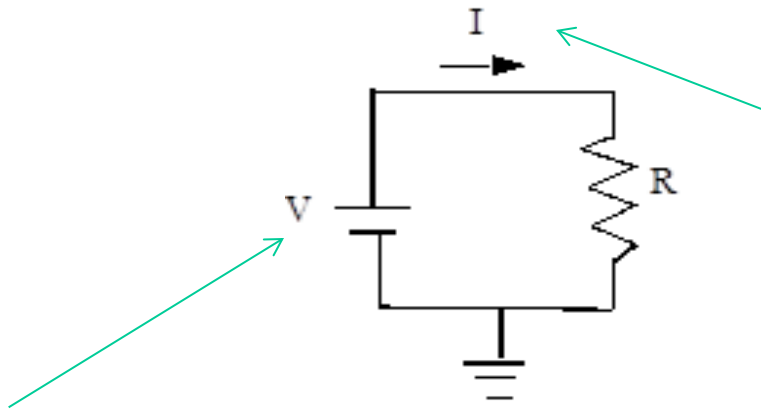# Basic Electricity

Wei-Chih Wang

engr100

Electrical Circuit

An electric circuit consists of interconnected electrical circuit elements through which electricity (or charge) can flow.

Electric current represents the flow of electric charge (usually electrons) through a wire or other conductor of electricity. Electric current is measured in units of Amperes (A) while charge is in units of Coulombs (C). The symbol I is used for current and Q for charge. Thus, a 1 A current represents the flow of 1 C/sec of charge.

The electrical voltage (or potential difference) between two points is defined as the work required to move a charge from one point to another. The unit of voltage (or potential difference) is the Volt (V). Thus, 1 V = 1 J/C where the Joule (J) is the SI unit of work or energy.
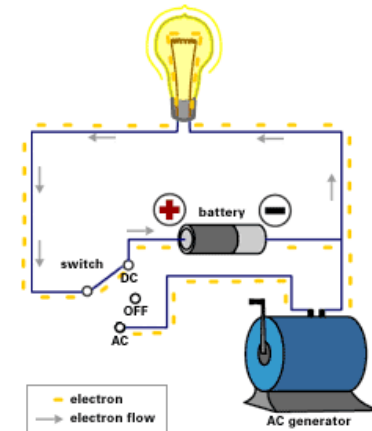
Whether a simple flashlight or part of a digital computer, all electrical circuits involves at least four things: energy sources, current, voltage and resistance. Energy sources provide the driving force that produces currents and voltages in the circuit.

Power and Energy

Unit of Electrical Power?

Nm = J (Joul)

V/m or N/C (electric field)

$$Energy = Work = \int_{x_1}^{x_2} F \bullet dx$$

V or J/C (electric potential

$$\propto (electrical\ potential energy) \quad P = qV = -q\int_{x_1}^{x_2} E \bullet dx \qquad CV = J \text{ (potential energy)}$$

PE = negative work; KE = positive work; other forms of energy = RF, heat, light etc..

Power = Energy/time

Watts= J/ sec
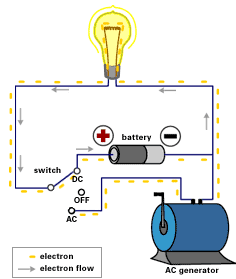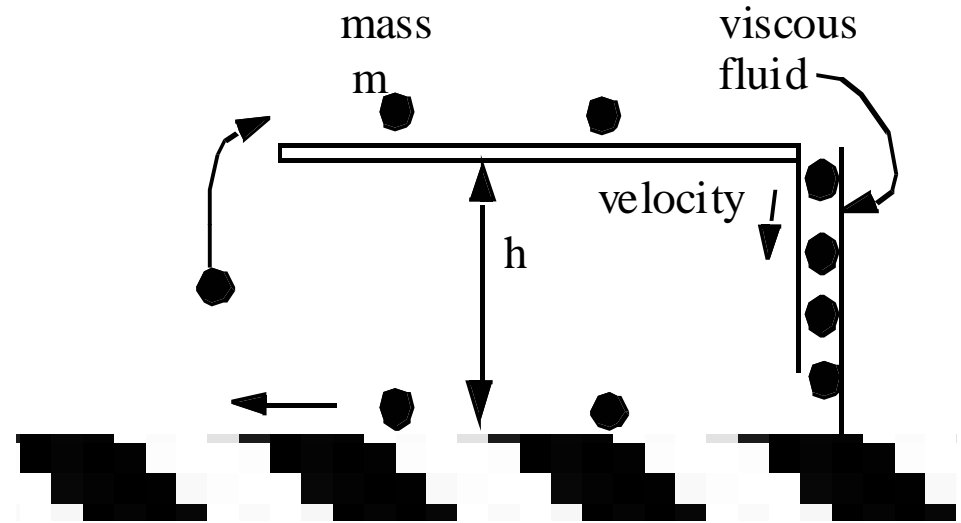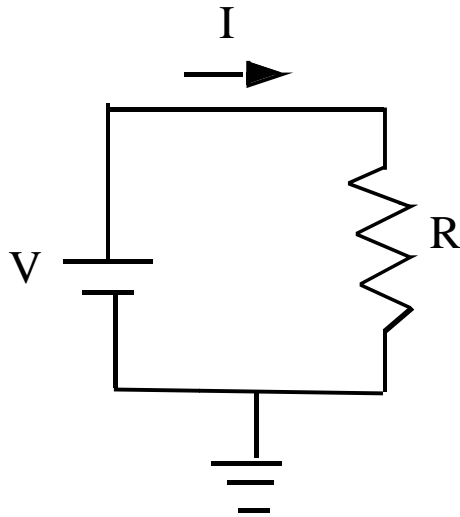
potential: $V \propto m*g*h$
current: $I \propto velocity$
power dissipation: $I^2R \propto$ damping coefficient* velocity^2
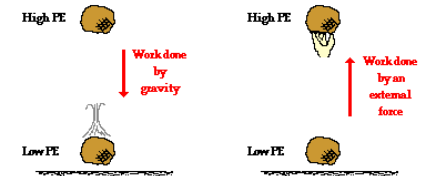
- **Figure shows how energy is transferred from a battery with certain potential energy (electrical potential) to thermal energy in resistor using a gravitational analog.**

Ohm's Law

A resistor is an electrical circuit element which "resists" the flow of current in such a manner that electric charge moves through it at **an approximately uniform velocity**. This velocity varies with the voltage across the resistor. The unit of resistance is the ohm (Ω).

Ohm's Law defines the relationship between voltage V and current I flowing through a resistor R:

$$V = I \times R$$

V= Electric potential measured in units of volts (V)
I = Electric current is measured in units of Amperes (A)
R = Resistor is measure in units of ohms (Ω)

Ohm's Law

Current (I)

1/R

Voltage (V)

Slope of the curve is proportional to resistance of the device (Ω)
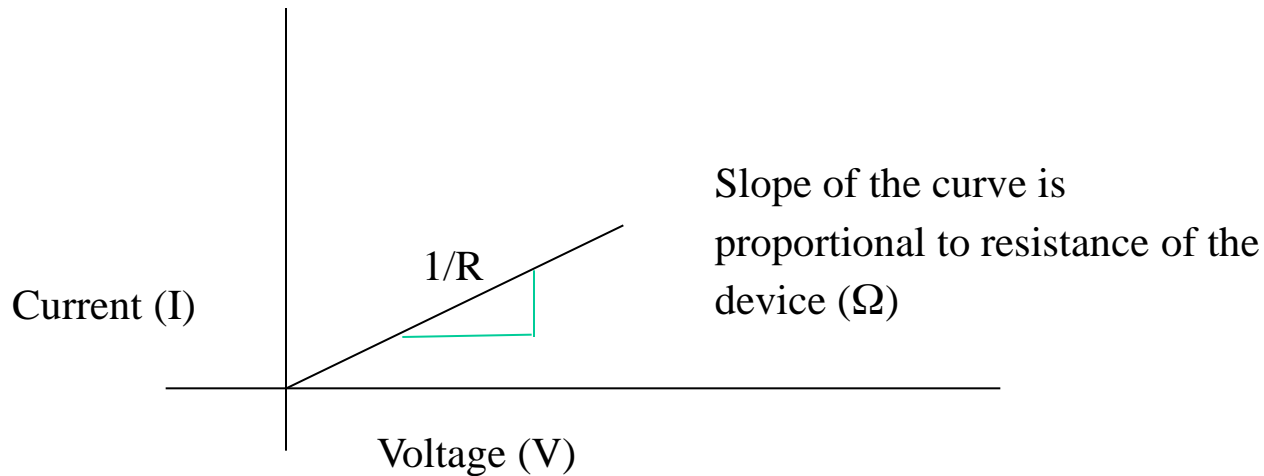
This clearly shows that a device follows Ohm's law as long as the resistance of the device is the same no matter what the applied voltage we use to measure it. The plot of current as a function of voltage appears as a straight line.

Light bulb is a Resistor

$$V = I \times R \quad (\text{Ohm's Law})$$

$$P = V \times I \quad (\text{power provided by power supply})$$

$$P_R = I^2 \times R \; (\text{power dissipated in resistor})$$
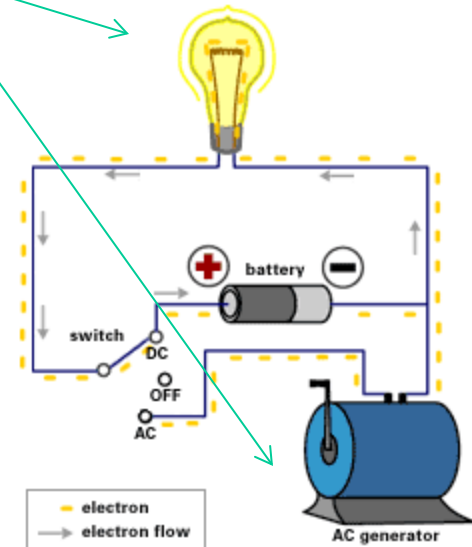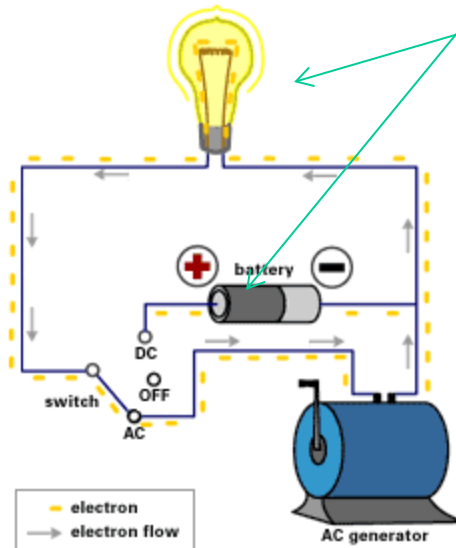
AC (household (60HZ)   DC

variable	unit	abbreviation	symbol	relation
charge	coulomb	C	$q(t)$	$(t) = \int i(t) d$
current	ampere	A	$i(t)$	$i(t) = \dfrac{dq}{dt}$
energy	joule	J	$w(t)$	$w(t) = \int p(t) dt$
voltage	volt	V	V(t)	$V(t) = \int V(t) dt$

Electrical and Mechanical System Analogy

$v_{in}(t)$ **B** **M**

frictionless

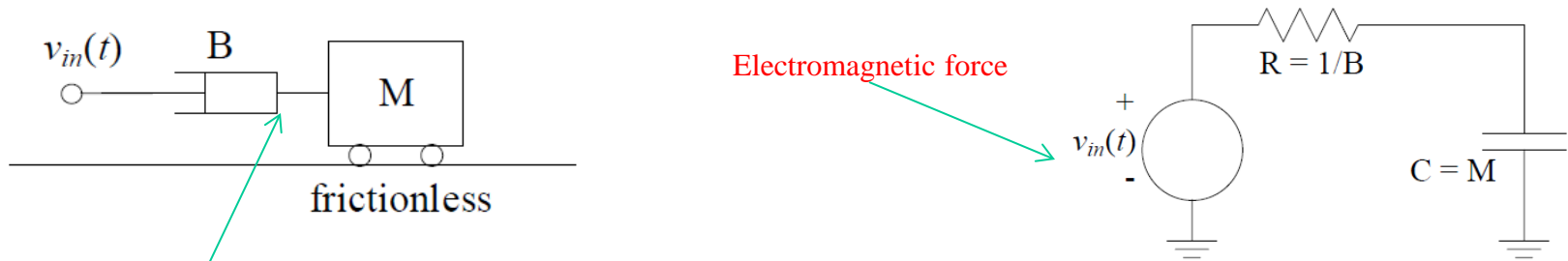Fig. 1. Mechanical system.

Electromagnetic force

$R = 1/B$

$v_{in}(t)$

$C = M$

Shock absorber

	'Forcing' Term	'Flow' Term	Time derivatives
Mechanical	Force	Velocity (displacement)	Displacement -> Velocity -> Acceleration
Electrical	Voltage	Current (Charge)	Charge -> Current -> di/dt

Analogy between Mechanical and Electrical Terms

	Mechanical Domain		Electrical Domain	
Store energy	Spring (k)	$f_s = kx_s$	Capacitor (C)	$V_c = \dfrac{1}{C} q_c$
Dissipate energy	Damper (b)	$f_d = bv_d = b\dot{x}_d$	Resistor (R)	$V_R = Ri_R = R\dot{q}_R$
'Inertial' behavior	Mass (m)	$f_m = ma_m = m\ddot{x}_m$	Inductor (L)	$V_I = L\dfrac{di}{dt} = L\ddot{q}_\iota$

Relationship between Constitutive Elements in Mechanical & Electrical Domains

How Power Distribution Grids Work
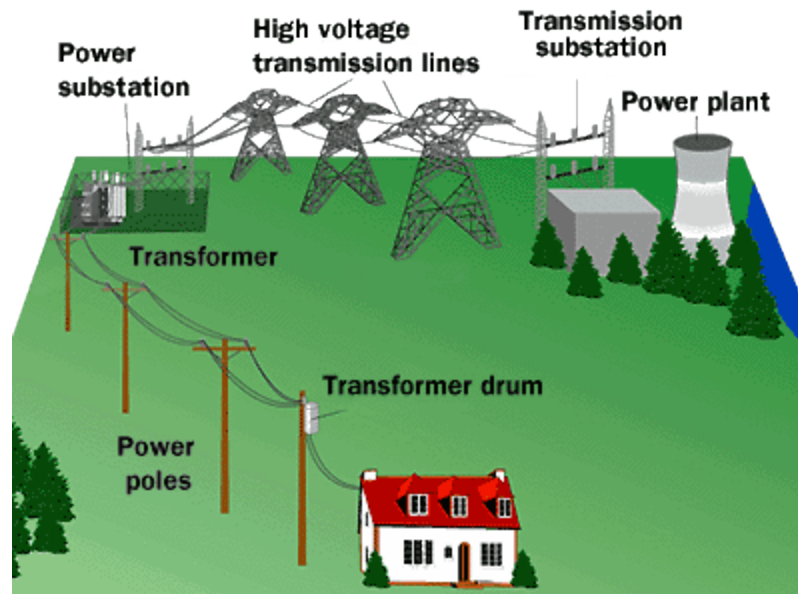
Power Plant

- power plant consists of a **spinning electrical generator**. Something has to spin that generator -- it might be a water wheel in a hydroelectric dam, a large diesel engine or a gas turbine. But in most cases, the thing spinning the generator is a **steam turbine**. The steam might be created by burning coal, oil or natural gas. Or the steam may come from a nuclear reactor like this one at the Shearon Harris nuclear power plant near Raleigh, North Carolina:

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CP&L
Carolina Power & Light

Harris Plant Safety Record

We have worked over 31-366 hours without a lost-time injury
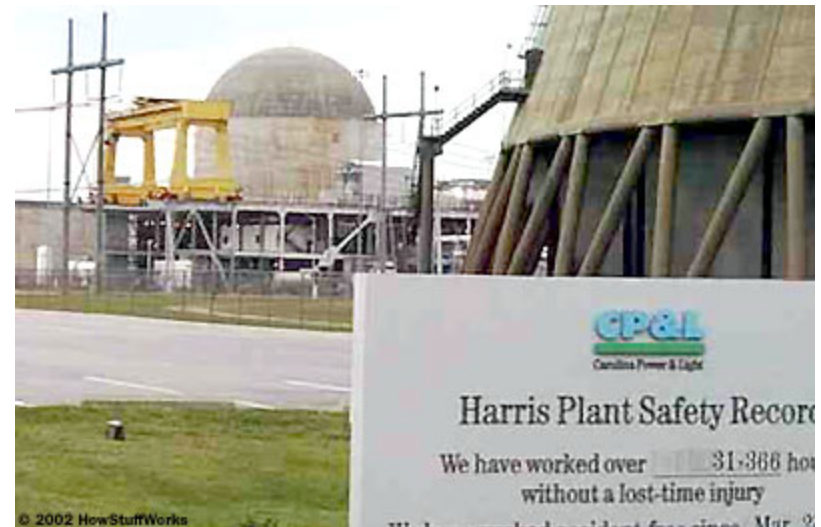
Alternating Current (AC) and Direct Current (DC)
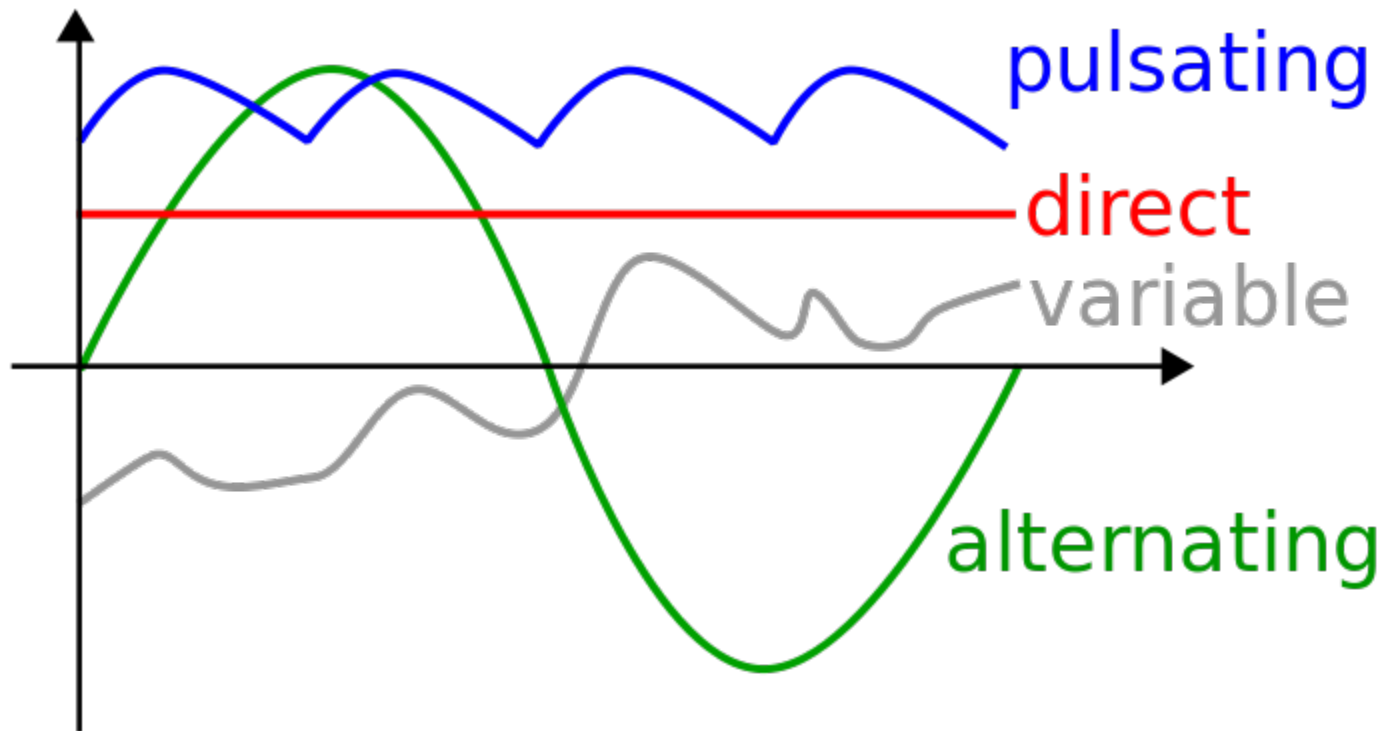
Electromagnetic Wave
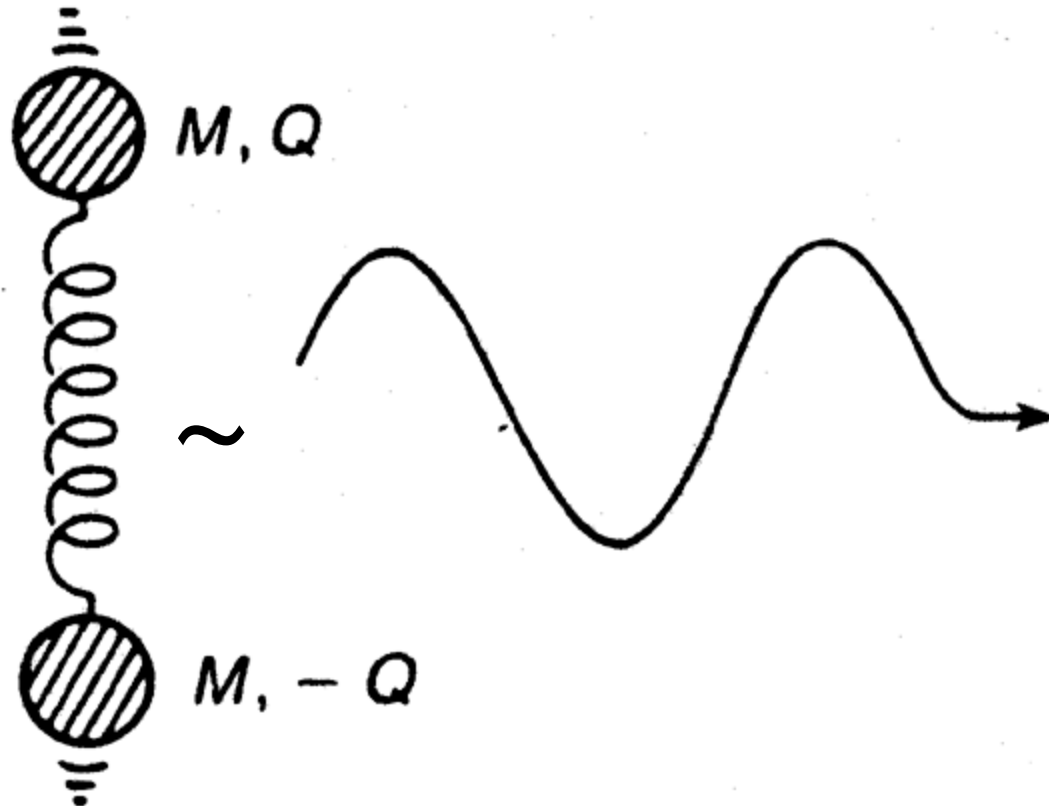
- Analogy between Electromagentic Wave and Mass-Spring mechanical system

Single-phase power

- household electrical service 120-volt AC (**alternating current)**

- Peak voltage=170 volt

- 120 volt = rms (root mean square)= $170/\sqrt{2}$

- three phases are **offset 120 degrees** from each other

- There are four wires coming out of every power plant: the **three phases** plus a neutral or **ground**
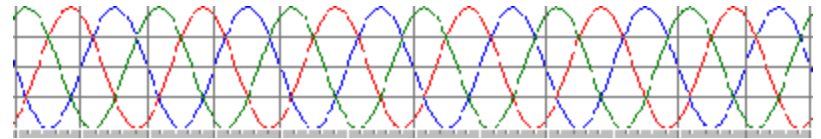
Why three phases?

- at any given moment one of the three phases is nearing a peak. High-power 3-phase motors (used in industrial applications) and things like 3-phase welding equipment therefore have <u>even</u> power output
- Four phases would not significantly improve things but would add a fourth wire, so 3-phase is the natural settling point

- AC has at least three advantages over DC in a power distribution grid:

1. Large electrical generators happen to generate AC naturally, so conversion to DC would involve an extra step.
2. Transformers must have alternating current to operate, and we will see that the power distribution grid depends on transformers.
3. It is easy to convert AC to DC but expensive to convert DC to AC, so if you were going to pick one or the other AC would be the better choice.
4. AC has less copper loss (I^2R Joule heat) than DC and it's easier and cheaper to produce too (high voltage transmission)

- Advantages of DC over AC

- reduction of noise and a reduction of danger. DC will not interfere with wireless devices or create that annoying hum in sound devices and is far less lethal than AC current.

- Energy can be stored

- thinner conductors can be used since HVDC does not suffer from the skin effect

Advantages of HVDC over AC transmission

The advantage of HVDC is the ability to transmit large amounts of power over long distances with lower capital costs and with lower losses than AC. Depending on voltage level and construction details, losses are quoted as about 3% per 1,000 km.[14] High-voltage direct current transmission allows efficient use of energy sources remote from load centers.

In a number of applications HVDC is more effective than AC transmission. Examples include:

- Undersea cables, where high capacitance causes additional AC losses. (e.g., 250 km Baltic Cable between Sweden and Germany,[15] the 600 km NorNed cable between Norway and the Netherlands, and 290 km Basslink between the Australian mainland and Tasmania[16])
- Endpoint-to-endpoint long-haul bulk power transmission without intermediate 'taps', for example, in remote areas
- Increasing the capacity of an existing power grid in situations where additional wires are difficult or expensive to install
- Power transmission and stabilization between unsynchronised AC distribution systems
- Connecting a remote generating plant to the distribution grid, for example Nelson River Bipole
- Stabilizing a predominantly AC power-grid, without increasing prospective short circuit current
- Reducing line cost. HVDC needs fewer conductors as there is no need to support multiple phases. Also, thinner conductors can be used since HVDC does not suffer from the skin effect
- Facilitate power transmission between different countries that use AC at differing voltages and/or frequencies
- Synchronize AC produced by renewable energy sources

The disadvantages of HVDC are in conversion, switching, control, availability and maintenance.

- HVDC is less reliable and has lower availability than AC systems, mainly due to the extra conversion equipment. Single pole systems have availability of about 98.5%, with about a third of the downtime unscheduled due to faults. Fault redundant bipole systems provide high availability for 50% of the link capacity, but availability of the full capacity is about 97% to 98%.[17]
- The required static inverters are expensive and have limited overload capacity. At smaller transmission distances the losses in the static inverters may be bigger than in an AC transmission line. The cost of the inverters may not be offset by reductions in line construction cost and lower line loss. With two exceptions, all former mercury rectifiers worldwide have been dismantled or replaced by thyristor units. Pole 1 of the HVDC scheme between the North and South Islands of New Zealand still uses mercury arc rectifiers, as does Pole 1 of the Vancouver Island link in Canada. Both are currently being replaced – in New Zealand by a new thyristor pole and in Canada by a three-phase AC link.
- In contrast to AC systems, realizing multiterminal systems is complex, as is expanding existing schemes to multiterminal systems. Controlling power flow in a multiterminal DC system requires good communication between all the terminals; power flow must be actively regulated by the inverter control system instead of the inherent impedance and phase angle properties of the transmission line.[18] Multi-terminal lines are rare. One is in operation at the Hydro Québec – New England transmission from Radisson to Sandy Pond.[19] Another example is the Sardinia-mainland Italy link which was modified in 1989 to also provide power to the island of Corsica.[20]
- High voltage DC circuit breakers are difficult to build because some mechanism must be included in the circuit breaker to force current to zero, otherwise arcing and contact wear would be too great to allow reliable switching.
- Operating a HVDC scheme requires many spare parts to be kept, often exclusively for one system as HVDC systems are less standardized than AC systems and technology changes faster.

Transmission substation

- substation uses large transformers to convert the generator's voltage (which is at the thousands of volts level) up to extremely high voltages for long-distance transmission on the transmission grid.
- . Typical voltages for long distance transmission are in the range of 155,000 to 765,000 volts in order to reduce line losses (low voltage requires a higher current and a higher voltage requires a lower current.)
- transmission distance is about 300 miles

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Ohm's Law

- $V = IR$
- $P = VI$ (power produced by generator)
- $P = I^2R$ (power dissipated in the power line)

low voltage requires a higher current and a higher voltage requires a lower current

High Power Transmission Line

- All power towers like this have three wires for the three phases. Many towers, like the ones shown above, have extra wires running along the tops of the towers. These are ground wires and are there primarily in an attempt to attract lightning.

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Power substation

- It has transformers that step transmission voltages (in the tens or hundreds of thousands of volts range) down to distribution voltages (typically less than 10,000 volts).

- It has a "bus" that can split the distribution power off in multiple directions.

- It often has circuit breakers and switches so that the substation can be disconnected from the transmission grid or separate distribution lines can be disconnected from the substation when necessary.

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Distribution Bus

- The bus distributes power to two separate sets of distribution lines at two different voltages. The smaller transformers attached to the bus are stepping the power down to standard line voltage (usually 7,200 volts) for one set of lines, while power leaves in the other direction at the higher voltage of the main transformer. The power leaves this substation in two sets of three wires, each headed down the road in a different direction

Distribution Bus

- In the typical scene pictured on the right, the three wires at the top of the poles are the three wires for the 3-phase power. The fourth wire lower on the poles is the ground wire. In some cases there will be additional wires, typically phone or cable TV lines riding on the same poles.


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Regulator Bank

- You will also find regulator banks located along the line, either underground or in the air. They regulate the voltage on the line to prevent undervoltage and overvoltage conditions.

Regulator bank

- Up toward the top are three switches that allow this regulator bank to be disconnected for maintenance when necessary:


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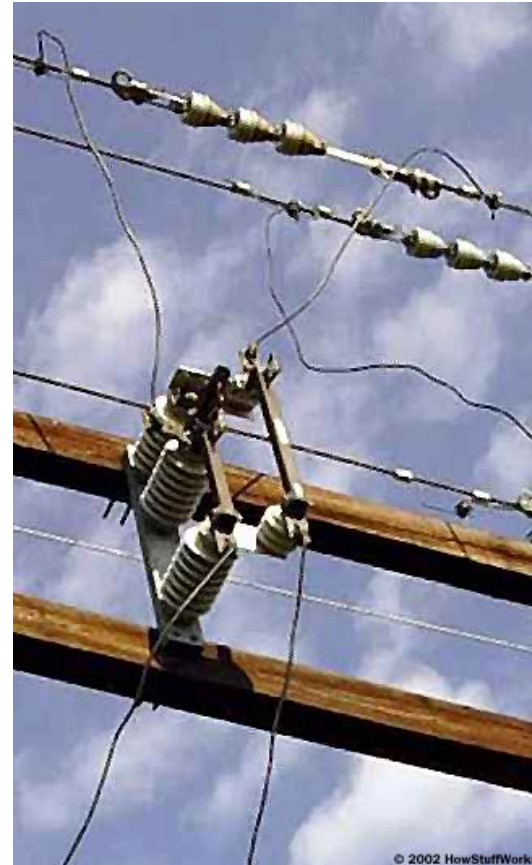
Neighborhood Bus line

- At this point, we have typical line voltage at something like 7,200 volts running through the neighborhood on three wires (with a fourth ground wire lower on the pole):

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Tap

- A house needs only one of the three phases, so typically you will see three wires running down a main road, and **taps** for one or two of the phases running off on side streets. Pictured below is a 3-phase to 2-phase tap, with the two phases running off to the right

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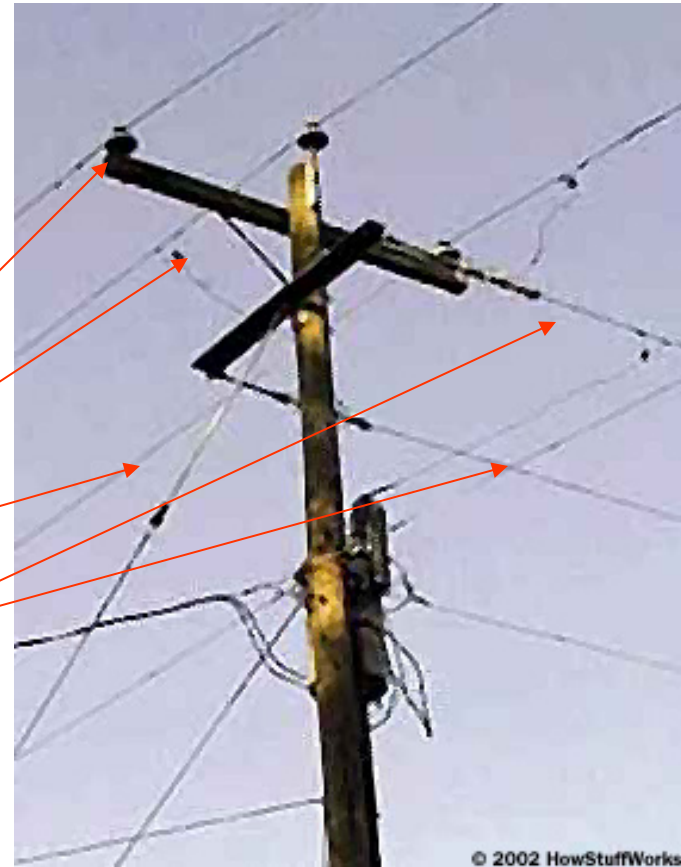
2 phase to 1 phase tap

- Here is a 2-phase to 1-phase tap, with the single phase running out to the right:


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- And finally we are down to the wire that brings power to your house! Past a typical house runs a set of poles with one phase of power (at **7,200 volts**) and a ground wire (although sometimes there will be two or three phases on the pole, depending on where the house is located in the distribution grid). At each house, there is a **transformer drum** attached to the pole, like this:

- **underground** and there are green transformer boxes at every house or two


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Transformer

- The transformer's job is to reduce the 7,200 volts down to the **240 volts** that makes up normal household electrical service. Let's look at this pole one more time, from the bottom, to see what is going on:
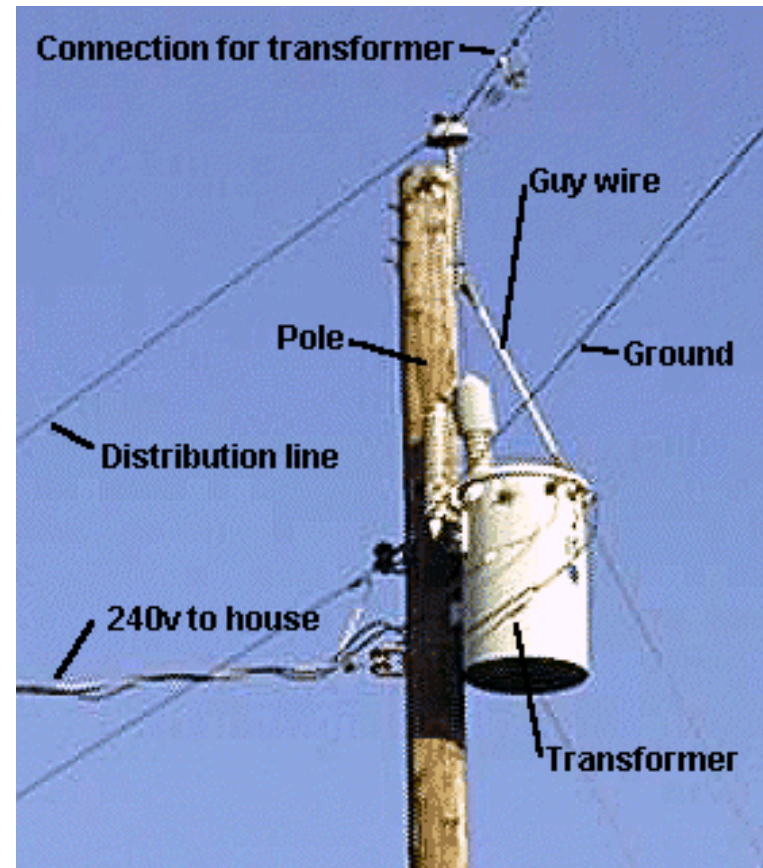
- There is a bare wire running down the pole. This is a grounding wire. Every utility pole on the planet has one. If you ever watch the power company install a new pole, you will see that the end of that bare wire is stapled in a coil to the base of the pole and therefore is in direct contact with the earth, running 6 to 10 feet (1.8 to 3 m) underground. It is a good, solid ground connection. If you examine a pole carefully, you will see that the ground wire running between poles (and often the guy wires) are attached to this direct connection to ground.
- There are two wires running out of the transformer and three wires running to the house.
The two from the transformer are insulated, and the third one is bare. The bare wire is the ground wire. The two insulated wires each carry 120 volts, but they are 180 degrees out of phase so the difference between them is 240 volts. This arrangement allows a homeowner to use both 120-volt and 240-volt appliances. The transformer is wired in this sort of configuration:
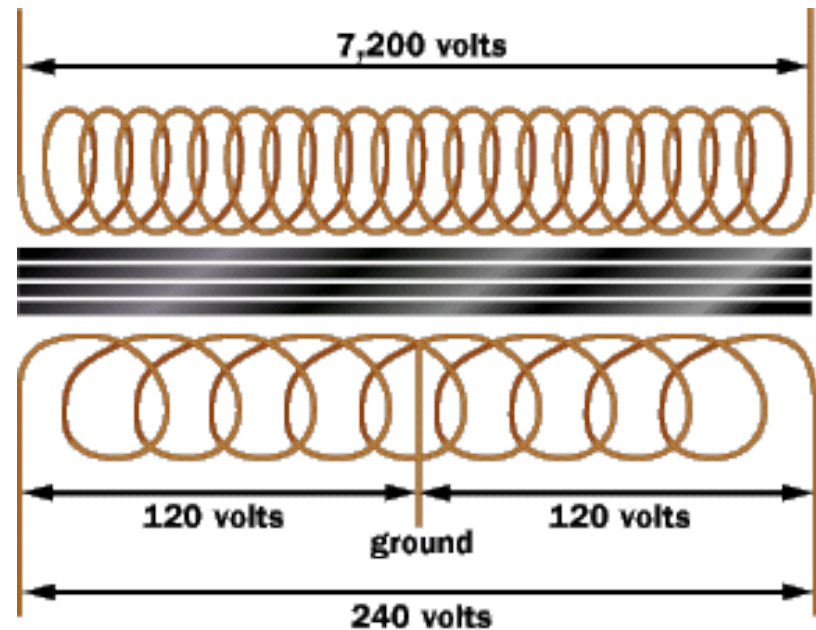
Meter

- The 240 volts enters your house through a typical **watt-hour meter** like this one:

Fuses and Circuit Breakers

- Fuses and circuit breakers are **safety devices**. Let's say that you did not have fuses or circuit breakers in your house and something "went wrong." What could possibly go wrong? Here are some examples:

- A fan motor burns out a bearing, seizes, overheats and melts, causing a direct connection between power and ground.

- A wire comes loose in a lamp and directly connects power to ground.

- A mouse chews through the insulation in a wire and directly connects power to ground.

- Someone accidentally vacuums up a lamp wire with the vacuum cleaner, cutting it in the process and directly connecting power to ground.

- A person is hanging a picture in the living room and the nail used for said picture happens to puncture a power line in the wall, directly connecting power to ground.

circuit breaker panel

Fuses and Circuit Breakers

- **Fuse** uses a thin piece of foil or wire quickly vaporizes when an overload of current runs through it

- **circuit breaker** uses the heat from an overload to trip a switch, and circuit breakers are therefore resettable.

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Fuses and Circuit Breakers

- The main breaker lets you cut power to the entire panel when necessary. Within this overall setup, all of the wires for the different outlets and lights in the house each have a separate circuit breaker or fuse:

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Outlet

- If the circuit breaker is on, then power flows through the wire in the wall and makes its way eventually to its final destination, the **outlet** or **Light switch**

Electrical Power

- Energy dissipated in an electrical or electronic circuit or device per unit of time. The electrical energy supplied by a current to an appliance enables it to do work or provide some other form of energy such as light or heat. Electric power is usually measured in Watts, kilowatts (1,000 watts), and megawatts (1,000,000 watts). The amount of electrical energy used by an appliance is found by multiplying its consumed power by the length of time of operation. The units of electrical energy are usually watt-seconds (joules), watt-hours, or kilowatt-hours. For commercial purposes the kilowatt-hour is the unit of choice.

Conserving Electricity

Unit of Electrical Power?

$$Energy = Work = \int_{x_1}^{x_2} F \bullet dx \qquad \text{Nm = J (Joul)}$$

PE = negative work; KE = positive work; other forms of energy = RF, heat, light etc..

Power = Energy/time

Watts= J/ sec

Rating Your Appliance

The electric company actually bills you for the amount of energy that you use. But your appliances are rated by the amount of power that they use. You can easily find the amount of energy used by solving the power equation for energy. You get:

Energy = Power x time

units of kilowatt hours

Calculating your electric bill

- Now all you need to know is how much your electric utility or company charges you for energy. This will usually be in the units of $ per kw hr. Then you just multiply the kw hrs by the $ per kw hr, and you end up with the cost for that appliance for the amount of time that you have used it.

Sample Calculations

- Let's say that you found that your microwave oven has a power rating of 120 watts. To convert that into kilowatts you must divide by 1000 as follows. Place this number in the table.

$$120\text{w}\left(\frac{1\text{kw}}{1000\text{w}}\right)=0.12\text{kw}$$

Sample Calculations

- You estimate that your microwave oven is used 3 hours per day. Multiply by 365 days per year to get the hours used per year as follows:

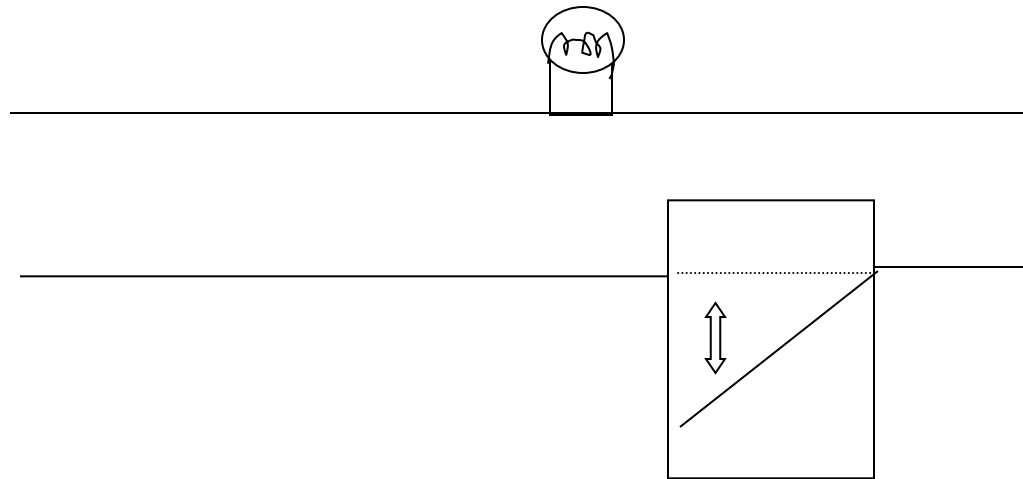$$\frac{3\,hr}{day}\left(\frac{365\,days}{1\,yr}\right) = 1095\ hr/year$$

Sample Calculations

- Now you can calculate your energy consumption by multiplying the power in kw times the time used in hr/yr as follows:
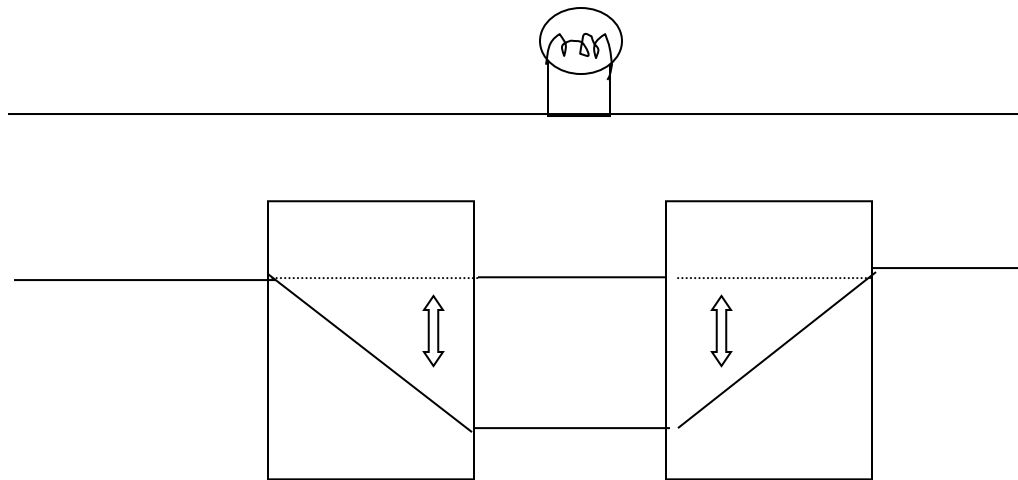
$$Energy = P\ t$$

$$E = (0.12\ kw)(1095\ hr/yr) = 131.4\ kw\ hr/yr$$

$$Cost = (131.4\ kw\ hr/yr)(0.077\ \$/kw\ hr) = \$10.12\ /\ yr$$

Single switch wiring

Two switches wiring

Electrical Wiring

SwitchLinc 2-Way Wiring Diagram
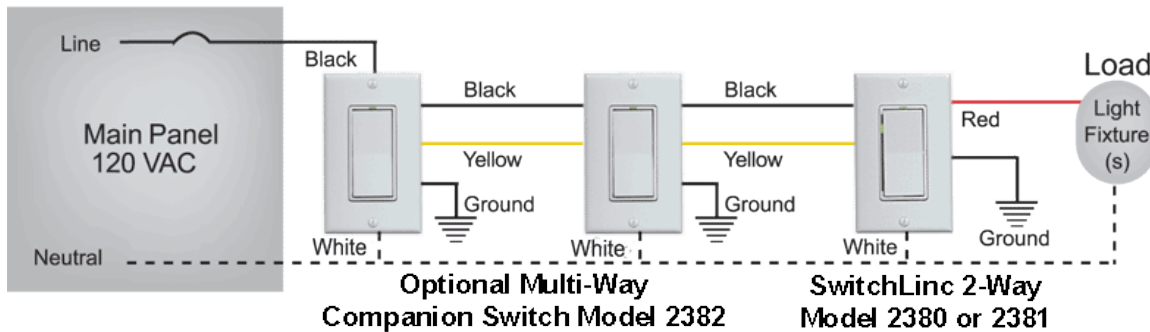(One switch controlling the load)

Line

Main Panel
120 VAC

Neutral

cap this lead

Black

Red

Yellow

White

Ground

Load
Light
Fixture
(s)

SwitchLinc 2-Way
Model 2380 or 2381
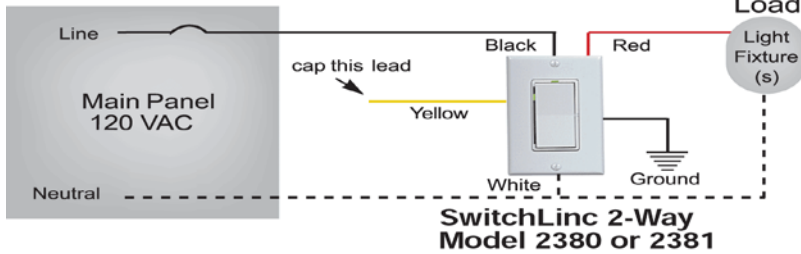
Using 2 SwitchLincs to Create a Virtual 3-Way Circuit

Line

Main Panel
120 VAC

Neutral

Black

Red

Yellow

White

Ground

Cap this lead

A

Light
Fixture
A

Neutral

Load

Black

Red

Yellow

White

Ground

Cap this lead

B

Light
Fixture
B

Neutral

Load

SwitchLinc 2-Way
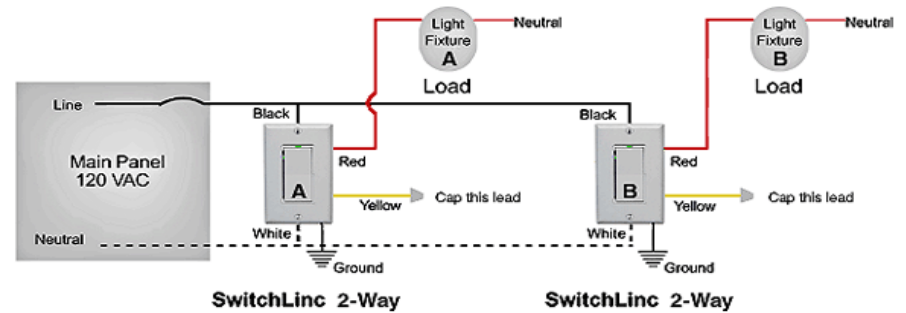
SwitchLinc 2-Way

Light fixtures A & B will work as if they were part of the
same 3-way circuit. Either switch A or B can be used to
turn on/off (dim/brighten for dimmers) lights A & B even
though there is no "traveller" wire.

SwitchLinc Multi-Way Wiring Diagram
(Two or more switches controlling the load)

Line

Main Panel
120 VAC

Neutral

Black

Black

Black

Red

Load
Light
Fixture
(s)

Yellow

Yellow

Ground

Ground

Ground

White

White

White

Optional Multi-Way
Companion Switch Model 2382

SwitchLinc 2-Way
Model 2380 or 2381

Assignment

- **Can you connect a switch to a light fixture? (10%)**
- **If you have more than one entrance to a room, it's handy to have more than one switch to turn the lights on and off.**
- **Can you figure out any other ways of connecting two switches?   (20%)**
- **Can you explain the way the current flow across the switches?   (20%)**

- **Can you do the three switches configuration?   (20%)**
- **How many different ways of wiring can you come up? (20%)**
- How to connect multiple light fixture to single or multiple switches? (10%)
- Any other configuration you can think of connecting the wire in your house safely? (extra credit (50%)