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Analysis of the Influence of Photovoltaic Production on Grid Voltage using Data from Inverters

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Paper 30032

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Instrumentación Electrónica Industrial

-Main research interests: Analysis and optimization of the production of photovoltaic plants and their impact in the power grid, *Modeling* of electricity consumption in the residential sector.

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solar del valle ingeniería e instalaciones

In collaboration with **Solar del Valle S.L**. company (responsible of photovoltaic installation where study was developed)

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Introduction

Renewable energy sources are playing an increasingly important role in the move towards decarbonization and the reduction of polluting gases.

Photovoltaic (PV) energy has been consolidated as one of the largest sources of renewable energy.

It is the technology whose installed capacity has experienced the **greatest growth** in recent years, already exceeding **2.2 TW** worldwide.

Introduction

The widespread implantation of PV is supported by the numerous **advantages** that this technology possesses.

- Solar energy is widely available throughout the world. → It can contribute to reduce dependence on energy imports.
- Simplicity of PV installations and its high reliability.
- Low prices and very low maintenance costs. → Competitive technology due to price reductions [1].
- The lack of noise due to the absence of moving parts. → Which enables its integration in buildings.

[1] https://www.irena.org/Publications/2025/Jun/Renewable-Power-Generation-Costs-in-2024

Introduction

The production of solar PV energy depends on:

- Daylight patterns
- Weather.
  - Cloud cover
  - Atmospheric turbidity.

Introduction

One of the main **inconveniences** of power PV systems are its inherent variability and uncertainty.

PV energy is highly **dependent on weather conditions**.

PV power output is intermittent and can **fluctuate significantly** in seconds

Introduction

The **intermittent nature** of PV output presents significant **stability challenges** for utility-scale integration

Difficulty of PV Output Forecasting

Fluctuations may cause undesirable effects on the distribution power grids.

Unpredictable voltage variations may appear, mainly in weak residential and rural grids, which must be added to the variations already present without distributed generation [2].

[2] A. Woyte, V.V. Thong, R. Belmans, J. Nijs, “Voltage fluctuations on distribution level introduced by Photovoltaic systems”, IEEE Transactions on energy conversion, vol 21, no. 1, pp. 202-209, 2006

Introduction

This variability can potentially act as a barrier to a greater expansion of this renewable technology.

Therefore, one of the main future **challenges** of PV is

to **understand voltage behaviour in the presence of renewable energy** production, important for developing and sizing effective mitigation techniques.

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Objectives

The aim of this work is to analyse **real voltage values** measured at the grid injection point by an **inverter** in a PV plant in operation located in Andalusia, Spain.

This work investigates how the **energy** produced by the **PV** panels **influences voltage variations** at that specific location.

Real production data were studied over a five-year period.

The data used are available across most PV installations.

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Methodology

PV Installation Specifications	
Nominal Power of the PV Park	4.4 MW
Location	South Spain (Rural Grid)
Inverter model	SMA SC-100
Nº Modules per inverter	663
Module model	BP-365
Module nominal Power (W)	165 W
Nominal Power associated to inverter	109 kW
Number of phases in the grid connection	3

Methodology

Measurement period	
November 2020	July 2025

1,705 days recorded, with 288 data points per day

Data were registered at a 5-min frequency.

Methodology

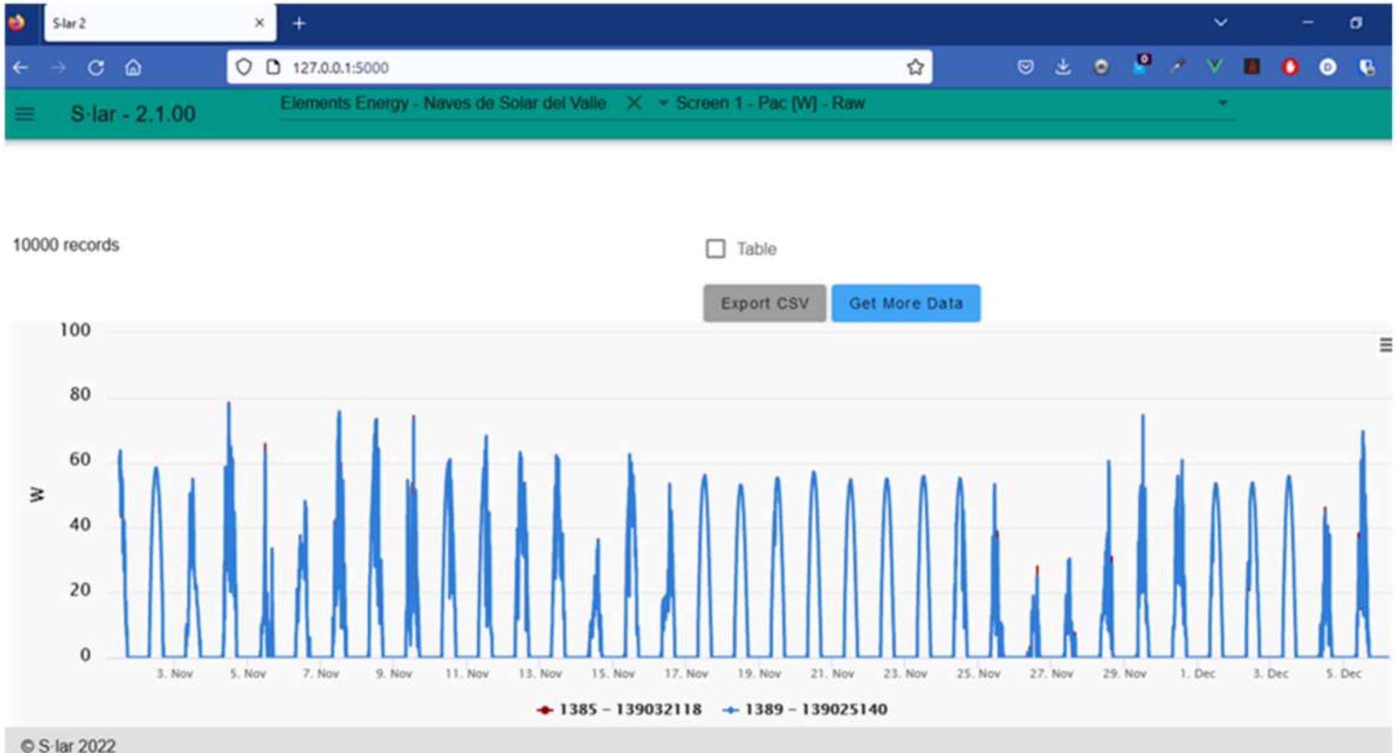
The inverter monitors the energy yield and the voltage at the point of common coupling among other parameters.

Grid Voltage at PCC

Methodology

The measured data were processed by means of ***S·lar*** software.

It was specifically developed to perform an automated analysis of data from the monitoring of grid-connected PV systems [3].



[3]
D. Trillo-Montero et al. “Design and Development of a Relational Database Management System (RDBMS) with Open Source Tools for the Processing of Data Monitored in a Set of Photovoltaic (PV) Plants” Applied Sciences., **2023**, *13*(3), 1357

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Results

Cloudy days accounted for 70% of the monthly total

Significant PV power fluctuations were observed during cloudy days

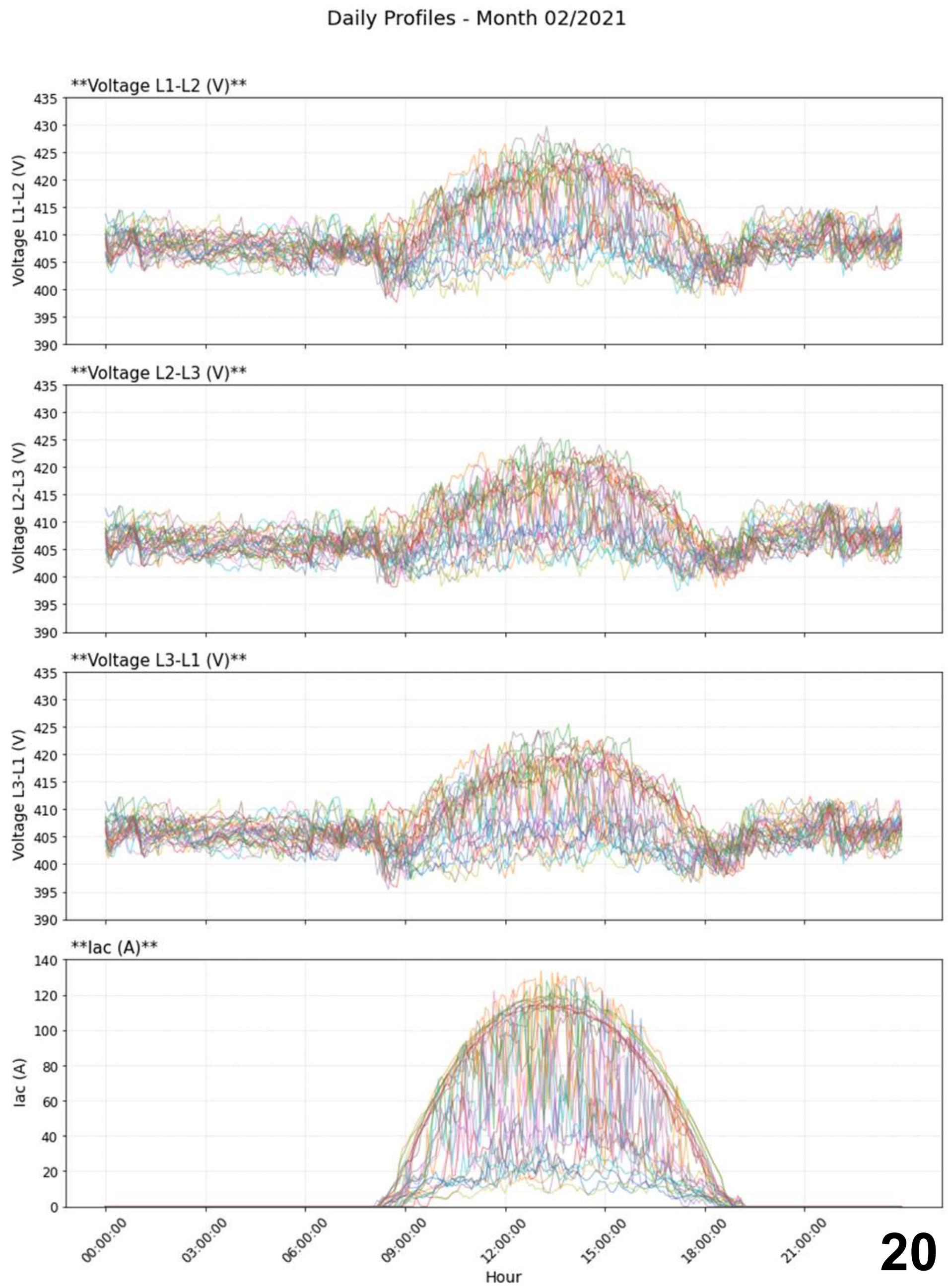

Figure 1. Daily profiles of line voltage in the three phases and the current generated during all days of **February 2021**.

Results

There was a voltage rise during hours with higher PV production

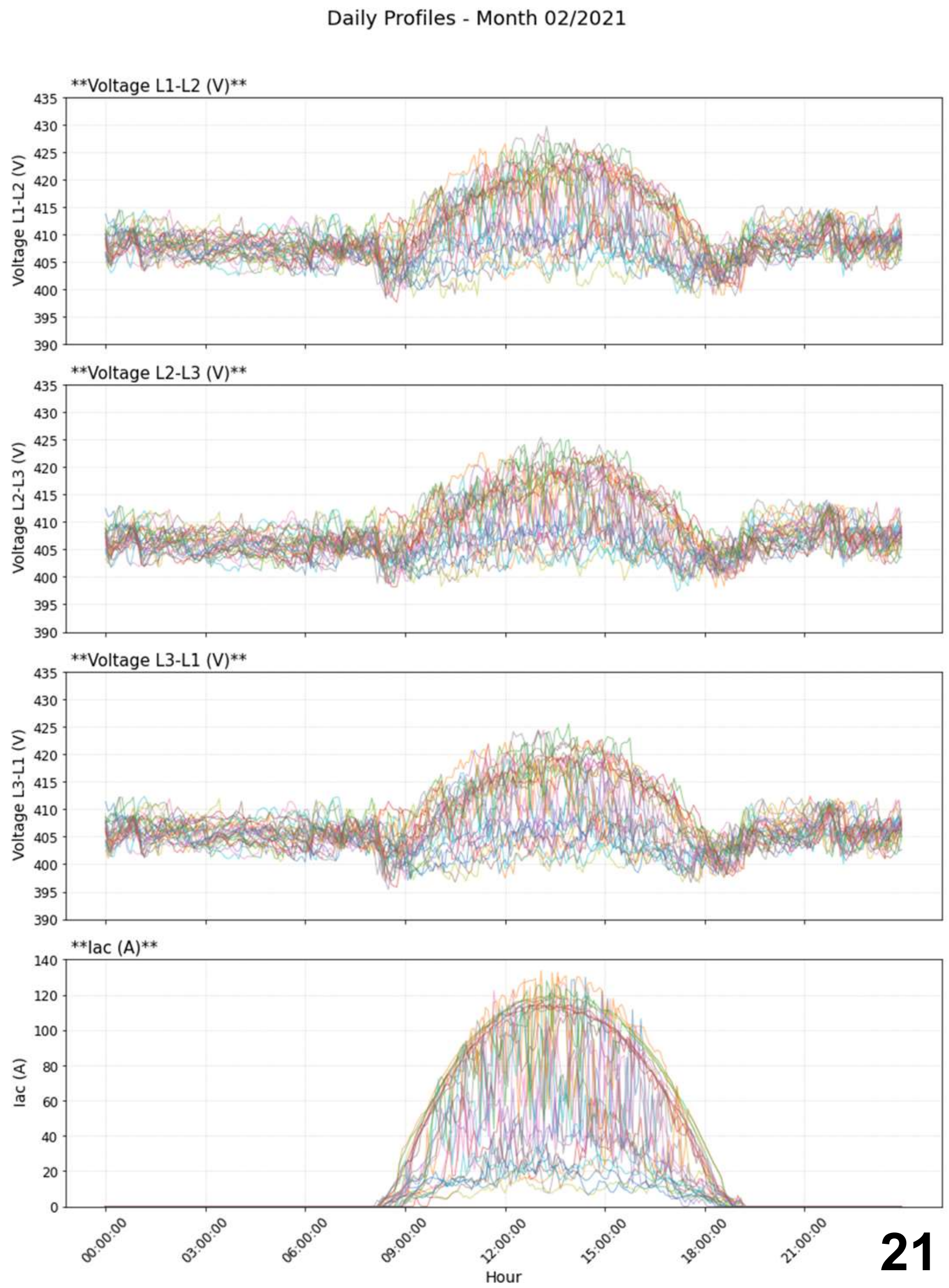

Figure 1. Daily profiles of line voltage in the three phases and the current generated during all days of **February 2021**.

Results

Voltage fluctuations were more pronounced during the day due to cloud-induced variability in PV generation

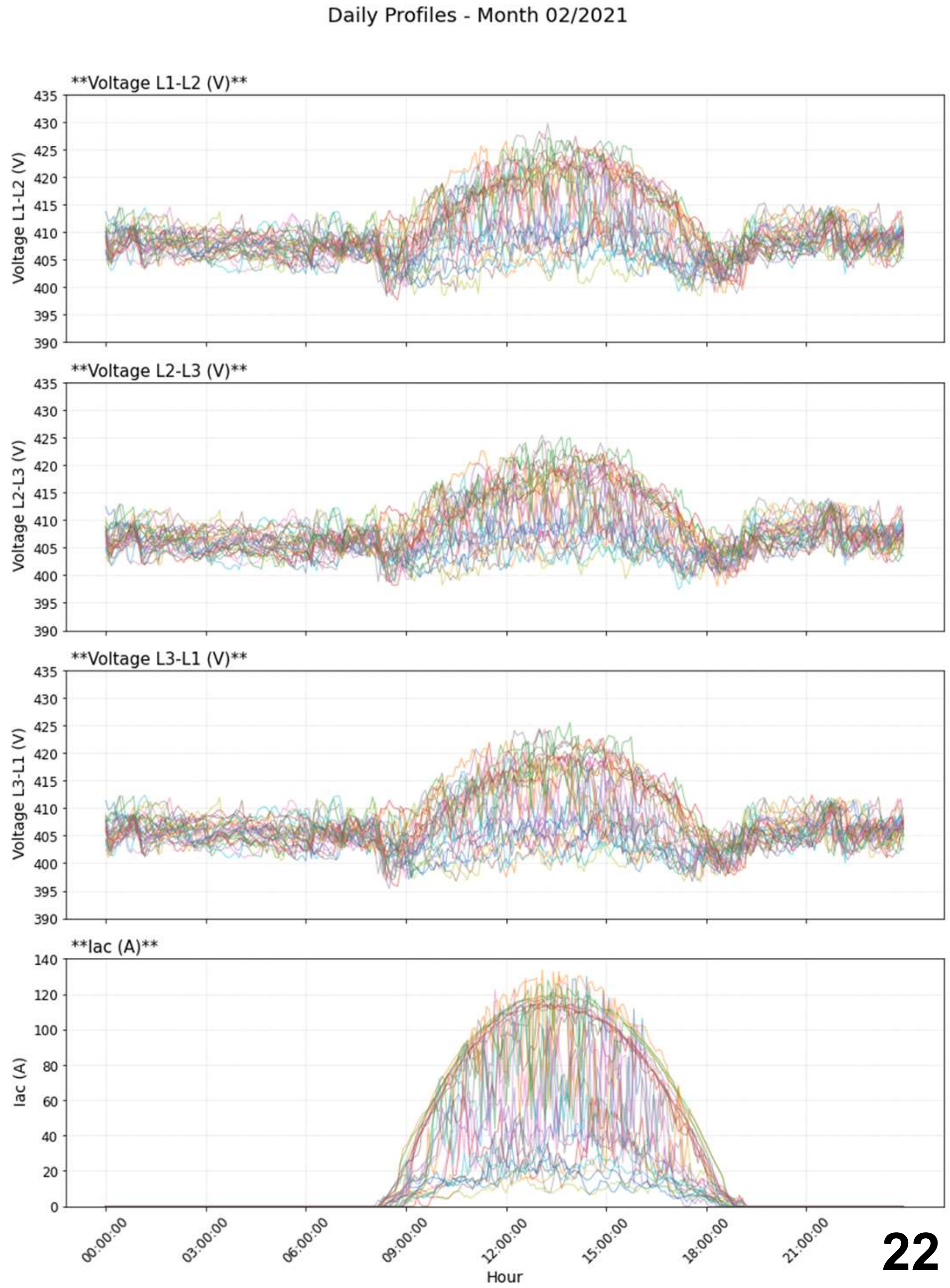

Figure 1. Daily profiles of line voltage in the three phases and the current generated during all days of **February 2021**.

Results

During the summer period, the reduced variability in PV generation results in more stable voltage levels

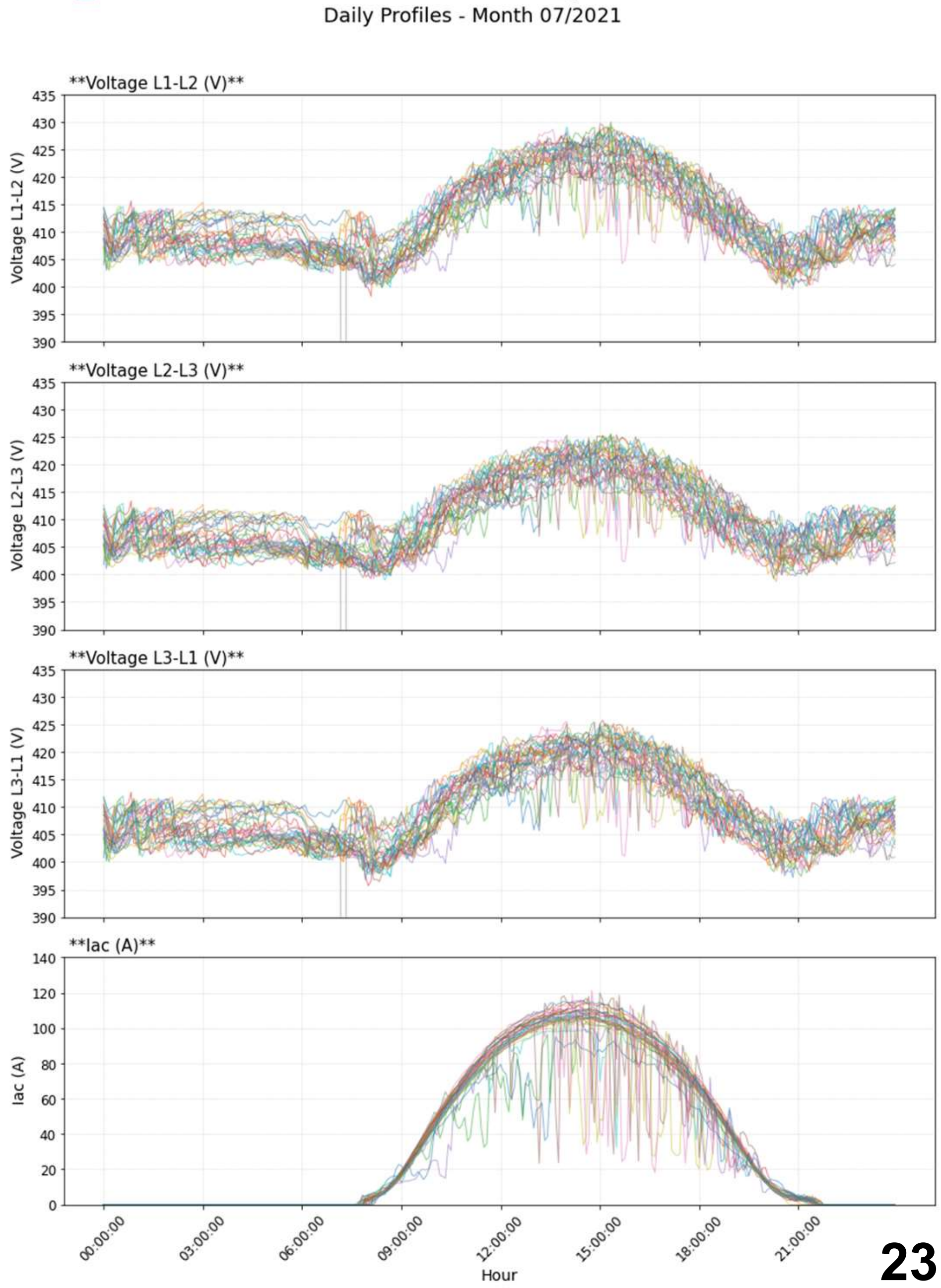

Figure 2. Daily profiles of line voltage in the three phases and the current generated during all days of **July 2021**.

Results

Clear sky day

Even under clear skies, inherent grid dynamics cause voltage fluctuations independent of PV power output

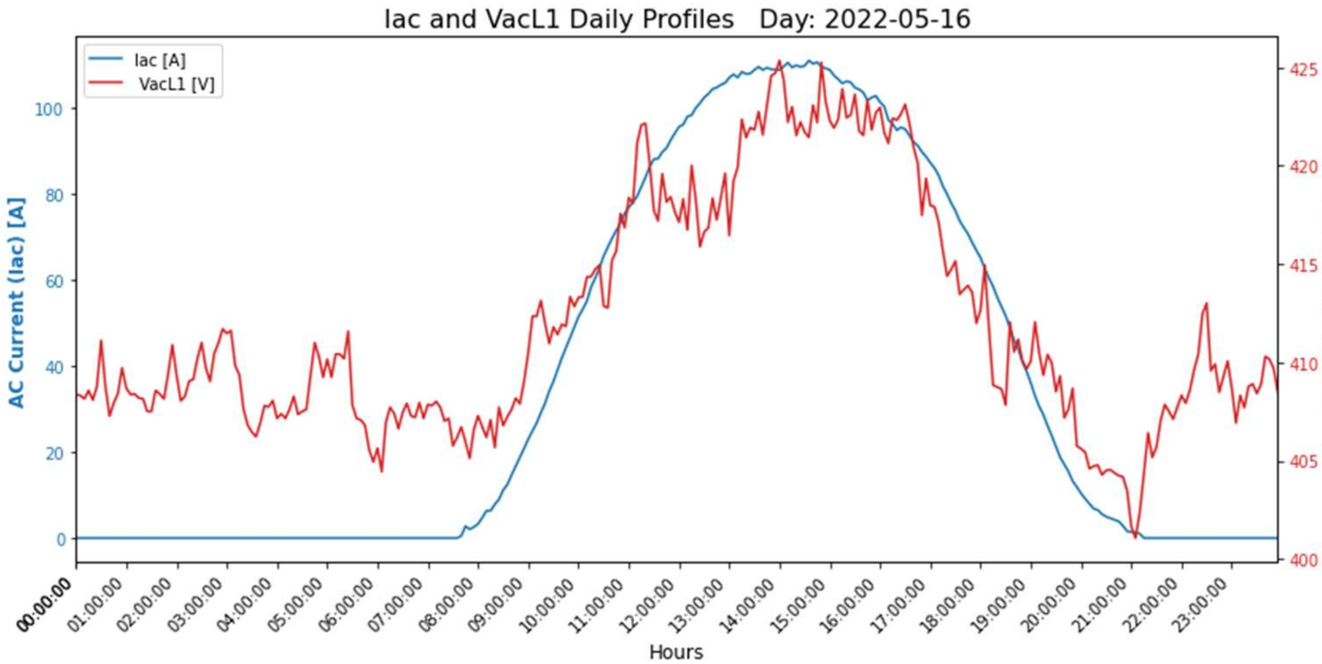

Figure 3. Daily profiles of line voltage in one phase and the current generated during a day of **May 2022**.

Results

Partly cloudy day

On cloudy days, PV-induced voltage fluctuations are superimposed on the inherent grid voltage dynamics

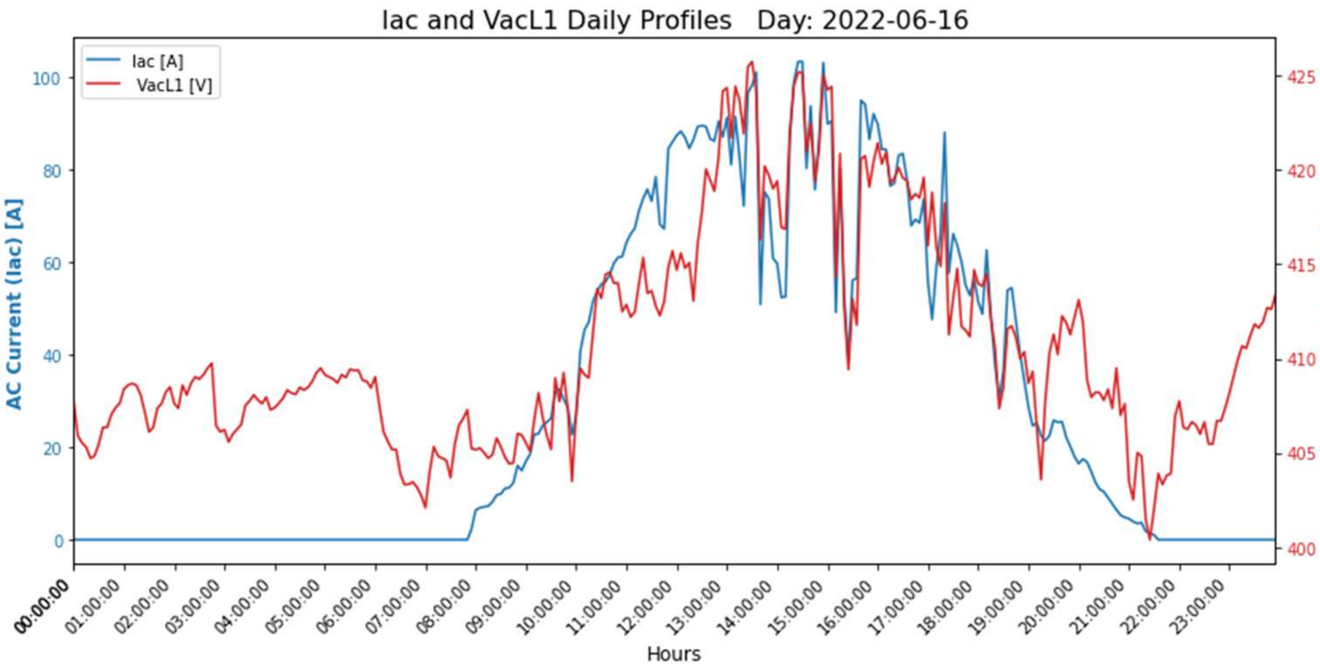

Figure 4. Daily profiles of line voltage in one phase and the current generated during a day of **June 2022**.

Results

A clear linear relationship is evident between these voltage levels and the PV power output.

Voltage levels rise when PV production is higher, particularly during peak generation hours

Correlation Voltage and PV current - Month 07/2021

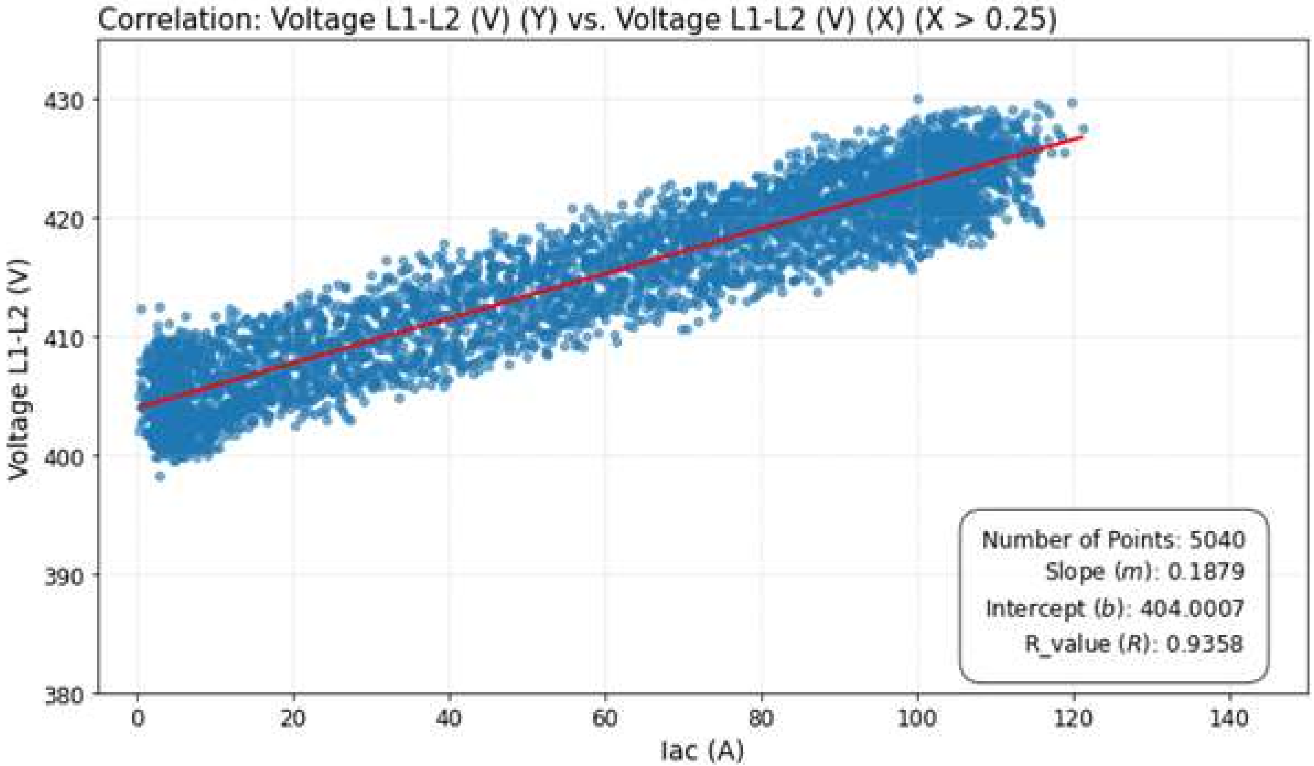

Figure 5. Correlation between the voltage values in one phase versus the current, when there is PV production, during the month of July 2021.

Results

Voltage values increase without exceeding regulatory thresholds.

Observed voltage slopes serve as an indicator of future hosting capacity constraints.

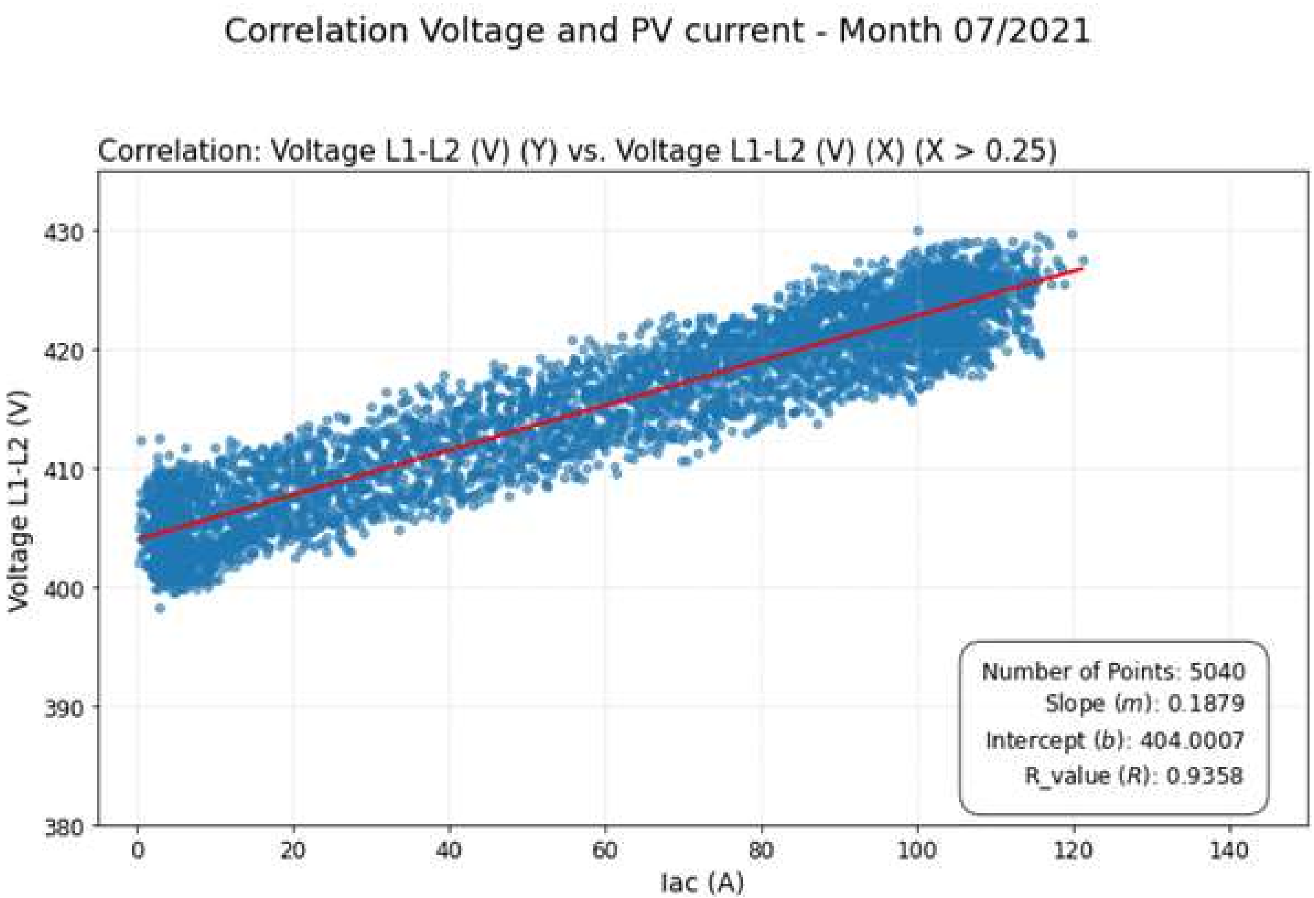

Figure 5. Correlation between the voltage values in one phase versus the current, when there is PV production, during the month of July 2021.

Results

The night-time distribution shows a narrow, single-peak behavior centered around 408 V, more stable voltage regime when the PV plant is inactive.

During production hours, the distribution becomes significantly broader and exhibits a bimodal behavior, with a second peak emerging near 420 V.

This shift toward higher voltage values confirms that solar energy injection elevates the local grid voltage. Inherent variations in grid management and the dynamics of connected loads, typically differ between daylight and night-time hours

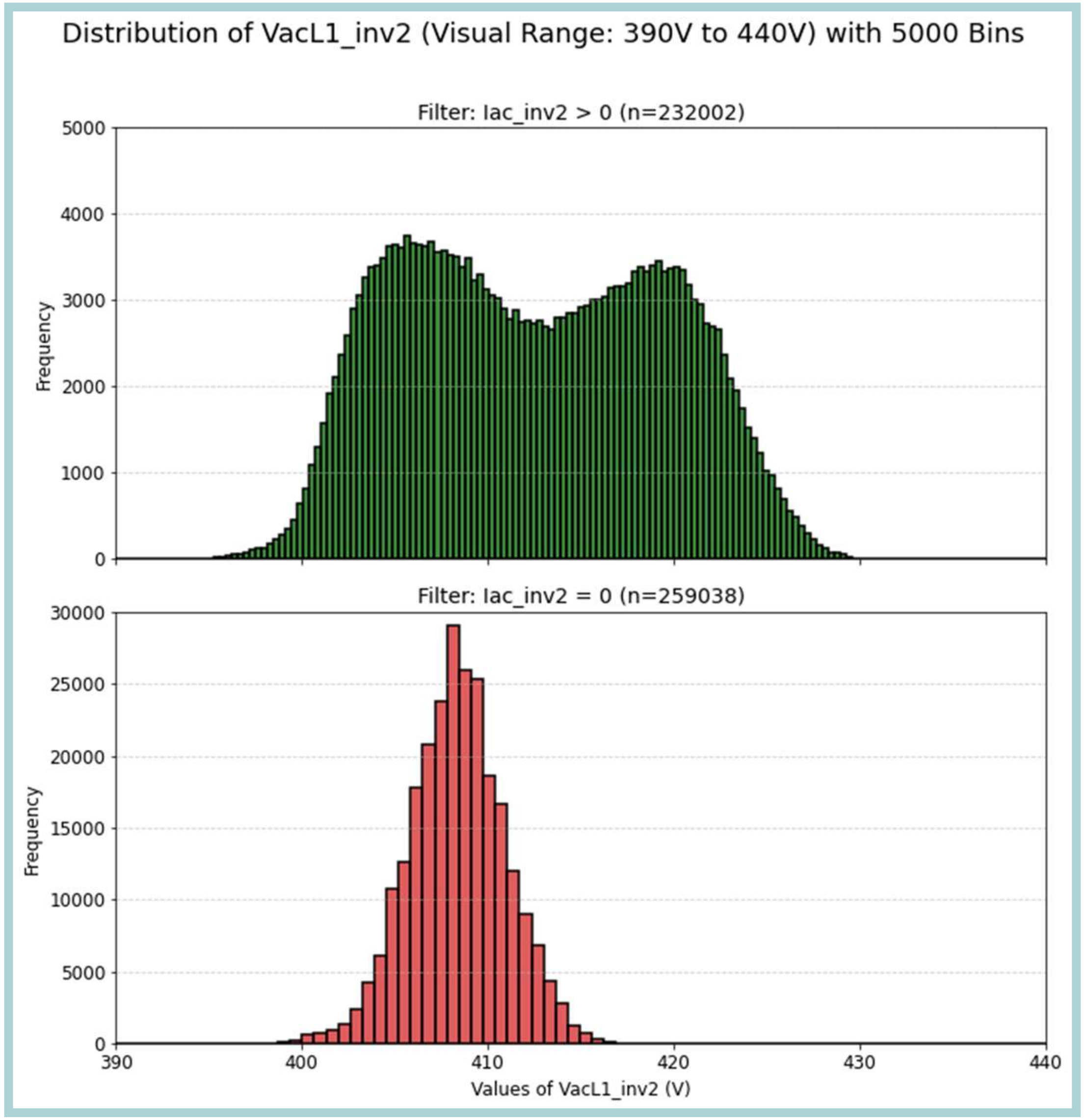

Figure 6. Histogram of the frequency with which voltage values are observed in one of the phases with and without PV power generation (Bins: intervals).

Results

During hours of photovoltaic production, fluctuations are primarily contained within a range of -12 V to 12 V.

In contrast, when the plant is inactive, the magnitude of these variations narrows significantly to between -7 V and 7 V.

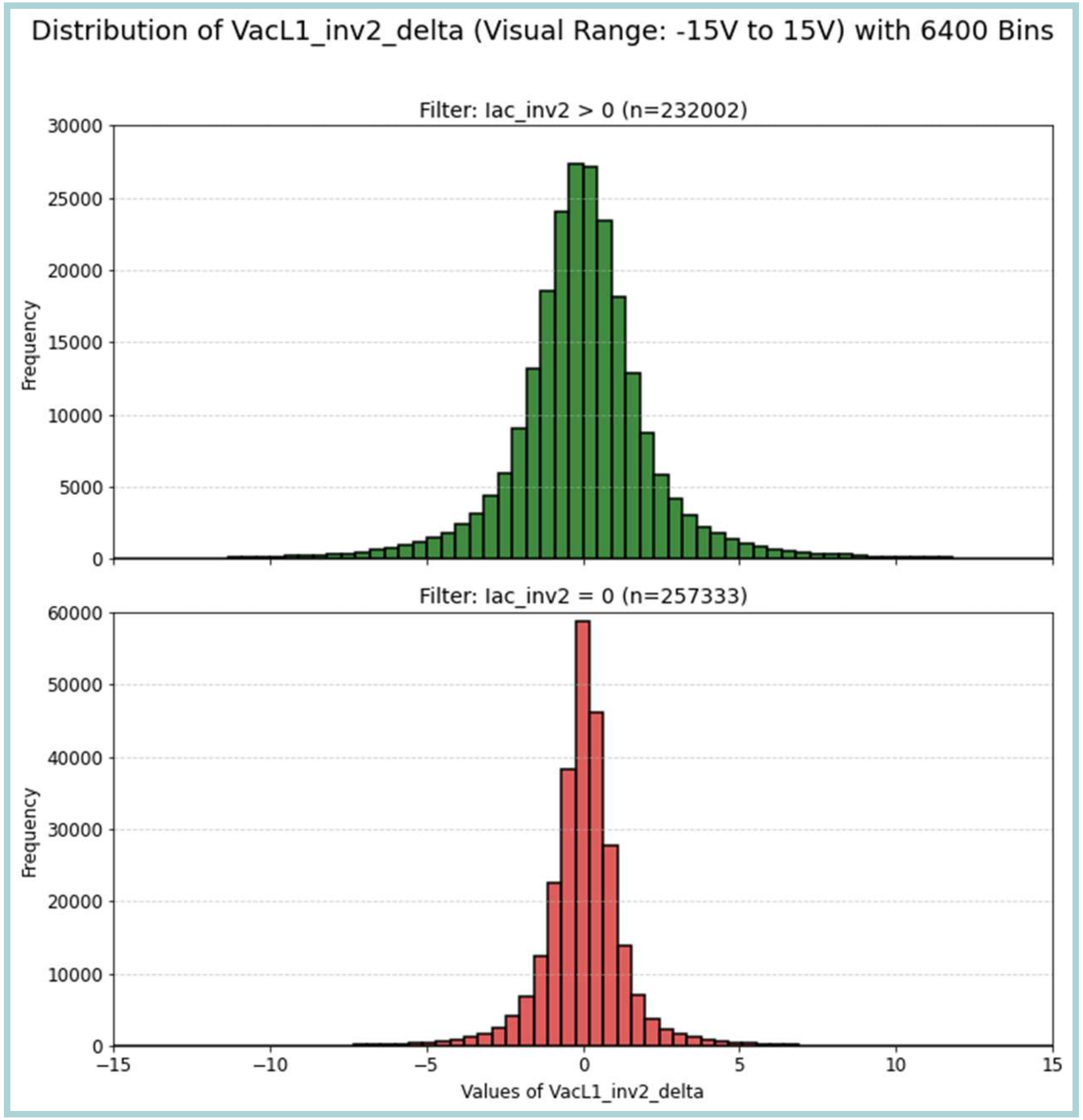

Figure 7. Histogram of the frequency with which voltage variation is observed in one of the phases with and without PV power generation (Bins: intervals).

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Conclusions

1. Data recorded by PV inverters provides valuable insights into the impact of solar production on power quality, particularly regarding grid voltage stability.

2. Although this impact is influenced by the grid's architecture, components, and operational management, a clear correlation exists between increased PV output and rising voltage levels.

Conclusions

3. There is a direct link between voltage variation and PV production variability caused by cloud transients.

4. These findings are essential for strategic grid planning and for determining the hosting capacity limits at specific injection points, ensuring that renewable integration does not compromise voltage regulation standards.

Future work

In future work, inverter-measured data will be benchmarked against a high-precision monitoring system for comparison

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Thank you very much for your attention

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