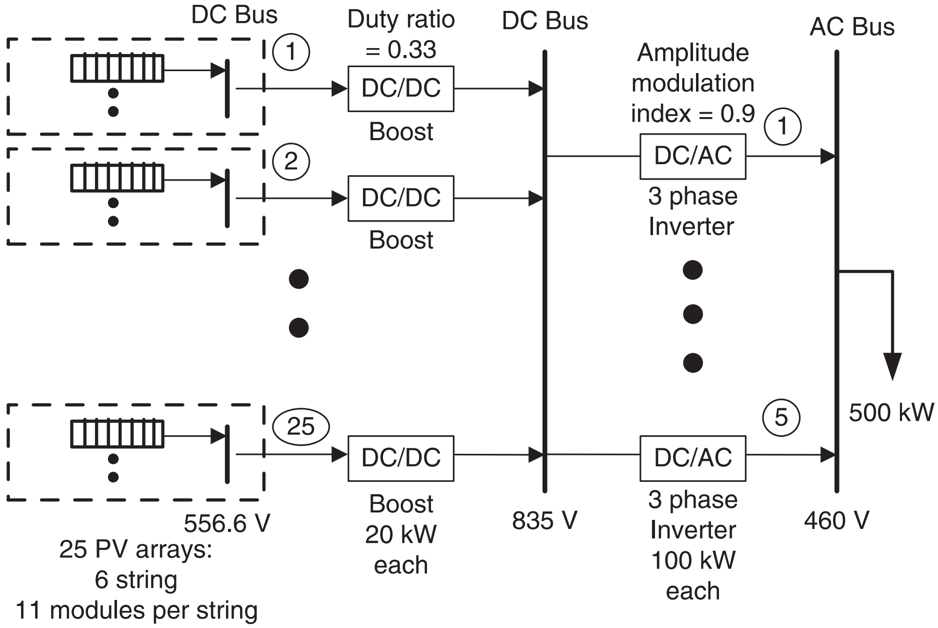


Figure 5.18 The One-Line Diagram of Example 5.2.

The output line-to-neutral voltage as a function of time is

$$\begin{aligned}
V_{ac} &= \frac{460\sqrt{2}}{\sqrt{3}} \cdot \sin(2\pi 60 \cdot t) + \frac{0.01}{100} \times \frac{460\sqrt{2}}{\sqrt{3}} \cdot \sin(2\pi \times 3 \times 60 \cdot t) \\
&\quad + \frac{0.02}{100} \times \frac{460\sqrt{2}}{\sqrt{3}} \cdot \sin(2\pi \times 5 \times 60 \cdot t) + \frac{0}{100} \times \frac{460\sqrt{2}}{\sqrt{3}} \cdot \sin(2\pi \times 7 \times 60 \cdot t) \\
&\quad + \frac{0.03}{100} \times \frac{460\sqrt{2}}{\sqrt{3}} \cdot \sin(2\pi \times 9 \times 60 \cdot t) \\
&= 376 \sin(2\pi 60 \cdot t) + 0.037 \sin(6\pi 60 \cdot t) + 0.075 \sin(10\pi 60 \cdot t) \\
&\quad + 0.113 \sin(18\pi 60 \cdot t)
\end{aligned}$$

The total harmonic distortion is given by

$$THD = \sqrt{\sum (\%harmonic)^2} = \sqrt{0.01^2 + 0.02^2 + 0^2 + 0.03^2} = 0.04\%$$

iv) The one-line diagram is given in Fig. 5.18

Example 5.3 Design a PV system to process 1000 kW of power at 460 V, 60 Hz three-phase AC using the PV data given in Table 5.12. Determine the following:

i) Number of modules in a string, number of strings in an array, number of arrays, surface area for PV, weight of PV, and cost

TABLE 5.12 Photovoltaic Data for Example 5.3.

Module	Type 1
Power (Max), W	190
Voltage at MPP, V	54.8
Current at MPP, A	3.47
V_{OC} (open-circuit voltage), V	67.5
I_{SC} (short-circuit current), A	3.75
Efficiency	16.40%
Cost	$870.00
Width	34.6″
Length	51.9″
Thickness	1.8″
Weight	33.07 lbs

ii) DC/AC Inverter and boost converter specifications and the one-line diagram of the system

Solution

The load is 1000 kW rated at 460 V AC. Based on the voltage of the load and an amplitude modulation index of 0.85, the input DC voltage for a three-phase inverter is:

$$V_{idc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}M_a} = \frac{2\sqrt{2} \times 460}{\sqrt{3} \times 0.85} = 884\ V$$

We will limit the maximum voltage that a string is allowed to have to 600 V. Therefore, we use a boost converter to boost the string voltage to 884 V.

i) If we select string approximate voltage of 550 V, the number of modules in a string, *NM*, is given as

$$NM = \frac{V_{string}}{V_{MPP}} = \frac{550}{54.8} \approx 10$$

where V_{MPP} is the voltage at MPP of the PV module.

$$SP = NM \times P_{MPP}$$

where P_{MPP} is the power generated by a PV module at MPP.

$$SP = 10 \times 190 = 1900\ W$$

And the string voltage, SV, is

$$SV = NM \times V_{MPP}$$

Therefore, the string voltage, SV, for this design is

$$SV = 10 \times 54.8 = 548\ V$$

If each array is to have a rating of 20 kW, the number of strings, NS, in an array is

$$NS = \frac{AP}{SP}$$

$$NS = \frac{20}{1.9} = 11$$

The number of arrays, NA, for this design is

$$NA = \frac{PV\ generation}{power\ of\ one\ array}$$

$$NA = \frac{1000}{20} = 50$$

The total number of PV modules, TNM, is given by the product of the number of modules per string, the number of strings per array, and the number of arrays:

$$TNM = NM \times NS \times NS$$

$$TNM = 10 \times 11 \times 50 = 5{,}500 \tag{5.19}$$

The surface area of one module, SM, is given by the product of its length and width.

$$SM = \frac{34.6 \times 51.9}{144} = 12.5\ ft^2$$

The total surface area, TS, is therefore given by the total number of modules and the surface area of each module.

$$TS = 5500 \times 12.5 = 68{,}750\ ft^2 = \frac{68{,}750}{43{,}560} = 1.57\ acre$$

The total cost of PV modules is given by the product of the number of PV modules and the cost of one module.

$$\text{The total cost} = 5500 \times 870 = \$4.78\ million$$

The total weight of PV modules is given by the product of the number of PV modules and the weight of one module.

$$\text{The total weight} = 5500 \times 33.07 = 181{,}885\ lb$$

ii) The inverters should be rated to withstand the output voltage of the boost converter and should be able to supply the required power. Selecting an inverter rated at 250 kW, we have the number of inverters, *NI*, needed to process the generation of 1000 kW as given by

$$NI = \frac{PV\ generation}{power\ of\ one\ inverter}$$

$$NI = \frac{1000}{250} = 4$$

Hence, we need to connect four inverters in parallel to supply the load of 1000 kW.

Selecting a switching frequency of 5.40 kHz, the frequency modulation index is given by

$$M_f = \frac{f_S}{f_e} = \frac{5400}{60} = 90$$

TABLE 5.13 Photovoltaic Specifications for 1000 kW Generation.

Modules per String	Strings per Array	Number of Arrays	String Voltage (V)	Total Area (ft^2)	Total Weight (lbs)	Total Cost (million $)
10	11	50	548	68,750	181,885	4.78

TABLE 5.14 Inverter Specifications.

Number of Inverters	Input Voltage V_{idc} (V)	Power Rating (kW)	Output Voltage, V_{AC} (V)	Amplitude Modulation Index, M_a	Frequency Modulation Index, M_f
4	884	250	460	0.85	90

TABLE 5.15 Boost Converter Specifications.

Number of Boost Converters	Input Voltage V_i (V)	Power Rating (kW)	Output Voltage, V_o (V)	Duty Ratio, D
50	548	20	884	0.38

The number of boost converters needed is the same as the number of arrays, which is 50. Selecting a boost converter rating of 20 kW and the boost converter input voltage to be equal to the string voltage:

$$V_i = 548\ V$$

The output voltage of the boost converter is equal to the inverter input voltage:

$$V_{idc} = V_o = 884\ V$$

The duty ratio of the boost converter is given by

$$D = 1 - \frac{V_i}{V_o}$$

$$\mathrm{D} = 1 - \frac{548}{884} = 0.38$$

The one-line diagram is given in Fig. 5.19.

5.8 THE MODELING OF A PHOTOVOLTAIC MODULE

As we discussed, a commercial PV module is constructed from a number of PV cells. A PV cell is constructed from a p-n homojunction material. This is when a p-type doped semiconductor is joined with an n-type doped semiconductor, and a p-n junction is formed. If the p-and the n-type semiconductors have the same bandgap energy, a homojunction is formed. The homojunction is a semiconductor interface, a phenomenon that takes place between layers of similar semiconductor material. These types of semiconductors have equal band gaps and they normally have different doping. The absorption of photons of energy generates DC power.

A PV cell is shown in Fig. 5.20. As irradiance energy of sun is received by the module, it is charged with electric energy. The model of a PV cell is similar to that of a diode and can be expressed by the well-known Shockley-Read equation.

The PV module can be modeled by a single exponential model. The model is presented in Fig. 5.21. The current is expressed in terms of voltage, current, and temperature as shown in Equation 5.20.

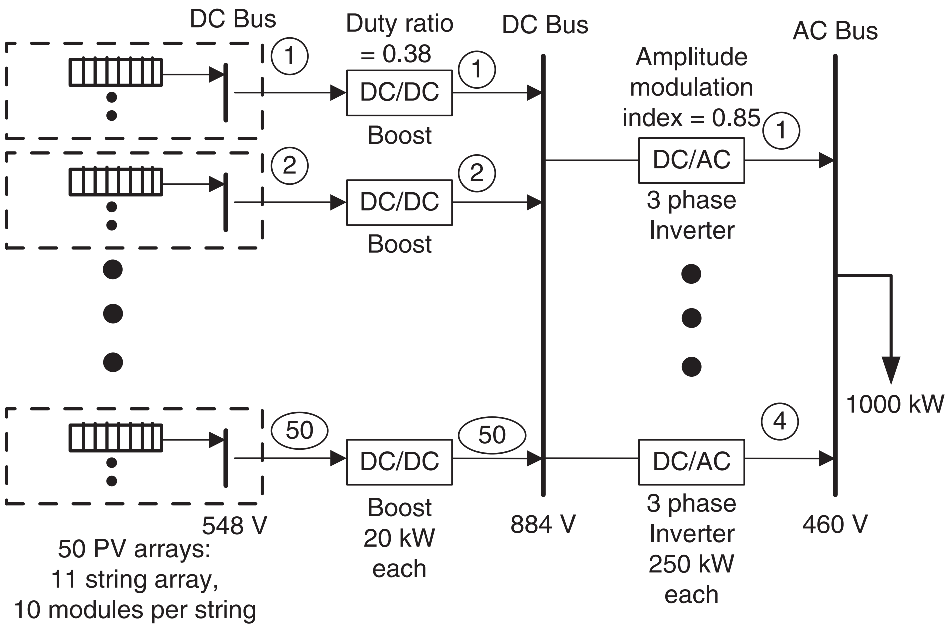


Figure 5.19 The One-Line Diagram of Example 5.3.

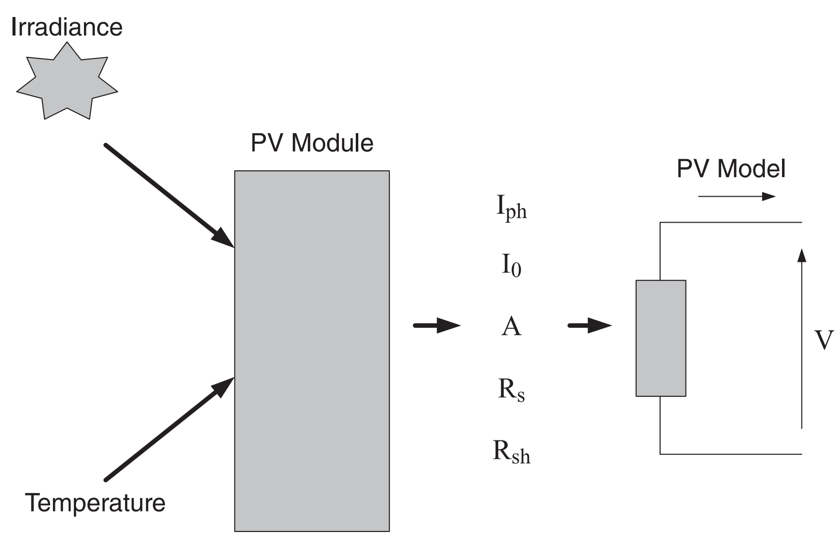


Figure 5.20 The Modeling of a Photovoltaic Module.

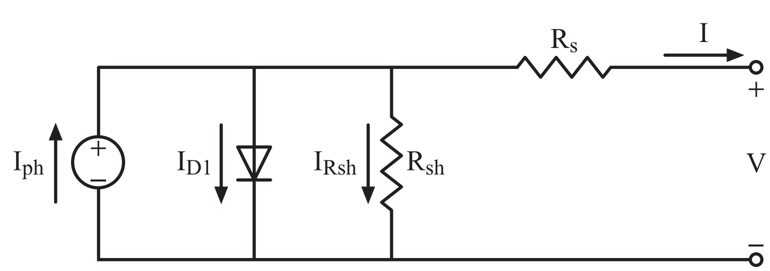


Figure 5.21 The Single Exponential Model of a Photovoltaic Module.

In the above model, the PV module is represented by a current source I_{ph} in parallel with the shunt resistance R_{sh}. The current flowing through the shunt resistance is designated as I_{Rsh}. The output DC voltage, V is in series with the internal resistance R_S. The PV model shown in Fig. 5.21 also depicts the power loss through current, I_{D1} circulating through the diode. The single exponential model is given by Equation 5.20.

$$I = I_{ph} - I_0\left\{\exp\left[\frac{q(V+IR_s)}{n_c AkT}\right]-1\right\} - \frac{V+IR_s}{R_{sh}} \tag{5.20}$$

Other parameters are the diode quality factor (A), n_c is the number of cells in the module, Boltzmann's constant (k), 1.38×10^{-23} J/K; the electronic charge (q), 1.6×10^{-19} C, and the ambient temperature (T) in Kelvin**.**

Equation 5.20 is nonlinear and its parameters I_{ph}, I_o, R_s, R_{sh}, and A are functions of temperature, irradiance and manufacturing tolerance. We can use numerical methods and curve fitting to estimate the parameters from test data provided by manufacturers. The estimation of a PV array model is quite involved. We will present the formulation of this problem at the end of this chapter.

5.9 THE MEASUREMENT OF PHOTOVOLTAIC PERFORMANCE

A PV module at a maximum constant level of irradiance can produce 1000 W/m^2. 1000 W/m^2 is also termed as one sun. The power output of the PV module is calibrated in relation to exposure to the sun. Table 5.16 depicts the irradiance in W/m^2.

The sun irradiance energy is calibrated for a PV array system based on the angle of incident. This data is used to operate the PV array at its MPP. In the next section, we will discuss how the power converters use digital controllers to operate a PV-generating station at its MPP.

TABLE 5.16 Sun Performance versus Incident Irradiance.

Sun Performance	Incident Irradiance
One Sun	1000 W/m^2
0.8 Sun	800 W/m^2
0.6 Sun	600 W/m^2
0.4 Sun	400 W/m^2
0.2 Sun	200 W/m^2

5.10 THE MAXIMUM POWER POINT OF A PHOTOVOLTAIC ARRAY

First, let us review the maximum power transfer in a resistive circuit. Consider the circuit of Fig. 5.23. Assume a voltage source with an input resistance, R_{in}. This source is connected to a load resistance, R_L.

The current supplied to the load is

$$I = \frac{V}{R_{in} + R_L} \tag{5.21}$$

The power delivered to the load R_L is

$$P = I^2 R_L \tag{5.22}$$

$$P = V^2 \frac{R_L}{(R_{in} + R_L)^2} \tag{5.23}$$

Differentiating with respect to R_L:

$$\frac{dP}{dR_L} = V^2 \frac{(R_{in} + R_L)^2 \dfrac{dR_L}{dR_L} - R_L \dfrac{d(R_{in} + R_L)^2}{dR_L}}{(R_{in} + R_L)^4}$$

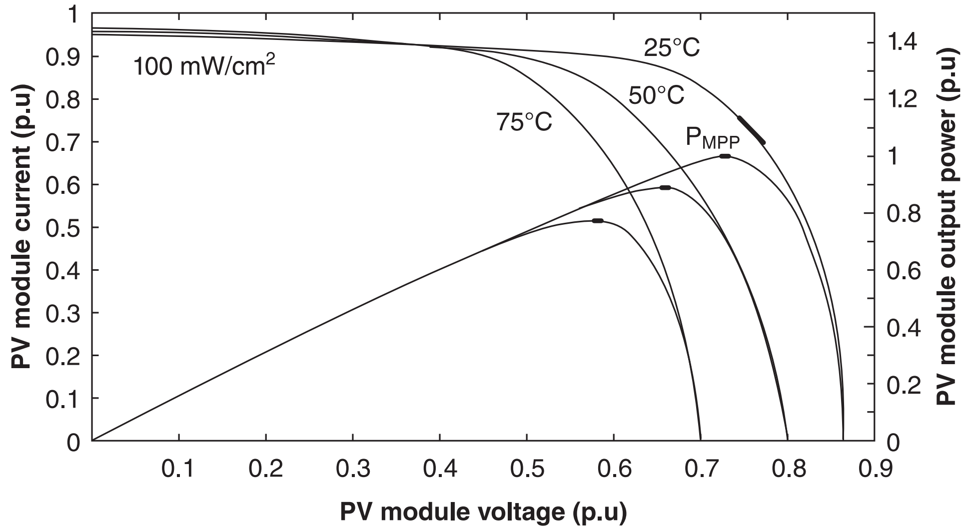
$$\frac{dP}{dR_L} = V^2 \frac{R_{in} - R_L}{(R_{in} + R_L)^3} \tag{5.24}$$

Setting the above to zero, we can calculate the operating point for the maximum power. The MPP can be delivered to the load when, $R_L = R_{in}$.

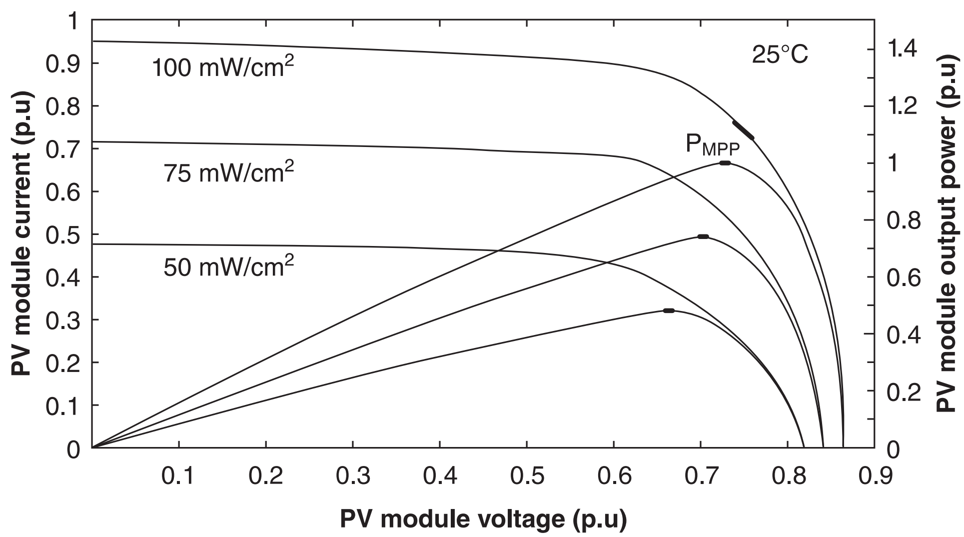
A PV module output power is the function of irradiance solar energy. Figure 5.22 depicts the output power in W/m^2 at various irradiances as a function of module current and output voltage.

The PV system should be operated to extract the maximum power from its PV array as the environmental conditions change in relation to the position of the sun, cloud cover, and daily temperature variations. The equivalent circuit model of a PV array depicted in Fig. 5.21 can be presented during its power transfer mode to a load R_L as shown in Fig. 5.24.

Figure 5.24 presents the circuit model for a PV source by a current source that has a shunt resistance, R_{sh} and series resistance, R_s.[20] The shunt resistance has a large value and series resistance is very small. The load resistance is represented by R_L. In Fig. 5.24, R_L is the reflected load because in practice the load is connected to the converter side if the PV operates as a standalone. When the PV is connected to the power grid, the load is based on the injected power to the power grid. The equivalent voltage source circuit model of current source model is depicted by Fig. 5.25.



(a)



(b)

Figure 5.22 (a)The PV Output Current versus Output Voltage and Output Power as a Function of Temperture Variation. (b) The Output power in W/m^2 at Various Irradiances as a Function of Module Current and Output Voltage.[10]

As can be seen in Fig. 5.22, the characteristics of a PV module are highly nonlinear. The input impedance of a PV array is affected by irradiance variation and temperature. The corresponding output power is also shown in Fig. 5.22.

Figure 5.26 depicts the PV energy processing system using a boost converter to step up the voltage and an inverter to convert the DC power to AC. To achieve maximum power transfer from the PV array, the input impedance of the PV generator must match the load. The MPPT control algorithm seeks to operate the boost converter at a point on the PV array current and voltage characteristics where the maximum output power can be obtained. For a PV

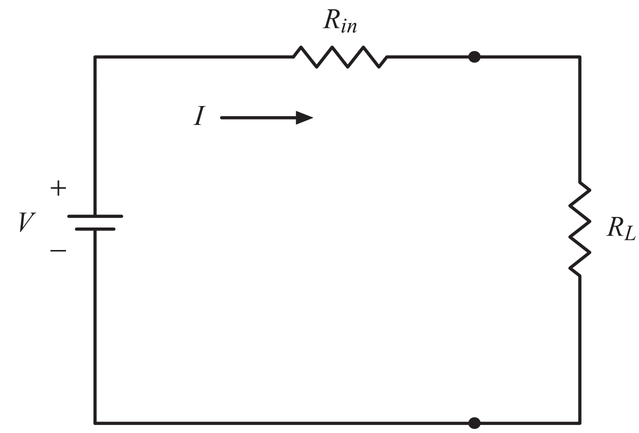


Figure 5.23 A DC Source with a Resistive Load.

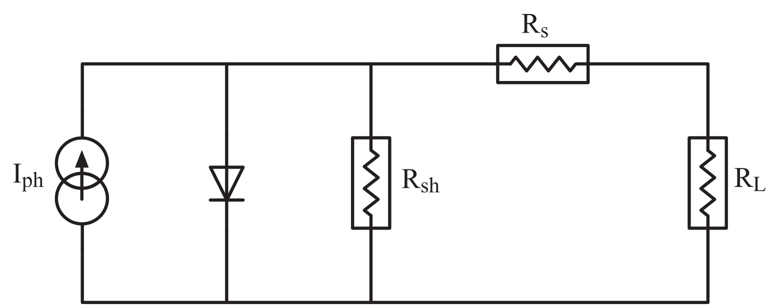


Figure 5.24 A Photovoltaic Model and Its Load.

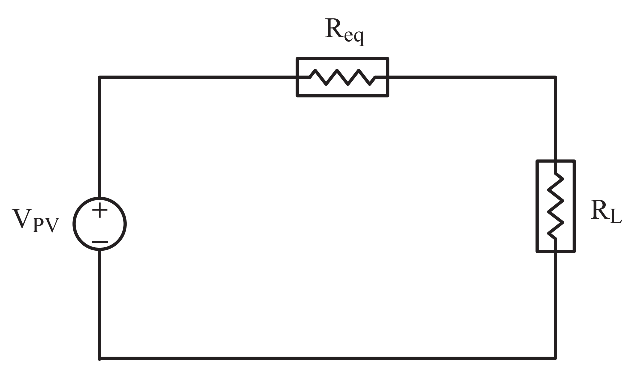


Figure 5.25 A Simple Voltage Source Equivalent Circuit Model of a Photovoltaic Array.

power generating station, the control algorithm computes the dP/dV > 0 and dP/dV < 0 to identify if the pick power has been obtained. Figure 5.27 depicts the control algorithm. If the PV system is to supply power to DC loads, then a DC/AC inverter is not needed.

Depending on application, a number of designs of a PV system can be proposed. When the PV system is to charge a battery storage system, the PV

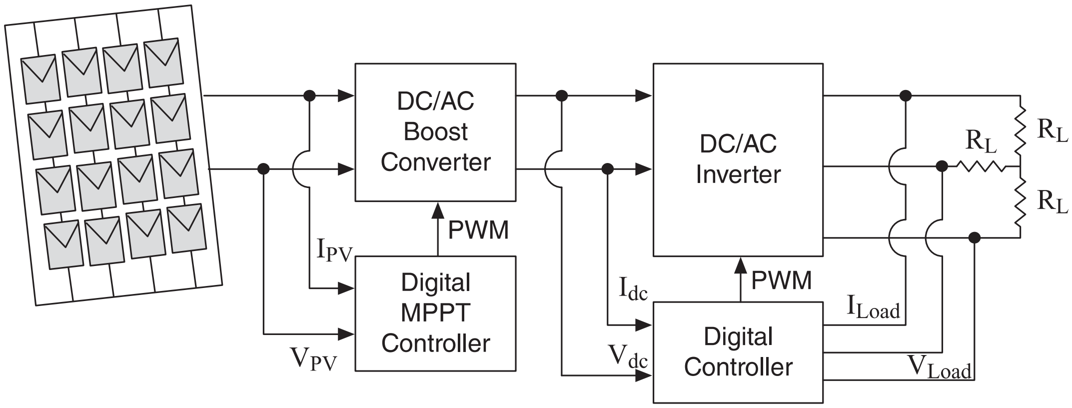


Figure 5.26 A Photovoltaic Energy Processing Using a Boost Converter to Step Up the Voltage and an Inverter.

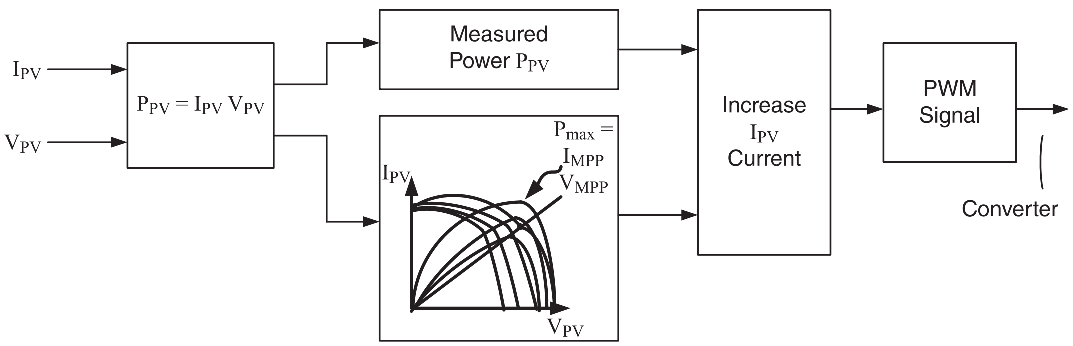


Figure 5.27 A Maximum Power Point Tracking Control Algorithm.

system can be designed as depicted by Fig. 5.28 using a boost converter or as in Fig. 5.29 using a buck converter. In this design again, the MPPT is accomplished using an MPPT control algorithm depicted by Fig. 5.27.

Figure 5.30 depicts the design of a PV-generating system and MPPT using an inverter when the PV-generating station is connected to a local utility. Again, the digital controller tracks the PV station output voltage and current and computes the MPPT point according to the control algorithm of Fig. 5.27. The control algorithm issues the PWM switching policy to control inverter current such that the PV station operates at its MPP. However, the resulting control algorithm may not result in minimum total harmonic distortion. The design presented by Fig. 5.27 has two control loops. The first control loop is designed to control DC/DC converter and the second control loop can control the total harmonic distortion and output voltage.

When the MPPT control is performed as part of the inverter as shown in Fig. 5.30, the tracking of MPPT may not be optimum. In this type of MPPT the current to the inverter flows though all modules in the string. However, the I-V curves may not be the same and some strings will not operate at their MPPT. Therefore, the resulting energy capture may not be as high and some energy will be lost in such systems.

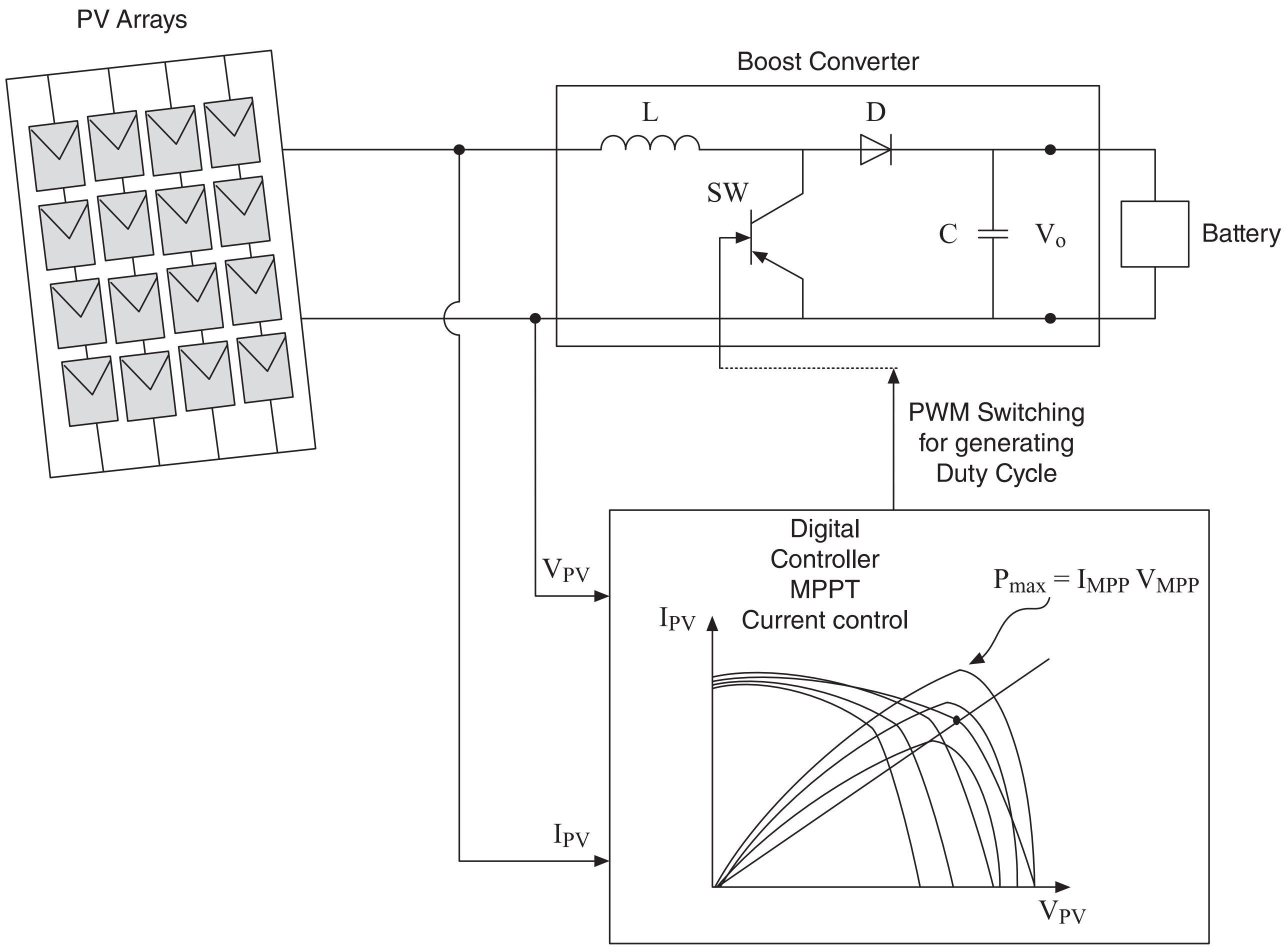


Figure 5.28 Maximum Power Point Tracking Using Only a Boost Converter.

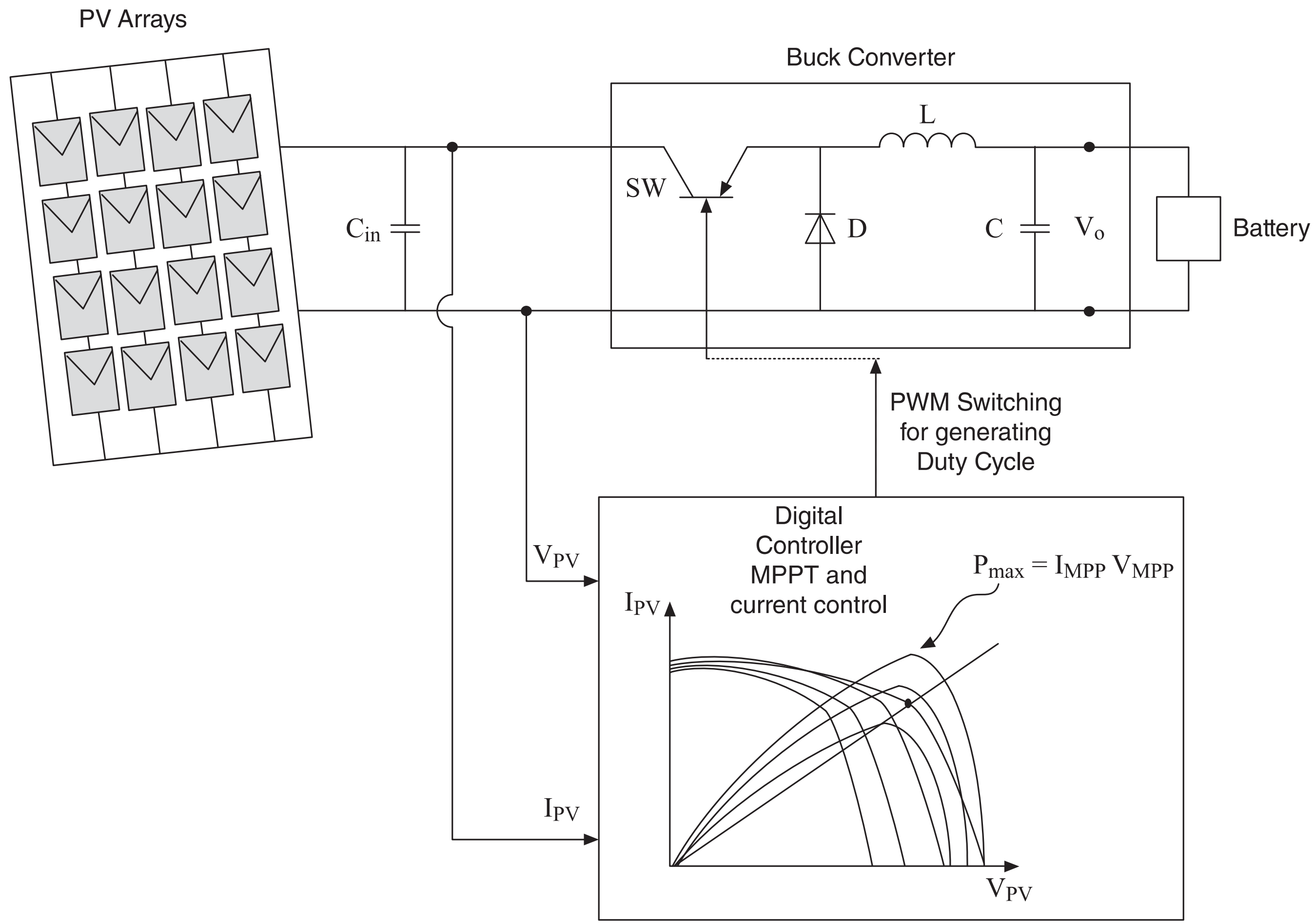


Figure 5.29 Maximum Power Point Tracking Using a Buck Converter.

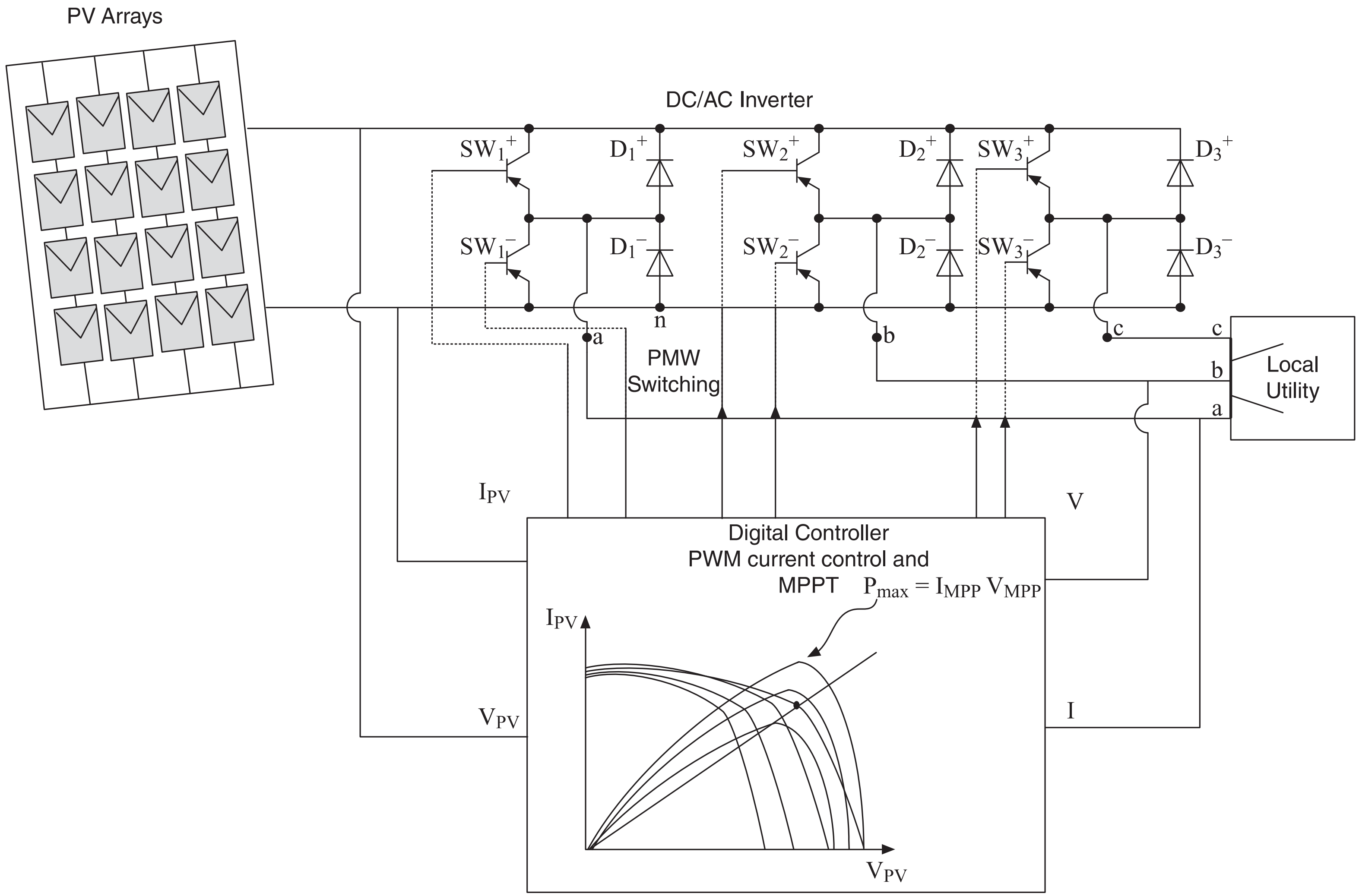


Figure 5.30 A Photovoltaic Generating Station Operating at Maximum Power Point Tracking when the Photovoltaic System Is Connected to a Local Power Grid.

Figure 5.31 depicts a PV-generating station with a battery storage system when the PV system is connected to the local utility. The DC/DC converter and its MPPT are referred to a charger controller. The charger controllers have a number of functions. Some charger controllers are used to detect the variations in the current-voltage characteristics of a PV array. MPPT controllers are necessary for a PV system to operate at voltage close to MPP to draw maximum available power as shown in Fig. 5.27. The charger controllers also perform battery power management. For normal operation, the controllers control the battery voltage, which varies between the acceptable maximum and minimum values. When the battery voltage reaches a critical value, the charge controller function is to charge the battery and protect the battery from an overcharge. This control is accomplished by two different voltage thresholds, namely, battery voltage and PV module voltage.

At lower voltage, typically 11.5 V, a controller switches the load off and charges the battery storage system. At higher voltage, usually 12.5 V for a 12 V battery storage system charge, a controller switches the load to the battery. The control algorithm adjusts the two voltage thresholds depending on the battery storage system.

DC/DC MPPT PV charger controllers facilitate standardization of integration of PV system for use in a local storage system. The system of Fig. 5.31 also can be used as a standalone microgrid that can deliver high-quality power for an uninterruptible power supply (UPS).

Example 5.4 Design a microgrid of PV system rated at 50 kW of power at 220 V, 60 Hz single-phase AC using a boost converter and single-phase DC/AC inverter. Use the data given in Table 5.17 for your design.

Determine the following:

i) Number of modules in a string for each PV type, number of strings in an array for each PV type, number of arrays and surface area, weight and cost for each PV type

ii) Boost converter and inverter specifications and the one-line diagram of this system

Solution

The load is 50 kW rated at 220 V AC. Based on the voltage of the load and an amplitude modulation index of 0.9, the input DC voltage for the inverter is

$$V_{idc} = \frac{\sqrt{2}V_{ac}}{M_a} = \frac{\sqrt{2} \times 220}{0.9} = 345\,V$$

i) If we select string voltage, SV of 250 V, the number of modules is

$$NM = \frac{string\ voltage}{V_{MPP}}$$

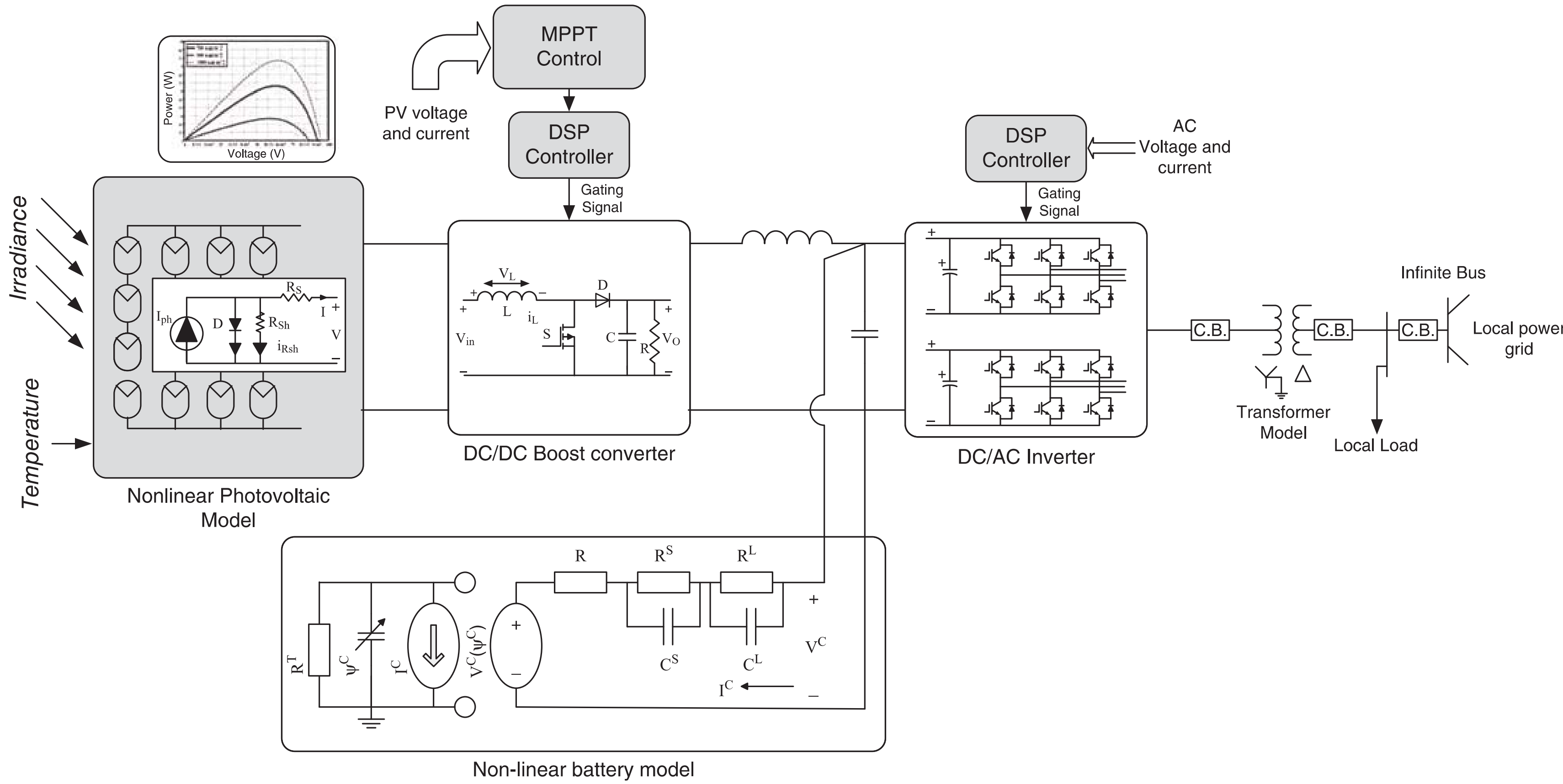


Figure 5.31 A Photovoltaic Generating Station Operating at Maximum Power Point Tracking with a Battery Storage System when the Photovoltaic System Is Connected to a Local Power Grid.

TABLE 5.17 Typical Photovoltaic Modules.

Module	Type 1	Type 2	Type 3	Type 4
Power (Max), W	190	200	170	87
Voltage at max. power point (MPP), V	54.8	26.3	28.7	17.4
Current at MPP, A	3.47	7.6	5.93	5.02
V_{OC} (open-circuit voltage), V	67.5	32.9	35.8	21.7
I_{SC} (short-circuit current), A	3.75	8.1	6.62	5.34
Efficiency	16.40%	13.10%	16.80%	>16%
Cost	$870.00	$695.00	$550.00	$397.00
Width	34.6″	38.6″	38.3″	25.7″
Length	51.9″	58.5″	63.8″	39.6″
Thickness	1.8″	1.4″	1.56″	2.3″
Weight	33.07 lbs	39 lbs	40.7 lbs	18.3 lbs

TABLE 5.18 Single-Phase Inverter Data.

Inverter	Type 1	Type 2	Type 3	Type 3
Power	500 W	5 kW	15 kW	4.7 kW
Input voltage DC	500 V	500 V max	500 V	500 V
Output voltage AC	230 VAC/60 Hz @ 2.17 A	230 VAC/ 60 Hz @ 27 A	220 VAC/ 60 Hz@ 68 A	230 VAC/ 60 Hz @ 17.4 A
Efficiency	Min. 78% @ full load	97.60%	>94%	96%
Length	15.5″	315 mm	625 mm	550 mm
Width	5″	540 mm	340 mm	300 mm
Height	5.3″	191 mm	720 mm	130 mm
Weight	9 lbs	23 lbs	170 kg	21 kg

TABLE 5.19 Typical Boost Converters.

Input Voltage (V)	Output Voltage (V)	Power (kW)
24–46	26–48	9.2
24–61	26–63	12.2
24–78	26–80	11.23
24–78	26–80	13.1
24–98	26–100	12.5
80–158	82–160	15.2
80–198	82–200	14.2
80–298	82–300	9.5
200–600	700–1000	20.0

where V_{MPP} is the voltage at MPP of the PV module.

$$\begin{aligned} NM &= \frac{250}{54.8} \approx 5 && \text{type 1} \\ &= \frac{250}{26.3} \approx 10 && \text{for type 2} \\ &= \frac{250}{28.7} \approx 9 && \text{for type 3} \\ &= \frac{250}{17.4} \approx 15 && \text{for type 4} \end{aligned}$$

The string voltage, SV is given as:

$$SV = NM \times V_{MPP}$$

Therefore, the string voltage, SV for this design is:

$$\begin{aligned} SV &= 5 \times 54.8 = 274\ V && \text{for type 1} \\ &= 10 \times 26.3 = 263\ V && \text{for type 2} \\ &= 9 \times 28.7 = 258.3\ V && \text{for type 3} \\ &= 15 \times 17.4 = 261\ V && \text{for type 4} \end{aligned}$$

Selecting the 15.2 kW boost converter from Table 5.19, the number of boost converters, NC, is

$$NC = \frac{PV\ generation}{boost\ converter\ power\ rating}$$

$$NC = \frac{50}{15.2} \approx 4$$

Therefore, the design should have four arrays: each with its boost converter. The array power, AP is

$$AP = \frac{PV\ generation}{number\ of\ arrays}$$

$$AP = 50/4 = 12.5\ \text{kW}.$$

String power, SP is given as

$$SP = NM \times P_{MPP}$$

where P_{MPP} is the power generated by the PV module at MPP.

$$\begin{aligned} SP &= 5\times 190 = 0.95\text{ kW} && \text{for type 1}\\ &= 10\times 200 = 2.0\text{ kW} && \text{for type 2}\\ &= 9\times 170 = 1.53\ kW && \text{for type 3}\\ &= 15\times 87 = 1.305\ kW && \text{for type 4} \end{aligned}$$

The number of strings, NS is given by

$$NS = \frac{power\ per\ array}{power\ per\ string}$$

$$\begin{aligned} NS &= \frac{12.5}{0.95} = 14 && \text{for type 1}\\ &= \frac{12.5}{2} = 7 && \text{for type 2}\\ &= \frac{12.5}{1.53} = 9 && \text{for type 3}\\ &= \frac{12.5}{1.305} = 10 && \text{for type 4} \end{aligned}$$

The total number of modules, TNM is given by:

$$TNM = NM \times NS \times NA$$

$$\begin{aligned} TNM &= 5\times 14\times 4 = 280 && \text{for type 1}\\ &= 10\times 7\times 4 = 280 && \text{for type 2}\\ &= 9\times 9\times 4 = 324 && \text{for type 3}\\ &= 15\times 10\times 4 = 600 && \text{for type 4} \end{aligned}$$

The surface area, TS needed by each PV type is given by the product of the total number of modules, and the length and the width of one PV module:

$$\begin{aligned} TS &= \frac{280\times 34.6\times 51.9}{144} = 3492\ sq\ ft && \text{for type 1}\\ &= \frac{280\times 38.6\times 58.5}{144} = 4391\ sq\ ft && \text{for type 2}\\ &= \frac{324\times 38.3\times 63.8}{144} = 5498\ sq\ ft && \text{for type 3}\\ &= \frac{600\times 25.7\times 39.6}{144} = 4241\ sq\ ft && \text{for type 4} \end{aligned}$$

TABLE 5.20 The Photovoltaic Specifications for Each Photovoltaic Type.

PV Type	Number of Modules per String	Number of Strings per Array	Number of Arrays	String Voltage (V)	Total Area of the PV (ft^2)	Total Weight of the PV (lb)	Total Cost of the PV ($)
1	5	14	4	274	3,492	9,260	243,600
2	10	7	4	263	4,391	10,920	194,600
3	9	9	4	258.3	5,498	13,187	178,200
4	15	10	4	261	4,241	11,040	238,200

The total weight needed for each PV type is the product of the number of modules and the weight of one module:

$$\begin{aligned}
\text{The total weight} &= 280 \times 33.07 = 9260\ lb \quad \text{for type 1} \\
&= 280 \times 39.00 = 10920\ lb \quad \text{for type 2} \\
&= 324 \times 40.70 = 13187\ lb \quad \text{for type 3} \\
&= 600 \times 18.40 = 11040\ lb \quad \text{for type 4}
\end{aligned}$$

The total cost for each PV type is the product of the number of modules and the cost of one module:

$$\begin{aligned}
\text{The total cost} &= 280 \times 870 = \$243,600 \quad \text{for type 1} \\
&= 280 \times 695 = \$194,600 \quad \text{for type 2} \\
&= 324 \times 550 = \$178,200 \quad \text{for type 3} \\
&= 600 \times 397 = \$238,200 \quad \text{for type 4}
\end{aligned}$$

ii) The boost converter rating is

$$\text{The boost converter power rating} = \frac{PV\ generation}{number\ of\ converters}$$

$$\text{The boost converter rating} = \frac{50}{4} = 12.5\ kW$$

Selecting the boost converter output voltage of $V_{idc} = V_o = 345\ V$ and input voltage equal to string voltage:

$V_i = 274\ V$ for type 1, $V_i = 263\ V$ for type 2, $V_i = 258.3\ V$ for type 3 and $V_i = 261\ V$ for type 4

TABLE 5.21 Boost Converter Specifications.

PV Type	Number of Boost Converters	Input Voltage V_i (V)	Power Rating (kW)	Output Voltage, V_o (V)	Duty Ratio, D
1	4	274	12.5	345	0.205
2	4	263	12.5	345	0.237
3	4	258.3	12.5	345	0.251
4	4	261	12.5	345	0.243

The duty ratio of the boost converter is given by

$$D = 1 - \frac{V_i}{V_o}$$

$$\begin{aligned} \mathrm{D} &= 1 - \frac{274}{345} = 0.205 && \text{for type 1 PV} \\ &= 1 - \frac{263}{345} = 0.237 && \text{for type 2 PV} \\ &= 1 - \frac{258.3}{345} = 0.251 && \text{for type 3 PV} \\ &= 1 - \frac{261}{345} = 0.243 && \text{for type 2 PV} \end{aligned}$$

The inverters should be rated to withstand the output voltage of the boost converter and should be able to supply the required power. Let each inverter have a rating of 10 kW.

The input voltage of the inverter is $V_{idc} = 345\,V$ with an amplitude modulation index of 0.90. The output voltage of the inverter is at 220 V AC

The number of inverters, *NI*, to process a generation of 50 kW is given by

$$NI = \frac{PV\ generation}{power\ of\ one\ inverter}$$

$$NI = \frac{50}{10} = 5$$

Hence, we need to connect five inverters in parallel to supply the load of 50 kW. Of course, we can also use one inverter with a higher rating to convert the DC power to AC. Naturally, many other designs are also possible.

Selecting a switching frequency of 5.1 kHz, the frequency modulation index will be given as

$$M_f = \frac{f_S}{f_e} = \frac{5100}{60} = 85$$

TABLE 5.22 Inverter Specifications.

Number of Inverters	Input Voltage V_{idc} (V)	Power Rating (kW)	Output Voltage, V_{AC} (V)	Amplitude Modulation Index, M_a	Frequency Modulation Index, M_f
5	345	10	220	0.90	85

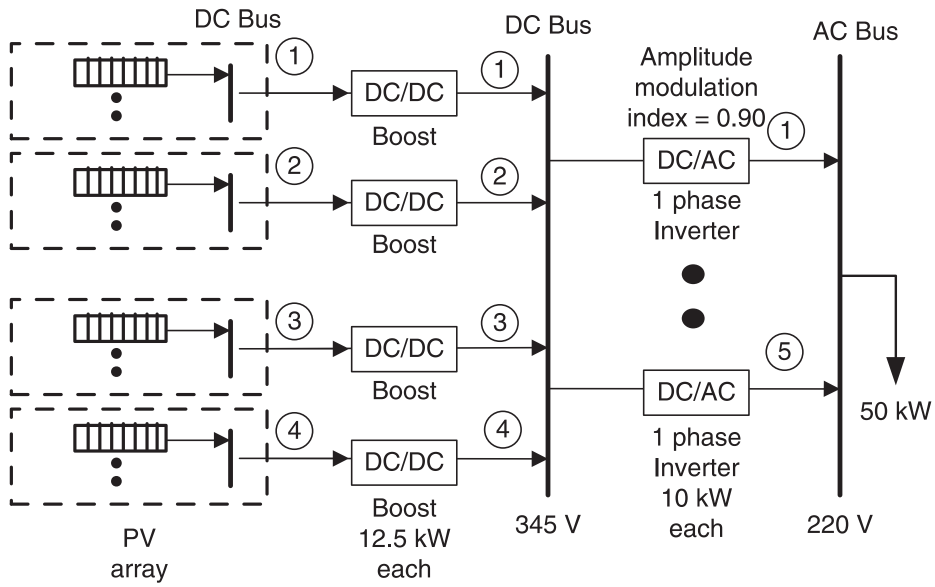


Figure 5.32 The One-Line Diagram of Example 5.4.

Students can compute the total harmonic distortion.

The one-line diagram of the system is shown in Fig. 5.32.

The selection of the type of PV system may be based on the weight and cost of the system. For residential and commercial systems with existing roof structures, the PV modules that have minimum weight are normally selected.

The selection of the boost converter is based on the power rating of the boost converter and its output voltage. The boost converter must be rated at the minimum output voltage of the PV system and the required DC input voltage of the inverter. The amplitude modulation index is selected to be less than one, but close to one for processing the maximum power of the DC source to the AC power. The frequency modulation index selected is based on the highest sampling time recommended by the manufacturer of the inverter to limit the total harmonic distortion. The number of strings and the number of modules in the string is based on the rating of the input voltage of the boost converter. The number of boost converters and inverters is based on the required output power of the PV-generating station.