Effect of the sampling rate on the analysis of measurements of photovoltaic systems

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***Abstract*—This paper describes the influence of the sampling rate on photovoltaic systems regarding seasons and different weather conditions. For this purpose, large data sets of smart meter measurements were analyzed based on different criteria, such as the measured maximum and minimum values, maximum jumps and the greatest deviation of the values compared to the highest sampling rate of 15 seconds. The considered sampling rates of 60 seconds, 5 minutes and 15 minutes were simulated from the actual sampling rate of 15 seconds.**

I. Introduction

The increasing percentage of renewable power generation like wind power, photovoltaic systems and hydropower has considerable influence on the power grid. Most of the solar plants feed into the low-voltage electric power grid. In order to increase the generated power from decentralized power plants, it is necessary to consider their effect on the low-voltage grid.

The strong solar radiation makes Bavaria the ideal location for the evaluation of the influence on the power grid caused by photovoltaic power generation. For this purpose multiple photovoltaic power plants, equipped with measuring instruments, were installed in Hof, Bavaria.

Every smart meter measures voltage, current and the phase angle between them every 15 seconds. The resulting data can be analyzed from many different aspects. This paper focuses on the the influence of the sampling rate on photovoltaic measurements.

Therefore, various key figures were developed, comparing the influence at different weather conditions and seasons.

II. Influence of the Sampling Rate on Photovoltaic System Measurements

For the comparison of different sampling rates, the sampling rates of 1 minute, 5 minutes and 15 minutes were simulated from the original 15 s measurements. For the sampling rate of 1 minute, every fourth value of the 15 s series was taken. The same principle underlies the 5 minute and 15 minute rate.

Before the analysis can take place, the reliability of the measurements must be verified.

A. Reliability of the measured data

Various criteria have to be fulfilled to ensure reliability. Besides measurement accuracy, time synchronization of the smart meter and the availability of the data, time discretization and therefore the sampling rate represents an important aspect for the reliability of measurements.

The smart meter has the accuracy class 2 for active power and accuracy class B for reactive power. The measurements of different smart meters can be assumed to be synchronous as the time delay does not exceed a few seconds.

1) Time discretization

With the conversion from analog signals to discrete values, a loss of information must be accepted.

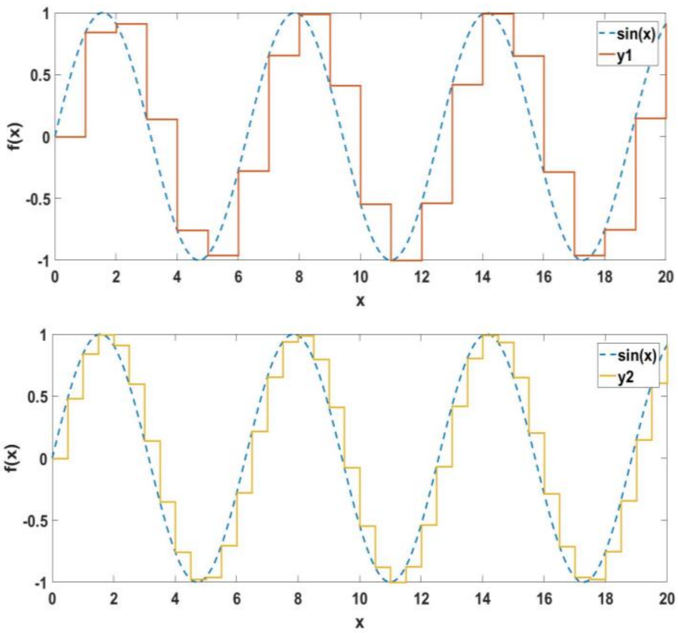

Figure 1. Time discrete diagram of a sinus function with different step sizes

The quantity of this information loss depends on the time span between two sampling times. The higher the sampling rate, the better is the approximation of an analog function. In Figure 1. an example for the influence of the sampling rate is shown.

In both figures the dashed blue graph depicts a sinus function. The red and orange graph both show discrete sinus waveforms with different sampling rates. It can be observed that the approximation of the sinus improves with higher sampling rates.

2) Availability of data

Availability is an important topic for the reliability of data. It means the completeness of a set of data as well as the reliability of the correct assignment of the data to their time stamps. If some data is lost for some reason in the database, the following values will shift towards an earlier time stamp as shown in Figure 2.

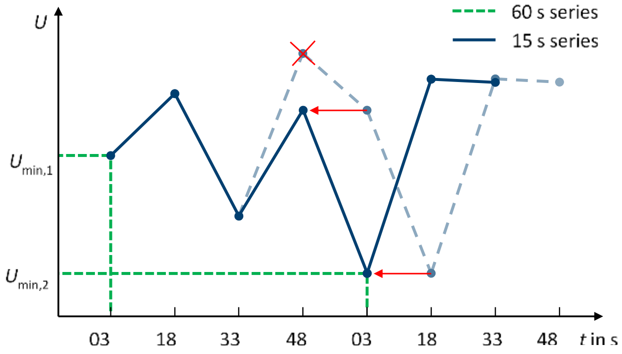

Figure 2. Time shift error for missing values

The value for the voltage *U* at t = 48 s misses in the dataset so that it seems to be a completely different voltage curve. Because the slower sampling rates base on the rate of 15 s, this shift of data causes serious distortion of comparison.

To compensate this error, the missing data must be replaced. For that, the missing data are interpolated before evaluating the lower sampling rates. This will not bring new information about the missing times stamps, but the rest of the data remains reliable.

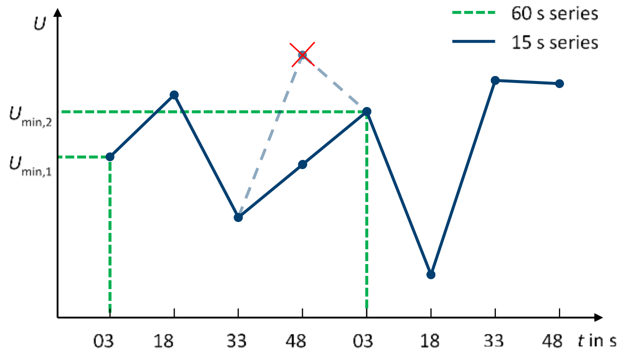

Figure 3. Interpolated missing data to ensure the order of the following time stamps

B. *Seasonal comparison*

The differences of the sampling rates by itself are not the only topic of this paper. Additionally, the differences of each season will be discussed by evaluating separate statistics for each season and key figure.

For an adequate look on the key figures, only daytime must be observed. But the sunrise and the sunset vary at the respective seasons.

That is why different periods will be considered for the different seasons:

TABLE I. CONSIDERED TIME OF THE SEASONS

Season	Considered time	
	From	to
summer	06:00 AM	08:00 PM
fall	07:00 AM	06:00 PM
winter	07:00 AM	05:00 PM
spring	07:00AM	07:00 PM

Furthermore, the different types of days will be discussed. The classification of a day is situated in the 5 hours of each day with the maximum power compared to the installed power of the plant:

- *Sunny day*
- *Sunny day with short cloudy periods*
- *Partly cloudy day*
- *Miscellaneous day*

On a *sunny day*, the absolute maximum and minimum of converted power is relatively high. So, the difference between both values is very small.

If there occur short cloudy periods during a day, the maximum power value stays high, but the minimum power value reduces significantly.

Both for *partly cloudy days* and *miscellaneous* days, the maximum power input can be high, medium or low and the minimum power may vary, too. The difference between both is that the emphasis on *partly cloudy days* is located in higher power values.

C. *Key figures for the analysis*

The aim of the analysis is to notice events like short voltage rises, power peaks, as well as big changes in a brief period in the grid depending on the sampling rate. The chosen key figures were designed for the analysis of data from a photovoltaic feed.

To process the occurring amount of data, the timeframe of an analysis was one hour.

1) Maximum deviation of an hour upwards and downwards Diff_max and Diff_min

As shown in Figure 4. the maximum deviation of the highest sampling rate of 15 s compared to the respective lower sampling rate in an hour indicates the difference between the sampling rates.

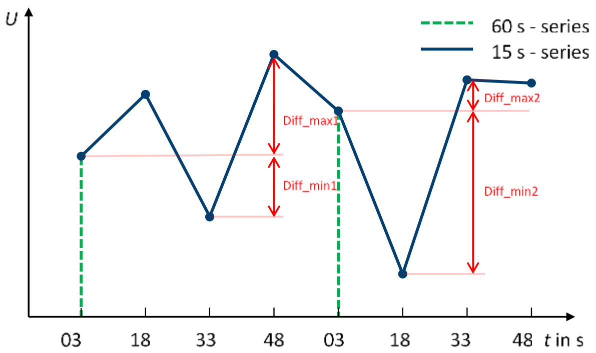

Figure 4. Key figures Diff_max and Diff_min

2) *Maximum jump of an hour Jump_max*

A jump is the difference between a value and its following value. With this key figure it is possible to evaluate how good a sampling rate can capture big power jumps.

Figure 5. illustrates the principle of the maximum jump of an hour.

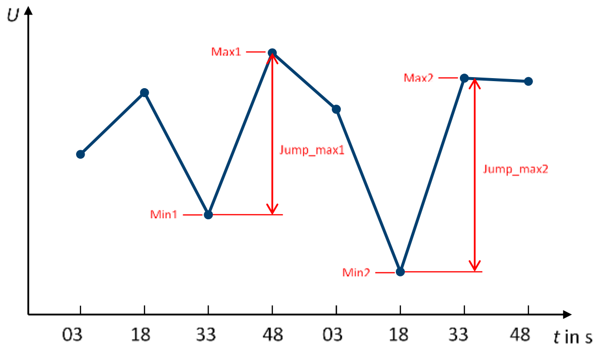

Figure 5. Key figures Max, Min and Jump_max

3) *Relation between the maximum values*

This figure is mainly used to compare the different types of days to each other. Therefore, the maximum value of each hour of the 15 s sampling rate will be divided by the maximum value of each hour of the 1 min, 5 min and 15 min rate.

III. Results

The following results were taken from a photovoltaic power plant with an installed power of 10.66 kW.

A. *Seasons*

Figure 6. to Figure 9. show that the statistical distribution moves towards greater power deviation with rising sampling times.

It can also be seen that the modal value may change for the 5 min and 15 min rate depending on the season. While the mode of the 5 min rate is clearly at 50 W in winter and fall, it almost equals in summer with 200 W and indeed equals with 200 W in spring. Only the 1 min rate has a modal value of 50 W power deviation for every season.

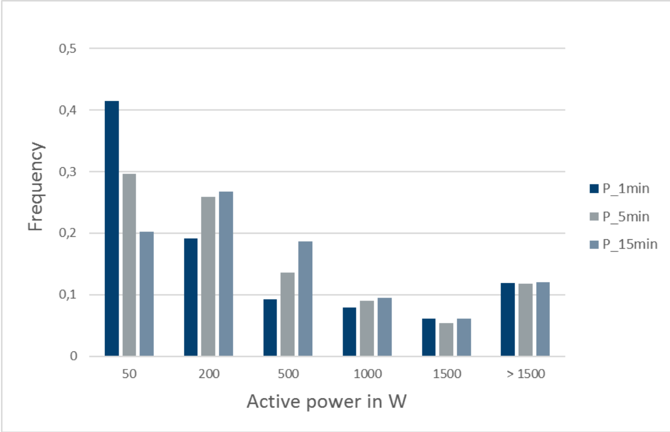

Figure 6. Statistics over the maximum deviation Diff_max for *summer* 2015

Remarkable in summer is the high percentage of deviations greater than 1500 W for all sampling rates. This can be explained with the high amount of *sunny days with short cloudy periods* in summer.

During this kind of day, the generated power stays high most of the time so that all sampling rates measure high values. The shadows of brief, small clouds cover the photovoltaic plant for a couple of seconds. The sampling rate of 15 s is the only one able to notice these temporary changes.

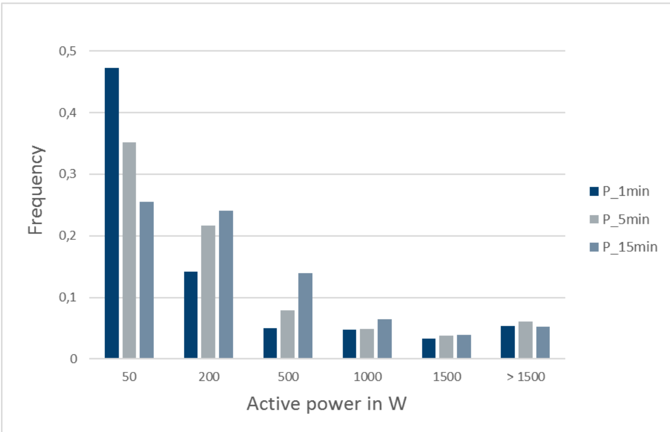

Figure 7. Statistics over the maximum deviation Diff_max for *fall* 2015

The diagrams for fall and winter are fairly equal. Compared to summer, all three distributions move their emphasis to smaller deviation values.

This is even more remarkable in winter, where the percentage of deviation of smaller than 50 W for the 1 min series covers more than 50 %.

Due to few *sunny days* combined with many cloudy and *miscellaneous days* the share of deviations greater than 1500 W is clearly smaller than in summer and spring.

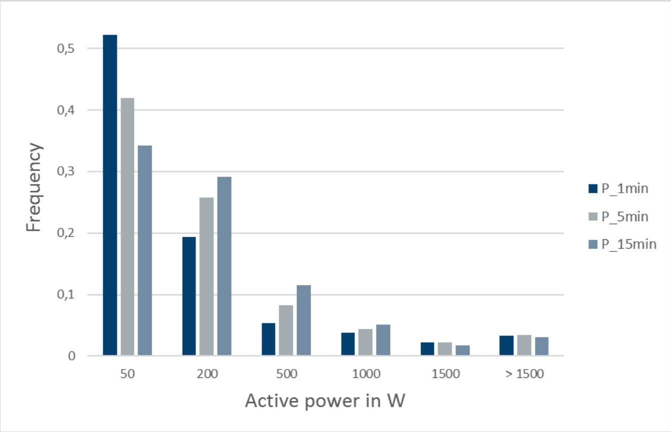

Figure 8. Statistics over the maximum deviation Diff_max for *winter* 2015

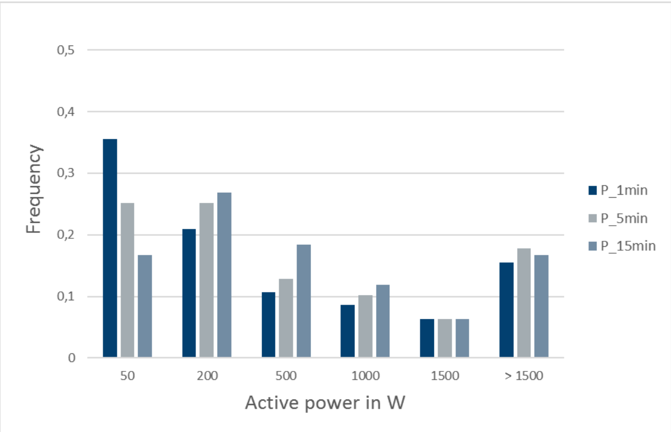

Figure 9. Statistics over the maximum deviation Diff_max for *spring* 2015

The typical distribution in spring is that there are more partly cloudy and *sunny days with short cloudy periods* than in winter and fall. But because there are also less completely *sunny days* in spring than in summer, the higher percentage of the deviations compared to summer is reasonable.

So basically in winter and fall the 1 min sampling rate can be seen as accurate enough due to the small power generation during these seasons.. At 80 % of the time, the maximum deviation is below 200 W.

If the power generation increases in spring and summer, the 1 min rate usually shows low deviation, but short changes in the power cannot be noticed accurately enough.

Depending on the purpose of the use of the measured data, it might be sufficient to measure every 5 minutes in winter or fall, but there are quite a lot of deviations of course. The 15 min rate is too inaccurate even in winter and fall.

At least in summer and spring the 5 min and 15 min rates are not able to notice all power changes due to more *sunny days with short cloudy periods* and less *miscellaneous* days.

B. Weather dependant results

Figure 10. to Figure 13. show typical curves of the ratio of the maximum power of a 15 s sampling rate to the lower ones during daytime for different weather conditions.

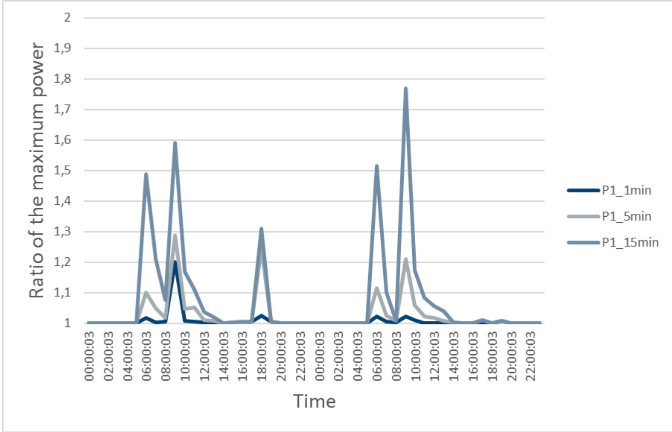

Figure 10. Ratio of the maximum power at a *sunny day*

It can be seen that both for *sunny days* and *sunny days with short cloudy periods* the 1 min sampling rate covers the maximum power values during the day very well.

In contrast, the 5 min and 15 min rates vary especially in the morning up to a factor of 1.8, which means that the actual power maximum in that particular hour is 80 % higher than the rate noticed. But it is remarkable that in noon and in the evening the power generation is very consistent that the rates of 5 minutes and 15 minutes notice the correct power peaks.

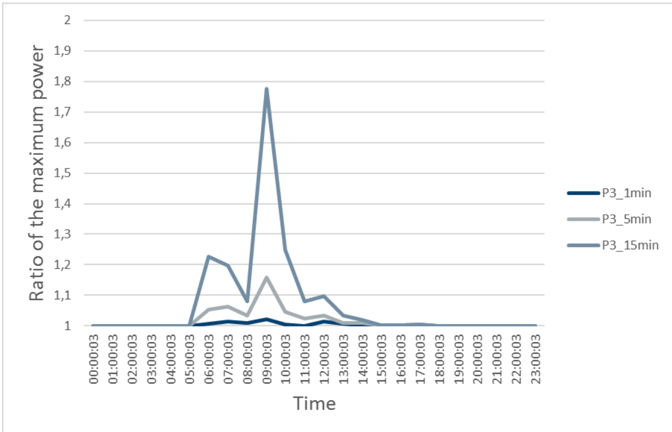

Figure 11. Ratio of the maximum power at a *sunny day with short cloudy periods*

For *partly cloudy days*, there are huge deviations over the whole daylight period for the 5 min and 15 min rates. Figure 12. shows the dependency of the accuracy of the measurement and the sampling rate.

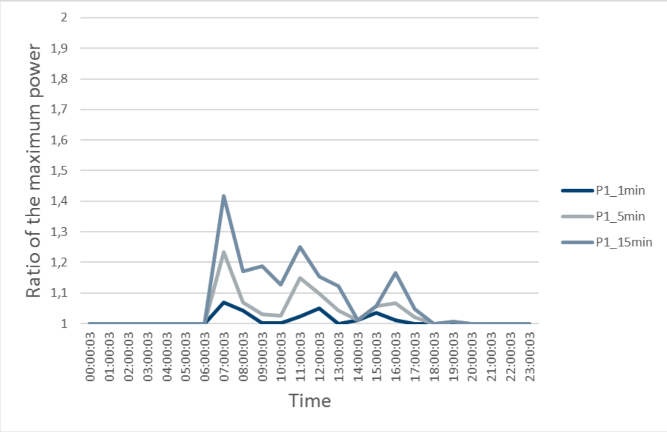

Figure 12. Ratio of the maximum power at a *partly cloudy day*

The 1 min sampling rate also covers the maximum power pretty well, but deviates stronger and more often than on *sunny days*. Still, it can be seen as a quite accurate sampling rate for *partly cloudy days.*

Only at *miscellaneous* days, where no precise classification about the weather of the day is possible, also the 1 min rate varies up to 60 % from the actual maximum value. The lower sampling rates vary even stronger during the whole day. At noon, they record only the half of the actual maximum value.

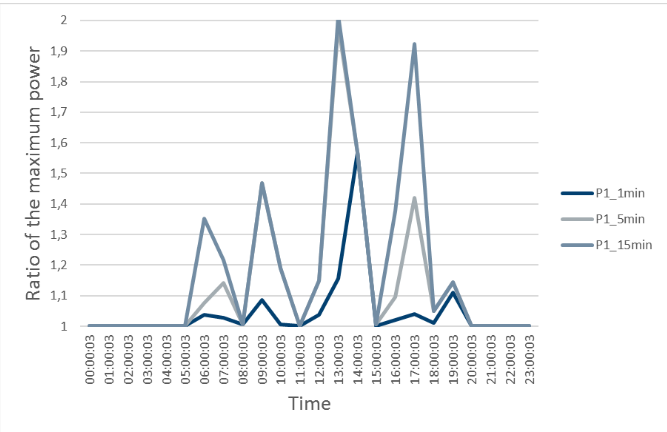

Figure 13. Ratio of the maximum power at a *miscellaneous day*

IV. CONCLUSION

The less predictable the weather is, the worse the measurement accuracy of low sampling rates gets. As the amount of completely *sunny days* is quite small and the amount of *sunny days with short cloudy periods* or *partly cloudy days* increases in summer and spring, it is necessary to measure accurately.

With a higher percentage of cloudy days in winter and fall with bad weather and low power generation of photovoltaic systems, the use of lower sampling rates is less severe.

With perspective to the power generation in smart grids, the most suitable sampling rate of the considered ones is 15 s to be able to react on power changes in the grid. Even this sampling rate is not able to measure all short changes.

Especially if the power generation from photovoltaic plants in the grid is expected to increase from different locations with different weather conditions, it must be ensured that all transient system incidents are captured by the measurement systems to guarantee the stability of the grid for every weather and daytime.

V. LITERATURE

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