transmission.

What happens if you connect a 60 Hertz motor to a 50 Hertz mains:

- The motor turns 17% slower
- The internal current goes up by 17%
- The power (watt) goes down with 17 %
- The mechanical cooling is less, because of 17% less turns

Frequency is the unified operating parameter in the whole power system.

Why in Asia 50 and in USA 60 Hz?

- **The difference in grid frequency depends on different calculation habits.**

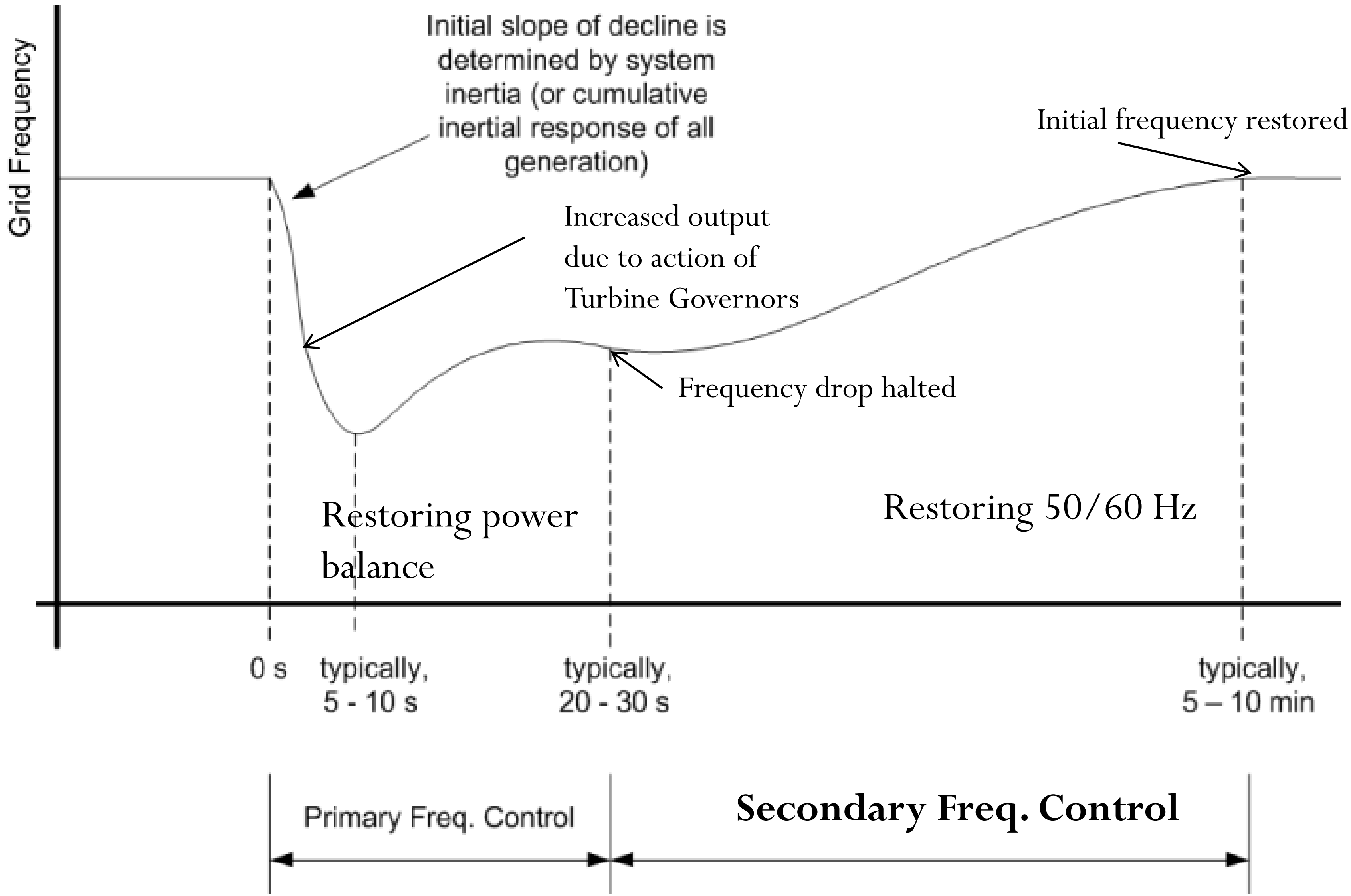
The large-scale power generations in America are earlier than other continents. At that time, the calculation tool was British (duodecimal number system) slide rule. For easy calculation, they used 60Hz. And then later, the power grids use decimal calculation, 50Hz is more convenient.

Do you know: Aircraft power supply uses 400Hz is in order to reduce the size and weight, it is a complex system. 400Hz being used on military and avionics is main reason that the high frequency generator or electro motor has small size and light weight due to the high rotating speed and low torque

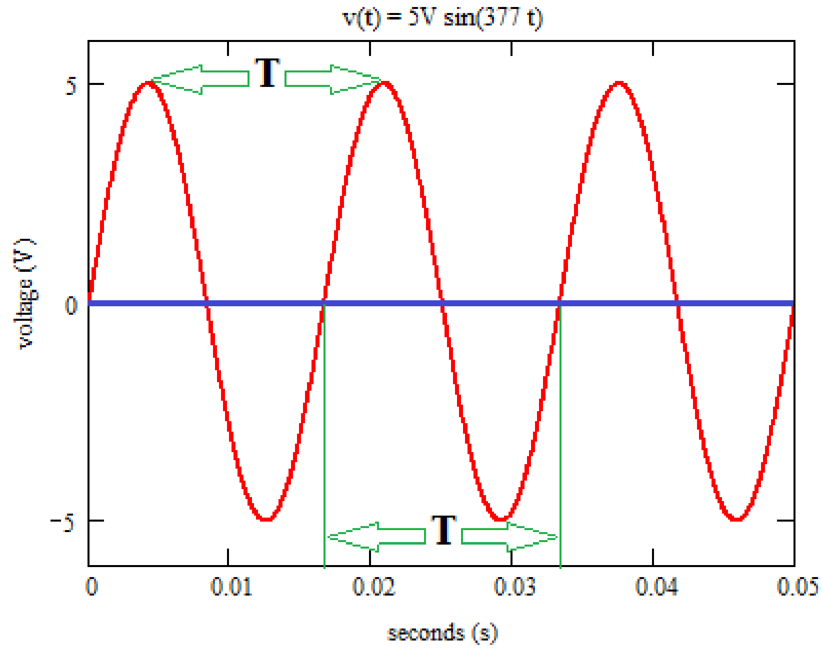
How to maintain this frequency?

Frequency control: how to maintain a power balance (generation=demand) in an AC system?

Frequency Balancing



Frequency: f



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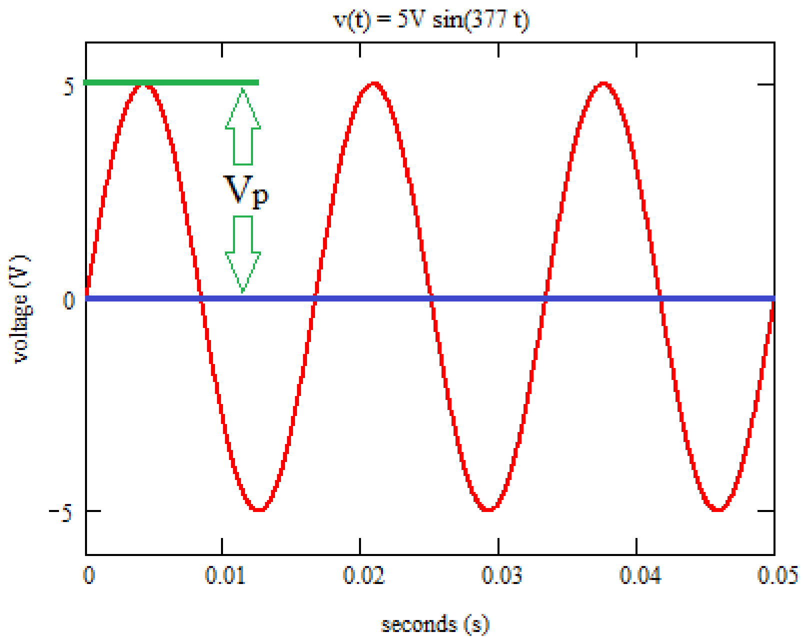
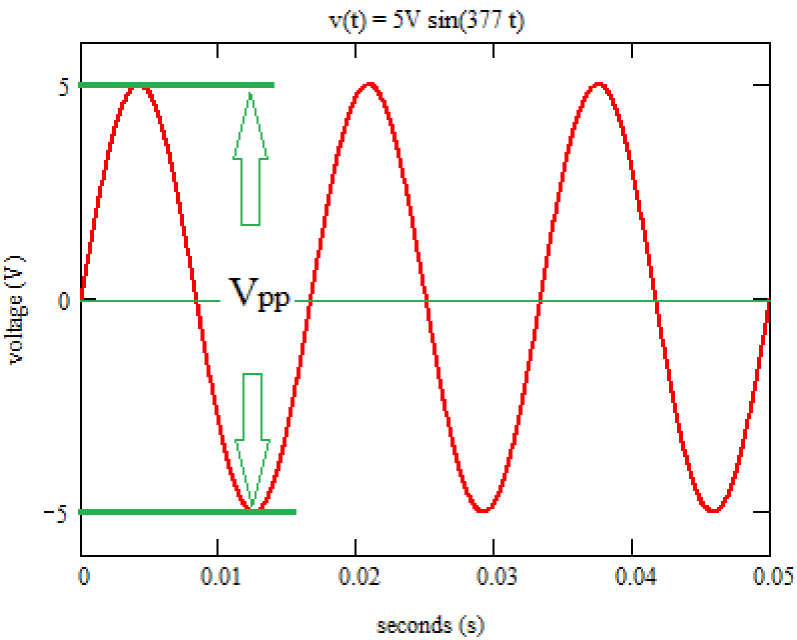
$$\boxed{\text{Frequency}, (f) = \frac{1}{\text{Periodic Time}} = \frac{1}{T} \quad \text{Hertz}}$$

Amplitude: A

- Peak amplitude



- Peak-to-Peak amplitude

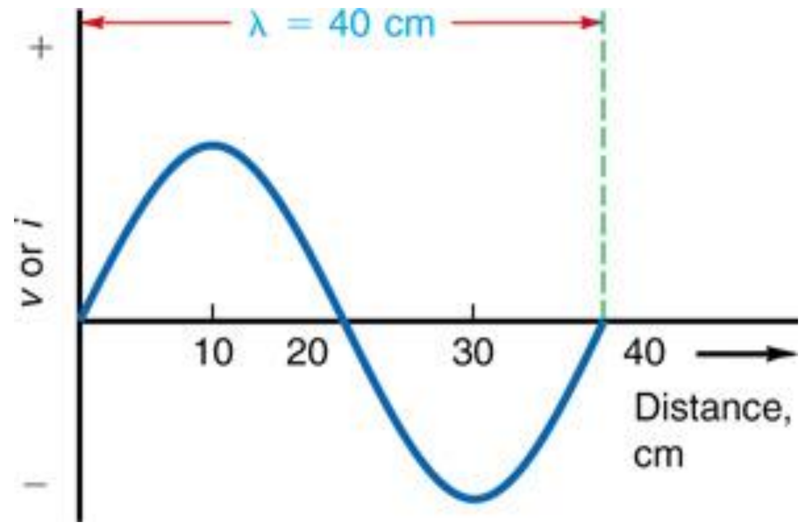


Peak value of a waveform is the maximum value from zero.

Peak to Peak is measured from positive peak to negative peak.

Wavelength

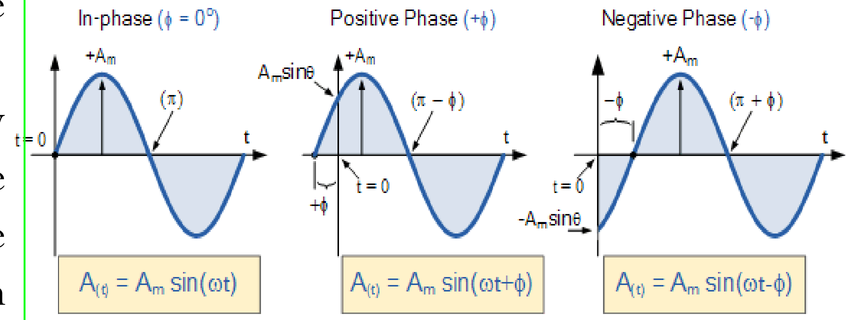
- **Wavelength** (λ) is the distance a wave travels in one cycle.
- $\lambda = v/f$, where:
  - λ = wavelength
    - $\lambda = \dfrac{1130 \text{ ft/s}}{f \text{ Hz}}$

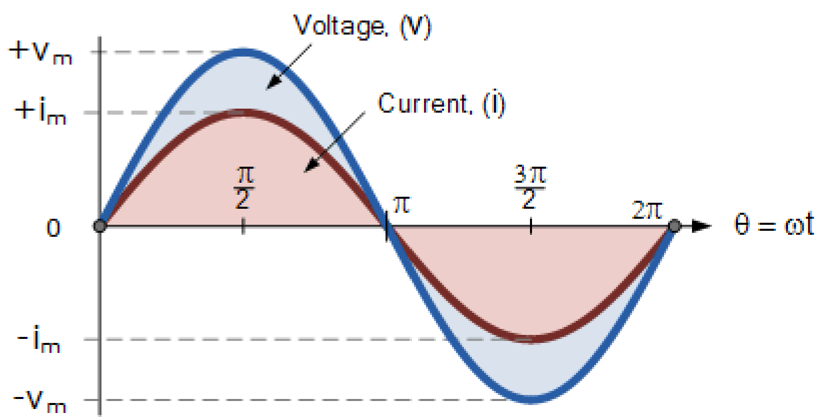


  - v = velocity of wave (such as sound or light)
    - in applications, velocity can be influenced by electromagnetic fields, air pressure, etc.
  - f = frequency
- The higher the frequency, the lower the wavelength.
- The velocity of a radio wave is 3×10^{10} cms/s (3×10^{8} meters/s).

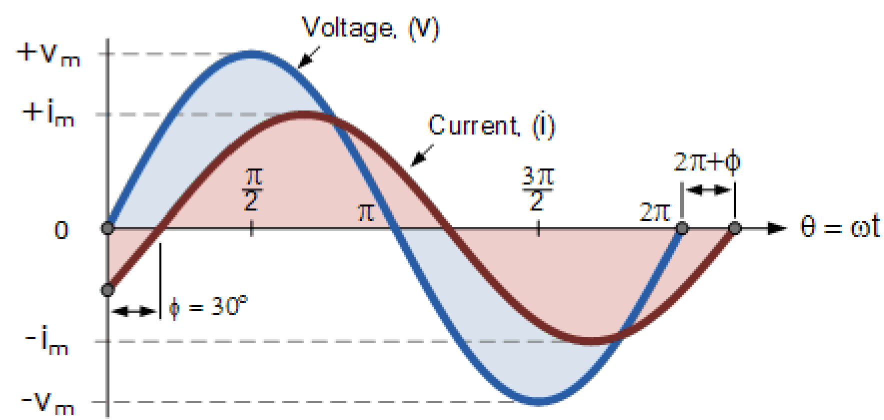
Phase Difference:

As an alternating quantity, sine waves have a positive maximum value at time $\pi/2$, a negative maximum value at time $3\pi/2$, with zero values occurring along the baseline at 0, π and 2π.
However, not all sinusoidal waveforms will pass exactly through the zero axis point at the same time but may be "shifted" to the right or to the left of 0° by some value when compared to another sine wave. This then produces an angular shift or **Phase Difference** between the two sinusoidal waveforms. Any sine wave that does not pass through zero at t = 0 has a phase shift.



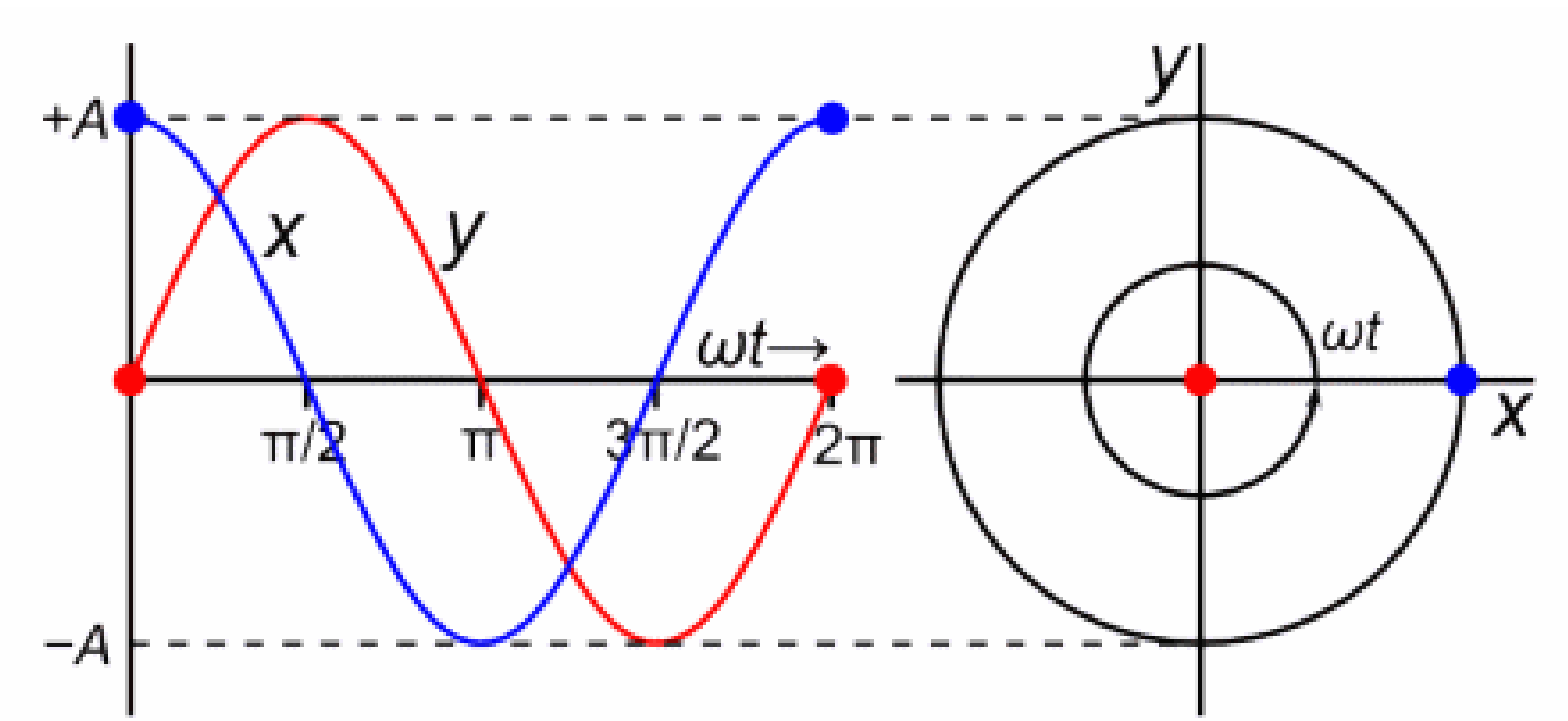


Two Sinusoidal Waveforms – "in-phase"



Two Sinusoidal Waveforms – "not in phase"

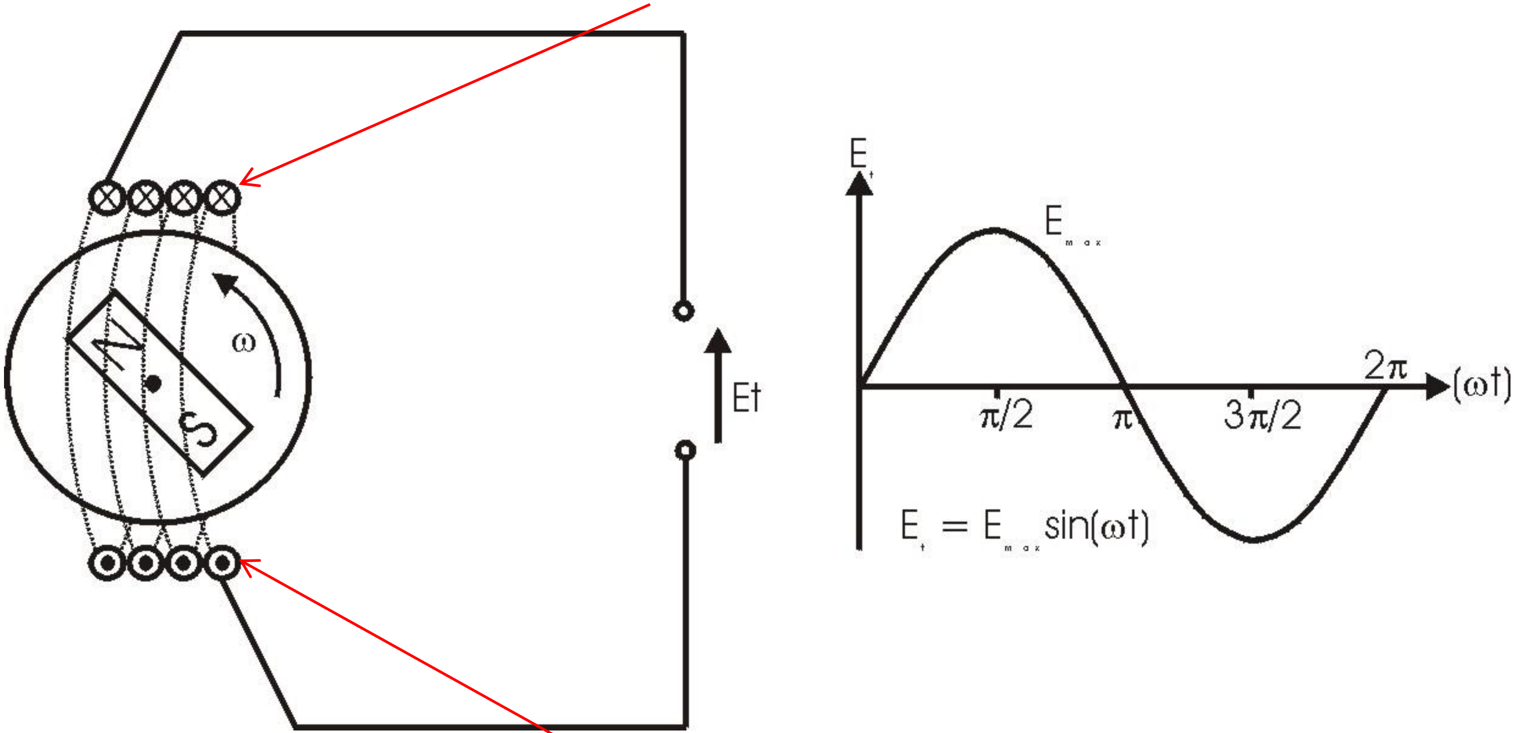
Phases:



Single Phase Synchronous Machine

Faraday's Law: induced voltage = rate of change of flux

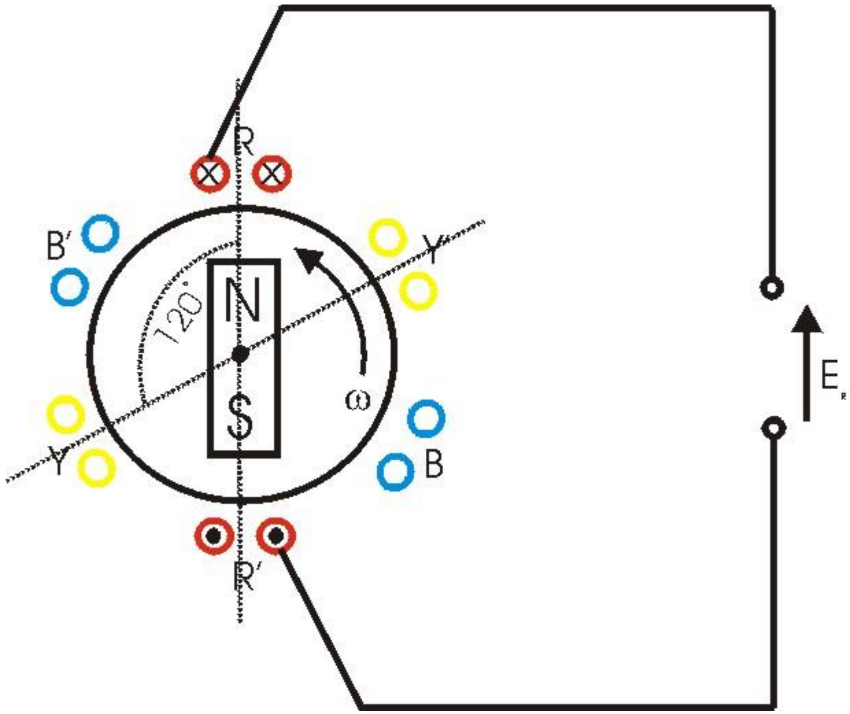
end of the arrow

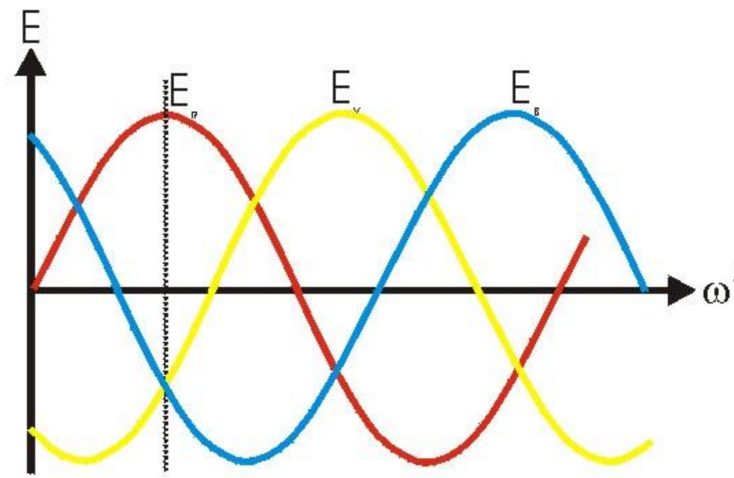


direction of winding: head of the arrow

A rotating magnet will induce a sinusoidal voltage in the stator's coil.

3 Phase Machine

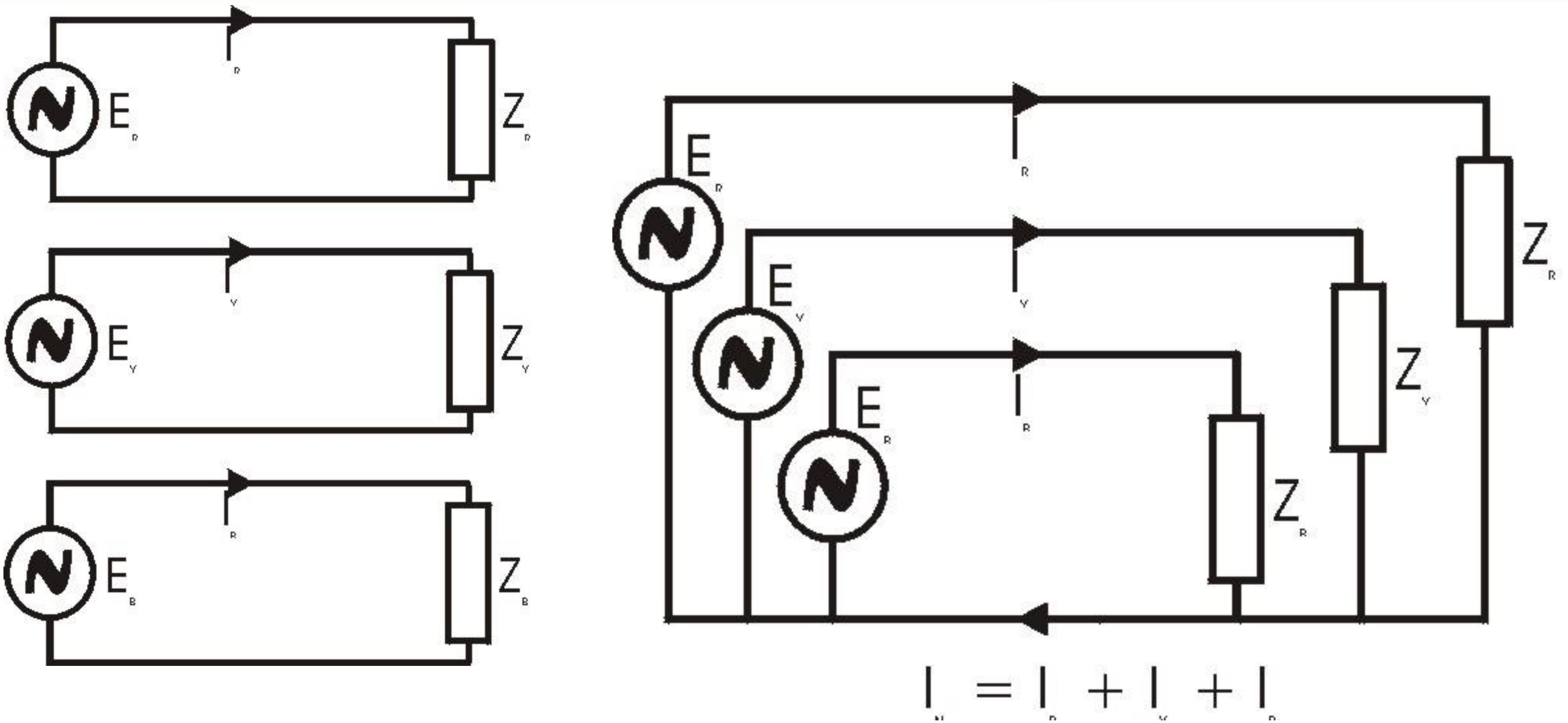




$$E_{max} \equiv E_0$$
$$E_R = E_0 sin\omega t$$
$$E_Y = E_0 sin(\omega t - 120^o)$$
$$E_B = E_0 sin(\omega t - 240^o) = E_0 sin(\omega t + 120^o)$$

The three windings produce three ac voltage waveforms (red, yellow and blue) shifted by $\pm 120^0$ in phase wrt each other

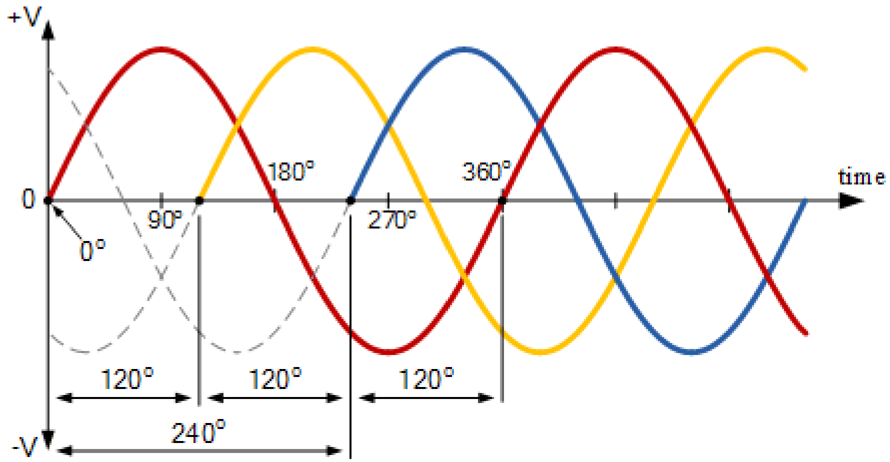
3 Phase Machine

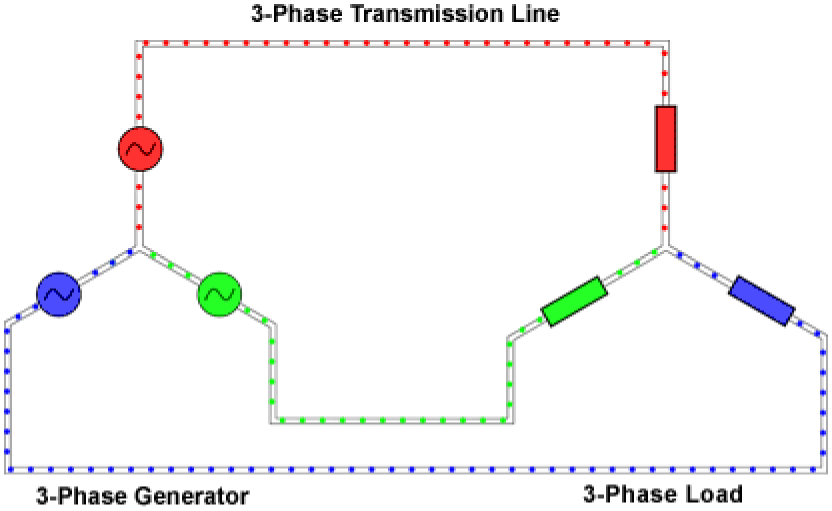


Three-Phase Circuit = 3 single-phase circuits with common return (neutral)

3-Phase AC Supply

A system with three voltages of equal magnitude and each of them displaced by 120^0 is called a three phase system.

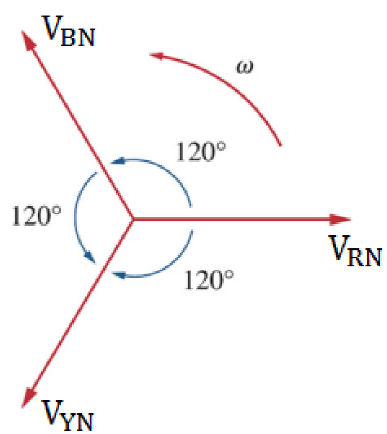




$$V_{RN} = V_m \sin \omega t$$

$$V_{YN} = V_m \sin(\omega t - 120)$$

$$V_{BN} = V_m \sin(\omega t - 240)$$



3-Phase AC Supply

Assuming balanced loading ($Z_R = Z_Y = Z_B$), the return current is:

$I_N = I_R + I_Y + I_B = I \sin(\omega t) + I \sin(\omega t + 120^0) + I \sin(\omega t - 120^0) =$
$= I (\sin(\omega t) + \sin(\omega t + 120^0) + \sin(\omega t - 120^0)) = 0$

As the return current is zero, the wire can be removed resulting in significant savings!

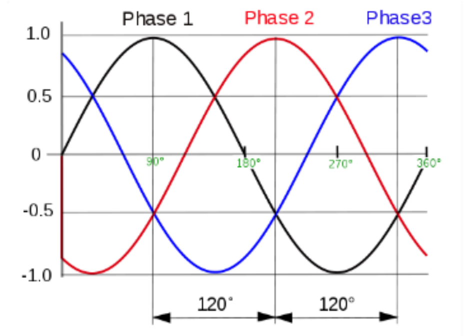
Three single-phase systems require 6 wires connecting the source and the load. An equivalent three-phase system requires only 3 wires so the saving is 50% on all transmission and distribution lines!

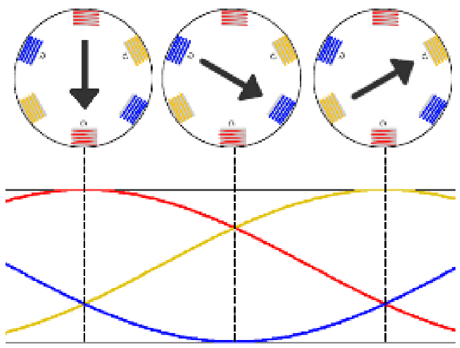
In practice there is always some amount of load imbalance so a return wire is usually provided. But the return current is small so the return wire may be much thinner than the phase wires – see the photo.

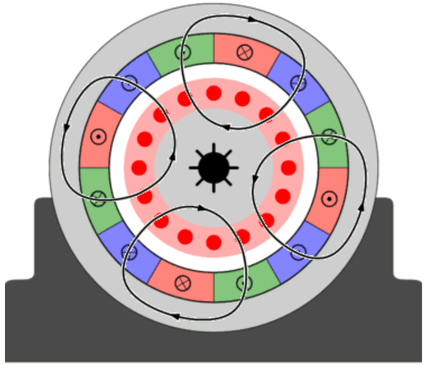
If the load is balanced, we use a single-circuit representation of a 3-phase circuit.

Three phase power transmission has become the standard for power distribution. **Three phase power** generation and distribution is advantageous over single phase power distribution.

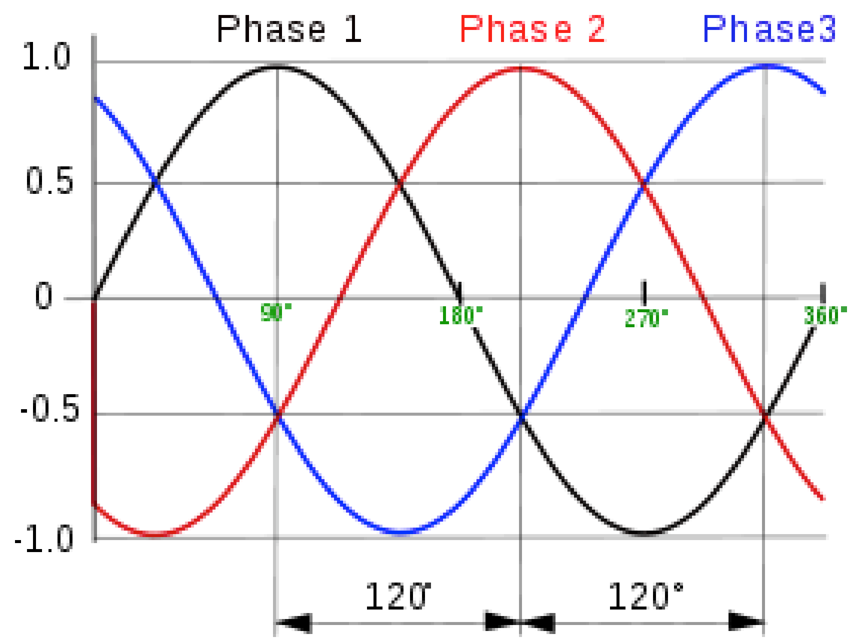
- requires lesser amount of copper or aluminium for transferring the same amount of power as compared to single phase power
- The size of a three phase motor is smaller than that of a single phase motor of the same rating.
- Three phase motors are self starting as they can produce a rotating magnetic field. The single phase motor requires a special starting winding as it produces only a pulsating magnetic field.
- In single phase motors, the power transferred in motors is a function of the instantaneous current which is constantly varying. Hence, single phase motors are more prone to vibrations. In three phase motors, however, the power transferred is uniform through out the cycle and hence vibrations are greatly reduced.
- The ripple factor of rectified DC produced from three phase power is less than the DC produced from single phase supply.
- have better power factor regulation.
- Motors above **10HP** are usually **three phase**.
- generators are smaller in size than single phase generators as winding phase can be more efficiently used. (source: wikipedia)





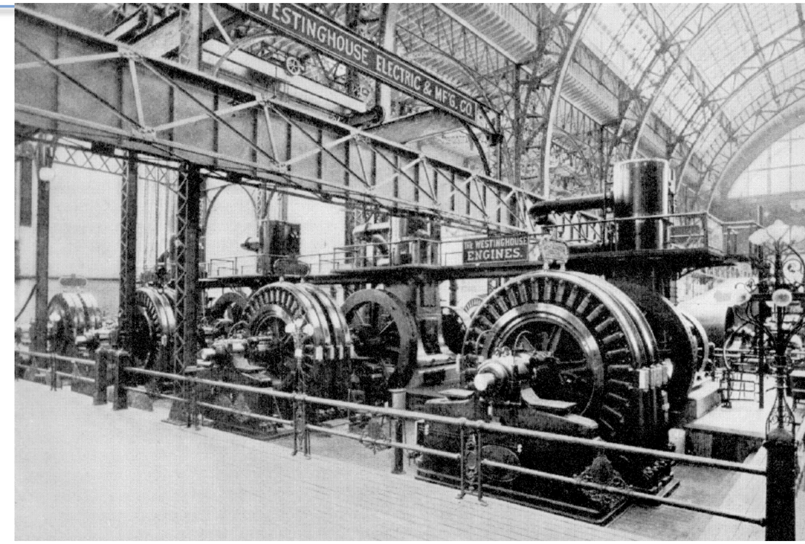


The Tesla Three-Phase AC Transmission System



The most common example is the Tesla three-phase power system used for industrial applications and for power transmission. The most obvious advantage of three phase power transmission using three wires, as compared to single phase power transmission over two wires, is that the power transmitted in the three-phase system is the voltage multiplied by the current in each wire times the square root of three (approximately 1.73). The power transmitted by the single-phase system is simply the voltage multiplied by the current. Thus, the three-phase system transmits 73% more power but uses only 50% more wire.

Niagara Falls and Steinmetz's Turning of the Screw



Against General Electric and Edison's proposal, Westinghouse, using Tesla's AC system, won the international Niagara Falls Commission contract. Tesla's three-phase AC transmission became the World's power-grid standard.

Transforming DC power from one voltage to another was difficult and expensive due to the need for a large spinning rotary converter or motor-generator set, whereas with AC the voltage changes can be done with simple and efficient transformer coils that have no moving parts and require no maintenance. <u>This was the key to the success of the AC system.</u> Modern transmission grids regularly use AC voltages up to 765,000 volts.

How to Compare AC and DC

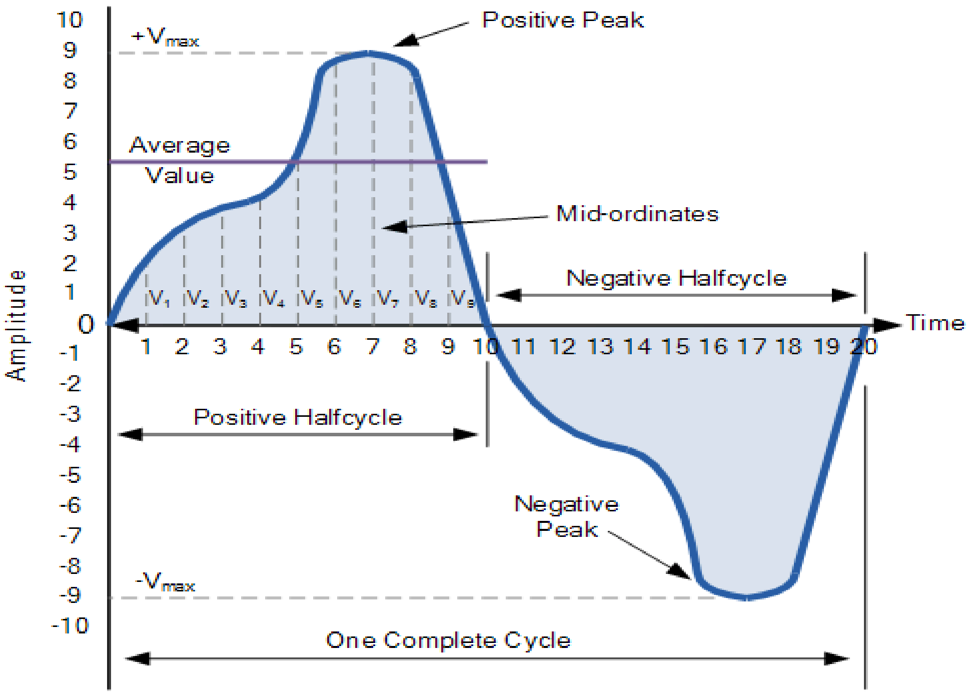
- **AC voltage** is usually expressed as a **root mean square (RMS)** value, written ***V*rms**. For a sinusoidal voltage:

$$V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}}$$

V*rms** is useful in calculating the power consumed by a load. If a **DC** voltage of ***V*DC** delivers a certain power ***P into a given load, then an **AC** voltage of ***V*peak** will deliver the same average power ***P*** into the same load if ***V*rms = *V*DC**. Because of this fact, **RMS** is the normal means of measuring **AC** voltage.

110VAC is actually the **RMS value** which is used from the energy companies in America. But the **voltage peak value** is **155.55V**.

Average and RMS values:



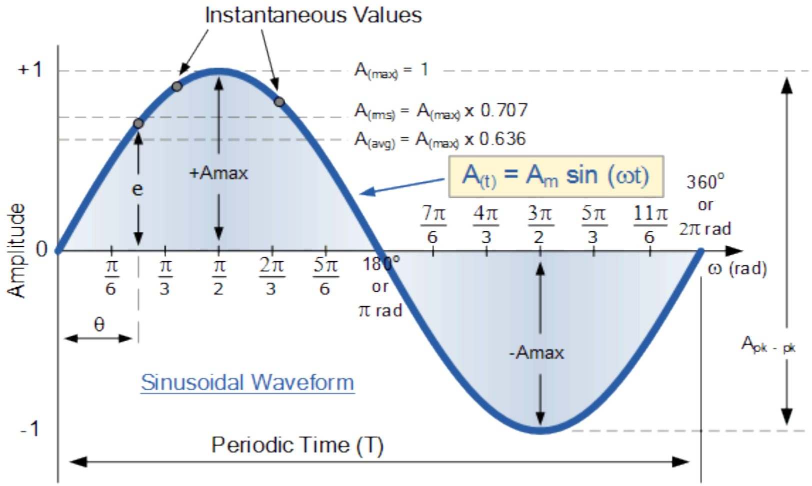
To find the average value of the waveform we need to calculate the area underneath the waveform using the mid-ordinate rule, trapezoidal rule or the Simpson's rule found commonly in mathematics.

$$V_{average} = \frac{V_1 + V_2 + V_3 + V_4 + \ldots + V_n}{n}$$

r.m.s. values are useful because their relationship to average power is similar to the corresponding DC values

Root Mean Square: $$V_{RMS} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}{n}}$$

Average and RMS values:



average value over one (or more) cycles is clearly zero

however, it is often useful to know the average magnitude of the waveform independent of its polarity

When we work out the effective voltage of an a.c. supply it is not the average value. The average value of a sine wave is zero!

$$P_{av} = V_{rms} I_{rms}$$

$$P_{av} = I_{rms}^{2} R$$

$$P_{av} = \frac{V_{rms}^{2}}{R}$$

$$V_{av} = \frac{1}{\pi}\int_0^{\pi} V_p \sin\theta \, d\theta$$

$$= \frac{V_p}{\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{2V_p}{\pi} = 0.637 \times V_p$$

RMS of AC

- Because of power analysis, the AC voltage is often expressed as a **root mean square (RMS) value, written as V_{RMS}.**
- ***For the sinusoidal waveform:***

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T [v(t)]^2 dt}$$

Or

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T (V_{max} sin(\omega t + \varphi))^2 \mathrm{d}t} = \frac{V_{max}}{\sqrt{2}}$$

$$\text{Form factor} = \frac{\text{r.m.s. value}}{\text{average value}}$$

$$\text{Peak factor} = \frac{\text{peak value}}{\text{r.m.s. value}}$$

For a pure sinusoidal waveform the Form Factor & will always be equal to 1.11 and Crest Factor will always be equal to 1.414

$$\text{Form Factor} = \frac{\text{R.M.S value}}{\text{Average value}} = \frac{0.707 \times \text{Vmax}}{0.637 \times \text{Vmax}}$$

$$\text{Crest Factor} = \frac{\text{Peak value}}{\text{R.M.S. value}} = \frac{\text{Vmax}}{0.707 \times \text{Vmax}}$$

This works for current too

Since an a.c. voltage is a sine wave, the current is also a sine wave.

$$\boxed{V_{rms} = \frac{V_{peak}}{\sqrt{2}}} \qquad \boxed{I_{rms} = \frac{I_{peak}}{\sqrt{2}}}$$

We can use Ohm's Law as normal with either peak or rms voltages and currents, just don't mix them up.

AC: Summary

- AC signals are sinusoidal functions.
  - The mathematical description of the sinusoid includes the peak amplitude and the angular frequency and may include a phase angle.

$$v(t) = V_p \sin(\omega t + \phi) \qquad \omega = 2\pi f = \frac{2\pi}{T}$$

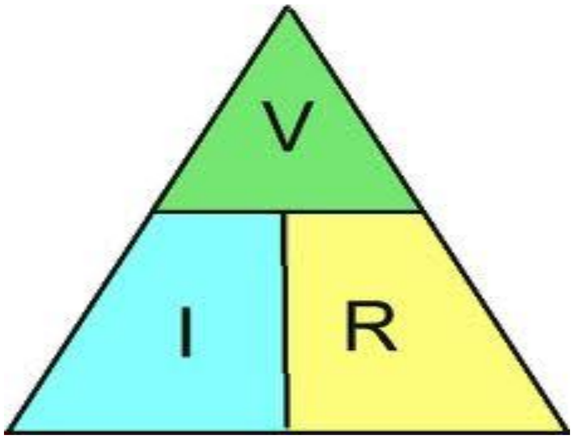
- RMS values of a sinusoid are calculated using the formula

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T [v(t)]^2 dt} \quad V_{RMS} = 0.707V_p$$

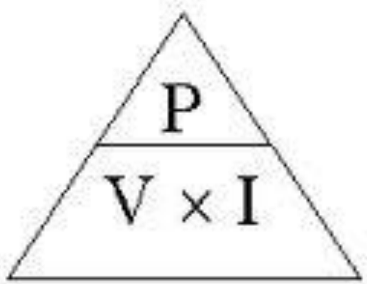
- Phase angle for a sinusoid is calculated with respect to a reference.
  - A signal lags a reference when $f_{signal} - f_{reference} < 0^o$.
  - It leads a reference when $f_{signal} - f_{reference} > 0^o$.

Ohm's Law

- An electron travelling through the wires encounters resistance. **Resistance** is the hindrance to the flow of charge. For an electron it is a zigzag path that results from countless collisions with fixed atoms within the conducting material
  - **Voltage = Current x Resistance**
    (Volts) (Amps) (Ohms)



$$\mathbf{V = IR}$$

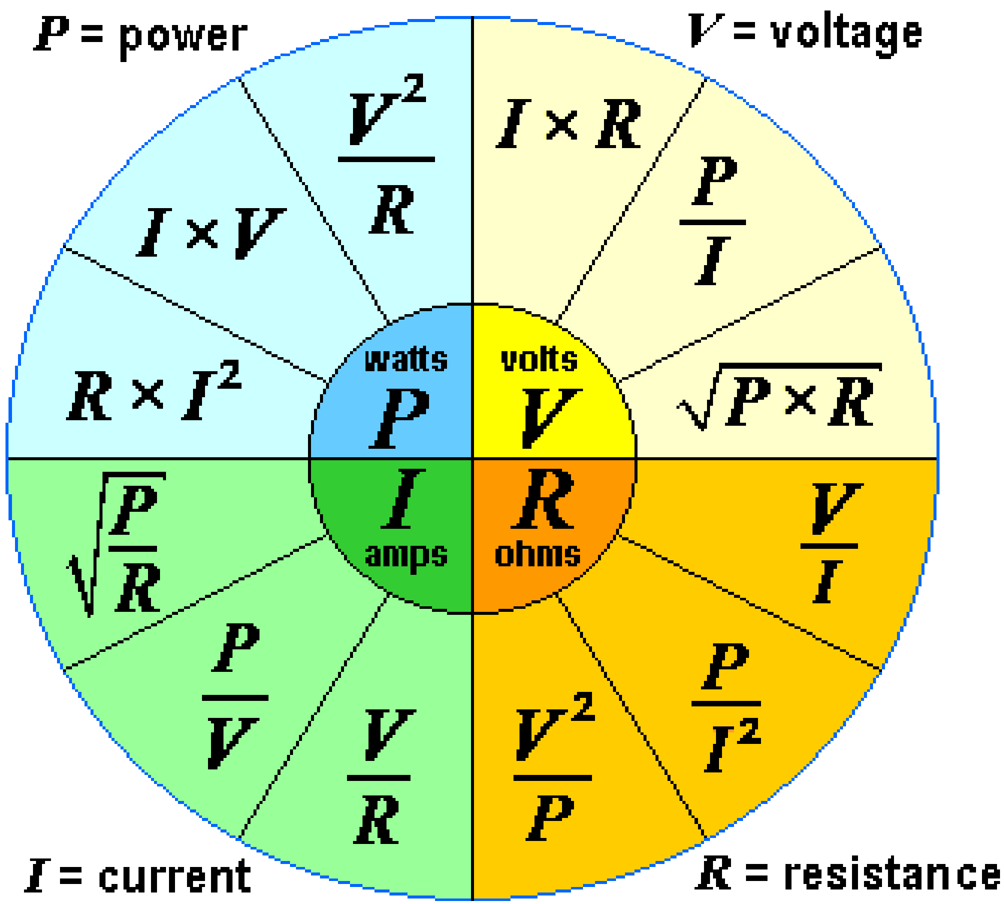


P=VI

Power = Voltage x Current
(Watt) (Volts) (Amps)

Ohms Law Pie Chart

Ohm's law equation (formula): V = I × R
Power law equation (formula): P = I × V



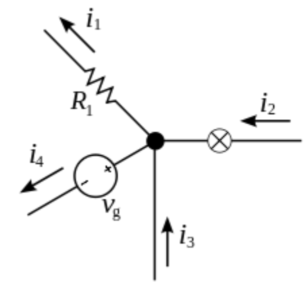
Kirchhoff's Law

- **Kirchhoff's Current Law**

At any node (junction) in an electrical circuit, the sum of the currents flowing into that node is equal to the sum of currents flowing out of that node

Or

The sum of currents in a network of conductors meeting at a point is zero



The current entering any junction is equal to the current leaving that junction. $i_2 + i_3 = i_1 + i_4$

- **Kirchhoff's Voltage Law**

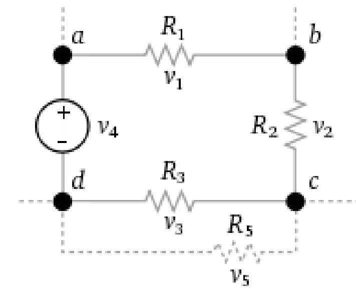
The directed sum of the electrical potential differences (voltage) around any closed network is zero

Or

The sum of the electro magnetic force in any closed loop is equivalent to the sum of the potential drops in that loop.

Or

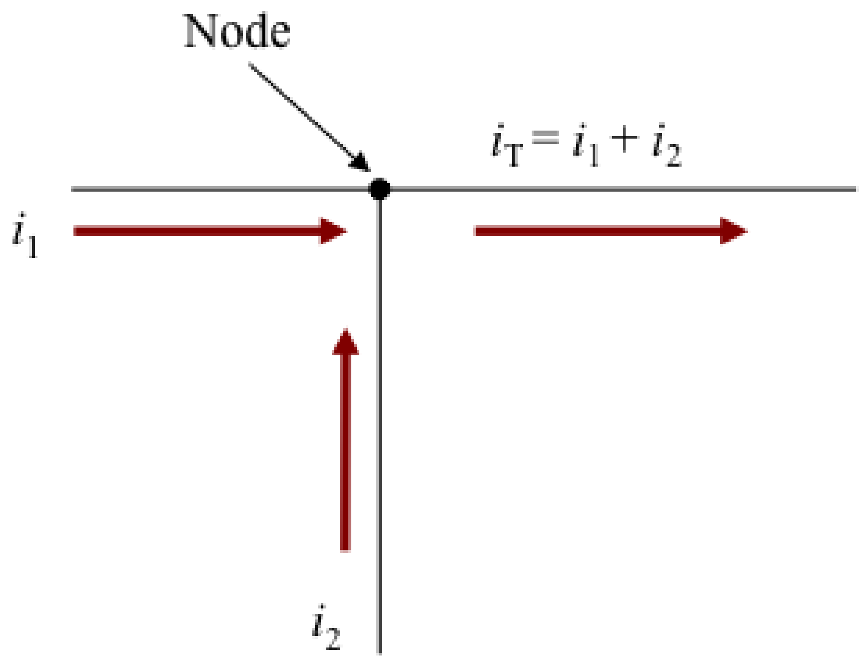
The algebraic sum of the products of the resistance of the conductors and the currents in them in a closed loop is equal to the total electromagnetic force available in the loop



The sum of all the voltages around the loop is equal to zero.
$v_1 + v_2 + v_3 - v_4 = 0$

Kirchoff's Current Law

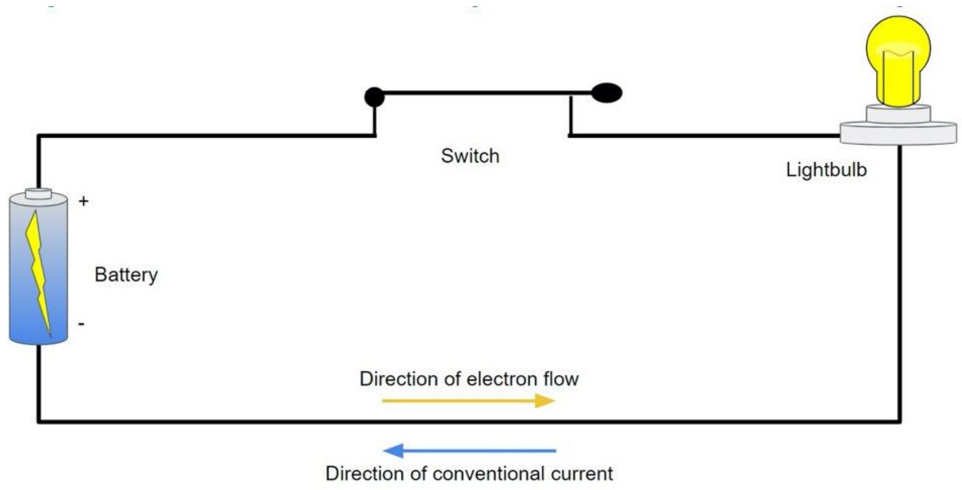
At every instant of time the sum of the currents flowing into any node of a circuit must equal the sum of the currents leaving the node.



Kirchoff's Voltage Law

The sum of voltages around any loop of a circuit at any time is zero.

Thus, if a voltage across the battery (from negative to positive node) is +12 V, the voltage across the light bulb is -12 V.



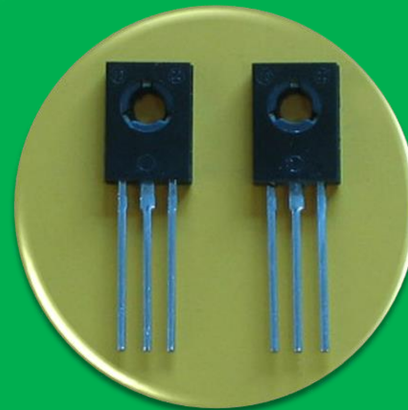
IDC102: What we will be doing

Operation of Electronic Equipment

- Voltmeters
- Ohmmeters
- Ammeters
- Power supplies
- function generator
- Oscilloscope

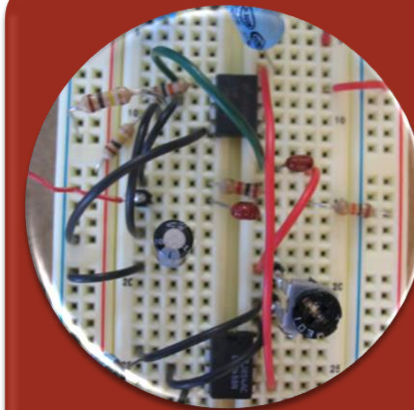
Passive Components

- Resistor
- Capacitor
- Inductor



Active Components

- Diode
  - Types
  - Datasheets
- Transistor
  - Types
  - Datasheets



Circuit Assembly

- Bread Board
  - Circuit Assembly
- Vero Board
  - Soldering
  - De-soldering
- PCB
  - Layout