**IDEAL VOLTAGE SOURCE**

An **ideal voltage source** is a **voltage source** that supplies **constant voltage** to a circuit despite the current which the circuit draws. ... When an **ideal voltage source** has zero internal resistance, it can drop all of its **voltage** perfectly across a load in a circuit.



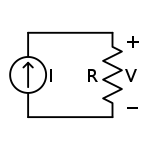
**A** **schematic diagram of a voltage source, *V*, driving a resistor, *R*, and creating a current *I***

**Constant voltage**' refers to the ability to fluctuate output current to maintain a set **voltage**. **Constant voltage** can be used for applications where the work pieces **do** not have flat surfaces, e.g. crossed wires, and where the resistance varies significantly, and for extremely short welds (less than 1 millisecond).

**IDEAL CURRENT SOURCE**

An **ideal current source** is a **current source** that supplies constant **current** to a circuit despite any other conditions present in the circuit. An **ideal current source** provides this constant **current** with 100% efficiency.

A **constant current source** is a power generator whose internal resistance is very high compared with the load resistance it is giving power to. Because its internal resistance is so high, it can **supply** a **constant current** to a load whose resistance value varies, even over a wide range.



**An ideal current source, *I*, driving a resistor, *R*, and creating a voltage *V***

**Constant current** LED drivers have a fixed **current** in amperes or milli-amperes and a variable **voltage**. **Constant voltage** drivers are similar, but opposite, with fixed **voltages** and variable currents.

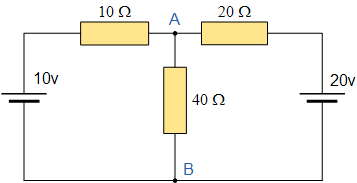
Most sources of electrical energy (the [mains](https://en.wikipedia.org/wiki/Mains_electricity), a [battery](https://en.wikipedia.org/wiki/Battery_(electricity))) are modeled as voltage sources. An *ideal* voltage source provides no energy when it is loaded by an [open circuit](https://en.wikipedia.org/wiki/Open-circuit_voltage) (i.e. an infinite [impedance](https://en.wikipedia.org/wiki/Electrical_impedance)), but approaches infinite energy and current when the [load resistance](https://en.wikipedia.org/wiki/Load_resistance) approaches zero (a [short circuit](https://en.wikipedia.org/wiki/Short_circuit)). Such a theoretical device would have a zero [ohm](https://en.wikipedia.org/wiki/Ohm_(unit)) [output impedance](https://en.wikipedia.org/wiki/Output_impedance) in series with the source. A real-world voltage source has a very low, but non-zero [internal resistance](https://en.wikipedia.org/wiki/Internal_resistance) and [output impedance](https://en.wikipedia.org/wiki/Output_impedance), often much less than 1 ohm.

Conversely, a [current source](https://en.wikipedia.org/wiki/Current_source) provides a constant current, as long as the load connected to the source terminals has sufficiently low impedance. An ideal current source would provide no energy to a short circuit and approach infinite energy and voltage as the [load resistance](https://en.wikipedia.org/wiki/Load_resistance) approaches infinity (an open circuit). An *ideal* current source has an [infinite](https://en.wikipedia.org/wiki/Infinity) [output impedance](https://en.wikipedia.org/wiki/Output_impedance) in parallel with the source. A *real-world* current source has a very high, but finite [output impedance](https://en.wikipedia.org/wiki/Output_impedance). In the case of transistor current sources, impedance of a few [megohms](https://en.wikipedia.org/wiki/Megohm" \o "Megohm) (at low frequencies) is typical.

Since no ideal sources of either variety exist (all real-world examples have finite and non-zero source impedance), any current source can be considered as a voltage source with the *same* [source impedance](https://en.wikipedia.org/wiki/Source_impedance) and vice versa. Voltage sources and current sources are sometimes said to be [duals](https://en.wikipedia.org/wiki/Dual_(electronics)) of each other and any non-ideal source can be converted from one to the other by applying [Norton's theorem](https://en.wikipedia.org/wiki/Norton%27s_theorem) or [Thévenin's theorem](https://en.wikipedia.org/wiki/Th%C3%A9venin%27s_theorem" \o "Thévenin's theorem).

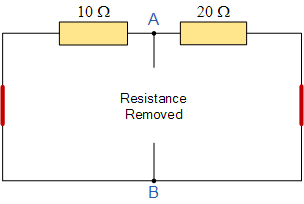
**Thevenin’s Theorem**.

**Thevenin’s Theorem** states that “Any linear circuit containing several voltages and resistances can be replaced by just one single voltage in series with a single resistance connected across the load“*.*

**

Firstly, to analyse the circuit we have to remove the centre 40Ω load resistor connected across the terminals A-B, and remove any internal resistance associated with the voltage source(s). This is done by shorting out all the voltage sources connected to the circuit, that is v = 0, or open circuit any connected current sources making i = 0. The reason for this is that we want to have an ideal voltage source or an ideal current source for the circuit analysis.

The value of the equivalent resistance, Rs is found by calculating the total resistance looking back from the terminals A and B with all the voltage sources shorted. We then get the following circuit.

**

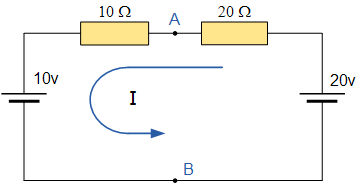
**Find the Equivalent Resistance (RT)**

**10Ω Resistance is parallel with 20 Ω Resistance**

**= 6.67 Ω**

The voltage VS is defined as the total voltage across the terminals A and B when there is an open circuit between them. That is without the load resistor RL connected.

**Find the Equivalent Voltage (VS)**

****

We now need to reconnect the two voltages back into the circuit, and as VS = VAB the current flowing around the loop is calculated as:

**I =**

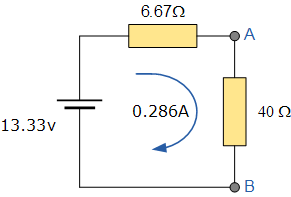
This current of 0.33 amperes (330mA) is common to both resistors so the voltage drop across the 20Ω resistor or the 10Ω resistor can be calculated as:

VAB  =  20  –  (20Ω x 0.33amps)  =   13.33 volts.

or

VAB  =  10  +  (10Ω x 0.33amps)  =   13.33 volts, the same.

Then the Thevenin’s Equivalent circuit would consist or a series resistance of 6.67Ω and a Voltage source of 13.33V. With the 40Ω resistor connected back into the circuit we get:

****

and from this the current flowing around the circuit is given as:

**I==**

which again, is the same value of 0.286 amps, we found using [**Kirchhoff’s circuit law**](https://www.electronics-tutorials.ws/dccircuits/dcp_4.html)

Ex1- To Find Thevenin’s equivalent resistance **RTH** and Voltage **VTH**

RTH = Z2 += 12Ω + = 12 Ω +8 Ω =20 Ω

**VTH**

**E=60 V**

**=10𝛀**

**12 𝛀**

**30 𝛀**

**40 𝛀**

Equivalent circuit-

**20 Ω**

48 V

**0.96 Amp**

**30 𝛀**

Load current will be- =

**Nortons Theorem-**

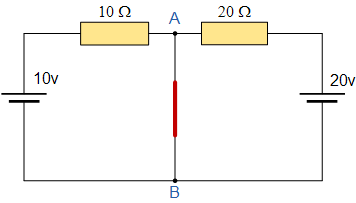
**Nortons Theorem** states that “Any linear circuit containing several energy sources and resistances can be replaced by a single Constant Current generator in parallel with a Single Resistor“.

As far as the load resistance, RL is concerned this single resistance, RS is the value of the resistance looking back into the network with all the current sources open circuited and IS is the short circuit current at the output terminals as shown below.

The value of this “constant current” is one which would flow if the two output terminals where shorted together while the source resistance would be measured looking back into the terminals, (the same as Thevenin).

For example, consider our now familiar circuit from the previous section.

To find the Nortons equivalent of the above circuit we firstly have to remove the centre 40Ω load resistor and short out the terminals A and B to give us the following circuit.



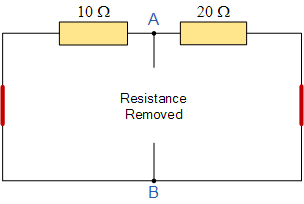
When the terminals A and B are shorted together the two resistors are connected in parallel across their two respective voltage sources and the currents flowing through each resistor as well as the total short circuit current can now be calculated as:

With A-B Shorted Out

 I1 =10V/10 Ω= 1 Amp , I2 = 20V/20 Ω = 1 Amp

Therefore Isthort-circuit = I1 + I2 = 1 Amp + 1Amp = 2 Amps

If we short-out the two voltage sources and open circuit terminals A and B, the two resistors are now effectively connected together in parallel. The value of the internal resistor Rs is found by calculating the total resistance at the terminals A and B giving us the following circuit.



**Find the Equivalent Resistance (Rs)**

**10Ω Resistance is parallel with 20 Ω Resistance**

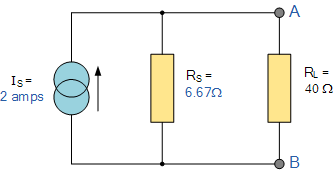
**= 6.67 Ω**

Having found both the short circuit current, Is and equivalent internal resistance, Rs this then gives us the following Nortons equivalent circuit.

### Nortons equivalent circuit

### C:\Users\Prabir\Desktop\dccircuits-dcp30.gif

We now have to solve with the original 40Ω load resistor connected across terminals A and B as shown below.



Again, the two resistors are connected in parallel across the terminals A and B which gives us a total resistance of:

**RT = = = 5.72**

The voltage across the terminals A and B with the load resistor connected is given as:

VAB  =  IxR = 2 Amp x 5.72 Ω =  11.44 Volt

Then the current flowing in the 40Ω load resistor can be found as:

I = = 0.286 Amp

Once again and using Nortons theorem, the value of current for I3 is still calculated as 0.286 amps, which we found using [**Kirchhoff´s circuit law**](https://www.electronics-tutorials.ws/dccircuits/dcp_4.html)

## Nortons Theorem Summary

The basic procedure for solving a circuit using **Nortons Theorem** is as follows:

**1.** Remove the load resistor RL or component concerned.

**2.** Find RS by shorting all voltage sources or by open circuiting all the current sources.

**3.** Find IS by placing a shorting link on the output terminals A and B.

**4.** Find the current flowing through the load resistor RL.

In a circuit, power supplied to the load is at its maximum when the load resistance is equal to the source resistance.

**Maximum Power Transfer**

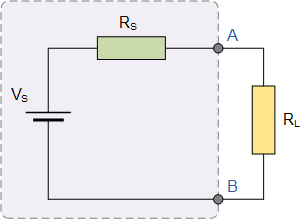
Maximum Power Transfer occurs when the resistive value of the load is equal in value to that of the voltage sources internal resistance allowing maximum power to be supplied.

Generally, this source resistance or even impedance if inductors or capacitors are involved is of a fixed value in Ohm´s.

However, when we connect a load resistance, RL across the output terminals of the power source, the impedance of the load will vary from an open-circuit state to a short-circuit state resulting in the power being absorbed by the load becoming dependent on the impedance of the actual power source. Then for the load resistance to absorb the maximum power possible it has to be “Matched” to the impedance of the power source and this forms the basis of **Maximum Power Transfer**.

The **Maximum Power Transfer Theorem** is another useful circuit analysis method to ensure that the maximum amount of power will be dissipated in the load resistance when the value of the load resistance is exactly equal to the resistance of the power source. The relationship between the load impedance and the internal impedance of the energy source will give the power in the load. Consider the circuit below.

**Thevenin’s Equivalent Circuit**

****

In our Thevenin equivalent circuit above, the maximum power transfer theorem states that “*the maximum amount of power will be dissipated in the load resistance if it is equal in value to the Thevenin or Norton source resistance of the network supplying the power*“.

In other words, the load resistance resulting in greatest power dissipation must be equal in value to the equivalent Thevenin source resistance, then RL = RS but if the load resistance is lower or higher in value than the Thevenin source resistance of the network, its dissipated power will be less than maximum.

For example, find the value of the load resistance, RL that will give the maximum power transfer in the following circuit.

**Maximum Power Transfer Example No1**

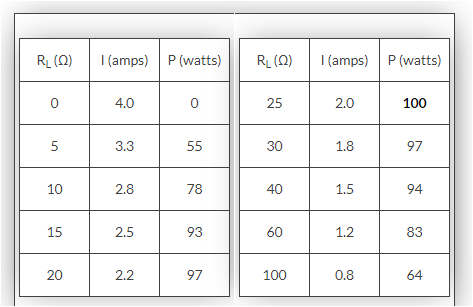
**VS = 100V, RS =25 Ω and RL is variable between = 0 Ω -100 Ω**

Then by using the following Ohm’s Law equations:

I = and Power P=

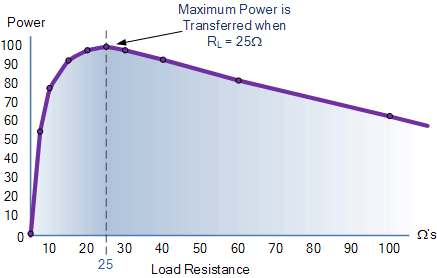
We can now complete the following table to determine the current and power in the circuit for different values of load resistance.

### Table of Current against Power



Using the data from the table above, we can plot a graph of load resistance, RL against power, P for different values of load resistance. Also notice that power is zero for an open-circuit (zero current condition) and also for a short-circuit (zero voltage condition).

### Graph of Power against Load Resistance

****

From the above table and graph we can see that the **Maximum Power Transfer** occurs in the load when the load resistance, RL is equal in value to the source resistance, RS that is: RS = RL = 25Ω. This is called a “matched condition” and as a general rule, maximum power is transferred from an active device such as a power supply or battery to an external device when the impedance of the external device exactly matches the impedance of the source.

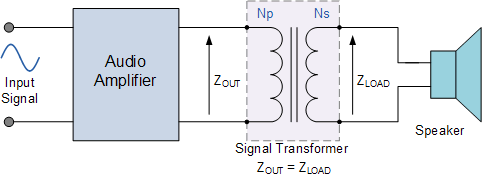
One good example of impedance matching is between an audio amplifier and a loudspeaker. The output impedance, ZOUT of the amplifier may be given as between 4Ω and 8Ω, while the nominal input impedance, ZIN of the loudspeaker may be given as 8Ω only.

Then if the 8Ω speaker is attached to the amplifiers output, the amplifier will see the speaker as an 8Ω load. Connecting two 8Ω speakers in parallel is equivalent to the amplifier driving one 4Ω speaker and both configurations are within the output specifications of the amplifier.

Improper impedance matching can lead to excessive power loss and heat dissipation. But how could you impedance match an amplifier and loudspeaker which have very different impedances. Well, there are loudspeaker impedance matching transformers available that can change impedances from 4Ω to 8Ω, or to 16Ω’s to allow impedance matching of many loudspeakers connected together in various combinations such as in PA (public address) systems.

## Transformer Impedance Matching

One very useful application of impedance matching in order to provide maximum power transfer between the source and the load is in the output stages of amplifier circuits. Signal transformers are used to match the loudspeakers higher or lower impedance value to the amplifiers output impedance to obtain maximum sound power output. These audio signal transformers are called “matching transformers” and couple the load to the amplifiers output as shown below.

****

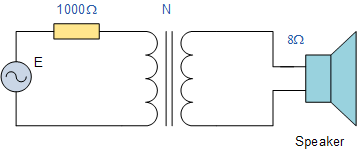
The maximum power transfer can be obtained even if the output impedance is not the same as the load impedance. This can be done using a suitable “turns ratio” on the transformer with the corresponding ratio of load impedance, ZLOAD to output impedance, ZOUT matches that of the ratio of the transformers primary turns to secondary turns as a resistance on one side of the transformer becomes a different value on the other.

If the load impedance, ZLOAD is purely resistive and the source impedance is purely resistive, ZOUT then the equation for finding the maximum power transfer is given as:

Where: NP is the number of primary turns and NS the number of secondary turns on the transformer. Then by varying the value of the transformers turns ratio the output impedance can be “matched” to the source impedance to achieve maximum power transfer. For example,

**Maximum Power Transfer Example No2**

If an 8Ω loudspeaker is to be connected to an amplifier with an output impedance of 1000Ω, calculate the turns ratio of the matching transformer required to provide maximum power transfer of the audio signal. Assume the amplifier source impedance is Z1, the load impedance is Z2 with the turns ratio given as N.

****

**= N = = =11.2 : 1**

**SUPERPOSITION THEOREM**

**Superposition theorem** is based on the concept of linearity between the response and excitation of an electrical circuit. It states that the response in a particular branch of a linear circuit when multiple independent sources are acting at the same time is equivalent to the sum of the responses due to each independent source acting at a time.

In this method, we will consider only **one independent source** at a time. So, we have to eliminate the remaining independent sources from the circuit. We can eliminate the voltage sources by shorting their two terminals and similarly, the current sources by opening their two terminals.

Therefore, we need to find the response in a particular branch **‘n’ times** if there are ‘n’ independent sources. The response in a particular branch could be either current flowing through that branch or voltage across that branch.

## Procedure of Superposition Theorem

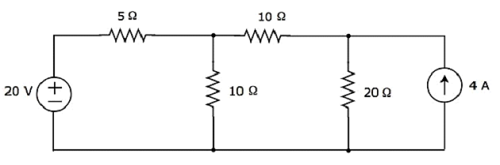
Follow these steps in order to find the response in a particular branch using superposition theorem.

**Step 1** − Find the response in a particular branch by considering one independent source and eliminating the remaining independent sources present in the network.

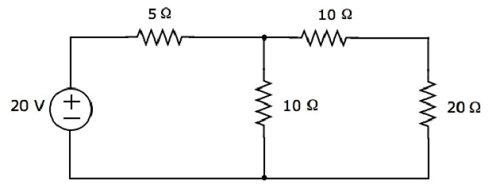
**Step 2** − Repeat Step 1 for all independent sources present in the network.

**Step 3** − Add all the responses in order to get the overall response in a particular branch when all independent sources are present in the network.

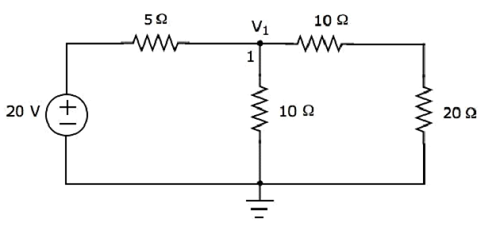
### Ex-1 Find the current flowing through 20 Ω resistor of the following circuit using superposition theorem.



**Step 1** − Let us find the current flowing through 20 Ω resistor by considering only **20 V voltage source**. In this case, we can eliminate the 4 A current source by making open circuit of it. The modified circuit diagram is shown in the following figure.



There is only one principal node except Ground in the above circuit. So, we can use **nodal analysis** method. The node voltage V1 is labelled in the following figure. Here, V1 is the voltage from node 1 with respect to ground.



The **nodal equation** at node 1 is

The **current flowing through 20 Ω resistor** can be found by doing the following simplification.

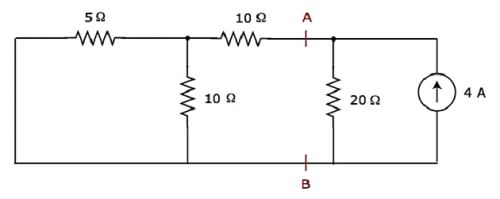
I1=

Substitute the value of V1 in the above equation.

I1=

Therefore, the current flowing through 20 Ω resistor is **0.4 A**, when only 20 V voltage source is considered.

**Step 2** − Let us find the current flowing through 20 Ω resistor by considering only **4 A current source**. In this case, we can eliminate the 20 V voltage source by making short-circuit of it. The modified circuit diagram is shown in the following figure.

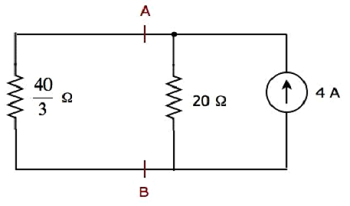


In the above circuit, there are three resistors to the left of terminals A & B. We can replace these resistors with a single **equivalent resistor**. Here, 5 Ω & 10 Ω resistors are connected in parallel and the entire combination is in series with 10 Ω resistor.

The **equivalent resistance** to the left of terminals A & B will be

**=+10=+10= Ω**

The simplified circuit diagram is shown in the following figure.



We can find the current flowing through 20 Ω resistor, by using **current division principle**.

=

Substitute =4A, =40/3Ω, and =20Ω in the above equation.

=4=4 =1.6A

Therefore, the current flowing through 20 Ω resistor is **1.6 A**, when only 4 A current source is considered.

**Step 3** − We will get the current flowing through 20 Ω resistor of the given circuit by doing the **addition of two currents** that we got in step 1 and step 2. Mathematically, it can be written as

I=I1+I2

Substitute, the values of *I1* and *I2* in the above equation.

I=0.4+1.6=2A

Therefore, the current flowing through 20 Ω resistor of given circuit is **2 A**.

**Note** − We can’t apply superposition theorem directly in order to find the amount of **power** delivered to any resistor that is present in a linear circuit, just by doing the addition of powers delivered to that resistor due to each independent source. Rather, we can calculate either total current flowing through or voltage across that resistor by using superposition theorem and from that, we can calculate the amount of power delivered to that resistor using R  or  **.**

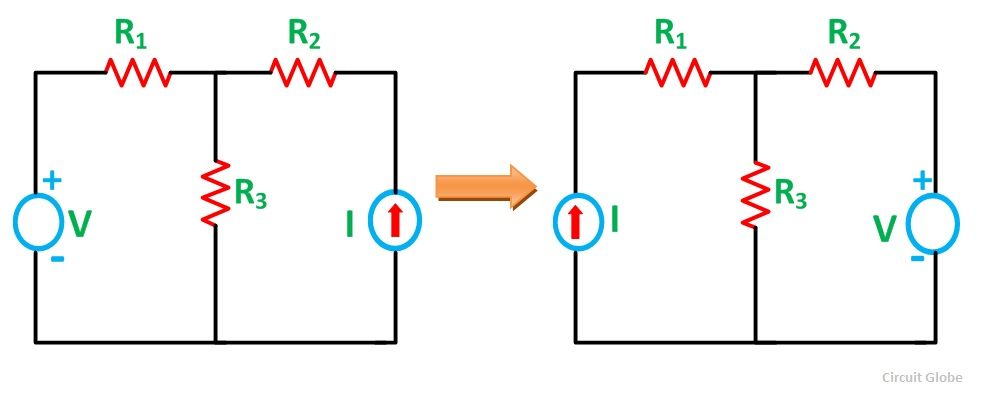
**Reciprocity theorem**

**Reciprocity Theorem** states that – In any branch of a network or circuit, the current due to a single source of voltage (V) in the network is equal to the current through that branch in which the source was originally placed when the source is again put in the branch in which the current was originally obtained. This theorem is used in the bilateral linear network which consists of bilateral components.

## Explanation of Reciprocity Theorem

The location of the voltage source and the current source may be interchanged without a change in current. However, the polarity of the voltage source should be identical with the direction of the branch current in each position.

The Reciprocity Theorem is explained with the help of the circuit diagram shown below

[](https://circuitglobe.com/wp-content/uploads/2015/10/reciprocity-theorem-fig-compressor.jpg)

The various resistances R1, R2, R3 are connected in the circuit diagram above with a voltage source (V) and a current source (I). It is clear from the figure above that the voltage source and current sources are interchanged for solving the network with the help of Reciprocity Theorem.

The limitation of this theorem is that it is applicable only to single source networks and not in the multi-source network. The network where reciprocity theorem is applied should be linear and consist of resistors, inductors, capacitors and coupled circuits. The circuit should not have any time-varying elements.  
**Steps for Solving a Network Utilizing Reciprocity Theorem**

**Step 1 –** Firstly, select the branches between which reciprocity has to be established.

**Step 2 –** The current in the branch is obtained using any conventional network analysis method.

**Step 3 –** The voltage source is interchanged between the branch which is selected.

**Step 4 –** The current in the branch where the voltage source was existing earlier is calculated.

**Step 5 –** Now, it is seen that the current obtained in the previous connection, i.e., in step 2 and the current which is calculated when the source is interchanged, i.e., in step 4 are identical to each other.

The amount of power received by a load is an important parameter in electrical and electronic applications. In DC circuits, we can represent the load with a resistor having resistance of RL ohms. Similarly, in AC circuits, we can represent it with a complex load having an impedance of ZL ohms.

**Maximum power transfer theorem** states that the DC voltage source will deliver maximum power to the variable load resistor only when the load resistance is equal to the source resistance.

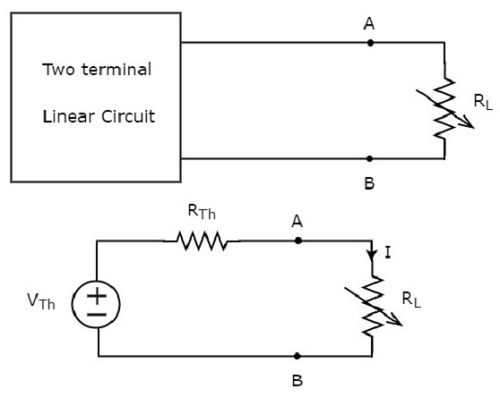
Similarly, **Maximum power transfer theorem** states that the AC voltage source will deliver maximum power to the variable complex load only when the load impedance is equal to the complex conjugate of source impedance.

In this chapter, let us discuss about the maximum power transfer theorem for DC circuits.

## Proof of Maximum Power Transfer Theorem

Replace any two terminal linear network or circuit to the left side of variable load resistor having resistance of RL ohms with a Thevenin’s equivalent circuit. We know that Thevenin’s equivalent circuit resembles a practical voltage source.

This concept is illustrated in following figures.



The amount of power dissipated across the load resistor is

PL=I2RLPL=I2RL

Substitute I=VThRTh+RLI=VThRTh+RL in the above equation.

PL=⟮VTh(RTh+RL)⟯2RLPL=⟮VTh(RTh+RL)⟯2RL

⇒PL=VTh2{RL(RTh+RL)2}⇒PL=VTh2{RL(RTh+RL)2}**Equation 1**

### Condition for Maximum Power Transfer

For maximum or minimum, first derivative will be zero. So, differentiate Equation 1 with respect to *RL* and make it equal to zero.

dPLdRL=VTh2{(RTh+RL)2×1−RL×2(RTh+RL)(RTh+RL)4}=0dPLdRL=VTh2{(RTh+RL)2×1−RL×2(RTh+RL)(RTh+RL)4}=0

⇒(RTh+RL)2−2RL(RTh+RL)=0⇒(RTh+RL)2−2RL(RTh+RL)=0

⇒(RTh+RL)(RTh+RL−2RL)=0⇒(RTh+RL)(RTh+RL−2RL)=0

⇒(RTh−RL)=0⇒(RTh−RL)=0

⇒RTh=RLorRL=RTh⇒RTh=RLorRL=RTh

Therefore, the **condition for maximum power** dissipation across the load is RL=RThRL=RTh. That means, if the value of load resistance is equal to the value of source resistance i.e., Thevenin’s resistance, then the power dissipated across the load will be of maximum value.

### The value of Maximum Power Transfer

Substitute RL=RTh&PL=PL,MaxRL=RTh&PL=PL,Max in Equation 1.

PL,Max=VTh2{RTh(RTh+RTh)2}PL,Max=VTh2{RTh(RTh+RTh)2}

PL,Max=VTh2{RTh4RTh2}PL,Max=VTh2{RTh4RTh2}

⇒PL,Max=VTh24RTh⇒PL,Max=VTh24RTh

⇒PL,Max=VTh24RL,sinceRL=RTh⇒PL,Max=VTh24RL,sinceRL=RTh

Therefore, the **maximum amount of power** transferred to the load is

PL,Max=VTh24RL=VTh24RThPL,Max=VTh24RL=VTh24RTh

## Efficiency of Maximum Power Transfer

We can calculate the efficiency of maximum power transfer, ηMaxηMax using following formula.

ηMax=PL,MaxPSηMax=PL,MaxPS **Equation 2**

Where,

* PL,MaxPL,Max is the maximum amount of power transferred to the load.
* PSPS is the amount of power generated by the source.

The **amount of power generated** by the source is

PS=I2RTh+I2RLPS=I2RTh+I2RL

⇒PS=2I2RTh,sinceRL=RTh⇒PS=2I2RTh,sinceRL=RTh

* Substitute I=VTh2RThI=VTh2RTh in the above equation.

PS=2⟮VTh2RTh⟯2RThPS=2⟮VTh2RTh⟯2RTh

⇒PS=2⟮VTh24RTh2⟯RTh⇒PS=2⟮VTh24RTh2⟯RTh

⇒PS=VTh22RTh⇒PS=VTh22RTh

* Substitute the values of PL,MaxPL,Max and PSPS in Equation 2.

ηMax=⟮VTh24RTh⟯⟮VTh22RTh⟯ηMax=⟮VTh24RTh⟯⟮VTh22RTh⟯

⇒ηMax=12⇒ηMax=12

We can represent the efficiency of maximum power transfer in terms of **percentage** as follows −

%ηMax=ηMax×100%%ηMax=ηMax×100%

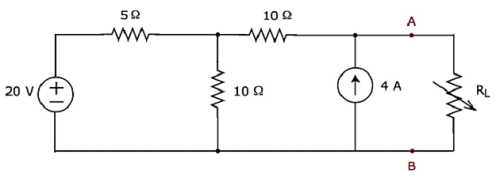
⇒%ηMax=⟮12⟯×100%⇒%ηMax=⟮12⟯×100%

⇒%ηMax=50%⇒%ηMax=50%

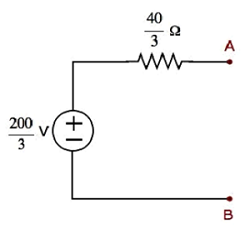
Therefore, the efficiency of maximum power transfer is **50 %**.

### Example

Find the **maximum power** that can be delivered to the load resistor RL of the circuit shown in the following figure.

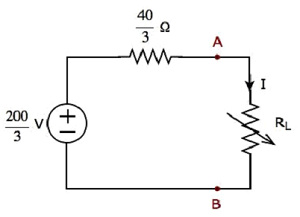


**Step 1** − In Thevenin’s Theorem chapter, we calculated the Thevenin’s equivalent circuit to the left side of terminals A & B. We can use this circuit now. It is shown in the following figure.



Here, Thevenin’s voltage VTh=2003VVTh=2003V and Thevenin’s resistance RTh=403ΩRTh=403Ω

**Step 2** − Replace the part of the circuit, which is left side of terminals A & B of the given circuit with the above Thevenin’s equivalent circuit. The resultant circuit diagram is shown in the following figure.



**Step 3** − We can find the maximum power that will be delivered to the load resistor, RL by using the following formula.

PL,Max=VTh24RThPL,Max=VTh24RTh

Substitute VTh=2003VVTh=2003V and RTh=403ΩRTh=403Ω in the above formula.

PL,Max=⟮2003⟯24⟮403⟯PL,Max=⟮2003⟯24⟮403⟯

PL,Max=2503WPL,Max=2503W

Therefore, the **maximum power** that will be delivered to the load resistor RL of the given circuit is 25032503 **W**