

## CALCULATION- AND VISUALIZATION-TOOL (CVT) FOR PARTIAL SHADING OF PHOTOVOLTAIC SYSTEMS

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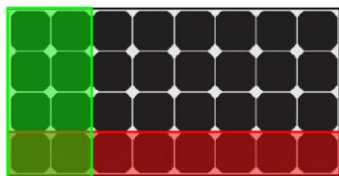
**ABSTRACT:** Partial shading of photovoltaic systems can lead to disproportionate power losses. To visualize and precisely calculate the characteristics of a partial shaded PV system, a new simulation tool has been developed. Compared to existing simulation tools that address a PV module as a whole, our new Calculation- and Visualisation Tool (CVT) for partial shading of photovoltaic systems is able to provide quantifications of power losses at individual photovoltaic cell level. Using the CVT, comparisons of calculations and measurements of the whole PV generator are possible. This is especially an advantage to analyse partially shaded situations of a PV generator.

**Keywords:** Photovoltaics, Shading, Power Losses, Simulation Tool

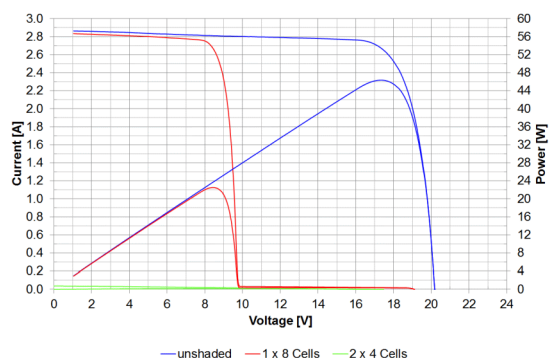
### 1 INTRODUCTION

This study addresses the partial shading effects on photovoltaic systems and was a bachelor-thesis in spring 2015 [2]. Partial shading of photovoltaic systems can lead to disproportionate power losses. Due to the nonlinear behaviour of the photovoltaic cells, the quantification of such power losses is challenging. So far, the determination of power losses is carried out using oversimplified algorithms.

Most simulation-tools to calculate power losses calculate the losses at photovoltaic module level rather than for individual photovoltaic cells. This is a major disadvantage because of the internal connections between the photovoltaic cells and the bypass diodes (see Figures 1a-b).



**Figure 1a:** SunPower SPR-95 differently shaded.



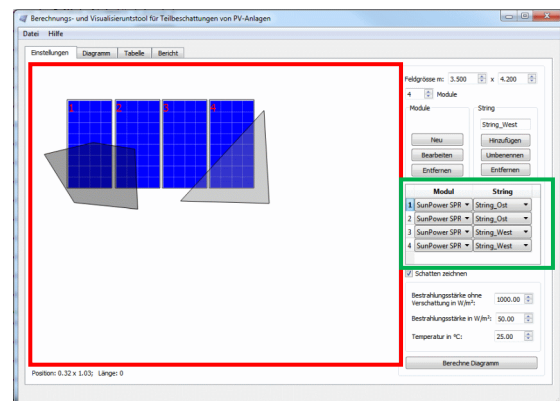
**Figure 1b:** Characteristics of differently shaded modules.

In order to remedy this gap, we developed a new Calculation- and Visualisation Tool (CVT) for partial shading of photovoltaic systems. The CVT considers the internal structure of the photovoltaic module and calculates the characteristic of each photovoltaic cell. Our tool consists of a drawing area, a setting area, a diagram and a table (see section 2) that are described below.

### 2 DESCRIPTION OF THE TOOL

#### 2.1 Structure

The main task of the CVT is to create and calculate the photovoltaic system. The different tasks of the tool are carried out in different Tabs.



**Figure 2:** Tab Settings.

The first tab (see Figure 2) includes all important settings to create a photovoltaic system. Here, the user is able to vary the count of modules for the photovoltaic system.

With the aid of another window (see Figure 3), it is possible to create different module types. In this window, the count of photovoltaic cells and bypass diodes within one module are set. Different calculation models for the photovoltaic cell and the bypass diode can also be chosen.

Once a module is created it is possible to save it or to load it for another calculation later. The user is thus enabled to create an own list of photovoltaic modules.

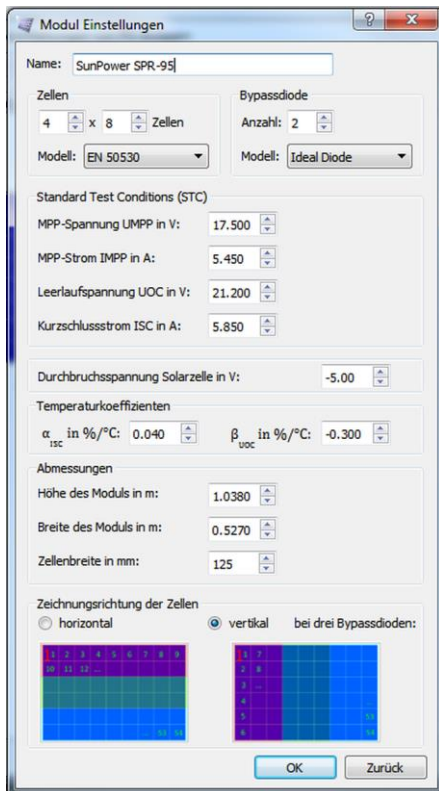


Figure 3: Window for defining the module properties.

Figure 2 shows a table (see Figure 2 green rectangle) which defines the selection of the type of module and which module belongs to which string.

Because of the calculation method, it is only possible to create crystalline modules at this stage. Also, the temperature can be defined for the whole photovoltaic system. The irradiation of each photovoltaic cell will be calculated separately.

The red rectangles on the left side of Figure 2 display a free area in which each module can be placed. The shadow can be painted with the mouse. Before the characteristics are calculated, and as a last step, the movement of the shadow in function of time is set.

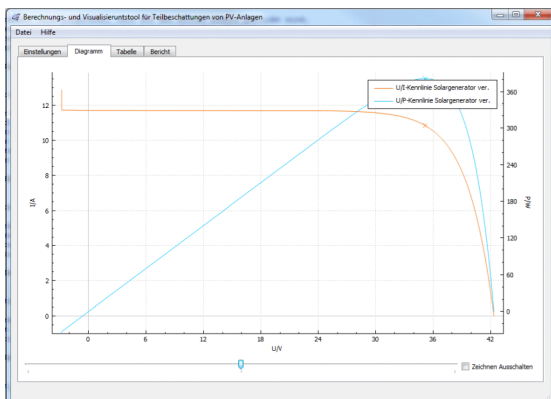


Figure 4: Tab Diagram.

In the second tab (see Figure 4), the characteristics can be displayed (e.g., of the whole photovoltaic system, of each module-string, of each module, of each cell-string and of each photovoltaic cell). The user can select from four different types of characteristics, being: V/I-characteristic (shaded or unshaded) and a V/P-characteristic (shaded or unshaded). Power losses can be visualised better when a shaded characteristic is compared with an unshaded characteristic. Inserted underneath the diagram in Figure 4 is a slider which serves to visualise the different time steps.

The calculated data can be exported into csv-files.

	U[MPP]	I[MPP]	P[MPP]	U[OC]	I[SC]
Solargenerator beschattet	35.1696	10.84	381.238	42.364	11.7
Solargenerator unbeschattet	35.1696	10.84	381.238	42.364	11.7
1. Modul: SunPower SPR-9S beschattet	17.5848	5.42	95.3096	21.182	5.85
1. Modul: SunPower SPR-9S unbeschattet	17.5848	5.42	95.3096	21.182	5.85
1. Zelle des 1. Moduls beschattet	0.549525	5.42	2.97842	0.661937	5.85
1. Zelle des 1. Moduls unbeschattet	0.549525	5.42	2.97842	0.661937	5.85

Figure 5: Tab Table.

The third tab (Figure 5) is a table containing the most important values, being: the maximum power point (MPP), the MPP-voltage, the MPP-current, the open circuit voltage and the short circuit current. As in the second tab diagram (Figure 4), it is possible to include the data from all characteristics, from the photovoltaic system to the cell level.

## 2.2 Design

Figure 6 shows the UML-diagram (Unified Modeling Language) of the CVT for partial shading of photovoltaic systems. The diagram reads from top to bottom and is described below:

A photovoltaic system consists of multiple module-strings. These module-strings are connected in parallel. A module-string is composed of multiple serial connected modules. A module is made up of multiple serial connected cell strings. One cell-string consists of multiple serial connected photovoltaic cells and one bypass diode. To choose between different calculation methods for the bypass diode and the photovoltaic cell, the bypass diode and the cell are implemented as abstract classes. An abstract class can be used like a model, and it is possible to implement multiple classes for both bypass diode and cell.

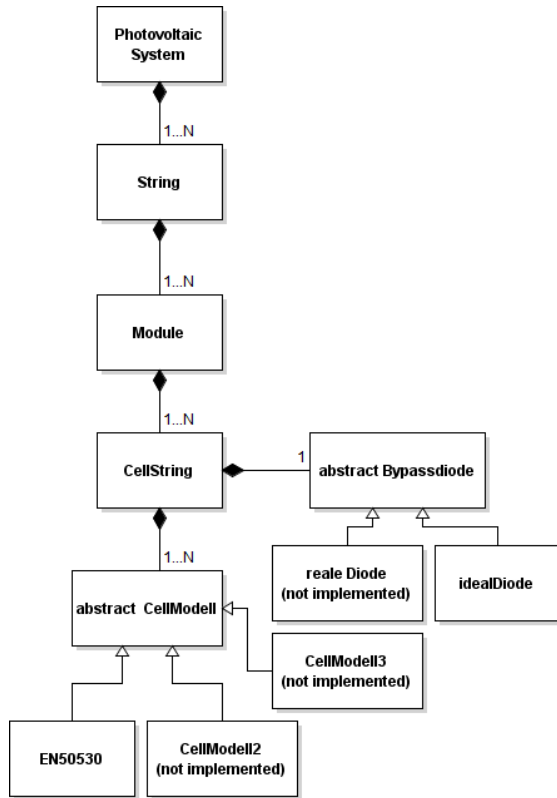


Figure 6: Design of the CVT

### 2.3 Calculations

There are multiple ways to calculate a characteristic of a photovoltaic cell. The best known calculation methods are the simplified model, the one-diode model and the two-diode model. In our tool, another model is implemented, namely a model from the standard EN50530 [1], with the formula:

$$I = I_{SC} - I_0 \cdot \left( e^{\frac{U}{U_{OC} \cdot C_{AQ}}} - 1 \right)$$

in which

$$C_{AQ} = \frac{FF U - 1}{\ln(1 - FF)}$$

$I_{SC}$ : short circuit current  
 $I_0$ : irradiation depending current  
 $U_{OC}$ : open circuit voltage  
 $FF$ : fill factor

After calculating the photovoltaic cell, the voltages of the photovoltaic cells are summed up to calculate the characteristic of the cell string. As the module strings are connected in parallel, the currents are added.

The radiation is calculated for each photovoltaic cell individually.

### 3 COMPARISION CVT AND MEASUREMENT

Figure 7 shows the difference of the calculated values from the CVT and the measured values from the flasher of the Photovoltaic Laboratory of the BFH. The module SPR-95 from SunPower was shaded in two different ways (see Figure 1a).

As Figure 7 shows the match of the characteristics is very height.

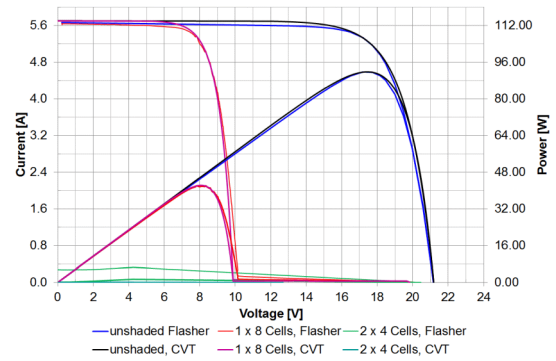


Figure 7: Comparison CVT and Flasher

### 4 SUMMARY AND FURTHER AVENUES

A Calculation- and Visualization-Tool (CVT) for partial shading of photovoltaic systems was developed. The CVT is able to simulate a photovoltaic system with modules arranged in a plane and consisting of crystalline cells. Different shadows can be defined and each module can be placed on a location within the drawing area in the tool. The radiation of each shadow can be set individually. The shadow can be moved to a specified direction for a predetermined number of steps. When each step is calculated it can be visualised by moving a slider. A table displays the most important values.

The tool allows different calculation methods for the characteristic of the photovoltaic cell and the bypass diode. From the results provided by the calculation, it is possible to select and visualise the characteristics for each individual cell, cell-string, module, module string and the complete photovoltaic system. The simulation results may serve e.g., as a reference for measurements of inverters that are under development.

The innovation of the CVT as compared to currently available tools is the quantification of the characteristics at individual PV cell level rather than at PV module level.

Among the planned extensions of the CVT are the implementation of various calculation models for the calculation of the solar cell and the bypass diode.

### 5 RESOURCES

[1] Standart EN50530  
 [2] F. Kuonen, bachelor-thesis: Berechnungs- und Visualisierungstool für Teilbeschattungen von Photovoltaikanlagen