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D6.4 Analysis of feasibility of the developed solutions at UGent Testfield

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Abstract for dissemination (PU)

This document presents a laboratory study of an EV-PV system to evaluate AC and DC configurations. The setup uses power emulators for the EV and PV systems, controlled and monitored via Modbus through the *pyCinergia* framework. The study examines the effects of temporal resolution, irradiance conditions, and operating voltage on the energy losses. Measurements of EV, PV, and grid power flows provide a detailed dataset for analyzing energy exchanges under several conditions, enabling an energetic comparison of AC and DC configurations.

Contents

1. Introduction

In this deliverable, laboratory test setups were developed at the EnSy/Lemcko research group of Ghent University, located in Kortrijk. These setups aim to investigate conversion losses in both AC and DC configurations. To enable testing of these configurations, two four-quadrant AC/DC emulators are employed in combination with a programmable DC power source. The emulators are operated using a custom-developed Python package, which allows control in various modes, the application of setpoints, and automatic data acquisition. This experimental setup enables the emulation of a system consisting of a photovoltaic installation coupled with an EV supply equipment, with the flexibility to vary voltage levels and apply different photovoltaic generation profiles.

2. Lab setup

2.1. Emulator devices

Table 1 provides an overview of the emulator devices employed in the two configurations. The measurements are mainly conducted using the internal measurement capabilities of the emulators, accessed via the MODBUS communication protocol.

Table 1 Emulator devices

AC		**DC**	
PV DC/AC	4Q AC/DC emulator 40kW	PV DC/DC	Chroma 1x 62050h-600 & 2x 62050h-600s[1] each 5kW
EV DC/AC	4Q AC/DC emulator 40kW	EV DC/DC	4Q AC/DC emulator 40kW
		GRID DC/AC	4Q AC/DC emulator 40kW

2.2. Configurations

The AC configuration, illustrated in Figure 1, employs two Cinergia emulators representing the photovoltaic (PV) installation and the electric vehicle supply equipment (EVSE), each equipped with a DC/AC inverter. In contrast, the DC configuration, shown in Figure 2, utilizes one Cinergia device as the EV emulator and another as the grid interlink inverter. Additionally, three Chroma programmable power sources, each rated at 5 kW, are deployed to emulate the PV installation, providing a combined capacity of 15 kW.

The Cinergia and Chroma emulators are controlled via the MODBUS protocol, using the custom Python package *pyCinergia* (see Figure 3). This package enables automated communication with the devices by writing setpoints (e.g., voltage, current, power) and retrieving internal measurements. Power at the emulator output is obtained directly from the MODBUS registers, allowing simultaneous device control and measurement without additional hardware.

[1] Voltage range of the Chroma power sources is between 120V and 600V

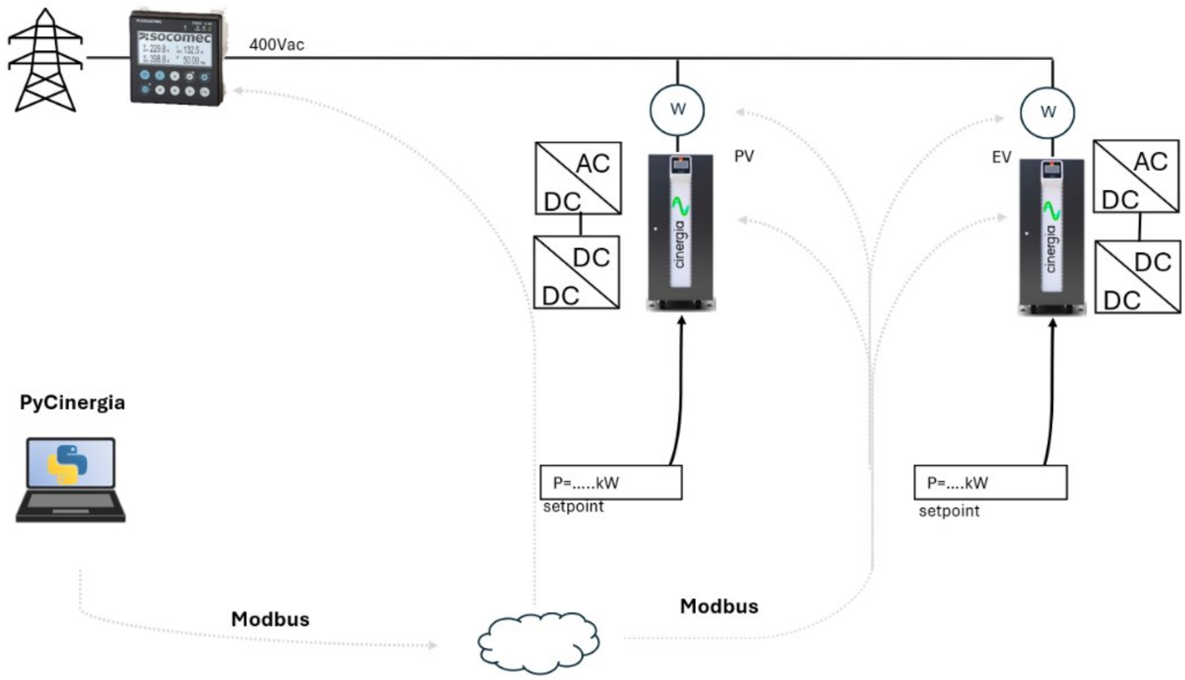

Figure 1 AC configuration

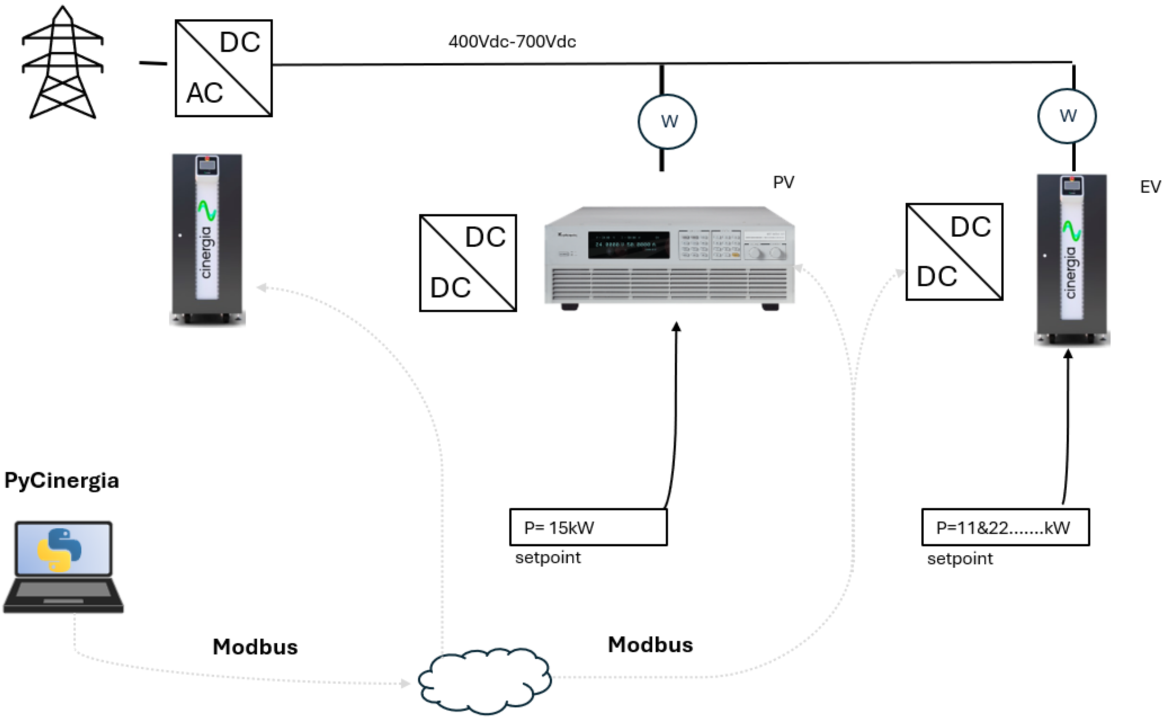

Figure 2 DC configuration

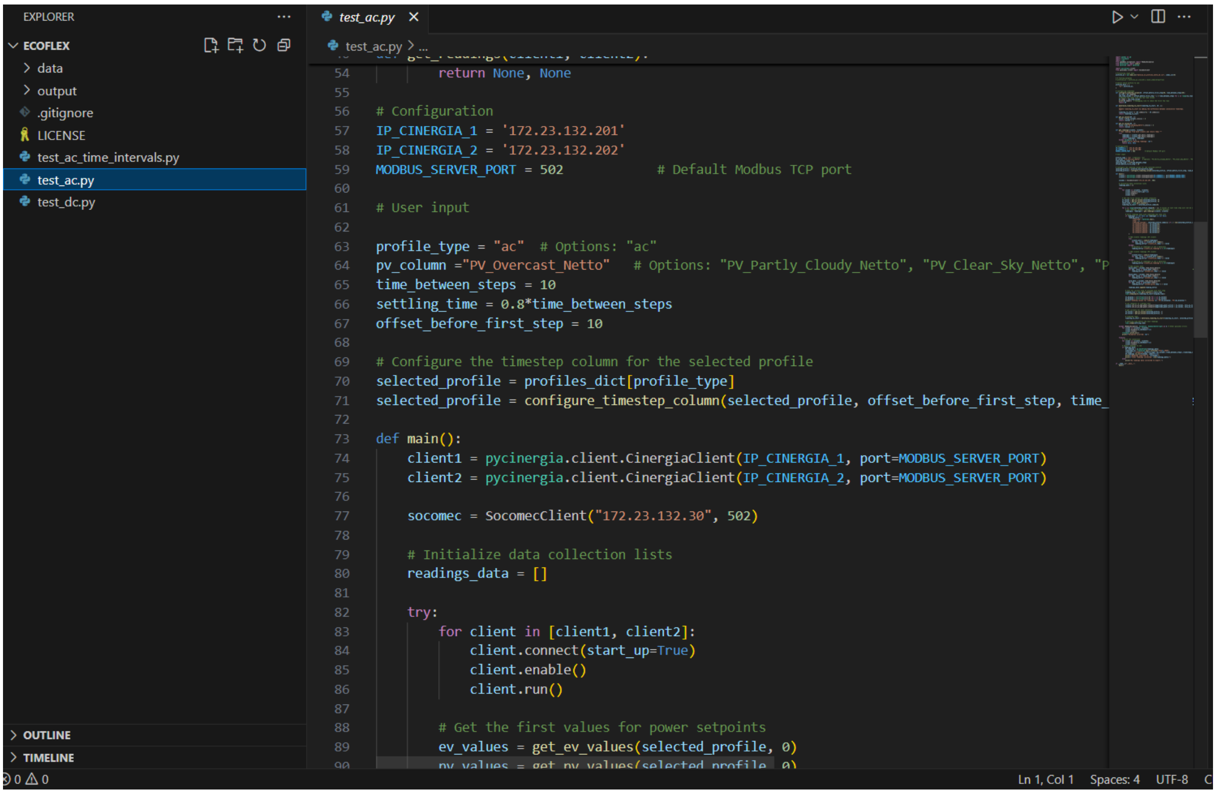

Figure 3 Screenshot of the Python code used to run the setup

2.3. Practical setup picture

Figure 4 illustrates the practical laboratory setup comprising two Cinergia emulators and one Chroma emulator. The devices are interconnected and equipped with the required protection components, including fuses and circuit breakers.

Figure 4 Practical setup picture

3. Datasets

The PV setpoints provided to the emulators are derived from profiles generated using meteorological data from the Belgian Royal Meteorological Institute, with a temporal resolution of 15 minutes. The EV charging profiles are constructed under the assumption that charging starts at 10:00 and continues until the battery is fully charged. An initial State of Charge (SoC) of 0% is considered, while the charging dynamics are modeled through a constant-current/constant-voltage (CC-CV) charging process based on the characteristics of the Nissan Leaf battery pack. This methodology is further elaborated in the report of deliverable D6.3.2. Figure 5 presents the four PV profiles, illustrating different levels of variability, ranging from a smooth clear-sky irradiance profile to an overcast day characterized by low irradiance.

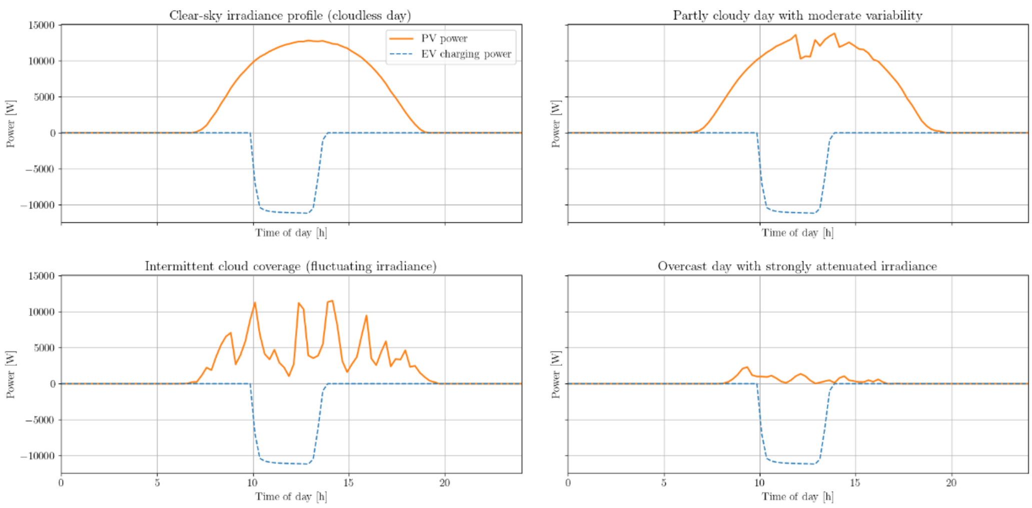

Figure 5 EV and PV profiles with varying irradiance conditions, from clear sky to overcast

4. Results

4.1. Impact of temporal resolution

An initial analysis was conducted to investigate the impact of temporal resolution on the power profiles. To this end, profiles with a 1-minute resolution were utilized and subsequently resampled to 5- and 15-minute intervals for comparison. High-resolution profiles result in a more dynamic and exponentially varying EV profile, whereas lower-resolution profiles exhibit more abrupt and piecewise changes. Similarly, the PV profile captures greater variability and intermittency at high temporal resolution, while coarser resolutions produce a smoother and less detailed representation of the power output. This effect is illustrated in Figure 6, which shows that the grid exchange also exhibits increased variability when high-resolution profiles are used. The aim of this analysis is to quantify the error in accuracy introduced when using coarser temporal resolutions, such as the standard 15-minute sampling interval, particularly in the estimation of energy losses in an AC configuration.

The energy loss analysis presented in Figure 7 indicates that, when using a 15-minute profile, EV converter energy losses are slightly underestimated: −0.55 % compared with the 5-minute resolution and −0.69 % compared with the 1-minute resolution.

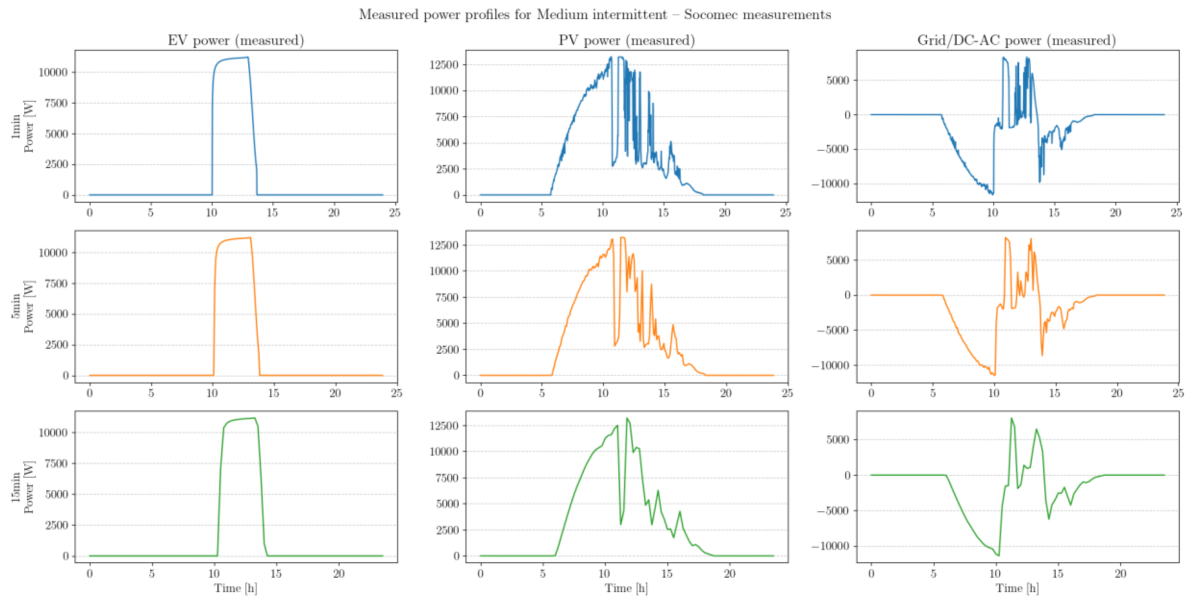

Figure 6: EV and PV power profiles and grid exchange at 1-, 5-, and 15-minute resolution

In contrast, the PV converter energy losses as a function of temporal resolution do not exhibit a clear and monotonic decrease with coarser resolution. Nevertheless, assuming the 1-minute resolution provides the most accurate reference, the difference observed with a 15-minute profile remains very small, corresponding to an underestimation of only −0.39 %.

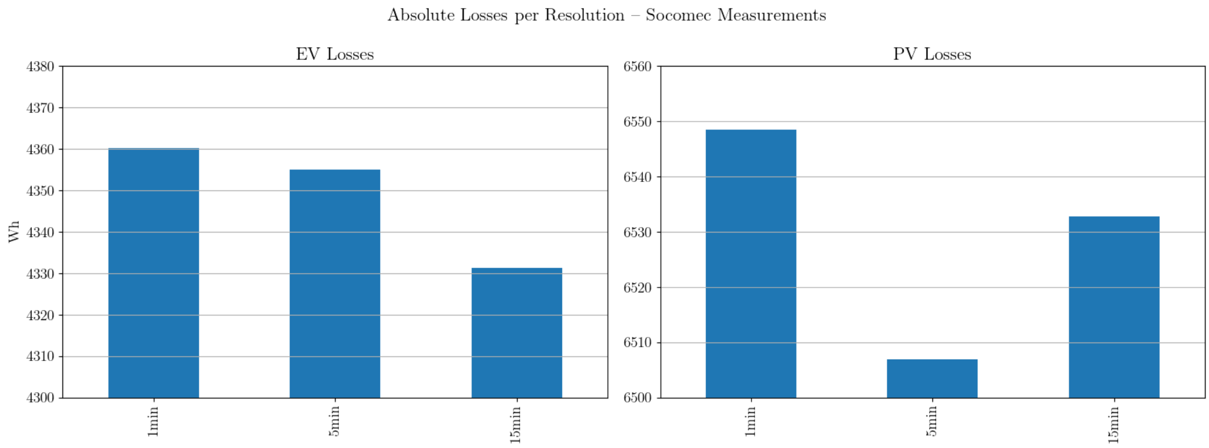

Figure 7 Energy losses for 1-, 5-, and 15-minute resolutions

The monotonic decrease in EV converter energy losses with coarser temporal resolution can be explained by the corresponding power density distributions. As shown by the density functions with the overlaid efficiency curve (Figure 8), higher-resolution profiles exhibit greater density in both the lower and upper power ranges where the converter efficiency is suboptimal. The increased variability captured at 1-minute resolution results in more operation in these efficiency-sensitive regions, leading to slightly higher calculated losses. Conversely, coarser resolutions (e.g., 15 min) smooth out these fluctuations, resulting in a marginal underestimation of losses. For PV converter energy losses, this relationship is less straightforward. The 5-minute profile actually yields slightly lower energy losses than the 15-minute profile, which can be attributed to its power density being very similar to that of the 15-minute profile in the lower and upper ranges, but slightly higher around certain intermediate power levels (e.g., ~2 kW and between 10–12 kW).

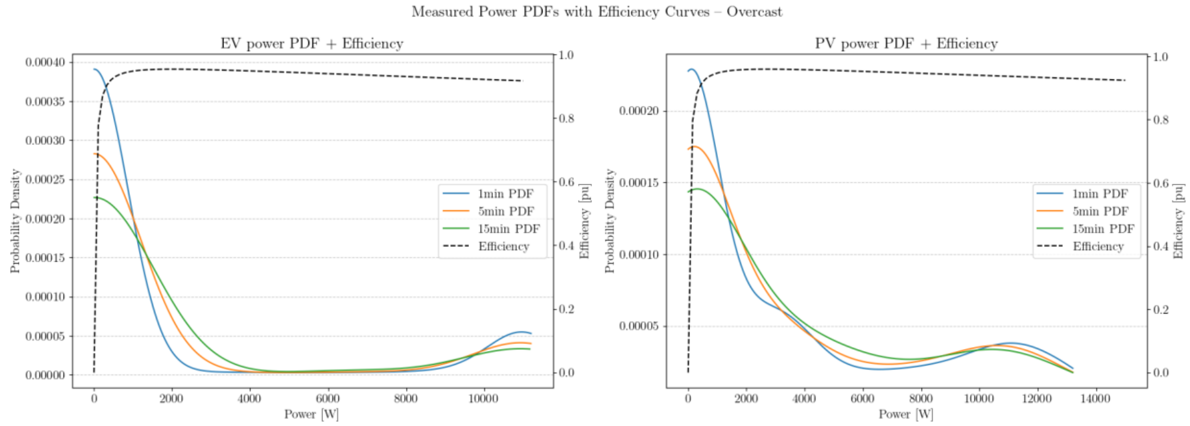

Figure 8 Density functions of EV and PV power, with overlaid converter efficiency curves

4.2. Energy losses

As an illustration Figure 9 shows the gross and net power profiles of the EV, PV and grid exchange for clear sky and overcast days

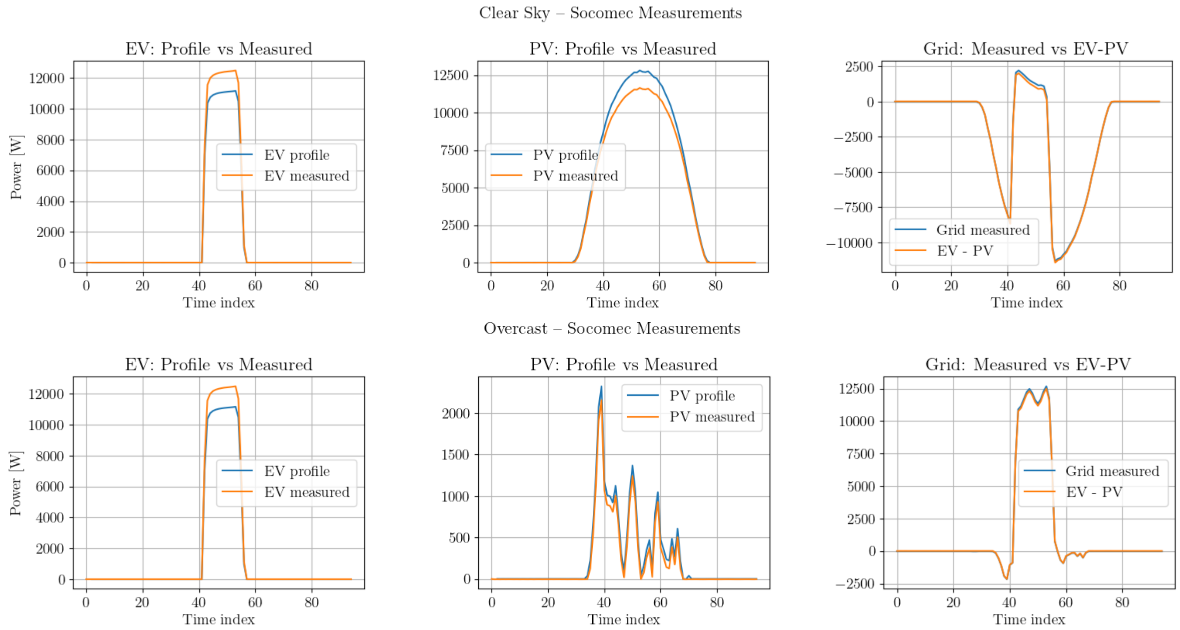

Figure 9 Gross and net EV and PV profiles, along with grid exchange for AC configuration.

The bar chart in Figure 10 presents the AC converter losses. The EV converter loss amounts to 4,227.06 Wh. The PV converter losses show a monotonic decrease with deteriorating irradiance conditions, which is expected given the corresponding reduction in energy yield. Interestingly, for the partly cloudy scenario, the converter losses exhibit a slight increase. This can be attributed to the marginally higher PV power in this case, resulting in a higher operating density in the higher power range of the converter efficiency curve, where efficiency is lower. The DC converter losses presented in Figure 11 show a substantial reduction in energy losses compared to the AC configuration, with a decrease by approximately a factor of 3 for the EV and up to a factor of 8 for the PV losses.

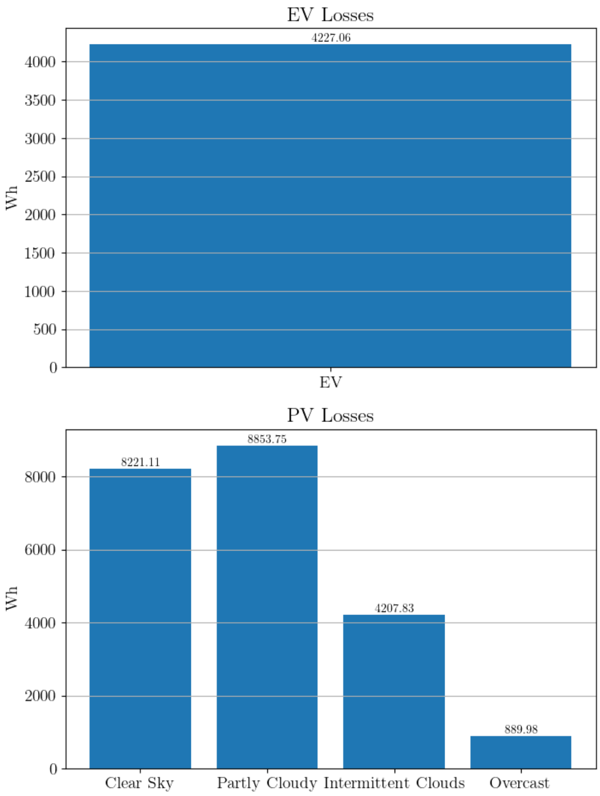

Figure 10 Bar charts of AC losses, showing EV converter losses (top) and PV converter losses (bottom) for clear-sky, partly cloudy, intermittent-cloud, and overcast conditions

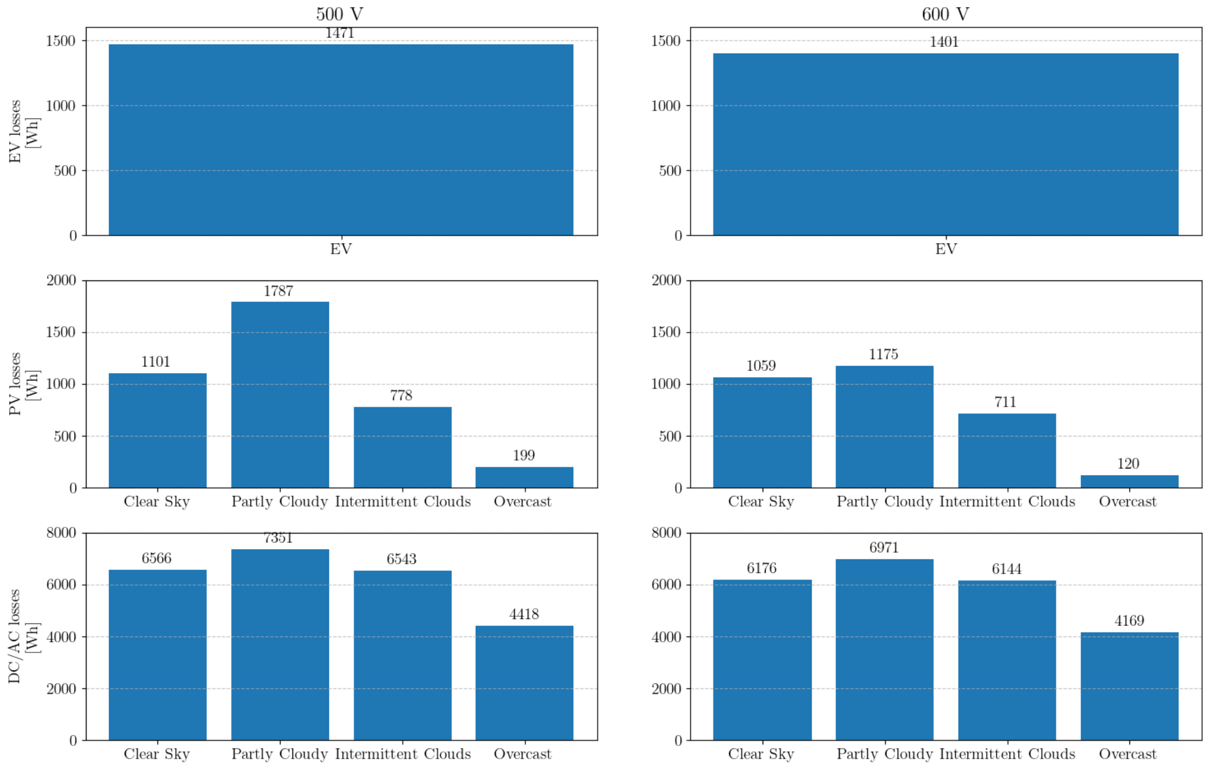

Figure 11 Bar charts of DC losses, showing EV converter losses (top), PV converter losses (middle), and DC/AC converter losses (bottom) under clear-sky, partly cloudy, intermittent-cloud, and overcast conditions, for voltages of 500V (left) and 600V (right)

It should be noted, however, that these results represent only the DC/DC converter losses. In the DC configuration, the DC/AC conversion stage is shared between the EV and PV systems, whereas in the AC configuration it is accounted for separately for each asset. The analysis of total losses, presented in Figure 12 and discussed below, helps to put these results into perspective. The PV and DC/AC converter losses exhibit trends similar to those observed for the AC PV converter losses. Nevertheless, the higher operating voltage of 600 V results in lower conduction losses and therefore lower overall losses. Lower and higher voltages (e.g., 400 V and 700 V) could not be analyzed, as the Chroma power source was limited by its maximum current and maximum voltage, respectively.

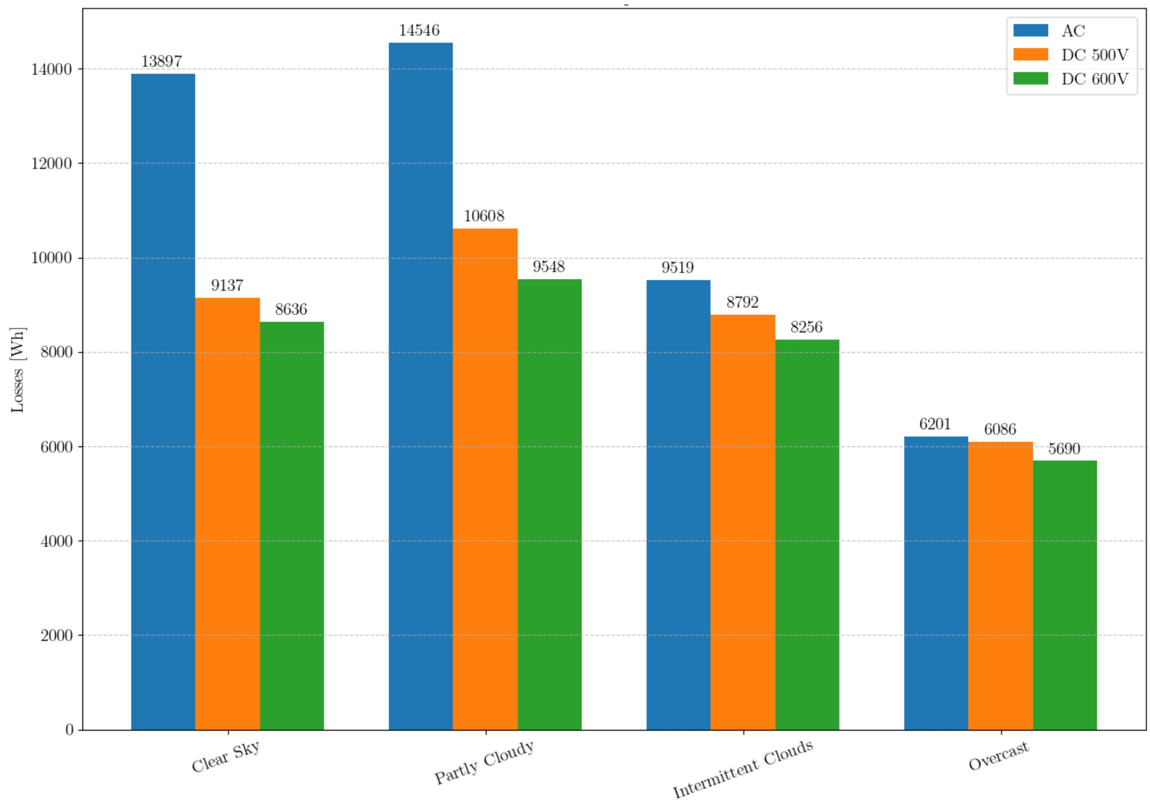

Figure 12 Comparison of total energy losses for clear-sky, partly cloudy, intermittent-cloud, and overcast conditions at DC operating voltages of 500 V and 600 V

Figure 12 provides an overview of the total energy losses for all analyzed scenarios. Across the four investigated irradiance conditions, the DC losses are consistently lower than the AC losses. Moreover, the losses are further reduced at 600 V due to the lower conduction losses. For high-irradiance profiles (i.e., clear-sky and partly cloudy), the difference between AC and DC configurations becomes more pronounced, primarily because a larger share of EV demand is directly supplied by PV generation. The overview table presented in Table 2 also includes the self-sufficiency index (SSI; its definition is provided in report D6.3.2). The table highlights several key observations:

- A clear correlation between Δ and SSI can be observed: the greater the fraction of EV demand directly covered by PV production, the higher the benefit of the DC configuration.
- Higher operating voltage further reduces DC losses, resulting in an increased Δ and a marginal improvement in SSI.
- Even under low-irradiance conditions, the DC configuration remains advantageous, particularly when a 600 V DC operating voltage is used.

Table 2 Overview table of the self-sufficiency index, energy losses, and absolute and relative differences under different irradiance conditions for DC operating voltages of 500V and 600V

		SSI		Energy losses (Wh)		Δ (Wh)	Δ (%)
DC voltage	PV profile	AC	DC	AC	DC		
500V	Clear Sky	98.18%	99.38%	13897	9137	-4760	-34.25%
	Cloudy with moderate variabilitiy	96.59%	97.62%	14546	10608	-3938	-27.07%
	Intermittent cloud coverage	44.20%	45.10%	9519	8792	-727	-7.64%
	Overcast with strongly attenuated irradiance	5.41%	5.85%	6201	6086	-115	-1.85%
600V	Clear Sky	98.18%	99.43%	13897	8636	-5261	-37.86%
	Cloudy with moderate variabilitiy	96.59%	97.67%	14546	9548	-4998	-34.36%
	Intermittent cloud coverage	44.20%	45.25%	9519	8256	-1263	-13.27%
	Overcast with strongly attenuated irradiance	5.41%	5.90%	6201	5690	-511	-8.24%

5. Conclusion

This report presents the laboratory measurements performed on a test setup consisting of emulators designed to assess AC and DC configurations of an EV supply equipment and a PV installation. The emulators are controlled via Modbus, and all measurements are also acquired through Modbus, managed using the *pyCinergia* framework. The tests aimed to analyze the impact of various parameters, including irradiance conditions and operating voltage levels, on the energy losses in both AC and DC configurations. Prior to this, the influence of temporal resolution on the accuracy of the energy loss calculations was investigated. It was found that, although the 1-minute resolution provides the most accurate results, the difference compared to a 15-minute resolution is less than 0.7 %.

The comparative energy loss analysis demonstrates that the DC configuration is overall more advantageous than the AC configuration, with reductions in energy losses of up to 38 %. These reductions are generally most pronounced at a DC operating voltage of 600 V, owing to lower conduction losses. Moreover, higher SSI values are associated with greater energy loss reductions, as a larger share of EV demand is directly supplied by PV generation, resulting in lower grid import and consequently reduced losses in the central DC/AC inverter of the DC configuration.