5.13 Consider a single 87.5 W, First Solar CdTe module (Table 5.3) used to charge a 12-V battery.

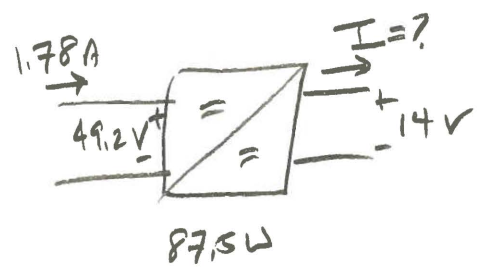
a. What duty cycle should be provided to a maximum-power-point, buck-boost converter to deliver 14-V to the battery when the module is working at standard test conditions (STC)? How many amps will it deliver to the battery under those conditions?

b. Suppose ambient temperature is 25°C with 1-sun of insolation. Recalculate the amps delivered to the battery.

TABLE 5.3 Examples of PV Module Performance Data Under Standard Test Conditions (1 kW/m^2, AM1.5, 25°C Cell Temperature)

Manufacturer	SunPower	Yingli	First Solar	NanoSolar	Sharp
Model	E20/435	YGE 245	FS Series 3	Utility 230	NS-F135G5
Material	c-Si	mc-Si	CdTe	CIGS	a-Si
Panel efficiency	20.1%	15.6%	12.2%	11.6%	9.6%
Rated power P_{MPP} (W_p)	435	245	87.5	230	135
Rated voltage V_{MPP} (V)	72.9	30.2	49.2	40.2	47
Rated current I_{MPP} (A)	5.97	8.11	1.78	6	2.88
Open-circuit voltage V_{OC} (V)	85.6	37.8	61	50.7	61.3
Short-circuit current I_{SC} (A)	6.43	8.63	1.98	6.7	3.41
NOCT (°C)	45	46	45	47	45
Temp. Coeff. of P_{max} (%/K)	−0.38	−0.45	−0.25	−0.39	−0.24
Temp. Coeff. V_{OC} (%/K)	−0.27	−0.33	−0.27	−0.30	−0.30
Temp. Coeff. I_{SC} (%/K)	0.05	0.06	0.04	0.00	0.07
Dimensions (m)	2.07 × 1.05	1.65 × 0.99	1.20 × 0.60	1.93 × 1.03	1.40 × 1.00
Weight (kg)	25.4	26.8	15	34.7	26

a) $$\frac{D}{1-D} V_{MP} = V_{BAT}$$



$$\frac{D}{(1-D)}(49.2) = 14$$

$$49.2\,D = 14(1-D)$$

$$(49.2 + 14.)\,D = 14$$

$$D = \frac{14}{63.2} = .2215 \text{ ANS}$$

ASSUME CONVERTER IS IDEAL (NO POWER LOSS)

$$I = \frac{87.5}{14} = 6.25A \text{ ANS.}$$

b) NEW CONDITIONS. $T_{AMBIENT} = 25°C$
(FIRST SOLAR'S FS SERIES 3 CELL) $1 \frac{KW}{M^2}$ INSOLATION.

STANDARD TEST CONDITIONS (STC):

$$S = 1 \frac{KW}{M^2} \text{ INSOLATION}$$

$$T_{CELL} = 25°C \quad T_{AMBIENT} = 20°$$

$$AM = 1.5 \quad (AM = \text{AIR TO MASS})$$

CALCULATE DERATED RATED POWER (P_{MPP})

$$T_{CELL} = T_{AMB} + \left(\frac{NOCT - 20°}{.8}\right) \cdot S$$

NOCT = NORMAL OPERATING CELL TEMP

FOR THIS CELL, NOCT = 45°

$$T_{CELL} = 25 + \left(\frac{45 - 20}{.8}\right)(1)$$

$$= 25 + 31.25 = 56.25°$$

% POWER DERATING $\frac{-.25\ \%}{°K}$

$$\%\ \text{POWER LOSS @}25°C = \left(\frac{-.25\ \%}{K}(56.25 - 25°)\right) 87.5$$

( )% ΔT — $T_{AMBIENT}$

$$= -7.81\%$$

$$P_{TCELL} = 87.5(1 - 0.078)$$

$$I = \frac{P_{TCELL}}{14} = \frac{80.39}{14} = 5.69\ A$$

ANS.

6.1 A clean, 1 m², 15% efficient module (STC), has its own 90% efficient inverter. Its NOCT is 45°C and its rated power degrades by 0.5%/°C above the 25°C STC.

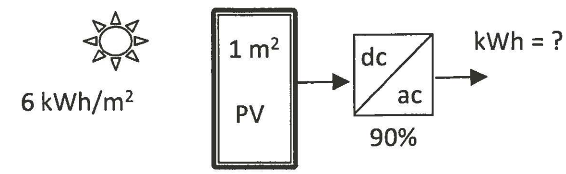


Figure P 6.1

a. What is its standard test condition (STC) rated power of the module?

b. For a day with 6 kWh/m² of insolation, find the kWh that it would deliver if it operates at its NOCT temperature. Assume the only deratings are due to temperature and inverter efficiency.

NOTE: THIS PROBLEM FOCUSES ON UNDERSTANDING P.V. POWER TERMINOLOGY

RECALL THAT STC (STANDARD TEST CONDITIONS) IS DEFINED:

- $\frac{1\ kW}{m^2}$ INSOLATION
- AM 1.5
- STANDARD CELL T = 25°C (NOT AMBIENT TEMP!)

a). STC OUTPUT $P_{dc,STC} = \underbrace{.15}_{15\%\ \text{EFFICIENT}} \cdot kW = .15\ kW$ ANS.

b) OPERATING AT NOCT,

$$\text{TEMP DERATING} = \left[1 - \frac{.5\%}{°C}(45 - 25°)\right]$$

(45 = NOCT; 25° = STANDARD TEST COND CELL TEMP)

$$= .9$$

INERVERTER DERATING: .9

TOTAL DERATING = .9 × .9 = .81

$$\text{ENERGY} = [.15\ kW] \times [.81] \times \left[6\ \frac{HR}{DAY}\right] = .729\ \frac{kWH}{DAY}$$

ANS.

6.6 A grid-connected PV array consisting of sixteen 150-W modules can be arranged in a number of series and parallel combinations: (16S, 1P), (8S, 2P), (4S, 4P), (2S, 8P), (1S, 16P). The array delivers power to a 2500-W inverter. The key characteristics of modules and inverter are given below.

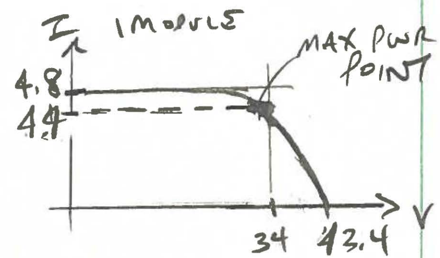
INVERTER		MODULE	
Maximum AC power	2500 W	Rated power Pdc,STC	150 W
Input voltage range for MPP	250 V - 550 V	Voltage at MPP	34 V
Maximum input voltage	600 V	Open-circuit voltage	43.4 V
Maximum input current	11 Amp	Current at MPP	4.40 A
		Short-circuit current	4.8 A

Table P 6.6

Using the input voltage range of the inverter maximum power point tracker and the maximum input voltage of the inverter as design constraints, what series/parallel combination of modules would best match the PVs to the inverter? Check the result to see whether the inverter maximum input current is satisfied. For this simple check, you don't need to worry about temperatures.

PV MODULES: $V_{oc} = 43.4V$

$I_{sc} = 4.8A$



a) (16S, 1P):

V_{oc}: $16 \times 43.4 = 694$ → EXCEEDS MAX INVERTER INPUT V

⇒ b) (8S, 2P)

ONLY THIS ARRAY SATISFIES REQ'TS ANS.

V_{oc}: $8 \times 43.4 = 347.2V$ → IN INVERTER RANGE V_{IN}

I_{sc}: $2 \times 4.8 = 9.6A$ → " " I_{IN}

c) (4S, 4P)

V_{oc}: $4 \times 43.4 = 173.6V$ → BELOW MIN INVERTER INPUT V.

I_{sc}: $4 \times 4.8 = 19.2A$ → EXCEEDS MAX INVERTER INPUT A

d) (2S, 8P) → BELOW MIN INVERTER V

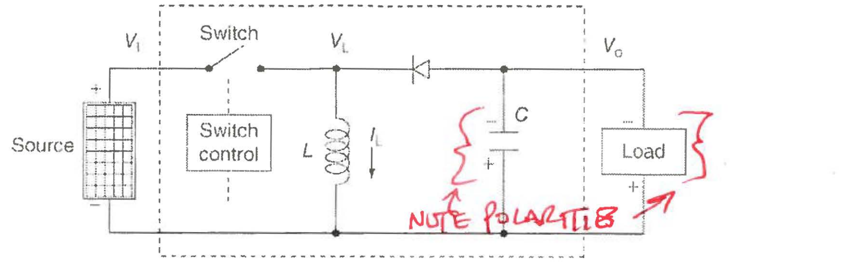
I_{sc}: $8 \times 4.8 = 38.4A$ → EXCEEDS MAX INVERTER INPUT A

e) (1S, 16P) → EXCEEDS → MAX INVERTER INPUT A

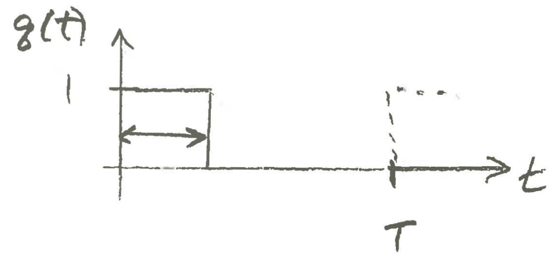
BELOW → MIN INVERTER V_{IN}.

Additional Problems:

Use the logic used to develop buck and boost DC-DC converters in class to develop duty cycle relationship for the buck-boost converter shown in Figure 5.52.



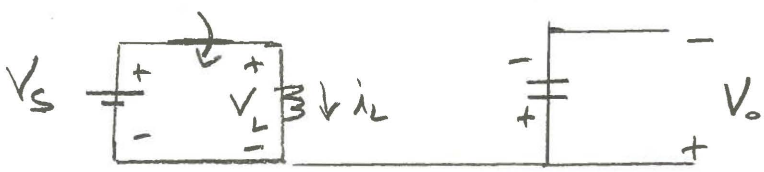
Buck–boost converter



WHEN $g(t) = 1$,

THE SWITCH IS OPEN
AND
THE DIODE IS REVERSE BIASED
$\Rightarrow$ NOT CONDUCTING

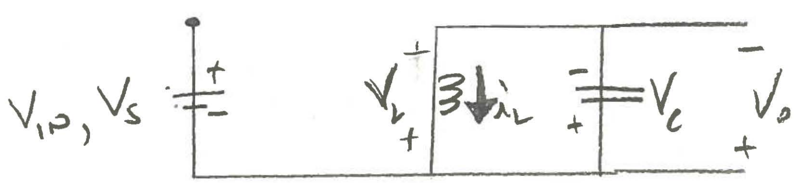
FOR $g(t) = 1$ THE CIRCUIT TOPOLOGY IS



$$V_L = V_s = V_{IN}$$

$$V_L = g(t)\, V_{IN}$$

FOR $g(t) = 0$, THE CIRCUIT TOPOLOGY IS



$$V_L = +(1 - g(t))\, V_o$$

NOTE THAT THE POLARITY OF V_L REVERSES INSTANTLY TO MATCH $V_o = V_c$

(CONT)

NOTE THE POLARITY OF V_L REVERSES INSTANTLY TO MATCH

$$V_O = V_C$$

- THE ACCUMULATED CHARGE ON THE CAPICTOR CANNOT CHANGE INSTANTLY; MOVING CHARGE REQUIRES TIME.

SIMILARLY,

- THE CURRENT IN THE INDUCTOR DOES NOT CHANGE INSTANTLY. WHEN THE VOLTAGE CHANGES INSTANTLY, THE INDUCTOR INSTANTLY CHANGES FROM AN ENERGY "SINK" TO AN ENERGY "SUPPLIER"

$$V_L = (1-\delta(t))V_o$$

OVER THE PERIOD T

$$V_L = \delta(t) V_{IN} + (1-\delta(t)) V_o$$

$$\langle V_L \rangle = 0$$

$$\Rightarrow \delta(t) V_{IN} = -(1-\delta(t)) V_o = (\delta(t)-1) V_o$$

$$V_o = \frac{D}{(D-1)} V_{IN}$$

ANS.

2. Define levelized cost of energy (LCOE) using a mathematical expression. What is LCOE used for in power system planning?

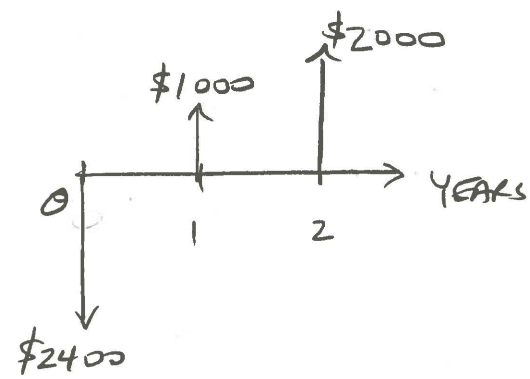
$$LCOE\left(\frac{\$}{kWh}\right) = \frac{[\text{ANNUALIZED FIXED COST} + \text{ANNUAL VARIABLE COST}]\ \$/yr}{\text{ANNUAL OUTPUT}\ (kWh/yr)}$$

THE LCOE IS A POWER SOURCE MEASURE AIMED TO PROVIDE A CONSISTENT BASIS FOR COMPARING ELECTRICITY GENERATION METHODS. IT IS AN ECONOMIC ASSESSMENT OF THE AVG TOTAL COST TO BUILD & OPERATE A POWER GENERATING ASSET OVER ITS LIFETIME.

THE LCOE CAN BE REGARDED AS THE AVG MIN PRICE AT WHICH ELECTRICITY MUST BE SOLD TO BREAK-EVEN OVER A POWER GENERATION SOURCE'S LIFETIME.

3. You have a project that returns \$1000 and \$2000 at the end of years 1 and 2 respectively. Your initial investment is \$2400 at the outset. Assume a 10% discount rate.
   a. Draw the cash flow diagram.
   b. What is the net present value?

a)



b)

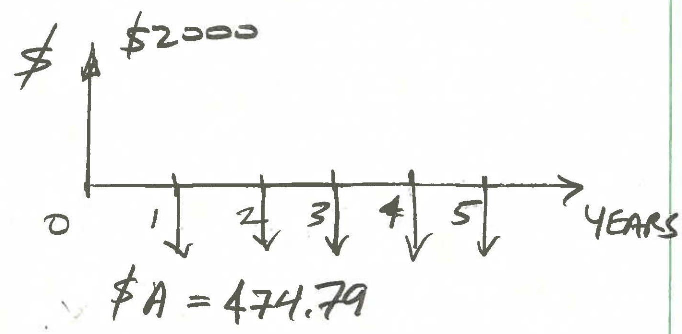
$$P_1 = 1000 \frac{1}{(1+.1)^1} = 909.$$

$$P_2 = 2000 \frac{1}{(1+.1)^2} = 1652.9$$

$$NPV = -2400 + 909 + 1652$$

$= \$161.98$ ANS.

4. You want to borrow \$2000 at 6% rate to be repaid back in equal payments over 5 years.
   a. Compute the annual payment.
   b. Draw the cash flow diagram.



USE CAPITAL RECOVERY FACTOR

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$A = P \cdot CRF$$

$$A = 2000 \cdot \frac{(.06)(1.06)^5}{(1.06)^5 - 1} = \$474.79 \text{ PER YEAR}$$

ANS.