14.3.2 Maximum Power Point Tracking

As already mentioned, the peak power in the P versus V curve will vary as sunlight varies. To adjust the maximum power point (MPP), we use a device to track this maximum power point. This device is called a MPP tracker (or MPPT). The device is in essence a DC-DC converter or buck-boost converter (Chapter 5). The output voltage is proportional to the input voltage $V_{out} = V_{in} \times \left(\frac{D}{1-D}\right)$, where the factor is depending on the duty cycle D of PWM signal controlling the switch.

Example 14.11

We want the MPPT to change from V_{in} = 11 V to V_{out} = 15 V. What is D? Answer: We should adjust D such that $15 = 11 \times \left(\frac{D}{1-D}\right)$, therefore $\left(\frac{D}{1-D}\right) = 15/11 = 1.36$, and solving for D we get $D = \frac{1.36}{2.36} = 0.57$.

14.3.3 Efficiency and Performance

Other factors lower a PV module's power efficiency by 20% to 40%. These include temperature, dirt and dust, inverter efficiency (if converted to AC), and mismatched modules.

Recall from Section 14.1.9 that for a given site, insolation S can be given in kWh/m^2 per day, or equivalently as hours/day of 1-sun, or hours of peak sun. For example, if the average solar radiation is 7.0 kWh/m^2 per day, then we have the equivalent of 7 hours of 1-sun per day. We can then use area A of the module (in m^2) and system efficiency η to evaluate energy produced by the system at a given site

$$E = S \times A \times \eta \tag{14.23}$$

either as kWh or hours of 1-sun.

Example 14.12

Assume we have ~~10~~ 30 m^2 of panels with efficiency of 40% at a site that has 7.0 kWh/m^2 per day on day 20 of the year when sunny. Calculate energy production assuming the panels capture all sunlight available. Answer: $E = S \times A \times \eta = 7 \times 30 \times 0.4$ kWh = 84 kWh for that day.

14.3.4 Impact of Temperature on Solar Panels

The temperature of a PV cell depends on ambient temperature and solar radiation; the cell gets hotter as the air gets warmer and radiation increases. The cell temperature T_c in °C can be calculated using the equation

$$T_c = T_a + \left(\frac{NOCT - 20°C}{0.8}\right) S \tag{14.24}$$

where T_a is ambient temperature (°C); S solar irradiation (in kW/m^2); and NOCT is the nominal operating cell temperature, which is the expected cell temperature when the ambient temperature is 20°C, the irradiation is 0.8 kW/m^2, and the wind speed 1 m/s. The NOCT is given by the cell manufacturer, and for many panels this number is in the 45°C to 47°C range (see, for example, Masters [4]).

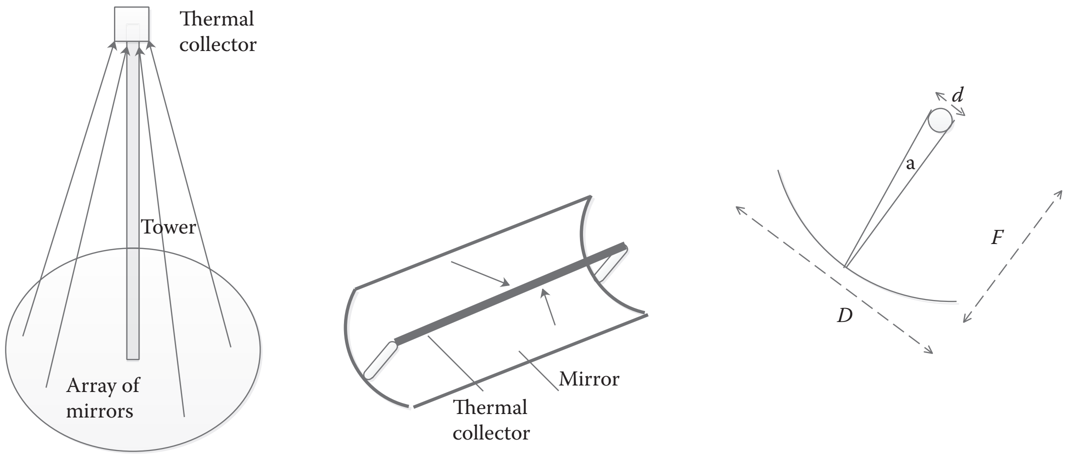

FIGURE 14.40 Solar thermal, concentrated solar power (CSP). Left: Field of mirrors, thermal collector on top of tower. Center: Parabolic trough. Right: Geometrical model.

Most solar thermal plants have been built in the United States and Spain. Large (200–400 MW) solar thermal plants have been built in the southwestern deserts of the United States. In Spain, most plants range from tens of MW to 100 MW, with some plants reaching the 200 MW capacity.

A great advantage of solar thermal or CSP is that it is possible to store thermal energy in hot fluids or other materials (e.g., molten salt), instead of chemical energy in a battery, to compensate for intermittency of the resource. For large thermal storage, say, 8 hours, it would be possible to run the plant during nighttime and provide power continuously.

New working fluids and other thermodynamic cycles are being researched. A promising technology is to employ supercritical carbon dioxide (sCO_2) and a Brayton cycle (Chapter 9) to improve CSP efficiency [20]. In its supercritical state (above the temperature and pressure critical point, Chapter 6), CO_2 acts like a gas but with the density of a liquid. Small changes in temperature or pressure cause large changes in density.

There are two major types of CSP plants. One type is an *array of mirrors* focusing sunlight on the thermal collector (e.g., a tank with the heat transfer fluid) located on top of a tower (Figure 14.40, left-hand side), and the other type is an array of cylindrical mirrors or *troughs* with linear thermal collectors (e.g., a tube with heat transfer fluid) (Figure 14.40, center).

The surface of the mirrors and the troughs can be *parabolic* or *spherical*, and simple geometrical considerations allow to calculate how much radiation is concentrated [21]. A lens or mirror surface of size D, with an axis pointing in the direction of the sun, forms an image of size d at the collector located at focal length F (Figure 14.40, right-hand side). The angle subtended by looking at the sun from Earth is $\alpha = 0.0093\cancel{^{\circ}}$ rad. For a parabolic surface, the *concentration ratio* (CR) is given by a linear relation between D and d

$$CR = \frac{D}{d} = \frac{D}{\alpha F} \tag{14.37}$$

whereas for a spherical surface, the CR is given by a ratio of area

$$CR = \left(\frac{D}{d}\right)^2 = \left(\frac{D}{\alpha F}\right)^2 \tag{14.38}$$