CLEAN ENERGY INSTITUTE
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Circuit types for Solar Energy

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Overview:

The purpose of this talk is to inform and remind the students beginning to construct solar panel projects how circuits behave so they can appropriately wire up the panels. This is suitable for high school students.

Materials:

None required, this can be just a 'chalk talk', though having some visuals may be desired. In this case:

- Incandescent flash-light bulbs (at least 2, more can be used)
- Power supply (I recommend at least two D or C cell batteries, more can be used)
- Connecting wire (will need at least 4, depends on the components from earlier)

Background:

before activity:

Electricity, or a flow of electrons, is typically encountered in two forms:

- Direct Current (DC) where the electrons flow from the 'hot' or supply to ground which is typically seen in small electronics and is delivered in most photovoltaic cells. It is what will be examined in today's investigation, and as such will be focused on in this discussion.
- Alternating Current (AC) where the electron flow is constantly switching. This form is the typical supply method for the US and several other countries, with the US delivering 120 volts at ~60 Hz (so the current switches 120 times per second aka it reverses, or cycles, 60 times per second) in typical household electrical systems.

To determine the amount of power or current within a (simple) circuit, Ohm's law can be used. Ohm's law states that the **voltage** (V, measured in volts, which is the difference in potential across two points) is equal to the **current** (I, measured in amps, which is the flow of the electric charge carried through the electrons) times the **resistance** (R, measured in ohms).

$$V = IR$$

This can be used, then, to determine the amount of work, or **power**, is needed to achieve a task, such as light a light bulb or spin a motor. This value (P, measured in watts) is equal to an electric current (I from before) made up of a charge (Q, measured in coulombs) passing through a voltage every t seconds.

$$P = \frac{VQ}{t} = IV$$

The circuit design designates the way that the current and voltage behave, and thus consideration should be given to what application the circuit is attempting to achieve.

For wiring simple circuits, there are two common choices, either wiring the circuits in parallel or in series. Many large scale circuits (such as a house or energy grid) are made up of combinations of these simple circuits in order to deliver power. There are several typical components for these circuits (wires, resistors, capacitors, inductors, diodes, etc.) which can be put into various configurations for various purposes. The voltage and current for these systems (at least in the simple cases for the demonstration today) can be readily calculated, and using Ohm's law from before the power available can be determined. In a **series** circuit, the current is equal across the entire circuit. In the case of multiple power supplies (many different solar cells or batteries) the total voltage of the system will be additive (aka: $V_{tot} = V_1 + V_2 + V_n$) as will the resistance of the system (aka: $R_{tot} = R_1 + R_2 + R_n$). This sort of circuit can be seen in several applications, for example a 12 volt battery (for a car) is typically made of 6, 2 volt cells wired together. This type of circuit has only one path for the current to flow and as such if one piece is disconnected the entire circuit is open (or dark) as in older holiday lights where if one light burns out the entire strand is dark unless the proper light bulb is replaced. In a **parallel** circuit, the current across each resistor (such as a light bulb, motor, etc.) can be determined through Ohm's law: $I_{total} = V(R_1^{-1} + R_2^{-1} + R_n^{-1})$ and the voltage is constant through the entire circuit, in this case the total resistance for the system can be calculated as the reciprocal sum of the reciprocal individual resistances: $R^{-1}{}_{Total} = R_1^{-1} + R_2^{-1} + R_n^{-1}$. Batteries attached in this method will be required to supply less current (~N^{-1} amperes per battery where N is the number of batteries or supplies) which can allow them to last longer than a battery in a series circuit, however upon adding additional load the batteries will increase the current they are providing to keep the voltage constant resulting in them running down faster than if there was less of a load on the circuit. Parallel wiring also will allow various parts to be disconnected without bringing down the entire circuit as long as there is still a path for the electron flow (much like turning off a light switch does not turn off an entire house).

Previous discussion has been centered around batteries and incandescent light bulbs as the sources and loads, what happens when we switch to PV cells and LEDs? Unlike batteries, PV cells don't 'run down' with continued usage as they are able to convert light into energy. In the case of these cells they will provide a voltage (which depends on the material used for the cells) and a current dependent on the size (surface area) of the cell. Due to this when the cells are wired in series the circuit will have additive voltage, but less current (and care should be taken here that the provided current of the cells are the same as wiring cells of differing current ratings will cause the circuit to only deliver the lowest). When the cells are wired in parallel the current of the cells will be additive, but the voltage will be constant, and care must be taken here that the cells have the same voltage or there will be inefficiencies, or even damages to the circuit. Typically when putting together a circuit the voltage and current are tuned for the application. An example of why this tuning is necessary can be seen if we switch to LEDs in our simple circuits. LEDs, while significantly more energy efficient than the incandescent light bulbs (less energy wasted through heat generation) they require specific operating voltages in order to work. Depending on the color of the LED (resulting from the material used to make them) differing voltages are needed to activate them, and they are unable to use higher voltages, unlike the incandescent bulbs which can take a range of voltages, so when determining the circuit one needs to keep in mind the intended application.

When changing from simple light bulbs to something like an electric motor, additional concerns need to be taken into consideration. This would be in cases where we are powering an electric pump, car, or other applications. Selecting the proper method for wiring together several PV cells to power such a device can be difficult. An ideal (permanent magnet DC) motor acts as a resistor and a voltage source wired in series. This is because the windings of the motor will give resistance, and the motor will generate voltage when it is turning (whether it is being driven from the electric current or by the mechanical energy of the motor and connected device), this voltage is variable with the speed at which the motor is turning and 'fights' the flow of current in the electric motor. This generated voltage is commonly referred to as 'back EMF'. As the motor spins faster this back EMF becomes greater causing a reduction in the torque of the motor (the torque is produced when current flows through the motor at the shaft), thus at a fixed voltage the torque and the speed of the motor are inversely proportional. For a fixed load, an increase in the voltage will render an increase in the speed, thus a difficult balancing act must be performed to both ensure that the voltage of the motor is high enough that it achieves a useful speed, but also that there is enough current present for the motor spin up with the load that it has attached (commonly a solar racer in these cases). The 'best' method for wiring several PV cells up to a motor will depend on the motor and PV available, also other factors such as the gearing of the motor and the weight of the attached vehicle will be important when deciding how to construct it.

Procedure:

for visual aid:

1. Wire the light bulbs in series.
    1. If using multiple light bulbs:
        1. Start with one bulb and then add the other, call attention to the decrease in light across the bulbs as the voltage is shared.
        2. Remove one light bulb (have it 'burn out') and show how the entire circuit goes dark.
    2. If using multiple batteries:
        1. Start with one, and then add the other, call attention to the increase in light as the voltage increases.
        2. Disconnect one battery from the circuit show that the entire circuit goes dark.
2. Wire the light bulbs in parallel:
    1. If using multiple light bulbs:
        1. Start with one bulb and then add the other, call attention to fact that the lights do not lose brightness.
        2. Remove one light bulb (have it 'burn out') and show how the entire circuit stays lit.
    2. If using multiple batteries:

1. Start with one, and then add the other, call attention to the fact that the lights do not increase in brightness.
2. Disconnect one battery from the circuit show that the entire circuit remains lit.

Post Presentation/ Discussion:
Some food for thought/ possible discussion questions for people in attendance:

1. If one were to think about constructing an electrical grid what are some of the considerations that should be taken into account?
2. What potential issues could arise from having several power sources with varying amounts of power production (e.g. solar/ wind sources) in a circuit? What are some methods to limit some of these issues?