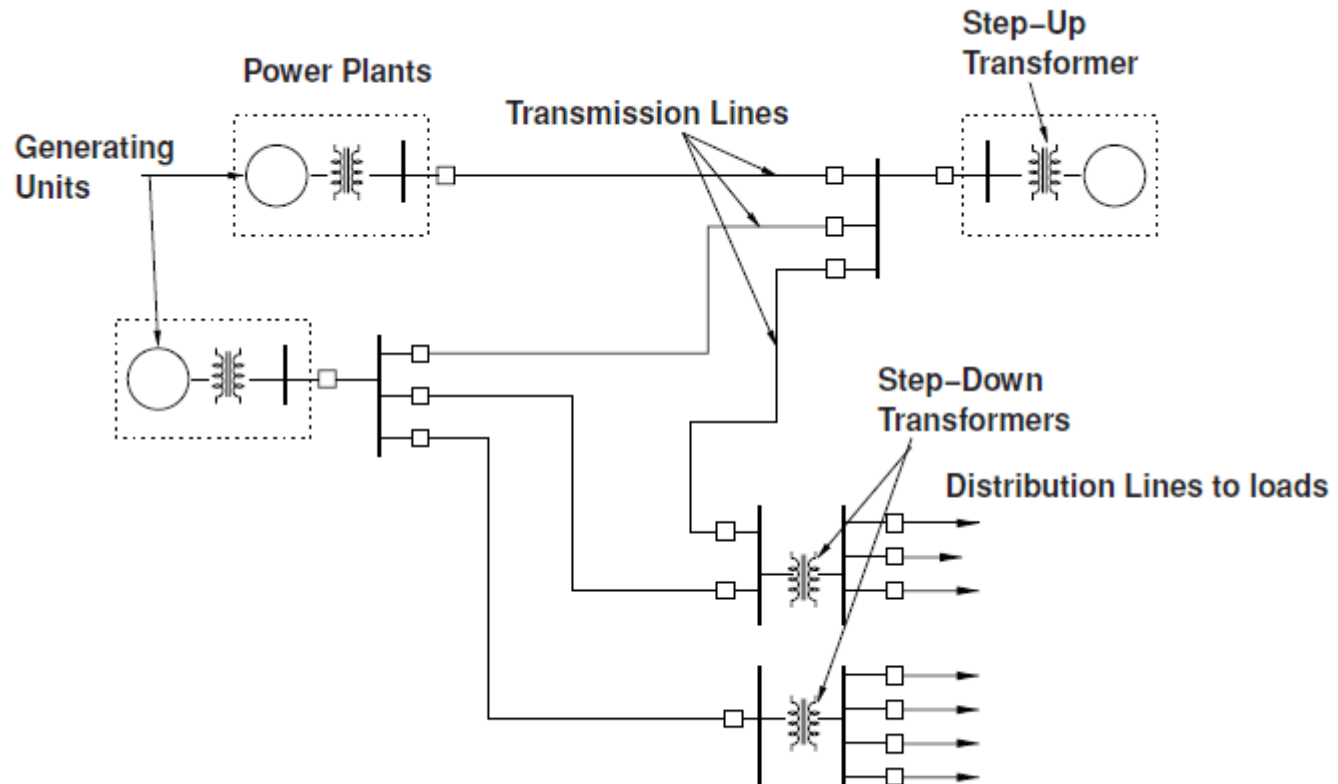


## 1.1. Electric Utility Systems

Electric power originates in 'power plants'.

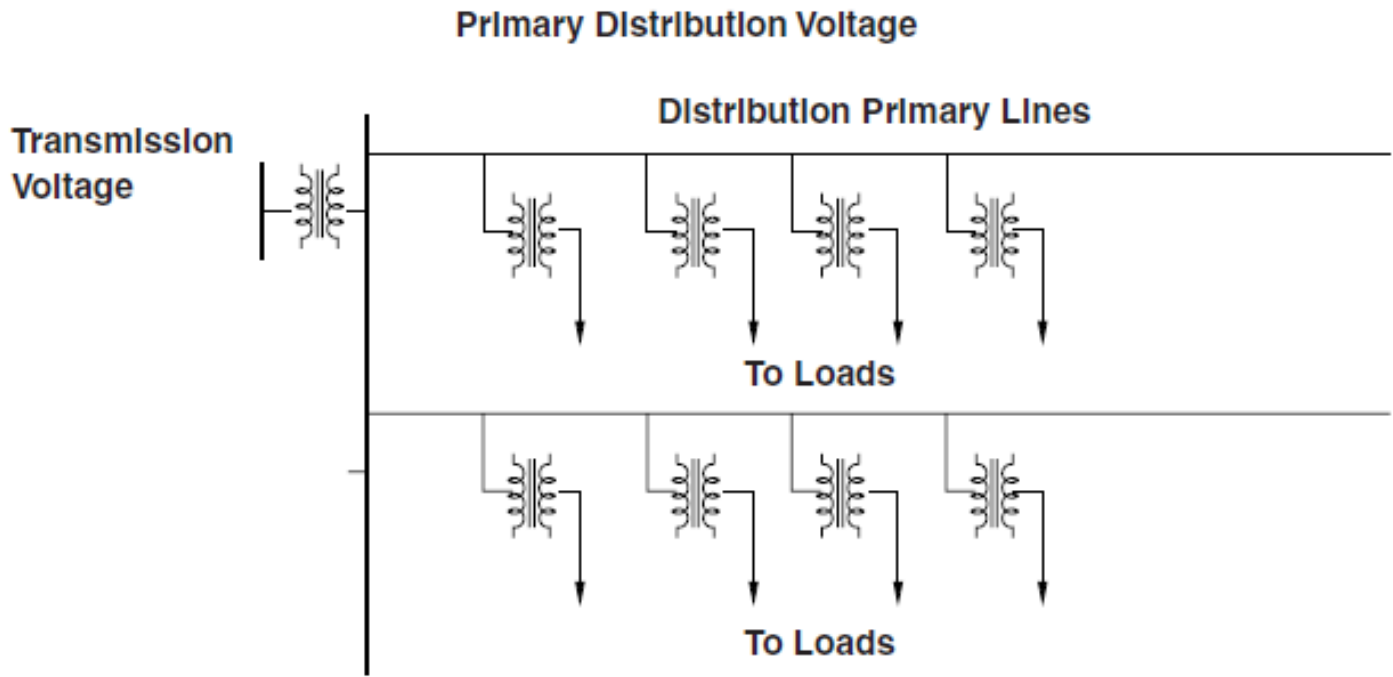
Voltage is first stepped up by transformers, from a efficiency for long-distance transmission

Near the loads the electric power is stepped down, by transformers, to a voltage useable by the customer



In modern utility systems there are thousands of power plants connected together through networks

The connections to actual loads is usually a bit more like



At the distribution level the connection is 'radial':

- a) there is one connection from the source of electric power (the 'grid'),
- b) and that is broken down into many load connections.

Usually the distribution primary line is at a voltage level intermediate between the transmission level and the voltage that is actually used by customers

## 1.2. Energy and Power

**Energy: joule (J)** is the energy expended by pushing a newton (N), a unit of force, over one meter. A joule is a newton-meter.

(A kilogram 'weighs' about 9.8 newtons at the surface of the earth).

**Energy: Calorie** is the amount of energy required to heat 1 gram of water 1 degree Celsius. This amounts to about 4.184 joules = 1 gram Calories

**Power: is the watt**, which is one joule/second. As it our predecessors crafted it, 1 watt is also 1 volt  $\times$  1 ampere.

a basic unit of energy is the kilowatt-hour (kWh), ( $3.6 \times 10^6$  J). *Electricity is sold at retail by the kilowatt-hour*

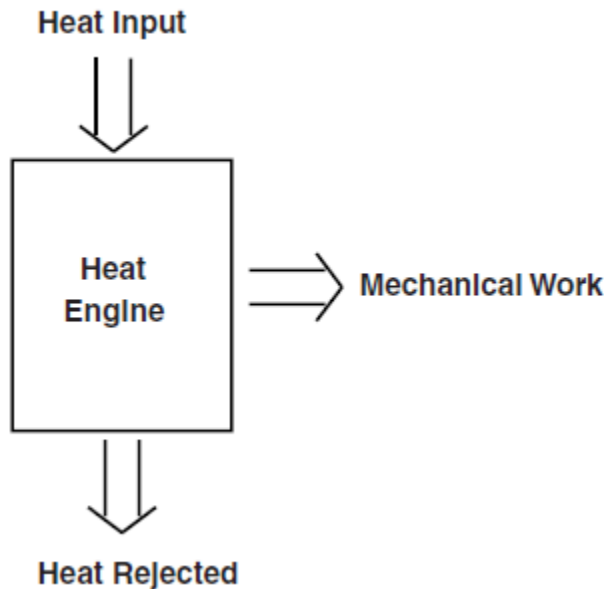
**Heat:** unit of heat that is commonly used in discussing power plants is the British Thermal Unit (**BTU**), which is the amount of heat required to raise 1 pound of water 1 degree Fahrenheit. This is about 0.252 kilogram calories or 1054 joules

### 1.3. Sources of Electric Power

Electric power production: a) by generators turned by some sort of 'prime mover'  
b) by direct conversion from a primary source such as sunlight, or conversion of chemical energy in fuel cells.

#### Prime Movers

Burn a primary fuel (coal or natural gas) and produce mechanical power (generally turning a shaft) that is used to drive a generator to produce electrical power



Carnot efficiency:

temperature of the input heat and the rejected heat.

heat input temperature

heat rejection temperature

$$W_m < Q_h \frac{T_h - T_\ell}{T_h}$$

input energy

Practical heat engines do not approach this Carnot limit very closely, but this expression is a guide to heat engine efficiency: generally higher heat input temperatures and lower heat rejection temperatures lead to more efficient heat engines.

one kilowatt-hour is 3.6 MJ or 3,414 BTU.

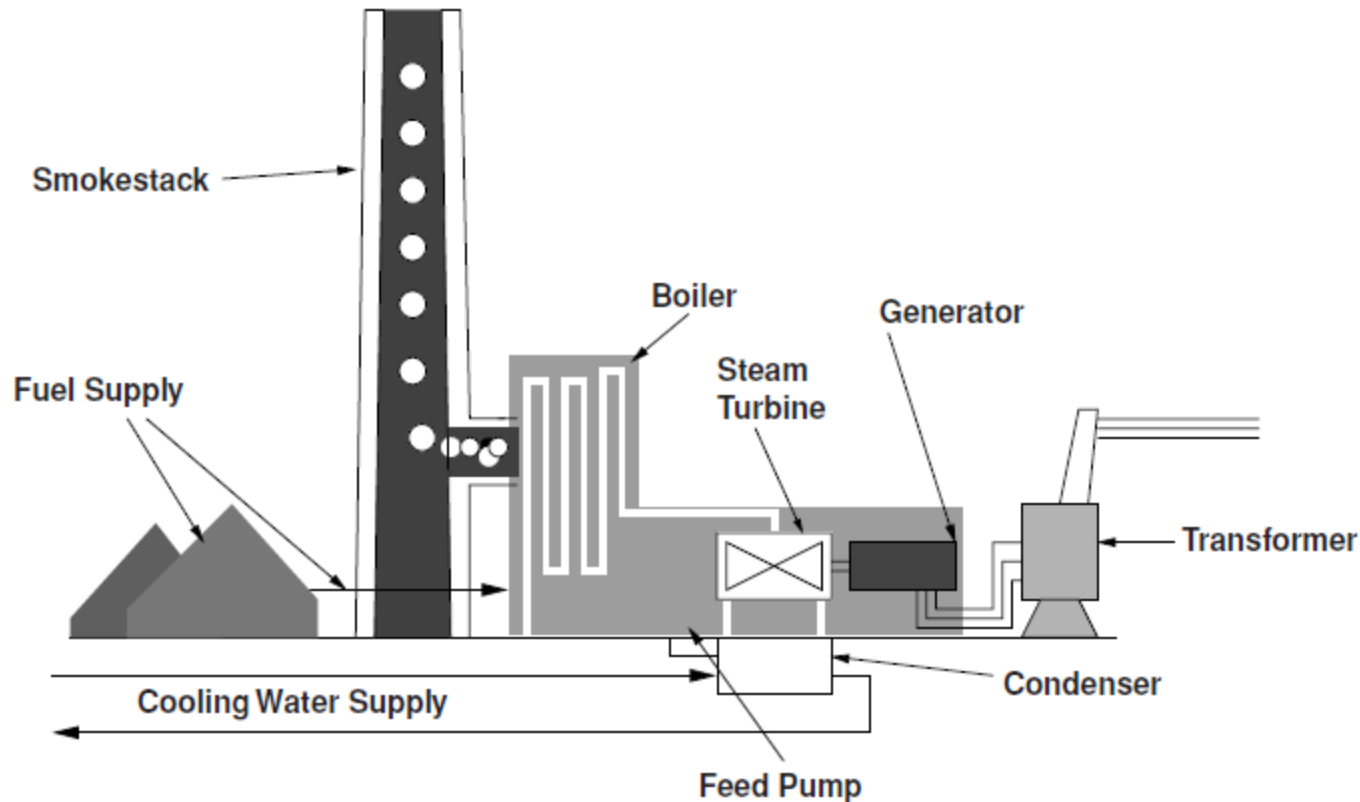
The fuel energy input to a power plant to produce one kilowatt hour is referred to as its 'heat rate', and this is inversely related to its thermal efficiency.

power plant that has a heat rate of, say, 10,000 BTU/kWh would have a net thermal efficiency

$$\eta = \frac{3414}{10000} \approx 0.3414.$$

## Power plant that burns fossil fuels

Water is first compressed and pumped into a 'boiler', where a fire heats it into steam. The steam is expanded through a turbine which turns a generator. The turbine exhaust is then fed to a 'condenser' where the waste heat is rejected.



Different rejected heat: rivers, lakes, the ocean, purpose built cooling ponds or cooling towers  
Generated electricity is generated at 'medium' voltage ('medium voltage' is generally taken to be between 1 kV and 100 kV, but power plant generators are generally limited to about 30 kV) and is usually stepped up to 'high' (100 to 230 kV) or 'extra high' (230 to 800 kV) voltage for transmission.

## Environmental Impact of Burning Fossil Fuels

Mercury is toxic in surprisingly small quantities, coal is burned, mercury is released in the effluent gas and/or 'fly ash' and then gets into some food chains.

Sulfur oxides and nitrogen oxides, the result of oxidation of nitrogen in the air. There are different oxidation states of both nitrogen and sulfur, so that this type of pollution is often referred to as '*SOX and NOX*'. *Not only do these chemicals produce acid rain, but they can (and do) react with hydrocarbons present in the air to form a visible haze that is often referred to as 'smog'.*

Fossil fuels generally contain carbon and hydrogen. impacts on the earth's heat balance

Fossil fuel carbon analysis	Coal	No. 6 Fuel Oil	Natural Gas
Fraction carbon	0.807	0.857	0.750
Fraction hydrogen	0.045	0.105	0.250
HHV (BTU/kg)	30 870	40 263	50 780
HHV (kJ/kg)	32 573	42 438	53 522
kg CO <sub>2</sub> /kg fuel	2.959	3.142	2.750
kg CO <sub>2</sub> /MBTU	95.9	78.0	54.2
kg CO <sub>2</sub> /kWh (at 10 000 BTU/kWh)	0.959	0.780	0.542
kg CO <sub>2</sub> /hour (at 1000 MW)	323 939	248 365	196 928
kg CO <sub>2</sub> /hour	958 536	780 446	541 552





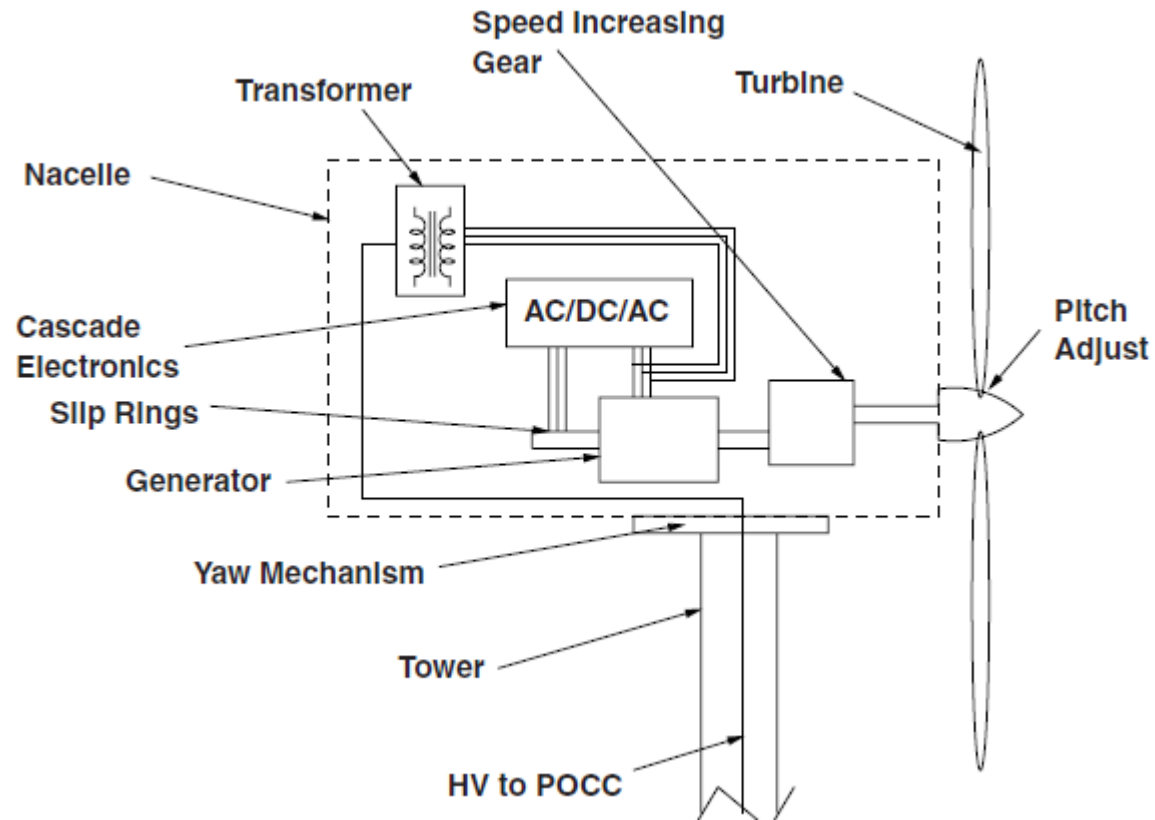
# Wind Turbines

1.5 MW wind turbines: blade disk diameter of about 77 m and 'hub height' of 65 to 100 m

$$\text{Power} \leftarrow P = \frac{1}{2} C_p \rho_{\text{air}} A u^3 \rightarrow \begin{array}{l} \text{Air velocity} \\ \text{Blade disc area} \\ \text{Air density (1.2 kg/m}^3\text{)} \end{array}$$

Power coefficient: Characteristic of wind speed, rotor angular velocity and blade pitch angle  
%50 - %59

variable speed, constant frequency (VSCF) machines used for wind wind speeds of about 3 m/s, to 11–13 m/s. This 'cut out' speed may be on the order of 30 m/s.



## Solar Power Generation

Radiation from the sun, in the visible and infrared, amounts to about 1 kW per square meter in the vicinity of the earth.

- The atmosphere captures and scatters some of the solar radiation
- earth turns, half the time the sun is not visible at all
- Clouds interfere with solar radiation
- Existing technologies for conversion of solar radiation into electricity are, currently, expensive relative to other sources.

There are two principal means of solar generation of electricity. One employs heat engines similar to fossil fuel or nuclear generation.

The second means of generating electricity from sunlight employs photovoltaic cells

large area junction diodes that, when sunlight shines on them and splits electron/hole pairs, produce a current.

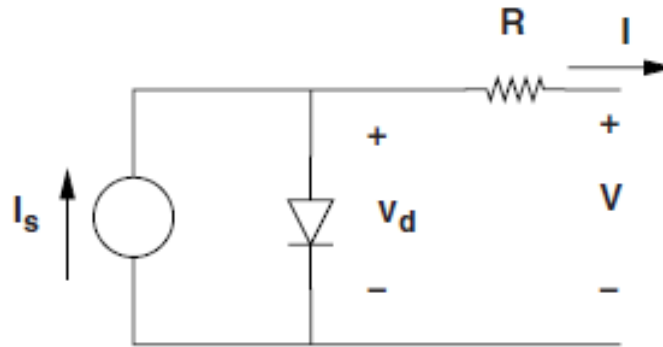
The source current  $I_s$  is the result of absorption of photons in sunlight that cause separation of valence electrons from their atoms. The resulting hole/electron pairs fall across the high field gradients present at the diode junction.

depends on junction area and on how the cell was constructed

cell current  $I = I_s - I_0 \left( e^{\frac{V_d}{kT/q}} - 1 \right)$

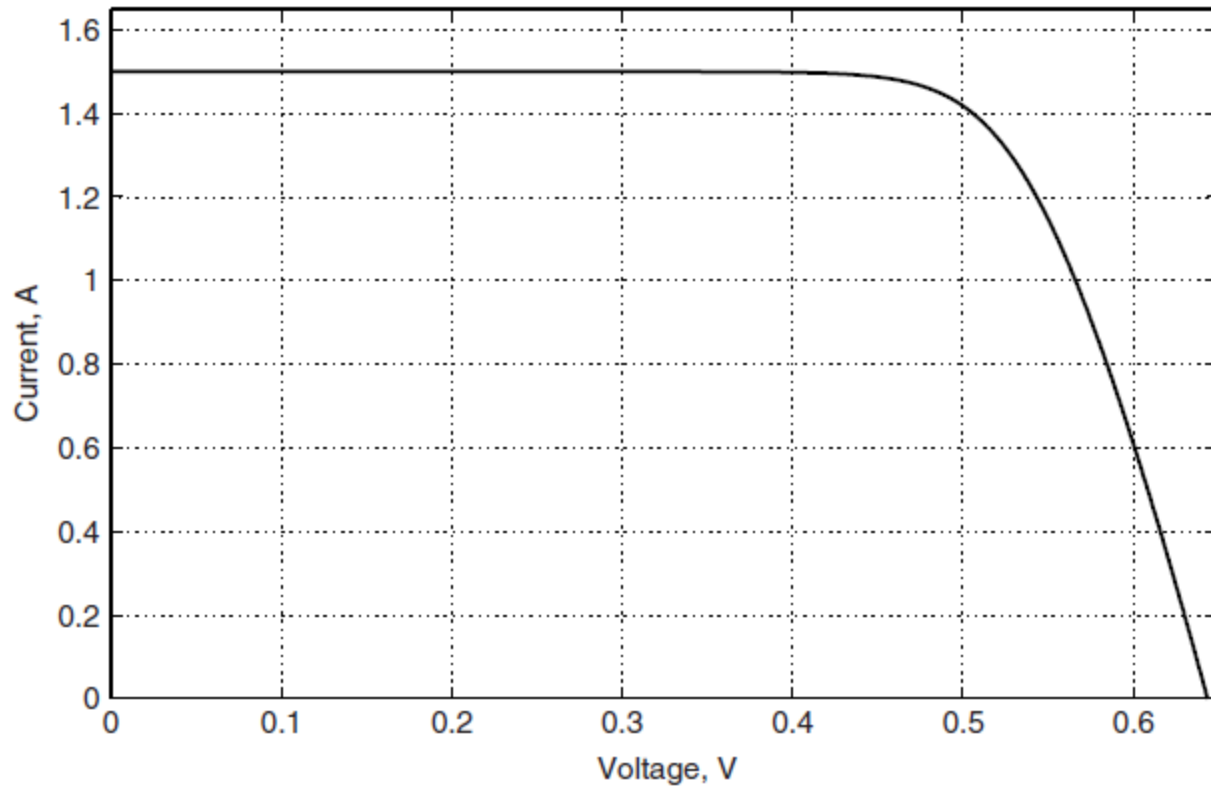
voltage  $kT/q$  is about 25 mV at room temperature

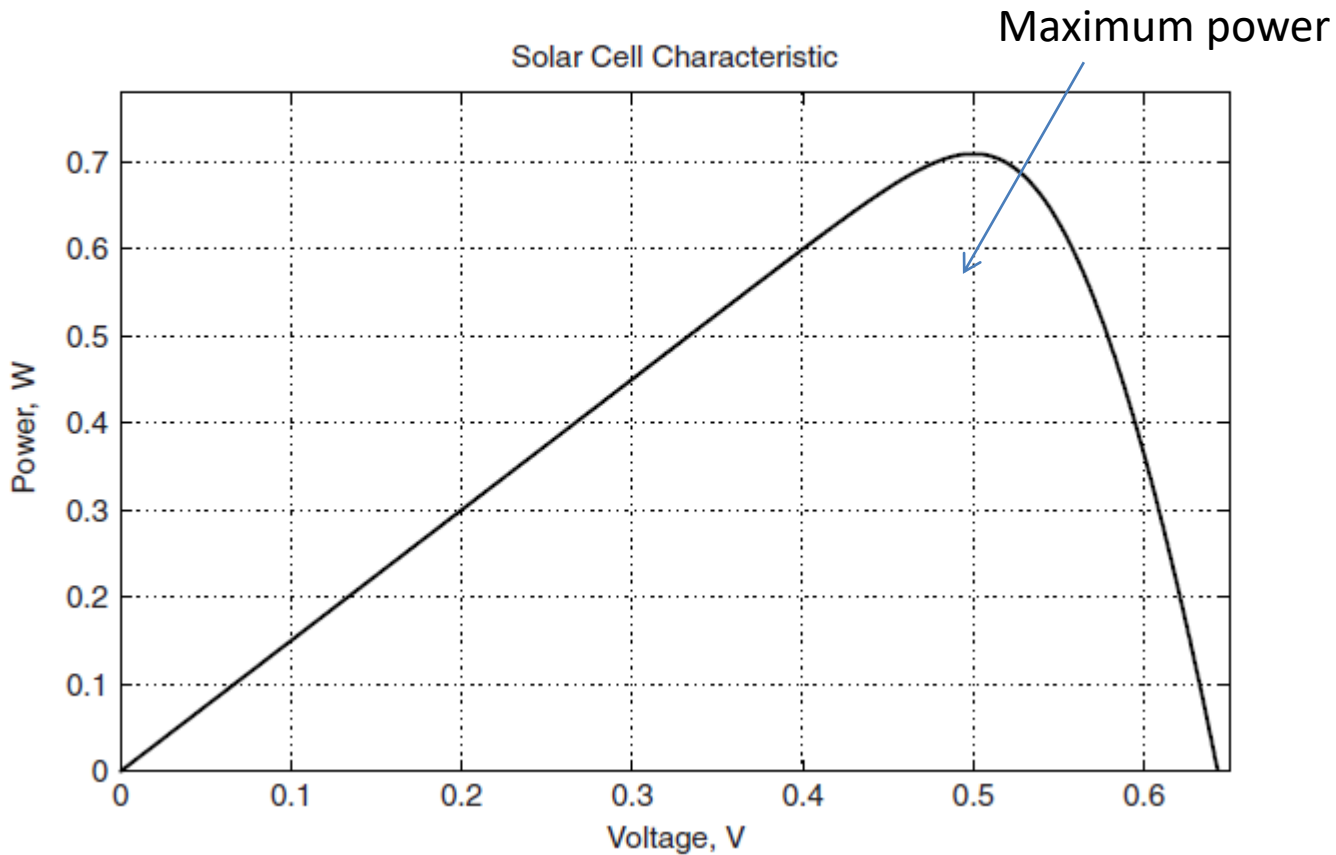
depends on the strength of solar radiation actually reaching the junction and on how strongly it is absorbed and on the junction area.



An equivalent circuit model of a solar array

Solar Cell Characteristic





maximum power point is a function of both temperature and radiation, so there is no simple way of loading the cells to get the maximum amount of power from them. The problem of maximum power point tracking (MPPT) has become an item of competitive art among manufacturers of solar cells and the electronics that go with them

electronic systems that absorb electric power from the cells, implement maximum power point tracking, and then convert the resulting DC power into utility frequency AC, single-phase (for small systems) or polyphase (for larger systems).