EE2029: Introduction to Electrical Energy Systems

Renewable Energy Integration

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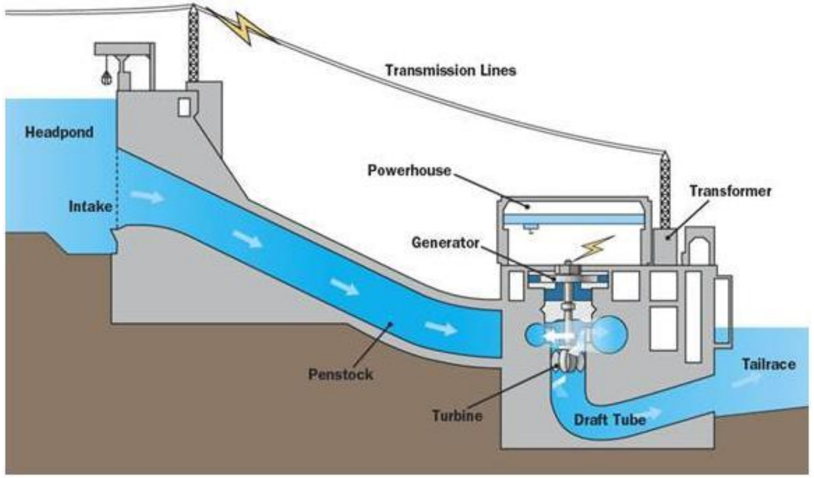
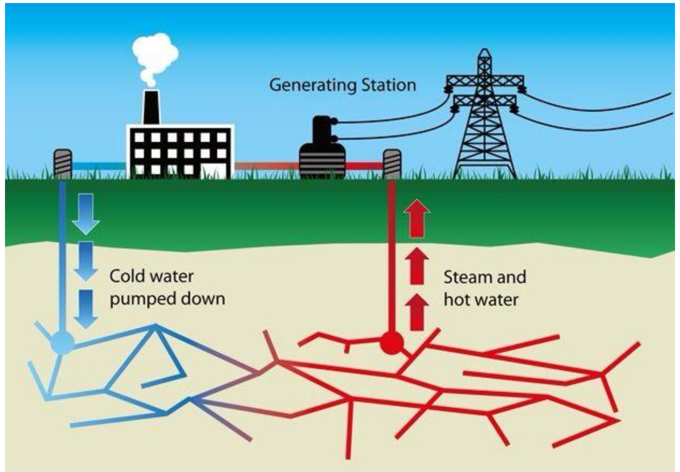
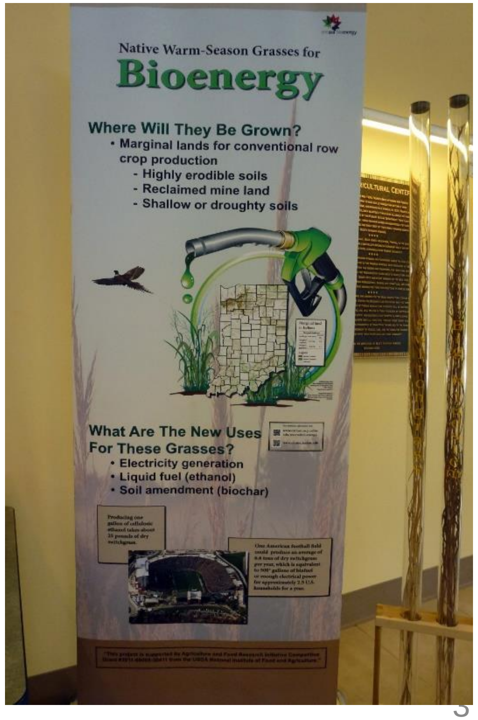
Learning Outcomes

- Explain the motivations for Renewable energy
- Describe Solar and Wind energy systems



Renewable energy





Motivations for Renewable Energy

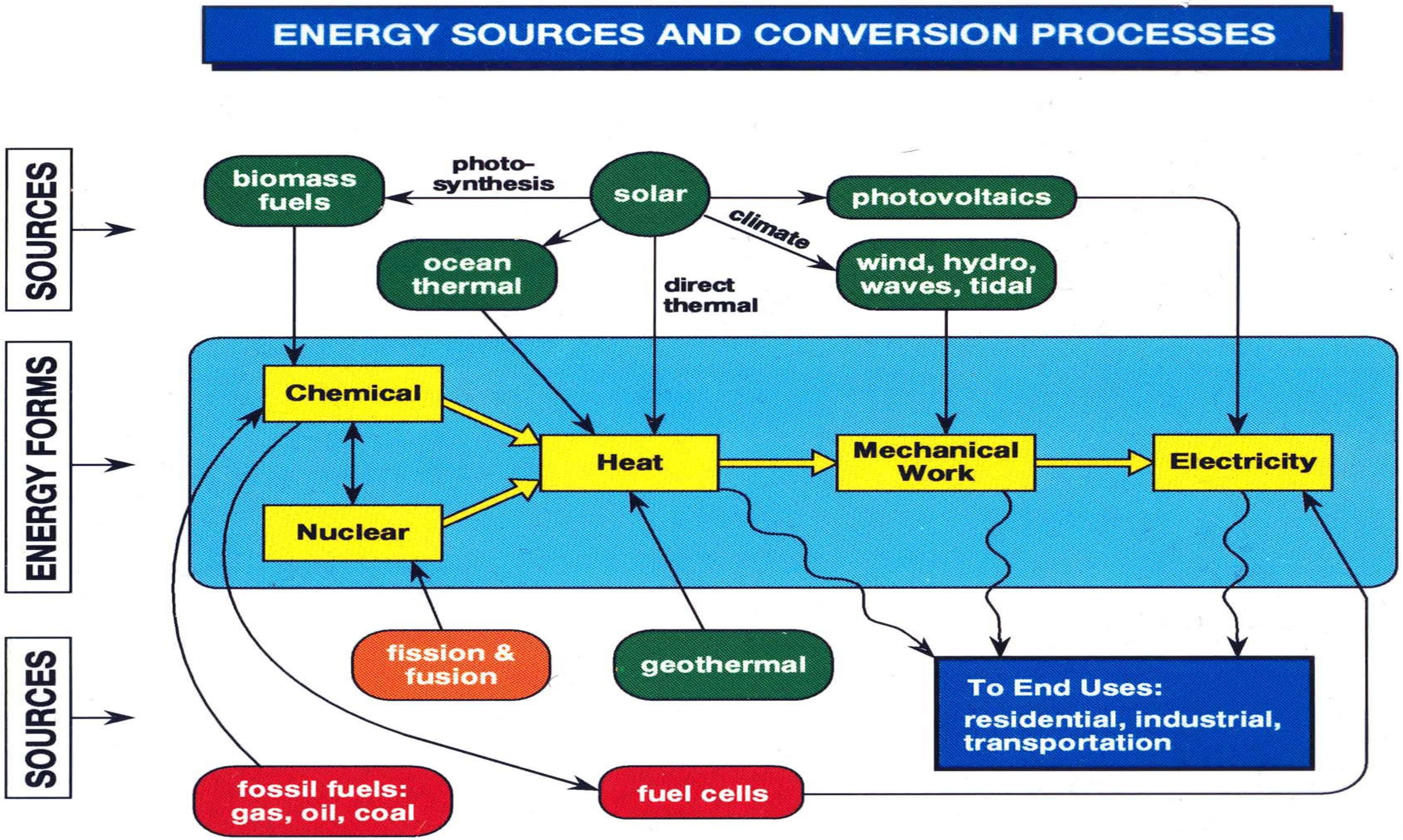
Fossil Fuels

Energy Efficiency

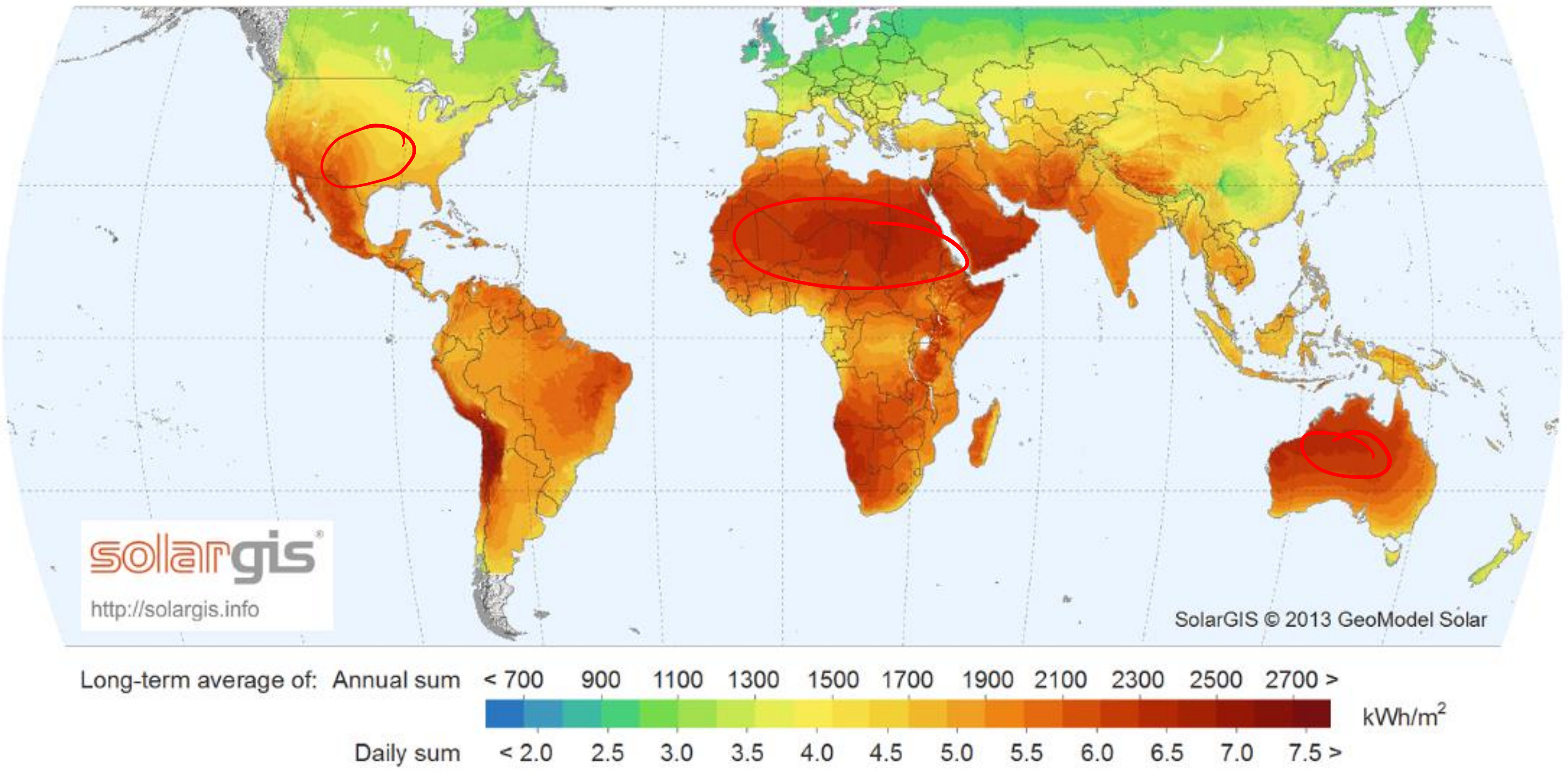
Off Grid Systems

How to make places more energy efficient?

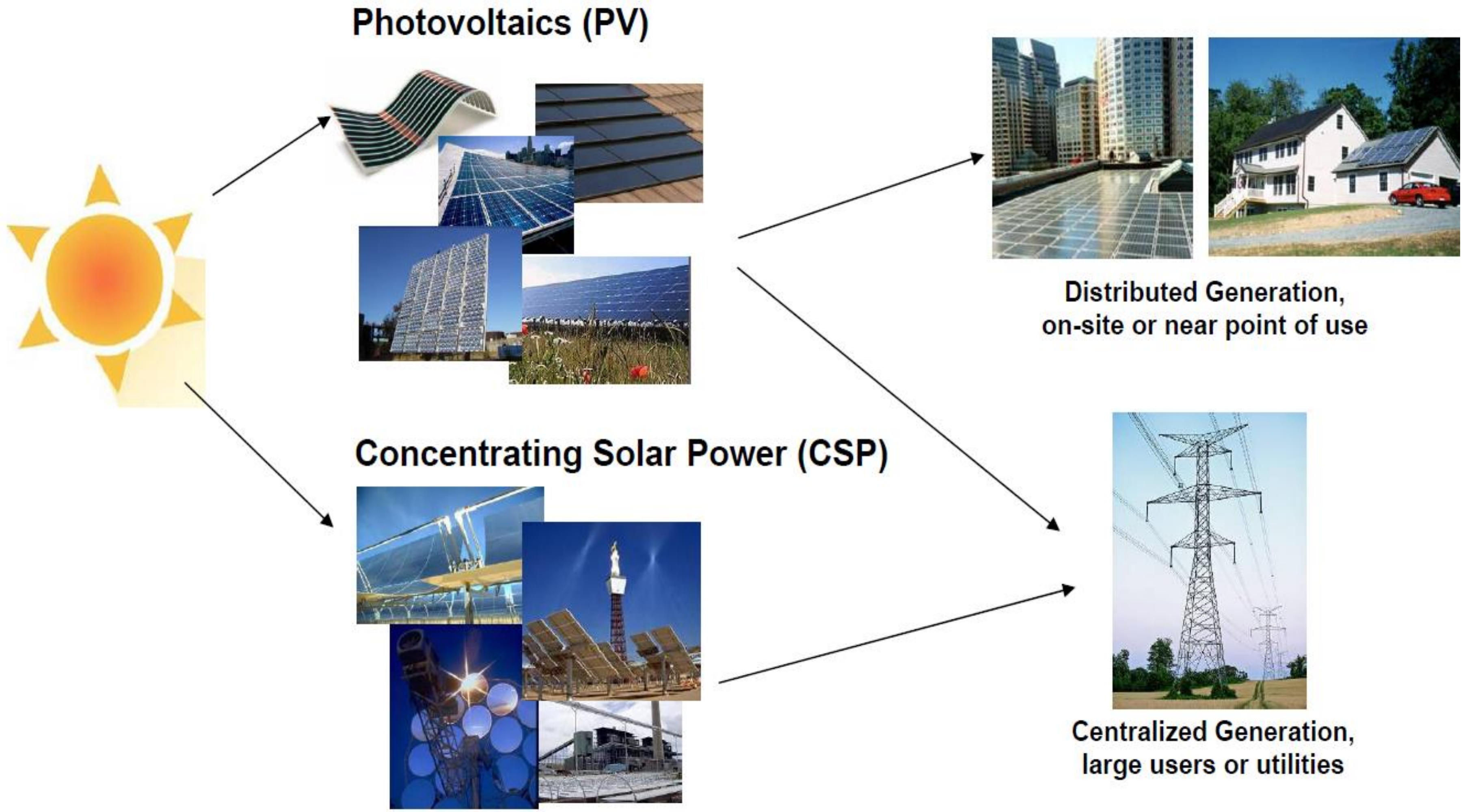
Solar Energy



Solar Irradiation of the World



Generating Electricity from the Sun



Solar Thermal Technologies

Kramer Junction, CA
5 x 33MW
1985
η = 15%

Parabolic Trough

Solar Two
Barstow, CA
10 MW
1995-1999
η = 15%

Solar Tower

Bakersfield, CA
5MW
2008
η = 20%

Fresnel Reflector

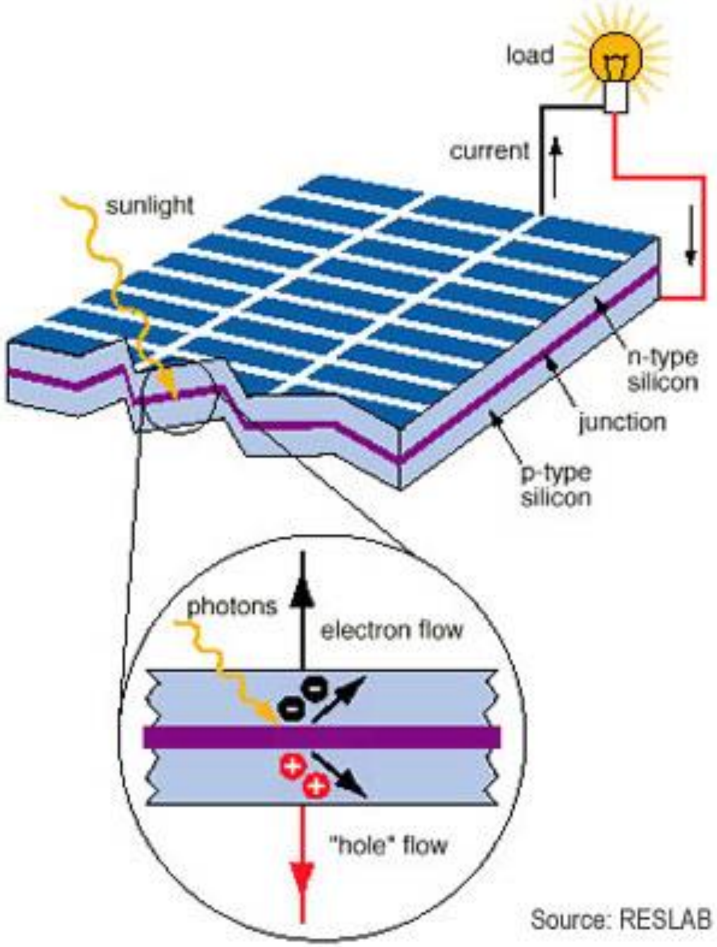
- Solar thermal systems capture and concentrate high-intensity sunlight focused onto working fluids

SNL Solar Stirling
25 kW
2005
η = 30%

Solar Dish

Solar PV Cell

- Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon
- Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction
- An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity

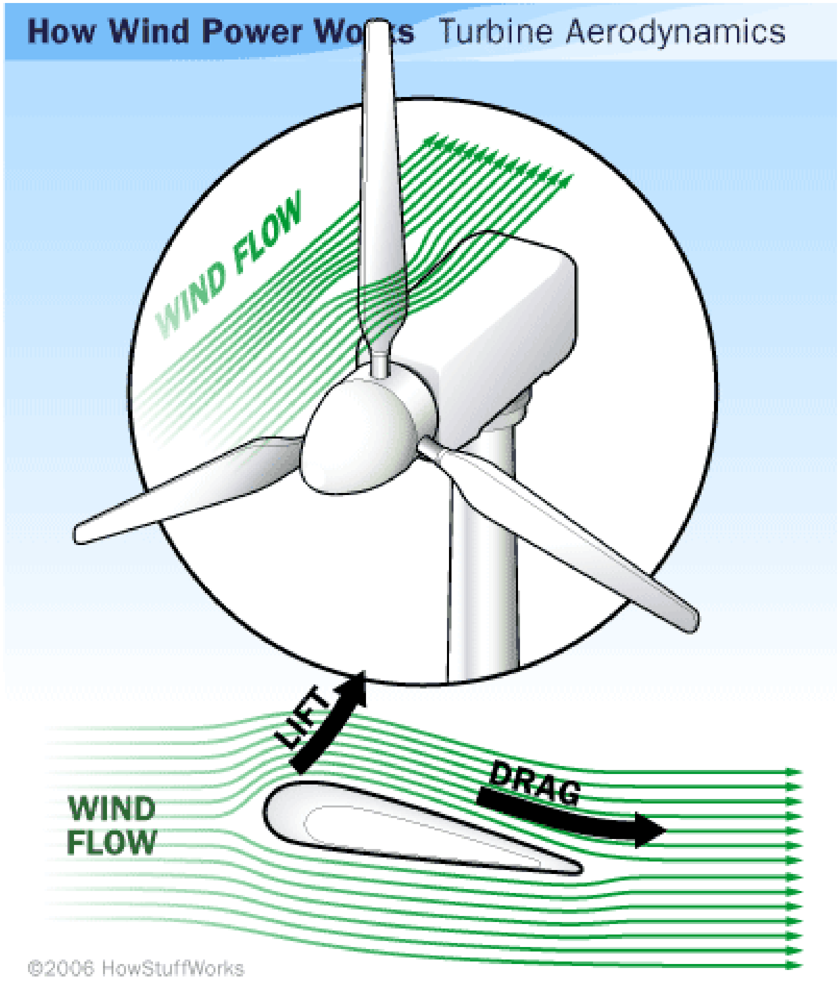


Source: RESLAB

Wind Energy

- A wind turbine extracts energy from moving air by slowing the wind down, and transferring this energy into a spinning shaft, which usually turns a generator to produce electricity.

- The power in the wind that's available for harvest depends on both the wind speed and the area that's swept by the turbine blades.



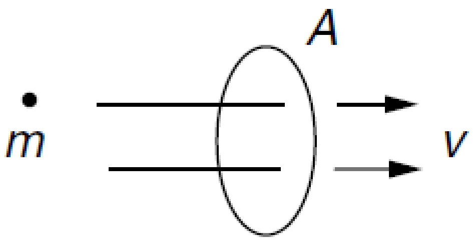
Types of Wind Turbines

- Two main types of turbines: Horizontal axis and Vertical axis.
- HAWT: It is possible to catch more wind and so the power output can be higher than that of vertical axis, but the tower is higher and more blade design parameters have to be defined.
- VAWT: No yaw system is required and it is easier to design. Maintenance is easier in vertical axis turbine whereas horizontal axis turbine offers better performance.

Horizontal axis wind Turbine (HAWT)

Vertical axis wind Turbine (VAWT)

Power In The Wind



Power through area $A = \frac{\text{Energy}}{\text{Time}} = \frac{1}{2}\left(\frac{\text{Mass}}{\text{Time}}\right) v^2$

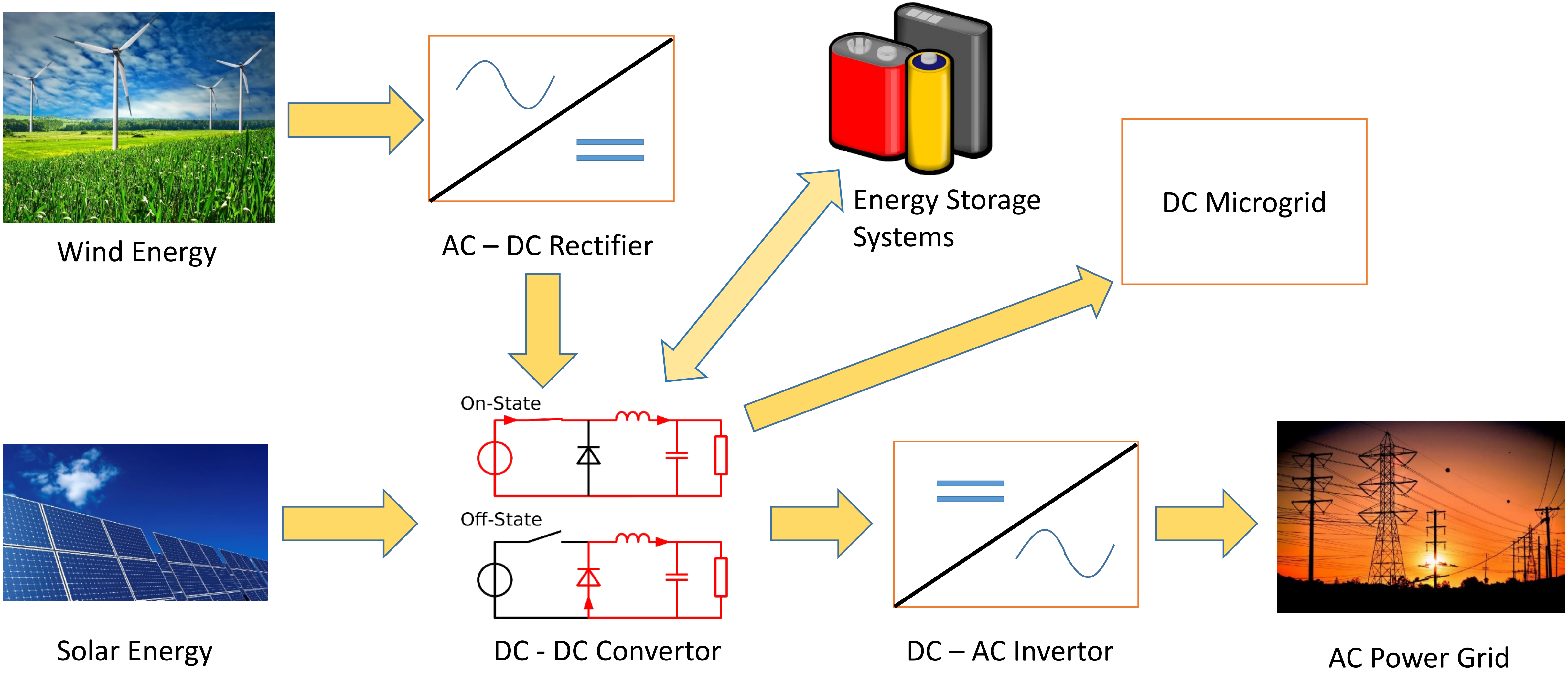
- The mass flow rate $\dot{m} = \left(\frac{Mass}{Time}\right)$, *through area A, is the product of air density* ρ, *speed* v, and cross-sectional area A:

$$\boxed{P_w = \frac{1}{2}\rho A v^3}$$

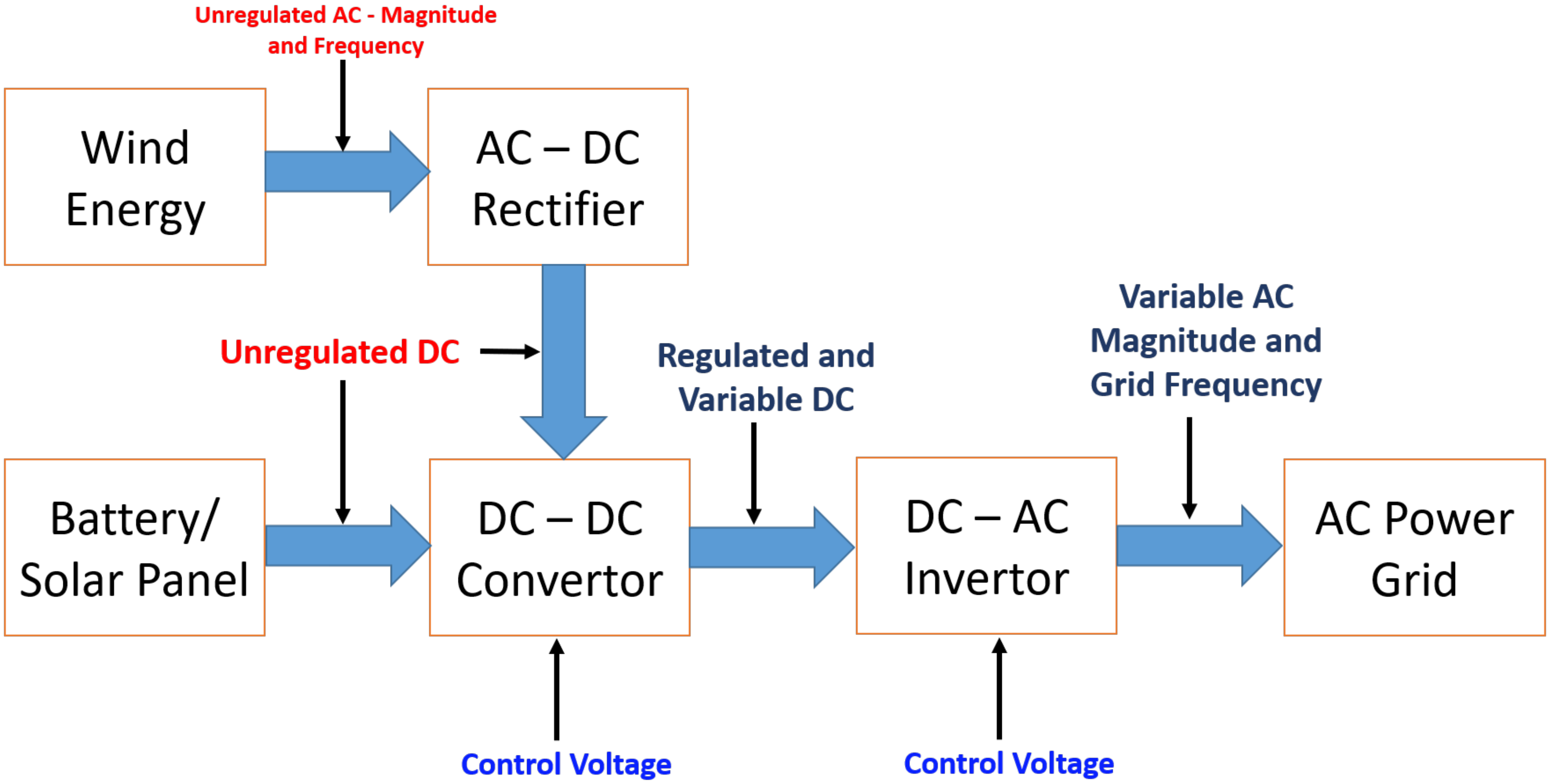
P_w is the power in the wind (watts)
ρ is the air density (kg/m^3)
A is the cross-sectional area
v = windspeed normal to A (m/s)

- Specific Power in the Wind is P_w per unit area or $\frac{P_w}{A} = \frac{1}{2}\rho v^3$

Renewable Energy and the Grid

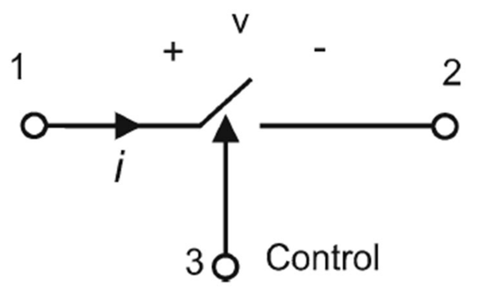


Renewable Energy and the Grid

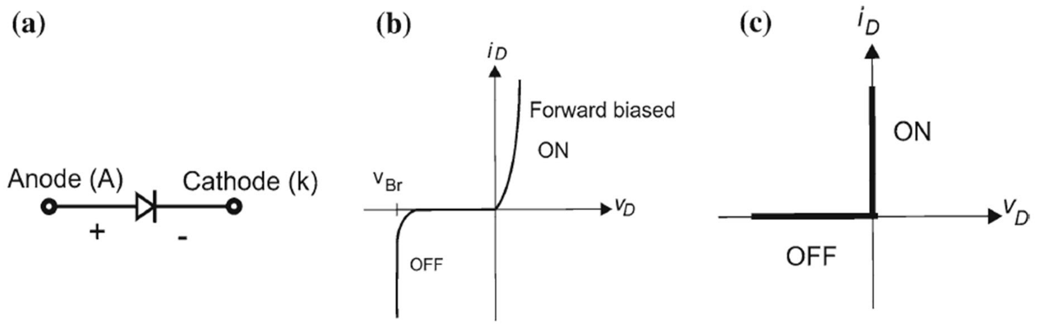


Power Semiconductor Switches

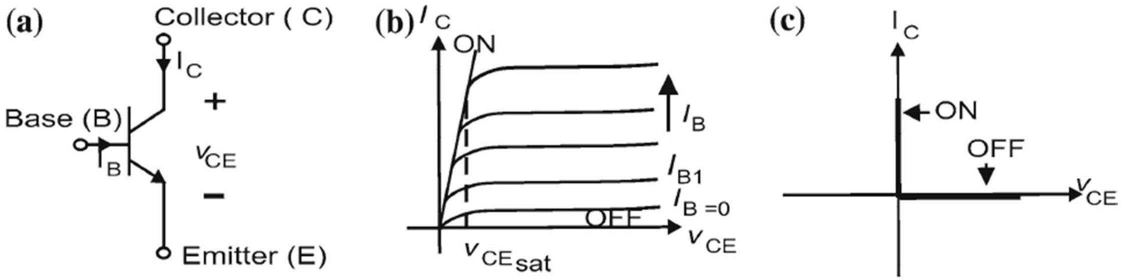
- Power semiconductor devices can be used as electronic switches capable of handling high voltage and current operations at high frequency
- An ideal power electronic switch can be represented as a three terminals device
- The ideal switch has
  - zero-voltage drop,
  - zero-leakage current, and
  - instantaneous transitions
- Diode is an uncontrolled switch
- Transistors are controlled switches



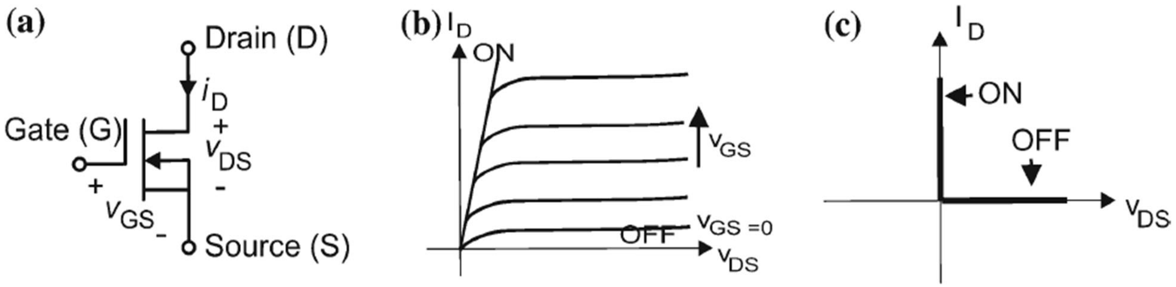
- Diode



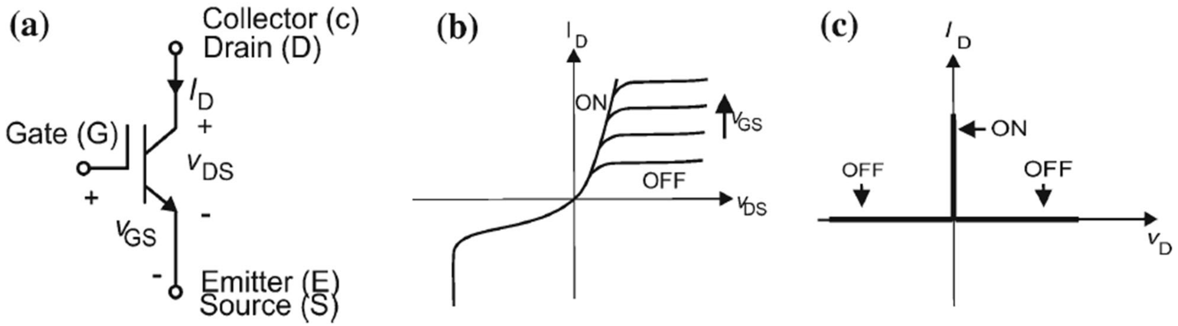
- Bipolar Junction Transistor (BJT)



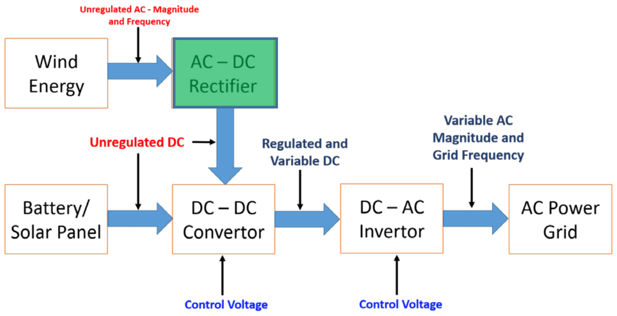
- Metal Oxide Semiconductor Field Effect Transistor (MOSFET)



- Insulated Gate Bipolar Transistor (IGBT)

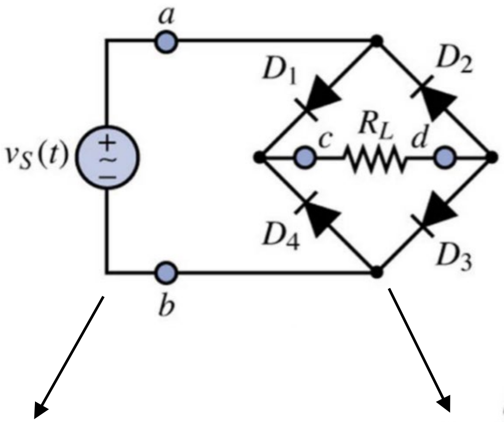


a) Symbol; b) i-v characteristics; c) idealized characteristics

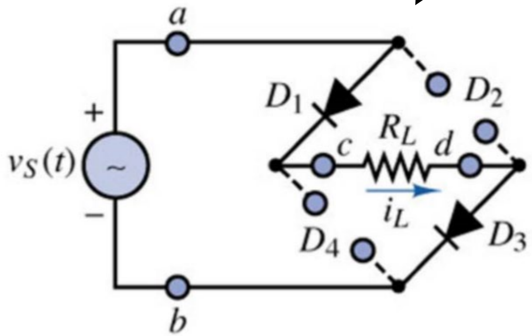


AC-DC Rectifier

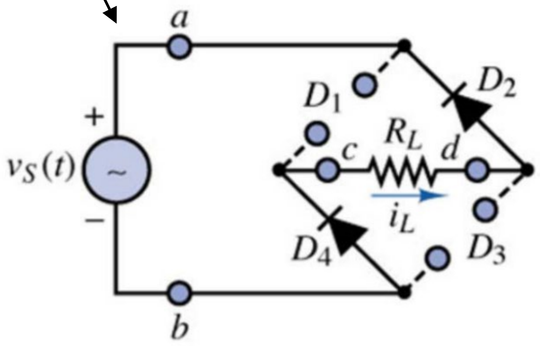
- Rectifier without capacitor



During the positive half cycle, the rectifier circuit simplifies to the following



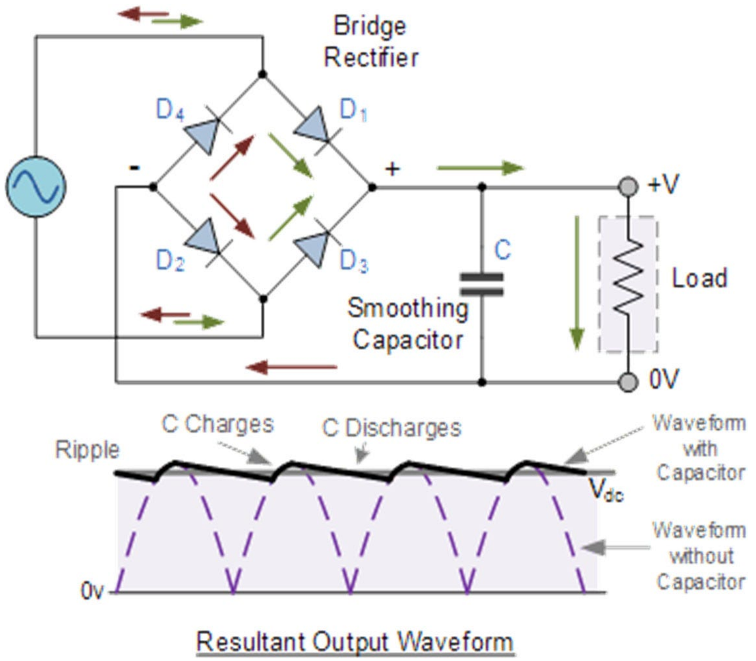
During the negative half cycle, the rectifier circuit simplifies to the following



$$V_{avg} = \frac{1}{\pi}\int_0^{\pi} V\sin\omega t\, d\omega t = \frac{2V}{\pi}$$

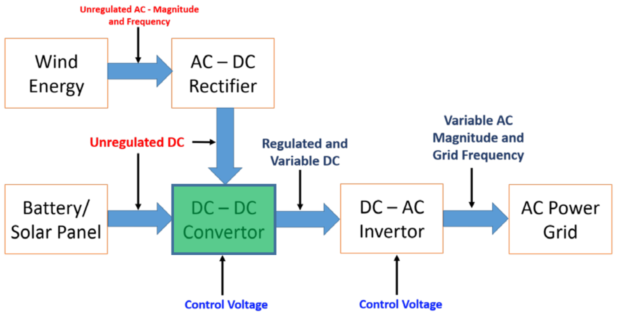
- Rectifier with filter capacitor

V_s, f_s



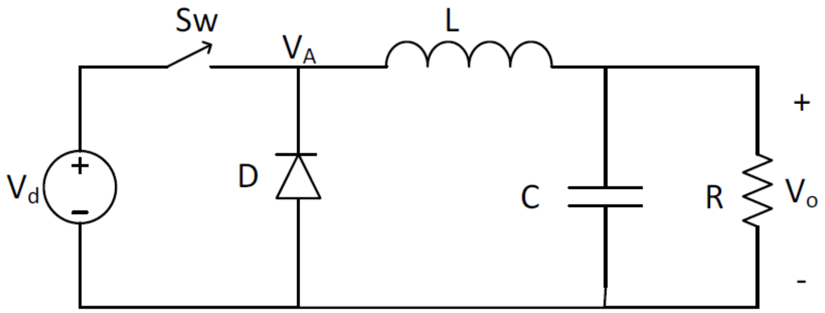
$$\Delta V_{ripple} = \frac{V_{load}}{R_{load}} \cdot \frac{1}{f_s} \cdot \frac{1}{C}$$

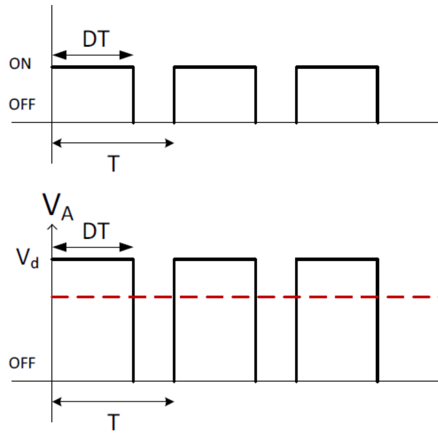
Example: The AC-DC rectifier circuit needs to deliver a current of 0.2 A to a load with an average voltage of 15 V. The AC source has a frequency of 50 Hz. The peak-to-peak voltage ripple is to be less than 0.5 V. Assume the diodes are ideal with no voltage drop. Find the minimum value of the filter capacitor needed.



DC-DC Convertors

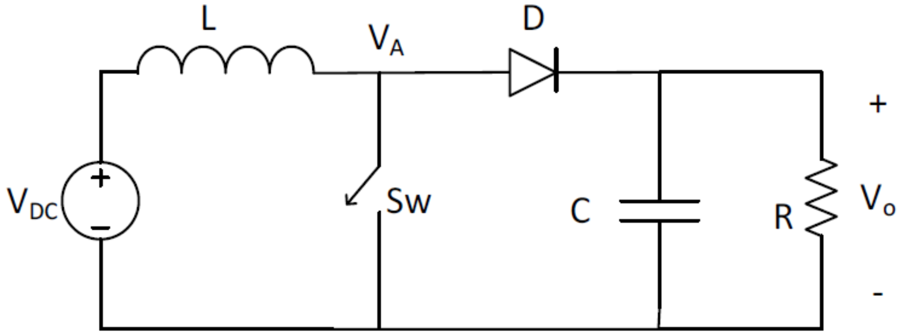
- **Buck Convertor**

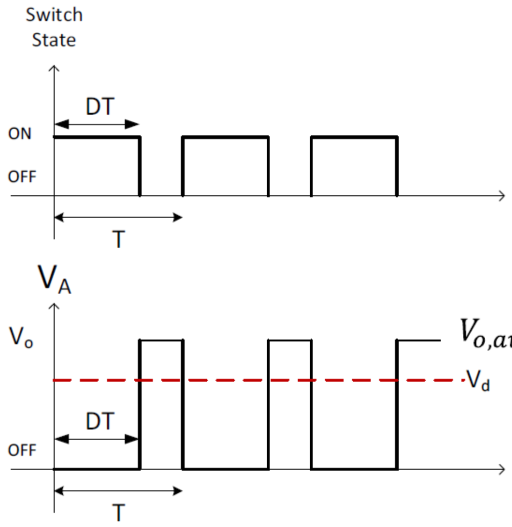




$$V_{o,avg} = V_d \times D$$

- **Boost Convertors**

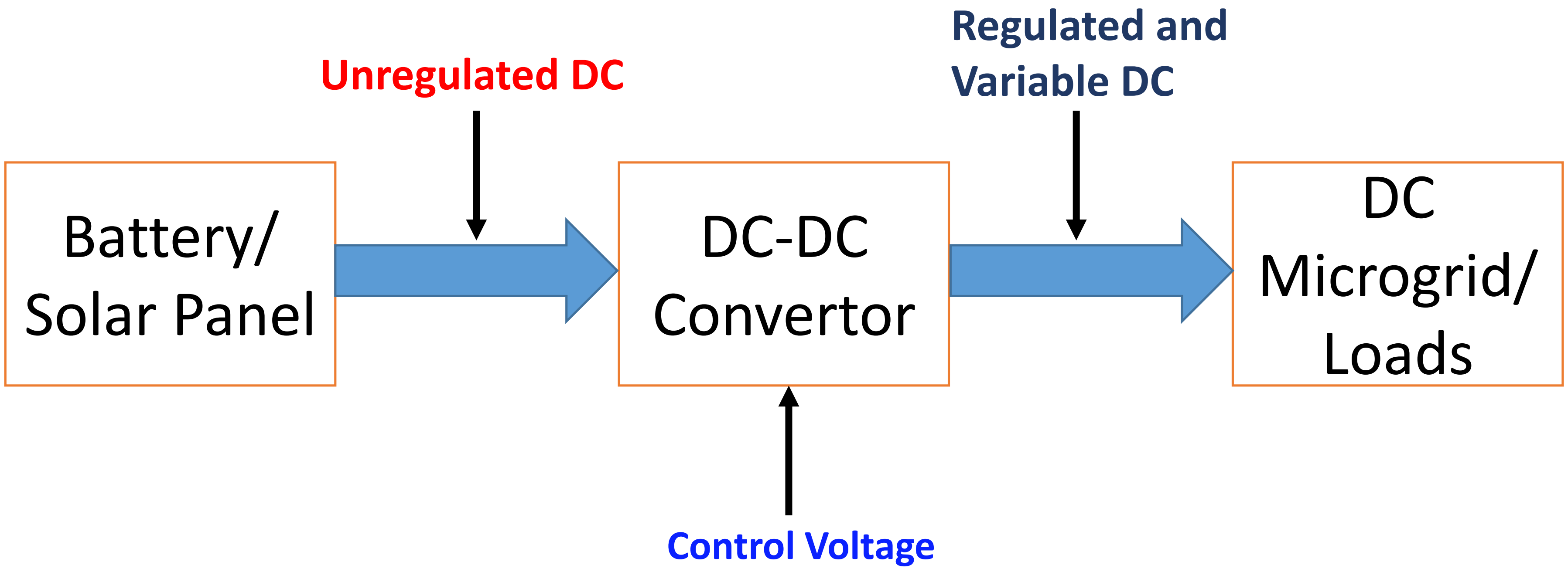




$$V_{o,avg} = V_d \times \frac{1}{1-D}$$

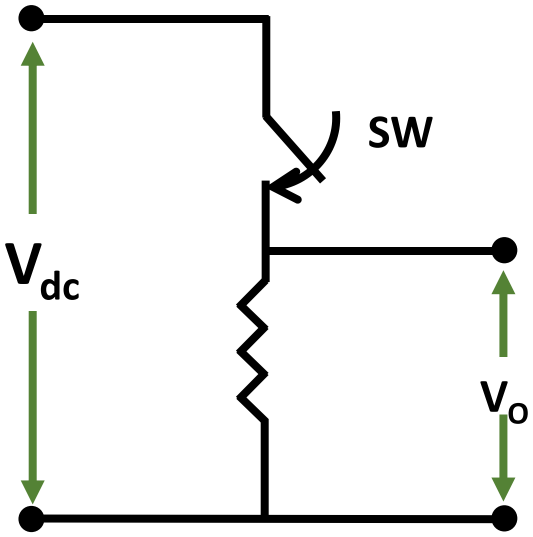
DC-DC Convertor

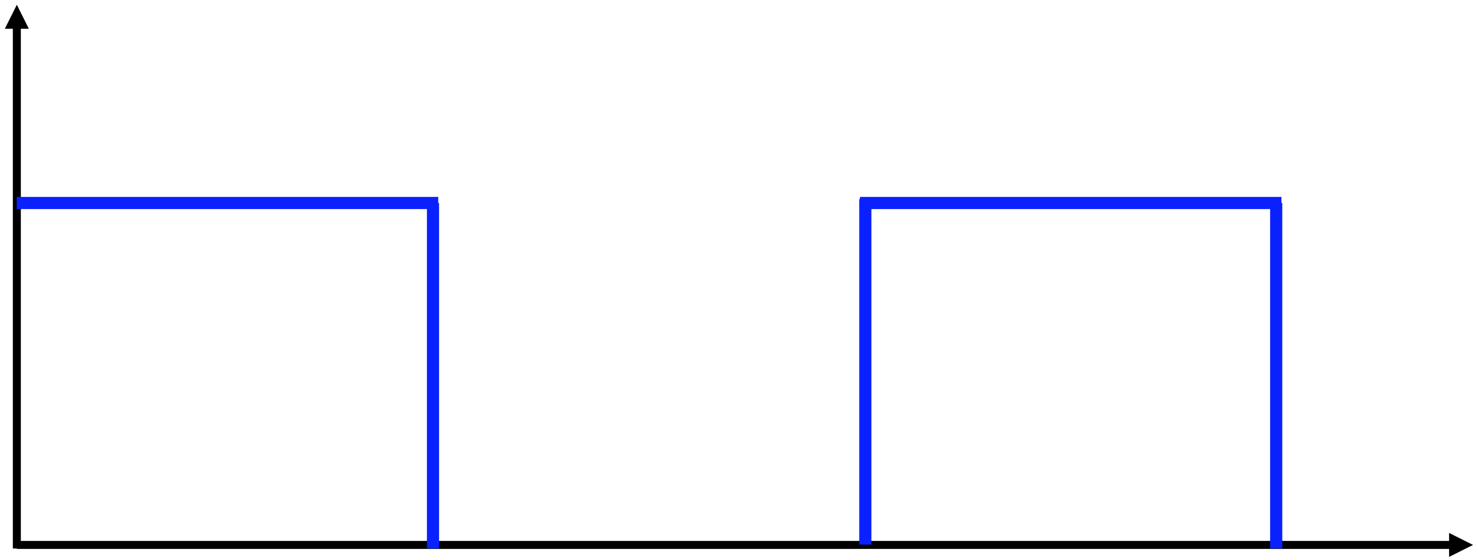
- DC Voltage from Battery/ Solar Panel



DC-DC Buck Convertor

- **Duty Cycle**

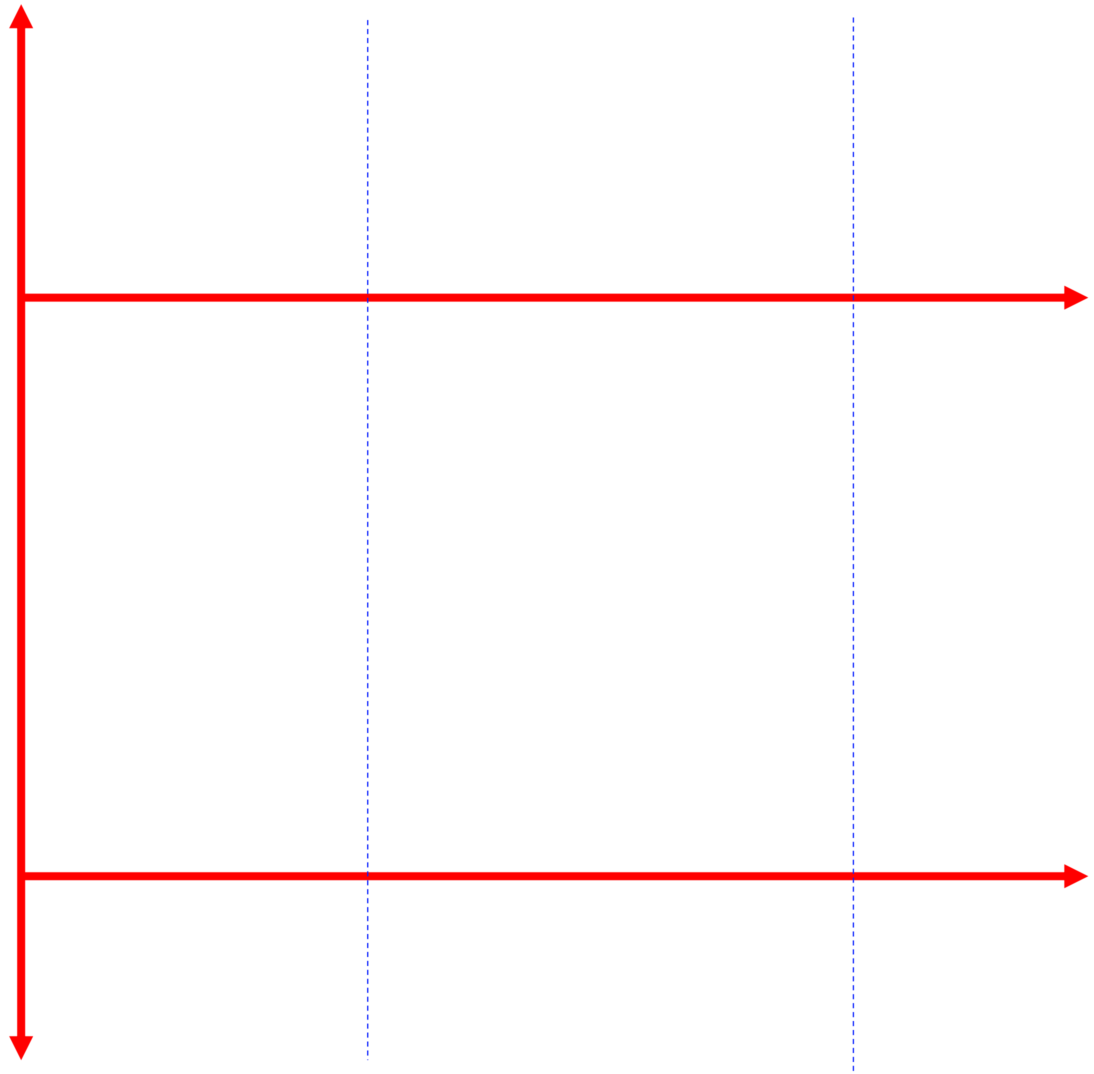


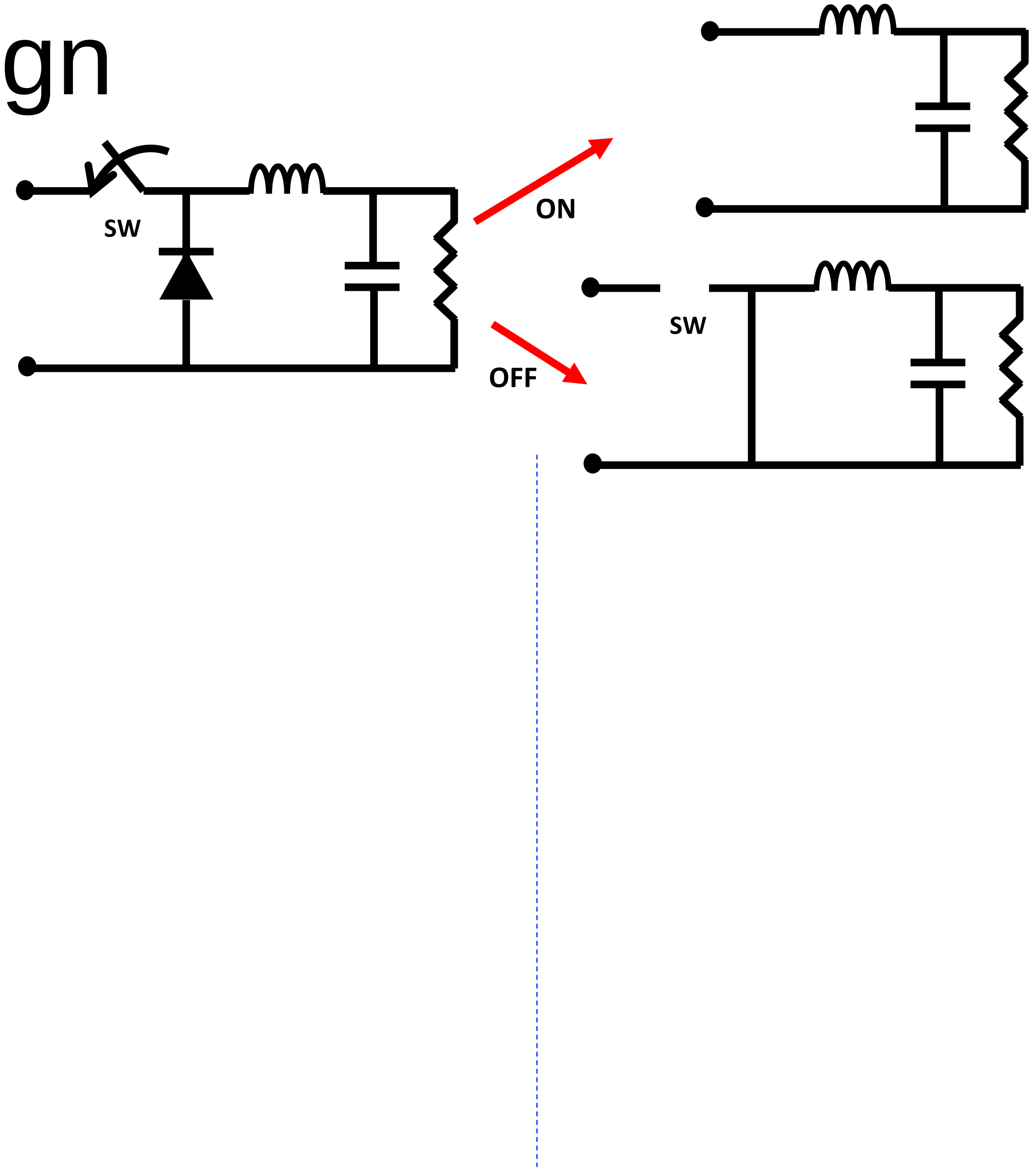


- **Output Voltage**

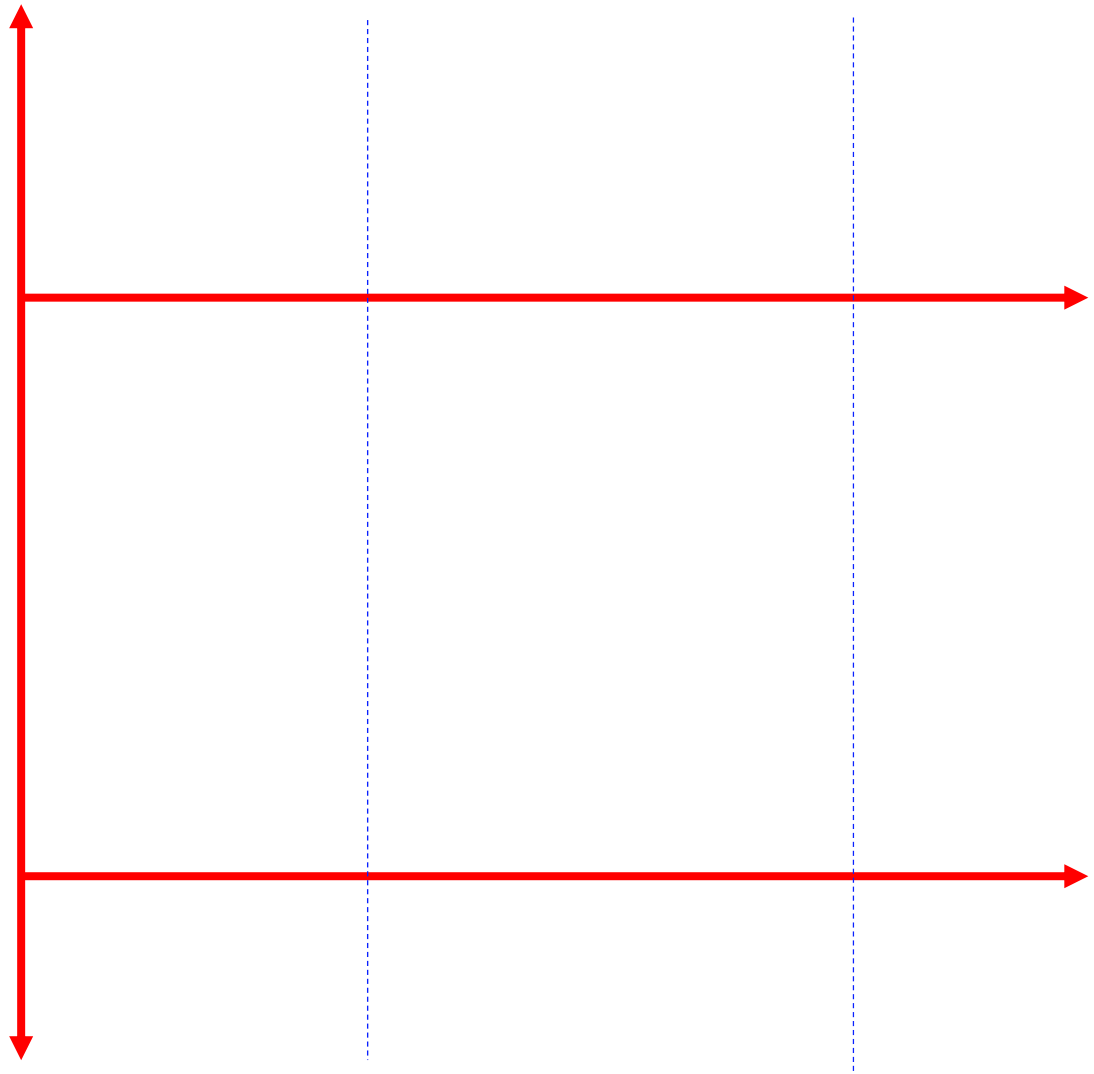
DC-DC Buck Convertor Design

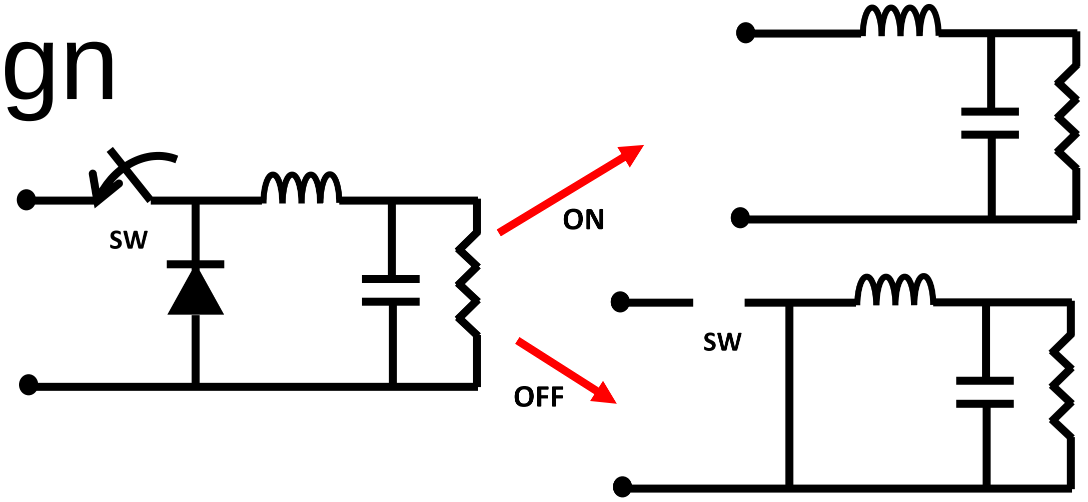
DC Buck Convertor Design





DC Buck Convertor Design





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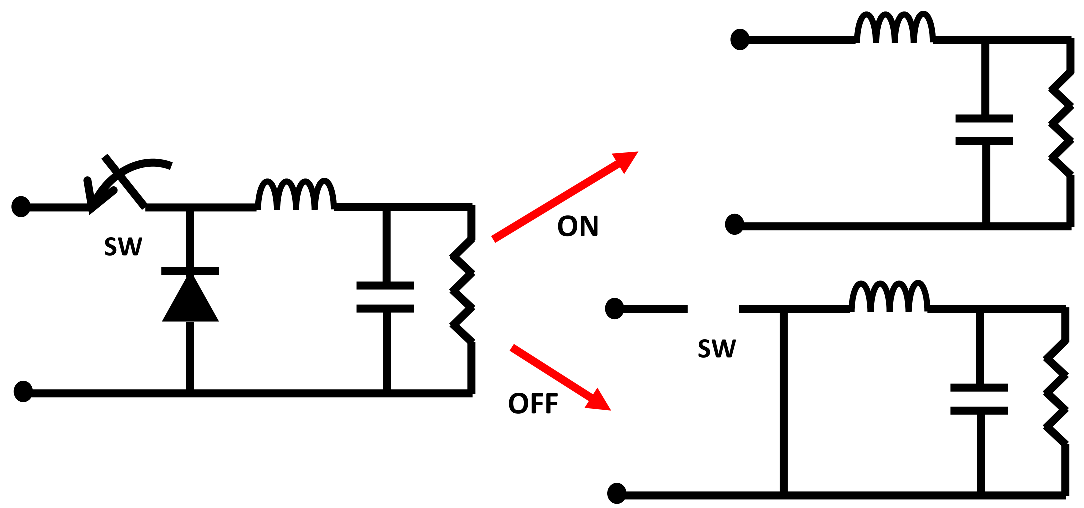
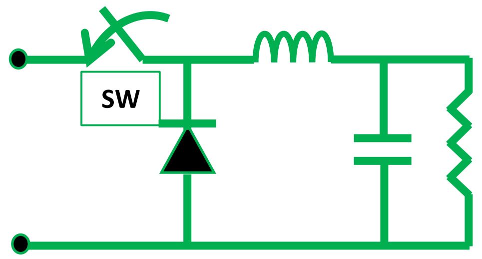
DC Buck Convertor Design



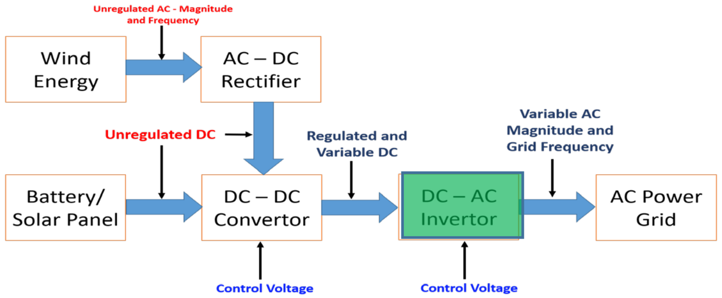
Example: A DC DC buck Convertor as shown below is switching at a frequency of fs = 1 kHz with a duty cycle of 50 %, L = 10mH, R=5Ω, C=100 μF ,V_d=100V.



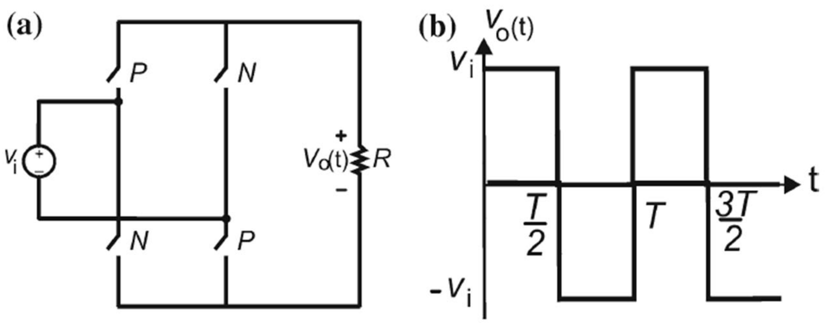
DC-AC Invertor

- Voltage Source Invertors
  - Pulse-width modulated inverter (e.g. Sine –PWM)
    - The inverter itself controls the frequency as well as magnitude of the ac output voltage by doing pulse-width modulation
  - Square Wave Invertors
    - Invertor needs to control only the frequency
    - The input DC voltage is controlled by external means (e.g. DC-DC Convertors)
    - The output of such a converter is more like a square-wave and therefore the name given as square-wave inverter
    - **Half-Bridge Invertor**
    - Full-Bridge Invertor

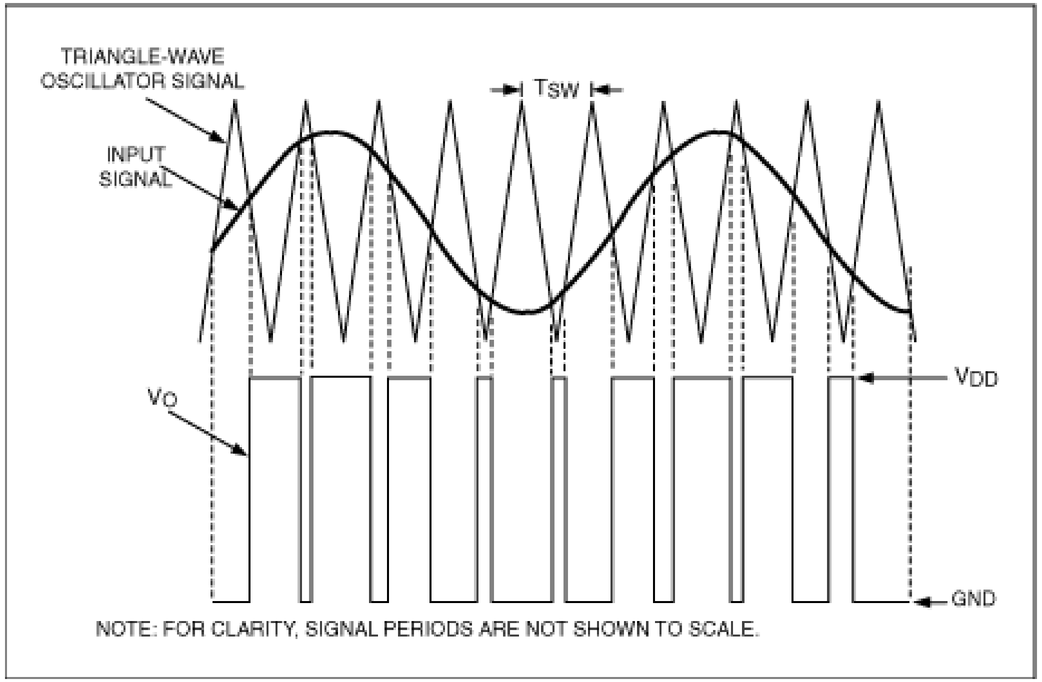
DC- AC Invertor



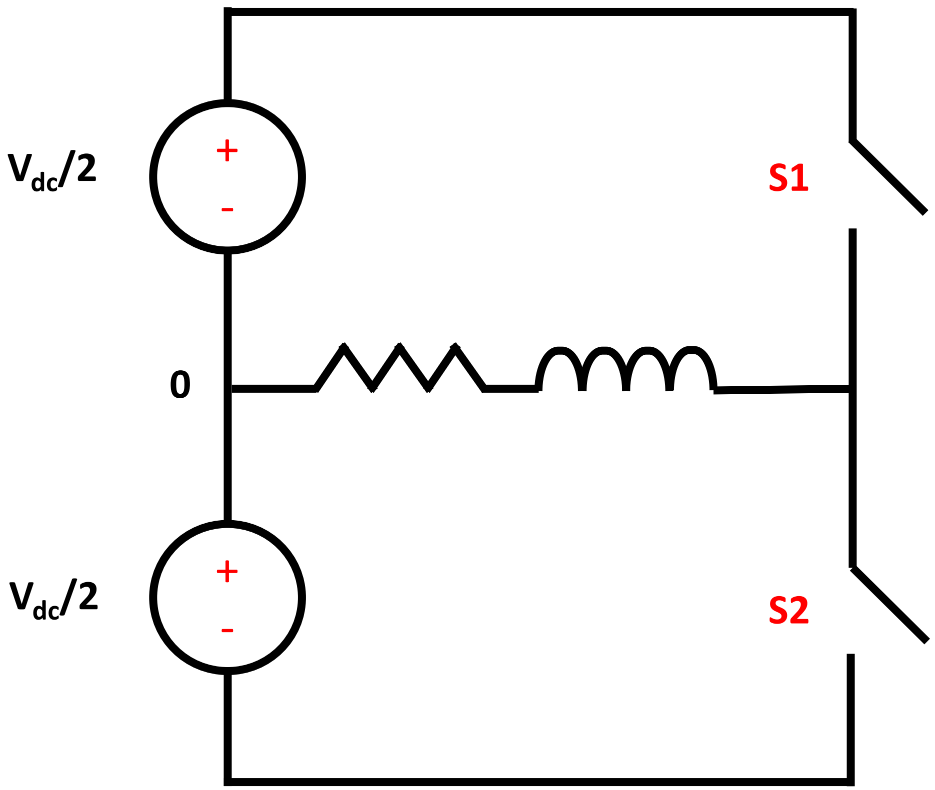
- Single Phase Square Wave Invertor



- Single Phase Sine PWM Invertor

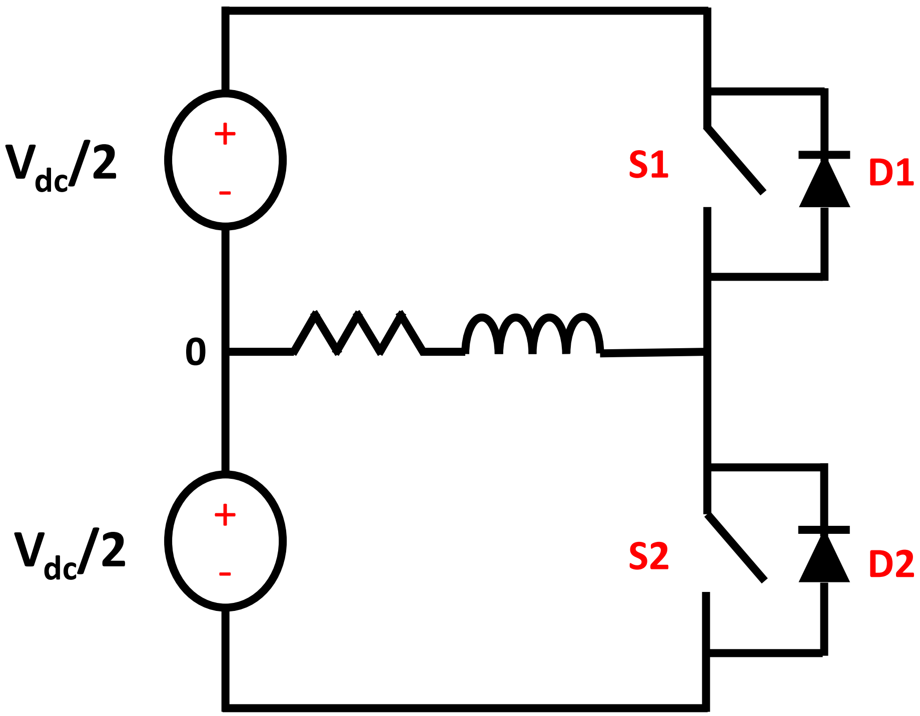


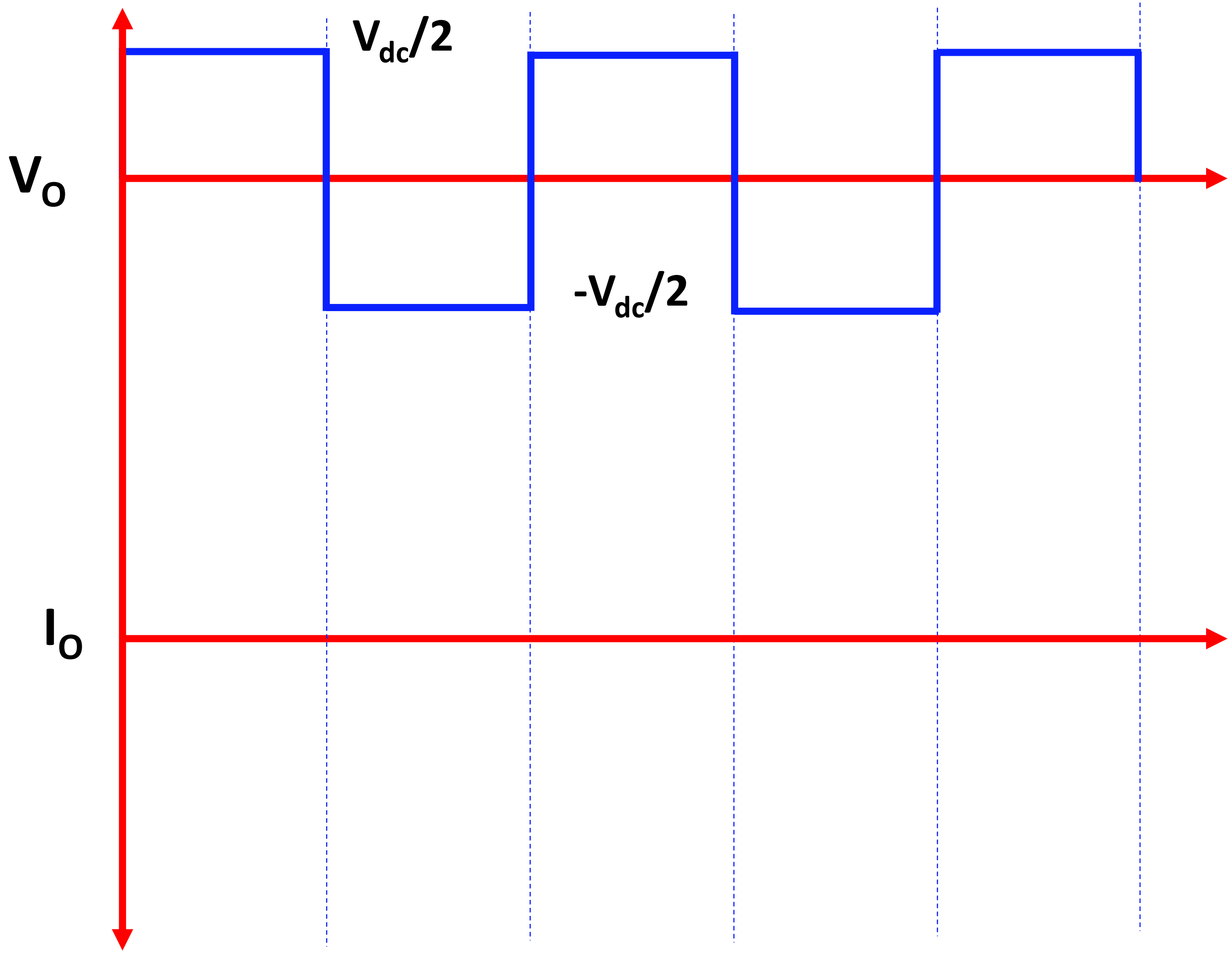
Half Bridge Square Invertor



Conducting Switch	Output Voltage
S1	
S2	

Half Bridge Square Invertor





Harmonic Distortion: Square Wave vs Sine Wave

- How Sinusoidal is the Square Wave???
- Express the Square wave as a Sum of Sine Waves (Fourier Series Analysis)

$$v_o = \sum_{n,odd}^{\infty} \frac{4\mathrm{V_{dc}}}{n\Pi} Sin(n\omega t)$$

$$v_1 = \frac{4V_{dc}}{\Pi} Sin(\omega t)$$

$$v_{1,rms} = \frac{4V_{dc}}{\sqrt{2}\Pi}$$

- **Total Harmonic Distortion**
- The quality of the ac output voltage can be determined from the Total Harmonic Distortion (THD) factor
- $V_{o,rms} = V_{dc} \quad (\text{RMS value of square wave})$
- $V_{1,rms} = \frac{4\,V_{dc}}{\sqrt{2}\Pi}$
- $THD_v = \frac{\sqrt{V_{o,rms}^2 - V_{1,rms}^2}}{V_{1,rms}}$

$$= \frac{\sqrt{(V_{dc})^2 - \left(\frac{4\,V_{dc}}{\sqrt{2}\Pi}\right)^2}}{\frac{4\,V_{dc}}{\sqrt{2}\Pi}} = 48.3\%$$

QUESTIONS