UNIT-1

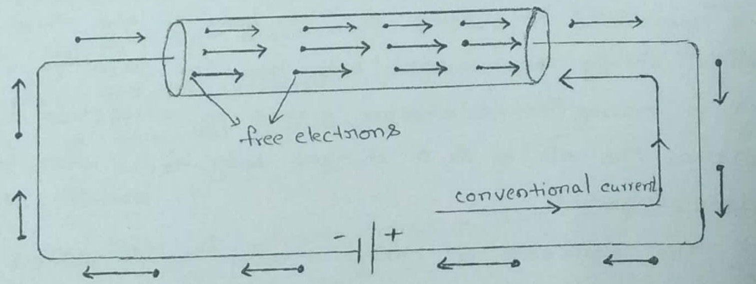
Introduction to Electrical circuits

Concept of circuit and Network - Types of Elements - R, L, C Parameters - Independent and Dependent sources - Source transformation - Kirchhoff's Laws

Network theory is the study of solving the Problems of electric circuits.

Electric Current:

The flow of free electrons is called electric current. The flow of electric current can be beautifully explained by referring to below figure. The copper strip has a large number of free electrons. When electric pressure or voltage is applied, then free electrons, being negatively charged, will start moving towards the Positive terminal



round the circuit as shown in figure. This directed flow of free electrons is called electric current. The actual direction of current (ie. flow of electrons) is from negative terminal to the Positive terminal. However, Prior to Electron theory, it was assumed that current flowed from Positive terminal to the negative terminal. This assumed direction is called conventional current.

Unit of current: The strength of electric current (I) is the rate of flow of electrons i.e. charge flowing per second.

$$I = \frac{dQ}{dt}$$

The charge Q is measured in coulombs and time 't' in seconds. Therefore, the unit of electric current will be coulombs/sec or **ampere**.

One ampere of current is said to flow through a wire if at any section one coulomb of charge flows in one second.

* 1 coulomb = charge on 6.24×10^{18} electrons.

Electric Potential or Voltage:

"The capacity of a charged body to do work is called electric Potential"

When a body is charged, work is done in charging it. This work done is stored in the body in the form of Potential energy. The charged body has the capacity to do work by moving other charges either by attraction or repulsion. The ability of a charged body to do work is called electric Potential.

The work done to charge a body to 1 coulomb will be a measure of its electric potential

$$\text{Electric potential, } V = \frac{\text{Work done}}{\text{Charge}} = \frac{W}{Q}$$

The work done is measured in joules and charge in coulombs. Therefore, the unit of electric Potential will be joules/coulomb or **volt**.

Hence
Volt
1 J cou

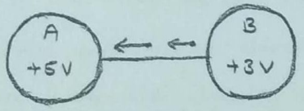
Scanned by CamScanner

Hence a body is said to have an electric potential of 1 volt if 1 joule of work is done to give it a charge of 1 coulomb.

Potential Difference:

"The difference in the potentials of two charged bodies is called potential difference"

If two bodies have different electric potentials, a potential difference exists between the bodies. Consider two bodies A and B having potentials of 5 volts and 3 volts respectively as shown. Body A is at higher potential than the body B. If the two bodies are joined through a conductor, then electrons will flow from body B to body A. When the two bodies attain the same potential, the flow of current stops. Therefore, we arrive at a very important conclusion that current will flow in a circuit if potential difference exists. No potential difference, no current flow. It may be noted that potential difference is sometimes called voltage. The unit of potential difference is also volt.



Electric Power:

The rate at which work is done in an electric circuit is called electric power.

$$\text{Electric Power} = \frac{\text{Work done in electric circuit}}{\text{Time}}$$

When voltage is applied to a circuit, it causes current to flow through it. clearly work is being done in moving the electrons in the circuit. This work done in moving the electrons in the circuit in a unit time is called the electric Power.

$$P = \frac{dW}{dt}$$

where 'W' is the electrical energy and is measured in Joules.

't' is the time and it is measured in seconds.

We can re-write the above equation as

$$P = \frac{dW}{dt} = \frac{dW}{dQ} \times \frac{dQ}{dt} = V \cdot I$$

Therefore, Power is nothing but the product of voltage 'V' and current I. Its unit is Watt.

Electrical Energy:

The total work done in an electric circuit is called electrical energy

i.e. Electrical energy = Electrical Power x time

$$= VI \times t$$

$$= VIt = I^2Rt = \frac{V^2}{R}t$$

In practice, electrical energy is measured in Kilowatt hour (kWh)

Energy in kWh = Power in kW x time in hours

The electricity bills are made on the basis of total electrical energy consumed by the consumer. The unit for charge of electricity is 1kWh. Thus when we say that a consumer has consumed 100 units of electricity, it means that electrical energy consumption is 100 kWh.

Types of Network Elements:

We can classify the network elements into various types based on some parameters. Following are the types of network elements.

1) Active Elements and Passive Elements
2) Linear Elements and Non-linear Elements
3) Bilateral Elements and Unilateral Elements
4) Lumped Elements and Distributed Elements

1) Active and Passive Elements:

The elements of an electric circuit can be classified into active and Passive elements.

→ Active Elements deliver Power to other elements, which are Present in an electric circuit.

Examples: voltage sources and current sources

→ Passive elements can't deliver Power to other elements, however they can absorb Power. These elements either dissipate Power in the form of heat or store energy in the form of either magnetic field or electric field.

Ex: Resistors, Inductors, capacitors.

2) Linear and Non-linear Elements:

We can classify the network elements into either linear or non-linear based on their characteristic to obey the property of linearity.

→ Linear elements are the elements that show a linear relationship between voltage and current. Ex: Resistors, Inductors, capacitors.

→ Non linear elements are those that do not show a linear relation between voltage and current

Ex: voltage sources and current sources.

3) Bilateral Elements and Unilateral Elements:

Net work elements can also be classified as either bilateral or unilateral based on the direction of current flows through the network element.

Bilateral Elements are the elements that allow the current in both directions and offer the same impedance in either direction of current flow. Ex: Resistors, Inductors, capacitors.

Unilateral Elements are those that allow the current in only one direction. Hence they offer different impedances in both directions. Ex: Diodes, Zenar diode.

4) Lumped and Distributed Elements:

Lumped elements are those elements which are very small in size and in which simultaneous actions takes place. Typical lumped elements are capacitors, resistors, inductors.

Distributed elements are those elements which are not electrically separable for analytical purposes. Ex: Transmission lines.

R-L-C Parameters:

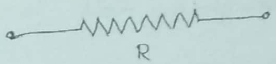
Resistor: (R)

Elements that restricts the flow of electrons are called resistors. Resistor is denoted by 'R'

Property of a material to restrict the flow of electrons is called **resistance.**

Symbol of resistor is shown in figure.

The unit of resistance is ohm(Ω).



Ohm is defined as the resistance offered by the material when a current of one ampere flows between two terminals with one volt applied across it.

Ohm's law: At constant temperature ratio of the voltage across the conductor to current flowing through the conductor is constant.

$$\frac{V}{I} = \text{constant}$$

$$= R$$

$$\Rightarrow I = \frac{V}{R} \Rightarrow V = IR$$

We can write the above equation in terms of charge

$$V = R\frac{dq}{dt}, \text{ or } i = \frac{V}{R} = GV$$

where 'G' is the conductance of a conductor.

When current flows through any resistive material, heat is generated by the collision of electrons with other atomic particles. The Power absorbed by the resistor is converted to heat. The Power absorbed by the resistor is given by

$$P = vi = (iR)i = i^2 R$$

Energy lost in a resistance in time t is given by

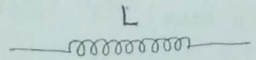
$$W = \int_0^t p\,dt = Pt = i^2 Rt = \frac{V^2}{R} t.$$

Inductor (L):

The element which stores energy in the form of electromagnetic field is called Inductor(L).

The Property of element which stores energy in the form of electromagnetic field is called inductance. The unit of inductance is **henry**, denoted by H.

The symbol for inductor is shown in figure. The current-voltage relation is given by



$$v = L\frac{di}{dt}$$

where 'v' is the voltage across inductor in volts, and 'i' is the current through inductor in amps. we can rewrite the above equations as

$$di = \frac{1}{L} v\,dt$$

Integrating both sides, we get

$$\int_0^t di = \frac{1}{L}\int_0^t v\,dt$$

$$i(t) - i(0) = \frac{1}{L}\int_0^t v\,dt$$

$$i(t) = \frac{1}{L}\int_0^t v\,dt + i(0)$$

From the above equation, we note that the current in an inductor is dependent upon the integral of the voltage across its terminals and the initial current in the coil, $i(0)$.

The power absorbed by the inductor is

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

The energy stored by the inductor is

$$W = \int_0^t P\,dt$$

$$= \int_0^t Li\frac{di}{dt}\,dt$$

$$= \frac{Li^2}{2}$$

From the above discussion, we can conclude the following:

→ The induced voltage across an inductor is zero if the current through it is constant. That means an inductor acts as short circuit to dc.

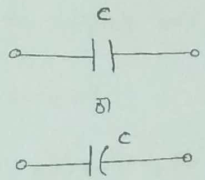
→ A small change in current within zero time through an inductor gives an infinite voltage across the inductor, which is physically impossible. In a fixed inductor, the current can not change abruptly.

→ A pure inductor never dissipates energy, only stores it.

Capacitor: (C):

The element which stores energy in the form of Electrostatic field is called capacitor (C).

The property of element which stores energy in the form of Electrostatic field is called capacitance.



Any two conducting surfaces separated by an insulating medium exhibit the property of a capacitor. The conducting surfaces are called electrodes, and the insulating medium is called dielectric. The unit of capacitor is Farad denoted by 'F'.

A capacitor is said to have greater capacitance if it can store more charge per unit voltage and capacitance is given by

$$C = \frac{Q}{V} \quad \text{or} \quad \frac{q}{v}$$

we can write the above equation in terms of current as

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

where 'v' is the voltage across capacitor and 'i' is the current through it.

$$dv = \frac{1}{C}\, i\, dt$$

Integrating both sides

$$\int_0^t dv = \frac{1}{C}\int_0^t i\, dt$$

$$v(t) - v(0) = \frac{1}{C}\int_0^t i\, dt$$

$$v(t) = \frac{1}{C}\int_0^t i\, dt + v(0)$$

where $v(0)$ indicates the initial voltage across the capacitor.

The power absorbed by the capacitor is given by

$$P = vi = vC\frac{dv}{dt}$$

The energy stored by the capacitor is

$$W = \int_0^t P\,dt = \int_0^t vC\frac{dv}{dt}\,dt$$

$$W = \frac{1}{2}Cv^2$$

From the above discussion, we can conclude the following:

→ The current in a capacitor is zero if the voltage across it is constant, i.e. the capacitor acts as an open circuit to dc.

→ A small change in voltage across a capacitor within zero time gives an infinite current through the capacitor, which is physically impossible. In a fixed capacitance the voltage can not change abruptly.

→ A pure capacitor never dissipates energy, but only stores it.

Energy sources: or Active Elements

Active Elements are the network elements that deliver power to other elements present in an electric circuit. So, active elements are also called as sources of voltage or current type.

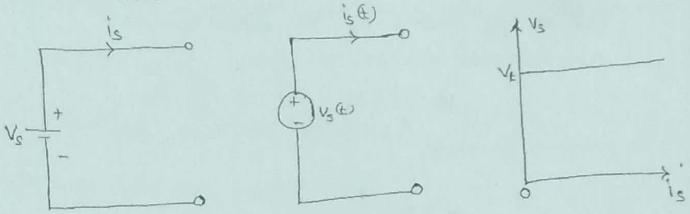
According to terminal voltage-current characteristics, electrical energy sources are categorised in to

→ Ideal voltage sources
→ Ideal current sources

} independent sources

Ideal voltage source:

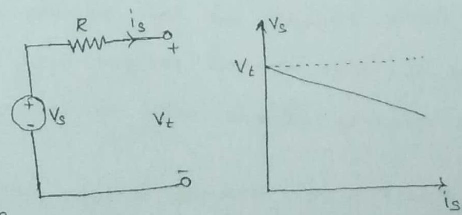
An ideal voltage source is a two terminal element in which the voltage V_s is completely independent of the current i_s through its terminals.



If we observe the v-i characteristics for an ideal voltage source at any time, the value of the terminal voltage V_s is constant with respect to the value of current i_s. When ever $V_s = 0$; the voltage source is the same as that of a short circuit. Voltage sources need not have constant magnitude. in many cases the specified voltage may be time-dependent like a sinusoidal wave form. Internal resistance of an ideal voltage source is zero.

Practical voltage source:

Internal resistance of an Practical voltage source is not equal to zero. The internal resistance of a practical voltage source is represented in series with the source as shown in figure. If we observe the v-i characteristics, the voltage across the terminals falls as the

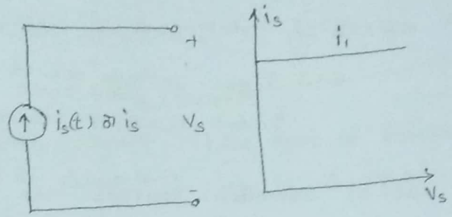


current through it increases. The terminal voltage V_t depends on the source current as shown.

$$V_t = V_s - i_s R$$

Ideal current source:

An ideal constant current source is a two terminal element in which the current is completely independent of the voltage V_s across its terminals.

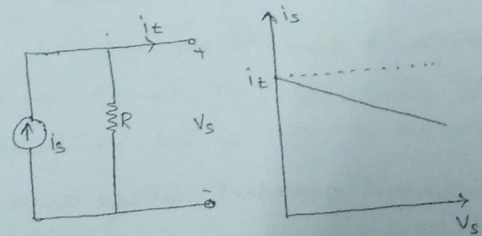


Like voltage sources we can have current sources of constant magnitude i_s or sources whose current varies with time $i_s(t)$. If we observe the v-i characteristics for an ideal current source, at any time the value of the current i_s is constant with respect to the voltage across it. The internal resistance of an ideal current source is infinity.

Practical current source:

The internal resistance of an practical current source is not equal to infinity it's value is high. The internal resistance of an practical current source is connected in parallel with current source as shown in figure.

In this the magnitude of the current falls as the voltage across its terminals increases.



Its terminal v-i characteristics shown in figure. The terminal current is given by $i_t = i_s - V_s/R$, where 'R' is the internal resistance of the ~~ideal~~ Practical current source.

Independent sources: and Dependent sources

The sources for which voltage and current are independent and are not affected by other parts of the circuit are called independent sources.

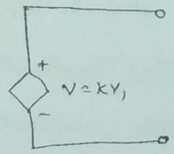
Ex: Ideal voltage source & Practical voltage source
Ideal current source & Practical current sources

In case of dependent sources the source voltage or current is not fixed, but is dependent on the voltage or current existing at some other location in the circuit.

Dependent or controlled sources are of the following types:

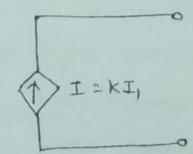
i) **Voltage Dependent Voltage source: (VDVS)**

It Produces a voltage as a function of voltages elsewhere in the given circuit.



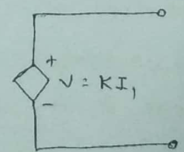
ii) **Current Dependent Current Source: (CDCS)**

It produces a current as a function of currents elsewhere in the given circuit.



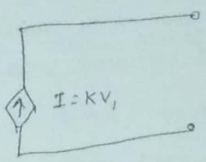
iii) **Current Dependent Voltage Source: (CDVS)**

It produces a voltage as a function of current elsewhere in the given circuit.



iv) Voltage Dependent Current Source: VDCS.

It produces a current as a function of voltage elsewhere in the given circuit.

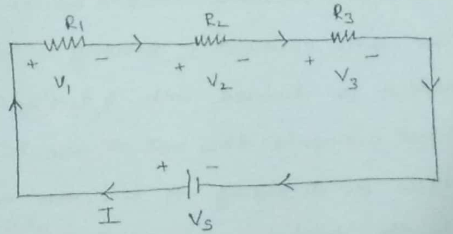


'K' is constant and V_1 and I_1 are the voltage and current respectively, present elsewhere in the given circuit. These types of sources mainly occur in the analysis of equivalent circuits of transistors.

Kirchhoff's Voltage Law:

Kirchhoff's voltage law states that "the algebraic sum of all branch voltages around any closed path in a circuit is always zero at all instants of time."

When the current passes through a resistor, there is a loss of energy and, therefore, a voltage drop. In any element, the current always flows from higher potential to lower potential. The direction of current I is leaves the positive terminal of the voltage source and enters into the negative terminal.



As the current passes through the circuit, the sum of the voltage drop around the loop is equal to the voltage in that loop.

$$\therefore V_s = V_1 + V_2 + V_3$$

By using ohm's law, we find the voltage across each resistor as follows

$$V_1 = IR_1 \qquad V_2 = IR_2 \qquad V_3 = IR_3$$

$\because \quad V = IR_1 + IR_2 + IR_3$

From the above equation, the current delivered by the source

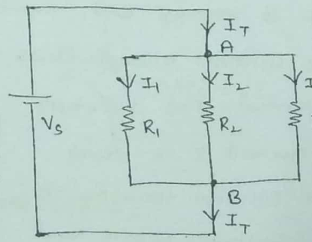
$$I = \frac{V}{R_1 + R_2 + R_3}.$$

Kirchhoff's Current Law: (KCL):

Kirchhoff's current law states that "the sum of the current entering in to any node is equal to the sum of the currents leaving that node."

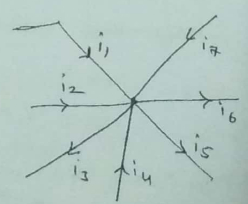
The node may be an interconnection of two or more branches. In any parallel circuit, the node is a junction point of two or more branches. The total current entering into a node is equal to the current leaving that node.

Consider the circuit shown, which contains two nodes A & B. The total current I_T entering node A is divided into I_1, I_2 & I_3. These currents flow out of the node A. According to KCL, the current into node A is equal to the total current out of the node A.



i.e. $\quad I_T = I_1 + I_2 + I_3$

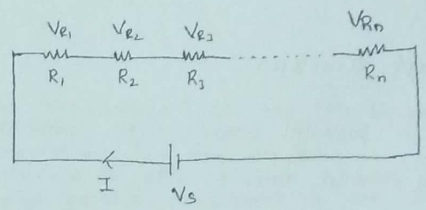
In the figure shown i_1, i_2, i_4 and i_7 are entering currents, i_3, i_5, i_6 are leaving currents.



$\therefore \quad i_1 + i_2 + i_4 + i_7 = i_3 + i_5 + i_6$

Voltage Division:

The series circuit acts as a voltage divider. since the same current flows through each resistor, the voltage drops are proportional to the values of resistors. Using this Principle, different voltages can be obtained from a single source, called a voltage divider.



If the circuit consists of a number of series resistors, the total current is given by the total voltage divided by equivalent resistance.

$$I = \frac{V_s}{R_1 + R_2 + R_3 + \cdots + R_n}$$

The voltage across any resistor is nothing but the current passing through it, multiplied by that particular resistor.

$$\therefore \quad V_{R_1} = IR_1$$

$$V_{R_2} = IR_2$$

$$V_{R_3} = IR_3$$

$$\vdots$$

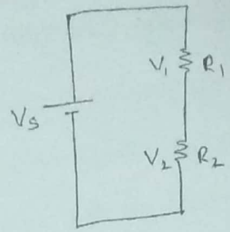
$$V_{R_n} = IR_n$$

$$\text{or} \quad V_{R_n} = \frac{V_s \; R_n}{R_1 + R_2 + R_3 + \cdots + R_n}$$

From the above equation, we can say that the voltage drop across any resistor, or a combination of resistors in a series circuit is equal to the ratio of that resistance value to the total resistance, multiplied by the source voltage.

$$V_n = \frac{R_n}{R_T} V_s.$$

For the figure shown.

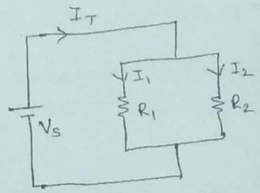


$$V_1 = \frac{R_1}{R_1+R_2} V_s$$

$$V_2 = \frac{R_2}{R_1+R_2} V_s.$$

Current Division:

In a parallel circuit, the current divides in all branches. Thus, a parallel circuit acts as a current divider. The total current entering into the parallel branches is divided into the branches currents according to resistance values.



The branch having higher resistance allows ~~more~~ lesser current, and the branch with lower resistance allows more current.

For the circuit shown, The voltage applied across each resistor is V_s. The current passing through each resistor is given by

$$I_1 = \frac{V_s}{R_1}, \quad I_2 = \frac{V_s}{R_2}$$

If R_T is the total resistance, which is given by $\frac{R_1 R_2}{R_1+R_2}$,

$$\text{Total current } I_T = \frac{V_s}{R_T} = \frac{V_s}{R_1 R_2}(R_1+R_2)$$

$$\text{or } I_T = \frac{I_1 R_1}{R_1 R_2}(R_1+R_2) \quad \because V_s = I_1 R_1$$

$$I_1 = I_T \cdot \frac{R_2}{R_1+R_2} \qquad I_2 = I_T \cdot \frac{R_1}{R_1+R_2}$$

From the above equation, we can conclude that the current in any branch is equal to the ratio of the opposite branch resistance to the total resistance value, multiplied by the total current in the circuit.

In general, if the circuit consists of 'n' branches, the current in any branch can be determined by

$$I_i = \frac{R_T}{R_i + R_T} I_T$$

where I_i represents the current in the ith branch.
R_i is the resistance in the ith branch.
R_T is the total parallel resistance to the ith branch
I_T is the total current entering the circuit.

Concept of circuit and Network:

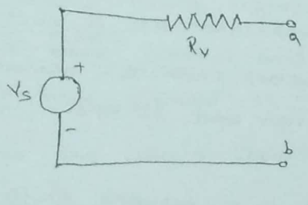
Network: Network is an interconnection of electrical elements such as resistors, inductors, capacitors, transmission lines, voltage sources, current sources and switches.

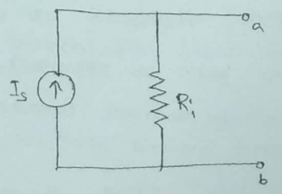
circuit: An Electrical circuit is a network which has a closed path that gives the direction for the flow of current.

An Electrical circuit or an Electrical Network consists of one or more Electrical energy sources connected to a number of circuit elements like active or Passive elements or both in such a way that there is a connection between the different elements causing a current to flow through the elements. The electrical circuit should be a closed circuit so that current can flow through it. If an Electrical circuit is open then no current can flow through the circuit.

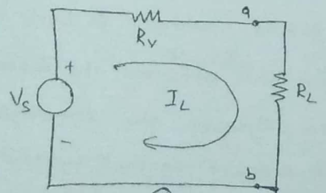
SOURCE TRANSFORMATION TECHNIQUE:

Basically energy sources are either voltage sources or current sources. Some-times it is necessary to convert a voltage source to a current source and vice-versa. Any practical voltage source consists of an ideal voltage source in series with an internal resistance. Similarly, a practical current source consists of an ideal current source in parallel with an internal resistance. Let R_v and R_i represent the internal resistances of the voltage source V_s, and current source I_s respectively.

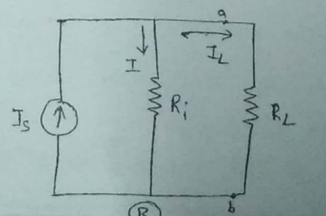




Any source, be it a current source or a voltage source, drives current through its load resistance, and the magnitude of the current depends on the value of the load resistance. figure below represents a practical voltage source and a practical current source connected to the same load resistance R_L.



(A)



(B)

The load voltage can be calculated by using kirchhoff's voltage law as

$$V_{ab} = V_s - I_L R_v \quad \rightarrow \text{from (A)}$$

The open circuit voltage $V_{oc} = V_s$

The short circuit current $I_{sc} = \frac{V_s}{R_v}$

From fig. (B) $I_L = I_s - I = I_s - \frac{V_{ab}}{R_i}$

The open-circuit voltage $V_{oc} = I_s R_i$

The short-circuit current $I_{sc} = I_s$

The above two sources are said to be equal, if they produce equal amount of current and voltage when they are connected to identical load resistances. Therefore, by equating the open-circuit voltages and short circuit currents of the above two sources, we obtain

$$V_{oc} = I_s R_i = V_s$$

$$I_{sc} = I_s = \frac{V_s}{R_v}$$

It follows that $R_i = R_v = R_s \therefore V_s = I_s R_s$

where R_s is the internal resistance of the voltage or current source. Therefore, any practical voltage source, having an ideal voltage V_s and internal series resistance R_s can be replaced by a current source $I_s = \frac{V_s}{R_s}$ in parallel with an internal resistance R_s. The reverse transformation is also possible. Thus, a practical current source in parallel with an internal resistance R_s can be replaced by a voltage source $V_s = I_s R_s$ in series with an internal resistance R_s.