# Alternative Energy

# Chapter 6 Part 2: PV Grid-Connected System Design

by
Mohd Shawal Jadin
Faculty of Electrical & Electronic Engineering
mohdshawal@ump.edu.my

# Chapter Description

- Expected Outcomes
  - To organize the system component integration

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

# System Sizing

- It is important to ensure that the array is matched to the inverter's input specifications so that all system components are appropriately sized to suit the site-specific conditions.
- Inverter should be chosen so that the maximum power output from the designed PV array (given in $W_p$) matches the inverter's maximum array power input (given in Wp).
- Avoided over—sizing of the inverter as it will reduce the inverter's operating efficiency and hence reduce overall power output.
- The designer needs to ensure that the inverter and PV array match in terms of voltage, current and power to ensure a safe and efficient PV system.

# Matching voltage specifications

There are two voltage specifications that need to be met.

- The maximum system voltage of the module. A PV array voltage must not exceed this voltage.
- The operating voltage of the inverter must not be exceeded.

**Typical Electrical Characteristics**

| | |
|---|---|
| Maximum Power ($P_{max}$) | 75W |
| Voltage at $P_{max}$ ($V_{mp}$) | 17.0V |
| Current at $P_{max}$ ($I_{mp}$) | 4.45A |
| Warranted minimum $P_{max}$ | 70W |
| Short circuit current ($I_{SC}$) | 4.75A |
| Open-cicuit voltage ($V_{OC}$) | 21.4V |
| Temperature coefficient of $I_{SC}$ | (0.065±0.015)%/°C |
| Temperature coefficient of $V_{OC}$ | –(80±10)mV/°C |
| Temperature coefficient of Power | –(0.5±0.05)%/°C |
| NOCT | 47±2°C |
| Maximum System Voltage | 600V |

# Matching voltage specifications

- The maximum input voltage is the maximum DC voltage that the inverter is designed to handle safely.
- If the array's open circuit voltage exceeds the maximum input voltage, it may damage the inverter's electronic components.
- The vast majority of grid interactive inverters also have a maximum power point tracking (MPPT) range with specified minimum and maximum voltages.
- Within this range, the inverter tracks the maximum power point to ensure the array' performs as well as possible; outside this range the array is likely to underperform.

# Inverter specifications

Inverter window operating voltage

PV array MPPT input voltage range

Maximum PV array voltage (must not exceed this value)

Maximum PV array current

Inverter Efficiency

| INPUT DATA | Fronius **IG** 300 | Fronius **IG** 400 |
|---|---|---|
| MPP voltage range | 210 - 420 V | 210 - 420 V |
| Max. input voltage (at 1000 W/m²; -10°C) | 530 V | 530 V |
| Recommended PV plant output | 24 kWp - 31 kWp | 32 kWp - 42 kWp |
| Max. input current | 123 A | 164 A |

| OUTPUT DATA | Fronius **IG** 300 | Fronius **IG** 400 |
|---|---|---|
| Nominal output | 24 KW | 32 kW |
| Max. power output | 24 kW | 32 kW |
| Max. efficiency | 94,3 % | 94,3 % |
| Euro efficiency | 93,3 % | 93,4 % |
| Mains voltage / frequency | | 3NPE~400 V / 50 Hz |
| Distortion factor | | < 5 % |
| Power factor | | 1 |
| Power consumption at night | | 9 W |

# Matching voltage specifications

- The first step to acquire maximum and minimum temperatures at the installation site. From these, the PV module cell temperatures can be calculated.
- The PV cells will operate at a much higher than the air temperature quoted in weather report.
- National codes should be consulted first as they may specify the ambient or cell temperatures that should be used in sizing calculations.
- In Malaysia, the minimum and maximum cell temperatures are 20℃ and 75℃, respectively.

# Matching voltage specifications

- Calculate the expected voltage output of the array that is affected by the change of cell temperatures.
- Datasheet generally provide at least one temperature coefficient for Voltage (a specific rating that describes the effect of temperature on the cell voltage).
- Usually expressed as a percentage or in volts per degree celcius, whereas some manufacturers only provide a Pmax (maximum power) temperature coefficient that can be used as an approximation for the Voltage temperature coefficient.

**Typical Electrical Characteristics**

| | |
|---|---|
| Maximum Power ($P_{max}$) | 75W |
| Voltage at $P_{max}$ ($V_{mp}$) | 17.0V |
| Current at $P_{max}$ ($I_{mp}$) | 4.45A |
| Warranted minimum $P_{max}$ | 70W |
| Short circuit current ($I_{sc}$) | 4.75A |
| Open-cicuit voltage ($V_{oc}$) | 21.4V |
| Temperature coefficient of $I_{sc}$ | (0.065±0.015)%/°C |
| Temperature coefficient of $V_{oc}$ | –(80±10)mV/°C |
| Temperature coefficient of Power | –(0.5±0.05)%/°C |
| NOCT | 47±2°C |
| Maximum System Voltage | 600V |

# Calculating Maximum Voltage

The module's maximum voltage ($V_{OC}$ is present at the minimum cell temperature which in this case is 25°C; it is therefore important to use the open-circuit voltage ($V_{OC}$) and adjust this figure according to the temperature coefficient when calculating the maximum voltage.

- $\gamma_{V_{OC}}$ given in percentage

$$V_{\max\_OC} = V_{OC\_STC} \times \{1 + (\gamma_{V_{OC}} \times (T_{cell\_min} - T_{STC}))\}$$

- $\gamma_{V_{OC}}$ given in absolute value

$$V_{\max\_OC} = V_{OC\_STC} + (\gamma_{V_{OC}} \times (T_{cell\_min} - T_{STC}))$$

# Calculating Minimum Voltage

- The module's minimum voltage will occur when the cell is hottest, i.e. at a cell temperature of $75°C$. This is calculated using the maximum power Voltage, $V_{mp}$ and corresponding temperature coefficient.
- A temperature coefficient is not given for maximum power voltage, so the temperature coefficient for maximum power should be used as an approximation - this is given in $\%/°\mathrm{C}$ on the data sheet and so must be converted to $\mathrm{V}/°\mathrm{C}$ :

| | |
|---|---|
| Temperature coefficient of $I_{SC}$ | (0.065±0.015)%/°C |
| Temperature coefficient of $V_{OC}$ | -(80±10)mV/°C |
| Temperature coefficient of Power | -(0.5±0.05)%/°C |

$$V_{\min\_mp} = V_{mp\_STC} + \left(\left\{\frac{\gamma_{P_{mp}}}{100} \times V_{mp\_STC}\right\} \times \left(T_{cell\_min} - T_{STC}\right)\right)$$

# Calculating Minimum Number of Modules in a String

| | |
|---|---|
| The minimum module voltage is multiplied by the voltage drop expected across the DC cables ($V_{dc\_drop}$) | $V_{\min\_mp\_eff} = V_{\min\_mp} \times V_{dc\_drop}$<br>$V_{dc\_drop}$ is voltage drop in percentage |
| The minimum inverter input voltage should be multiplied by 1.1 to account for the 10% **safety margin** required | $V_{\min\_win\_inv\_allow} = 1.1 \times V_{\min\_win\_inv}$ |
| Finally, the minimum number of modules in the string is calculated by dividing this figure by the minimum module voltage | $N_{\min\_module} = \frac{V_{\min\_win\_inv\_allow}}{V_{\min\_mp\_eff}}$ |

# Calculating Maximum Number of Modules in a String

| | |
|---|---|
| The maximum inverter input voltage is reduced to account for the 5% safety margin | $V_{\max\_win\_inv\_allow} = 0.95 \times V_{\max\_win\_inv}$ |
| The maximum inverter voltage should be divided by the maximum module voltage (as previously calculated to determine the maximum allowable modules in a string) | $N_{\max\_module} = \dfrac{V_{\max\_win\_inv\_allow}}{V_{\max\_OC}}$ |

# Inverter-PV Array Matching

- The number of module in a string can be selected between $N_{min\_module}$ and $N_{max\_module}$
- In practice, it is recommended that the actual number of modules in the string that is close to 75% of the allowable voltage window.
- This should ensure that the array MPP voltage is always operating within the window in times of high temperature and also if shading occur

# Matching current specifications

- An array normally has several strings connected in parallel and the input DC current will be the sum of the currents of all the strings connected to the İnverter.
- The short-circuit current is used in these calculations because it is the largest current the module will produce.
- To calculate the Maximum number of parallel string of the array :

$$N_{\max\_parallel\_string} = \frac{I_{\max\_dc\_inv}}{f_{safety} \times I_{SC\_string}}$$

$I_{\max\_dc\_inv}$ - maximum inverter DC input current
$f_{safety}$ - safety factor (range betwen 1.1 to 1.25)
$I_{SC\_string}$ - short circuit current of string at STC

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

# Thank You