IMPACT OF RAPID CHANGES IN SOLAR IRRADIANCE ON PV INSTALLATIONS

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ABSTRACT: It has been demonstrated that rapid changes in solar irradiance lead to short-term power changes in photovoltaic (PV) modules. As the grid may be affected, it is hence of outmost importance to investigate the impact of such rapid changes in solar irradiance on large PV installations. Here, we present an experimental study using data from the open-field Mont-Soleil PV installation at 1'270 m asl in the Jura mountains, Switzerland, and the PV installation on the roof of the BFH at 533 m asl in Burgdorf. The results of these measurements show that the larger the installed power per area, the greater the power changes. It also shows that the inverter has a major influence on the power changes. It was also recognized that the maximum irradiation change achieved had a big difference in the two measuring locations.
Keywords: PV System, solar irradiance transients, power changes,

1 INTRODUCTION

Rapid changes in irradiation lead to power changes in the photovoltaic systems, which also affects the power fed into the grid. In the paper "Model-free computation of ultra-short-term prediction intervals" [1], a module was measured and high power changes were measured on the basis of rapid solar irradiation changes.

As part of a Master project work [2], the measurement was repeated at the PV plant Mont-Soleil (Jura, Switzerland). The hypothesis was confirmed that smaller power changes occur with a large PV system than with a single module.

Now the measurement was repeated on a PV plant in Burgdorf (Switzerland) and the results compared with the results of the measurements of the Mont-Soleil PV plant.

2 MEASUREMENTS

It was measured in two different locations. In each case the irradiation as well as the DC and the AC power were measured. Each measurement with a measurement interval of 100 ms.

2.1 Mont-Soleil

The PV plant Mont-Soleil (1270 m asl) has an installed capacity of 555 kW and an area of 15'347 m^2. The PV plant was built in 1992. The installed modules are M55 modules from Siemens. The system was measured from 01.01.2017 to 08.06.2017.

Figure 1: PV plant Mont-Soleil

From 18.05.2017 to 08.06.2017 a measurement with a single module from Meyer Burger AG was carried out at the same location. This module has a power of 305 W and an area of 1.66 m^2.

Figure 2: single module (right) at Mont-Soleil

2.2 Burgdorf Tiergarten

The PV plant "Tiergarten" is located on the roof of the BFH Burgdorf. It is divided into East and West and was measured separately. The performance of the system is 44.88 kW. The entire facility spans an area of 1867 m^2. It was built in 1994 also with the M55 modules from Siemens. The system was measured from 10.02.2018 to 04.07.2018.

Figure 3: Roof-top PV plant in Burgdorf consisting of three areas: Building East (right), Building west (left) and

glass atrium in the middle without PV-power.

3 EVALUATIONS

Since the measured values are samples, the value often jumped between two values. To counter this, the data was averaged with a moving average. In the case of the PV plant Mont-Solei, the average was calculated with three values and the PV plant "Tiergarten" was averaged with four values. The formula for the moving average of the PV plant Mont-Soleil is thus:

$$I_{i\_average} = \frac{I_i + I_{i+1} + I_{i+2}}{3} \qquad i \in [0, n-2]$$

The PV plant "Tiergarten" possessed many additional disturbances. With a Fourier transformation, the disturbing frequencies were detected and from this a low-pass filter was generated. Afterwards it was checked, if only the disturbances were filtered out.

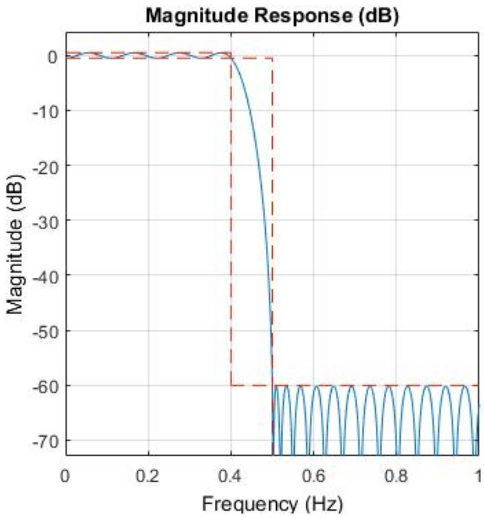

Figure 4: Filter Response

4 RESULTS

4.1 Mont-Soleil

At the PV plant Mont-Soleil, solar irradiation changes were measured up to 1204 W/m²/s. The power changes were ≤ 10 %/s except for two days.

Quite different values were found in the measurement of the individual module. Here, much higher power changes were detected with the same solar irradiation changes. The module achieved power changes of up to 274 %/s.

When looking at the individual days, it is noticeable that the power changes caused by the inverter are higher than the power changes caused by the weather. The following graphics show the measurement of 03.02.2017. On this day there were solar irradiation changes of up to 732 W/m²/s.

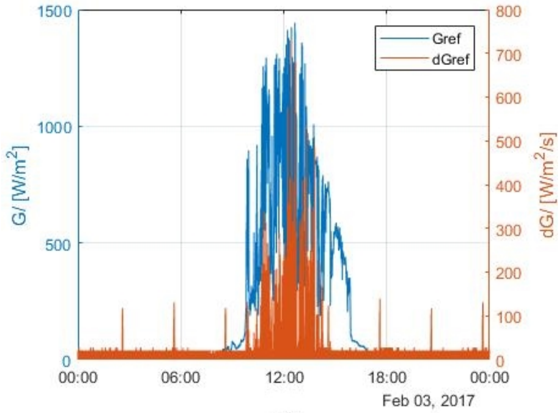

Figure 5: solar irradiation (blue) and solar irradiation changes (red)

Figure 6 above shows the DC power, which stops abruptly shortly after noon. The power changes caused by the inverter reached values of up to 338 %/s. Since only the weather-related power changes are of interest in this work, the power changes caused by the inverter failure were filtered out. Figure 7 shows the same characteristic as Fig. 6 with a smaller scale. Thus, the power changes caused by the weather can be considered. These have a maximum of 6.3 %/s.

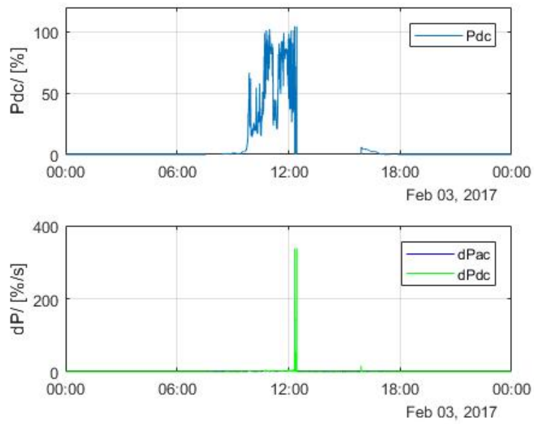

Figure 6: power (above) and power changes (below)

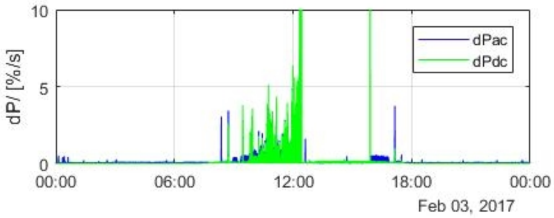

Figure 7: power changes smaller scale

4.2 Tiergarten

The PV plant "Tiergarten" is in central Switzerland. Here occurred solar irradiation changes of up to 603 W/m²/s. The entire system produces power changes of up to 33.7 %/s. Looking at the East and West subsystems individually, the East and West wind PV plants both achieved power changes of up to 44 %/s.

4.3 Power density

To be able to compare the PV plants correctly with one another, the ratio of the installed capacity to the area of each installation was calculated. Table I shows that Mont-Soleil, Tiergarten East and Tiergarten West have almost the same power density. The single module has by far the highest power density of the measured systems.

Table I: Power density of the PV plants

PV plant	power	area	Power density
Burgdorf	44.88 kW	1867 m^2	24.04 W/m^2
Burgdorf East	23.76 kW	690 m^2	34.43 W/m^2
Burgdorf West	21.12 kW	538 m^2	39.25 W/m^2
Mont-Soleil	555 kW	15'347 m^2	36.16 W/m^2
Single Modul	305 W	1.067 m^2	285.84 W/m^2

4.4 Maxima

To get a rough overview, the daily maxima of the solar irradiation changes and power changes of each system were compiled. These are presented in a box plot.

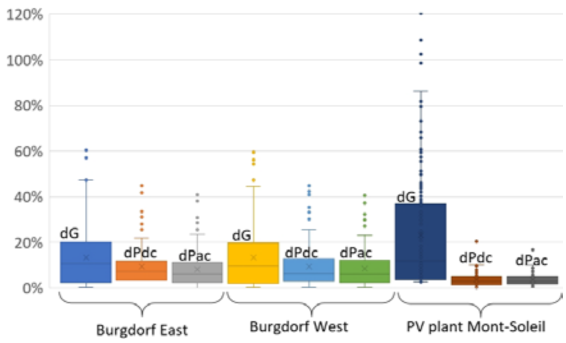

Figure 8: Daily maxima of irradiation and power changes of PV plants Tiergarten and Mont-Soleil

Figure 8 shows that at Mont-Soleil significantly higher changes in solar irradiation were observed than in Burgdorf. Nevertheless, the PV plant Mont-Soleil experienced smaller power changes than the PV plants in Burgdorf. Since both systems have a similar power density, it is probably due to the inverter. The inverters of the PV plant "Tiergarten" seems to be able to react faster to solar irradiation changes than the inverter of the PV plant Mont-Soleil. Furthermore, the modules of the PV plant Mont-Soleil are not all in the same orientation (difference of 15°). This also has an influence.

The measurement of the single module at Mont-Soleil shows a completely different picture (see Figure 9). The power changes of the single module achieved significantly higher values. The single module has the smallest area and the highest power density of all systems measured. A change in the solar irradiation is more significant here.

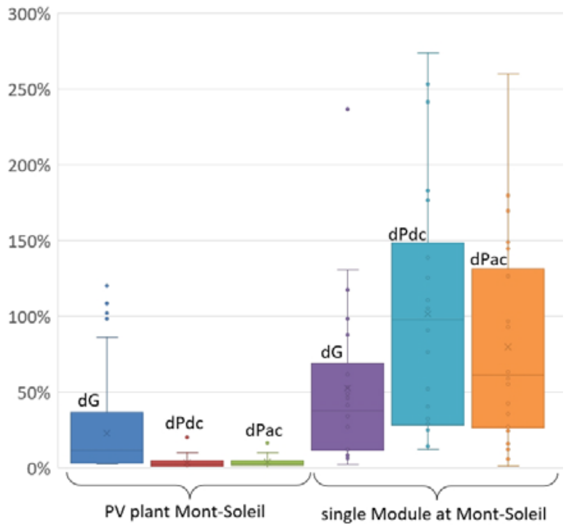

Figure 9: Daily maxima of the solar irradiation and power changes at the PV plant Mont-Soleil and the single module

When measuring the PV plant Mont-Soleil and the PV plant "Tiergarten", the solar irradiance was measured using a reference cell with the same solar cell as used in the installed modules. This happened differently when measuring the single module. Here, the Apogee SP-230 was used, the same measuring device that was also used for the measurement in the paper [1]. Therefore, it is not surprising that the measured values of the two measuring devices deviate.

4.5 Comparison

To assess the effects of rapid solar irradiation changes on the power, for all irradiation changes higher than 100 $W/m^2/s$, the maximum power changes were read out within ± 2.5 seconds and composed. For the single module, the maximum power change was selected within ± 1 second.

Figure 10 shows the dependence of the solar irradiation changes on the power changes of the PV plant Mont-Soleil. However, there is no dependency.

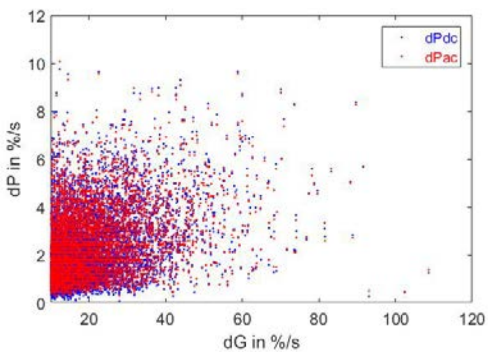

Figure 10: No dependence solar irradiation changes to power changes of the PV plant Mont-Soleil

This is different when looking at the measurement of the PV plant "Tiergarten". Figure 10 shows the dependency of the change in solar irradiation on the power change of the PV plant "Tiergarten". It is a straight line recognizable.

In addition, the trend line is drawn in for each measurement. Looking more closely at this trend line, the PV plant "Tiergarten" has the lowest slope. This can be seen more precisely in the functions of the Trendline.

Tiergarten: $dG = 0.3638 \cdot dPdc - 0.0883$

Tiergarten East: $dG = 0.587 \cdot dPdc - 1.1149$

Tiergarten West: $dG = 0.6176 \cdot dPdc - 1.3048$

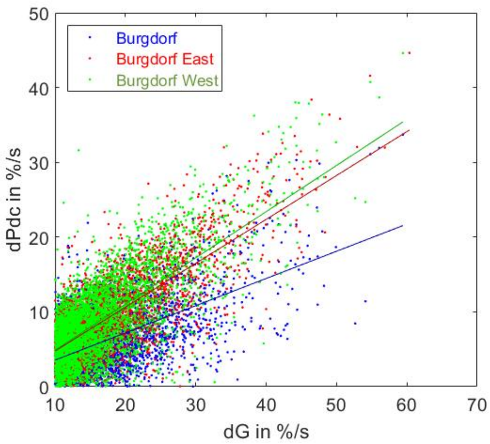

Figure 11: Dependence of solar irradiation changes to power changes of the PV plant "Tiergarten"

The lower slope of the PV plant "Tiergarten" can be explained by the lower power density. Due to the larger area and the lower power per area, one cloud takes longer to cover the same power.

A direct comparison of the PV plants Mont-Soleil, Tiergarten and the single module is shown in Figure 12. In Figure 12, the trend lines for the PV plant "Tiergarten" and for the single module were plotted. These show that the single module has a lower slope than the PV plant "Tiergarten". The PV plant Mont-Soleil is recognizable only at the left edge.

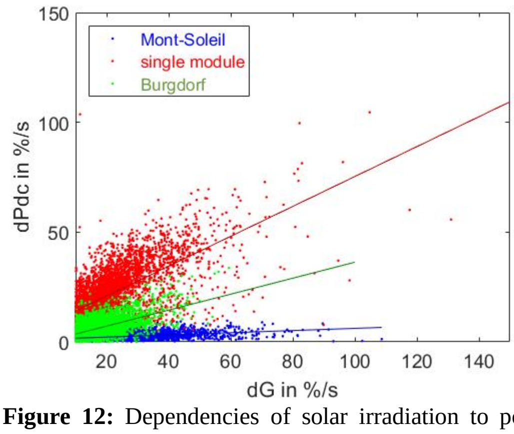

Figure 12: Dependencies of solar irradiation to power changes of the PV plants Mont-Soleil, Tiergarten and the single module

5 CONCLUSIONS

The power changes caused by the inverter reach significantly higher values than the weather-related power changes. This is what the measurements of the Mont-Solei plant have shown.

Another issue is the differences in solar irradiation changes on the two locations. In Burgdorf solar irradiation changes occurred of up to 603 $W/m^2/s$. On Mont-Solei, however, there were changes in solar irradiation of up to 1204 $W/m^2/s$.

The measurements have shown that various factors influence the power changes. The comparison with the measurement of the single module with the other systems has shown that an important factor is the installed power per area. The higher this is, the higher the power changes are. The measurements of the PV plants Mont-Soleil and Tiergarten have shown that other factors must also be included. In this case, it can be assumed that the inverter reacts more slowly on the PV plant Mont-Soleil than the inverter in the PV plant "Tiergarten". In conclusion, there are two possibilities to slow down the power changes: lower power per area and slower inverter behavior.

6 ACKNOWLEDGMENTS

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7 REFERENCES

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