The Impact of Shading on a PV System

Whitepaper

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Business Unit Solar Energy

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1 Objective

The objective of this whitepaper is to show how Fronius inverters, all with integrated Dynamic Peak Manager can be used to minimize yield losses in partially shaded PV systems – without the use of DC optimizers that offer no significant yield advantages. With current electricity prices, many PV Systems are no longer dimensioned to match electricity consumption and instead the aim is to install the maximum kWp that fits the roof. For this reason, shaded areas on the roof are also used. Customers are then often unsure if the shading management of a classic string inverter is sufficient or if additional components like DC optimizers are needed. With Fronius Dynamic Peak Manager, the highest yields can be achieved even when there is partial shading.

2 Introduction

The performance of a photovoltaic (PV) system depends not only on solar irradiance and temperature but also on shading and configuration. Shading can be one of the main causes for losses in PV systems, reducing overall production. It also leads to the loss of energy conversion and causes nonlinearity on the I-V characteristics. Under normal conditions, sunlight is uniformly distributed over the PV modules and the characteristic power-voltage curve has a single maximum power point at which the highest power can be extracted. Due to the presence of shading – which can be caused by clouds, trees, nearby buildings, other modules, module dust or various objects – PV modules may not receive an equal amount of solar irradiance. The impact of shading will depend on the number of shaded cells. When a single cell is shaded, the current or voltage through the substring is reduced and the shaded cells can become reverse biased. They consume power instead of generating it, leading to reduced power generation. An intelligent system design and efficient shade management are therefore essential to achieving the best possible operation of a shaded PV system. Shading not only causes a decrease in power output but also may cause hotspots to occur as a result of the increased mismatch between PV modules. In extreme cases of shading, the reverse bias on the solar cell can exceed its breakdown voltage and cause irreparable damage. To protect the modules from this, bypass diodes are included on every module to bypass the shaded PV cell or module.

3 Behavior of bypass diodes in shaded and unshaded PV modules

This chapter describes the behavior of bypass diodes and PV modules in shaded and unshaded conditions. A scenario is presented in which the inverter – the active component – is activating the bypass diode in order to achieve a higher yield.

3.1 Bypass diodes

Bypass diodes are part of every crystalline PV module. The bypass diodes are connected in parallel but with opposite polarity to a PV cell and have no effect on the PV module output when they are not activated. A standard PV module with 60 cells is built with 3 substrings, wherein each substring has 20 cells and is protected by a bypass diode. Many commercial PV cell modules have integrated the bypass diode into the module junction box. The bypass diodes are used in PV modules to prevent the application of high reverse voltage and to allow the current to “skip over” the shaded cells of the PV module. The purpose is to allow the module current to bypass shaded or broken cells to prevent hot spot or hot cell damage resulting from reverse voltage biasing from other cells in that module.

3.2 Behavior of unshaded/shaded PV modules

This is a standard PV module with 60 cells, where each PV cell produces about 0.5V, each substring has 10V, and the current for the PV module is up to 10A. Under normal operating conditions, when there is no shadow, each PV cell will be forward biased and the bypass diode will be reverse biased, and the current will circulate through all the cells. When all the cells are illuminated, the bypass diode is blocked and the PV module will have 30V and 10A across it.

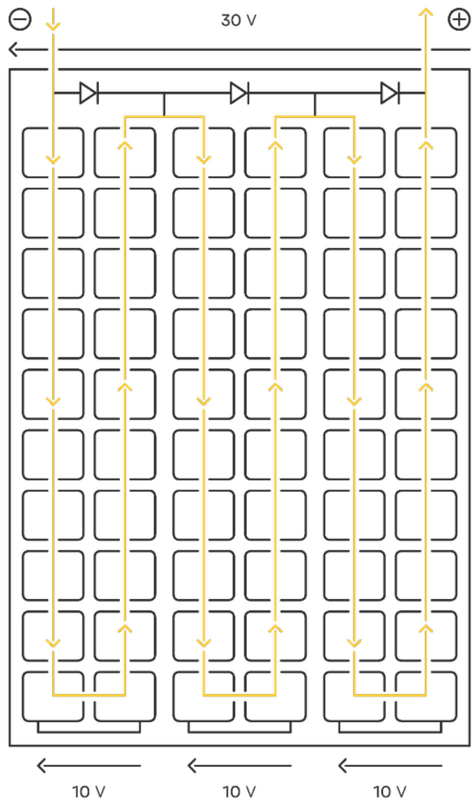

Figure 1: Standard PV module with no shading

If there is shading on one or more cells, the inverter can control the voltage to make the bypass diode conductive. This allows the full current to bypass the cells of the shaded substring, protecting it from heating up and hotspotting. The voltage at the bypass diode becomes negative and the current passes through it.

In the shaded substring, the bypass diode is “activated” with a voltage drop of approximately -0.6V. The second and the third substring will have 10V each. This amounts to 19.4 V ($V_{module}=V_{string1}+V_{string2}+V_{string3}$= -0.6V+10V+10V) across the entire PV module. As a result, the full current (e.g.10A) can flow.

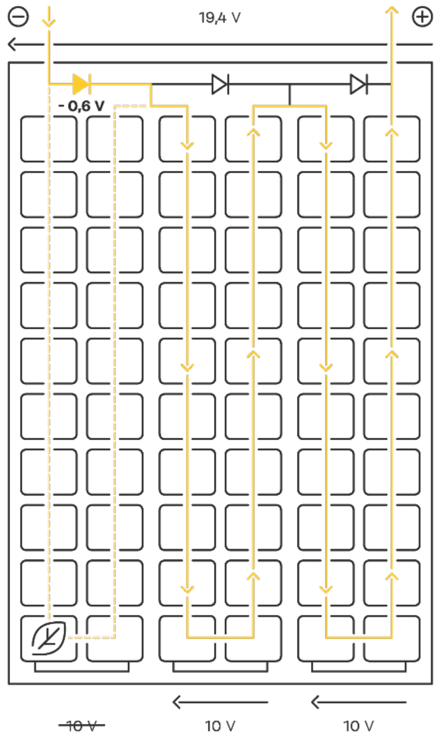

Figure 2: Standard PV module with shading

Half-cut cell PV modules can have an advantage, depending on which part of the PV module is under shade and how they are positioned. If they are positioned vertically and the lower part of the half-cut PV module is under shade, the remaining upper part still has a lot of power compared to the full-size standard PV module, since the whole module is lost in such cases and there is no power production. With the half-cut cell PV module, 5A can in this case still flow through each substring of the unshaded half, and the voltage will be 10V through each substring, with a total voltage of 30V. This provides a power output of 150W, which is half of the PV module’s rated power. If the half-cut cell PV module is positioned horizontally and the shading covers 1/3 of the PV module (from bottom to top or vice versa) then there is no yield difference compared to a full-size, standard PV module.

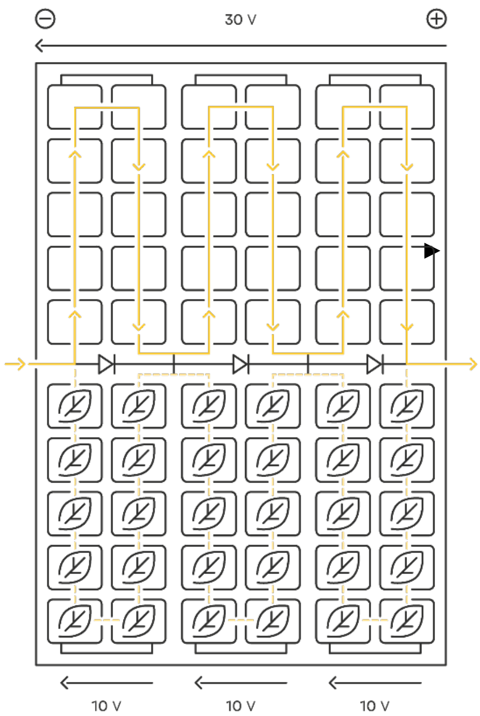

Figure 3: Half-cut cell PV module with shading

3.3 Practical example

System with 20 modules without shading:

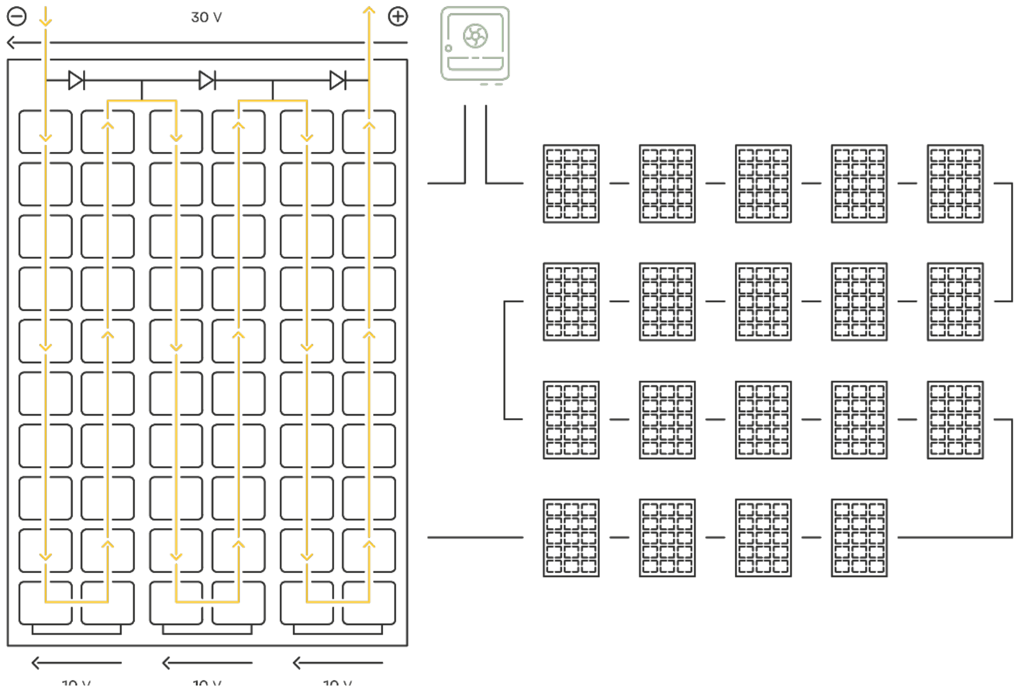

Figure 4: PV system with 20 modules without shading

System with 20 modules with shading:

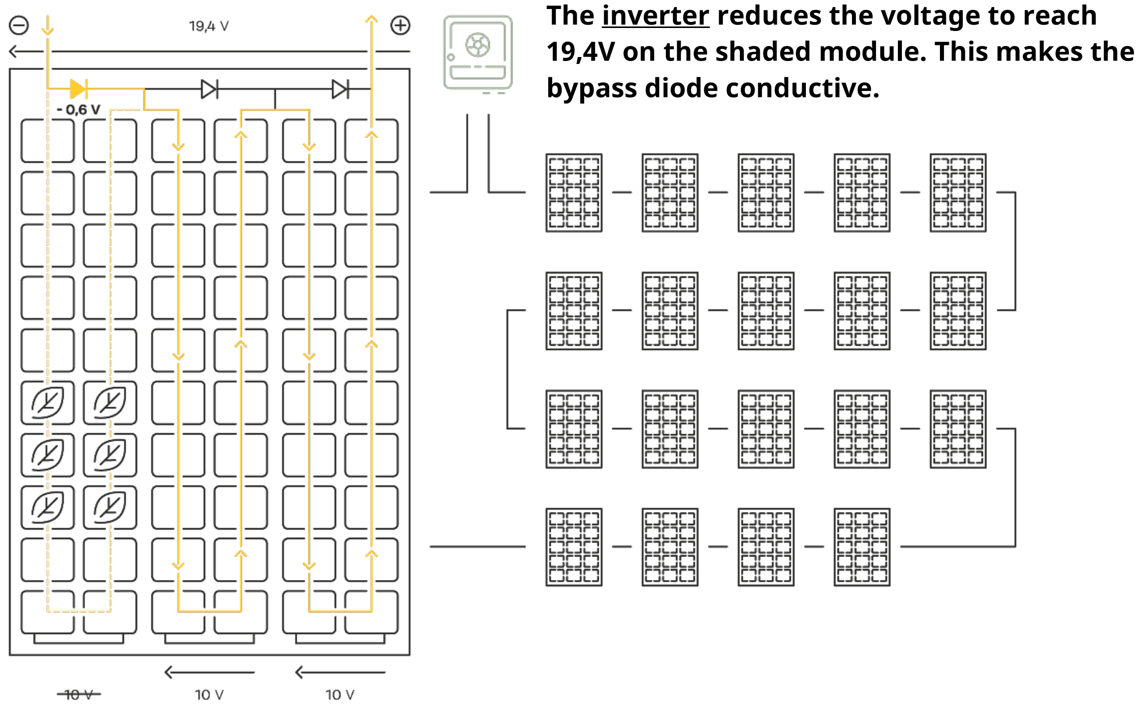

Figure 5: PV system with 20 modules with shading

Let's take as an example a system with 20 PV modules, each with 30V and 10A, connected in series to a string inverter. Normally, if we don't have shading, the bypass diode is passive and is not conducting, so it will not conduct current, and we will have 600V and 10A across the system with a power output of 6000W (Figure 4). Shading occurs when, for example, leaves fall on one of the modules (Figure 5). When shading occurs, two things are possible:

1. The inverter will stay at 600V, since each substring will theoretically still produce 10V but not 10A due to the shading, so that only a 3A current can pass in the first submodule and each submodule will be limited to 3A current. In this case, the system output will be 1800W.
2. **The inverter will reduce the voltage and make the bypass diode conductive.** To be conductive, the bypass diode needs a voltage in its forward direction. In this example the voltage will be reduced from 600V to 589.4 V, and the bypass diode will be activated by the inverter with a total voltage drop of -0.6V. In the shaded substring, the 10A string current will be diverted by the bypass diode: 7A will pass through the bypass diode and 3A will pass through the shaded and unshaded cells. A 10A current will circulate in the shaded substring, through the other unshaded substrings and PV modules. In this case, when the inverter – the active component – reduces the voltage, the system output is 5894 W, and the power output is higher compared to the first option.

The bypass diode is simply a passive component and it changes something only if the inverter – the active component – does something (such as reducing the voltage) that leads the bypass diode to react to the system conditions.

Ideally, there will be no shading in the system, but this is unfortunately not the reality in many cases. When designing a system, we advise you to try to avoid shading in the times when irradiance is above 500W/m^2.

4 Maximum Power Point Tracking

The inverter is a part of any PV system. It controls the voltage and current as well as the quality of the output power, and it uses Maximum Power Point Tracking (MPPT) to get the maximum possible power from the PV modules.

MPPT is a control strategy technology (higher efficiency DC-DC converter technology) that optimizes the power output available from PV modules in less-than-ideal sunlight conditions as well as at any time during its operation. It can implement various algorithms (e.g. current sweep, hill-climbing, perturb and observe, constant voltage, etc.) used in charge controllers to extract the maximum available power from the PV module under certain conditions. The power delivered depends on where in the point it operates.

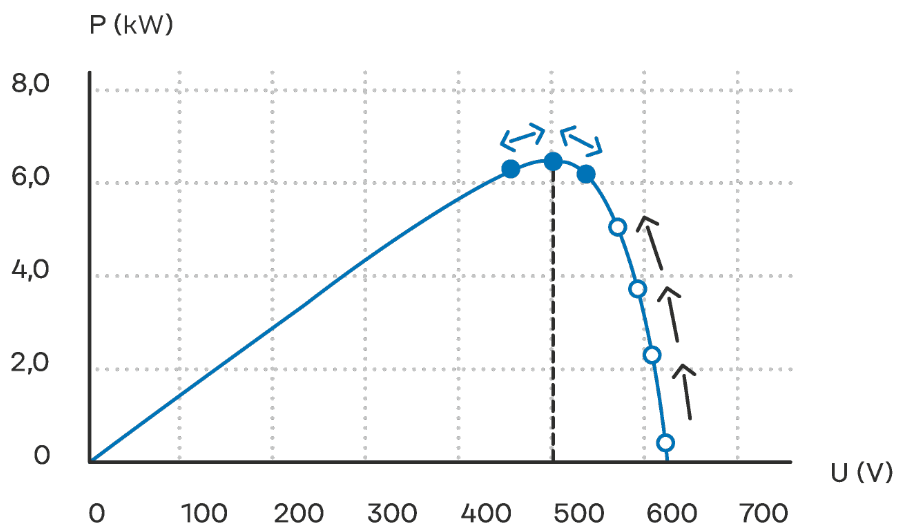

Figure 6: Hill climbing MPP tracking algorithm

The power curve has a power peak at a specific voltage, specified as maximum power point (MPP) voltage. Variation of the PV cell temperature and irradiance throughout the day affects the location of the MPP voltage. Figure 6 shows the hill-climbing principle, which is most commonly used. In this process the voltage is incremented or decremented, searching for the MPP voltage. It begins with an increment/decrement in the voltage tracked by the measurement of the corresponding amount of the generated power. Whenever the generated power increases, the algorithm continues to change the voltage in the same direction, whereas when it decreases, the algorithm changes the voltage in the opposite direction. The procedure repeats until the voltage reaches the MPP voltage.

The algorithm scans the P-V curve and tries to find the optimal operating point, called the Global Maximum Power Point (GMPP). If there is shading, the tracker stays at the Local Maximum Power Point (LMPP) without finding the GMPP. This is because the tracker scans within a limited area around the LMPP, which makes the tracker remain at the LMPP and leads to losses of available power. For this reason, Fronius has developed a very efficient shading management method to improve the operation of the PV system and reduce the power losses.

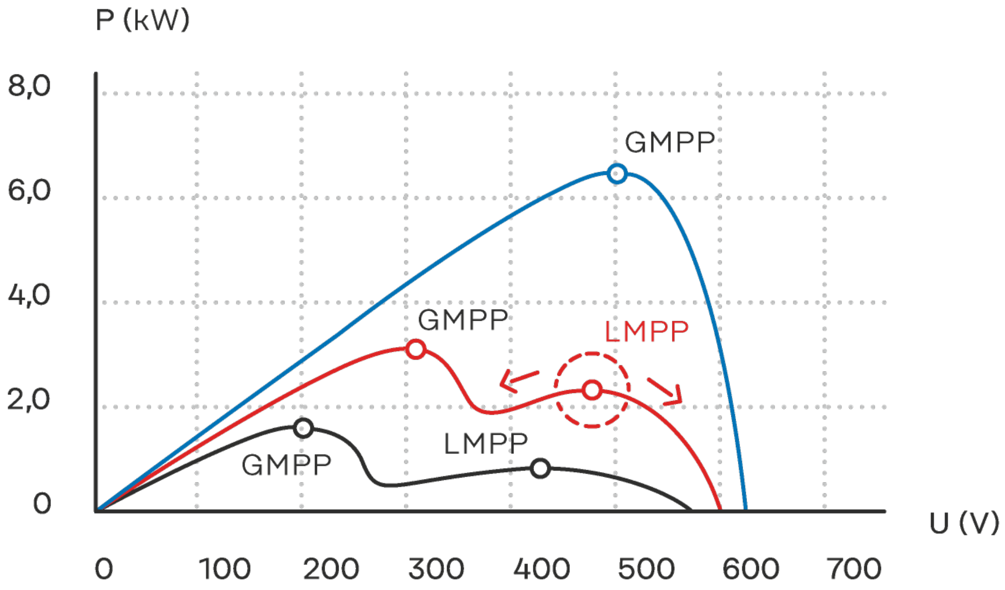

Figure 7: P-V curve with presented GMPP and LMPP

4.1 Dynamic Peak Manager

Even when there is partial shading, the Fronius Dynamic Peak Manager can always provide the customer with the best performance.
The Dynamic Peak Manager (DPM) is a highly efficient shade-tolerant MPP tracking algorithm that dynamically adapts its behavior when searching for the optimal operating point. This highly efficient MPP tracking algorithm detects any shade and optimizes the yield at the string level. The Dynamic Peak Manager finds the Global Maximum Power Point by checking the entire characteristic curve at regular 10- to 11-minute intervals. No additional, sensitive components are needed at the module level, since this is already integrated into the inverter.

The advantages of the Fronius DPM:

- Maximum yields, even in the case of partial shading
- Optimization at string level
- No additional components needed
- Greater system reliability
- No installation work needed

5 DC Optimizers

1. A DC optimizer tries to optimize each module with its individual MPP, but if there is shading, it might also activate the bypass diode, in which case it does not provide an advantage.
2. If the PV array voltage is different from the input voltage of the inverter, the optimizers will try to tune this by boost/buck-boost, which makes the system less efficient. This reduction or decrease in efficiency is not found anywhere in the data sheets, but the reduction is definitely relevant as these losses can add up to several %. An IEC technical specification currently under development will address this efficiency issue for shaded PV systems using optimizers. This document, based on studies conducted at the Zurich University of Applied Sciences, showed that optimizer efficiency is strongly dependent on the ratio between input and output voltage. The figure below shows the efficiency curve of DC/DC optimizers as a function of this ratio. As soon as this ratio deviates from 1 (Uin=Uout), there is a significant difference (2% or more) from the efficiency values declared in the datasheets for optimizers (typically around 99%).
   Let us take as an example a 3-phase system with 10kWp, consisting of around 30-33 modules operating at 40V each. This would be equivalent to ~1350 V array voltage, which means that the optimizers would have to buck the voltage down to the maximum input voltage of the inverter, which we'll set in this example at 750V. The optimizer ratio in this case is Uin/Uout=1350V/750V=1.8, meaning that the conversion efficiency of the optimizer alone (without inverter) would be around 96.7%.

   Assuming an annual production of a 10 kWp PV system in Central Europe of approx. 12,000 kWh, losses of 396 kWh would occur at an efficiency of 96.7%. This would be 147€ losses per year at an electricity price of 37.12 Cent/kWh (Average electricity price in Austria 2022, including taxes and levies [1]). In 10 years, this results in **losses of 1470€** (and in this calculation the efficiency of the inverter itself has not been taken into account, only that of the optimizers).

   Our findings also showed that calculation software does not account for optimizer efficiency losses and they overestimate the benefits of optimizers in cases of module mismatch, where the efficiency of the optimizers is less than that stated in the datasheet.

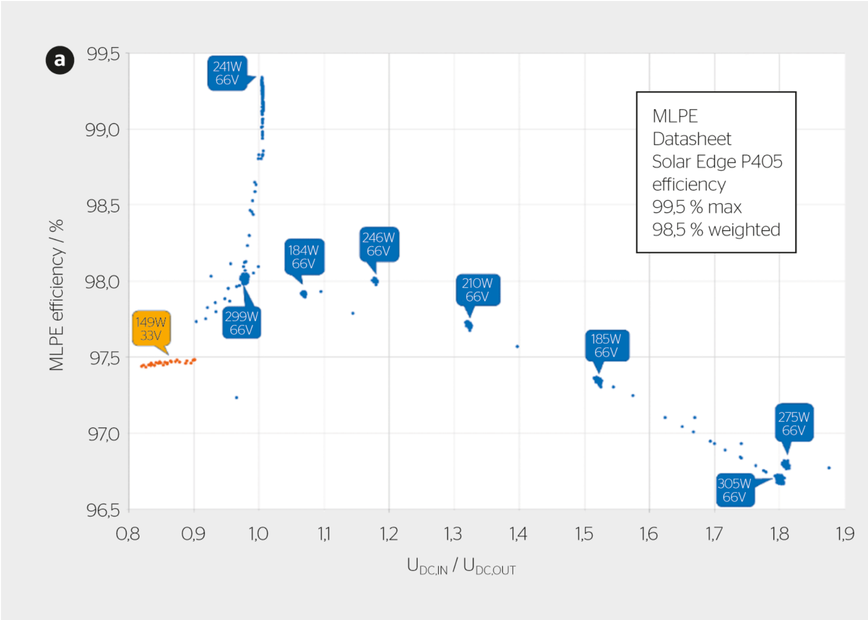

Figure 8: DC/DC optimizer efficiency curve
[Source 1: Bulletin.ch 5/21, Franz Baumgartner, Optimizer: Nur ein Hype oder die Zukunft?]

3. Without shading and at high irradiation, the DC optimizer still results in losses instead of advantages. Even if it is not doing anything ("standby mode") and there is no shade, the DC optimizer results in losses because it consumes energy itself.
4. Another disadvantage of a DC-optimized system is the large number of components on the roof. Each power optimizer sits directly behind the solar module and is therefore exposed year-round to all weather conditions. This is unhealthy for the sensitive power electronics and can have repercussions in terms of lifetime servicing and fire risks.

6 Practice examples

In this chapter, various practical shading scenarios of PV systems with string inverters were simulated in the dynamic simulation program PV SOL.

6.1 PV SOL

PV SOL premium is a dynamic simulation program with 3D visualization and detailed shading analysis used to calculate photovoltaic systems in combination with appliances, battery systems and electric vehicles. PV SOL [2] lets the user choose the type of system, the type of design (3D or 2D simulation), the time step for simulation (1 hour simulation (faster) or 1 minute simulation (more precise)), and the climate data (by using the software data or attaching a file with the climate data). In the 3D design, there is a variety of PV field options (map selection, import 3D model, different types of house with a roof, open field area). With the 3D analysis there is better visualization of shading objects (trees, houses, chimney, etc.) and it has the complexity to model partial shading systems. PV SOL provides the option to combine multiple inverters and precise connection to various MPPT. This software evaluates system parameters such as total energy production, surplus energy, module specific partial shading, mismatch (shading), system efficiency, and others.

6.2 Configuration

Analysis and simulations using PV SOL are carried out exclusively and independently by Fronius International without any collaboration or promotion of the software. Fronius uses PV SOL to perform shading analysis as a practical example on a PV system installed on the roof of a house in Brandenburg an der Havel, Germany. The PV modules used for the simulations were chosen without any collaboration; they are half-cut cell PV modules from Trina Solar with 395 W power output. 30 half-cut cell PV modules are installed on the roof of the house with a south direction. In the analysis, a Symo GEN24 10.0 Plus inverter is used with 2 MPPT. On the first MPPT, two strings are connected in parallel with 10 half-cut cell PV modules connected in series on each of the strings, and on the second MPPT, one string of 10 half-cut cell PV modules are connected in series. The PV installation has a sizing factor of 118.5%. The unshaded annual yield of the PV system is 14 485.54 kWh.

Separate simulations have been performed with the PV modules installed horizontally and vertically.

Different scenarios for shading have been analyzed:

- Shading from a chimney
- Shading from an antenna

- Shading from a tree
- Shading from another house
- Shading from a pillar

6.3 Results

In this chapter the results of the various simulations are described.

6.3.1 Shading from a chimney

The simulation with shading from a chimney was performed with the half-cut cell PV modules positioned horizontally and vertically. The results of shading are presented in Table 1 and 2.

Type of losses due to shading	Losses in %	Losses in kWh	
Module-specific partial shading	-0.18%	26.07 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0.06%	8.7 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 1: Shading results on a yearly basis from the simulation with PV modules positioned horizontally

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

In the table we have presented two losses: **module-specific partial shading loss** and **mismatch (configuration/shading) loss**.

The **module-specific partial shading losses** are due to lower irradiance that can reach the modules, blockage of sunlight due to the object that is causing the shading. These losses describe the lost energy compared to a fully insolated PV module and cannot be influenced by an inverter, DC optimizer, microinverter, etc. As the modules can be arranged in horizontal or vertical and this will cause a change in the shape of the array (width and height) this may cause slightly differences in these losses.

- The **mismatch (configuration/shading)** is loss we can influence. These are losses that occur in a shaded system due to the configuration. With a configuration using a Fronius inverter, a better performance can be achieved by the use of highly efficient shadow-tolerant MPP tracking algorithm. An example would be losses due to series connection in a shaded string.
- **Total losses:** Because of the shading occurring, the total losses will be the sum of these two losses.

When there is shading due to an object near the PV modules, the majority of losses are due to lower irradiance reaching the modules, which leads to higher module-specific partial shading losses, and the mismatch losses go up to 1% only because the decreased irradiance is -10% or higher. This means that when using the Dynamic Peak Manager, mismatch losses are always 10 to 20 times lower than the losses due to decreased light reaching the modules.

The previous explanation and differences for the two types of losses also applies for all the following cases.

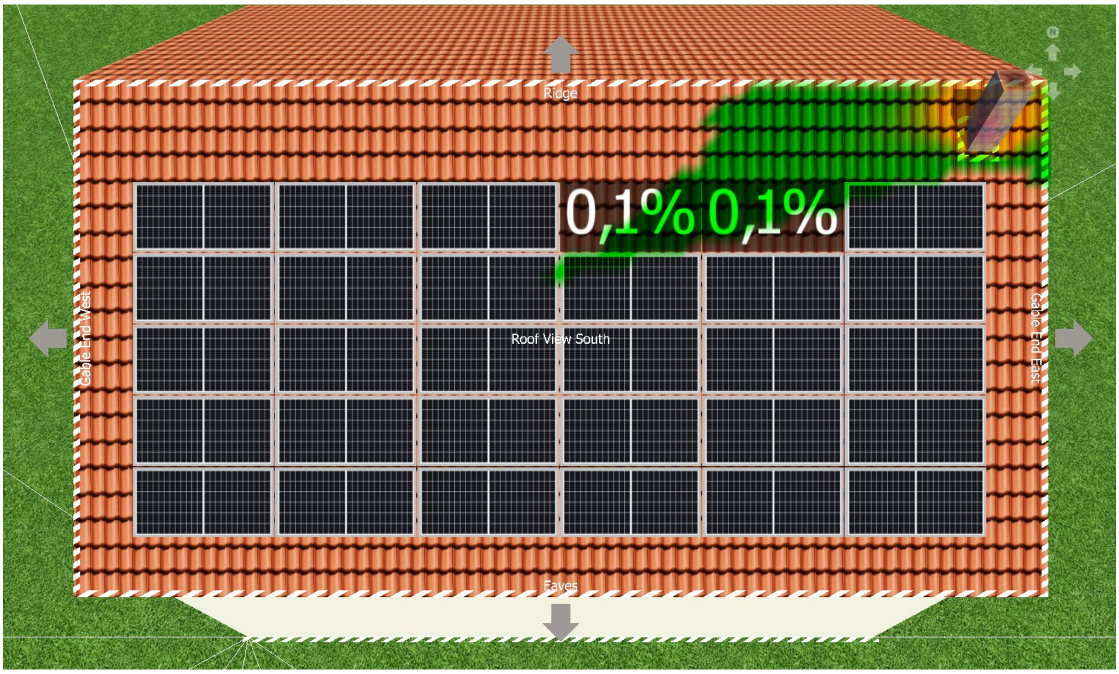

Figure 9: Shading on a yearly basis from a chimney, with PV modules positioned horizontally

Figure 9 shows the roof of the house with half-cut cell PV modules positioned horizontally and shading from a chimney occurring on the modules. This shows how much loss will occur on each of the modules on a yearly basis.

Type of losses due to shading	**Losses in %**	**Losses in kWh**	
Module-specific partial shading	-0.29%	42 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0.21%	30.4 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 2: Shading results on a yearly basis from the simulation with PV modules positioned vertically

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

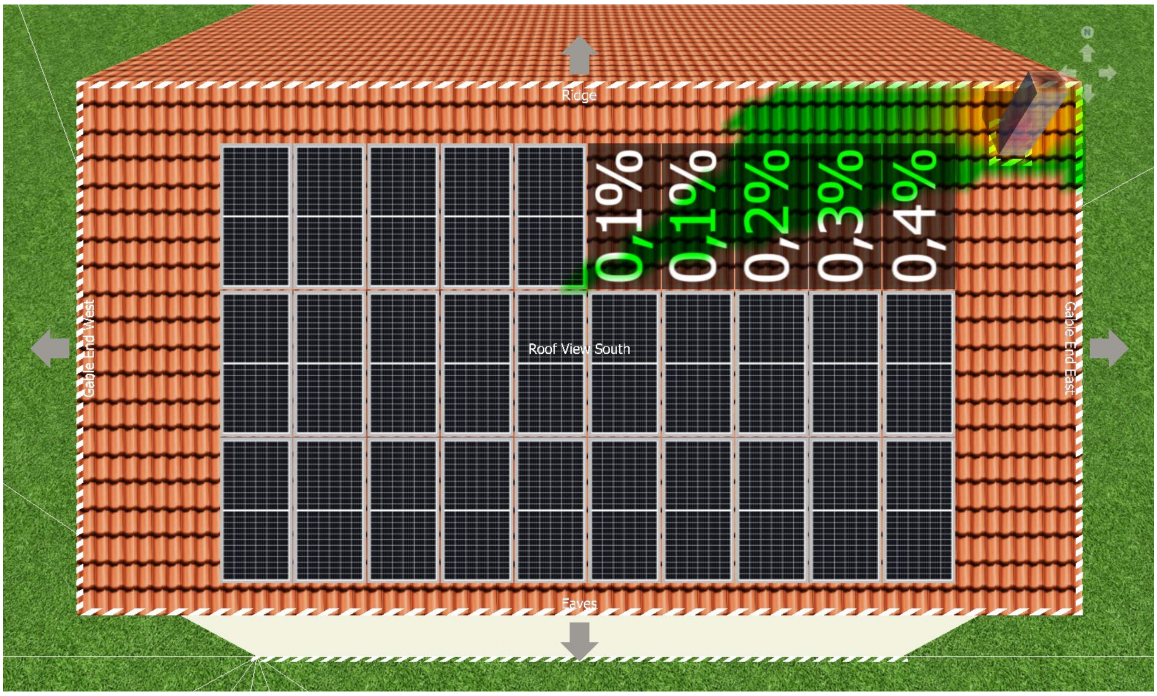

Figure 10: Shading on a yearly basis from a chimney with PV modules positioned vertically

6.3.2 Shading from an antenna

The simulation with shading from an antenna was performed with the half-cut cell PV modules positioned horizontally and vertically. The results of shading are presented in Table 3 and 4.

As the modules can be arranged in horizontal or vertical and this will cause a change in the shape of the array (width and height) this may cause slightly differences in the module specific partial shading losses.

Type of losses due to shading	Losses in %	Losses in kWh	
Module-specific partial shading	-0,57%	82.6 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0,38%	55 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 3: Shading results on a yearly basis from the simulation with PV modules positioned horizontally

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

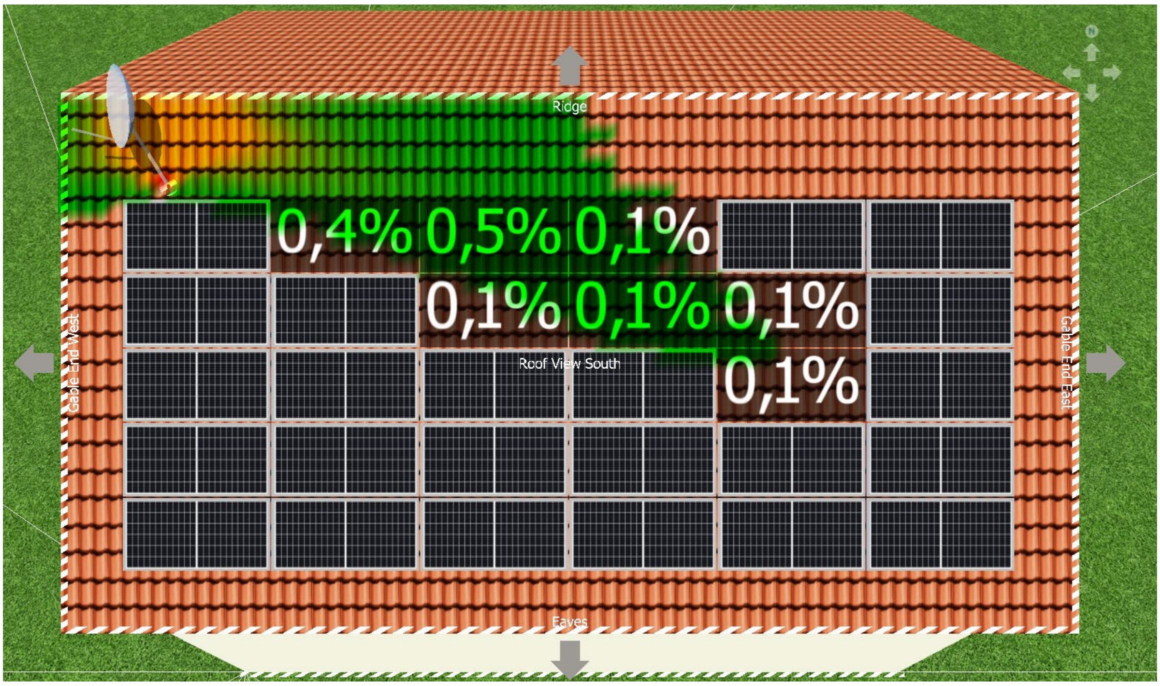

Figure 11: Shading from an antenna with PV modules positioned horizontally

Type of losses due to shading	Losses in %	Losses in kWh	
Module-specific partial shading	-0.94%	136.2 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0.86%	124.6 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 4: Shading results on a yearly basis from the simulation with PV modules positioned vertically

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

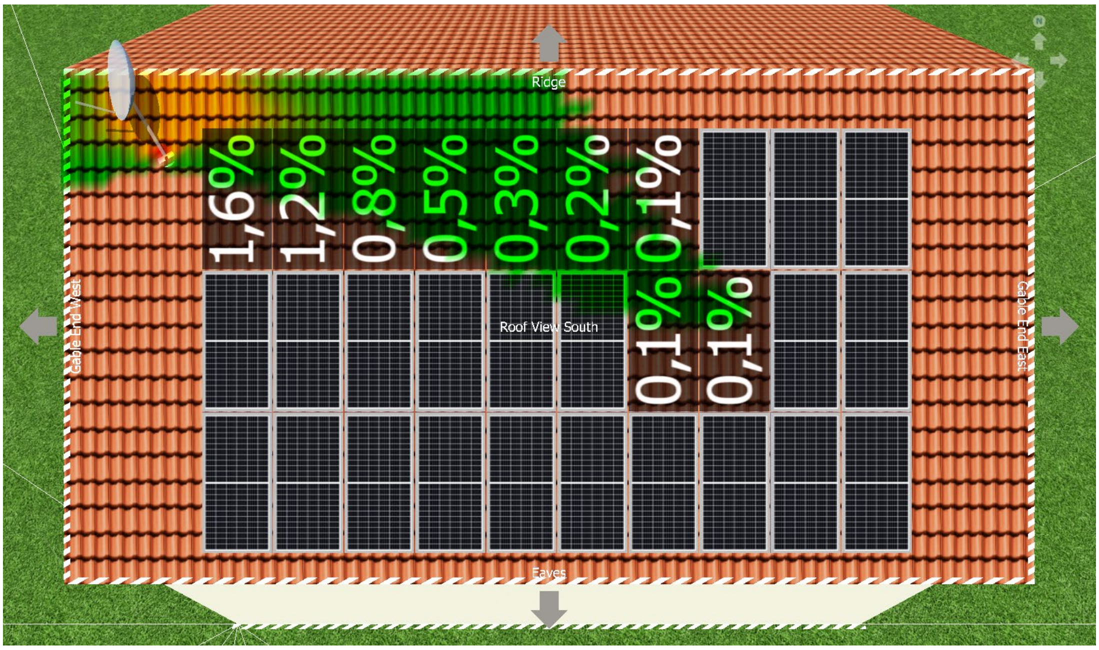

Figure 12: Shading from an antenna with PV modules positioned vertically

6.3.3 Shading from a tree

The simulation with shading from a tree was performed with the half-cut cell PV modules positioned horizontally and vertically. The results of shading are presented in Table 5 and 6.
As the modules can be arranged in horizontal or vertical and this will cause a change in the shape of the array (width and height) this may cause slightly differences in the module specific partial shading losses.

Type of losses due to shading	**Losses in %**	**Losses in kWh**	
Module-specific partial shading	-0.89%	128.9 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0.29%	42 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 5: Shading results on a yearly basis from the simulation with PV modules positioned horizontally

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

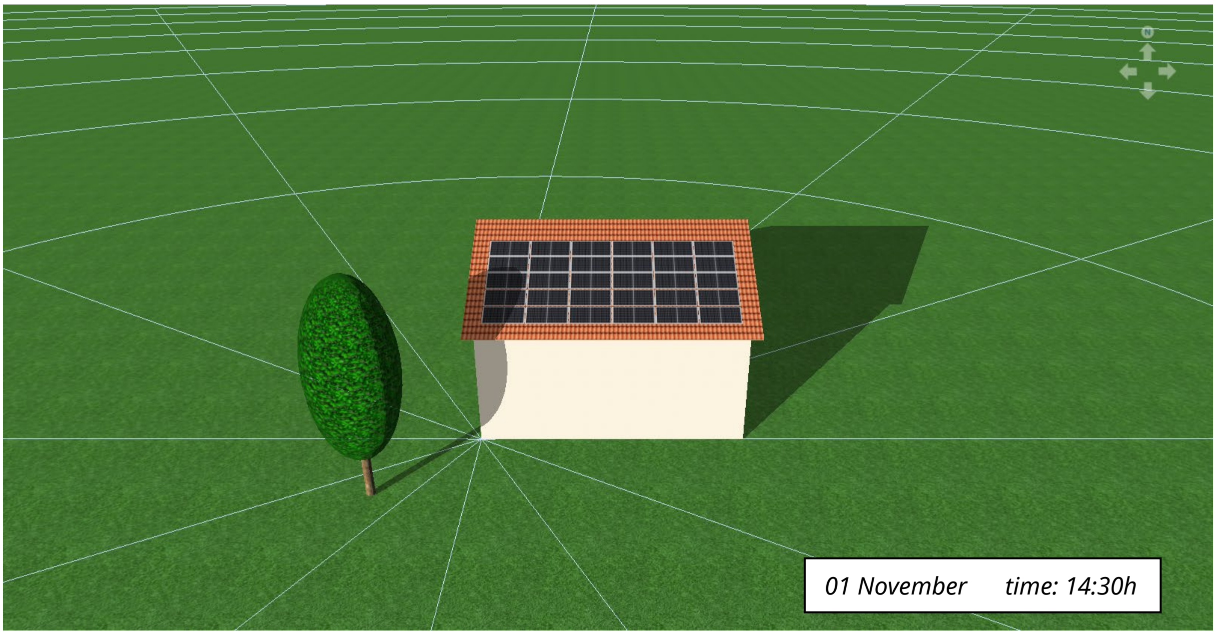

Figure 13: Exemplary representation of the simulation

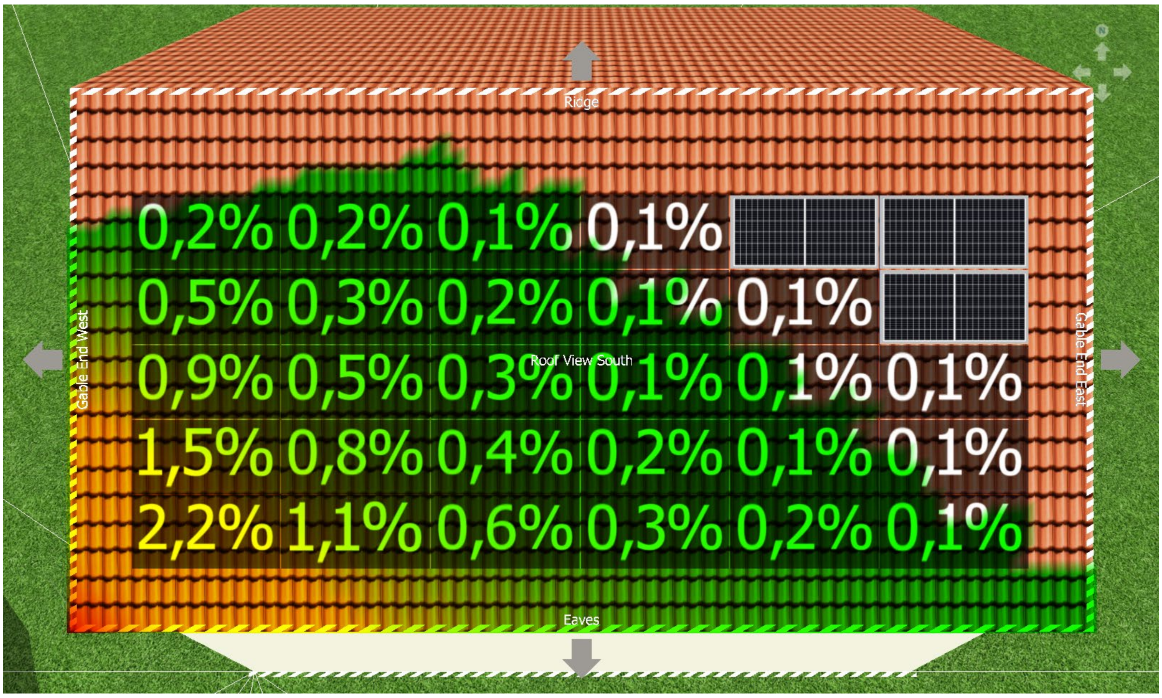

Figure 14: Shading on a yearly basis from a tree with PV modules positioned horizontally

Figure 14 shows how much each of the half-cut PV modules, positioned horizontally, will have shading from a tree during the whole year.

Type of losses due to shading	Losses in %	Losses in kWh	
Module-specific partial shading	-0.79%	114.4 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0.22%	31.9 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 6: Shading results on a yearly basis from the simulation with PV modules positioned vertically

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

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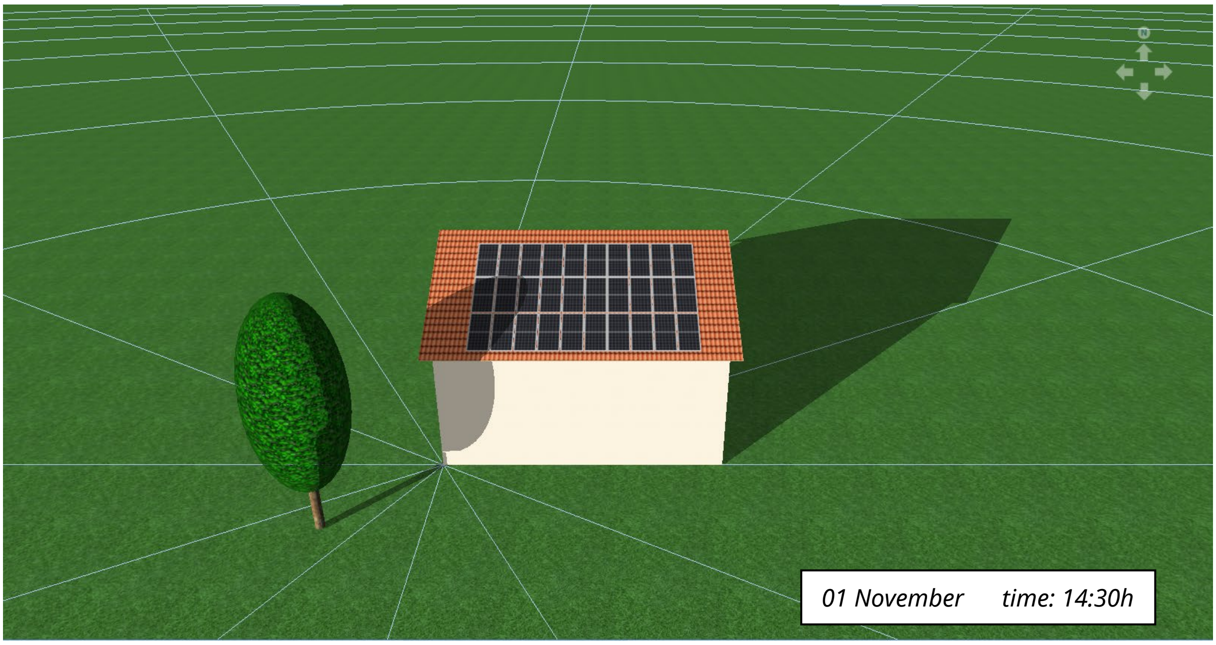

Figure 15: Exemplary representation of the simulation

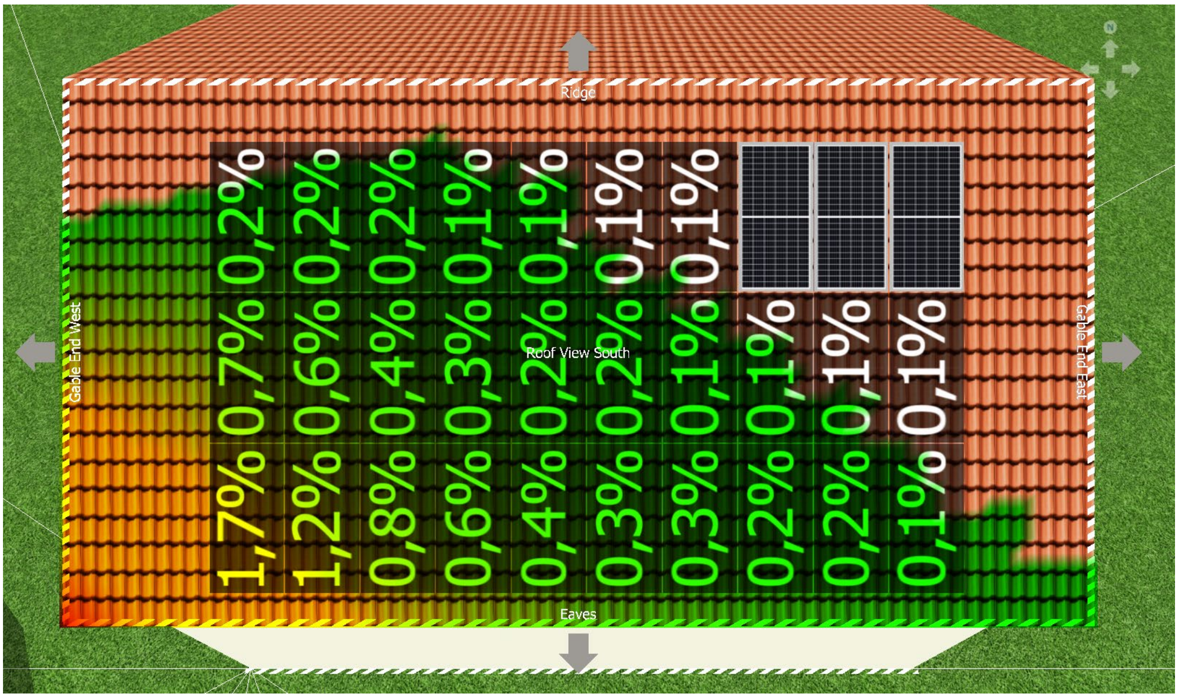

Figure 16: Shading on a yearly basis from a tree with PV modules positioned vertically

6.3.4 Shading from another house

The simulation with shading from another house was performed with the half-cut cell PV modules positioned horizontally and vertically. The results of shading are presented in Table 7 and 8.

As the modules can be arranged in horizontal or vertical and this will cause a change in the shape of the array (width and height) this may cause slightly differences in the module specific partial shading losses.

Type of losses due to shading	Losses in %	Losses in kWh	
Module-specific partial shading	-8.12%	1 176 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-1.64%	237.6 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 7: Shading results on a yearly basis from the simulation with PV modules positioned horizontally

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

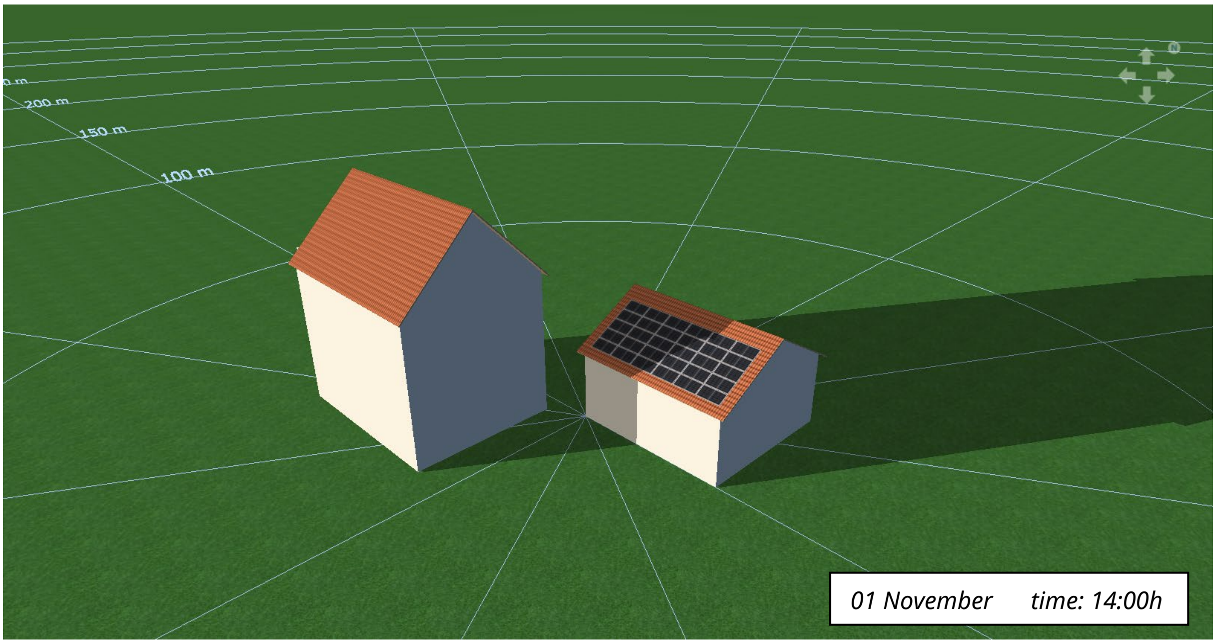

Figure 17: Exemplary representation of the simulation

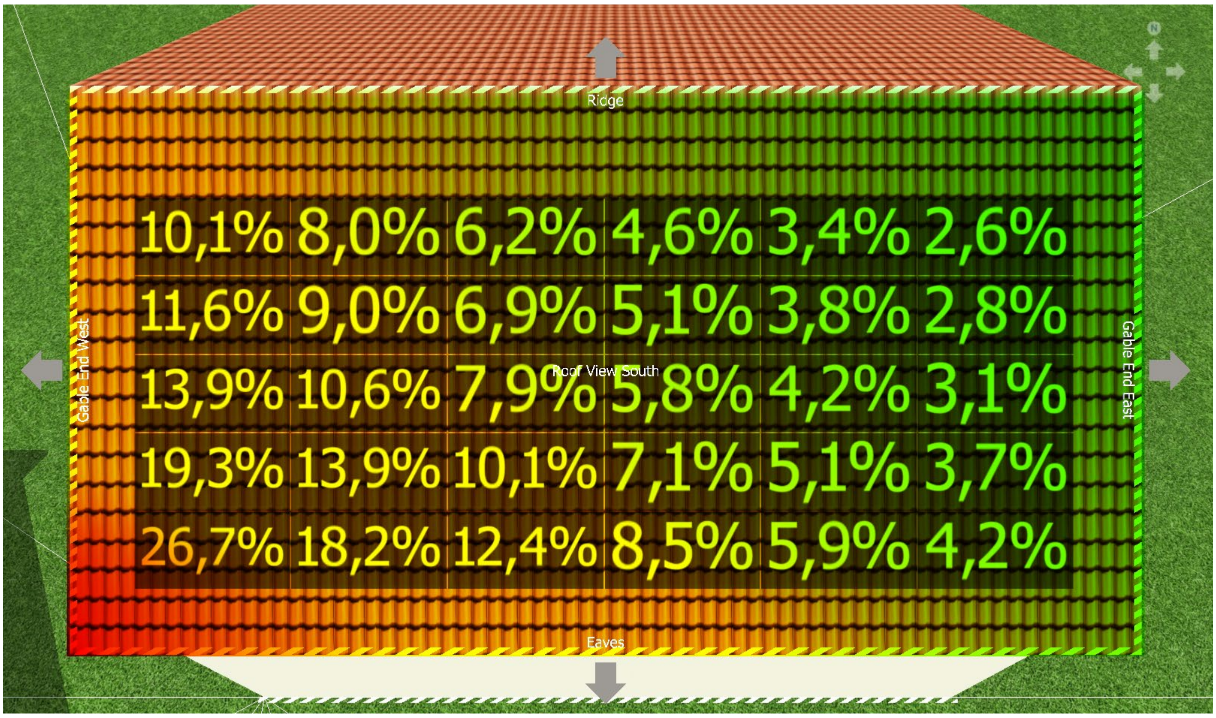

Figure 18: Shading on a yearly basis from another house with PV modules positioned horizontally

Type of losses due to shading	Losses in %	Losses in kWh	
Module-specific partial shading	-7.75%	1 122.6 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-1.24%	179.6 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 8: Shading results from the simulation with PV modules positioned vertically

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

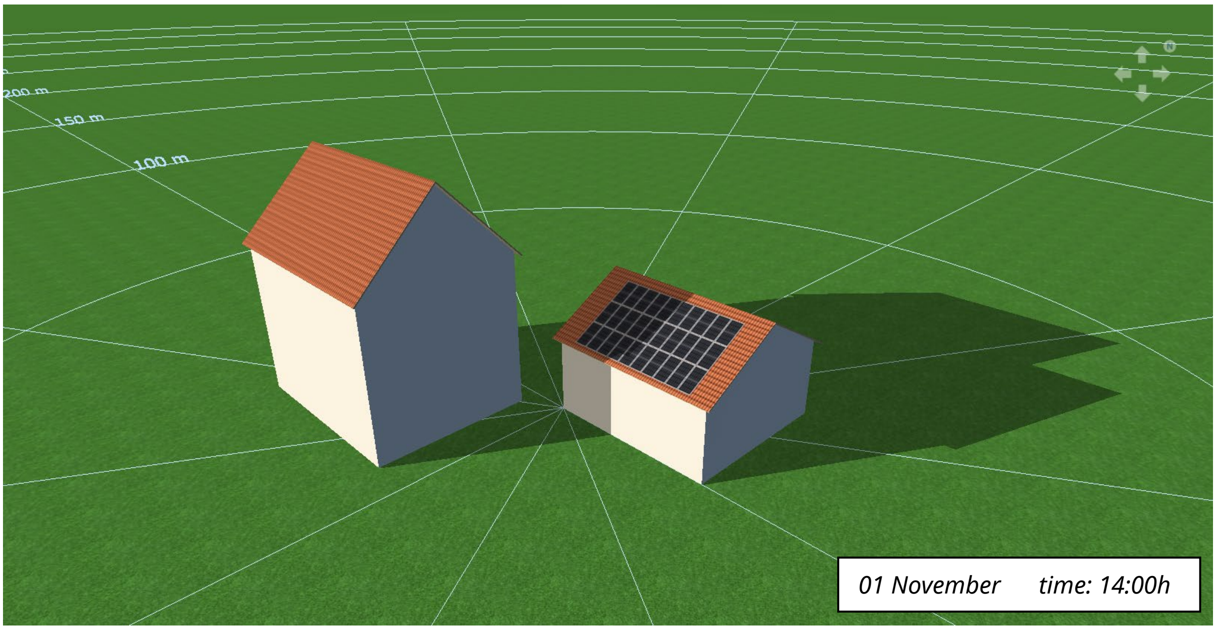

Figure 19: Exemplary representation of the simulation

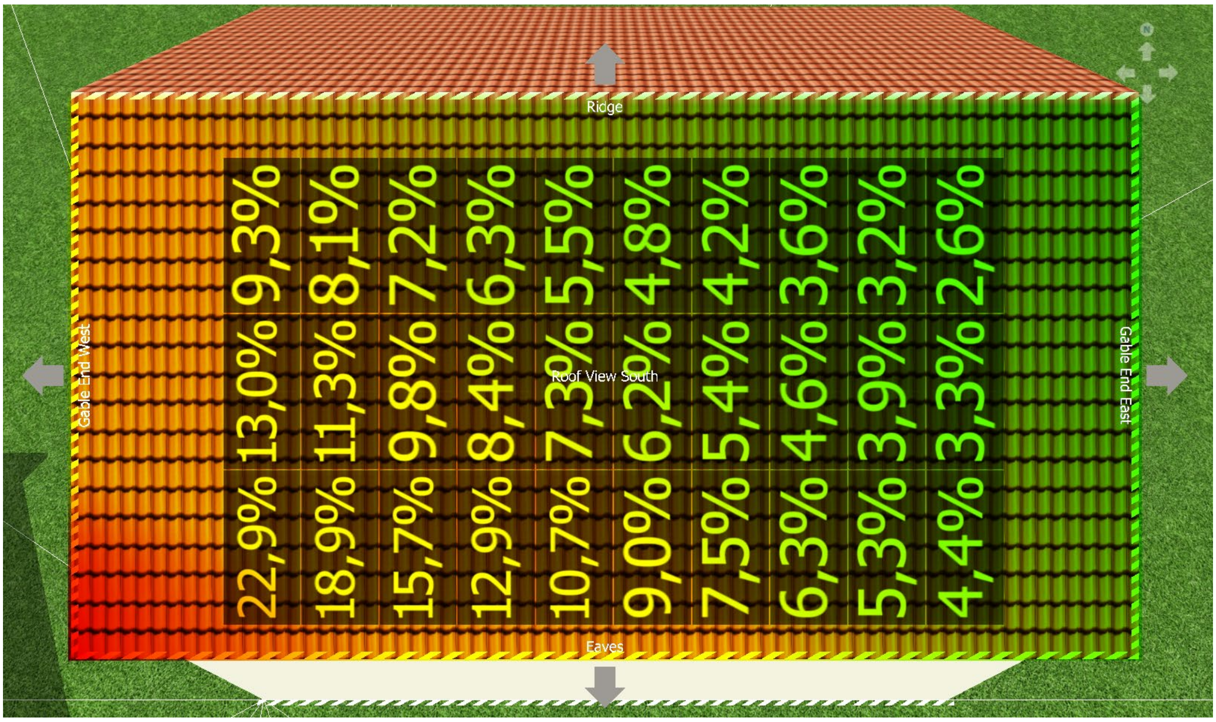

Figure 20: Shading on a yearly basis from another house with PV modules positioned vertically

Figure 20 presents a case where the half-cut PV modules are positioned vertically, with hard shading from a nearby house. The shading object will have an effect during the whole year, meaning the first module will have a total of 22.9% lower irradiance for the year.

6.3.5 Shading from a pillar

The simulation with shading from a pillar was performed with the half-cut cell PV modules positioned horizontally and vertically. The results of shading are presented in Table 9 and 10.

As the modules can be arranged in horizontal or vertical and this will cause a change in the shape of the array (width and height) this may cause slightly differences in the module specific partial shading losses.

Type of losses due to shading	**Losses in %**	**Losses in kWh**	
Module-specific partial shading	-2.89%	418.6 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0.97%	140.5 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 9: Shading results on a yearly basis from the simulation with PV modules positioned horizontally

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

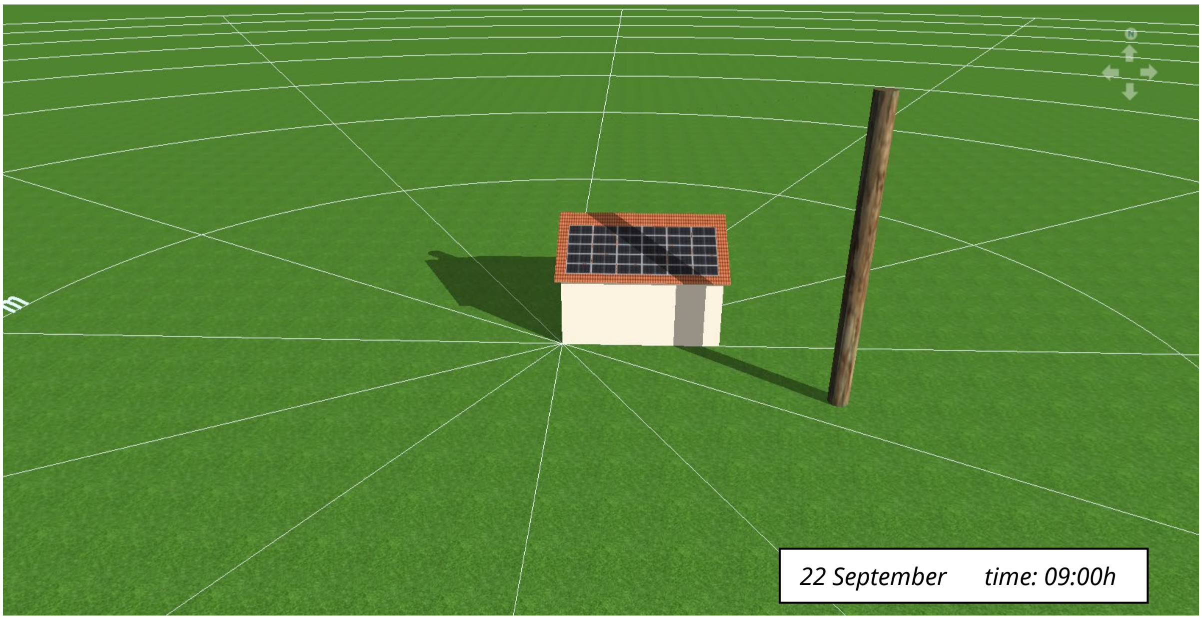

Figure 21: Exemplary representation of the simulation

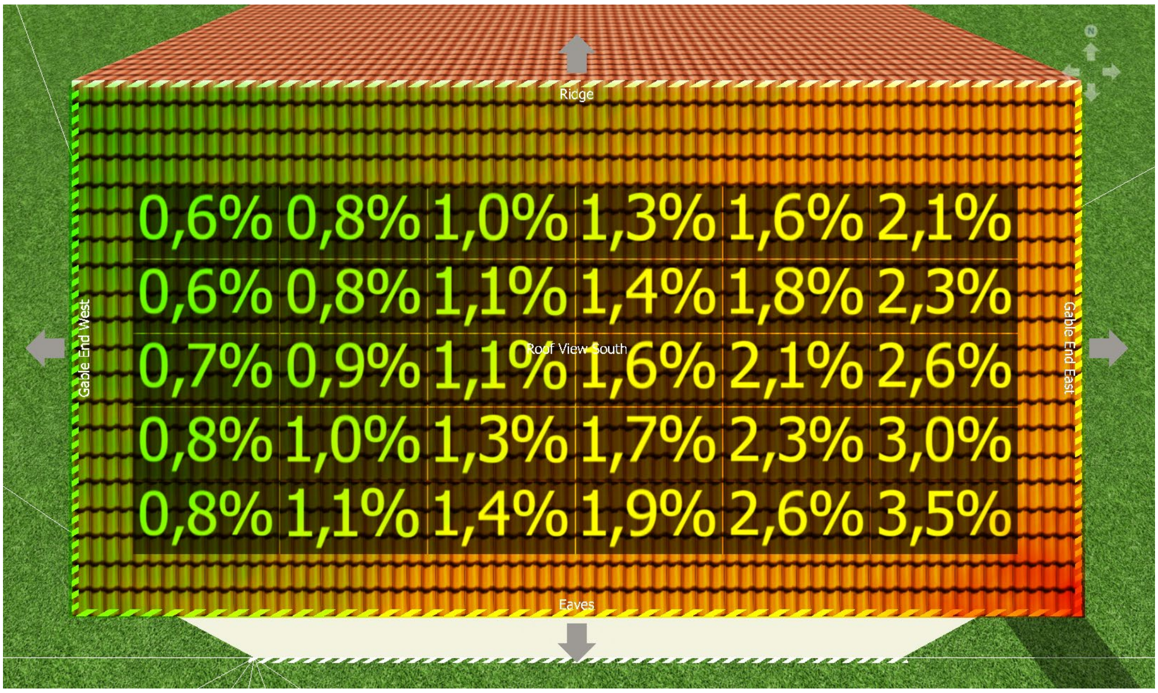

Figure 22: Shading from another house with PV modules positioned horizontally

Type of losses due to shading	Losses in %	Losses in kWh	
Module-specific partial shading	-2.95%	427.3 kWh (of 14 485 kWh)	**Cannot be influenced by inverters, optimizers, etc.**
Mismatch (configuration/shading)	-0.80%	115.9 kWh (of 14 485 kWh)	**Strongly reduced by Dynamic Peak Manager**

Table 10: Shading results on a yearly basis from the simulation with PV modules positioned vertically

The table shows that thanks to the Fronius Dynamic Peak Manager the influenceable losses are already reduced to a minimum. A further reduction would only be possible by eliminating the shading itself.

Figure 23: Exemplary representation of the simulation

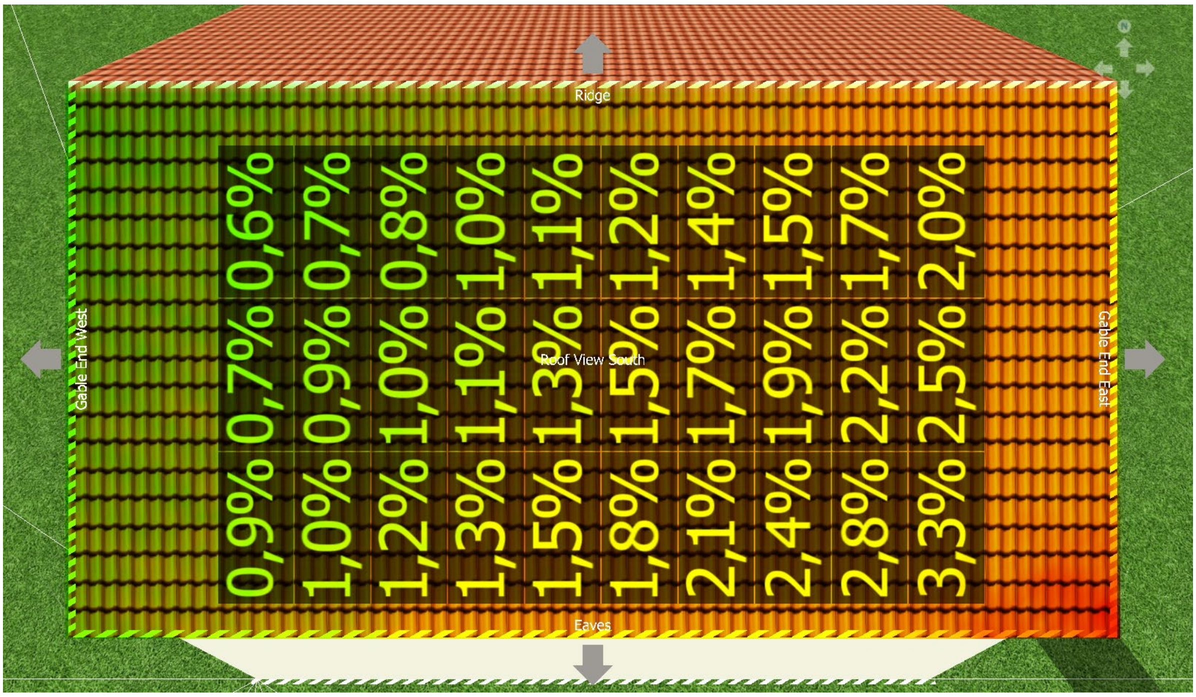

Figure 24: Shading on a yearly basis from another house with PV modules positioned vertically

7 Conclusion

Several cases with various shading objects have been presented and discussed in these results. Shading losses occurring in the PV system have been observed.
In cases where shading is occurring, there is a blockage of sunlight on multiple PV modules due to objects causing the shading. This blockage of sunlight causes module-specific partial shading losses that cannot be changed or influenced except by getting rid of the object that is causing the shading.

Mismatch (configuration/shading) losses can occur due to uneven shading of the modules that are connected in series or in a parallel configuration, and these losses are up to 5 times lower than the module-specific partial shading losses. Keeping this in mind, only the mismatch (configuration/shading) losses are something that can be influenced by e.g., the Dynamic Peak Manager but the module-specific partial shading losses (which are much higher) cannot be influenced by an inverter, DC optimizer, microinverter, etc. at all.

We see in the result that some of the modules experience hard shading due to objects near them. Even though the objects are very near, we can conclude that the use of the Dynamic Peak Manager is beneficial, since losses in a case like this are still quite low.
In a case with hard shading, and even in cases, where only a few modules are shaded, the use of optimizers will most likely not be beneficial. Optimizers in all of these cases will cause an additional loss in the system of 1-2% or even more, due to the consumption by the optimizers themselves

8 References

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