LESSON 1

BASIC CONCEPTS OF ELECTRICITY

Overview:

Rural electrification is the process of bringing electrical power to rural and remote areas. Electricity is used not only for lighting and household purposes, but it also allows for mechanization of many farming operations, such as threshing, milking, heating and hoisting grain for storage. Electricity in the rural or in the farm can increase output per worker, improved quality of product, reduce risk, add convenience, and save time and labor.

This lesson explains some basic concepts in order to have a full grasp of electricity and electrification and will acquaint you with some common forms of dc and ac.

Peace Concept: Transformation

Learning Objectives: At the end of this lesson, the students can

1. define basic terms in electricity;
2. differentiate the two types of current;
3. use Ohm's law in solving the resistance, current, potential difference, and power in an electric circuit; and
4. solve instantaneous power, phase shift angle, effective power, reactive power, and power factor in ac system.

Materials Needed:

- Handouts Whiteboard
- Wyte board pen
- Book
- LCD/LED monitor or smart tv
- Computer/laptop
- Internet service

Duration: 3 weeks

Learning Content:

ELECTRICAL TERMS

Electricity – is the *movement of electrons.* It is a broad term which includes that field of science dealing with the activity of electrons, the force that causes the activity, and the result, control, or use which made of the *movement of electrons.*

Electric – from Greek word for *amber.*

Compound – is a combination of elements

Molecule – the smallest particle of any compound is that retains the original characteristics of that compound

where E_{12} = potential difference in volts, V
W_{12} = energy expended or absorbed in joules, J
Q_{12} = charge measured in coulombs, C

Voltage – is the pressure that causes the electron movement by the attraction of the positive terminal and repelling action of the negative terminal and is measured in volts (E). This can be generated by means of mechanical, magnetic, pressure, thermal, radiation, or chemical effects

Voltmeter – is used to measure voltage, does not break the circuit, but instead is placed across an element or a part of the circuit for which the potential is to be measured or place the voltmeter between the terminals of the circuit.

Ammeter – is an instrument which measures current in line. The circuit must be, must be broken in order to determine the flow in the circuit. Ammeter also measures the current flowing in one terminal and out the other.

Power – the rate of work or energy use, the unit is watt (W). It can also be defines as the product of the potential difference and the current.

$$\text{Power (watts)} = \frac{\text{Work or Energy used (joules)}}{\text{Time (seconds)}}$$

$$\text{Voltage}\left(\frac{\text{Work}}{\text{Charge}}\right) \times \text{Current}\left(\frac{\text{Charge}}{\text{Time}}\right) = \text{Power}\left(\frac{\text{Work}}{\text{Time}}\right)$$

$$\text{Power (watts)} = \text{P} = \text{Potential (volts)} \times \text{Current (amperes)} = \text{E I}$$

Energy – is the ability or power of electrical appliance to work or make an effort

Energy = Power x Time = volts x amperes x second = watts x seconds

Wattmeter – an instrument that measure power. It gives a reading of the product of the current and voltage in a circuit. Older style meters have a minimum of two terminals for voltage sensing and two terminals for current measurement. Newer meters may use a clamp-on ammeter to measure the current. As we will explain in Chapter 3, when current runs through a wire it creates a magnetic field around the wire. The clamp-on ammeter senses this magnetic field to determine the current flow.

Watt-hour or Kilowatt-hour meter – measures the total energy use over a period of time or accumulated power. This type of meter is used for billing customers for electrical usage. This device sums the energy consumption over time and gives either a digital or dial display of the total.

$$kWh = \frac{P\,t}{1000}$$

where P = power in watts, W
t = time in hours, h

Energy use billing is then based on the energy used and the cost per unit of energy.

Cost = Total kWh × (Cost /kWh)

Conductors – are materials that have large atoms and very orderly structures, such as metals, in which the electrons in the outer shells have a low resistance to movement.

Insulators – are materials that do not readily release their outer electrons to form current such as rubber, glass, bakelite, and mica

Semiconductors – are intermediate group of materials, which offers an intermediate resistance to electron flow. They form the materials used in construction of solid-state electronic devices such as diodes and transistors

Load – All devices (or their equivalent resistance, capacitance, and inductance) connected to an electrical circuit

Example 1.1
An energy source forces a constant current of 2 A for 10 s to flow through a light bulb. If 2.3 kJ is given off in the form of light and heat energy, calculate the voltage drop across the bulb.

Solution:

The total charge is

$$Q = It = 2\text{ A }(10\text{ s}) = 20\text{ C}$$

The voltage drop is

$$V = W/Q = (2.3\times10^3\text{ J}) \div 20\text{ C} = 115\text{ V}$$

Example 1.2
How much energy does a 100-W electric bulb consume in two hours?

Solution:

$$E = Pt = 100\text{ W }(2\text{ h}) = 200\text{ Wh}$$

Example 1.3
A homeowner consumes 700 kWh in January. Determine the electricity bill for the month using the following residential rate schedule:

Base monthly charge of ₱50.00.
First 100 kWh per month at ₱6/kWh.
Next 200 kWh per month at ₱4/kWh.
Over 300 kWh per month at ₱1.5/kWh.

What is the average cost of electric energy?

Solution:
The calculation of electric bill is as follows:

Base monthly charge	=	₱50.00
First 100 kWh per month at ₱6/kWh	=	₱600.00
Next 200 kWh per month at ₱4/kWh	=	₱800.00
Over 300 kWh per month at ₱1.5/kWh	=	₱600.00
Total charge	=	₱2050.00

Element – is a substance that cannot be decomposed to form simpler substances by any chemical means.

Atom – the smallest portion into which an element can be subdivided without losing its physical and chemical properties. It composed of subatomic particles of *neutrons*, *protons*, and *electrons* in various combinations.

Neutron – electrically uncharged masses found in the nucleus

Proton – is the fundamental positive (+) charge of electricity also found in the nucleus.

Electron – is the fundamental negative (–) charge of electricity that is distributed in the shells of the atom and revolves about the nucleus

no. of protons = no. of electrons

Valence electrons – the electrons in the outer shell farthest from the nucleus that experience a comparatively weak attraction to nucleus, control the electrical and chemical properties of the atom, and may wander into outer shells of nearby atoms.

Current – is the result of this nonrandom movement of electrons due to some outside force, such as a battery or the application of heat that disturbs the balance, which the loosely bound outer electrons may tend to move in one direction.

This is measured in terms of units of electrical charge per unit time that pass a plane perpendicular to the direction of current flow. The greater the amount of charge that flows per unit time, the greater the current.

$$\text{Current} = \frac{\text{Charge}}{\text{Time}} \text{ or } I = \frac{Q}{t}$$

where I = current in amperes, A
Q = charge in coulombs, C
t = time in seconds, s

By definition, one coulomb is equivalent to 6.25×10^{18} electrons. Therefore, that number of electrons passing in one second is defined as one ampere.

$$1 \frac{\text{coulumb}}{\text{second}} = 1 \text{ ampere} = 1 \text{ A}$$

The term ampere is in honor of French scientist André Ampere (1775-1836) who laid the foundation for electrodynamics. The coulomb is named after Charles Augustin Coulomb (1736-1806), a French engineer.

Electromotive force (emf) – is produced by a device that supplies the energy to move electrons in a circuit. The unit of electromotive force is the **volt** and it has the letter symbol E or V. E is used in this text because V is the abbreviation for the unit of volt.

Potential difference – or **potential**, is the difference in voltage measured between two points in an electrical circuit.

The potential difference between any two points, 1 and 2, in an electrical system is determined by

$$E_{12} = \frac{W_{12}}{Q_{12}}$$

Average cost = ₱2050.00 ÷ (100 + 200 + 400) = ₱2.92 per kWh

OHM'S LAW

Ohm's law – states that "Current is directly proportional to the pressure and inversely proportional to the resistance". In equation form,

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

Resistance– is the relative difficulty in a material with which current can be transmitted. It is a property of the material itself. The resistance is measured in units of **ohms**. The greater the resistance to flow of electrons, the less the resulting current. This is expressed in **Ohm's Law** as

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

where I = current in amperes, A
E = potential in volts, V
R = resistance in ohms, ohm or Ω

The resistance of a conductor or wire is dependent upon the nature of the material and the physical dimensions. Resistance is directly proportional to length of the path and inversely proportional to the cross-sectional area. The proportionality constant is called **resistivity**. This relationship can be expressed as

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

where R = resistance, ohm
L = length
A = cross-sectional area
ρ = resistivity, Ω-m, Ω-cm or Ω-CM/ft

Table 1.1 Resistivity of Metals

MATERIAL	RESISTIVITY AT 20° C in units of 10^{-8} Ω-m
Aluminum	2.83
Brass	6.16
Carbon (Graphite)	800
Copper (Annealed)	1.72
Copper (Hard-Drawn)	1.77
Iron (Electrolytic)	9.95
Lead	22
Mercury	96
Nichrome	1.0
Silver	1.64
Gold	2.44
Tungsten	4.37

Conductance of a conductor is the reciprocal of the resistance expressed in mho (℧) or Siemen (S). One Siemen is equal to 1/Ω.

Temperature coefficient of resistance of a conductor – is defined as the proportional change in resistance per degree temperature difference from some reference temperature (usually 20°C). Hence resistance can be expressed as a function of temperature as

$$R_t = R_i\,(1 + \alpha\ \Delta T)\ \text{ohm}$$

where R_t = resistance at specified temperature, ohm
R_i = resistance at reference temperature, ohm
α = temperature coefficient of resistance, 1/°C
ΔT = difference temperature between specified and reference, °C

Table 1.2 Temperature Coefficients at 20°C

MATERIAL	Coefficient (1/°C)
Aluminum	3.9×10^{-3}
Copper (Annealed)	3.9×10^{-3}
Iron (Electrolytic)	5.0×10^{-3}

Conductance - is a useful quantity in circuit analysis is the reciprocal of resistance R, known as conductance and denoted by G. It measures of how well an element will conduct electric current. The unit of conductance is the mho (ohm spelled backward) or reciprocal ohm, with symbol ℧. The SI unit is Siemen (S).

$$G = \frac{1}{R} = \frac{I}{V}$$

Power Relations:

$$P = E\,I = I^2 R = \frac{E^2}{R}$$

where P = power in watts, W
I = current in amperes, A
E = potential in volts, V
R = resistance in ohms, ohm

Direct current (*dc*) is the current that moves through a conductor or circuit in one direction only. The reason for the unidirectional current is that voltage sources such as cells and batteries maintain the same polarity of output voltage. The voltage supplied by these sources is called *direct-current voltage*, or simply *dc voltage*. A dc voltage source can change the amount of its output voltage, but if the same polarity is maintained, direct current will flow in one direction only.

Example 1.4
An electric iron draws 2 A at 120 V. Find its resistance.

Solution:

From Ohm's law

$$R = V/I = 120 \div 2 = 60\ \Omega$$

Example 1.5
The current through a 100 Ω resistor to be used in a circuit is 0.20 A. Find the power rating of the resistor.

Solution:

From Ohm's law

$$P = I^2 R = (0.2\ \text{A})^2\ (100\ \Omega) = 4\ \text{W}$$

Example 1.6
A copper bus bar has a rectangular cross-section of dimensions 6 in. by 8 in. Determine the cross-sectional area in CM.

Solution:

$$A = LW = 6 \times 8 = 48\ \text{in}^2 \times \left(\frac{1000\ \text{mil}}{1\ \text{in}}\right)^2 \times \left(\frac{1\ \text{CM}}{(\pi/4)\text{mil}^2}\right)$$
$$= 61.12\text{x}10^6\ \text{CM} \quad \text{or}$$
$$= 61.12\ \text{MCM}$$

Example 1.7
A 1-m length of wire is found to have a resistance of 25 Ω. If the diameter of the wire is 1 mm, determine the resistivity in Ω-m.

Solution:

$$A = \pi d^2/4 = \left(\frac{\pi}{4}\right) \text{x} \left(\frac{1}{1000}\right)^2 = 7.854\text{x}10^{-7}\ \text{m}^2$$

$$\rho = \frac{\text{RA}}{\text{L}} = \frac{25\ \Omega\ (7.854\times10^{-7}\ \text{m}^2)}{1\ \text{m}} = 1.963\text{x}10^{-5}\ \Omega\text{-m}$$

Example 1.8
An aluminum conductor with a diameter of 0.2 in. was badly damaged during a short-circuit. It was decided that a hard-drawn copper conductor with the same resistance will be used in its place. What should be the diameter of this copper conductor?

Solution:

$$R1 = R2$$
$$\frac{\rho_1 L_1}{A_1} = \frac{\rho_2 L_2}{A_2}$$
$$\frac{\rho_1}{{D_1}^2} = \frac{\rho_1}{{D_1}^2}$$
$$\frac{1.77\times10^{-8}}{{D_1}^2} = \frac{2.83\times10^{-8}}{0.2}$$
$$D_1 = 0.158\ \text{in.}$$

THE EQUIVALENT RESISTANCE

SERIES CIRCUIT

A series circuit is a circuit in which there is only one path for current to flow along. In the series circuit, the current I is the same in all parts of the circuit.

There are three basic laws that describe the behavior of series circuits

1. The first law states that the individual resistance is a series circuit add up to the total circuit resistance.
2. The second law states that the current has the same value at any point within a series circuit.
3. The third law states that the individual voltages across the resistor in a series circuit add up to the total voltage applied to that circuit.

PARALLEL CIRCUIT

A parallel circuit is a circuit where there is more than one path for current to flow through.

The three laws of parallel circuits are:

1. The total voltage of the parallel circuit is the same cross each branch of that circuit.
2. The total current in a parallel circuit is equal to the sum of the individual branch circuits.
3. The total resistance in a parallel circuit is always less or approximately equal to the values of the smallest resistive branch.

KIRCHHOFF'S LAWS

Kirchhoff's 1^{st} Law

Gustav Kirkchhoff's Current Law (KCL) states that the total current entering a junction equals the total current leaving the junction. This is based on charge conservation.

Kirchhoff's 2^{nd} Law

Gustav Kirkchhoff's Voltage Law (KVL) states that the sum of all voltages around any closed loop in a circuit is zero. This reflects the principle of energy conservation.

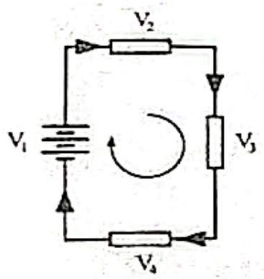

Fig. a

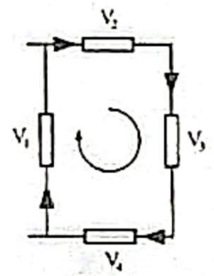

Fig. b

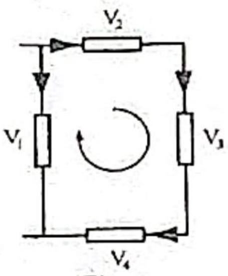

Fig. c

Fig. a	two closed loops with a power	V1 – V2 – V3 – V4 = 0
Fig. b	Without power supply assumed	V1 + V2 + V3 + V4 = 0

	current direction	
Fig. c	without a power supply with actual current direction	V2 + V3 + V4 = V1

ALTERNATING CURRENT

Alternating current (ac) is the current that periodically reverses direction because the voltage source periodically reverses or alternates in polarity too. The ac power line used in most homes is a common example. The voltage and current direction go through many reversals each second in these systems.

Generating Alternating Voltage

- The volt (V) is the unit of electromotive force (EMF). One volt is developed by cutting 100 million magnetic lines of force in 1 second. The simplest method of generating EMF is by turning a coil of wire between two magnetic field poles.
- *One cycle* of alternating current is defined as current that increases from zero to a positive maximum, returns to zero, and then increases to a negative maximum and returns to zero again. In other words, a cycle occurs from a point on the waveform to another point where the waveform begins to repeat itself. The terms "positive" and "negative" are used to indicate opposite directions.

AC Waveforms

- ***Square waves*** are generally produced by electronic devices called oscillators. Oscillator is often used to change the 12-volt DC of an automobile battery into 120-volt AC to operate electric handtools such as drills and saws. The instantaneous amplitude remains constant.

- ***Triangle wave*** is a linear wave. Linear waves from straight lines when plotted on a graph. The rise and decay are both finite and equal.

- ***Sine wave*** or **sinusoidal** is the most common of all AC waveforms. Sine waves are produced by all rotating machines such as alternators, and therefore can be compared to circles. The current at the wall outlets in your house is an almost perfect AC sine wave with a frequency of 60 Hz.

  Sine waves are so named because the voltage at any point along the waveform is equal to the maximum or peak value times the sine of the angle of rotation.

- ***Sawtooth waves*** are the AC waves that rise and/or fall in straight, sloping lines seen on an oscilloscope screen. Sawtooth waves are generated by certain electronic test devices and also by electronic sound synthesizers. Sawtooth wave may have *fast rise and slow decay*, and *slow rise and fast decay*. The *slow rise, fast decay* sawtooth wave is often called a ramp. It is useful in scanning television sets and oscilloscopes.

Sine Wave – is the voltage and current waveform. The instantaneous value of voltage at any point on the sine wave is expressed by the equation

$$e = E_m \sin \theta \qquad i = I_M \sin \theta$$

where e = the instantaneous voltage
E_m = maximum voltage
i = instantaneous current
I_m = maximum current
θ = angle

In vector form

$$e = E_m \sin \omega t \qquad i = I_m \sin \omega t$$

where e = instantaneous voltage, V
E_m = maximum or peak voltage, V
i = instantaneous current, A
I_m = maximum or peak current, A
ω = angular velocity in degrees/s
t = time in seconds, s
$\omega t = \phi$ = angle of rotation in degrees

Example 1.9
A sine wave voltage varies from zero to a maximum of 10 V. What is the value of voltage at the instant that the cycle is at 30° and 45° ?

SOLUTION: $E_m = 10$ V

$$e = E_m \sin \phi$$

a) $e = 10 \sin 30° = 5$ V
b) $e = 10 \sin 45° = 7.07$ V

Frequency

Frequency (f) of an alternating current or voltage – is the number of complete cycles occurring in each second. Frequency is generally given in units of *hertz* (Hz), one hertz equaling one cycle per second. In the Philippines the common frequency is 60 Hz.

- AC waves which have only one frequency are called ***pure***.
- ***Frequency*** is the number of complete cycles that occur in one second
- ***Period***, when measured in seconds, is denoted by T.
- Formulas commonly used to find frequency, speed, period, and number of poles follow:

$$f = \frac{NP}{120} \qquad (1)$$

$$f = \frac{1}{T} \qquad (2)$$

Where f = frequency in hertz
N = speed in r/min
P = number of poles
T = period in second

Example 1.10
An ac current varies through one complete cycle in 1/100 s. What are the period and frequency?

Solution:

T = 1/100 s or 0.01 s or 10 ms

f = 1/T
= 1 ÷ 1/100
= 100 Hz

Peak value – is the maximum value E_{peak} or I_{peak}. It applies to either the positive or negative peak. The peak-to-peak (p-p) value may be specified and is double the peak value when the positive and negative peaks are symmetrical.

Oscilloscope – is a special meter that measures the maximum amplitude of either the positive or the negative part of the cycle of a sine wave.

Root-mean-square value – or effective value is 0.707 times the peak value

$$E_{rms} = \frac{E_{peak}}{\sqrt{2}}$$

and

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

Example 1.11
If the peak voltage for an ac wave is 60 V, what is the rms value?

Solution:

E_{rms} = 0.707 x peak value = 0.707 (60) = 42.42 V

Instantaneous power – is the product of the current I and the voltage E at that instant of time t

$$P = E\,I$$

Phase-shift angle (ϕ) – or phase shift, or phase angle, is the extent, expressed in degrees, to which the current and the voltage differ in phase. If there is no reactance, then $\phi = 0°$. If there is a pure reactance, then either $\phi = +90°$ (if the reactance is inductive) or else $\phi = -90°$ (if the reactance is capacitive). The power factor is equal to the cosine of the phase angle:

Effective power – is referred to as true, real, or in-phase power. It is the product of the rms voltage and current and is always positive. It can also be viewed as the average constant value over the cycle. Real power can be considered as resistive power that is dissipated as heat.

True power in an ac circuit can be calculated by

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

where E = voltage, V
I = current, A
ϕ = phase-shift angle

Reactive power (Q)– is referred to as wattles, volt-ampere, VA, or apparent power. It does no useful work. Reactive power can be measured with a VAr meter. VAr means volt-ampere reactive. One unit of reactive power, one VAr, and one unit of true power, one watt, are numerically equal, but the distinction is that the VAr does no useful work.

$$\text{Reactive power} = E_x I_x = EI\sin\theta,\ \text{VA}$$

(always negative or lagging)

Apparent power (S)– is the product of the line voltage and line current

$$\text{Apparent Power} = E\,I,\ \text{in VA}$$

Power factor (pf)– is the ratio of true power to apparent power for a circuit. It is also equal to the cosine of the phase-shift angle. The optimum situation for transferring power in an ac system exists when the power factor of the load equals unity that is, when the phase shift between current and voltage is zero, $\phi = 0$.

$$\text{pf} = \cos\phi = \frac{\text{True Power}}{\text{Apparent power}} = \frac{\text{watts}}{\text{volts} \times \text{amperes}}$$

Losses due to the resistance of the conductors in a circuit or a transmission line can be minimized by improving the power factor.

Example 1.12
In the RLC series ac circuit, the line current of 2 A lags the applied voltage of 17 V by 61.9°. Find pf, P, Q, and S.

Solution:

(a) power factor, pf

$$\text{Pf} = \cos\theta = \cos 61.9°$$

(b) true power, P

$$P = EI\cos\theta = (17)(2)\cos 61.9° = 16\ \text{W} \quad \text{or}$$

$$P = I_2R = 22\,(4) = 16\ \text{W}$$

(c) reactive power, Q

$$Q = EI\sin\theta = 17\,(2)\sin 61.9° = 30\ \text{VA lagging}$$

(d) apparent power, S

$$S = EI = 17\ (2) = 34\ VA$$

Inductor – Is a coil found in motor or transformer winding, is an electrical component that oppose the flow of ac by temporarily storing energy as magnetic fields.

Inductance – is the property of creating an opposition to change in current flow. It is measured in units of henries (H).

Inductive reactance (X_L) – is the amount of opposition to current change and is a function of the frequency of the source and the inductance.

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

where X_L = opposition to current flow, Ω
f = frequency in hertz, Hz
L = inductance in henries, H
π = 3.1416

Voltage across and current through an inductor are described by Ohm's Law for an inductor as

$$E = I\ X_L$$

Self-inductance – occurs when the varying lines of magnetic force established by a changing current in a coil induce an electromotive force in the coil itself.

Mutual inductance – is change in current in one conductor or coil has an effect on a second conductor or coil. Transformers are an example of the use of mutual inductance.

Example 1.13
The primary coil of a power transformer has an inductance of 30mH with negligible resistance. Find its inductive reactance at a frequency of 60 Hz and the current it will draw from a 120-V line.

Solution:

$$X_L = 2\ \pi\ f\ L = 2\ \pi\ (60)\ (30\times10^{-3}) = 11.3\ \Omega$$

$$I = E/X_L = 120 \div 11.3 = 10.6\ A$$

Transformer – is a machine which changes the amount of voltage from one value to another value. If the number of turns of wire in the primary and secondary coils are different, the voltage levels will vary as expressed by the equation

$$\frac{E_{primary}}{E_{secondary}} = \frac{N_{primary}}{N_{secondary}}$$

step-down transformer – if the primary has more turns than the secondary, the primary voltage will be higher than the secondary voltage.

step-up transformer – if the primary winding has fewer turns than the secondary, the secondary voltage will be higher than the primary.

One to one (1:1) transformer – has an equal number of turns in both the primary and secondary windings, the induced voltage in the secondary is the same magnitude as the voltage applied to the primary. A 1:1 isolation transformer as a protective device against electrical shock and for protection of expensive test equipment.

Ideal transformer – no power is lost

$$P_{primary} = P_{secondary}$$

$$E_P I_P = E_S I_S$$

$$\frac{E_P}{E_S} = \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

Example 1.14
An iron-core transformer operating from a 120-V line has 500 turns in the primary and 100 turns in the secondary. Find the secondary voltage.

Solution:

$$\frac{E_P}{E_S} = \frac{N_P}{N_S}$$

$$\frac{120}{E_S} = \frac{500}{100}$$

E_s = 24 V

Capacitor – is a coil found in motor or transformer winding, is an electrical components that oppose the flow of ac by temporarily storing energy as an electric fields. Consists of two conducting plates of metal separated by an insulating material called a *dielectric.*

Dielectric – is a material where the capacitor stores electric charge.

Capacitance – is the amount of electrical charge that a capacitor can store for each volt of applied potential. It is measured in units of farads, F.

Capacitive reactance (X_C) – is the amount of opposition to current flow

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

where X_C = opposition to current flow, Ω
f = frequency in hertz, Hz
C = inductance in farads, F
π = 3.1416

Addition of capacitors for power factor improvement must be based on an economic analysis of the particular situation. Power factor improvements up to 90% to 95% are generally economically practical.

Example 1.15
A 120-Hz 25-mA ac current flows in a circuit containing a 10µF capacitor. What is the voltage drop across the capacitor?

Solution:

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(120)(10\times10^{-6})} = 132.5\ \Omega$$

$$V_C = I_C X_C = (25\times10^{-3})(132.5) = 3.31\ V$$

RLC CIRCUIT

The rate of charging of a capacitor in an RC circuit is described using the time constant of the circuit, τ (tau), where

$$\tau = RC \text{ seconds}$$

In equation form, voltage across and current through the capacitor as it charges can be expressed as

$$I_C = (E/R)\, e^{-t/\tau}$$

$$E_C = E\,(1 - e^{-t/\tau})$$

where t is time in seconds.

The time constant for RL circuit is defined as

$$\tau = L/R \text{ seconds}$$

The equation for current flow through the inductor, I_L, is of the same form as that for voltage across a capacitor, E_C, or

$$I_L = (E/R)\,(1 - e^{-t/\tau})$$

The final value, at large t, for the current is simply E/R.

Example 1.15
When inductive reactance XL and capacitive reactance Xc are exactly equal in a series RLC circuit, a condition called series resonance exists. If in a series circuit $R = 4\ \Omega$ and $X_L = X_C = 19.5\ \Omega$, find Z and V_T.

Solution:

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

$$X = X_L - X_C = 19.5 - 19.5 = 0$$

$$Z = \sqrt{R^2} = R = 4\ \Omega$$

$V_T = IZ = 2 \times 4 = 8$ V

Example 1.16

A 400-Ω resistor, a 50-Ω inductive reactance, and a 40-Ω capacitive reactance are placed in parallel across a 120-V ac line. Find the phasor branch currents, total current, phase angle, and impedance.

Solution:

(a) phasor branch currents

$I_R = V_T/R = 120 \div 400 = 0.3$ A

$I_L = V_T/X_L = 120 \div 50 = 2.4$ A

$I_C = V_T/X_C = 120 \div 40 = 3.0$ A

(b) total current

$$I_T = \sqrt{I_R^2 + (I_C - I_L)^2} = \sqrt{(0.3)^2 + (3.0 - 2.4)^2} = 0.671 \text{ A}$$

(c) phase angle

$$\theta = \arctan \frac{I_C - I_L}{I_R} = \arctan \frac{3.0 - 2.4}{0.3} = 63.4°$$

(d) impedance

$Z_T = V_T/I_T = 120 \div 0.671 = 179$ Ω