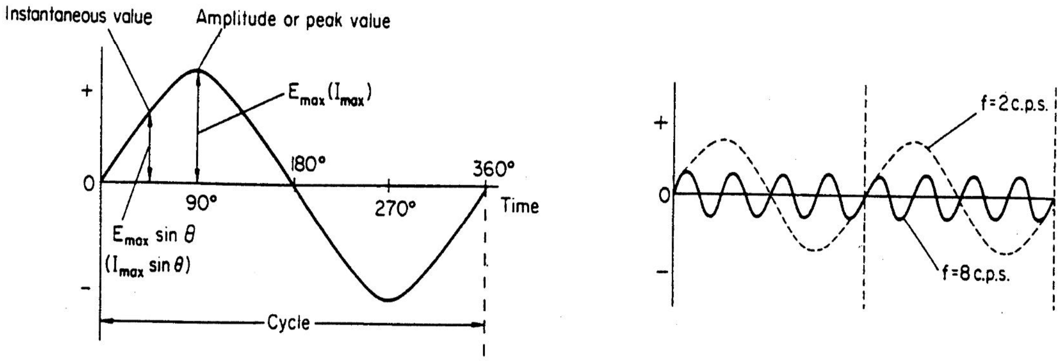
ALTERNATING CURRENT THEORY

Some of the following terms have already been used in previous chapters on DC generation and systems and they are therefore common to both types of power. These descriptions relate mainly to the graphical representation of alternating current.

Where only one sine wave is generated, it is known as a single phase AC.



AC GENERATED BY A ROTARY DEVICE IS A SINE WAVE.

Amplitude - is the maximum peak value of the generated voltage (positive or negative) of the Sine Wave.

Cycle -is one 'complete' series of values of a wave form where further changes would be repetition to the same wave form.

Period -the time taken to complete one cycle.

Frequency -The number of cycles that take place each second. One cycle per second = 1 Hertz

THE EFFECTIVE VALUE

As the alternating current sine wave varies in both amplitude and polarity, it appears difficult to measure. To average a sign wave, one period would produce a zero result. This is clearly not correct, as the voltage, current and power are obvious when AC is connected to a circuit. The method used to determine the effective value is based on averaging the squares of the individual values so that all the energy levels are of the same polarity The method is known as the root mean square (RMS).

$$\text{RMS} = \sqrt{\frac{\text{sum of squares of individual values}}{\text{total number of values}}}$$

It is the RMS of an alternating current which determines the heat or TRUE POWER generated in a resistance ($P = 1^2R$). Consequently, the RMS value is used because it allows AC voltages and currents to obey 'Ohm's Law' when applied to resistive circuits exactly the same way DC obeys Ohm's Law.

All ordinary AC measuring instruments give RMS values of voltage and current. If the sine wave was presented on an oscilloscope where the peak value could be measured, the RMS value can be easily calculated because it is .707 of the peak value. Incidentally, the sine of 45° is .707

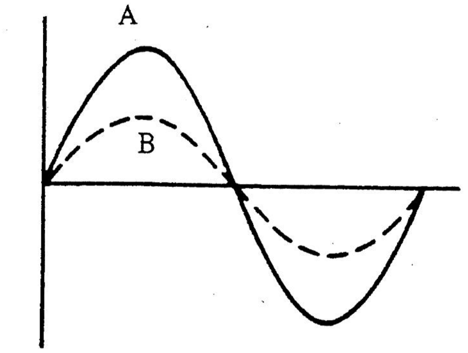
$$\text{RMS} = \text{Peak value} \times .707 \qquad \text{Peak value} = \frac{\text{RMS}}{.707}$$

AC Voltmeters and Ammeters are calibrated to measure the RMS values. The Peak Value is much higher than the indicated value; an 115 VAC aircraft voltage is an RMS value, the peak value is approximately 162 VAC.

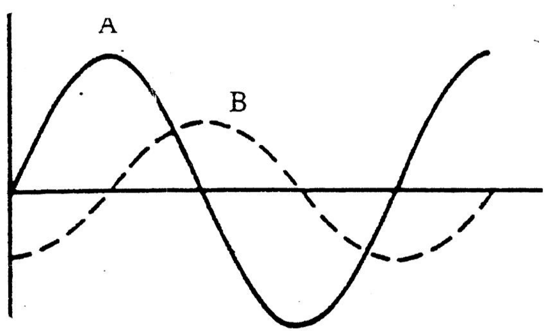
PHASE

The sine wave discussed so far, represents a two pole generating device which produces a single phase AC. The generation of the sine wave relates to the angle of rotation of the armature of the alternator. This means that at the start or zero position, the voltage is zero and at the 90° position the voltage is maximum (positive).

When two alternating voltages of the same frequency are compared and their wave shapes (angles of rotation) correspond, they are said to be in phase.



Voltages A and B are of different peak values but they are exactly ***in phase.***



Voltage B lags A by 90° and is therefore '***90 degrees out of phase***'.

This phase relationship is not only important when comparing voltages because in AC circuits, a separation phase between the voltage and the current waves can occur. These relationships are discussed during the application of capacitance and inductance.

AC GENERATION

Alternating current producing devices are known as 'alternators'. However, in large aircraft they are usually referred to as AC generators which if AC is the primary power, simply becomes GENERATORS.

Electro-Magnetic Induction

Electricity is made by rotating conductors wound onto an armature inside a magnetic field. As seen in the magneto, electricity can be made by rotating a magnet inside a set of windings. These processes are consistent and relate to :

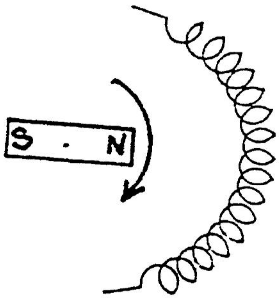
(a) Strength of a magnetic fields.
(b) No. of conductors (windings)
(c) Rate of movement (change).

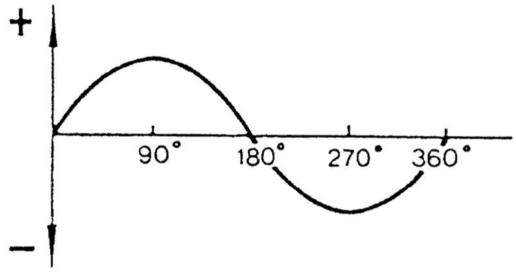
There are other factors involved with the efficiency of induction. These include the proximity of the magnetic field to the coil and the angle at which lines of magnetic flux and coils meet.

The following generator schematics show a rotating magnetic field system. The same result would be achieved by holding the magnetic field stationary and rotating the output windings.

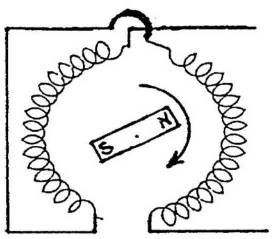
Single Phase AC

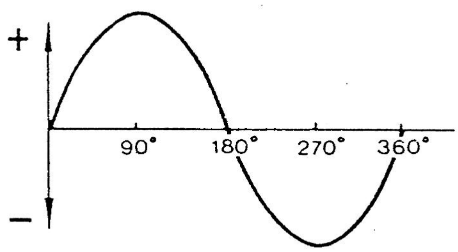
The production of simple single sine wave alternating current is known as single phase (1∅) AC. This is sufficient for many electricity supplies.





This schematic produces AC as indicated. In reality better use would be made of the other pole of the magnet because it too is moving.

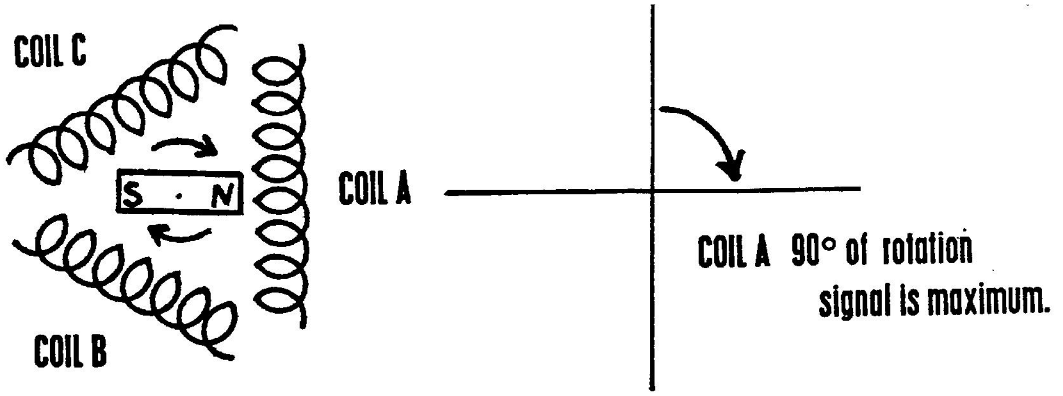




Here the principle is the same, but the second device would be more efficient by producing a greater voltage output. The frequency is the same, as it is always directly related to the RPM of the rotating element. However, if two pole pairs were used, the frequency would double, as the number of pole pairs has increased from one to two.

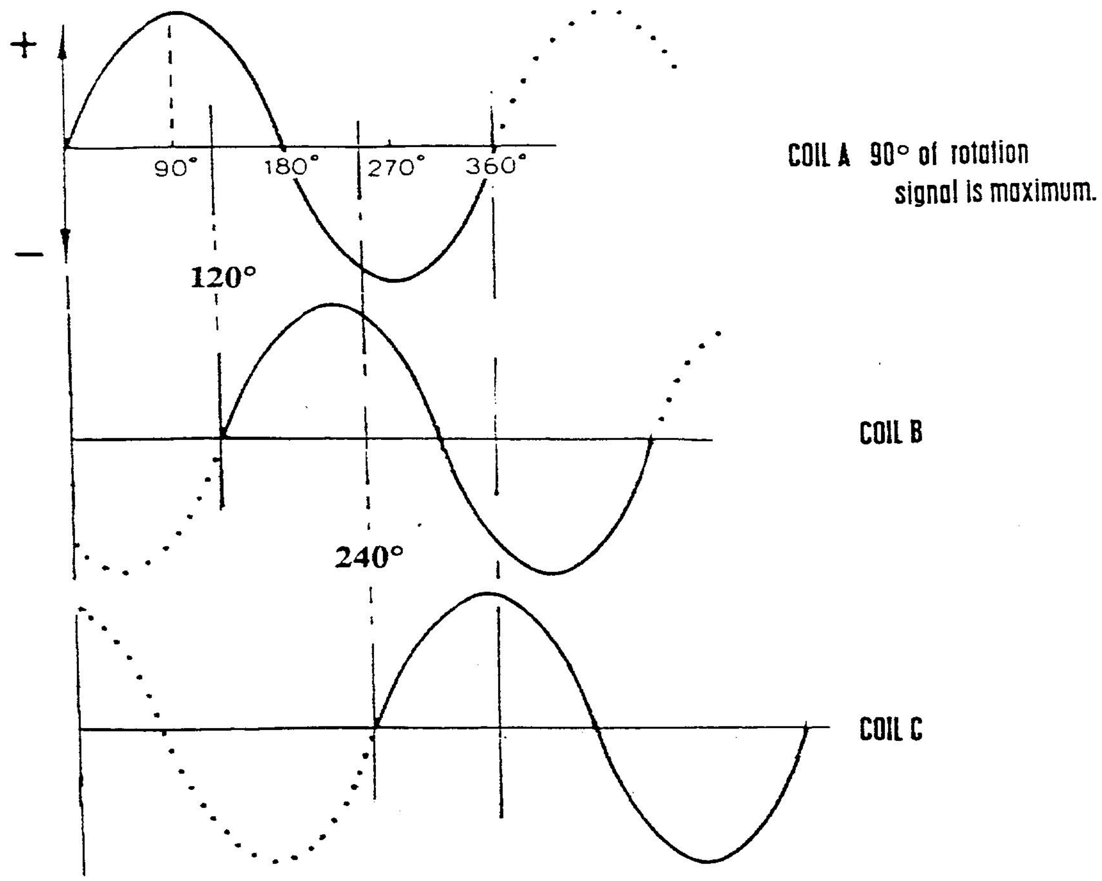
THREE PHASE AC (3∅)

Generators that produce single phase AC power are very rare as it is far more efficient to produce three phase power. Single phase AC is of course available from a three phase supply. Domestic power is usually 240 VAC, 220 VAC or 110 VAC 50 or 60 Hz single phase (1∅). Aircraft AC power is usually 115 VAC 400 Hz, 3∅ or 1∅.
Using the rotating magnetic concept, three coils of stationary windings form the stator of the alternator. Individually, single phase AC is induced into each coil.



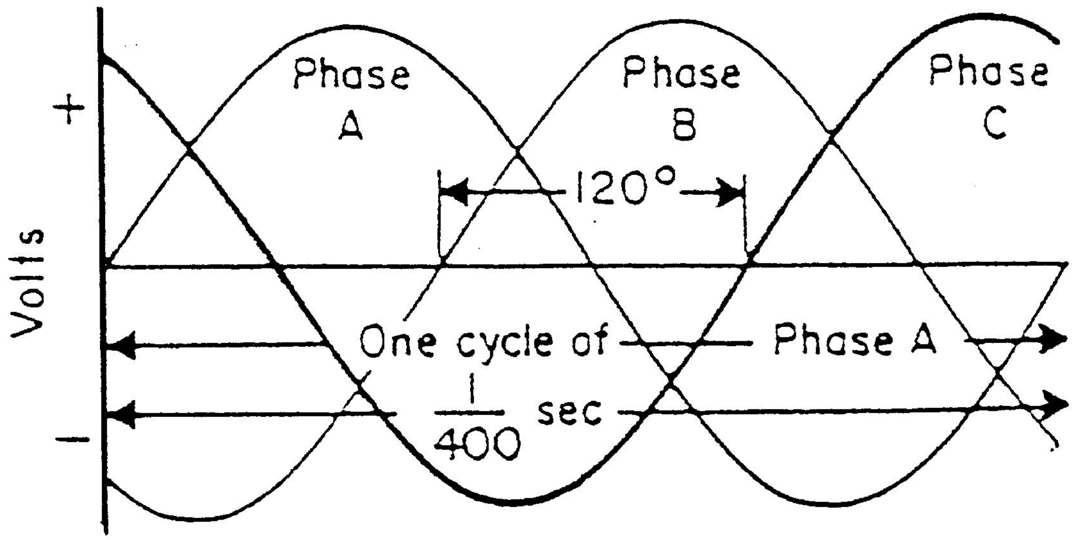
A COMMON 3∅ PICTORIAL

The physical separation between each of the coils means the induction in each coil is almost exactly the same amount but it takes place at a different time. The three coils are evenly spaced around the stator and each is separated by 120° angle of rotation.



3∅ ENERGY ON INDIVIDUAL LINES

Three phase AC can be depicted as three individual wave forms but is more commonly shown as one graph with A, B and C phases separated by 120°.



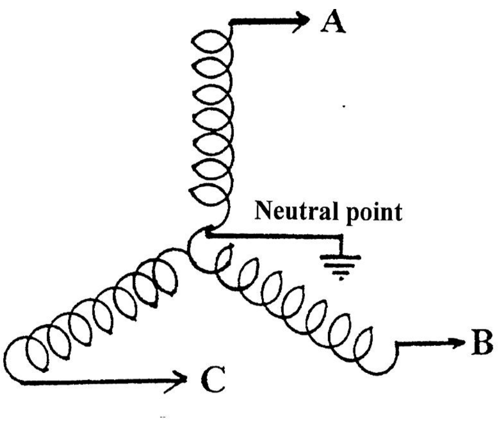
A COMMON 3∅ PICTORIAL

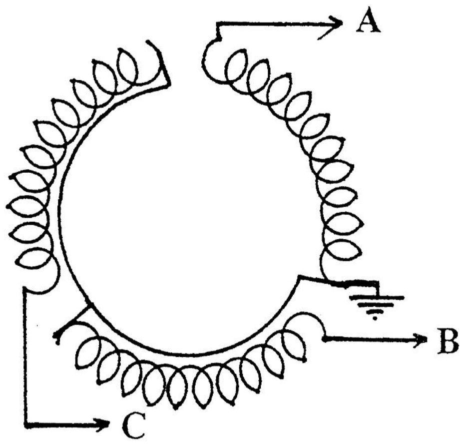
Note that these three phases of electrical energy while generated inside the same device must be kept **electrically separate,** because at any particular time there is a significant potential difference between phases. Individual phases can exist only on their own line or bus.

These generator schematics show a rotating magnetic field system. The same result would be achieved by holding the magnetic field stationary and rotating the output windings.

There are two methods of connecting generator output coils to provide three phase power.

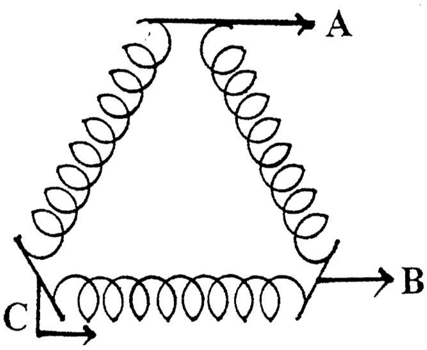
The STAR connection

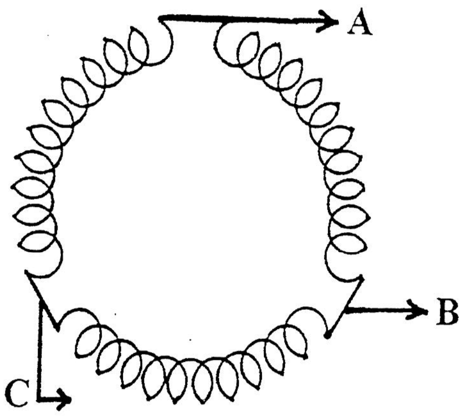




The STAR connection is sometimes used as a three or a four wire connection which produces a phase voltage between each phase winding and the common EARTH. The line voltage, which is 1.73 x phase voltage for the STAR connection can be drawn between any two output lines. Most large aircraft generators produce 115 VAC 400 Hz 1∅ and 200 VAC 3∅. The line voltage from a three phase star alternator (AC GENERATOR) is 200 volts. Should a single phase 200 VAC be required, it can be made available.

The Delta Connection





Generator coils can simply be joined from end to end, creating the 3∅ Delta connection. This is a three-wire arrangement where the line voltage is the same as the phase voltage. As the output can only be taken across a phase winding, it is the phase voltage that determines the output.

These coil arrangements have been discussed in the context of generator output coils but these connections are also common to AC motors, transformers and other inductive devices.

INTERCONNECTION OF ELECTRICAL POWER

Batteries and DC generators can be connected in series or parallel with relative ease. However, the joining of AC power supplies is more difficult because the instantaneous potential values of each generator can be very different.

AC generators are **never** connected in series. The only real application of series connections of AC supplies is to increase output voltage. This is not necessary as AC power is very flexible and transformers can change voltage accurately and easily with no moving parts. AC generators are designed to operate as individual units powering separate circuits or they can be paralleled, so that three or four generators tied together can act as a total supplier of all circuits.

To connect AC generators in parallel, the following conditions between the generators must be met:

1. Voltages equal.
2. Frequencies equal, and
3. Phase rotation sequence is the same (3∅).

Additionally, if these three conditions are met, consideration must be given to synchronizing the generators so that the reference phase in each generator is produced simultaneously. Thankfully, this synchronization task is automated by the computers in modern aircraft.

AIRCRAFT ALTERNATING CURRENT SUPPLY

The AC generator is the 'supplying' device in an AC system. It is critical that the voltage, frequency and phase rotation of the AC Generator is produced within the small tolerances of 115V ± 5V and 400Hz ± 5Hz. As with DC supplies, significant under or over voltages will cause a change in the amount of current flow through the equipment. Should the amount of current be outside the design operating range of that equipment, malfunctions will occur. Most AC equipment is frequency sensitive and under or over-frequencies will cause an increase or decrease in current flow respectively. Again, should the amount of current flow be outside the design operating range, malfunctions will occur. The phase rotation sequence is set by the generator manufacturer and the aircraft wiring and can not be changed unless a physical wiring error is made. The capability of the voltage regulator determines the output voltage range. The capability of the frequency regulation system (includes CSDU) determines the output frequency range.

AC generators and their systems are discussed in Chapter 11 of these notes but for now, note that aircraft AC power is usually:

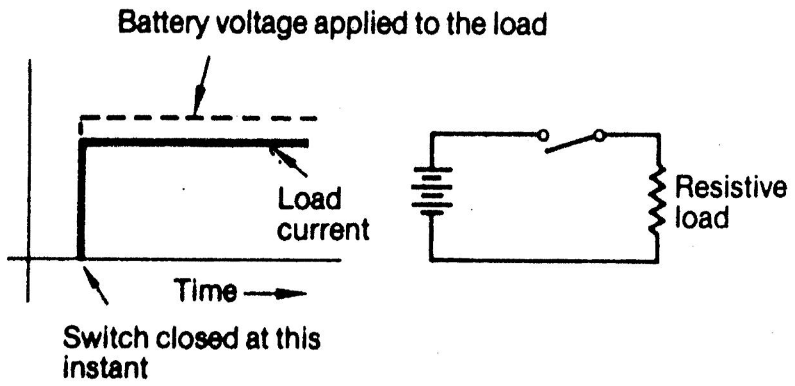
115 VAC ± 5V 400 Hz ± 5Hz 3∅ or 1∅

26 VAC ± 1V 400 Hz ± 5Hz 3∅ or 1∅

UNDERSTANDING IMPEDANCE

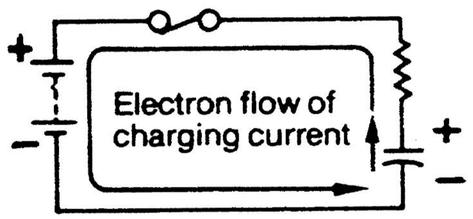
Resistance

Resistance in AC circuits has exactly the same effect on current flow as it does in DC circuits in that it obeys Ohms law. In a pure resistive AC circuit the voltage and current response is a direct relationship - increase the voltage and the current increases. Voltage and current are said to remain in phase.



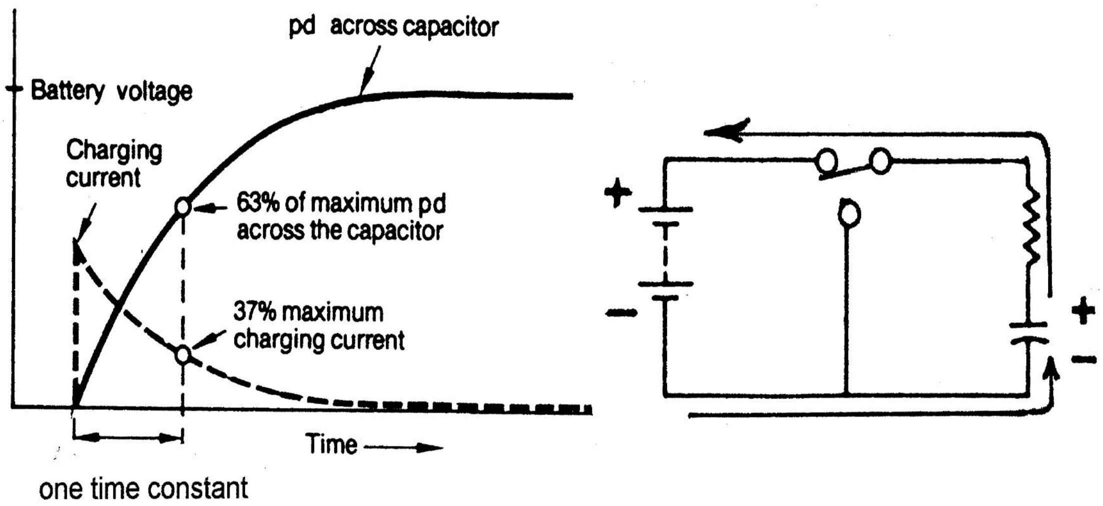
Capacitance

To understand the voltage and current relationship in a capacitive circuit, apply a small positive DC voltage across a capacitor. Initially this would look like a zero resistance path and a very high current would flow and damage the capacitor. A resistor should be placed in series with the capacitor to control the amount of current flow, and hence the rate of charge or discharge.

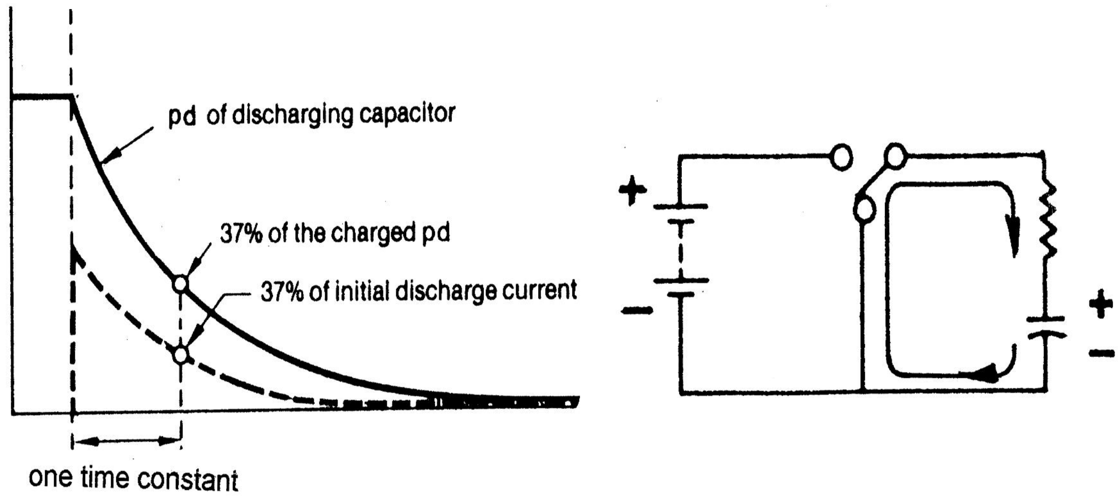


When the positive DC voltage is switched on, a current will flow, as determined by the applied voltage and the circuit resistance. Initially, maximum current will flow while the potential difference (PD) at the capacitor is 'pulled down' to a very low value. As current flows and a charge builds up on the capacitor plates, the PD between the capacitor and the supply decreases and consequently the current decreases. This process continues until the capacitor is fully charged. When the voltage at the capacitor equals the voltage at the supply, the current stops flowing. Should the supply be removed and the capacitor shorted, discharge would occur at the rate determined by the capacitor voltage and the circuit resistance.

THE FACTS:
- A CAPACITOR CAN BE CHARGED AND DISCHARGED
- IT TAKES TIME TO CHARGE AND DISCHARGE
- CURRENT AND VOLTAGE RELATIONSHIP AT THE CAPACITOR IS SEPARATED BY TIME



CAPACITOR CHARGE



CAPACITOR DISCHARGE

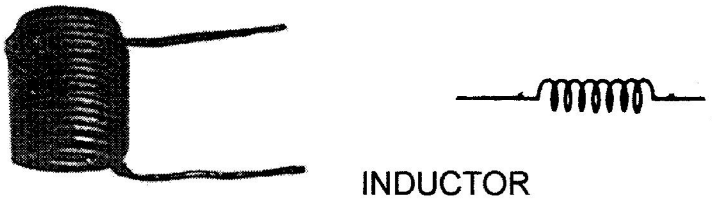
Recognizing the voltage current relationship and the time factor is important to the understanding of capacitance in AC circuits. Because the AC voltage wave form varies at a designed rate (frequency), the time available for a capacitive circuit to charge or discharge is therefore limited by the frequency. Take the case where the frequency is very high. As maximum current flows at each change and insufficient time is available for a full charge to occur, the resistance (reactance) to current flow is low, consequently the current flow is high. Therefore in capacitive AC circuits the amount of current flow is affected by the supply frequency. This effect is known as Capacitive Reactance (X_C) and is measure in ohms.

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

In a pure capacitive AC circuit the current leads the voltage by 90°. Opposition to AC current flow caused by capacitance and the frequency, is known as capacitive reactance X_C (ohms).

Inductance

Inductors are not unlike capacitors in their behavior and react in exactly the opposite sense. An inductor is simply a coil of conducting wire, which may be wound around a ferromagnetic core or be made self-supporting, having an air core.

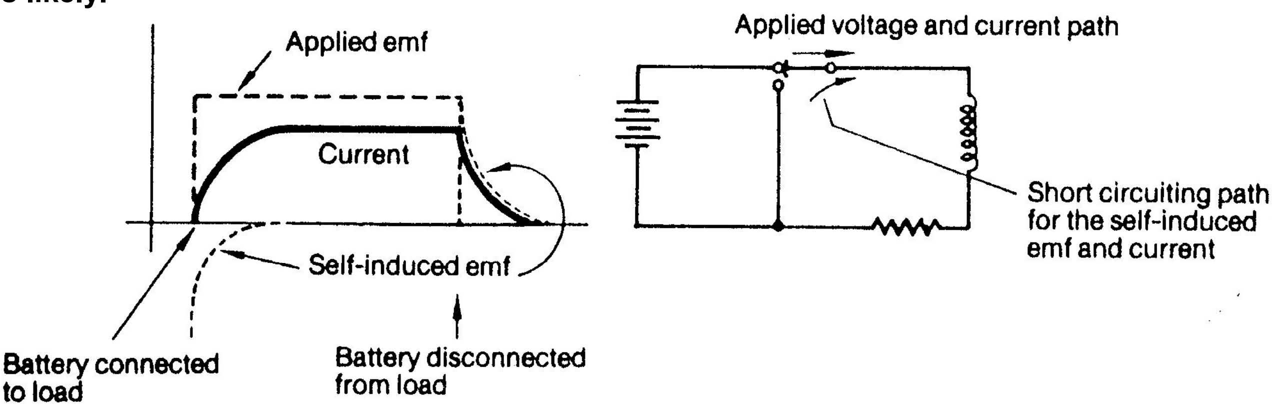


INDUCTOR

When a small positive DC voltage is applied, a current starts flowing immediately because the wire appears initially as a very low resistance path. However, as the current increases, it generates a changing field (expanding) around each coil of the inductor. This changing field 'induces back EMF' in to adjacent coils. The opposing EMF limits the current rate of increase of current flow (inductive reactance is high) and the maximum current can only flow after a definite time as determined by the applied voltage, and the value of the inductor. An inductor does not hold a charge in exactly the same way as a capacitor but its self induced (back EMF) characteristics do cause a similar but opposite reaction. When this circuit is shorted out the stored energy will discharge. As the current flows from the inductor the field will collapse by only at the rate permitted by the back EMF effect, this is known as inductive reactance (X_L) and is measured in ohms. Inductors and other inductive devices are dependent on the time factor for their operation. When AC is applied to an inductive circuit, initially the current is minimal if the frequency is high, inductive reactance is high and current flow is low. Inductive reactance is directly related to the applied frequency.

$X_L = 2\pi \, f \, L$

Inductive devices are frequency dependent for their correct function. Should an **under-frequency** supply be connected, inductive reactance will reduce from its design value and an increase in current will occur. **The inductive device will overheat and failure is likely.**



INDUCTOR CHARGE, DISCHARGE

In a pure inductive AC circuit the current lags the voltage by 90°. Opposition to the flow caused by inductance is known as inductive reactance X_L (ohms).

Impedance

As discussed in Chapter One Ohm's law was introduced under constant voltage (steady state) conditions in DC circuits in which $R = \frac{E}{I}$ in every case.

In AC circuits which have constantly changing voltage and current, the 'opposition' to current flow is made up of three elements and the **vector sum** of the elements is impedance. They are:

1. Resistance R (ohms)
2. Inductive reactance X_L (ohms)
3. Capacitive reactance X_C (ohms)

Impedance is the total opposition to current flow in an AC circuit and is designated Z with units of ohms. Ohms law applied in AC circuits is now $\frac{E}{I} = Z$.

However in some simple circuits, usually lighting and heating circuits, like incandescent light bulbs and panel heaters, the impedance would be mostly resistive, the inductive All AC circuits contain some resistance, inductive reactance and capacitive reactance. and capacitive reactances so small they can be ignored. This allows another option with AC generators which by design do not produce constant frequency AC

POWER IN AC CIRCUITS

Power is the rate of doing work and in DC electrical circuits: P = EI. In any type of circuit current flowing through resistance generates heat proportional to I^2R. This is known as **True Power**. Sometimes the terms Real or Effective Power are used. The unit of true power is watts (W).

AC circuits involve current flow through impedance, but only part of the impedance is resistance. The resistive portion of the circuit produces heat (true power). The remaining part of the impedance is 'reactance' and produces reactive power. As generators are coil wound devices, the inductive reactance causes the current to lag the voltage production. The unit of **reactive power** is volt amps reactive (VAR).

The product of EI gives True Power in pure resistive circuits. The product of EI in AC circuits also gives reactive power. The vector sum of the resistive power element and the reactive power element is known as **apparent power**. As True Power is only part of apparent power, apparent power is always greater than or equal to true power. It is only possible for apparent and true power to be equal in a pure resistive circuit.

The units of apparent power are volt amps (VA). In a 200 volt circuit, if 5 amps were used, the product of EI gives 1000 watts which equals one kVA. It will depend on circuit resistance as to how much true power is consumed. In a pure resistive circuit true power would be 1000 watts. In a pure reactive circuit true power would be zero watts.

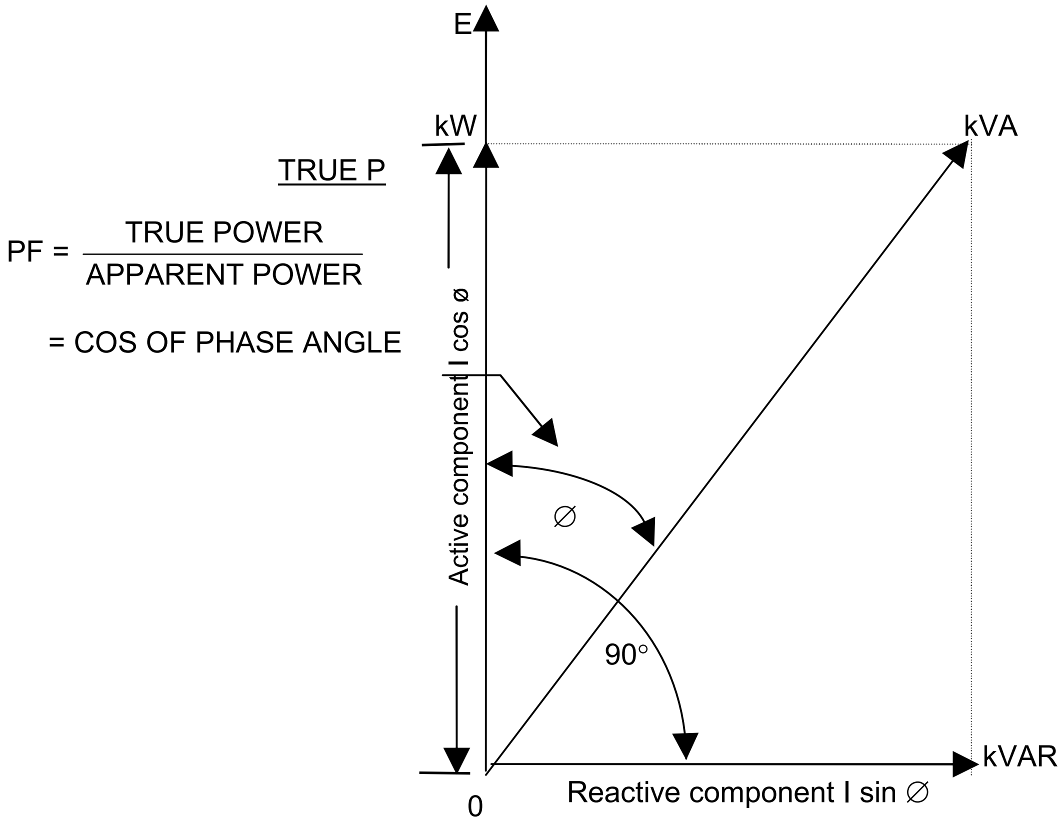
POWER FACTOR

The ratio between TRUE POWER and APPARENT POWER is called the power factor.

$$\text{POWER FACTOR} = \frac{\text{TRUE POWER (W)}}{\text{APPARENT POWER (VA)}}$$

As true power is one component of apparent power in AC circuits, it is possible that in a pure resistive circuit, the PF is 1. It is more likely for the PF to be 0.8 or 0.9, depending on the value of circuit reactance.

The difference between true and apparent power exists because of the reactive nature of capacitive and inductive circuits that produces a phase shift between voltage and current. In the vector diagram below, the power is resolved into two components at right angles, active wattful power, where voltage and current are in phase, and reactive wattless power, where a 90° phase shift between voltage and current has occurred.



An AC Generator may be rated at 50 kVA @ PF .9. This means that the maximum output power of 50 kVA x .9 = 45 kW. However, the product of voltage by amperes under any condition must not exceed 50 kVA.