# SIZING THE MAXIMUM DC VOLTAGE OF PV SYSTEMS

The maximum DC voltage commonly is a safety relevant limit for sizing a PV system.
All components (modules, inverters, cables, connections, fuses, surge arrestors, ….) have a certain maximum voltage they can withstand or handle safely.
If this voltage gets exceeded, damage or even worse harm can result.

**New technologies established a new standard, to build PV systems with voltages up to 1000V (for special purposes in big PV power plants with central inverter topology even 1500V are used). This makes sense by causing lower losses (power / energy, voltage-drop) and gaining higher efficiencies (inverter). This is also reducing the string number and so far reducing cabling, connectors, fuses and so on, which leads to lower space requirements and higher reliability (less parts).**

So the challenge is to size a PV system with the highest possible and safe DC voltage.

## Open Circuit Voltage of a PV module

On the datasheet of a PV module the open circuit voltage normally is specified at STC.
(= Standard Test Conditions; defining the irradiation at 1000W/m² and a cell temperature at 25°C)
As the voltage correlates nearly linear with the cell temperature, a temperature coefficient (TC,Uoc) is specified, either in V/°C or %/°C.
This is an inverse correlation, meaning **the highest voltage occurs with the lowest cell temperature**.

Naturally also irradiation is necessary to produce voltage (and power).
So the voltage shows also a non-linear dependency from the irradiation, meaning **at low irradiations also the voltages will be low**.

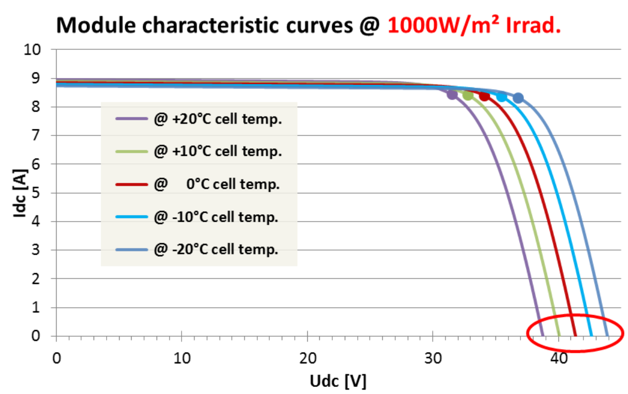


**Figure 1: temperature dependency of the open circuit voltage @ constant irradiation (1000W/m²)**

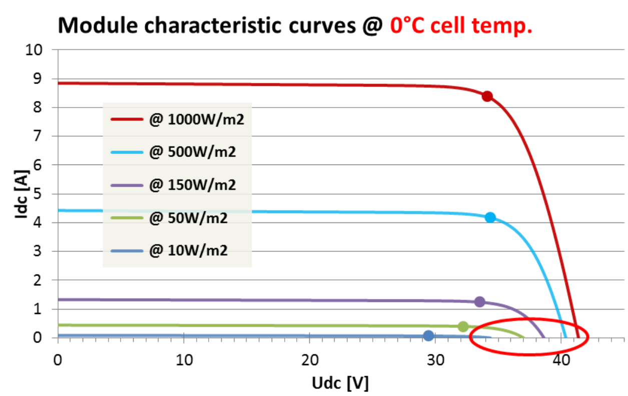


**Figure 2: irradiation dependency of the open circuit voltage @ constant cell temperature (0°C)**

Modern PV Modules have an efficiency of 15% to 20% (often also given on the datasheet).
While this percentage is converted into electricity the bigger "rest" (80% - 85%) of the irradiation is mostly converted into heat, meaning the PV cell (module) gets heated-up quite quickly.
As a matter of fact, with irradiation (= at daytime!) the **cell temperature almost always will be higher than the ambient temperature**. (see also Table 1 below)

## Calculating the maximally arising DC Voltage (Open Circuit Voltage = Uoc,max)

The most established and easiest way to calculate the maximum open circuit voltage is to use the STC value from the datasheet with a certain estimated lowest occurring cell temperature.

**Uoc,max = Uoc,stc [V] + Uoc,stc [V] * (Tcell,min [°C] – Tstc [°C]) * TC,Uoc [%/°C] / 100**

As a matter of fact, STC (1000W/m²) doesn't take into account the influence from the irradiation.
(lower voltages at lower irradiations)

> **For finding the real (correct) Maximum DC Voltage (Open Circuit Voltage), a complete set of module characteristic curves with different irradiation levels and the resulting cell temperatures at the lowest occurring ambient temperature (Tamb,min) would have to be made. (graphs in figure 3)**

As this would be quite a big effort (software, module detail data, …), the upper formula can be used with a modified Minimum Cell Temperature (Tcell,min).

| cell temperature @ 0°C ambient temperature and irradiation = |
|---|
| 1000W/m2 := +26°C cell temp. |
| 500W/m2 := +13°C cell temp. |
| 150W/m2 := +4°C cell temp. |
| 50W/m2 := +1°C cell temp. |
| 10W/m2 := +0°C cell temp. |

**Table 1: resulting cell temperatures at an constant <u>ambient</u> temperature (0°C) at different irradiation levels.**

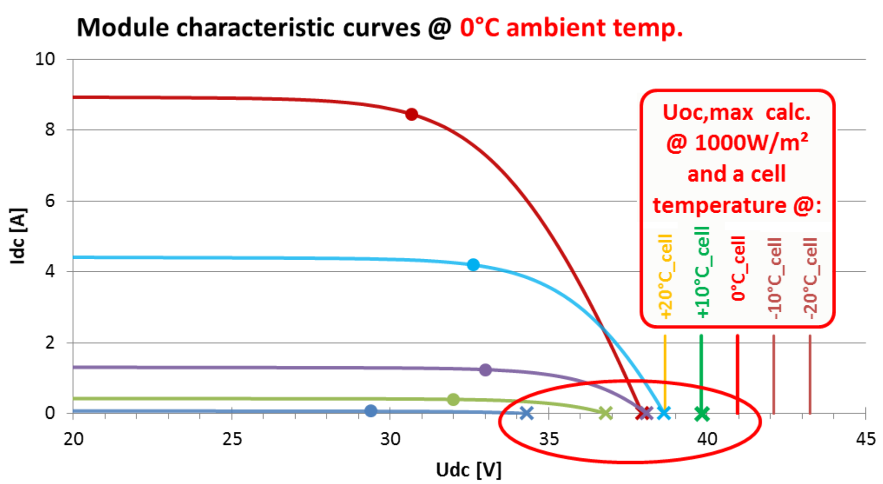


**Figure 3: realistic open circuit voltages versus calculation with simple formula**

For most modules the highest open circuit voltages would occur at an irradiation of 400 – 500 W/m² (see figure 3).
At normal operation, high open circuit voltages won't appear because the PV system (inverter) operates in its MPP (dots in figures 1 – 3).
As a matter of fact the PV system (inverter) would have to shut down exactly at a moment @ lowest ambient temperature and @ high irradiation, only then the highest open circuit voltage can appear!
(= quite unlikely worst worst case)

# DEFINING THE MINIMUM CELL TEMPERATURE FOR CALCULATING THE MAXIMUM DC VOLTAGE WITH STC VALUES

For the design of a photovoltaic system, the cell temperature limits established on the international market are minimum -10 °C and maximum +70 °C.
Commonly these temperatures are used with the STC values of a module for the calculation of the extreme voltages.

Especially in countries with a high level of solar irradiation and mostly also high temperatures this is a quite unrealistic expectation.

Using the Minimum Ambient Temperature of a site as Minimum Cell Temperature and the STC values of a module to calculate the Maximum DC Voltage, the result is clearly overestimating the real Maximum DC Voltage!
(see figure 3)

The lowest expected ambient temperature of a certain site, often easily can be found from official recordings, web research and so on.
(In the examples the Minimum Ambient Temperature is at 0°C.)
Actually these lowest temperatures normally don't appear with high irradiations.

## Defining the Minimum Cell Temperature at +10°C higher than the Minimum Ambient Temperature

When calculating the Maximum DC Voltage with STC values and setting the **Minimum Cell Temperature +10°C above the Minimum Ambient Temperature** the result is **still providing a safety of approximately 10°C** to the real behavior of the cell (module). (see figure 3)

As shown in Figure 3, a calculation with the established formula and a minimum cell temperature of +10°C will still provide safety even if the ambient temperature would drop below 0°C!
(A calculation with a minimum cell temperature of +10°C could be critical only from ambient temperatures below -10°C!)

Taking into account, that the lowest temperatures appear at night, modules are mounted on roofs where the surrounding air temperature is higher (heated up from the building, less dissipation of heat) and so on, even a higher difference (> +10°C) between the lowest Minimum Ambient Temperature and the lowest Minimum Cell Temperature can be assumed.

All these influences and correlations can be seen in innumerable PV systems, monitored and equipped with sensors.

**Fronius International GmbH**

Solar Energy Division

Wels, January 12th 2016