Whitepaper on PR vs. CUF

This Whitepaper is about the difference between PR and CUF. It is provided by CHROSIS Sustainable Solutions for information purpose only.

On Performance Ratio (PR) and Capacity Utilization Factor (CUF)

On Performance Ratio (PR)

Performance ratio (PR) is stated as percentage and describes the relationship between the real and the theoretical possible energy output of a solar PV plant. It shows the proportion of the energy that is actually available for export to the grid after deduction of energy losses (e.g. thermal losses, soiling, etc.) and energy consumption for operation.

The closer the PR value for a PV plant approaches 100 %, the more efficient the respective PV plant is operating. Since losses will always be present, a PR of 100% cannot be achieved. In other words: If the calculated PR is > 100%, something with the measuring method is wrong.

What are the insights you can get from performance ratio?

Performance ratio gives insights how efficient the available solar energy is converted into electrical energy. It is possible to compare the performance of various plants at different locations on a normalized – independent from climate conditions - level over a long period of time. Deviations in the PR (e.g. values below the expected range) indicate a possible fault or problem in the solar PV plant. PR can therefore be understood as an early warning system.

How performance ratio is calculated

Different variables are needed to calculate the performance ratio of a PV plant. First and foremost, the irradiation data for the respective plant are needed. This can be achieved with an irradiance sensor (preferred a Pyranometer). Other values are the ambient temperature and the panel temperature, since the efficiency of the panel will drop with temperature. There are many reliable Monitoring and Control solutions available on the market that enable a convenient measurement and DAQ of all values needed and also offer the PR calculated automatically.

Values that do not change will also play a role in the PR calculations. E.g. the active surface of the panels and the efficiency of the panels. Both information can be found in the datasheets of the panel manufacturer.

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Requirements for calculation

The orientation of the PV modules and the irradiance sensor must be the identical to calculate the PR value correctly. It is a must that the PV modules and the irradiance sensor are exposed to the same quantities of solar irradiation. It is nearly impossible to "re-calculate" the irradiance data measured from a Pyranometer with horizontal alignment for the plane of the panels.

Analysis period

The typical analysis period for performance ratio calculations is one year. Other time periods are possible.

Manual calculation

It is possible to calculate the performance ratio manually. The following formula is used for this: The energy generated or measured divided by the energy modeled:

$$PR = \frac{Energy\ \ Measured\ \ (kWh)}{Energy\ \ Modelled\ \ (kWh)}$$

Where,

$$Energy\ \ modelled\ = Irradiance_{measured\ \ on\ \ location}\left(\frac{kWh}{m^2}\right) \cdot Active\ \ Area\ \ of\ \ PV\ \ panels\ \ (m^2) \cdot \eta$$

$$\eta\ = module\ \ efficiency$$
$$Irradiance\ \ is\ \ measured\ \ at\ \ the\ \ specific\ \ location$$
$$Active\ \ Area\ \ is\ \ the\ \ active\ \ area\ \ of\ \ the\ \ PV\text{-}Panels$$

Before this irradiation value can be determined, the mean value of the irradiation values measured by the measuring gage must be determined. The determined irradiation value per m^2 is then extrapolated to the entire modular surface of the PV plant (= generator area). You can obtain the modular efficiency in the data sheet for the PV plant.

Please note that the panel temperature and therefore the loss of efficiency of the panel is not taken into account in this example. A detailed description of all calculations can be found in the IEC 61724 – Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis. The IEC 61724

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also mentions the measurement of wind speeds. These are not needed for calculation, but can be understood as optional values especially if the plant is located in an area with very rough climate conditions.

Example: Calculation of the performance ratio for an analysis period of 1 year

The following information is needed to do a manual PR calculation:

Analysis period:

- Define the analysis period in advance. The optimum analysis period is one year.
- Generator area of the PV plant: The active area of the PV system is known (or can be calculated)
- PV panel efficiency: As given in the datasheets
- Measured plant output: As given by the energy meter
- Calculated, nominal plant output: This value will be calculated separately (see below)
- In-plane irradiance data: Value as given by the irradiance sensor (preferred a Pyranometer)

The following specific conditions and values are given for the example:

- Analysis period: 1 year
- Measured average solar irradiation intensity in 1 year: 120 kWh/m^2
- Generator area of the PV plant: 10 m^2
- Efficiency factor of the PV modules: 15 %
- Electrical energy actually exported by plant to grid: 110 kWh

The irradiation values measured on location yields an average solar irradiation for the entire analysis period of 120 kWh/m^2 .This irradiation value is extrapolated to the modular area of the PV plant as follows:

Irradiation value in kWh/m^2 x plant area in m^2 = 120 kWh/m^2 x 10 m^2 = 1,200 kWh

In order to subsequently calculate the nominal plant output, the irradiation value for the PV plant is multiplied by the modular efficiency:

1,200 kWh x 15 % = 1,200 kWh x 0.15 = 180 kWh

The nominal plant output of 180kWh corresponds to a PR of 100%. Since the actual energy feed into the grid is only 110kWh, the performance ratio can be calculated using this formula:

$$PR=\frac{110kWh}{180kWh}\approx 0.61 \quad or \quad 61\%$$

The PR is therefore about 61% - or about 39% of the solar energy was not converted into electrical energy that was feed into the grid.

Typically an EPC will always run a simulation for PR based on the design. So if the PR simulated is 75% and the PR achieved is 61%, then this should be understood as a warning signal that something might be wrong with the plant.

Especially in desert like conditions it is possible that soiling causes a drop in PR. We recommend to clean the irradiance sensor on a daily basis in order to achieve quality data. A soiled irradiance sensor might behave completely different from a well cleaned one. It is not true that soiling has the same effect on the irradiance sensor as it has on the panels.

Which factors influence the performance ratio?

The following factors can have influence to the PR value:

- Environmental factors
  - Temperature of the PV module
  - Solar irradiation
  - Pyranometer is shaded or soiled
  - PV panels are shaded or soiled
- Other factors
  - Recording period
  - Conduction losses
  - Efficiency of the PV modules
  - Efficiency of the inverter

Temperature of the PV module

Performance and efficiency of a solar cell depend, amongst others, on the temperature of the PV module. At lower temperatures, the PV module will be more efficient that at higher temperatures. This is very important for Indian climate conditions.

Pyranometer is shaded or soiled

Depending on how installed, it could happen that the Pyranometer is shaded. It is also likely that not only the panels will get covered with dust or "soiled", but also the Pyranometer. A typical result of this is a PR of more than 100%, since the influence of shade, dust or soil may be higher in the Pyranometer than on the panels. A good practise to avoid this is to install the Pyranometer at a location, where it can be cleaned easily and where shading is avoided.

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Shading of the PV modules

It is likely that the individual PV panels of various rows will shade each other in the morning or the evening. This will result in lower power output. Here is an example for a shading analysis of a solar PV system installed at Rajasthan.

On January 1st with sunrise at 7:45 am the lower row of panels will be shaded (Figure 1).

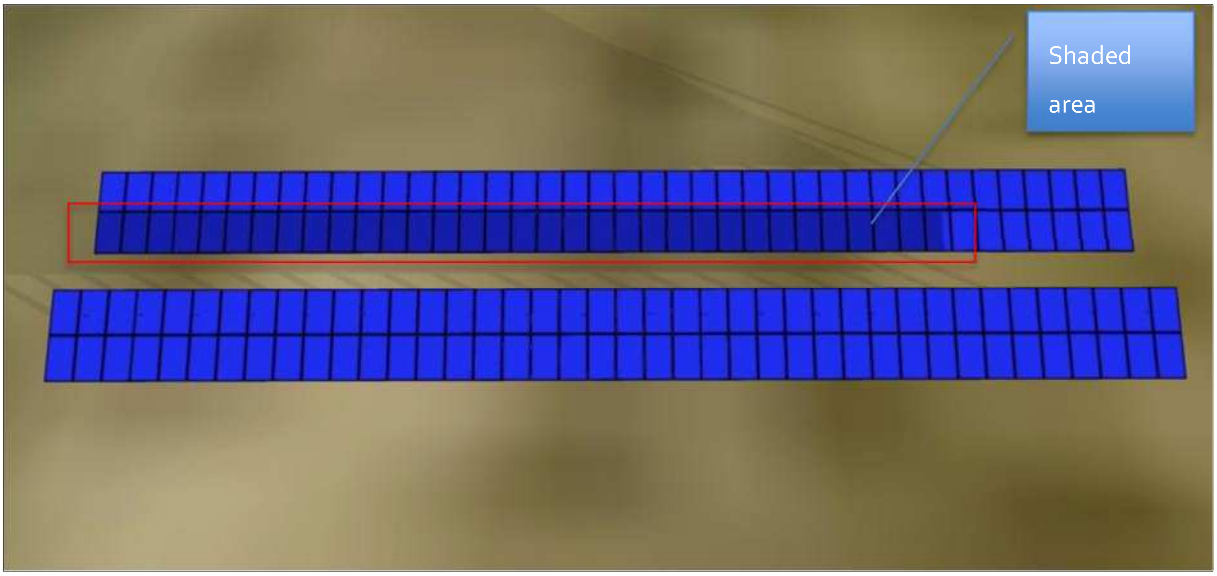

Figure 1 – Simulation result for January 1st @ 8 am

The shading will still be there at 8:30 am (Figure 2).

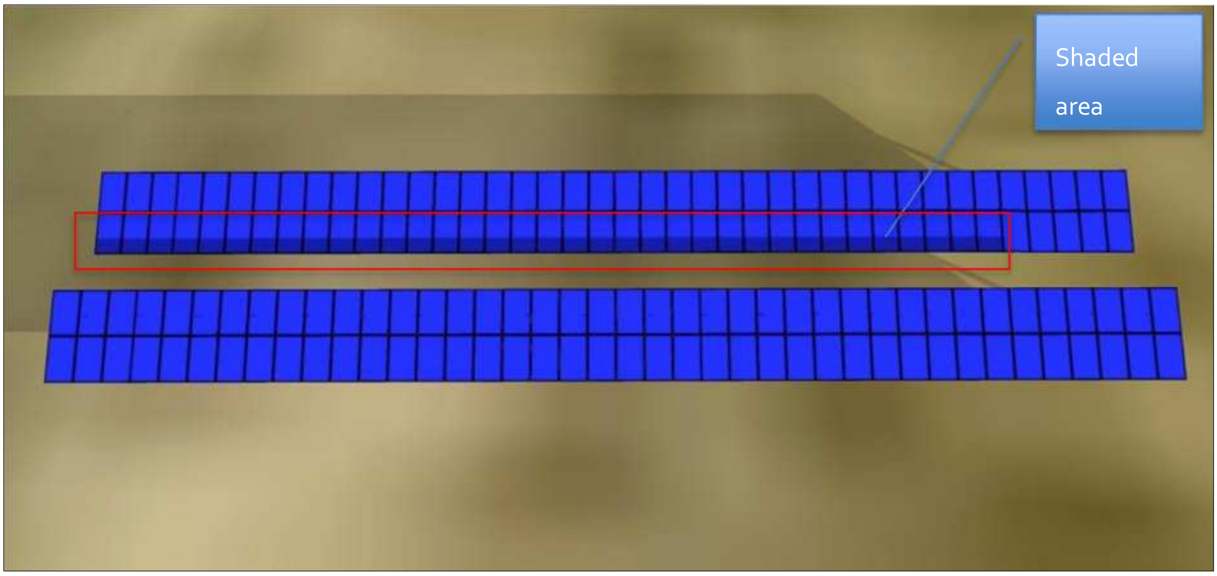

Figure 2 – Simulation result for January 1st @ 8:30 am

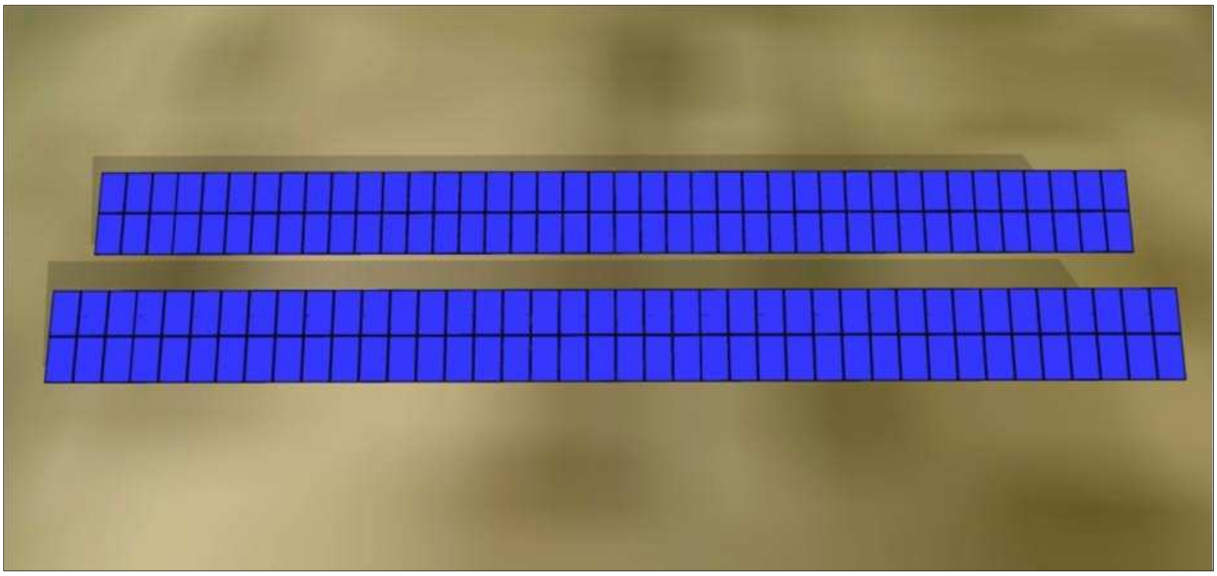

Figure 3 – Simulation result for January 1st @ 9 am

At 9 am there will be no more shading (Figure 3).

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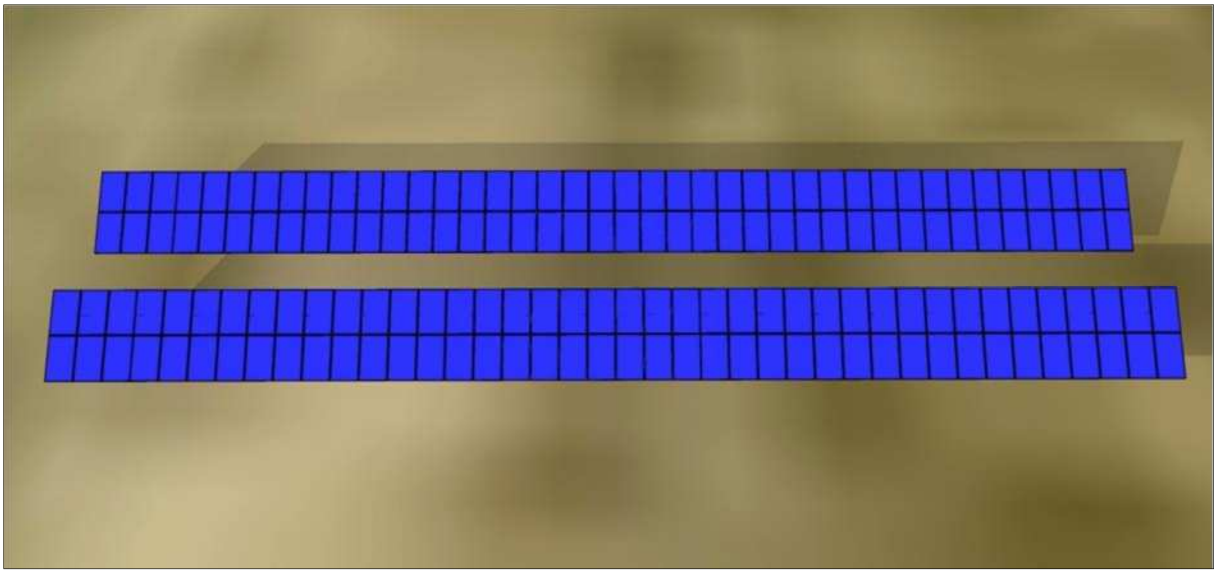

Figure 4 – Simulation result for January 1st @ 4 pm

At four pm there is no shading according to this simulation (Figure 4).

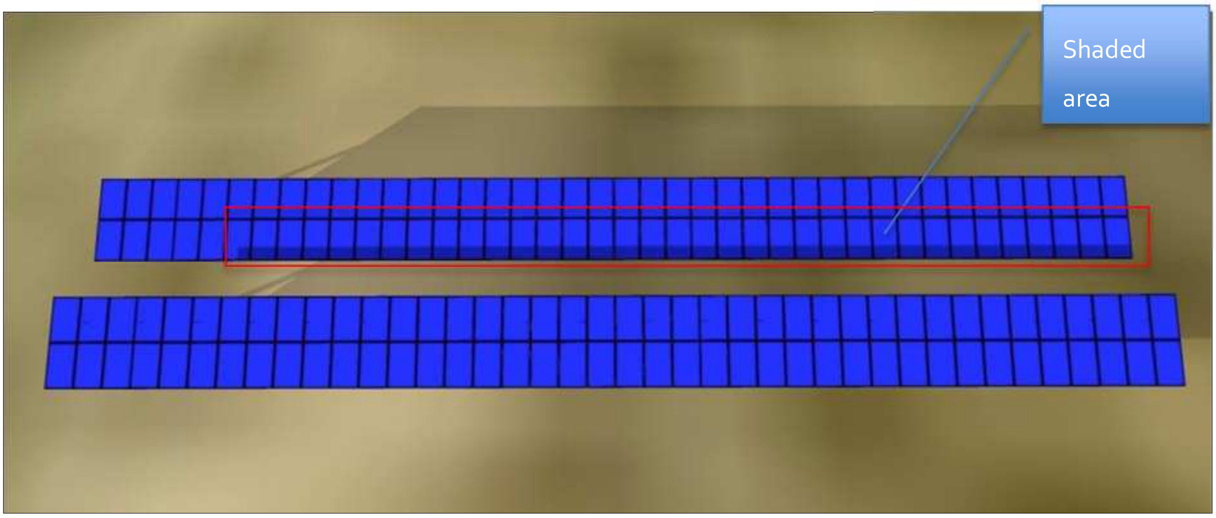

Figure 5 – Simulation result for January 1st @ 5 pm

Shading will start at five pm and will cover some panels of the lower row (Figure 5).

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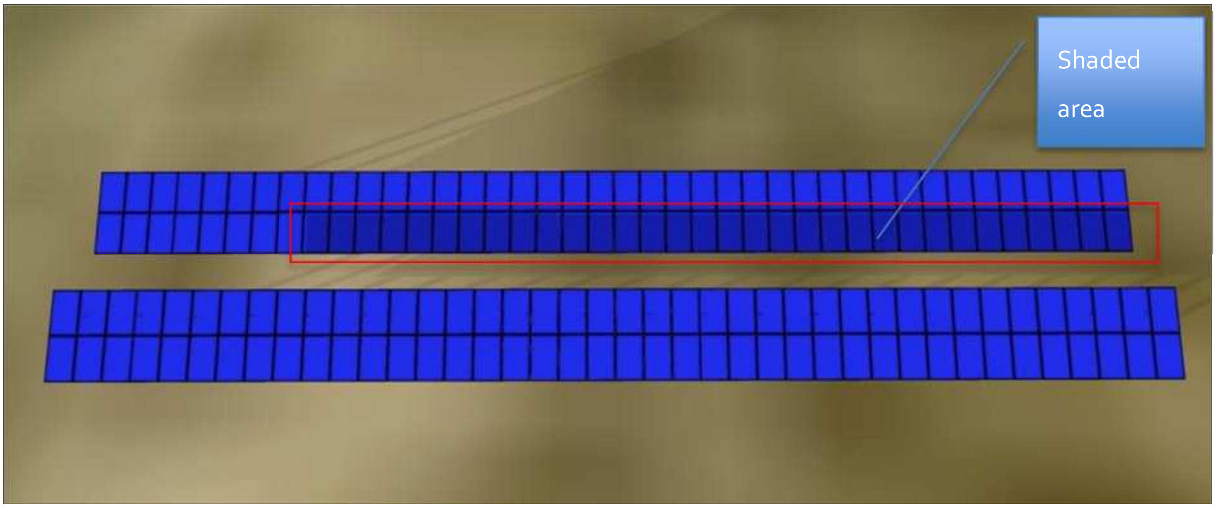

Figure 6 – Simulation result for January 1st @ 5:30 pm

On this specific day, sunset will happen at 5:45 pm. At 5:30 pm some panels are shaded and the shading will continue until sunset (Figure 6).

Depending on the location of the Pyranometer, the Pyranometer itself will get shaded or the PR will drop during the timeframe when the panels are shaded. Since shading of the panels cannot be avoided in total, it is a good approach to install the Pyranometer on the upper row of the panels.

Measurement period

If the measurement period is too short (i.e. less than 1 month), chances are that "non-typical" events like rainfalls, cloudy weather, etc. will influence the measurements. A longer time frame of DAQ will bring more reliable PR results.

Conduction losses

Conduction losses (DC and AC) will influence the PR: the higher the losses, the lower the PR.

Efficiency of the PV modules

The higher the efficiency of the PV modules, the higher the PR value (with corresponding ambient conditions such as higher solar irradiation at the location, etc.). A constantly falling PR can therefore be understood as an indicator of panel de-rating.

Efficiency and "intelligence" of the inverter

The inverters have a huge impact on PR. Most people are not aware, that the inverter is one of the most critical components in the PV plant. Inverters with high efficiency will typically lead to a good PR. But one must also be aware, that a fast and accurate MPP tracking is also important for a high PR. The more independent MPP trackers an inverter offers the better. In the example given above, all the panels on the "lower row" that might be shaded, can be attached to one MPP tracker and all the panels on the upper row can be attached to a different MPP tracker. By doing so, the lesser performance of the panels from the lower row will not influence the MPP tracking of the panels on the upper row.

Degradation of the solar cells

As pointed out above, the degradation or de-rating of the solar cells can result in lower PR values.

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Difference between PR and CUF

PR is a worldwide accepted standard for measuring the performance of a pv plant's performance. Sometimes investors or developers talk about the Capacity Utilization Factor (CUF) and want to compare the plant's performance based on this indicator.

PR is defined as

$$PR = \frac{Energy\ Measured\ (kWh)}{Energy\ Modelled\ (kWh)}$$

Where,

$$Energy\ modelled\ =\ Irradiance_{measured\ on\ location}\left(\frac{kWh}{m^2}\right)\cdot Active\ Area\ of\ PV\ panels\ (m^2)\cdot \eta$$

$$\eta\ =\ module\ efficiency$$
$$Irradiance\ is\ measured\ at\ the\ specific\ location$$
$$Active\ Area\ is\ the\ active\ area\ of\ the\ PV\text{-}Panels$$

CUF is defined as

$$CUF = \frac{Energy\ measured\ (kWh)}{Installed\ Capacity\ (kW)\ \cdot\ 8760\ hours}$$

The CUF does not take into account any environmental factor like variation on irradiance from one year to another nor does it take into account the de-rating or degradation of the panels. Therefore we are not convinced that the CUF is a good tool to provide insights into a solar PV system.

So on one side PR is a measure for the performance of a PV system taking into account environmental factors (temperature, irradiation, etc.) and on the other side is CUF that completely ignores all these factors.

Some more factors that can also be important when comparing PR vs. CUF:

- PR will take into account the availability of the grid, CUF will not
- PR will take into account the minimum level of irradiation needed to generate electrical energy, CUF will not

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- PR will take into account irradiation levels at a given period of time, CUF will not

PR can be used as a tool to compare different solar PV systems with each other – even if they are located at different locations since all environmental factors will be taken into account. Therefore only the design and the ability of the system to convert solar energy into electrical energy will be compared with each other.

With high quality Monitoring and Control solutions, it is possible to automatically calculate the PR. Typically, the M&C will also provide further insights like string currents etc. Therefore an in-depth analysis of the PV plant is possible at almost all times.

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