Electrical Power
Electron Theory of Matter

Molecules are made up of even smaller particles, each of which is called an atom.
Atoms, in turn, can be broken down into even smaller particles. These smaller subatomic particles are known as electrons, protons, and neutrons. The features that make one atom different from another also determine the atom's electrical properties.
Structure of An Atom

Electrons are prevented from flying off into space by the attraction between the negative electron and the positive nucleus of the atom. Electrons are prevented from being pulled into the nucleus by the force of their momentum.
Aluminum Atom

The particles that can be found in the nucleus are called protons and neutrons.

A proton has a positive (+) electrical charge that is exactly equal in strength to that of the negative (−) charge of an electron.

No. Protons = No. Electrons

13 = 13

Therefore, net electric charge is neutral or zero.
Energy Levels and Shells

A shell is an orbiting layer or energy level of one or more electrons.

There are a maximum number of electrons that can be contained in each shell.

<table>
<thead>
<tr>
<th>SHELL LETTER</th>
<th>MAX. ELECTRONS IT CAN HOLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>2</td>
</tr>
<tr>
<td>L</td>
<td>8</td>
</tr>
<tr>
<td>M</td>
<td>18</td>
</tr>
<tr>
<td>N</td>
<td>32</td>
</tr>
</tbody>
</table>
Placement of Electrons in A Copper Atom

- "K" Shell complete (2)
- "L" Shell complete (8)
- "M" Shell complete (18)
- "N" Shell incomplete (1)

Shell K (or #1) = 2 (full)
Shell L (or #2) = 8 (full)
Shell M (or #3) = 18 (full)
Shell N (or #4) = 1 (incomplete)

[Room for 31 more]
Ionization Process

ATOM

4 Electrons and
4 Protons
∴ Neutral charge

NEGATIVE ION
5 Electrons and
4 Protons
Negative Charge

Electron removed

Electron added
Electricity – the flow of free electrons
The energy source supplies the voltage required to move the free electrons along the conducting path of the circuit. It is also referred to as the power supply. Two types of sources, direct current (DC) and alternating current (AC), are used.

DC Voltage Sources

The current flow in a circuit will always be in the same direction, if the polarity of the source always remains the same. This type of current flow is called direct current, and the source is called a direct current source. Any circuit that uses a direct-current (DC) source is then a direct-current circuit.
Direct Current (DC)

There are several types of direct current and all depend upon the value of the current in relation to time.

*Pure or constant* direct current shows no variations in value over a period of time.
Direct Current (DC)

Pulsating or digital direct current variations are uniform and repeat at regular intervals.

*Pulsating* direct current associated with electronic DC-power supplies
When voltage polarity of the power source changes, or alternates, the direction of the current flow will also alternate. This type of current flow is called alternating current, and the source is called an alternating current source. Any circuit that uses an alternating-current (AC) source is then an alternating-current circuit.
Alternating Current (AC)

Alternating current changes in both value and direction.

The current increases from zero to some maximum value and then drops back to zero as it flows in one direction.

The sine wave is the most common waveform for alternating current.

This same pattern is then repeated as it flows in the opposite direction.
Alternating Current (AC)

The waveform or exact manner in which the current increases and decreases is determined by the type of AC voltage source used.

- Sine wave
- Square wave
- Sawtooth wave

The *sine wave* is the most common waveform for alternating current.

An AC waveform crosses the zero reference line.
If we move the conductor through the magnetic field, a force is exerted by the magnetic field on each of the free electrons within the conductor. These forces add together and the effect is that voltage is generated or induced into the conductor.
Induced Voltage

The amount of voltage induced in a conductor as it moves through a magnetic field depends upon:

*The strength of the magnetic field*; the stronger the field the more voltage induced.
Induced Voltage

The amount of voltage induced in a conductor as it moves through a magnetic field depends upon:

The angle at which the conductor cuts the flux; maximum voltage is induced when the conductor cuts the flux at 90 degrees and less voltage is induced when the angle is less than 90 degrees.
The number of voltage cycles induced in the armature each second is called the *frequency* of the generated sine wave.

The standard frequency of AC power generated in North America is 60 Hz or 60 cycles per second.
Sine Wave Frequency

The frequency of the induced voltage in each phase of a 3-phase alternator is directly related to the number of field poles of the rotor, the winding of the stator coils and to the rotational speed of the rotor.

The formulas used to determine the frequency of an AC generator are:

\[
\text{Frequency (F)} = \frac{\text{No. of poles (P)} \times \text{Revolutions per second (S)}}{2}
\]

\[
\text{Frequency (F)} = \frac{\text{No. of poles (P)} \times \text{Revolutions per minute (S)}}{120}
\]
Calculating Frequency

Problem What is the output frequency of an alternator with a rotor that has six poles and turns at 1000 rpm?

Solution

\[
F = \frac{PS}{120}
\]

\[
= \frac{6 \times 1000}{120}
\]

\[
= 50 \text{ Hz}
\]
Ohm’s Law
Three fundamental quantities—voltage, current, and resistance—are present in every electric circuit.

Voltage (E) – pressure that cases the flow of electrons.

Current (I) – rate of flow of electrons.

Resistance (R) – opposition to the flow of electrons.
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit of Measure</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>E</td>
<td>Voltage which makes current flow</td>
</tr>
<tr>
<td>Current</td>
<td>I</td>
<td>Rate of flow of electrons</td>
</tr>
<tr>
<td>Resistance</td>
<td>R</td>
<td>Opposition to current flow</td>
</tr>
</tbody>
</table>
Ohm’s Law Formulas

Mathematically, Ohm’s law can be expressed in the form of three formulas: one basic formula and two others derived from it. Using these three formulas, and knowing any two of the values for voltage, current, or resistance, it is possible to find the third value.

<table>
<thead>
<tr>
<th>Find Current</th>
<th>Find Voltage</th>
<th>Find Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I = \frac{E}{R} )</td>
<td>( E = I \times R )</td>
<td>( R = \frac{E}{I} )</td>
</tr>
<tr>
<td>Current equals voltage divided by resistance</td>
<td>Voltage equals current multiplied by resistance</td>
<td>Resistance equals voltage divided by current</td>
</tr>
</tbody>
</table>
There are three basic measurements made on electrical circuits: voltage (E), current (I), and resistance (R).
Applying Ohm’s Law to Calculate Current

By using Ohm’s law, we can predict what is going to happen in a circuit before we apply power. When any two of the three quantities (V, I, or R) are known, the third can be calculated. For example, if the voltage and resistance are known, the current can be calculated.

\[ I = \frac{E}{R} \]

\[ I = \frac{120 \text{ V}}{15 \text{ } \Omega} = 8 \text{ A} \]
Applying Ohm’s Law to Calculate Voltage

Find the voltage using ohm’s law

\[ E = I \times R \]

\[ = 2.5 \, \text{A} \times 5 \, \Omega \]

\[ = 12.5 \, \text{V} \]
Power (P) is the amount of work performed by an electric circuit when the voltage forces current to flow through the resistance. The base unit used to measure power is the watt (W).

The basic power formula is:

\[ P = E \times I \]

\( W = 2,000 \) Watts
\( I = 10 \) Amps
\( E = 200 \) Volts
Series Circuit
If two or more loads are connected end-to-end, they are said to be connected in series. This is called a series circuit. The same amount of current flows through each of them. Also, there is only one possible path through which the current flows.

The current stops if this path is opened or the circuit is broken at any point. For example, if two lamps are connected in series and one burns out, both lamps will go out.
When loads are connected in series, each receives part of the applied source voltage. For example, if three identical lamps are connected in series, each will receive one-third of the applied source voltage. The amount of voltage each load in series receives is directly proportional to its electrical resistance. The higher the resistance of the load connected in series, the more voltage it receives.
The filaments of some types of holiday tree lamps illustrate loads that are connected in series. These are of the type that if one lamp goes out, all lamps will go out. Lamps with identical resistance are used so each receives the same amount of voltage. The number of lamps connected in series determines the voltage rating of each lamp in the string. For example, in a ten string set of series connected lamps designed to operate from a 120 volt source, each lamp would require a minimum voltage rating of 12 volts (120V/10).
Solving DC Series Circuits

In solving a DC series circuit problem, you must know the voltage, current, resistance, and power characteristics of the circuit.

They are most easily remembered by recalling the following equations for a series DC circuit:

\[ I_T = I_1 = I_2 = I_3 \ldots \]

\[ E_T = E_1 + E_2 + E_3 \ldots \]

\[ R_T = R_1 + R_2 + R_3 \ldots \]

\[ P_T = P_1 + P_2 + P_3 \ldots \]
Solving DC Series Circuits

One helpful method of solving circuits is to use a table to help organize the steps used in solving the problem. Start by recording all given values of voltage, current, resistance, and power. Next calculate the unknown values and record each in the table as they are determined.

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁</td>
<td>E₁</td>
<td>I₁</td>
<td>R₁</td>
<td>P₁</td>
</tr>
<tr>
<td>R₂</td>
<td>E₂</td>
<td>I₂</td>
<td>R₂</td>
<td>P₂</td>
</tr>
<tr>
<td>Total</td>
<td>Eₜ</td>
<td>Iₜ</td>
<td>Rₜ</td>
<td>Pₜ</td>
</tr>
</tbody>
</table>
Solving DC Series Circuits

Problem: Find all the unknown values of $E$, $I$, $R$, and $P$, for the series circuit shown.

$E_T = 24$ V

$R_1 = 12$ Ω

$R_2 = 4$ Ω
Solving DC Series Circuits

**STEP 1** Make a table and record all known values.

![Series Circuit Diagram]

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td></td>
<td></td>
<td>12 $\Omega$</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td></td>
<td></td>
<td>4 $\Omega$</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>24 V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solving DC Series Circuits

**STEP 2** Calculate $R_T$ and enter the value in the table.

$$R_T = R_1 + R_2$$
$$= 12 \, \Omega + 4 \, \Omega$$
$$= 16 \, \Omega$$

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td></td>
<td></td>
<td>12 , \Omega</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td></td>
<td></td>
<td>4 , \Omega</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>24 V</td>
<td></td>
<td>16 , \Omega</td>
<td></td>
</tr>
</tbody>
</table>
Solving DC Series Circuits

STEP 3 Calculate \( I_T, I_1, I_2 \) and enter the values in the table.

\[
I_T = \frac{E_T}{R_T} = \frac{24 \text{ V}}{16 \Omega} = 1.5 \text{ A}
\]

\[
I_T = I_1 = I_2 = 1.5 \text{ A}
\]

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_1 )</td>
<td></td>
<td>1.5 A</td>
<td>12 ( \Omega )</td>
<td></td>
</tr>
<tr>
<td>( R_2 )</td>
<td></td>
<td>1.5 A</td>
<td>4 ( \Omega )</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>24 V</td>
<td>1.5 A</td>
<td>16 ( \Omega )</td>
<td></td>
</tr>
</tbody>
</table>
Solving DC Series Circuits

**STEP 4** Calculate $E_1$ and $E_2$ and enter the values in the table.

$$E_1 = I_1 \times R_1$$
$$= 1.5 \, \text{A} \times 12 \, \Omega$$
$$= 18 \, \text{V}$$

$$E_2 = I_2 \times R_2$$
$$= 1.5 \, \text{A} \times 4 \, \Omega$$
$$= 6 \, \text{V}$$

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>18 V</td>
<td>1.5 A</td>
<td>12 Ω</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td>6 V</td>
<td>1.5 A</td>
<td>4 Ω</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24 V</strong></td>
<td><strong>1.5 A</strong></td>
<td><strong>16 Ω</strong></td>
<td></td>
</tr>
</tbody>
</table>
Solving DC Series Circuits

**STEP 5** Calculate $P_T$, $P_1$, $P_2$ and enter the values in the table.

\[
P_T = E_T \times I_T = 24 \text{ V} \times 1.5 \text{ A} = 36 \text{ W}
\]

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>18 V</td>
<td>1.5 A</td>
<td>12 $\Omega$</td>
</tr>
<tr>
<td>$R_2$</td>
<td>6 V</td>
<td>1.5 A</td>
<td>4 $\Omega$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>24 V</td>
<td>1.5 A</td>
<td>16 $\Omega$</td>
</tr>
</tbody>
</table>
Parallel Circuit
Parallel-Connected Loads

If two or more loads are connected across the two voltage source leads they are said to be connected in parallel. This is called a parallel circuit.
The parallel connection of load devices is used for circuits where each device is designed to operate at the same voltage as the power supply.

Each load operates at the voltage value of the source.
Home lighting and small appliance circuits are designed to operate at 120 VAC. All appliances and lights connected in parallel to these branch circuits must be rated for 120 V. The use of lower voltage devices, such as 12-V devices would cause such units to burn out. The use of higher voltage devices on these circuits, such as 240-V devices would cause such units not to operate properly.
A parallel circuit has the same amount of voltage applied to each device. However, the current to each device will vary with the resistance of the device. The amount of current each in-parallel load passes is inversely proportional to its resistance value. The higher the resistance of the load connected in parallel, the less current it passes.
When load devices are operated in parallel, each load operates *independently* of the others.
Parallel-Connected Loads

If two lamps are connected in parallel, there will be two paths created.

- If one lamp burns out, the other will not be affected.

Remains "on"

Burnt out (open)
Parallel-Connected Loads

Holiday tree lamp strings wired in parallel have the advantage that if any one lamp goes out, the other lamps in the string will continue to operate.

All lamps in a parallel string are rated for 120 V regardless of the number of lamps used.
Solving DC Parallel Circuits

The procedure for solving parallel-circuit values of voltage, current, resistance, and power is similar to that used for solving values for series circuits.

Ohm’s law as it applies to the circuit as a whole and to individual loads, as well, is used.

\[ I = \frac{E}{R} \quad E = I \times R \]

\[ R = \frac{E}{I} \]

The parallel-circuit characteristics of voltage, current, resistance, and power.

\[ I_T = I_1 + I_2 + I_3 \ldots \]

\[ E_T = E_1 = E_2 = E_3 \ldots \]

\[ P_T = P_1 + P_2 + P_3 \ldots \]
Solving DC Parallel Circuits

Problem: Find all the unknown values of E, I, R, and P, for the parallel circuit shown.
Solving DC Parallel Circuits

STEP 1  Make a table and record all known values.

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td></td>
<td></td>
<td>24 $\Omega$</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12 V</td>
<td></td>
<td>6 $\Omega$</td>
<td></td>
</tr>
</tbody>
</table>
Solving DC Parallel Circuits

**STEP 2** Calculate $E_1$ and $E_2$ enter the values in the table.

\[
E_T = E_1 = E_2 = 24 \text{ V}
\]

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>12 V</td>
<td></td>
<td>24 Ω</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td>12 V</td>
<td></td>
<td>6 Ω</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>12 V</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solving DC Parallel Circuits

**STEP 3** Calculate $I_1$, $I_2$, $I_T$ and enter the values in the table.

$I_1 = \frac{E_1}{R_1}$

$= \frac{12 \text{ V}}{24 \Omega}$

$= 0.5 \text{ A}$

$I_2 = \frac{E_2}{R_2}$

$= \frac{12 \text{ V}}{6 \Omega}$

$= 2 \text{ A}$

$I_T = I_1 + I_2$

$= 0.5 \text{ A} + 2 \text{ A}$

$= 2.5 \text{ A}$

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>12 V</td>
<td>0.5 A</td>
</tr>
<tr>
<td>$R_2$</td>
<td>12 V</td>
<td>2 A</td>
</tr>
<tr>
<td>Total</td>
<td>12 V</td>
<td>2.5 A</td>
</tr>
</tbody>
</table>
**Solving DC Parallel Circuits**

**STEP 4** Calculate the value of $R_T$ and enter the value in the table.

\[
R_T = \frac{E_T}{I_T} = \frac{12 \text{ V}}{2.5 \text{ A}} = 4.8 \Omega
\]

\[
R_T = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{24 \Omega \times 6 \Omega}{24 \Omega + 6 \Omega} = \frac{144}{30} = 4.8 \Omega
\]

---

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>12 V</td>
<td>0.5 A</td>
<td>24 Ω</td>
<td></td>
</tr>
<tr>
<td>$R_2$</td>
<td>12 V</td>
<td>2 A</td>
<td>6 Ω</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>12 V</td>
<td>2.5 A</td>
<td>4.8 Ω</td>
<td></td>
</tr>
</tbody>
</table>
Solving DC Parallel Circuits

**STEP 5** Calculate $P_T$, $P_1$, $P_2$ and enter the values in the table.

$$P_T = E_T \times I_T$$
$$= 12 \text{ V} \times 2.5 \text{ A}$$
$$= 30 \text{ W}$$

$$P_1 = E_1 \times I_1$$
$$= 12 \text{ V} \times 0.5 \text{ A}$$
$$= 6 \text{ W}$$

$$P_2 = E_2 \times I_2$$
$$= 12 \text{ V} \times 2 \text{ A}$$
$$= 24 \text{ W}$$

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
<th>Resistance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>12 V</td>
<td>0.5 A</td>
<td>24 $\Omega$</td>
<td>6 W</td>
</tr>
<tr>
<td>$R_2$</td>
<td>12 V</td>
<td>2 A</td>
<td>6 $\Omega$</td>
<td>24 W</td>
</tr>
<tr>
<td>Total</td>
<td>12 V</td>
<td>2.5 A</td>
<td>4.8 $\Omega$</td>
<td>30 W</td>
</tr>
</tbody>
</table>
Photovoltaic Electrical Basics
Solar Power Basics

- Solar radiation – energy coming from the sun in the form of waves and small particles
- Solar noon – time of day when the sun is at its highest point in the sky
- Solar constant – energy of 1000 W/m² at the equator at sea level at solar noon
Typical PV Module
Electrical Basics

-One amp of current flowing for 1 hour is equal to 1 amp-hour.
-Watt Hours equals the electrical power consumed multiplied by the length of time the load has been operated.
-PV Systems can be configured in Series, Parallel, or Series Parallel.
**Electrical Basics-Series Configuration**

**Figure 3-3**

PV modules and batteries in a series configuration.

- **24 Volt PV Module**
- **12 Volt, 100 Ah Battery**

48 VDC
Electrical Basics-Parallel Configuration

**Figure 3-4**
PV modules and batteries in a parallel configuration.
Electrical Basics-Parallel Configuration

**Figure 3-5**

PV modules and batteries in a series-parallel configuration.
Blocking diodes prevent current from reversing from the battery bank and are installed in the charge controllers.
Example

Calculating the voltage drop on the PV output circuit conductors from a roof-mounted PV array to a charge controller in a stand-alone system.
The Installation of new technology “smart meters” creates an easy way for solar PV energy Systems to be connected to the utility grid. Smart Meters have the capability of measuring the electrical energy generated by a PV system, as well as the electrical energy received from the utility grid.

**Figure 1-14**

In a net-metering system, the net meter moves forward when electricity is flowing from the utility into the house, and the meter moves backward when excess solar energy flows back to the utility grid. At the end of the month, the customer is billed for the amount of electricity consumed less the amount of electricity produced.
Charge Controllers
-Batteries used in a PV system need a charge controller to prevent over-charging and over-discharging.
Inverters
Xantrex-6048
Inverters

An inverter at its most simplistic application takes a DC voltage source, and turns it into an AC voltage source, generally 120/240 Volts at 60 hertz.
Inverters

A bimodal inverter can work as either a grid-tie or stand-alone inverter.
Design
Equipment

**IMPORTANT:**
All configurations must comply with local and national electrical code jurisdiction. Consult your local certified installer or local electrical authority to ensure compliance. Actual wiring requirements may vary.
WIND POWER
Wind Power
Utility Scale Wind Turbines

- Hub with 3 blades
- Machine head
- Top tower
- Mid tower
- Base tower
- DTA
Equipment Changes

- Increased blade length
Wind Power

- TOUR THE INSIDE OF A WIND TURBINE
Be Green!