PANAMA

PRESCRIPTIVE SOLAR ANALYTICS & ADVANCED WORKFORCE MANAGEMENT

M2.1

„Routines to diagnose failures”

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EXECUTIVE SUMMARY

Within the PANAMA project, the milestone 2.1 is the outcome of the Task 2.1. Both are due at the sixth project month, which is the end of 2020.

In the project proposal, the outcome was described as:

> In this task failure diagnosis routines that will detect and classify system failures by analyzing acquired system data will be developed with the use of advanced data-driven machine learning algorithms that capture the behavior of exhibited failures and provide fast on-line comparisons between data feeds.
>
> More specifically, the main exhibited failures on PV modules (open/short conditions, bypass diode and string mismatch) and inverters (MPPT module, overheating, isolation fault, ventilation system and electronic components) will be first profiled in order to build models that will compare data feeds and detect abnormal performance operating conditions. Detected abnormal operating conditions (obtained by comparing data feeds against set threshold levels and modelled expected performance) are then passed to the final classification stage.
>
> Finally, the routines perform real-time comparisons against the known failure profiles in order to first identify and then quantify the loss.

The promised methods were developed as intended.

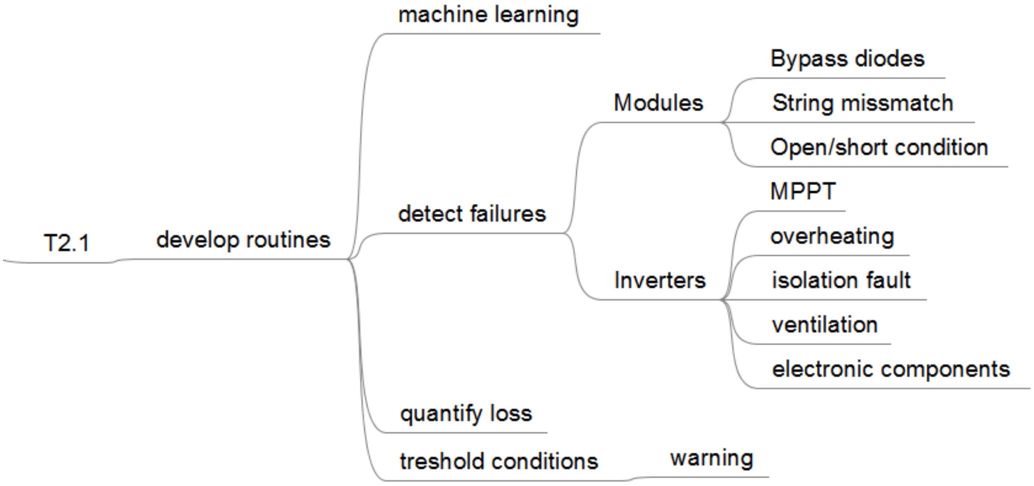

Figure 1: Mindmap representation of the content of Task 2.1.

1. Results of Milestone 2.1

While monitoring larger Photovoltaic (PV) generators (“plants”), typically there are three different sources of data: data recorded by inverters, weather sensors, and finally the electric meters. Most commonly, data is uploaded to a web-based data platform.

From there, data can be downloaded for further analysis. Most commonly, the data is provided in text files.

Typical data from inverters contains on the AC side: power, grid frequency and phase currents. On the module DC side, commonly the working point is recorded (U_mpp, I_mpp) for possibly multiple MPP trackers per inverter.

1.1 Inverter Analytics

By calculating the inverter efficiency from monitoring data, quantitative information can be obtained. Along the two-dimensional efficiency characteristics only a small subsection is traversed during a typical day by the inverter. Therefore, point clouds with the horizontal axis being the irradiation, and the vertical axis being the efficiency can be used for further analysis. These point clouds can additionally be colorized by features (module temperature, day hour, day in year, etc.) to analyze possible deviations from normal operation. Furthermore, a 2D histogram reflecting the density of points can be obtained, that makes certain behavior more visible as shown in Figure 1.

In many model designs, large inverters are assemblies of similar sub-blocks (modular design). Under low production conditions, efficiency can be improved by deactivating some of these blocks, operating each active block at its optimum conversion efficiency. The switching conditions require a hysteresis setting in the firmware. A failure of this switching operation, as observed in previous projects, as shown in Figure 1.

From these graphs, scalar metrics can be extracted by defining regions of interest and performing statistical analysis on all data points that are contained therein, see also figures 2 and 3. For larger systems, these values are then reported in data tables.

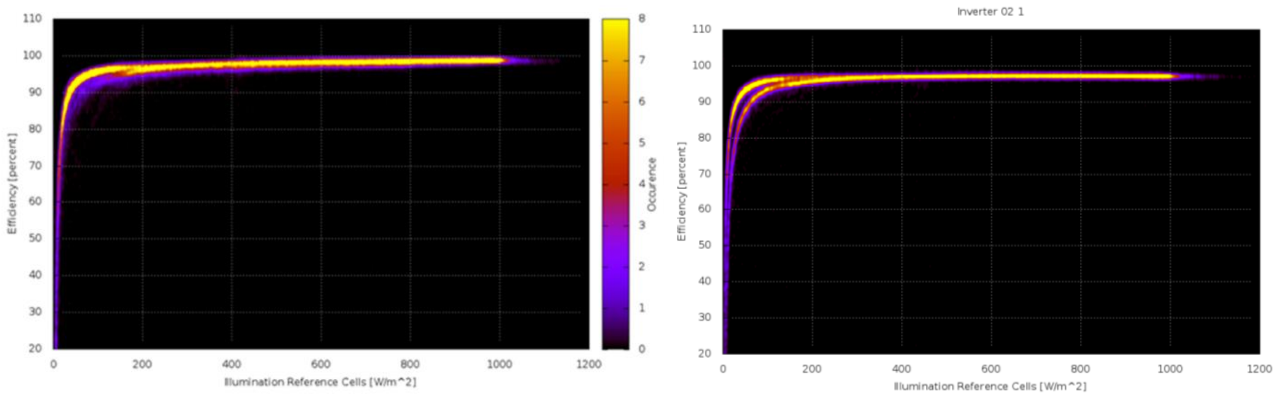

Figure 1: Left, a normal operation of an exemplary inverter. At 150W/m^2 irradiation, the switching of inverter blocks occurs. Right: Here, clearly the firmware has problems choosing the correct amount of active sub-blocks, creating a bad structure that is distinguishable by the day hour.

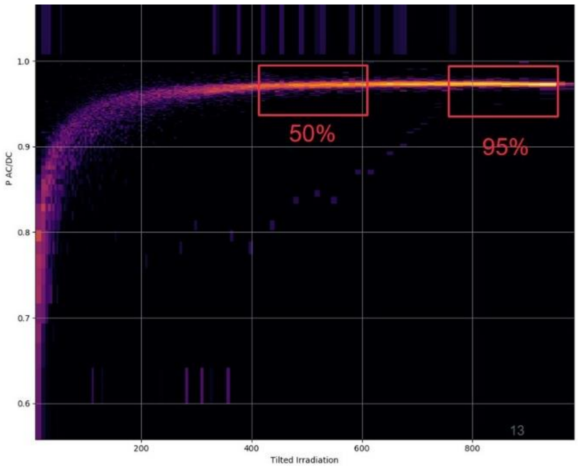

Figure 2 : Two-dimensional histogram of the density of points (irradiation, inverter efficiency). The region of interest that are evaluated to the half and full power efficiency are indicated.

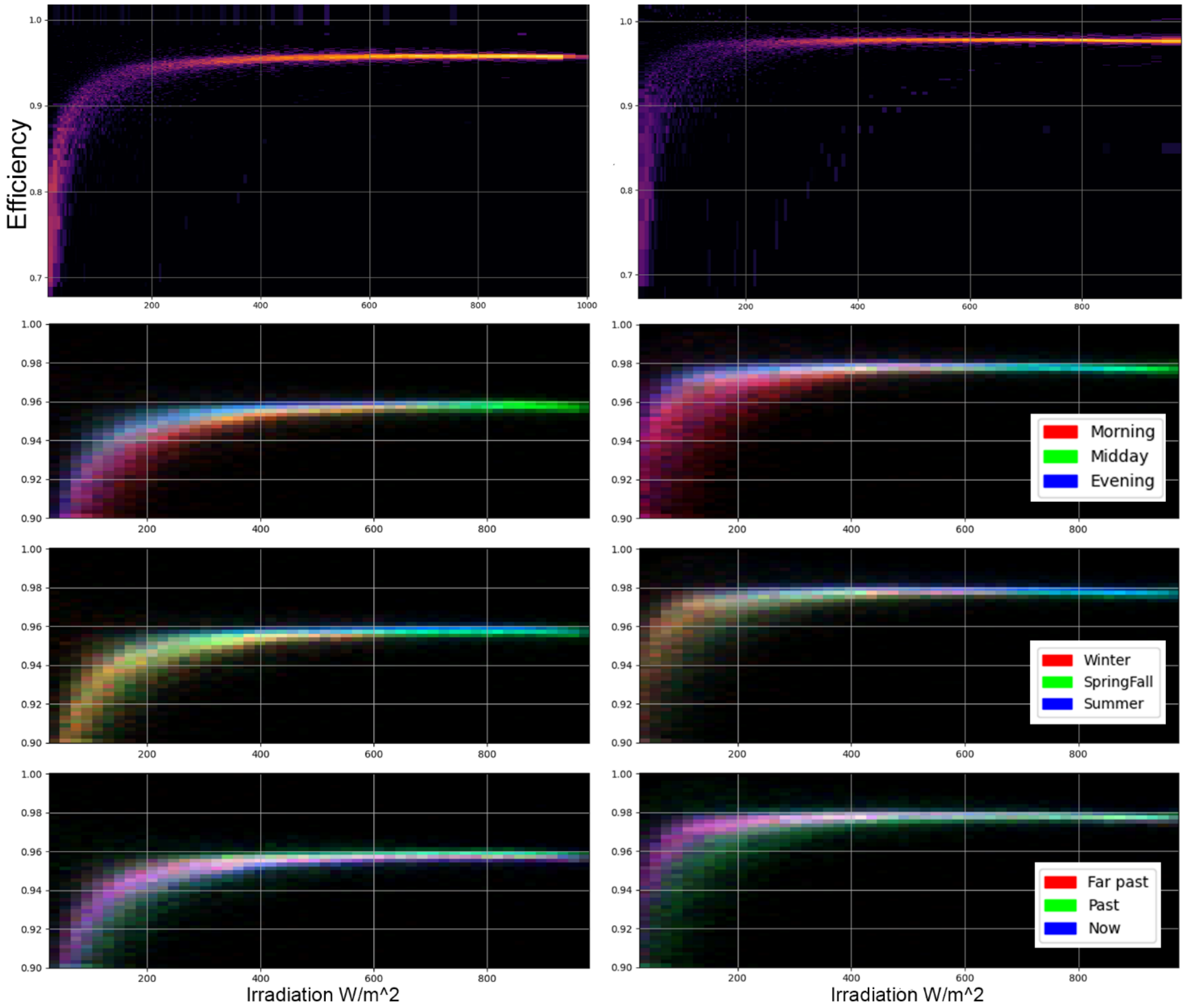

Figure 3: Comparison of exemplary inverters. The 2D histogram point density (top) was additionally colorized with three features using additive color mixing. Hence, an overlap of “red” and “blue” appears “violet”. Using the colorizations, additional structures can be observed: In the right example, in the evening the inverter efficiency is slightly better than in the morning hours. The last row of figures labels the current year in blue, the year before in green, and the second-last year in red, e.g. to exhibit potential inverter degradation.

1.2 MPP Analytics:

In typical inverters, the DC voltage and current are monitored, while an additional sensor monitors irradiation in the module plane as well as the module temperatures. While it is clear, that the module temperature varies between different locations in the PV-plant, and even, depending on the location, on the backside of a single module, it reflects the general trend of temperatures.

A changing irradiation causes the maximum power point (MPP: voltage V/ current I) to change, leading to the well-known IV characteristic of PV cells and modules, see Figure 4 (depending on module type, cable resistance and other losses). The red highlighted shape of the MPP tracking line can also be observed in the corresponding plot of the monitoring data, although less pronounced, see Figure 5. Many of the deviations from the ideal line originate from volatile irradiation conditions, where the inverter is not fast enough to follow the changing MPP.

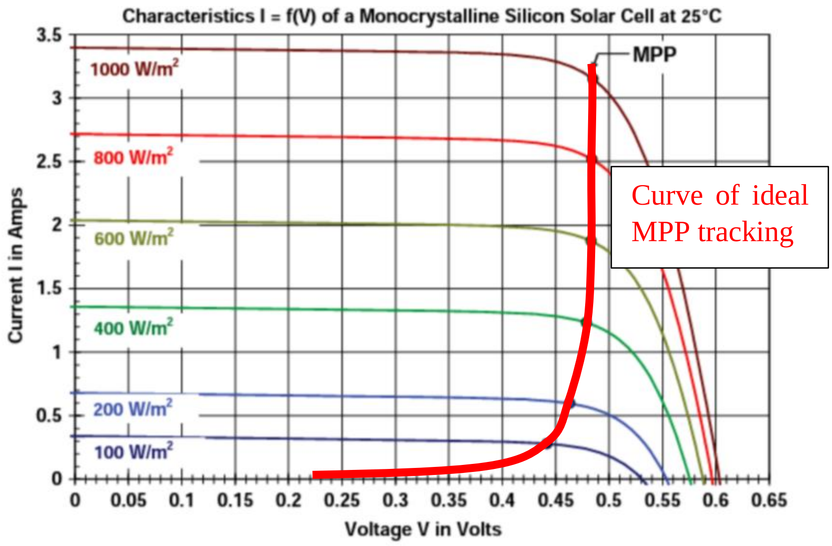

Figure 4: The MPP, apart from a small temperature effect, strongly depends on the irradiation (red curve). For larger irradiations, the voltage stays mostly constant, while the current is proportional to the irradiance. However, for less than 150W/m^2, the power decreases towards zero, causing a larger than linear decrease of production compared to irradiation.

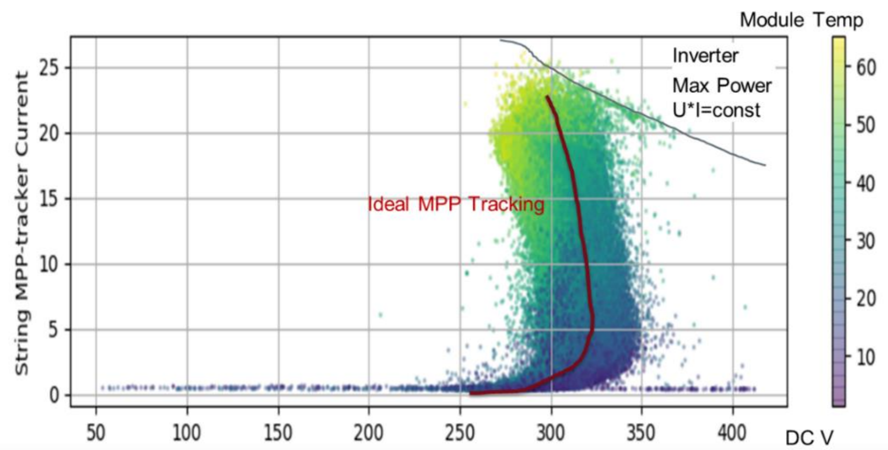

Figure 5: The inverters monitor the MPP voltage and current, and the corresponding point cloud shows quite a diffuse expansion that is typically centered around the theoretical MPP (irradiation) curve.

A small additional variation of the shapes would occur due to the module temperature and its effect on the MPP, which is mostly avoided by using a temperature corrected MPP voltage in the plots. The power at MPP itself has a well-known correction coefficient, that is stated e.g. in data sheets. The temperature coefficient of the open circuit voltage (Uoc) is typically ~10 times larger than the coefficient of the short circuit current (Isc). This justifies the approximation of only correcting the voltage of the MPP data points using a factor slightly less than the one for Uoc.

The MPP-clouds can be colorized with additional features, see Figure 6. Methods suitable for automatic processing can be used to extract metrics from graphs to avoid the manual inspection of a huge amount of graphical information. This is performed using regions of interest, see Figure 7. Furthermore, from a set of data multiple MPP clouds can be created, that are distinguished by feature groups: e.g. hours of the day, months, quarters, or years. From these sets of clouds, again the scalar features can be extracted, and plotted over the index of the feature group. This enables to plot the change of the MPP voltage or current over the time of day, the season, see Figure 8, or in accordance for long-term degradation sources, see Figure 89.

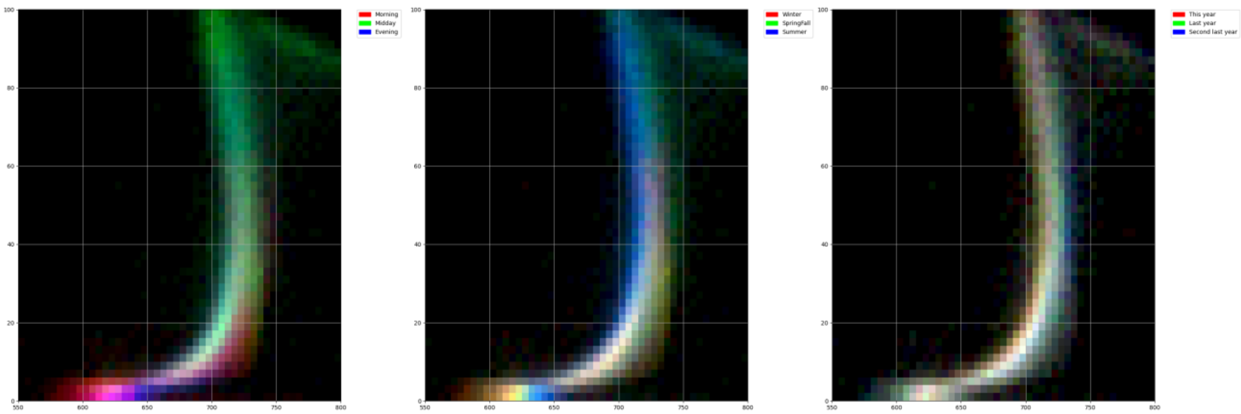

Figure 6: MPP-clouds, displayed as colorized 2D-histograms. In summer (center, blue) the voltage is slightly lower. Also, in the morning hours (left, red) the voltage is slightly larger for low irradiations than in the evening hours. The right graph exhibits that there is no dramatic degradation over time, as red+green+blue are color-mixed to white.

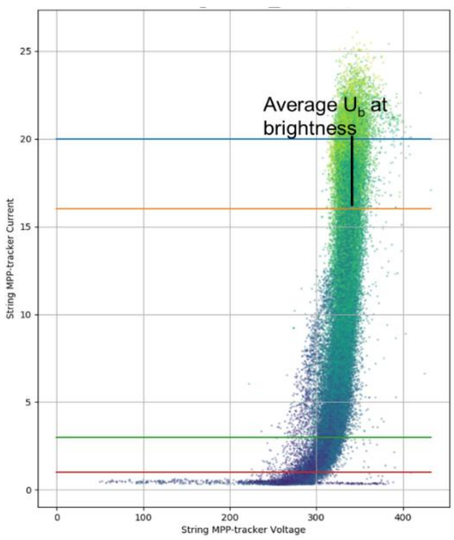

Figure 7: Within the MPP cloud, regions of interest can be defined, e.g. between the orange and blue line. The voltages of the selection band are then analyzed statistically, e.g. the average, standard-deviation, quantiles, or the band structure can be extracted.

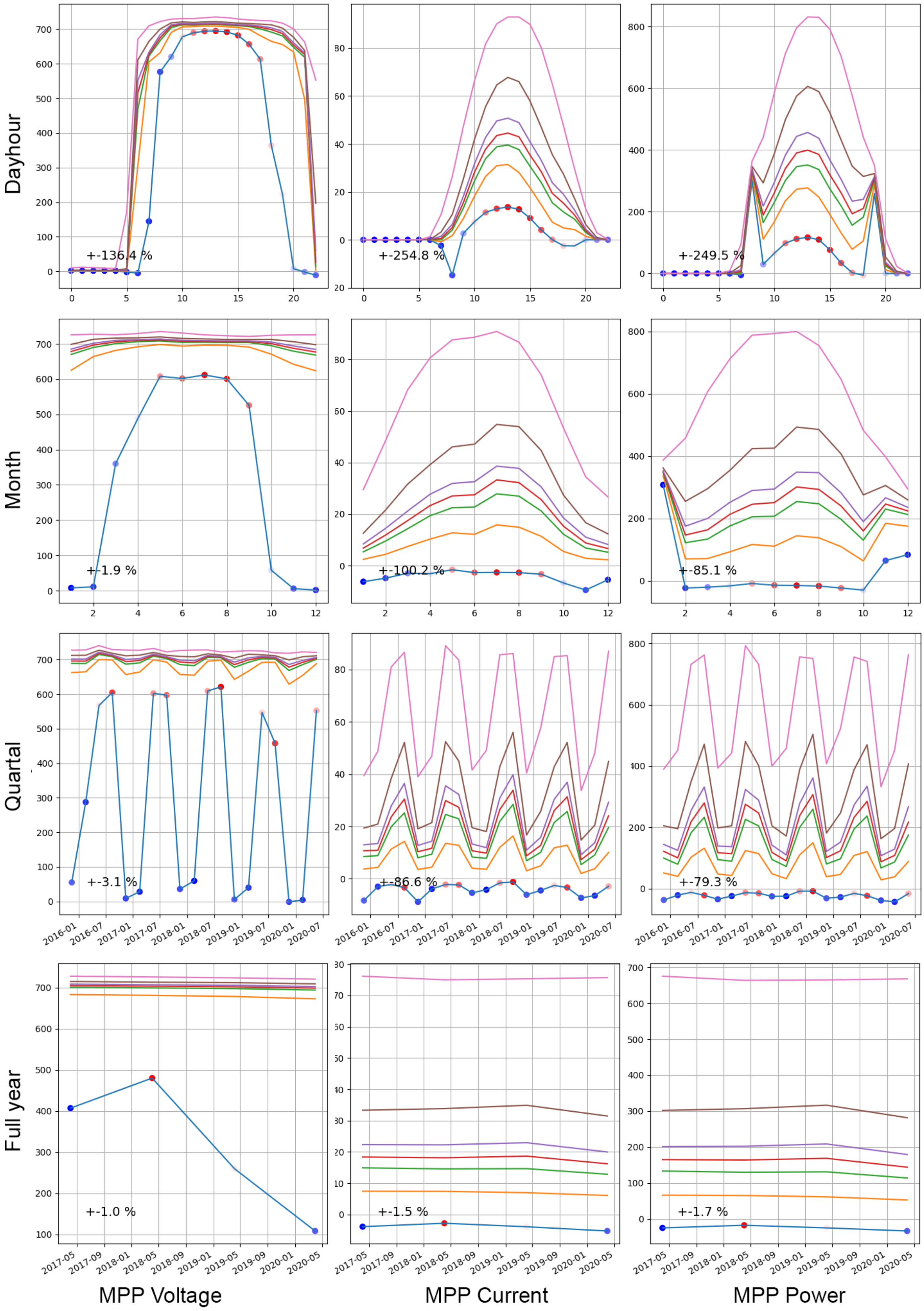

Figure 8: Development of the quantiles extracted from the MPP clouds (10% blue, 33% orange, 45% green, 50% red, 55% violet, 66%brown,90% pink). This exhibits daily changes, seasonal changes, and long-term changes of relevant metrics.

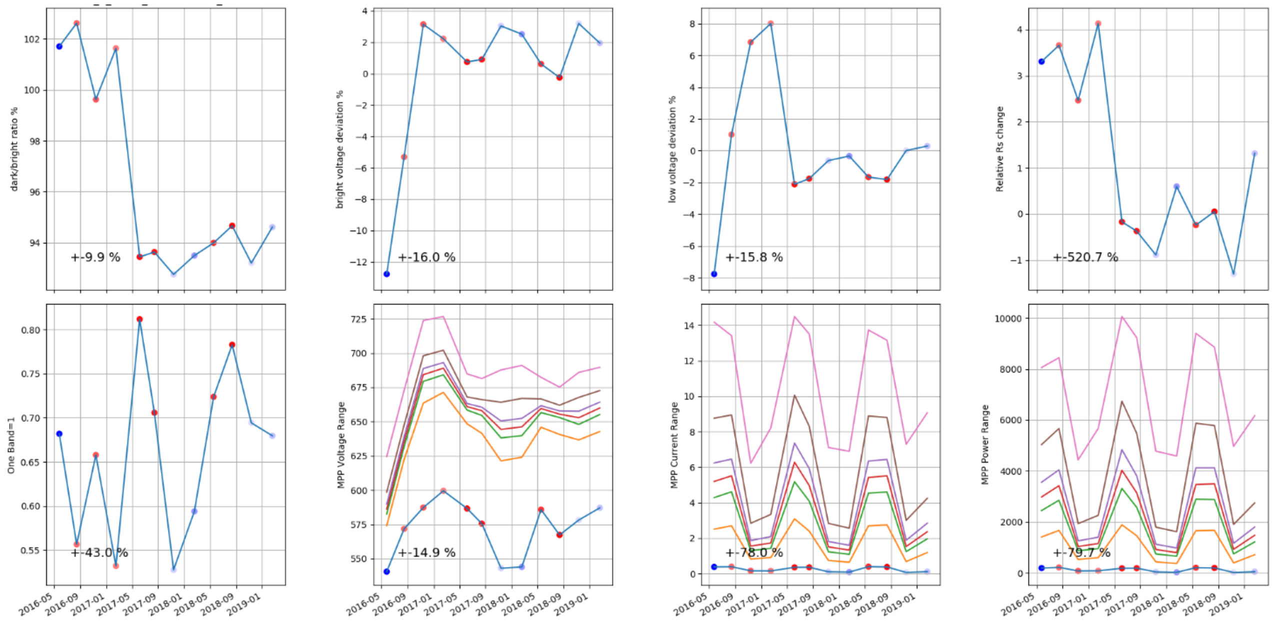

Figure 9: In the full metric graphs, here plotted over the quartals, indicators are given that can be used to indicate potential-induced degradation (PID), shading, serial resistance change, voltage and current degradation.