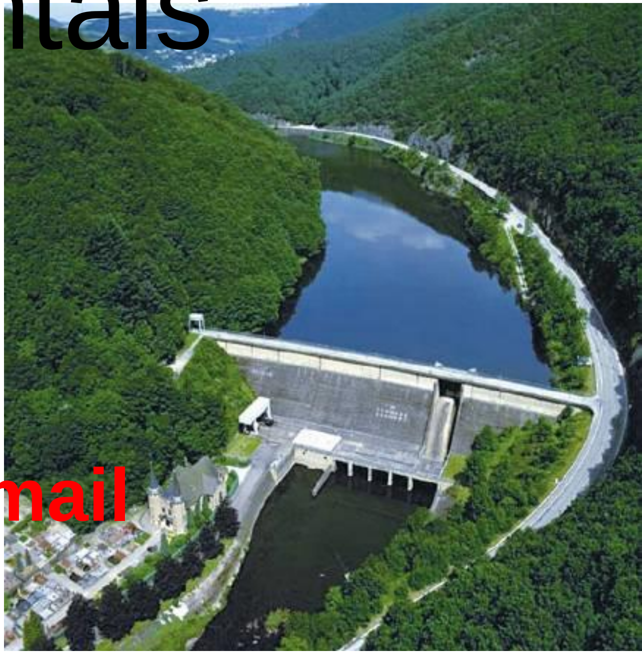
L3 Online continued 4/3/2024

Renewable Energy and Photovoltaic Power Systems (ENEE5307)

L3- Energy Fundamentals

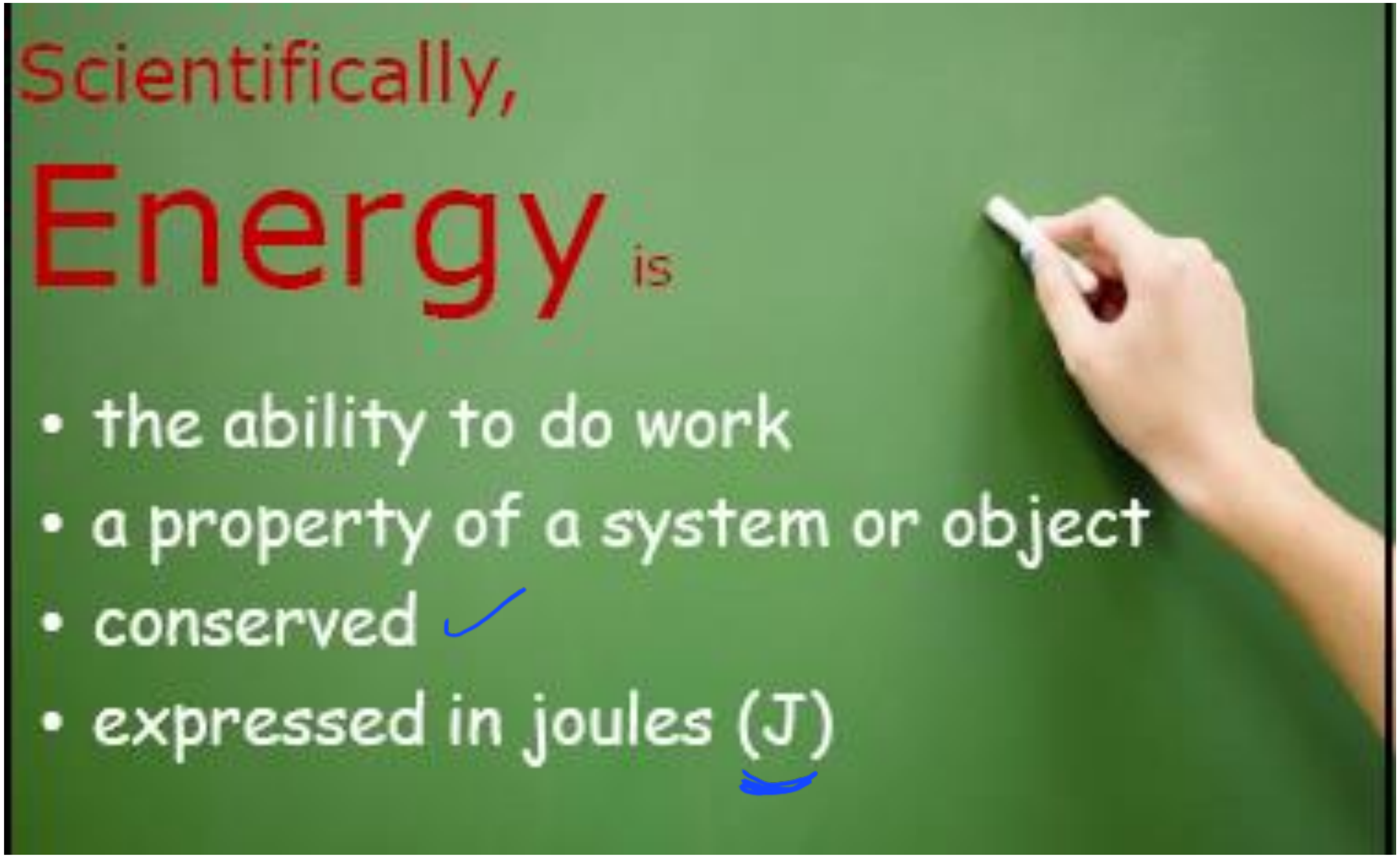


Instructor : Nasser Ismail

Overview

- Energy
- Forms of Energy
- Conversion of Energy
- Power
- Capacity Factor

What is Energy?



Energy and Units

- Energy: measured in joule (J):
- 1 J=1kg. m^2/s^2
- Watt-hour (Wh) is a measure of electrical energy (consumption and production)
- 1 calorie =4.18 J * (energy required to heat 1kg of water 1K)
- 1kWh=3.6 MJ *
- 1BTU=1055J * (British Thermal Unit)
- 1kWh =3428BTU *

Energy Content

- Rough Equivalent:
  - 1 gallon of gasoline=130 MJ=36.1 kWh
  - 1 pound of coal=16 MJ=4.44 kWh
  - 1 standard cubic foot of natural gas=1.1 MJ=0.31 kWh
  - An average candy bar=1 MJ=0.27 kWh

Energy

- A marathon runner burns 2,000 calories during the race (26.2 miles)
- The race is completed in 4 hours
- ***How many kWh does he burn?***
- Answer:
- 2,000 calories=2000x4.18 J/Calorie

=8.36x10^6 J

= 8.36x10^6 J /(3.6x10^6 J/kWh)

= 2.32 kWh

Forms of Energy

- Kinetic Energy
- Gravitational (potential)
- Nuclear
- Electrical

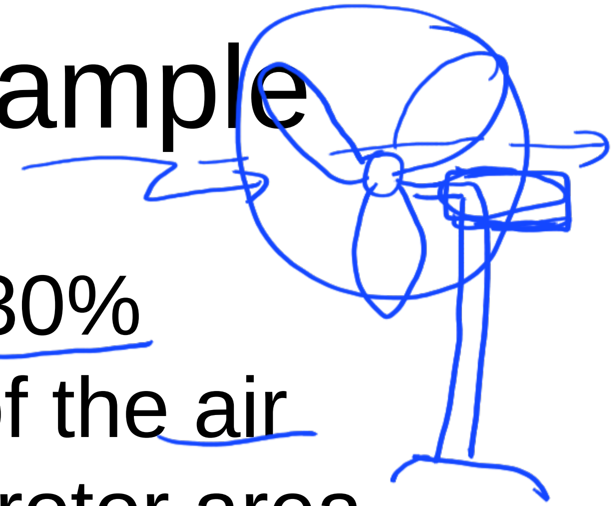
Kinetic Energy

- Energy of a Moving object

$$E_k = \frac{1}{2} m V^2$$

  - m: mass of the object (kg)
  - V: velocity of the object (m/s)
- Used in wind turbines, wave powered generators, run-of-river hydro generators

Kinetic Energy - example



- A wind turbine converts with 30% efficiency the kinetic energy of the air mass that passes through its rotor area
- Assume the air is travelling at a speed of 10m/s, the density of air is 1.2 kg/m^3 and the rotor diameter is 90 m
- ***How much electric energy, in kWh, does the wind turbine produce during one hour?***

Kinetic Energy

- Mass of the air: area x length x density
- Area: $A = \left(\frac{90}{2}\right)^2 \pi = 6361\, m^2$
- Length: $L = 10x60x60 = 36000\, m$
- Density: $= 1.2\, kg/m^3$
- M$ass = 274{,}818{,}420\, kg$

Kinetic Energy

- Applying: $E_k = \frac{1}{2}mV^2$
- $E_k = \frac{1}{2}(274{,}818{,}420)10^2 = 13.7\ GJ$
- Accounting for efficiency:

Energy =0.3x13.7 GJ=4.11 GJ

Converting to MWh:

$$Energy = \frac{4.11\ GJ}{3600\left(\frac{MJ}{MWh}\right)}$$=1.15 MWh

Kinetic Energy (Heat)

- Temperature and heat are related by specific heat and mass of a substance
- $\frac{\Delta Q}{\Delta T} = mC_h$
- Where:
- C_h: specific heat (J/K)
- ΔQ : change in heat (J)
- ΔT : change in temperature (K)

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Kinetic Energy

- Standard units of temperature
- $T(°C) = T(K) - 273.15$
- $T(°F) = 1.8\,T(°C) + 32$
- Where
- T temperature
- K: Kelvin
- °C : Celsius
- °F : Fahrenheit

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Kinetic Energy

120F = ? °C
$(120 - 32) \times \frac{5}{9} \simeq 49°C$

- You plan on using large mirrors to reflect sun light onto a container to heat your shower water
- You will use 30 liters of water in your shower at temperature of 120 degrees F, the unheated water is at 60 degrees F
- *How much energy must be applied to the water?*
- Ignore the presence of the container in the calculation
- Note: C_h=4186 J/K for water, 1L weighs 1 kg

given

Kinetic Energy

- First convert to K: $120°\text{F} = 322\ K$
- $60°\text{F} = 289\ K$
- Mass of the water : 30 kg
- Now apply:
- $\Delta Q = (\Delta T)mC_h$=4.14 MJ
- =1.15 kWh
- (since 1 kWh=3.6 MJ)
- Thermal energy is used in solar thermal generation, geothermal generation

Gravitational Energy

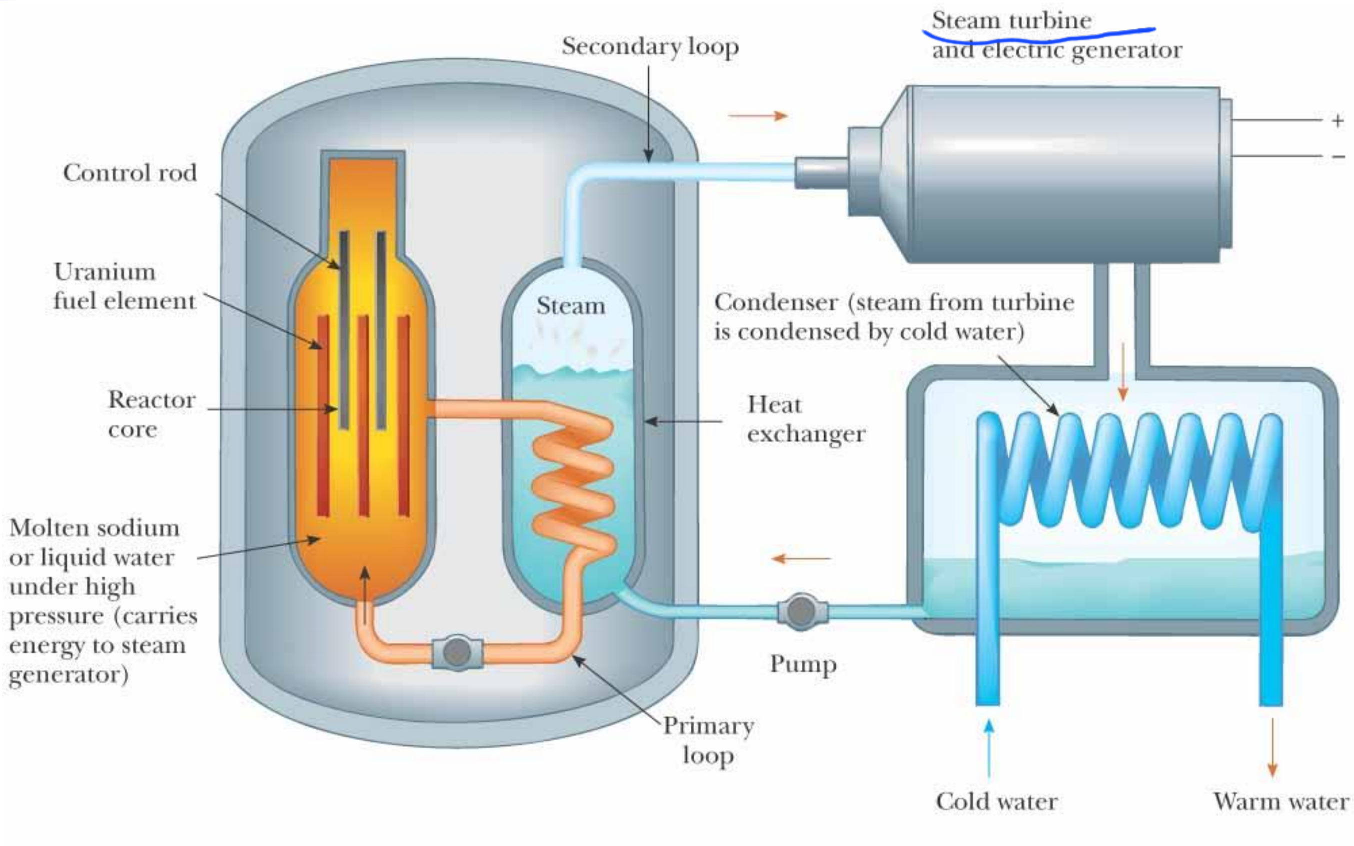
- Potential Energy

  $$Ep=mgh$$

- Where;
  - m: mass of the object (kg)
  - g: acceleration caused by gravity (9.8 m/s^2)
  - h: height (head) of the object (h)
- Gravitational energy is used in tidal generation and hydro generation

Nuclear Energy

- Energy bound up in the nucleus of an atom
- Nuclear fusion is used in nuclear power plants



Power ≡ W   Energy ≡ Wh

- The derivative of energy with respect to time $$P = \frac{dE}{dt}$$
- Where :
- E: energy (J)
- T: time (s)
- Rate of energy change, unit of power is Watt (W)
- Common conversions:
- 1 horse power (electric) =746 W

Power

- A marathon runner burns 2000 Calories during the 26.2 mile race which is completed in 4 hours.
- What is the average power output?

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- Solution: 2000 calories=2.32 kWh
- Average power =2320/4=580 W

Power and Energy

- The terms “power” الطاقة and energy القدرة are used interchangeably
- This can cause confusion, especially in renewable energy systems

Power and Energy

- A 10 kW continuous electrical load is connected to the electrical grid and a 2 kW PV array
- Can the owner rightfully claim that 20 % of the load is supplied by renewable energy?
- The answer is
- NO
- The PV will only produce power when the sun is shining on it

Capacity Factor

- A 2 kW PV over the course of a day might only produce ~9.6 kWh of energy due to sunset, clouds, angle of the sun, etc
- If the sun was shining overhead 24 hours a day, then E= 2 kW x 24=48 kWh
- The ration of between average energy generated over a period of time to the theoretical maximum energy generated over that time is known as **capacity factor**

Capacity Factor

- $CF = E_{actual}/E_{theory}$
  - CF: capacity factor (usually expressed in %)
  - E_{actual}: actual energy produced over H hours (MWh)
  - E_{theory}: maximum theoretical energy produced over H hours (MWh)
- $E_{theory} = C \times H$
  - C: Rated capacity of the generator (MW)

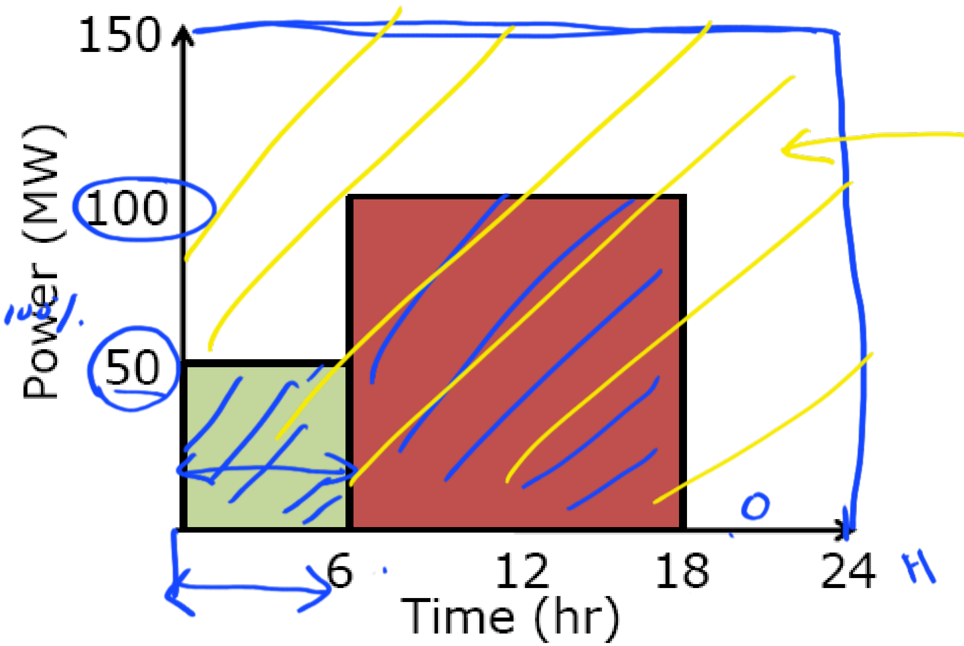
Capacity Factor

- Typical Lengths of time are:
  - ➢Lifetime of the plant
  - ➢Year
  - ➢Day
- In the PV Example :
- CF=9.6Wh/48 kWh= 0.20=20%

Example

Capacity Factor

- A 150 MW wind power plant produces the following output:

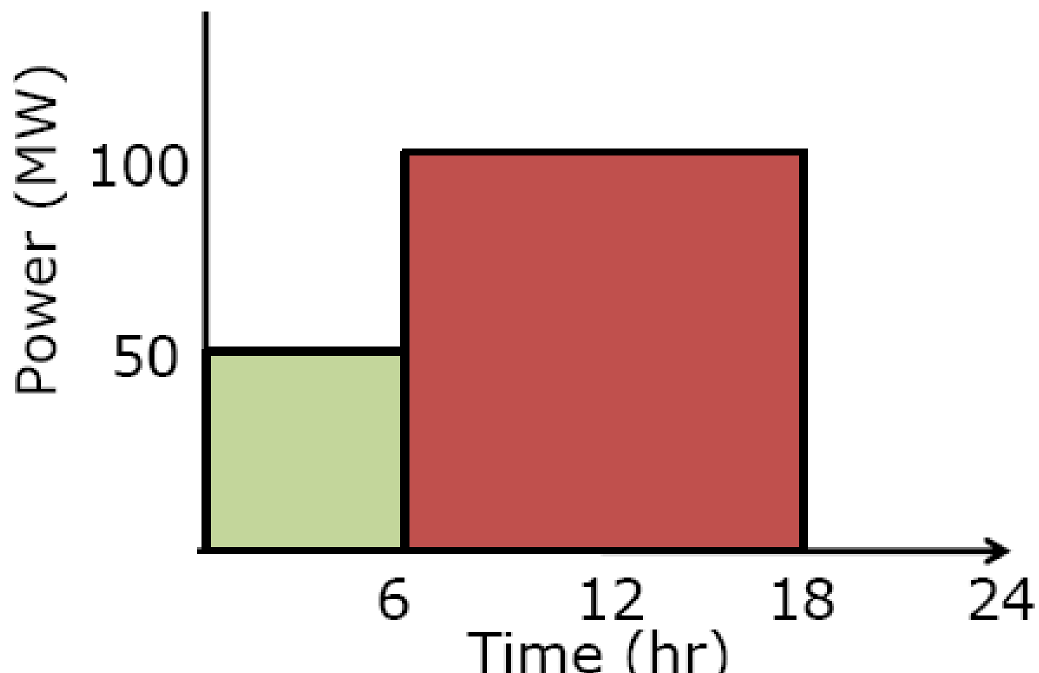


$$CF = \frac{E_{actual}}{E_{theory}} = \frac{50 \times 6 + 100 \times 12 \cdot 100\%}{150 \times 24}$$

=

- Find its capacity factor for the day?

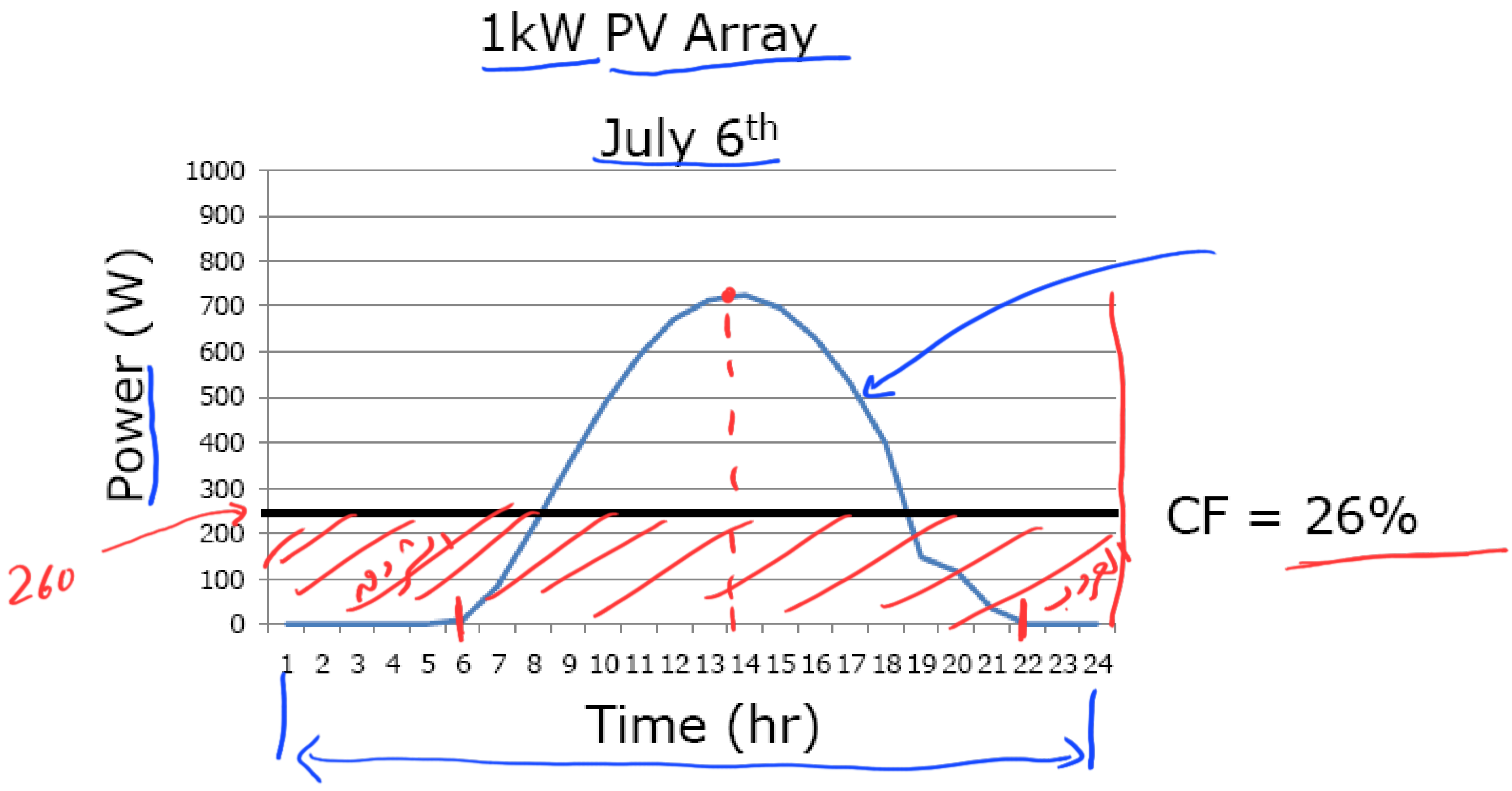
- Eactual=(50x6+100x12)=1500 MW
- Etheory=24x150=3600 MW
- CF=1500/3600=0.417
- CF=41.7%



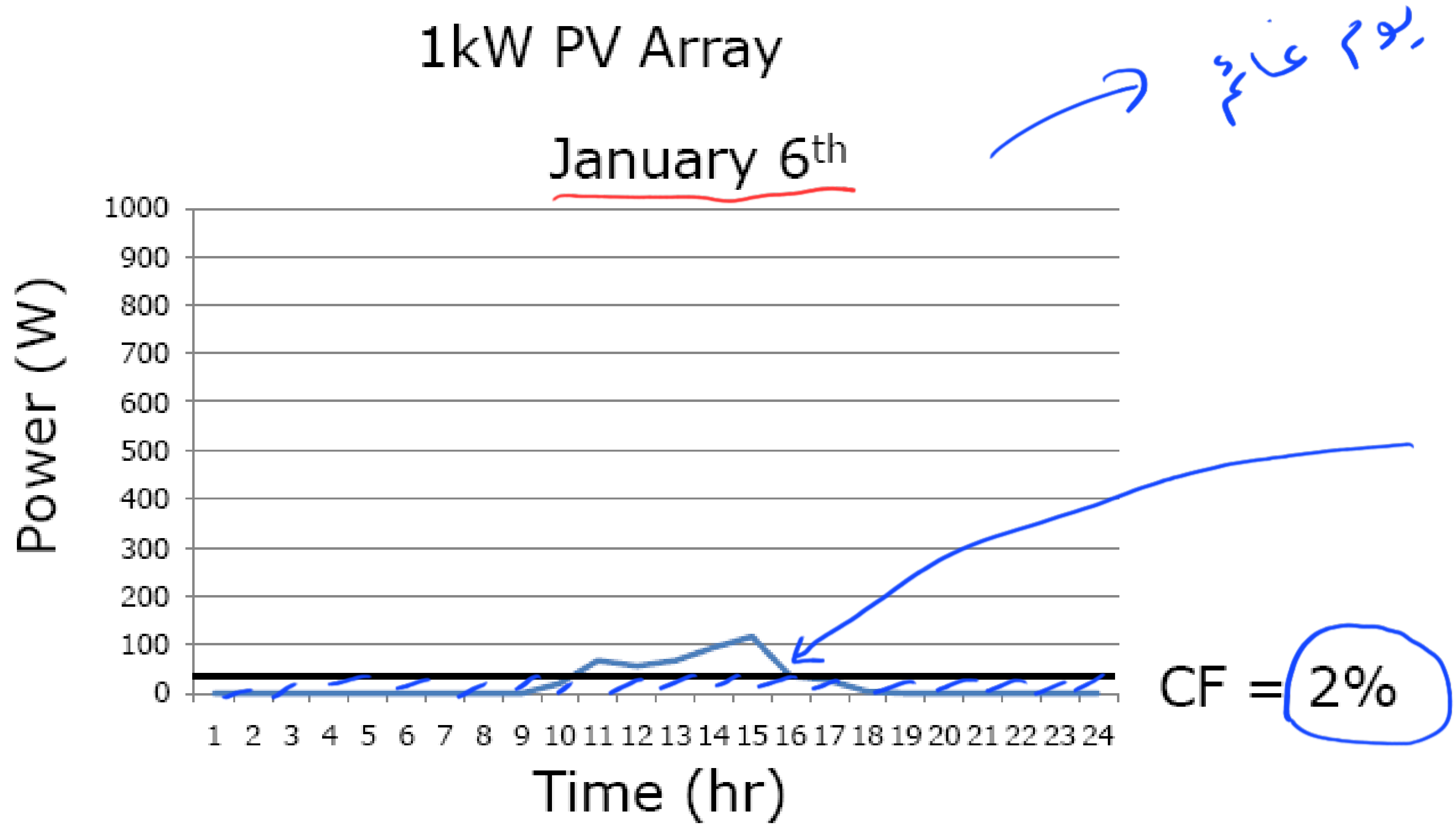
Capacity Factor For Renewable Sources

- Capacity factors vary substantially for different renewable energy systems:
  - Wind : 20-40%
  - Solar: 10-25%
  - Hydro: 50-80%
- Capacity factors often have seasonal variations

Capacity Factor



Capacity Factor



CF = 2%

Capacity Factor

- In 2008, wind plants in the US supplied 52 Million MWh of energy. The total installed wind plant capacity was approximately 25,000 MW. What is the average capacity factor of the wind plants in the US?

365x24 = 8760 h/year

  - $E_{actual} = 52 \times 10^6$ MWh
  - $E_{theory} = 25 \times 10^3$ MWh x 8760 = 219×10^6 MWh

- CF = 52/219 = 23.7%
  - Note: this is an underestimation because the 25,000 MW was the year-end total