Lesson 25: Solar Panels and Economics of Solar Power

ET 332a

Dc Motors, Generators and Energy Conversion Devices

Learning Objectives

After this presentation you will be able to:

- Identify and interpret a solar panel ratings
- Estimate the energy production from a solar panel array
- Indentify the main components required to set up a solar panel application
- Compare the costs of electricity sources
- Determine the economic benefit of installing a solar array.

Solar Panels

Solar panels built from individual cells in series/parallel combinations

Typical (silicon) cell V_{oc} =0.6 V A=125 cm^2 40 cells V_{oc} =24 V A=0.5 m^2

Output with solar intensity of 1000 W/m^2 = 75 W for η_c = 15%

Panel rating: Watts peak = power panel produces at solar intensity of 1000 W/m^2 (Wp)

Example: A panel rated at 1 kWp produces 1 kW with solar intensity of 1000 W/m^2.

Output varies with solar intensity. 1 kWp will produce 1800 W in So. California and 850 W in Northern States

Numerically the same as annual solar energy per square meter

Solar Panels Example

Example 25-1: A solar panel is made of 40 silicon cells in series with V_{oc}=0.6V an area of 0.01 m^2, and a fill factor of 0.7. The short circuit current under AM1.5 is 400 A/m^2. In southern Illinois the daily solar radiation is 5.0 kWh/m^2/day. If a house has 8 m^2 of roof area available for solar panels, estimate the annual energy production from the panels.

$$E_I := 5.0 \cdot \frac{kWh}{m^2 \cdot day}$$ Average daily energy per unit area

$$J_{sc} := 400 \cdot amp \cdot m^{-2}$$ Panel Short Circuit Current Density

Convert to annual energy per unit area

$$E_A := E_I \cdot 365 \cdot day \qquad E_A = 1825 \frac{1}{m^2} kWh$$

5 kWh/m^2-day

Example 25-1 Solution Continued (2)

AM1.5 gives 1000 W/m2. Find the equivalent continuous Illumination, P_{inc}.

$P_I := 1000 \cdot \frac{W}{m^2}$ $t := 8760 \cdot hr$

$P_{inc} \cdot t = E_A$ $P_{inc} := \frac{E_A}{t}$

1825 kWh/m2

8760 hr

$P_{inc} = 0.208 \frac{1}{m^2} kW$

400 A/m2

J_{sc} is proportional to P_{inc} so...

$J_{sc1} := J_{sc} \cdot \frac{P_{inc}}{P_I}$

$J_{sc1} = 83.3 \frac{A}{m^2}$

Example 25-1 Solution Continued (3)

Multiply cell area by number of cells to find total panel area

$A_c := 0.01 \cdot m^2$ 0.01 m2 $A_T := A_c \cdot 40$ $A_T = 0.4 m^2$

Cell Open Circuit Voltage is $V_{OC} := 0.6 \cdot volt$

0.6 V

$V_{OCP} := V_{OC} \cdot 40$ $V_{OCP} = 24 volt$ Open Circuit panel voltage

Compute panel short circuit current

83.3 A/m2

$I_{sc} := J_{sc1} \cdot A_c$ 0.01 m2 $I_{sc} = 0.833 A$

panels connected in parallel so that multiple panel current add. So....

$I_{sca} := I_{sc} \cdot \left(\frac{8 \cdot m^2}{0.4 \cdot m^2} \right)$ $I_{sca} = 16.7 A$

Example 25-1 Solution Continued (4)

Find the power output using the Fill Factor $FF := 0.7$

0.7

$P_{out} := FF \cdot I_{sca} \cdot V_{OCP}$ 24 V $P_{out} = 0.28\, kW$

8760 hr

$E_{tot} := t \cdot P_{out}$ 16.7 A $E_{tot} = 2453\, kWh$ 2453 kWh

Total incident solar energy

$E_{totI} := E_A \cdot 8 \cdot m^2$ $E_{totI} = 14600\, kWh$ 14,600 kWh

1825 kWh/m²

$\eta_c := \frac{E_{tot}}{E_{totI}} \cdot 100$ $\eta_c = 16.8$

Solar Panel Applications

- Solar Panels and Storage Batteries
  - Batteries provide nearly constant Voltage
  - Cell currents charge battery
  - Delivered power close to maximum
- Inverters
  - Convert DC to AC
- DC-DC converters
  - Resistive loads give V proportional to I
  - Converters match V to achieve max P transfer

Economics of Solar Power Comparative Costs 2007

Technology	Energy Cost (Cents/kWh)	Capital Cost ($/kW)
Coal	6.4 – 11.48	1500-2600
Gas	6.8 – 9.74	550 -1200
Nuclear	8.0	2400
Wind	4.9	1500
Efficiency	1.3 – 3.2	400
Solar PV	15.3 – 21.4	4800[1]

1. Assumes volume purchase of modules. Including inverter and installation adds $700/kW.

http://www.pickocc.org/publications/electric/Comparative_Cost_of_Generation.pdf

Solar Power Economics

Example: The capital cost of installing a PV array that produce 1 kWp is $5500/kW including a power inverter. The daily energy density for southern Illinois is 5.0 kWh/m ^{2}/day. Calculate the per kWh cost of electricity from this array. Assume that the panels have a life of 20 years and that interest rates are 4% Repeat this calculation for So. California. with a daily energy density 6.0 kWh/m ^{2}/day. Asumme panel area of 1 m^2.

Break the capital cost down to an annual cost over the lifetime of the array. Use the following formula.

$$A_{cost} = \frac{r \cdot C_{cap}}{1 - (1 + r)^{-N}}$$

Where: r = annual interest rate
Ccap = Capital cost ($/kW)
N = array lifetime (years)
Acost = annual cost to own array.

Economics of Solar Power

For Southern Illinois

$E_I := 5.0 \cdot \frac{kWh}{m^2 \cdot day}$ Average daily energy per unit area

Convert to annual energy per unit area

$E_{ASI} := E_I \cdot 365 \cdot day \cdot 1 \cdot m^2$ $E_{ASI} = 1825\ kWh$

For Southern California

$E_I := 6.0 \cdot \frac{kWh}{m^2 \cdot day}$ Average daily energy per unit area

Convert to annual energy per unit area

$E_{ASC} := E_I \cdot 365 \cdot day \cdot 1 \cdot m^2$ $E_{ASC} = 2190\ kWh$

Economics of Solar Power

Calculate A_{cost}

$r := 0.04$ $N := 20$ $C_{cap} := 5500 \cdot dollars$

Calculation ignores tax credits and other government incentives

$$A_{cost} := \frac{r \cdot C_{cap}}{1 - (1 + r)^{-N}}$$

$A_{cost} = 404.7\ dollars$

Southern Illinois Price

$P_{SI} := \frac{A_{cost}}{E_{ASI}}$ $P_{SI} = 0.222 \frac{dollars}{kWh}$

Southern California Price

$P_{SC} := \frac{A_{cost}}{E_{ASC}}$ $P_{SC} = 0.185 \frac{dollars}{kWh}$

Average AmerenCIPS Rate 2008 $P := 0.084 \cdot \frac{dollars}{kWh}$

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END LESSON 25