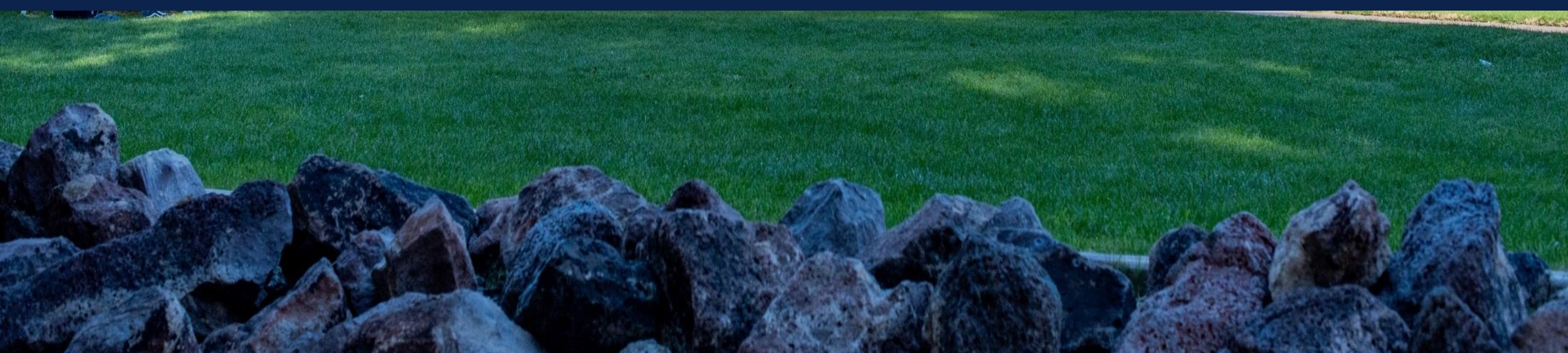
NSF NRT-InFEWS: Indigenous Food, Energy, and Water Security and Sovereignty Presents:

Food, Energy and Water (FEWS) Learning Modules

June 2021



Electrical Design Basics and Considerations

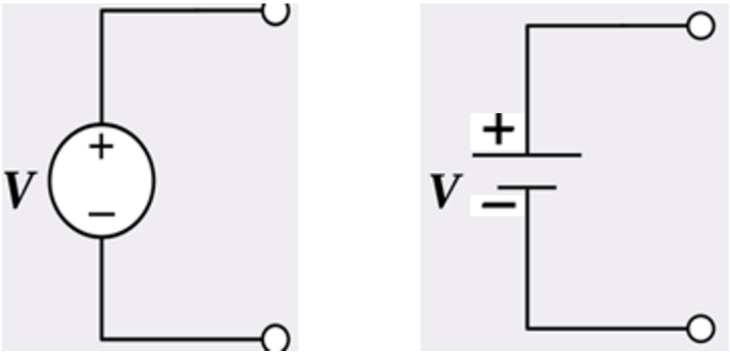
Presented by Frances Willberg

Please have a calculator on hand (phone, computer, handheld, etc)

Voltage

Voltage (Volts) is a quantity that measures electrical potential in an electrical system. The symbol (V) is used to represent voltage.

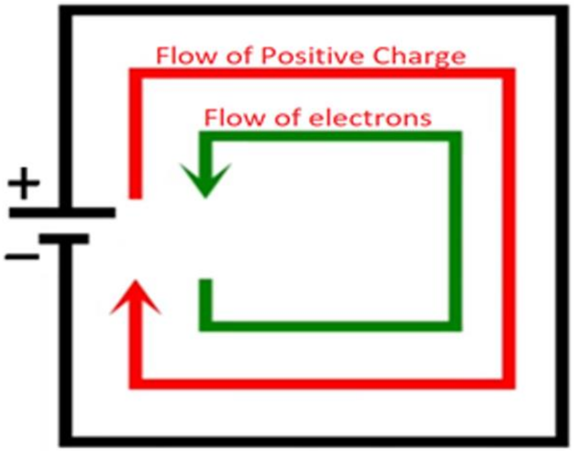
Batteries and energy sources (PV) are viewed as voltage sources.

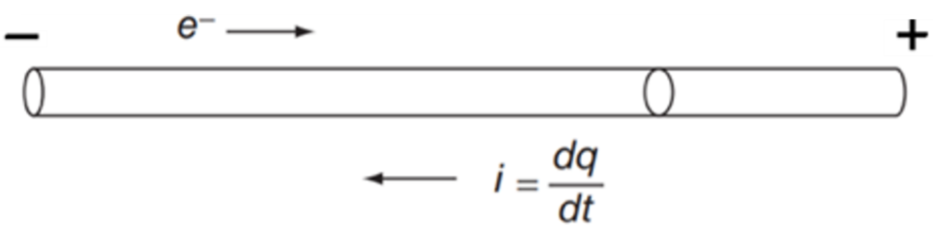


Current

Current (Amps, A) represents the rate of electron charge flow. The symbol (I) is used to represent current.

By convention, negative charges moving in one direction constitutes a positive current flow in the opposite direction





Resistance

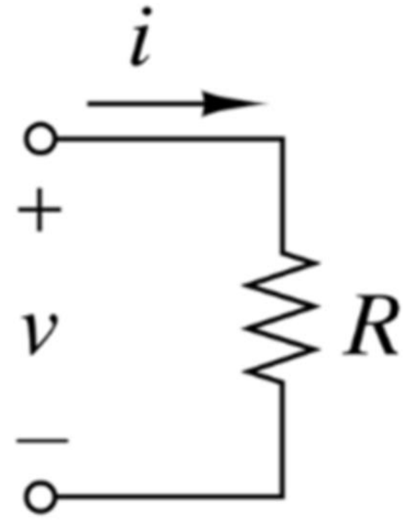
Resistance (Ohms, Ω) is the opposition to the flow of current. The symbol (R) is used to represent resistance.

- Ohm's Law:

$$V = IR$$

$$I = \frac{V}{R}$$

$$R = \frac{V}{I}$$

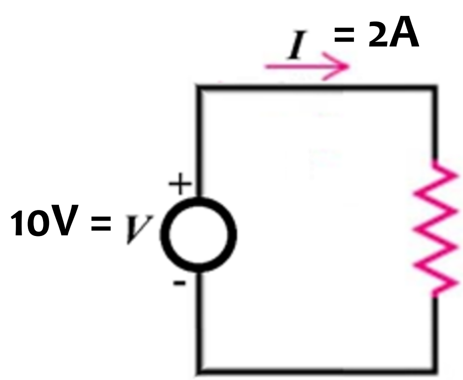


Ohm's Law Example

Solve for the unknown quantity

Solution: $\boldsymbol{Ohm's\ Law}: V = IR$

V = Voltage (V)
I = Current (A)
R = Resistance (Ω)



$$\mathbf{R} = \frac{V}{I} = \frac{10V}{2A} = \boxed{5\ \Omega}$$

Power

Power (Watts) is the measure of energy per unit time.

$$P = V * I = (voltage) * (current) = \frac{V^2}{R} = I^2 R$$

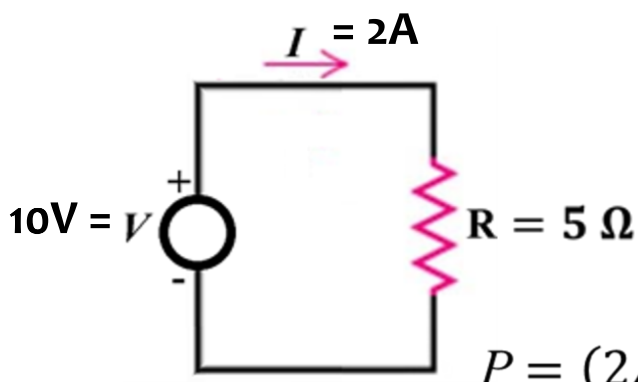
V = Voltage (V)
I = Current (A)
R = Resistance (Ω)

Power Example

Solve for the power absorbed by the resistor

Solution: $\boldsymbol{Power}: P = IV = I^2R$

V = Voltage (V)
I = Current (A)
R = Resistance (Ω)
P = Power (P)



$P = (2A)(10V) = \boxed{20W}$

Energy

Energy is the power consumed over a period of time (seconds or hours).

Energy = Power x time = Watts x sec

e.g. 10Ws, 5 kWh (5000Wh)

$$E/t = P$$
$$E = P * t = IVt$$

V = Voltage (V)
I = Current (A)
t = Time (hr/sec)

Energy Example

Solve for the energy absorbed by a 500W heater over 3 hours
P = 500W
t = 3 hours

$$\boldsymbol{Energy}: E = Pt = IVt$$

Solution:

$$E = Pt = (500W)(3hr)$$
$$= \boxed{1500Whr = 1.5\ kWhr}$$

V = Voltage (V)
I = Current (A)
R = Resistance (Ω)
P = Power (P)
E = Energy (Whr)

Equations & Conversions

- Power = V x I = I^2R = Energy ÷ time

  1000 Watts = 1 kiloWatt (kW)

  1 Watt = 1 Volt x 1 Amp
- Voltage = I x R

  1 Volt = 1000 milliVolts (mV)
- Current = V/R

  1 Amp = 1000 milliAmps (mA)
- Resistance = V / I

  1 Ohm = 1 Volt ÷ 1 Amp
- Energy = P x t

  1 kiloWatt hour (kWhr) = 1000 Watt hours (Wh)

Units and Dimensions

1 kilo = 1,000x
1 mega = 1,000,000x
1 giga = 1, 000,000,000x
1 tera = 1,000,000,000,000x

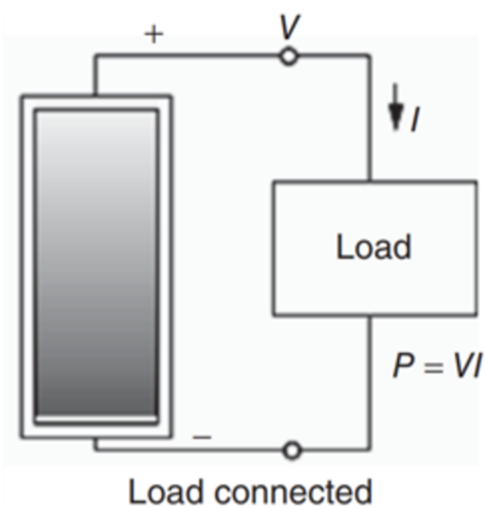
- **Power** = rate of energy expenditure (Watts, kilowatts, ...)
- Electrical power = voltage x current = 1 Watt = 1 Volt x 1 Amp
- 1 horsepower = 746 Watts

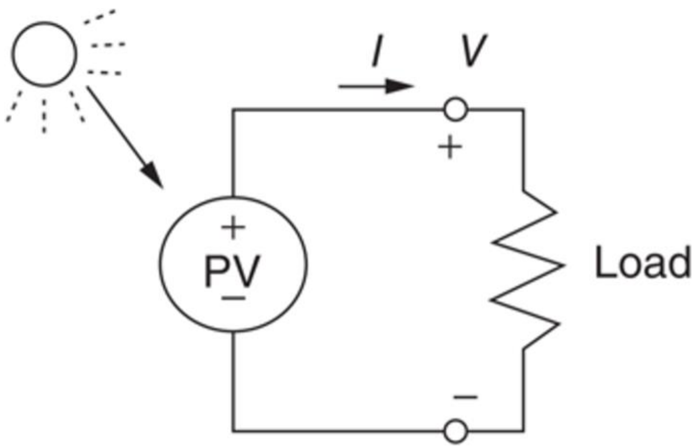
- **Energy** = power use over time (watt-hour, BTU, Joule, Calorie)
- 1,000 BTU's = 293 W-hr
- 1,000 calories = 1.16 W-hr
- 1,000 Joules = 1,000 Newton-meter = 0.278 W-hr
- 1 W-hr = 2.25×10^{22} electron volts

PV as a Power Source:

PV circuit representation:

* PV is used as a voltage source



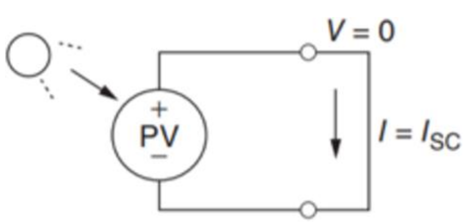


PV as a Power Source:

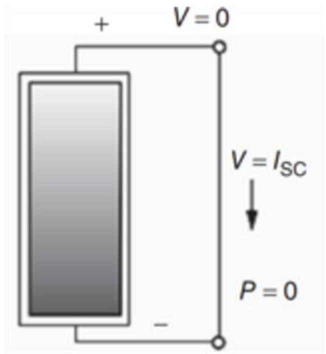
Two conditions of interest

* Short-circuit current, I_{SC}
  * Terminals are shorted, current is measured

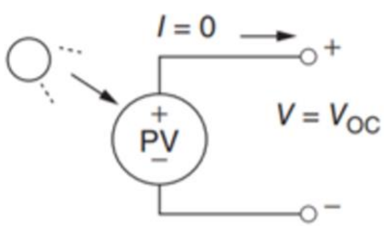
* Open-circuit voltage, V_{OC}
  * Terminals are open, voltage is measured



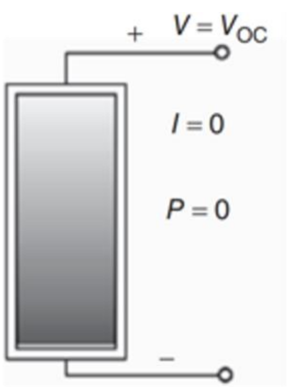
(a) Short-circuit current



Short circuit



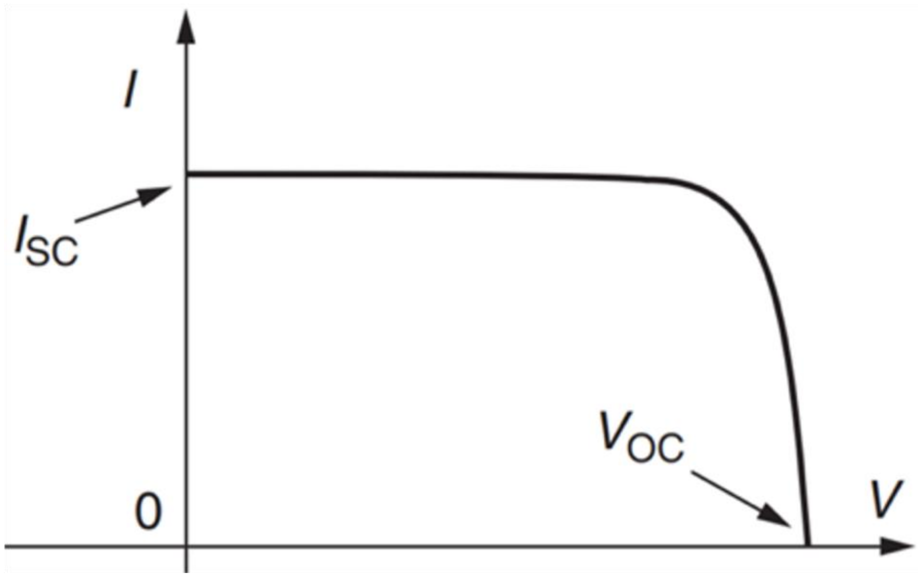
(b) Open-circuit voltage



Open circuit

PV I-V Relationship:

V.curve shows the relationship between voltage and current for a PV cell.



- Remember that Power is equal to Voltage x Current (P = IV).
- Maximum Power is the point at which the product of voltage and current is maximum.
- Notice that current is maximum at I_{sc} but voltage is zero.
- Likewise, the voltage is maximum at V_{oc} but current is zero.

PV Sticker Information


Trinasolar
Smart Energy Together

TSM-305PC14

Made in China

Maximum Power (P_{max})	305W $^{+3\%}_{0}$
Maximum Power Voltage (V_{mp})	36.6V
Maximum Power Current (I_{mp})	8.33A
Open Circuit Voltage (V_{oc})	45.5V
Short Circuit Current (I_{sc})	8.81A
Maximum System Voltage	DC1000V
Maximum Series Fuse	15A
Module Application	Class A

For field connections,use minimum 4mm² copper wires insulated for a minimum 90℃

Electrical Rating At STC
AM=1.5 IRRADIANCE=1000W/m² Temp.=25℃

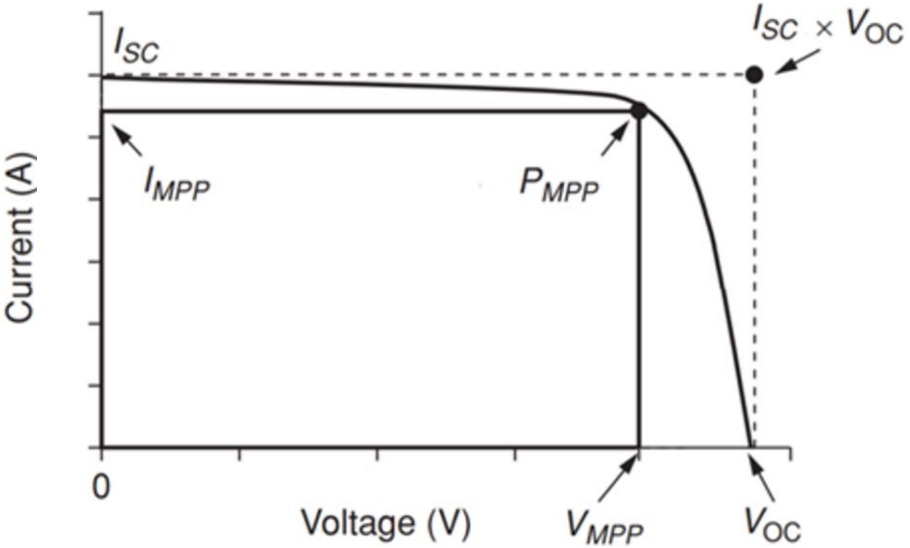
EU-28 WEEE Compliant

Electrical Hazard

This module produces electricity when exposed to light.
Follow all applicable electrical safety precautions.

Changzhou Trina Solar Energy Co.,Ltd.
www.trinasolar.com

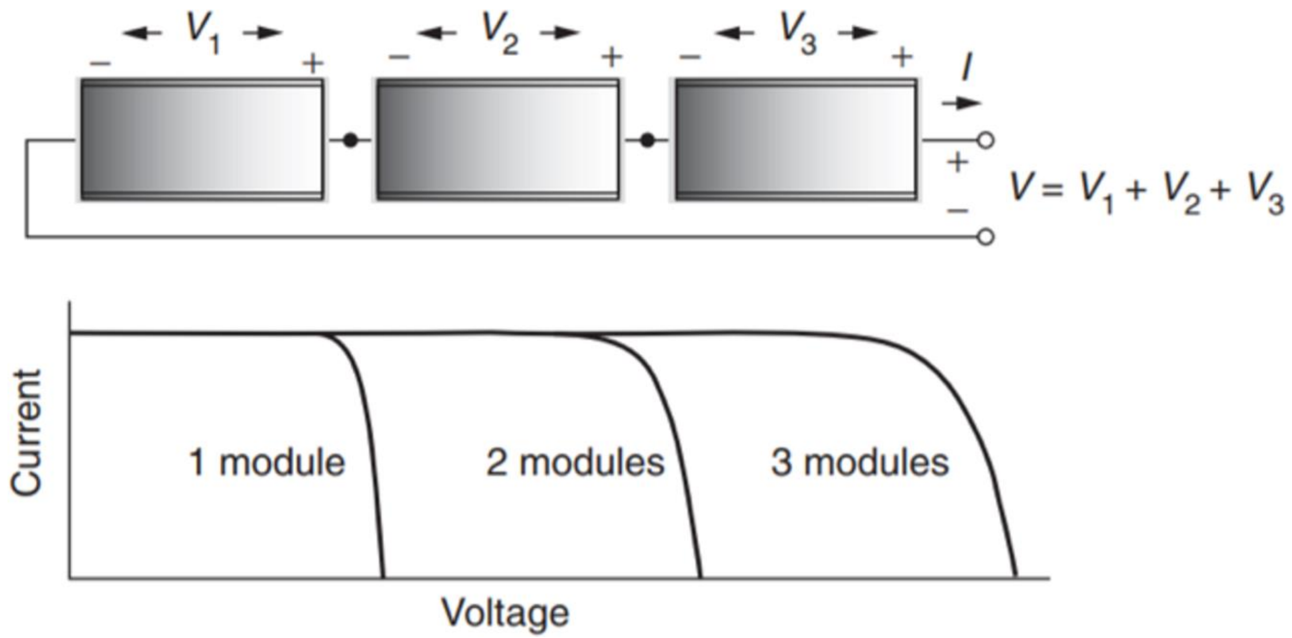
Remember that $P_{MPP} = I_{MPP} \times V_{MPP}$



PV Panels in Series:

For PV modules in series,

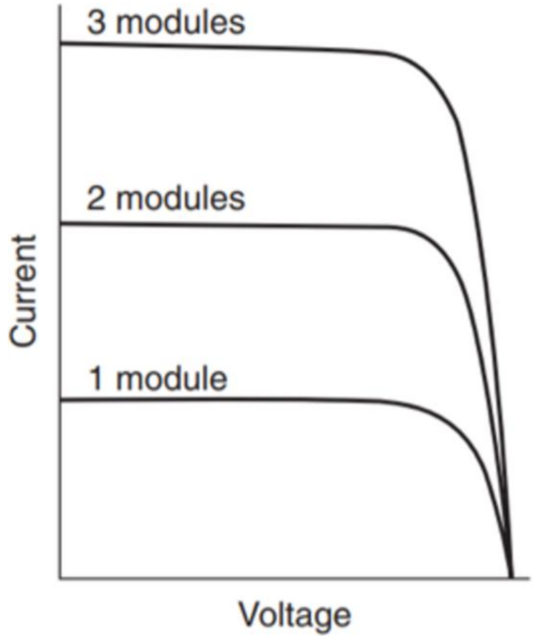
* Voltage adds
* Current remains constant

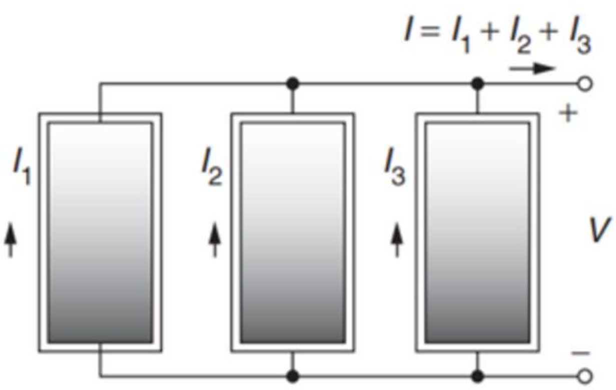


PV Panels in Parallel:

For PV modules in parallel,

* Current adds
* Voltage remains constant





Useful Information

* Power = V x I = I^2R = Energy ÷ time
  1000 Watts = 1 kiloWatt (kW) 1
  Watt = 1 Volt x 1 Amp
* Voltage = I x R
  1 Volt = 1000 milliVolts (mV)
* Current = V/R
  1 Amp = 1000 milliAmps (mA)
* Resistance = V / I
  1 Ohm = 1 Volt ÷ 1 Amp
* Energy = P x t
  1 kiloWatt hour (kWh) = 1000 Watt hours (Wh)

PV panels in series:

- Current remains constant
- Voltages add

PV panels in parallel:

- Voltage remains constant
- Currents add

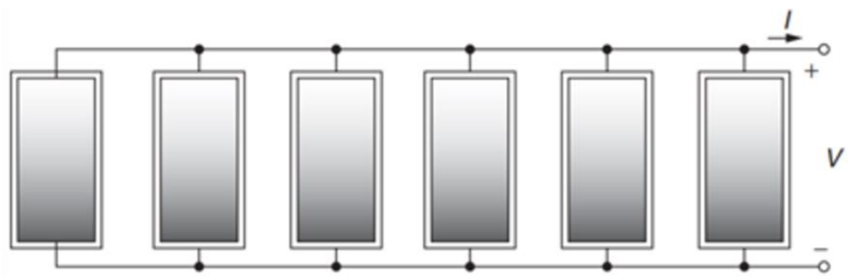
PV Configurations Example

Suppose each PV panel has the following:

I_{sc} = 2A, V_{oc} = 10V. What should the total I_{SC} and V_{oc} be for the following array configurations?

Remember that voltage adds in series and current adds in parallel

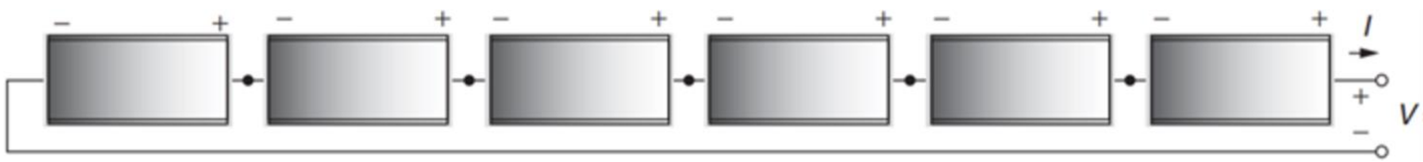
a)



$I_{SC} =$ ___
$V_{OC} =$ ___

b)

$I_{SC} =$ ___
$V_{OC} =$ ___

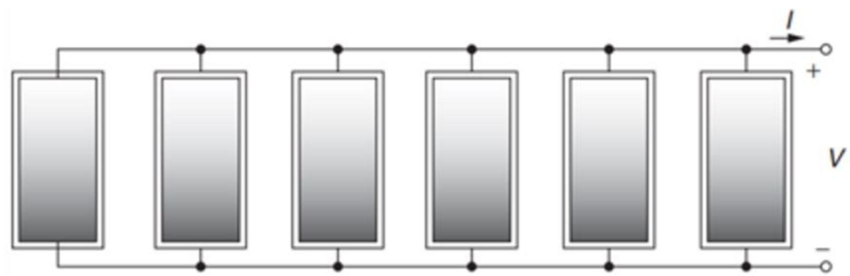


PV Configurations Example

Suppose each PV panel has the following:
I_{sc} = 2A, V_{oc} = 10V. What should the total I_{SC} and V_{oc} be for the following array configurations?
Remember that voltage adds in series and current adds in parallel

Solution:

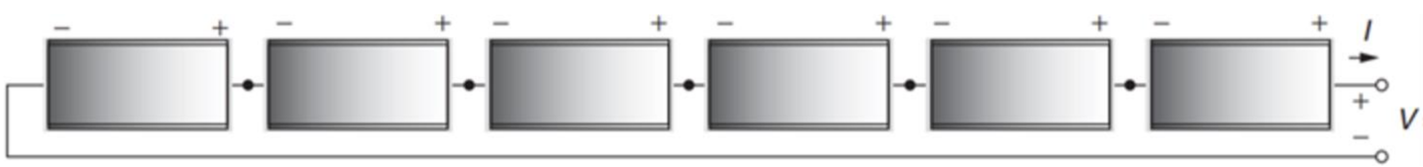
a)



$$I_{SC} = (2A)(6) = \boxed{12A}$$
$$V_{OC} = \boxed{10V}$$

b)

$$I_{SC} = \boxed{2A}$$
$$V_{OC} = (10V)(6) = \boxed{60V}$$



PV Configurations Example

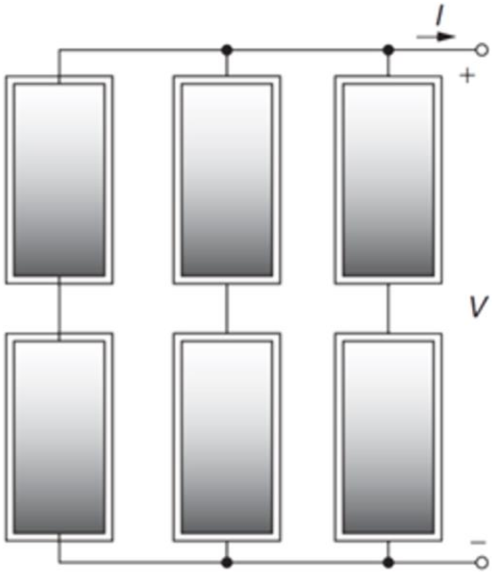
Suppose each PV panel has the following:

I_{sc} = 2A, V_{oc} = 10V. What should the total I_{SC} and V_{oc} be for the following array configurations?

Remember that voltage adds in series and current adds in parallel

Solution:

c)



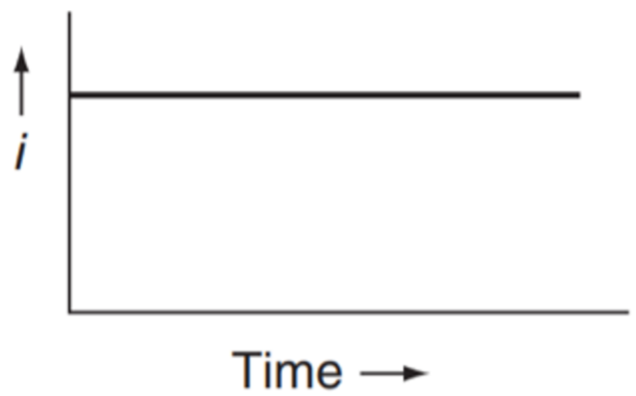
Add panels in series first, then add strings of panels in parallel

$$I_{SC} = (2A)(3) = \boxed{6A}$$
$$V_{OC} = (10V)(2) = \boxed{20V}$$

Direct Current

Direct Current (DC) is when charge flows at a steady rate in **one direction** only

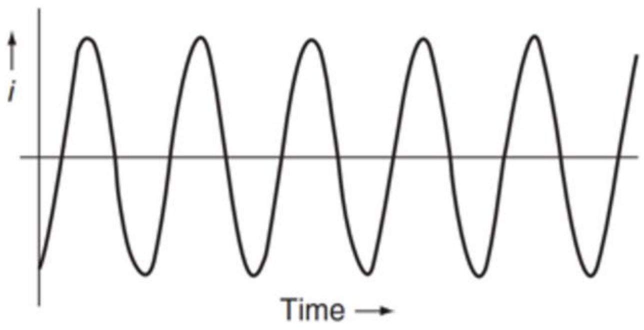
Batteries, PV, Wind provide DC current.

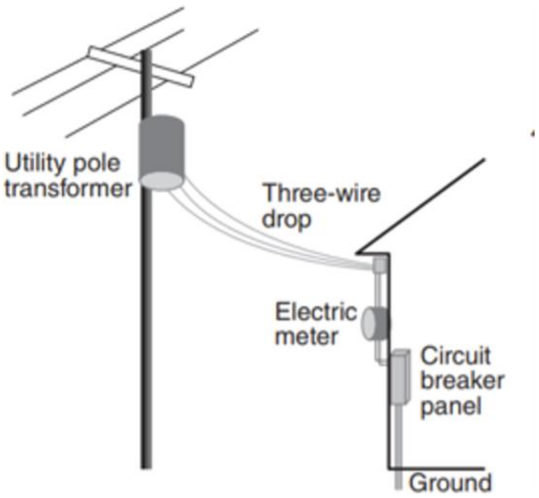


Alternating Current

Alternating Current (AC) is when charge flows back and forth sinusoidally.

* AC electricity in the US delivered by utility has a frequency (the rate at which the direction changes) of 60 cycles/s or 60 Hz
* Inverters can be used convert from DC to AC





Digital Multimeter

Alternating Current (AC): ~

Direct Current (DC): ⎓

AC/DC Toggle Button

Display

Control Dial

Negative probe (Black)

Positive Probe (Red)

Voltage/resistance/diode measurement input

Amp (A) input

Miliamp (mA) / microamp (μA) input

COM (negative) input

Digital Multimeter PV Measurement Demonstration

Power Consumption

When computing the impact of any appliance on total power consumption, it is very important to look not just at the rate of power use (in watts per hour), but also at the number of hours per day (or year) of typical use.

Example:

- A laptop computer uses 15-60 watts per hour, 10 hours per day = 150 to 600 Watts of energy consumed each day
- A toaster oven uses 1200 watts per hour, 5 minutes per day

  (1200 W/hr) ÷ (60 minutes/hour) = 20 Watts per minute

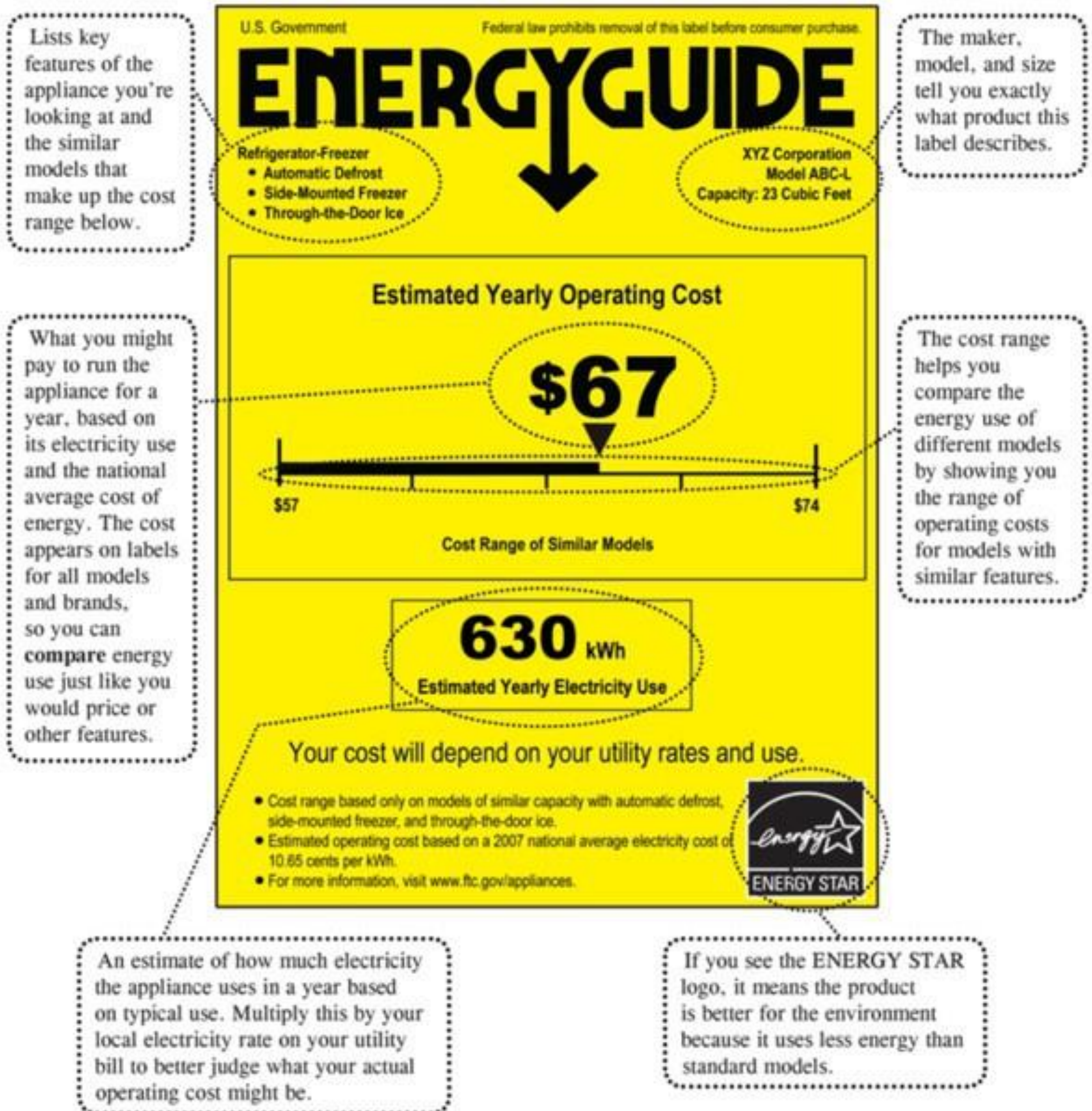
  (20 W/min) x (5 minutes) = 100 W per day

EnergyStar Appliances

EnergyStar appliances are held to strict standards by the US Environmental Protection Agency (EPA) to be more energy efficient than their conventional counterparts.

They can be more expensive upfront, but the energy savings they deliver can result in significant cost savings over the life of the appliance.

https://www.energystar.gov/products/what_makes_product_energy_star



https://www.consumer.ftc.gov/articles/0072-shopping-home-appliances-use-energyguide-label

Annual Energy Consumption of Common Appliances

Conventional Appliances:

* Refrigerator: 327 kWh
* Washing Machine: 187 kWh

EnergyStar Appliances:

* Refrigerator: 297 kWh
* Washing Machine: 93 kWh

No EnergyStar Rating:

* Laptop: 175 kWh
* Cell Phone Charger: 20 kWh
* Microwave: 220 kWh

References

1“*Digital Multimeter and PV Panel Demo for TCUP 2021*”, Frances Willberg, 25-May-2021. [Online]. Available: https://www.youtube.com/watch?v=aefBZXKdhw8

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3“*How to Use the EnergyGuide Label to Shop for Home Appliances*”, Federal Trade Commission Consumer Information. [Online]. Available: https://www.consumer.ftc.gov/articles/how-use-energyguide-label-shop-home-appliances

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RESEARCH, INNOVATION & IMPACT
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