Alternative Energy

Chapter 6 Part 3: PV Grid-Connected System Performance

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Chapter Description

- Expected Outcomes
  - analyze the grid-connected PV system performance

- References
  - Grid-connected Solar Electric Systems: The Earthscan Expert Handbook by Geoff Stapleton and Susan Neill, 2010.

Power Losses

Unfortunately the solar power that impinge on a solar array each day cannot be completely converted to electrical power in the grid. All of the follow affect the conversion of solar power to electrical power in a PV system:

1. Efficiency of PV cells/module
2. Temperature of the PV module
3. Dirt
4. Manufacturer's tolerances and module mismatch
5. Voltage drop in DC cables to inverter
6. Inverter efficiency
7. Voltage drop in AC cables to point of connection to grid
8. Shadows
9. Ageing
10. Tilt and orientation angles of the PV array

Losses in grid-connected PV system

Dirt and soiling

- If dirt and debris (such as leaves) build up on the surface of a PV module, they will shade the module and reduce its power output.
- The reduction in power output will depend largely on the site and the factors influencing soiling such as the tilt angle at which the modules are installed
- The de-rating factor due to soiling can only be estimated.
- It is fairly common practice to use f_{dirt}= 0.90 (10% reduction due to soiling) for very dirty sites and 0.95 (5% reduction due to soiling) for relatively clean sites that experience regular rainfall.

Losses in grid-connected PV system

Manufacturer's tolerance

- Account for the small output variations between individual modules produced by the same manufacturer and is normally specified on the module data sheet.
- If the manufacturers tolerance shows -3%, the peak power of the module may be 3% less than given on the data sheet, i.e. the minimum peak power from the 315 W_p modules produced by that manufacturer is 305.55 W_p.

Shading and module orientation

1. Can be a major contributor to loss of system performance:
   - Shading leads to a voltage drop and if enough of the PV array is shaded the voltage may drop outside the inverter's voltage window causing the inverter to turn off and the system will produce no power.
   - Where multiple strings are connected in parallel, the shading on one string may impact on the others.
2. Current and voltage are directly affected by the irradiation received and when the module is shaded or not at a proper tilt angle and orientation, it does not receive as much irradiation.

Voltage drop

- Voltage drop in a wire are a function of three parameters:
  - Conductor cross sectional area (mm^2)
  - Length of wire (m)
  - Current flow in the wire (A)
- Voltage drop in a cable, due to the resistance is a result of power losses in the cable.
- Excessively long cable can result in loss of power to the inverter and lower system efficiency.
- MS1837:2005 - the cables from the solar array should be selected so that the Voltage drop is less than 5%.

Voltage drop

$$V_{drop\_dc} = \frac{2 \times L_{DC\_cable} \times I_{DC} \times \rho}{A_{DC\_cable}}$$

L_{DC_cable} - length of DC cable
I_{DC} - DC current
ρ - resistivity of wire (copper = 1/56, aluminium = 1/34)
A_{DC_cable} - cross section area of DC cable in mm^2

$$V_{drop\_AC} = \frac{2 \times L_{AC\_cable} \times I_{AC} \times \rho \times cos\varphi}{A_{DC\_cable}}$$

L_{AC_cable} - length of AC cable
I_{AC} - AC current
$cos\varphi$ - power factor
A_{AC_cable} - cross section area of AC cable in mm^2

Cable size

- When designing a system, the string current is known once the module is selected while the DC main current is known once the size of the array is specified.
- What must be determined is the minimum cable size required to meet the required voltage drop.
- The minimum DC and AC Cable Sizes are calculated as

Cable size

$$A_{DC\_cable} = \frac{2 \times L_{DC\_cable} \times I_{DC} \times \rho}{LOSS \times V_{mp\_string}}$$

$LOSS$ - maximum voltage in conductor
V_{mp_string} - MPP voltage of the string or array
ρ - resistivity of wire (copper = 1/56, aluminium = 1/34)

$$A_{AC\_cable} = \frac{2 \times L_{AC\_cable} \times I_{AC} \times \rho \times \cos\varphi}{LOSS \times V_{AC}}$$

$\cos\varphi$ - power factor
V_{AC} - grid voltage

Cable size

- The typical modules or string cables are 1.5 mm², 2.5 mm², 4.0 mm² and 6 mm².
- MS1837:20OS states that 2.5 mm² is the minimum cable size that can be used in the string, PV sub-array and PV array cables.
- Once the cable has been selected, the actual voltage drop or power loss can be calculated.
- Then the DC Power Loss can be expressed either as a % or as an absolute real value by using Ohm's Law.

$$P_{DC\_LOSS} = \frac{2 \times L_{DC\_cable} \times I_{DC}^2 \times \rho}{A_{DC\_cable}} \qquad P_{AC\_LOSS} = \frac{2 \times L_{AC\_cable} \times I_{AC}^2 \times \rho \times cos\varphi}{A_{AC\_cable}}$$

PV system performance

- It is the system designer's job to provide an estimate of the energy yield the system can provide. This information may be provided as an annual yield or since the available solar irradiation does vary throughout the year It can be provided as a monthly yield.
- PV energy yield can be calculated as

$$E_{Sys} = P_{array\_stc} \times PSH_{period} \times f_{temp} \times f_{dirt} \times f_{mm} \times \eta_{pv\_inv} \times \eta_{inv}$$

PSH_{period} - Peak sun hour over the period of interest

η_{pv_inv} - power losses in ca

f_{temp} - temperature derating factor

η_{inv} – inverter efficiency

f_{dirt} - dirt factor

f_{mm} - manufacturer tolerance

PV system performance

- Specific yield can be calculated as:

$$SY = \frac{E_{sys}}{P_{array\_stc}}$$

P_{array_stc} – array power at STC

- Performance ratio: $$PR = \frac{E_{sys}}{E_{ideal}}$$

E_{ideal} - ideal energy output from the PV array at STC

Thank You