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ELECTRICAL FUNDAMENTS

For Students, Professionals and Beyond

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ASPENCORE

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1. Electrons and Holes

The periodic table of elements is a tabulated list of all the chemical elements currently known to exist. The list of elements is organized and presented in numerical order of their increasing atomic number from atomic number 1, hydrogen (H) to number 118, Oganesson (Og). These 118 known elements exist in the form of solids, gases, and liquids.

But only about one third of these elements, such as copper, aluminium, silicon, lithium, neon, gold, etc. are used in the electrical and electronics industry with the most important elements being the conductive metals.

While all of these elements exist naturally in nature, they can be used as pure elements on their own, or combined chemically with others to form different substances. For example, Iron (Fe) and Carbon (C) to make steel, (Fe3C). But each element or combination of elements all have one thing in common. They are all made using atoms.

Every element consists of just one distinct atom, and atoms are the building blocks of all matter. They are not solid structures but are composed of three fundamental particles: neutrons, protons, and electrons arranged in various combinations. It is the number of neutrons, protons, and electrons that makes each atom different from another one.

The electron (e) is defined as being negatively (-) charged and revolves around the nucleus of the atom in various concentric paths called orbits. The proton (p) is defined as being positively (+) charged.

> *An atom is extremely small and can only be viewed using a special microscope*

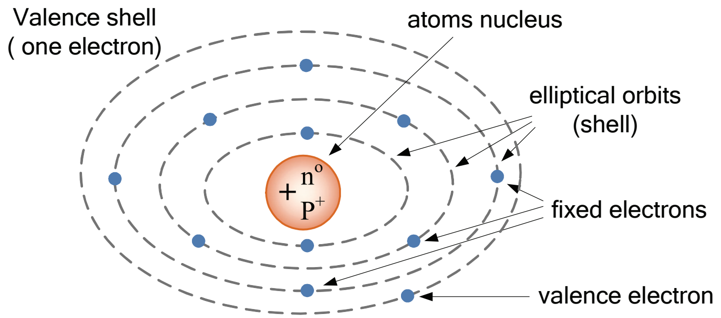
Neutrons (n) are defined as being uncharged or neutral. Protons and neutrons are tightly bound together within the atoms nucleus and are therefore not free or allowed to orbit.

In a single atom the number of negative electrons and positive protons are the same, making it electrically neutral. The number of protons present within the atoms nucleus specifies its atomic number. For example, the atomic number of copper is 29, that is it has 29 protons.

An atoms electrons are arranged in different elliptical orbits, called shells, around the nucleus. Electrons in different orbits can rotate around the nucleus in different directions, thus producing a three-dimensional atom.

Electrons in the nearest orbit have a much greater force of attraction to the nucleus, while the electrons in the farthest orbit have the least force of attraction. Electrons in the farthest orbit which are loosely held to the nucleus are called valence electrons and therefore rotate around the valence shell as shown in Figure 1. Copper for instance, has one valence electron which is free to move about.

Figure 1. The Structure of an Atom



The loosely held electrons in the outer valence shell are allowed to break free due to the application of an energy source, for example heat, or an electrical voltage. This allows them to move randomly around through the space in between the various orbits of the other atoms. Such loose electrons are called “free electrons” and together constitute a negative electrical charge.

An atom that loses an electron in this way is left positively charged since it now has an excess of protons. If more electrons attach themselves to the valence shell, then there are more electrons than protons and the atom becomes negatively charged.

Note that the basic structure of the atom shown in Figure 1. with electrons circulating its nucleus is commonly called the Bohr Model. This simple depiction is sufficient for showing and describing the properties of atoms here.

2. The Unit of Charge

Elements can contain two types of electric charge, one type being positive and the other negative. If an element contains equal amounts of both types of charge it is said to be electrically neutral. If the element contains more positive charge than negative charge, it is said to be positively charged, and if it contains more negative than positive charge it is therefore said to be a negatively charged.

The amount of electric charge an element possesses is very small with the smallest amount of charge being that of an electron. So instead the unit of charge is called the Coulomb, C (after Charles Coulomb).

The symbol given for a constant electric charge is the uppercase Q, and the lowercase q for charge which varies with time. The charge of one electron is given as: $1.6\text{x}10^{-19}$ coulombs. Thus one Coulomb of charge is equal to $1/1.6\text{x}10^{-19}$ or **$6.25\text{x}10^{18}$** electrons.

$$Q = 1 \text{ coulomb} = 6.25 \text{ x } 10^{18} \text{ electrons}$$

The flow of electric charge, Q around a closed circuit over time is called an electric current.

3. Electric Current

Electric current is the flow of electric charge in the form of free electrons around a closed circuit. Current is measured by the number of free electrons passing a particular point within a circuit per second.

An electric current of one ampere will flow in a circuit when a charge of one coulomb passes a given point in one second

Therefore, electric current can be defined as the unit of charge per unit of time in second.

Thus when electric charge moves at the rate of $6.25 \text{ x } 10^{18}$ electrons flowing past a given point per second, the value of the current past a point is one ampere. This is the same as saying one coulomb of charge per second.

The **SI** (International System of Units) unit of current is the ampere with letter symbol "**A**". Thus a constant steady current has uppercase symbol "**I**", while a time-varying current has the lowercase symbol "**i**" for intensity.

Mathematically we can define the relationship between charge (Q) and electric current (I) as being:

$$I(\text{amperes}) = \frac{Q(\text{coulombs})}{t(\text{seconds})}$$

Where:

I = Average Current flowing

Q = Total Charge passing a Fixed Point

t = Time taken to Pass a Fixed Point

Electric current, (A) always has a direction of flow associated with it. Conventional current flow is in the direction of positive charge movement from positive point to a more negative point. Electron flow is in the opposite direction from a more negative to a more positive point. The arrow in a circuit specifies the direction of positive current flow.

In solid metals only negatively charged free electrons move to produce a current flow, the positive protons cannot move. But in a liquid or a gas, both the positive protons and negative electrons can move. Although electric charge can be continuously transferred between different parts of a circuit, the total amount of charge (electrons or protons) does not change as charge is neither created nor destroyed.

Electric current is also a measure of how concentrated or intense the flow of electrons is past a particular point within a circuit. Current is usually expressed in units of amperes (A) or kiloamperes ($1\text{kA} = 10^3$ A) for large values of current.

Sub-multiples of: milliamperes ($1\text{mA} = 10^{-3}$ A), microamperes ($1\text{uA} = 10^{-6}$ A), nanoamperes ($1 \text{ nA} = 10^{-9}$ A), or picoamperes ($1 \text{ pA} = 10^{-12}$ A) are used to indicate very small current flows.

4. Potential Difference

When two positive charges or two negative charges are brought near to each other they will repel while a positive and negative charge are attracted to each other. Then a charged particle has the ability to do work so energy must be expended, that is, WORK must be done in order to move an electric charge.

The ability of a charged particle to do work is called an electric potential. Thus two dissimilar charges have a difference of potential and the unit of potential difference (pd) is called the volt.

The **volt** unit of potential difference, named after Alessandro Volta, involves work which is the measure of the amount of work required to move an electric charge, which in turn involves force and distance. The **SI** unit of work is the joule with unit symbol **J**, the SI unit of force is the newton with unit symbol **N**, and the SI unit for distance is the meter with unit symbol **m**.

$$W\ (\text{joules}) = N\ (\text{newtons}) \times m\ (\text{meters})$$

Energy is the capacity to do work. Potential energy, which is the energy a body has because of its physical position.

> *The potential difference between two points will be equal to one volt if one joule of work is done displacing one coulomb of charge*

In electrical engineering, potential difference between two points is commonly referred to as voltage. It is given the symbol V.

Sometimes the letters U or E for emf (electromotive force) are also used, but the standard symbol V represents any potential difference between two fixed points.

This applies equally to either the voltage generated by a source such as a battery or solar cell, or to the voltage dropped across a passive component such as a resistor.

The voltage difference between two points is the work done in joules (**J**) required to move one coulomb (**C**) of charge from one point in a circuit to another through a potential difference of one volt (1V). The SI unit of voltage is the volt and is given as:

$$V\,(\text{volts}) = \frac{W\,(\text{joules})}{Q\,(\text{coulombs})}$$

Where:

V = The Voltage in Volts

W = The Work being Done

Q = The Total Charge passing a Fixed Point

Thus by definition, the potential difference between any two points in an electrical circuit is known as Voltage whether that is from a source to ground, or across a component or device.

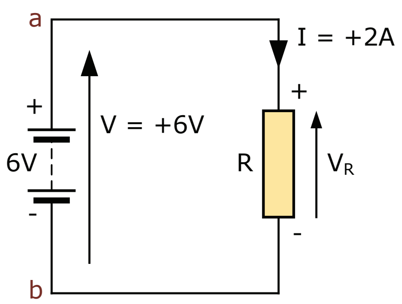
The unit of potential difference between two points is the Volt (V) with voltages usually expressed in volts (V), kilovolts (1 kV = 10^3 V) or megavolts (1MV = 10^6 V) for larger voltage values, and smaller sub-multiples of: millivolts (1mV = 10^{-3} V), or microvolts (1uV =10^{-6} V) for very small values of voltage.

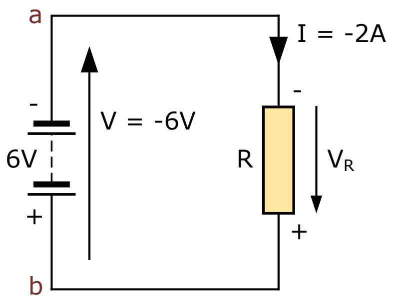
There are two distinct ways of indicating the voltage difference between two points or nodes in a circuit. One way is presented as a straight line with an arrow pointing towards the point whose voltage is higher than that of the other point.

Another way is use of a plus (**+**) symbol to indicate the higher voltage point and a negative (**-**) symbol to indicate the lower voltage point, such as those found for a battery.

If point a is more positive with respect to point b, moving a positive charge around a closed circuit from a to b (or a negative charge from b to a) requires work. The difference between the two points is the voltage polarity. This voltage polarity is indicated by a positive sign (**+**) at point a and a negative sign (**-**) at point b.

Figure 2. Direction of Current Flow





In the circuit of Figure 2, the arrow indicates the direction of current flow. If the arrow points in the same direction of the positive charge carriers (conventional current flow) the numeric vale of the current receives a positive sign, +2A.

If current flow is opposite (electron flow), the numerical value receives a minus sign, -2A. The sign indicates the direction of current flow with the arrow (+) or in reverse (-).

Then Conventional Current Flow gives the flow of electrical current from positive to negative and Electron Current Flow around a circuit from the negative terminal to the positive. The item which provides a path for the electrons to flow is called a conductor or wire.

The polarity of the voltage is also indicated by the direction of an arrow. If the arrow points from more positive to more negative potential, the numerical value of the voltage has a positive sign, +6V. If it points from a more negative to a more positive potential, then the numerical value has a minus sign, -6V.

The battery symbol is often used to denote a DC voltage source, either as a single cell or multiples of cells. But the symbol may not always represent an actual battery but a DC source.

Usually the positive (+) and negative (-) signs which indicate the positive and negative battery terminals are not shown because, by convention, the long end thin line denotes the positive terminal (the Anode) and the short end fatter line the negative terminal (the Cathode). Thus, it maybe not necessary to put + and - signs on the diagram.

5. DC and AC Voltages and Currents

By definition there are two types of electrical voltages and currents. One is described as being Direct Current, DC, while the other is described as being Alternating Current, AC. Although the terminology of AC and DC is used, it relates to both voltages and currents.

Direct current (dc) is current that moves or flows around a circuit in one direction only. That is, it is a unidirectional current supply. This is because the voltage sources that supply it, batteries, photovoltaic cells, etc. maintain the same voltage polarity, for example 12 VDC at their output terminals. Thus the voltage supplied by these types of sources is called direct-current voltage, or simply dc voltage.

Alternating current (ac) is current that periodically reverses or changes is direction and polarity over time making it a bi-directional current supply. This is because ac voltages and currents are created by rotating machine such as alternators and generators.

Voltage or Current can take the form of a steady state (DC) supply or an alternating (AC) supply

Thus ac current flows from the positive terminal and back to the negative terminal during one half cycle of rotation, and the current reverses its direction when the generator alternates its voltage polarity during the second half cycle of rotation.

The power supply used to power homes, offices and industry is alternating AC voltage, for example 120 VAC or 240 VAC. As the voltage and currents direction goes through one full reversal, the number of reversals, known as cycles, each and every second determines its frequency. That is the revolutions per second is called frequency.

One cycle per second is known as 1 hertz, thus fifty cycles per second is 50 hertz (Hz), and sixty cycles per second is 60 hertz (60Hz). Also, the time taken to complete one full cycle is known as the periodic time of the ac supply. The periodic time in seconds is the reciprocal of the frequency, that is 1/50 = 20ms, and 1/60 = 16.67ms.

6. Sources of Electrical Energy

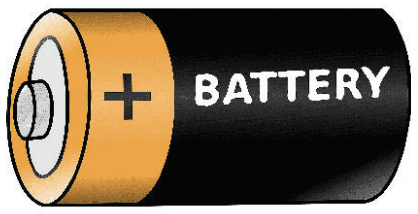
All electrical and electronic circuits require some form of electrical energy in the form of a voltage supply to operate, and as we have seen, the potential energy of a supply is given by its voltage which has the potential to provide an electrical current.

The type, voltage and current levels required will depend on the type of circuit, with the most common sources of electrical energy being:

1. Chemical Battery of Cells
2. Electrical Alternators and Generators
3. Photovoltaic Solar Cell
4. Photoelectric Cell
5. Thermocouple Sensors
6. Renewable Energy Devices

and many more.

Figure 3. A typical Battery



7. Voltage and Current Sources

An electrical supply or simply, "a source", is a device that supplies electrical power to a circuit in the form of a voltage or a current. An electrical source is generally a two-terminal element representing a battery, or generator, etc. that maintains a specified amount of voltage or current between its terminals. For example, 5V, 12V, 3A, 10A.

7.1 An Independent Voltage Source

An ideal voltage source is defined as a two terminal active element that is capable of supplying and maintaining the same voltage, (v) across its terminals regardless of the current, (i) flowing through it.

In other words, an ideal voltage source will supply a constant voltage at all times regardless of the value of the current being supplied. Thus producing a standard current-voltage (I-V) characteristic represented by a straight vertical line.

Figure 4. An Independent Voltage Source

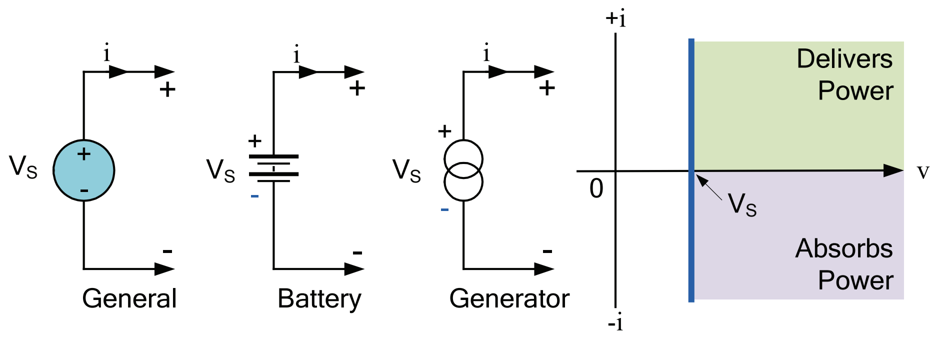


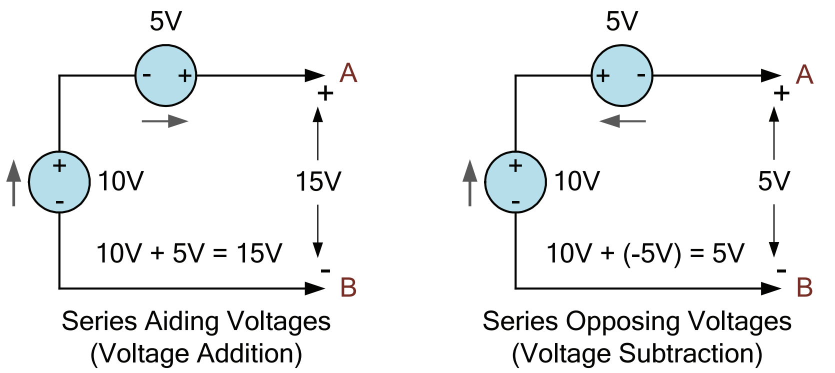
Figure 4 shows the schematic symbols for three typical independent voltage sources. They are referred to as being "independent", because their output voltage is not controlled or dependent upon the value of the current flowing through the source or its direction. It is assumed to be completely independent of any current (ideal source).

If the direction of conventional current flow is from the positive terminal to the negative terminal, the voltage source is delivering energy (and power) to the connected circuit or load. If the flow of current is the opposite, negative to positive terminal, then the voltage source is absorbing power.

Thus independent voltage sources can supply or absorb power and there is no limit to the amount of electrical energy (power) an ideal independent voltage source can either deliver or absorb.

Ideal independent voltage sources can be connected series with their voltage values add together. Ideal voltage sources of different values can be connected together in series to form one single voltage source whose output will be the algebraic addition or subtraction of the independent voltages used. Their resulting connection will be as either: series-aiding or series-opposing voltages as shown in Figure 5.

Figure 5. Series Aiding and Series Opposing Voltage Sources



Thus, for series aiding voltage sources the two voltages of 10V and 5V of the first circuit are added, for a V_S of 10 + 5 = 15V. So the voltage across terminals A and B is 15 volts.

For series opposing voltage sources the voltages are subtracted from each other, resulting in a V_S of 10 – 5 = 5V across terminals A and B.

7.2 An Independent Current Source

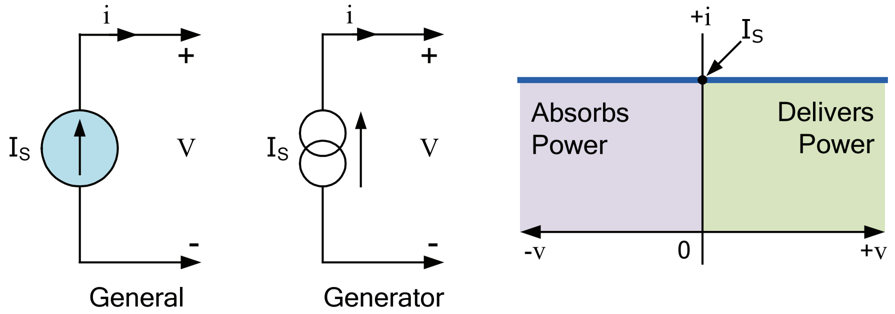
An ideal independent current source is another two-terminal circuit element which maintains, supplies, or receives a constant amount of current regardless of the voltage developed across its terminals, as this voltage is determined by other circuit elements.

That is, an ideal constant current source continually provides a specified amount of current regardless of the impedance that it is driving and as such, an ideal current source could, in theory, supply an infinite amount of energy.

Ideal constant current sources are represented in a similar manner to voltage sources, but this time the current source symbol is that of a circle with an arrow inside to indicates the direction of the flow of the current.

The direction of the current will correspond to the polarity of the corresponding voltage, flowing out from the positive terminal. This is shown in Figure 6.

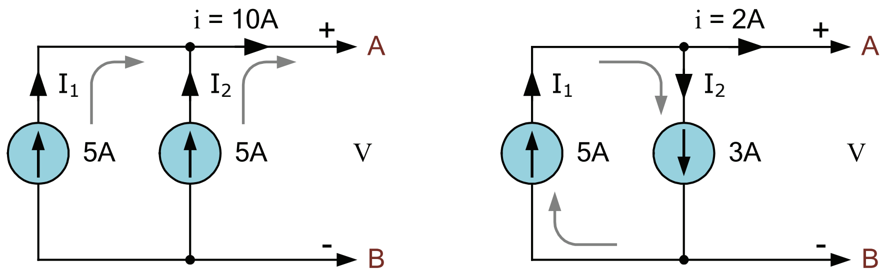
Figure 6. An Independent Current Source



As with independent voltage sources, ideal constant current sources can also be connected together to increase (or decrease) the value of the available circuit current. Connecting two or more current sources in parallel is equivalent to having one single current source whose total current output is given as the algebraic addition or subtraction of the individual source currents.

Thus ideal independent current sources of different values may be connected together in parallel. For example, one of 5 amps and one of 3 amps would combined to give a single current source of 8 amperes.

Figure 7. Parallel Aiding and Parallel Opposing Current Source



In Figure 7a, two 5 amp current sources are combined together in parallel aiding to produce 10 amps as $I_T = I_1 + I_2 = 5 + 5 = 10A$. The directional arrows representing the current source both point in the same direction. Thus the two currents are summed together.

Figure 7b, shows the two currents are of different values, 5A and 3A. As the arrows representing the current source are pointing in different directions. The total current will therefore be the subtracted value with the smaller current subtracted from the larger current. Resulting in a current source, I_T of 5 – 3 = 2A. Thus the two source currents are subtracted from each other.

7.3 A Dependent Voltage Source

A dependent voltage source or controlled voltage source, provides a voltage supply whose magnitude depends on either the voltage across or current flowing through some other circuit element connected to it.

A dependent voltage source is indicated with a diamond shape and are used as equivalent electrical sources for many electronic devices, such as transistors and operational amplifiers.

There exist two possible types of dependent voltage sources:

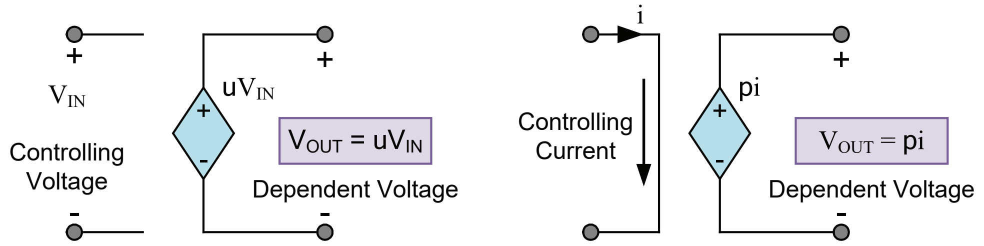
1. Voltage-controlled Voltage Source (VCVS) whose output voltage is “controlled” or depends upon an external input voltage.
2. Current-controlled Voltage Source (CCVS) whose output voltage “controlled” or depends upon an external input current.

Ideal dependent voltage sources are commonly used in analysing the input and/or output characteristics, or the gain of an active circuit element. Generally, an ideal voltage dependent source, either voltage or current controlled is designated by a diamond-shaped symbol.

An ideal dependent voltage-controlled voltage source (VCVS) shown in Figure 8a, maintains an output voltage equal to some multiplying constant (basically a constant amplification factor) times the controlling voltage present elsewhere in the circuit.

Thus the VCVS output voltage is determined by the following equation: $V_{OUT} = \mu{*}V_{IN}$. Note that the multiplying constant “µ” is dimensionless . This is because it is purely a scaling factor as: $\mu = V_{OUT}/V_{IN}$ Therefore its units would be volts/volts (V/V).

FIGURE 8. DEPENDENT VOLTAGE SOURCES



The ideal dependent current-controlled voltage source (CCVS) shown in Figure 8b left, maintains an output voltage equal to some multiplying constant (rho), times a controlling current. This input current is generated elsewhere within the connected circuit.

Then the output voltage “depends” on the value of the input current, again making it a dependent voltage source.

The controlling current, I_{IN} determines the magnitude of the output voltage, V_{OUT} times the magnification constant ρ (rho), this allows us to model a current-controlled voltage source as a trans-resistance amplifier as the multiplying constant, “ρ” gives us the following equation: $V_{OUT} = \rho{*}I_{IN}$.

This multiplying constant ρ (rho) has the units of Ohm’s because $\rho = V_{OUT}/I_{IN}$, and its units will therefore be volts/amperes (V/A).

7.4 A Dependent Current Source

A controlled or dependent current source changes its available current depending upon the voltage across, or the current through, some other external circuit element, that is the output of a dependent current source is controlled by another voltage or current.

Voltage or Current can be either Independent or Dependent sources

In other words, the output current “depends” on the value of input voltage making it a dependent current source.

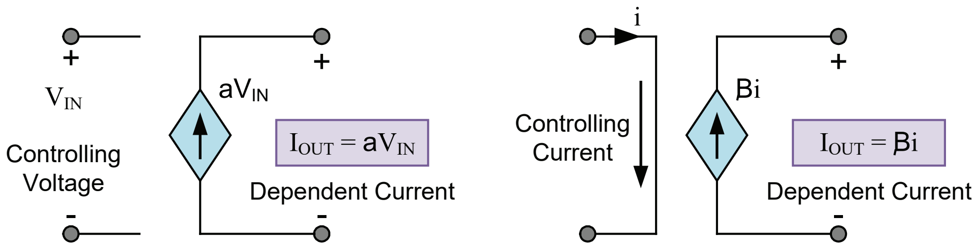
As with the previous dependent voltage sources, there exist two possible types of dependent current sources:

1. Voltage-controlled Current Source (VCCS) whose current is "controlled" or depends upon an external input voltage.
2. Current-controlled Current Source (CCCS) whose current is "controlled" or depends upon an external input current.

Generally, an ideal current dependent source, either voltage or current controlled is designated by a diamond-shaped symbol where an arrow indicates the direction of the current, i as shown.

The ideal dependent voltage-controlled current source (VCCS) shown in figure 9a, maintains an output current, I_{OUT} that is proportional to the controlling input voltage, V_{IN}. Thus the VCCS output current is defined by the following equation: $I_{OUT} = \alpha * V_{IN}$.

Figure 9. Dependent Current Sources



This multiplying constant "α" (alpha) has the SI units of mhos, ℧ (an inverted Ohms sign) because $\alpha = I_{OUT}/V_{IN}$, and its units will therefore be amperes/volt.

An ideal dependent current-controlled current source (CCCS) shown in Figure 9b, maintains an output current that is proportional to a controlling input current. Then the output current "depends" on the value of the input current.

As a controlling current, I_{IN} determines the magnitude of the output current, I_{OUT} times the magnification constant "β" (beta), the output current for a CCCS element is determined by the following equation: $I_{OUT} = \beta * I_{IN}$.

Note that the multiplying constant β is also a dimensionless scaling factor. Because it is current related as $\beta = I_{OUT}/I_{IN}$ Therefore its units would be amperes/amperes (A/A).

8. Electrical Energy and Power

The standard unit of Electrical Energy is the Joule. Previously we said that the strength of an electric current (**I**) is the rate of flow of electrons passing a point over time. Therefore current $I = Q/t$. Where charge (**Q**) is measured in coulombs and time, (**t**) in seconds.

Then we can correctly say that 1 ampere of electric current will flow if 1 coulomb of electric charge passes a fixed point or node in 1 second. That is: 1 amp = 1 coulomb/1 sec

We also saw that the ability of the charged body to do work is called electric potential, and that the work done to move charge is also measured in joules, with electric charge in coulombs.

Voltage is defined as: joules/coulomb

Current is defined as: coulombs/second

Then: $V = W/Q$. Where 1 volt is created if 1 joule of energy is used to move 1 coulomb of charge. That is: 1 volt = 1 joule/1 coulomb.

Then we can define voltage and current as being:

$$V\left(\text{volts}\right) = \frac{W\left(\text{joules}\right)}{Q\left(\text{coulombs}\right)} \quad \text{and} \quad I\left(\text{amperes}\right) = \frac{Q\left(\text{coulombs}\right)}{t\left(\text{seconds}\right)}$$

The electric power is the rate of delivering the energy over an amount of time. Thus the time rate of doing work, expressed in joules per second, is given the unit of watts. That is, electrical power is measured in watts which is equal to one joule per second.

The standard symbol used for a watt is "**P**" for power. Power in watts is found by multiplying a circuits voltage (**V**) by its current (**I**). We can prove this using the two formulas given previously in which we said that: Volts = joules per coulomb and Current = coulombs per second.

$$P = V \times I = \frac{\text{joules}}{\cancel{\text{coulombs}}} \times \frac{\cancel{\text{coulombs}}}{\text{seconds}} = \frac{\text{joules}}{\text{seconds}} \text{ (watts)}$$

Thus electrical power which is the rate of using energy in watts is equal to: V x I. This is given as: joules per second. So if a potential difference of 1 volt is applied across a circuit and a current of 1 ampere flows through it for a time duration of 1 second, then the work done or amount of electrical energy would be equal to 1 joule or watt-second.

Although electrical energy is measured in Joules it can become a very large value when used to calculate the energy consumed by a component.

For example, if a 100-watt light bulb is illuminated for 24 hours, the energy consumed will be 8,640,000 Joules (100W x 86,400 seconds), so prefixes such as kilojoules (kJ = 10^3J) or megajoules (MJ = 10^6J) are used instead. Thus the energy consumed by the lamp will be 8.64MJ (mega-joules).

Watts is the time rate of doing work expressed in joules per second

But dealing with joules, kilojoules or megajoules to express electrical energy is not a very practical method as the maths involved can end up with some big numbers and lots of zero's. Therefore, it is much easier and more practical to express the electrical energy consumed by a circuit or device in watt-hours, or Wh.

8.1 Kilowatt Hours, (kWh)

Electrical power suppliers and utility companies measure the amount of electrical energy consumed by a user in watts or kilowatts (thousands of watts), with the time duration measured in hours not seconds, resulting in the unit of electrical energy being the kilowatt-hour, (kWh).

Therefore, 1 kilowatt-hour (1 kWh) is the amount of electrical energy consumed (or delivered) by a circuit or device rated at 1000 watts (1 kW) during a time duration of one hour.

The "kWh" is the commonly used "Unit of Electricity". It is this electrical unit that is measured by the utility meter and we as consumers purchase from our electricity suppliers when we receive our bills and therefore how much we pay. Thus 1.0 kWh of electrical energy is equivalent to:

$$1.0 \text{ kWh} = (1.0 \times 10^3 \text{ J/s})(1\text{h}) = (1.0 \times 10^3 \text{ J/s})(3600 \text{ s}) = 3.6 \text{ MJ}$$

That is 1.0 kWh is equivalent to 3.6 mega-joules (MJ) of electrical energy. The energy consumed by a standard 100 watt light bulb will be 2,400 (100W x 24h) watt-hours or 2.4 kWh, which is much easier to understand than 8,640,000 joules or 8.64MJ.

So if we switch "on" an electric heating element rated at 1000 watts for 1 hour we will have consumed 1.0 kWhr of electricity. If you switched on two electric heating elements each with 1000 watt rating for half an hour the total consumption would be exactly the same amount of electricity – 1kWhr.

So, consuming 1000 watts for one hour uses the same amount of power as 2000 watts (twice as much) for half an hour (half the time). Then for a 100 watt light bulb to use 1 kWhr or one unit of electrical energy it would need to be switched on for a total of 10 hours (10 x 100 = 1000 = 1kWhr).

9. Open and Closed Circuits

An electrical circuit (or simply a circuit) is a circular closed path of wires and components which allows the flow of electric charge around itself. Electric charge in the form of a current flows from a connected power source to a load via the interconnected wires.

Wire is a good conductor that allows electrical current to easily flow through it. Metals such as copper, aluminium, gold and silver, are types of good conductors.

The connected load converts the electrical energy it receives into another type of energy. For example, heat, light and mechanical movement. Thus a complete electrical circuit is required in order to make the use and control of electricity practical.

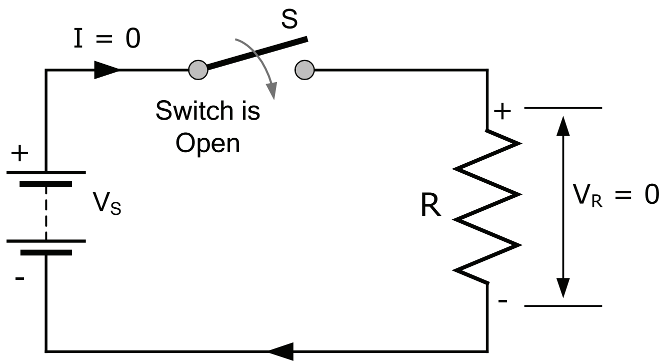
We use circuit diagrams and symbols to represent the component parts of an electrical circuit, making it easier for us to understand how a particular circuit works.

9.1 An Open Circuit Condition

An open electrical circuit (or network) is a circuit in which the conducting path has been broken or "opened" at some point so that current cannot flow around it, either intentionally using a switch or by the creation of a fault (loose wire). Therefore, an open circuit has infinite resistance and zero current.

Figure 10 shows the circuit diagram of a simple electrical circuit consisting of a voltage source, V_S a switch (S) acting as a control device to turn the circuit "ON" or "OFF", a resistive load (R) which converts the electrical energy supplied by the voltage source into work (heat), and conducting wires that provide an electrical path to and from the power source.

FIGURE 10. AN OPEN CIRCUIT CONDITION



With the switch (S) of figure 10 open, the circuit is incomplete so no current can flow around it. Thus I = 0 amps. As there is no current flowing through the resistor (R), due to the switch being open, there is no voltage drop developed across it. Then $V_R = 0$ volts.

The electrical power in watts consumed by an open circuit condition will therefore be zero, as V x I = V x 0 = 0 watts. That is no power is supplied by the source.

9.2 A Closed Circuit Condition

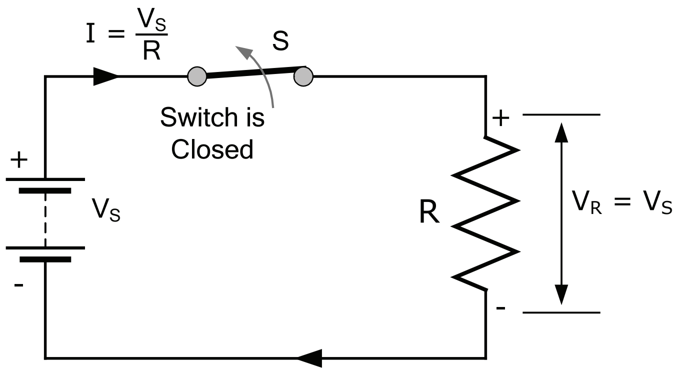
A closed electrical circuit (or network) is a circuit where the conducting path is completely connected so that electrical current can easily flow (or circulate) around it from source to load. Therefore, a closed loop circuit has a resistive value equal to the connected load.

Electric circuits can be classed as Open or Closed. An open circuit is called Incomplete. A closed circuit is called Complete

With the switch of Figure 11 now in the closed position, the circuit is complete and electric current will flow around it in a loop from voltage source to resistive load and back again to source.

The value of current flowing around the closed circuit will be equal to V/R (ohms law) and as there will be this value of current flowing through the resistive load, (R) the voltage drop across it will be equal to I^2R volts. Thus, in this example, $V_R = V_S$.

FIGURE 11. A CLOSED CIRCUIT CONDITION



As an electrical current flows around the closed circuit, power is consumed and dissipated by the resistor (load). This is given as: **$P = V_S \times I$**, or **$I^2 \times R$** in watts.

9.3 A Short Circuit Condition

A short circuit occurs when there is a very low-resistance connection between any two circuit points. The unintentional and undesirable creation of a short circuit condition between two circuit points is called an "electrical fault" and is demonstrated in Figure 12.

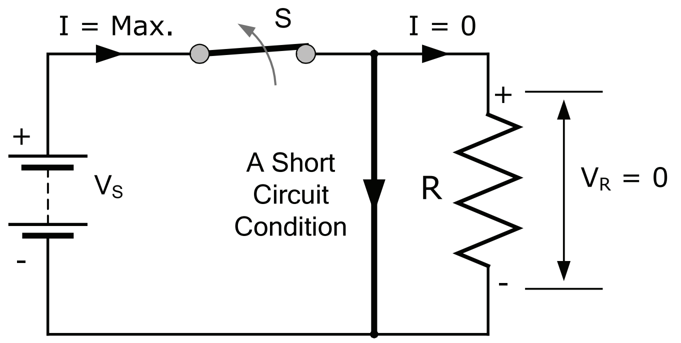


FIGURE 12. A SHORT CIRCUIT CONDITION

Electrical current will always follow the path of "least resistance". So a short circuit condition is ideal for the flow of current. This usually creates an instantaneous increase in electrical current supplied by the voltage source resulting in the activation of the circuits protection device such as a fuse, fusible link or circuit breaker.

Generally a voltage source hates a short-circuit (fault) condition as for an instant in time it must supply the maximum short-circuit current possible at zero voltage.

10. DC Series and Parallel Circuits

Electrical circuits can be arranged and connected in two distinct ways. As a Series Circuit, and as a Parallel Circuit. These two circuit topologies can also be mixed and connected together to create one called a combined or combination circuit.

10.1 A Series Connected Circuit

In a series connected circuit, the components and devices present within the circuit are all connected to each other end to end. The electrical current flowing through the first component (light bulb) has no other way to go so it must also pass through the second component and the third and so on as shown in Figure 13.

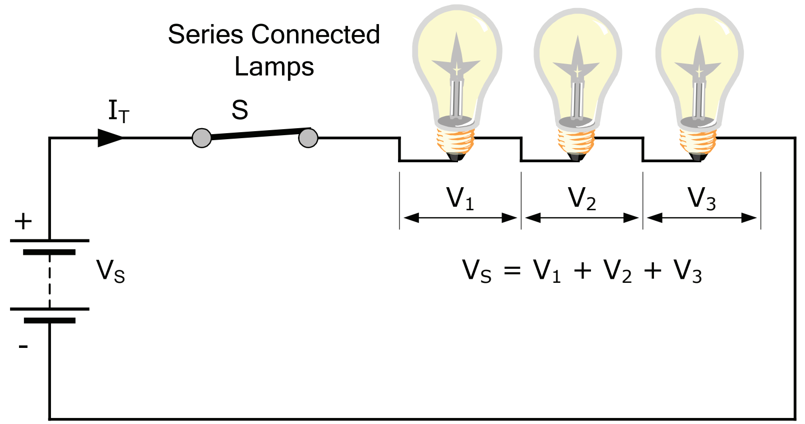


FIGURE 13. SERIES CONNECTED LAMPS

Thus for the series connected circuit of Figure 13, the current is common to ALL circuit components and devices everywhere within the circuit as there is only one closed path for current to flow.

While the current in a series circuit is common to all components, voltage is not. The supply voltage, V_S is divided proportionally between all the series components. The result is that the sum of the potential differences across each series component is equal to the supply voltage. For example, $\mathbf{V_S = V_1 + V_2 + V_3 + ..}$ **etc.**

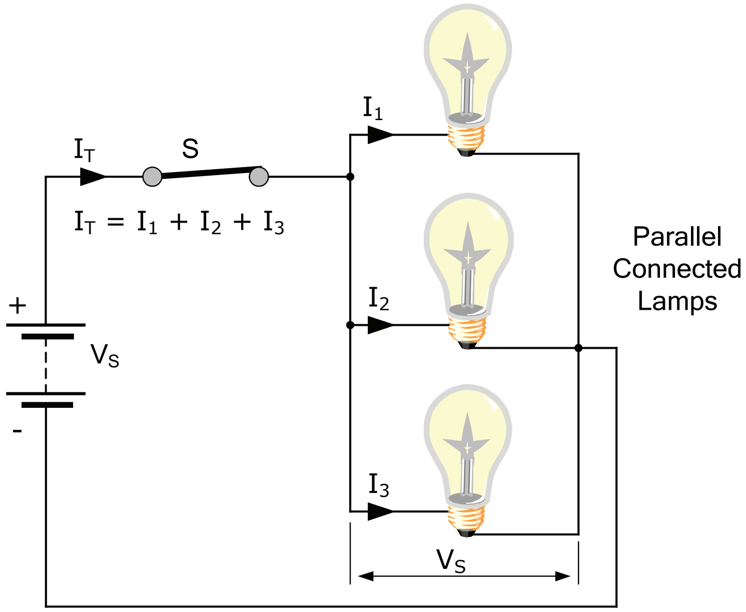
The voltage value across each component will be equal to its IR voltage drop. Then series connected circuits can also be thought of as "voltage dividers".

Also in a series circuit, if a one components (a lamp) breaks or is disconnected, the circuit is broken (incomplete) and all the components stop working and I_T becomes zero.

10.2 A Parallel Connected Circuit

In a parallel connected circuit, the components and devices are connected such that both of their terminals are connected to each terminal respectively of the other component in the parallel branch.

FIGURE 14. PARALLEL CONNECTED LAMPS



In a parallel circuit of Figure 14, there are more than one circuit path for current to follow. The supply current divides itself according to the resistive value of each path. Thus, in the parallel connected circuit current divides into separate paths. For example, **I_1, I_2, I_3, etc.**

Current is common in a Series circuit. Voltage is common in a Parallel circuit

Since there are multiple paths for the supply current to flow through, the current may not be the same through all the parallel branch paths.

However, the voltage drop across all of the components or devices in a parallel circuit IS the same. Then, parallel connected circuits have a common voltage across them and this is true for all parallel connected components.

While the voltage across each circuit component within a parallel combination is exactly the same and is equal to the supply voltage, V_S the branch currents flowing through them are not the same as it is determined by the resistive value of each component. Then parallel connected circuits can also be thought of as "current dividers".

Also in a parallel connected circuit, if a one components (a lamp) breaks or is disconnected, the circuit is still complete) and all the components connected to the other branches continue working.

End of this Electrical Fundamentals eBook

Last revision: March 2022

With the completion of this Electrical Fundamentals eBook you should have gained a basic understanding and knowledge of electrical circuits. The information provided here should give you a firm foundation for continuing your study of electronics and electrical engineering. In ebook 2 you will learn about DC Circuit Theory.

For more information about any of the topics covered here please visit our website at:

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