Power and Power Measurement

ENGR 10 – Intro to Engineering
College of Engineering
San Jose State University
(Ping Hsu and Ken Youssefi)
Power is the rate at which work is done.

Electric power is the rate at which electric energy is transferred by an electric circuit.

Mechanical power is the combination of forces and movement. Force x velocity or torque x rotational speed.

Hydraulic, chemical, thermal, nuclear, ....
In the following circuit, energy is carried by the wires from the battery to the light bulb.

Power (J/s or Watt) = Voltage (Volts) x Current (Amperes)
Mechanical Power (Hydraulic)

Hand-pump

Sourcing power

Low pressure

Power flow

Hydraulic Motor

Receiving power

High pressure
Analogy

**Electrical Circuit**
- Voltage (V)
- Current (A)
- (Charge flow rate)

**Hydraulic system**
- Pressure (psi)
- Fluid flow rate (gal/sec)

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**Diagram**

- Electrical Circuit: A diagram of a simple circuit with a battery, light bulb, and wires, illustrating the flow of current.
- Hydraulic system: A diagram of a hydraulic system with a pump and a motor, illustrating the flow of fluid.

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Ohm’s Law

If the ‘circuit’ is a simple resistor, the voltage, current, and the resistance of the resistor is related by **Ohm’s Law**:

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

Resistance is measured in Ohm (\( \Omega \))

In the above circuit, \( V = 12 \) volts, \( R = 3 \Omega \)

What is the current \( I = ? \)

\[ I = \frac{V}{R} = \frac{12}{3} = 4 \text{ amps} \]
"Open Circuit" Case

Power = $V \times I = V \times 0 = 0$

"Open Circuit" Case

Power = Pressure $\times 0 = 0$

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Clicker Question

1 - From the values given in the diagram below, what is the resistance (R) of an IPod?

A. 0.3 Ω
B. 3.1 Ω
C. 0.03 Ω
D. 0.9 Ω
E. 30 Ω

You receive 10 points for answering all three questions (right or wrong), you also get 5 points for answering each question correctly. So if we have three iClicker questions in a session and you answer all questions correct you receive 25 points.
Basic Principles of Electric Circuits

Relationships between a simple circuit’s parameters

\[ V = I \times R \]
\[ P = V \times I = \frac{V^2}{R} \]
Energy Source in a Circuit

Power supplies are specified by Voltage and Current, 12 V DC at 300 mA (rated current)

The output voltage from a typical power source stays the same regardless of its output current \(I\) so long as it is less than the sources’ rated current value. Within this range, the output current \(I\) only depends on the resistance \(R\) of the equipment (i.e., the load) connected to the source.

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

and the power is \[ P = V \times I = \frac{V^2}{R} \]

The smaller the resistance is, the higher the output current (and the power), but \(V\) stays the same as long as the current is less than rated current of the source.
Load down effect

If an equipment tries to draw higher than rated current of the source (having a really small load resistance). The voltage will sag. This condition is called “Load down”.

No load

Normal load

Over load (Voltage is loaded down.)
The maximum output power of a source can be determined by varying load resistance from high to low.

\[ V = IR \]

<table>
<thead>
<tr>
<th>Voltage (Volt)</th>
<th>Current (Amp)</th>
<th>Power ((P = VI))</th>
<th>Equivalent loading resistance (V/I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>infinite (open circuit)</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>20</td>
<td>5 (\Omega) (Light load)</td>
</tr>
<tr>
<td>9.8</td>
<td>4</td>
<td>39.2</td>
<td>2.45 (\Omega) (Normal)</td>
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<tr>
<td>9.4</td>
<td>5</td>
<td>47</td>
<td>1.88 (\Omega) (Normal)</td>
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<tr>
<td>8.5</td>
<td>6</td>
<td>51</td>
<td>1.41 (\Omega) (MAX POWER)</td>
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<tr>
<td>7.2</td>
<td>7</td>
<td>50.4</td>
<td>1.03 (\Omega) Over load</td>
</tr>
<tr>
<td>5.2</td>
<td>8</td>
<td>41.6</td>
<td>0.65 (\Omega) Over load</td>
</tr>
<tr>
<td>3.0</td>
<td>9</td>
<td>27</td>
<td>0.33 (\Omega) Over load</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0 (shorted)</td>
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</tbody>
</table>

Normal operating range. The voltage is loaded down. Maximum output power of the source. Maximum output current.
Voltage vs. current and Power vs. current of a source

Voltage is “loaded down”

Maximum power

Maximum power load current

Load Current (Amp)

Power (W)

Light

Load Current

Heavy

Voltage

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Key Concepts

- A source’s output voltage drops when ‘too much’ current is drawn from it (namely, the “load down” effect.)

- While it is possible to increase output current even when the voltage is loaded down, the output power (voltage x current) stops increase due to decreasing voltage.

- A source outputs its maximum power at a specific output voltage and current. (A very important parameter for characterizing solar cell.)
Clicker Question

2 - Which of the following statements is **false**?

A) A source’s voltage varies with output current.
B) A source’s current varies with output power.
C) A source’s output current varies with load.
D) A source’s maximum output power is its maximum output voltage times its maximum output current.

\[ P_{\text{max}} = V_{\text{max}} \times I_{\text{max}} \]
To the circuit, the solar cell is an energy source.

A variable resistor (potentiometer or POT) is used as the load in experimentally determining the V vs. I curve of a solar cell.

The same procedure is used in the wind turbine experiment.
By changing the POT resistance, the current drawn from the solar cells can be varied.

The output voltage, current, and power is recorded at each current level, from high to low.

A voltage vs. current and power vs. current can be plotted from the data.
Solar lab components

Power meter

Solar meter measures solar intensity

Solar cells

Your wire connection (choose a pair)

Motor, gearhead and pulley assembly

Potentiometer (Pot)

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Solar cell voltage, current, and power output

- For most applications (i.e. laptop computer), we only draw as much current (or power) as needed from the source.

- For solar energy generation, however, we want to draw as much power as it can generate. Therefore, it is important to find this maximum power point.
# Data Collection Form

## A. Single Cell Measurements

<table>
<thead>
<tr>
<th>Voltage V</th>
<th>Current mA</th>
<th>Power W</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
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</table>

## B. Serial Cell Measurements

<table>
<thead>
<tr>
<th>Voltage V</th>
<th>Current mA</th>
<th>Power mW</th>
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<tbody>
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</table>

## C. Parallel Cell Measurements

<table>
<thead>
<tr>
<th>Voltage V</th>
<th>Current mA</th>
<th>Power mW</th>
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</thead>
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</tbody>
</table>

## D. Weight Lifting Experiment

Circle the selected setup below:

1. Cell Combination: (a) 4 Series (b) 4 Parallel (c) 2S/2P
2. Gear Rotation: (a) 30:1 (red) (b) 190:1 (gray)
3. Spool Diameter: (a) Smaller (b) Larger
4. Selected Weight:
5. Power at 15 sec:
6. Height at 15 sec:

Write a tech. report on this project as specified in lab guidelines and include:
- Plots of V vs. I and P vs. I for all cell combinations tested.
- Define:
  1. Input/output energy per Lab Guidelines
  2. Does the gear-head assembly affect performance?
  3. Discuss the maximum power usage of the weight lifting setup.
In an energy conversion process, the ratio between the desired output power and the input power is the **efficiency** of this process.

\[
\text{Efficiency} = \frac{\text{output power}}{\text{input power}}
\]

In the process, some power is inevitably converted to a form that we don’t care about (such as heating of the panel).

**Solar Lab:** Solar to Electrical energy efficiency and Solar or Electrical to Mechanical energy efficiency.
Solar Cells in series

Two or more cells can be connected in a cascade configuration (in \textit{series}).

- The combined output \textit{voltage} is the sum of cells output voltages.
- The combined output \textit{current} (and the current rating) is the same.
- The combined \textit{power} (and the power rating) is the sum of the individual cells’ power.

\[
P = (V_1 + V_2)I_1 = (V_1 + V_2)I_2 = (V_1 + V_2)I
\]
Solar Cells in parallel

Two or more cells can be connected in \textit{parallel}.

- The combined output current (and current rating) is the sum of cells output current.
- The combined output voltage is the same.
- The combined power (and power rating) is the sum of the individual cells’ power.

\[ P = V(I_1 + I_2) = VI \]

\[ I = I_1 + I_2 \]
Series and Parallel Connection

**Series*** --- Voltage is the sum and current (and current capacity) is the same.

\[
\begin{align*}
\text{Cell 1} & \quad \text{Cell 2} \\
I_1 & \quad V_1 \\
& \quad + \\
& \quad + \\
& \quad - \\
& \quad + \\
& \quad - \\
& \quad I = I_1 = I_2 \\
\end{align*}
\]

**Parallel*** --- Voltage is the same and current (and current capacity) is the sum.

\[
\begin{align*}
\text{Cell 1} & \quad \text{Cell 2} \\
I_1 & \quad I_2 \\
& \quad V = V_1 + V_2 \\
\end{align*}
\]
Solar Cells in parallel

Example: A solar cell is rated 3 volts @ 3 amp. How many cells are required to power a circuit that needs 3 volts @ 5 amp?

Answer: Two cells in parallel. This circuit provides 3V and has a rating of 6 amps (therefore, it can certainly supply 5 amps).

\[ I = I_1 + I_2 \]

\[ I_1 \quad \text{Cell 1} \]
\[ I_2 \quad \text{Cell 2} \]

Same V

motor

Note: A source rated 3v @ 3 amp outputs 3v regardless of how much current is drawn from it by the load as long as it is below 3 amp.
Example Question

There are 2 solar cells. Each one is rated 1 volt @ 2 Amp. To power a load that needs 1 volt @ 3 Amp, how should these two cells be connected?

a) In parallel.  ✓
b) In series.
c) back-to-back
d) by glue
e) there is no way.
There are 2 solar cells. Each one is rated 3 volt @ 2 Amp. To obtain output of 4 volt and 4 Amp, how should these two cells be connected?

a) In parallel.  
Parallel: 3V, 4A

b) In series.  
Series: 6V, 2A

c) back-to-back

d) by glue

e) there is no way.
Example Question – 4 Cells

There are 4 solar cells. Each one is capable of output 1 volt voltage and 2 Amp current. To obtain output 2 volts and 8W, how should these 4 cells be connected?

a) All in parallel.
b) All in series.
c) make two 2-in-parallel sets and connect these two sets in series
d) 3 in series and 1 is not connected
e) 2 in series and 2 are not connected.

Series --- Voltage is the sum and current is the same.
Parallel --- Voltage is the same and current is the sum

What is the output current in this case?
(a) 1A  (b) 2A  (c) 3A  (d) 4A  (d) 5A
Answer to 4 Cells Question

Where $I = 2$, $V = 1$. The total output current is $I_o = 2 \times 2 = 4$ Amp
Output voltage is $V_o = 2V = 2$ volts
Output power is $I_o \times V_o = 4 \times 2 = 8W$. 

![Diagram of a circuit with four cells connected in series](image)
Alternate answer to 4 Cells Question

The same output voltage, current, and power can be achieved by connection two 2-in-series sets first and then connect these two sets in parallel.

\[
\text{Cell 1} \quad \text{Cell 2} \quad \text{Cell 3} \quad \text{Cell 4}
\]

\[
I_1 = I_2 = I_3 = I_4 = I
\]

\[
V_1 = V_2 = V_3 = V_4 = V
\]

\[
I_0 = 2I
\]

\[
V_0 = 2V
\]

Motor
Pros and Cons of Electrical Power

Pros: Convenience for transmission and distribution, clean, easy to control, easily transformed into many forms of power (mechanical, heat, light, etc.)

Cons: Requiring power conversion equipment (solar panels, heaters, motors, etc.). There is always some conversion loss.

39% of the power used in the US is converted into electric form first.

The pros clearly outweighs the cons.
The solar panel converts the power from sunlight to electric power. If 100% of the power from the sun is converted, the following equality holds.

\[ P_{\text{sun}} = P_e = V*I \]

In reality, however, only a fraction of the sun power (typically 15%) can be converted.
Power from the sun on earth at noon is about 1350 W/m². For a solar panel of the size of 2 m², with an efficiency of 15%, the output power is

$$1350 \text{ W/m}^2 \times 2 \text{ m}^2 \times 0.15 = 405 \text{ W}.$$ 

At this output power level, if the output voltage of the panel is 50 V, the output current is 8.1 amp.