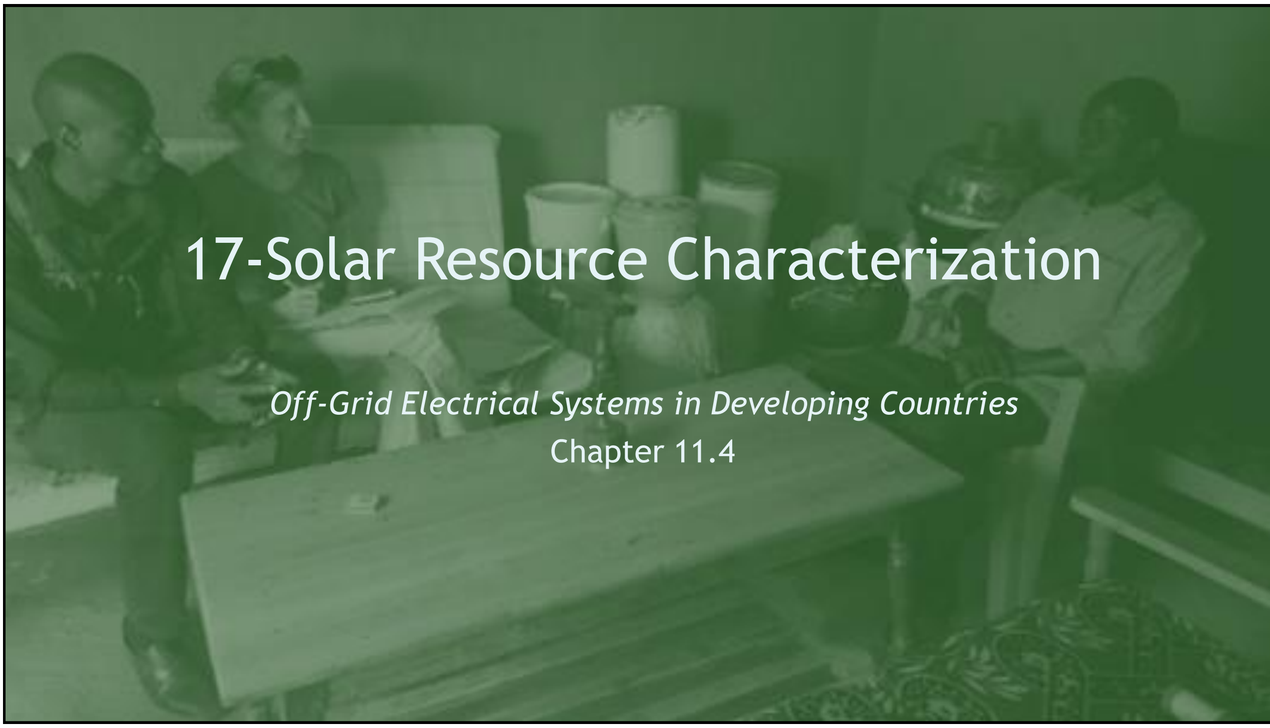

17-Solar Resource Characterization

Off-Grid Electrical Systems in Developing Countries

Chapter 11.4

1

Learning Outcomes

At the end of this lecture, you will be able to:

- ✓define and calculate *Capacity Factor* as it pertains to off-grid systems
- ✓use the Capacity Factor to produce a preliminary design of a PV array
- ✓understand the conditions that affect the Capacity Factor of a PV array

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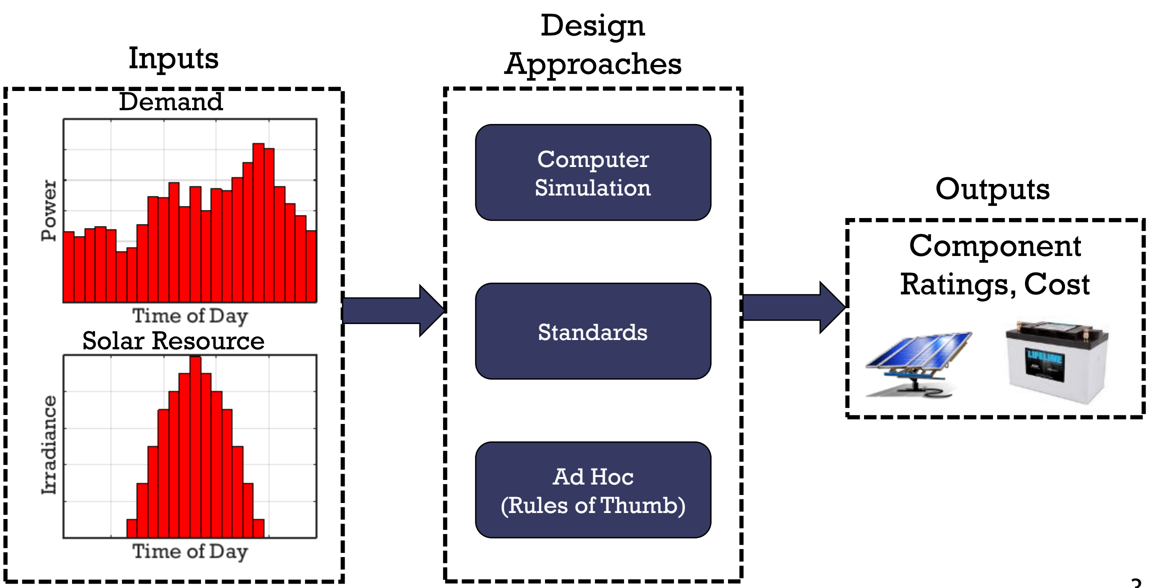

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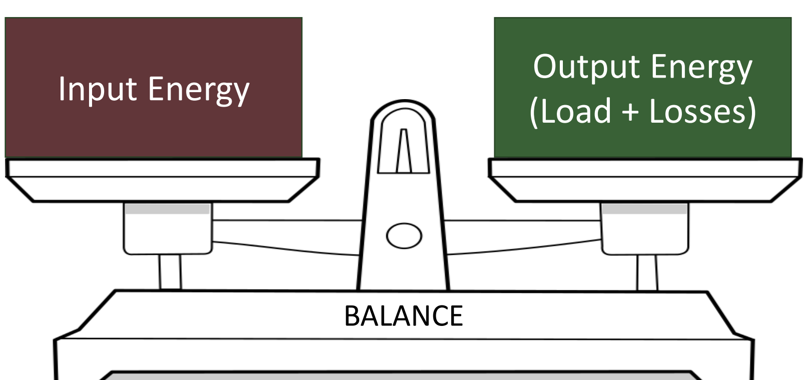
A technically-appropriate design is one that…

strikes a reasonable balance between the cost of implementing and operating the system with the ability of the system to reliably and safely meet the needs of its users



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Selecting Energy Conversion Technologies

Which do you expect to produce more energy, a 1 kW hydro turbine, or a 3 kW PV array?

Capacity Factor

- A 2kW 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 the energy it would produce is: 2 kW x 24 = 48 kWh
- The ratio between the actual (or anticipated) average energy generated over a period of time to the energy it would produce if operated at rated power over that time is known as the Capacity Factor

Capacity Factor

Capacity Factor is calculated as:

$$Capacity\ Factor = \frac{\hat{E}}{T \times P_{rated}}$$

Capacity Factor is also often expressed as a percent

$\hat{E}$: estimated (or actual) energy production (kWh)
T : period of time considered (h)
P_{rated}: rated power output of the energy conversion technology (kW)

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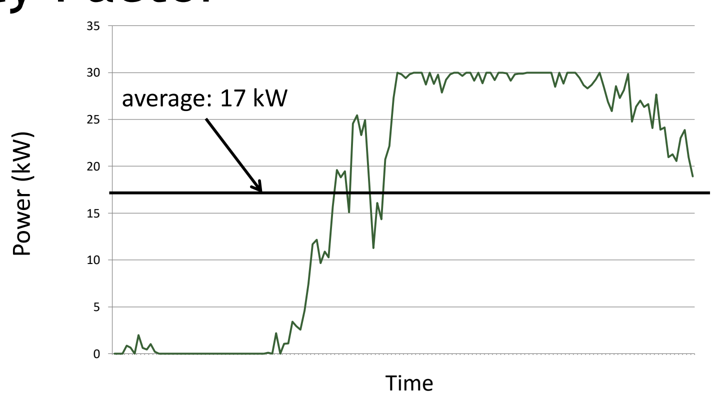
Capacity Factor



Capacity Factor: 57%

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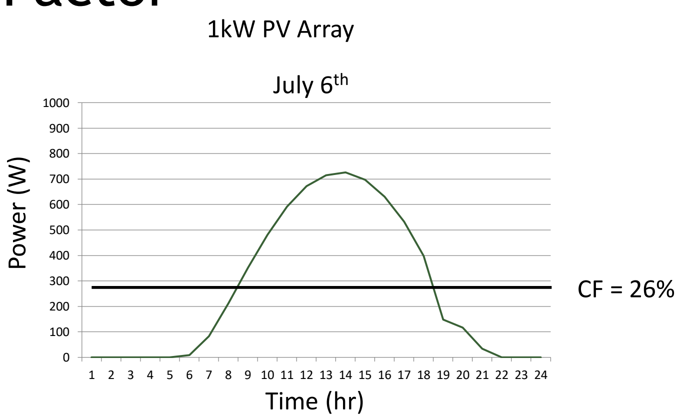
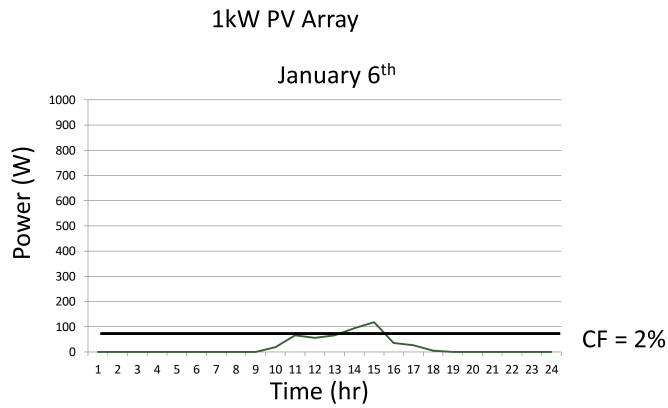
Capacity Factor

- Time period consider is often
  - Lifetime of the energy conversion technology
  - Year
  - Season
- Many energy conversion technologies exhibit seasonal variation in Capacity Factor

Capacity Factor



Capacity Factor



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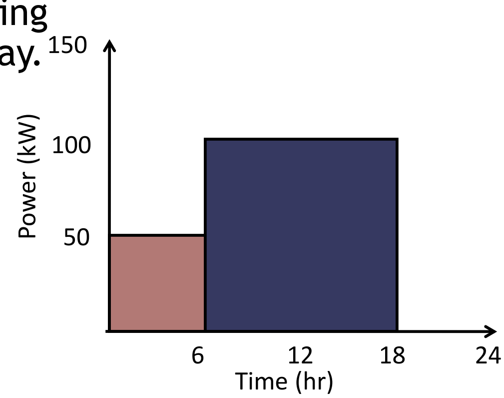
Exercise

A 150 kW wind plant produces the following output. Find its capacity factor for the day.



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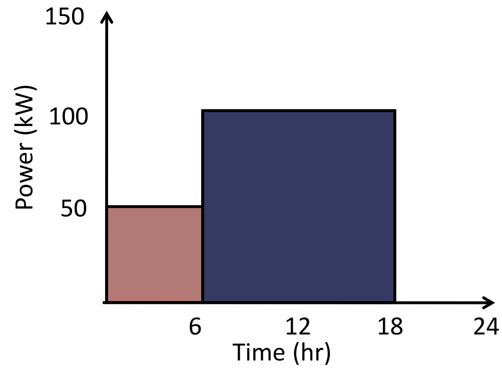
Exercise

CF = (50 x 6 + 100 x 12)/(24 x 150) = 0.417

Capacity factor of 41.7%



Capacity Factor

In the early stages of off-grid system resource selection, Capacity Factor is often calculated assuming:

- downtime for maintenance and repair is negligible
- the load is large enough so that all the energy that is capable of being produced is used (i.e. the energy conversion technology is never "throttled")

When calculated using actual historical data, these assumptions do not apply

Capacity Factor

Technology	Approx. Capacity Factor	Capacity need to produce 24 kWh/day (kW)
Gen set	0.90-1.00	1.00-1.11
PV	0.15-0.24	4.1-6.67
MHP	0.90-0.95	1.05-1.11
WEC	0.20-0.30	3.33-5.00

Capacity Factors vary substantially for different energy conversion technologies

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Capacity Factor

- Capacity Factor is a useful metric to evaluate and compare the utilization of energy conversion technologies under different scenarios
- A <u>relatively</u> low Capacity Factor <u>may</u> indicate that an energy conversion technology is under-utilized or over-sized

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Exercise

A mini-grid will have an estimated load of 48 kWh per day. If served by a MHP system, the water resource is such that the capacity factor of the MHP will be 0.91. If the load is served by a PV array, the capacity factor will be 0.18. Compute the required capacity of the MHP system and the PV array to supply the load.

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Exercise

A mini-grid will have an estimated load of 48 kWh per day. If served by a MHP system, the water resource is such that the capacity factor of the MHP will be 0.91. If the load is served by a PV array, the capacity factor will be 0.18. Compute the required capacity of the MHP system and the PV array to supply the load.

$$P_{\text{rated,MHP}} = \frac{\hat{E}}{T \times Capacity\,Factor} = \frac{48.0}{24 \times 0.91} = 2.20 \text{ kW}$$

$$P_{\text{rated,PV}} = \frac{48.0}{24 \times 0.18} = 11.11 \text{ kW}$$

Note that a much larger capacity PV array is required

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Sun Hours

- Recall that the insolation over the course of a day *d* is:

$$I_d = \int_{t=0}^{24} G_d(t)\, dt$$

Units of I_d are kWh/m²/day if t is expressed in hours and G_d are in kW/m²

- The average insolation across *D* days is simply:

$$\overline{I}_D = \frac{\sum_{d \in D} I_d}{D}$$

$\overline{I}_D$ is sometimes referred to as "sun hours" or "full sun hours", since irradiance of 1000 W/m² is often called "full sun"

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Capacity Factor of a PV Array

- Recall that if temperature effects are ignored, the power produced by a PV array is

$$P_{PV} = P^*_{STC} \times G$$

Note: we are assuming G is expressed in kW/m², not W/m²

- The estimated energy production for day *d* is therefore:

$$\hat{E}_{PV,d} = P^*_{STC} \int_{t=0}^{24} G_d(t)\, dt = P^*_{STC} I_d$$

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Capacity Factor of a PV Array

- The estimated total production for a month is therefore:

$$\hat{E}_{\mathrm{PV},D} = P^{*}_{\mathrm{STC}} \sum_{d \in D} I_d = P^{*}_{\mathrm{STC}} \times \overline{I} \times D$$

- And the Capacity Factor is:

$$Capacity\ Factor = \frac{\hat{E}_{\mathrm{PV},D}}{24 \times D \times P^{*}_{\mathrm{STC}}} = \frac{P^{*}_{\mathrm{STC}} \overline{I} D}{24 \times D \times P^{*}_{\mathrm{STC}}} = \frac{\overline{I}}{24}$$

In other words, the Capacity Factor is independent of the PV array rating, and is simply the number of sun hours divided by 24

Capacity Factor of a PV Array

- This result is useful for back-of-the-envelope calculations and preliminary design
- We must remember that PV arrays are affected by temperature and there are other losses that should be accounted for during the design stage
- Typical insolation for SSA ranges from 4 to 7 kWh/m^2/day, depending on the location and season
- Keep in mind that the insolation must correspond to the plane that the PV array will be installed

Exercise

The average insolation on the Itek 350 SE module for the month of July is 4.7 kWh/m^2/day. What is the average energy produced by the module each day? What is the corresponding Capacity Factor?

Exercise

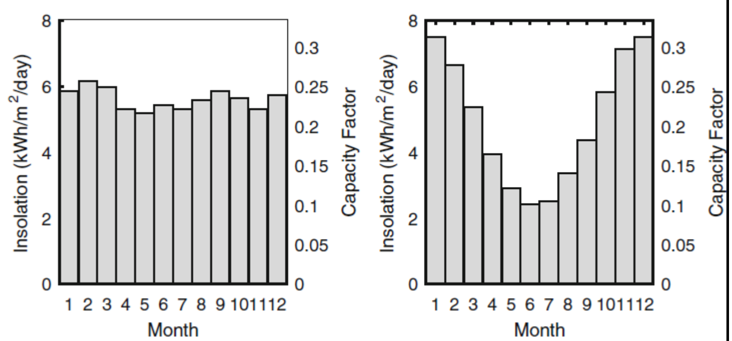
The average insolation on the Itek 350 SE module for the month of July is 4.7 kWh/m^2/day. What is the average energy produced by the module each day? What is the corresponding Capacity Factor?

$$\bar{E}_{PV} = 350 \times 4.7 = 1645 \text{ Wh}$$

$$\text{Capacity Factor } = 100 \times \frac{1645}{350 \times 24} = 19.6\%$$

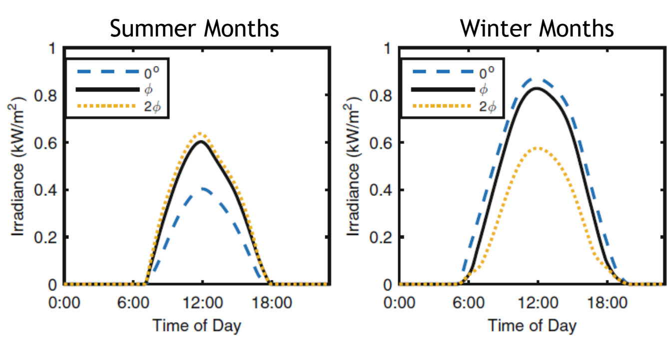
Capacity Factor is Influenced by

- Season (day of year)
- Location (lat. and long.)
- Weather conditions
- Orientation of array



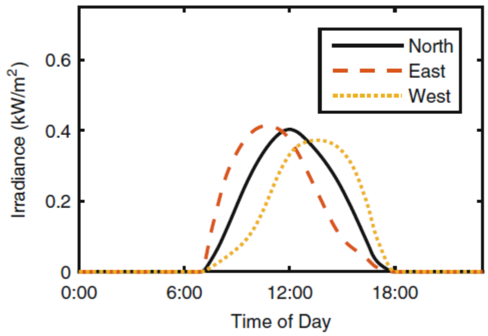
Insolation and capacity factor for a horizontal arrays near the equator and 34º S

Affects of Tilt



Affects of Azimuth

Azimuth is the skewness from north or south



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Optimal Tilt

Rule-of-thumb: tilt the PV array at the latitude in which it is installed, and have it face the equator (i.e. face North in the southern hemisphere; face South in the northern hemisphere)

A minimum tilt of 5 to 10 degrees is advised to prevent collection of debris

Ellensburg

Singapore

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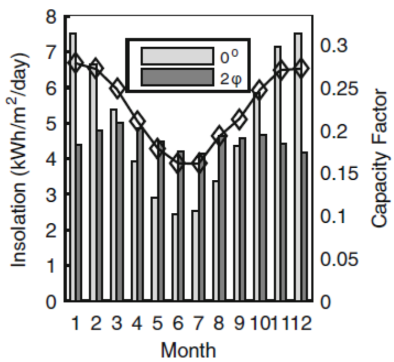
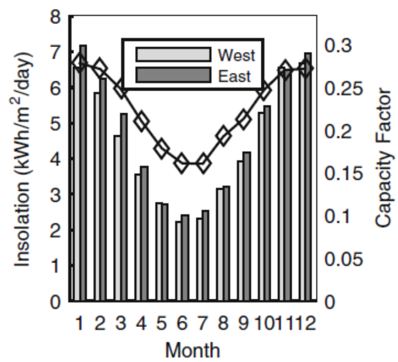
Effects of Tilt





Insolation and capacity factor for arrays near the equator and 34° S

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Contact Information

Henry Louie, PhD

Associate Professor

Fr. Wood Endowed Research Chair

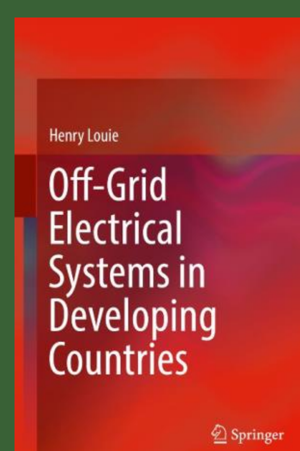
Seattle University

@henrylouie

hlouie@ieee.org

www.drhenrylouie.com

Office: +1-206-398-4619



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