

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

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**Abstract**—Renewable energy sources are playing an increasingly important role in the move towards decarbonization and the reduction of polluting gases. Specifically, photovoltaic solar energy is the technology whose installed capacity has experienced the greatest growth in recent years, already exceeding 2.2 TW worldwide. This type of clean energy generation has other drawbacks. Its dependence on atmospheric conditions not only affects its availability, but its fluctuating nature, which can change rapidly with the passage of clouds, can affect the stability of the grid and make it difficult to manage. Specifically, this inherent variability influences on grid voltage values, among other factors, potentially leading to fluctuations as a result of changes in photovoltaic output power. This paper presents an analysis of the grid voltage values recorded by an inverter located in a solar park over a period of almost five years with a frequency of 5 minutes. The effect of photovoltaic generation on the increase in voltage values during the middle of the day, when output power is at its highest is clearly observed, as well as an increase in the fluctuations experienced by this parameter at the point where photovoltaic output power is injected into the grid.

**Keywords:** Photovoltaic plants; grid voltage fluctuation; inverters.

### I. INTRODUCTION

The trend towards decarbonization of the current energy system has led to a gradual increase in the use of renewable energy sources. Among these, photovoltaic (PV) energy has established itself as one of the cleanest energy sources with the highest installed capacity and has been the technology with the highest growth rate in recent years. This increase must continue in the coming years in order to meet the polluting emission reduction targets set by various organizations [1] [2] [3] [4].

However, PV energy is inherently variable and intermittent, highly dependent on weather conditions. The output of a PV plant can change dramatically in a few seconds or minutes due to phenomena such as passing cloud, creating variability that the electrical grid must accommodate. Specifically, this uncontrolled fluctuation has a direct and negative impact on power quality, particularly

regarding the voltage levels at the injection points of PV installations. This issue is more critical in weak grids and will become more pronounced as the penetration of this type of renewable generation increases. Such variability poses significant challenges not only for the quality of the electricity signal, but also for grid operation and stability [5], potentially acting as a barrier to the future expansion of renewable energy resources [6]. Consequently, understanding voltage behaviour in the presence of renewable energy production is important for developing and sizing effective mitigation techniques [5]. Although studies that simulate network behaviour provide valuable insights [7] [8], the analysis of real data is also equally indispensable.

In this context, the objective of this study was to analyze the real voltage values measured at the grid injection point by an inverter in a PV plant in operation over a period of several years. Specifically, it investigates how the energy produced by the PV panels influences voltage variations at that specific inverter location.

The remainder of this article is organized as follows: Section II describes the methodology, Section III presents the experimental results, and finally, Section IV summarizes the conclusions of this work.

### II. METHODOLOGY

The analysis conducted in this study utilizes data recorded by an inverter in a PV plant. The inverter is an SMA SMC-100 model. Among other parameters, the inverter records the value of the PV current produced at the inverter output, as well as the voltage values in the three phases at the grid injection point. The inverter provides measurements five minutes intervals. Data is available for almost five years, from November 3, 2020, to July 4, 2025, representing a total of 1,705 days recorded, with 288 data points per day. The raw daily data provided by the inverter has been stored in a database developed in previous work by the authors, designed for the automated management of the entire volume of data recorded at various PV plants [9]. A total of 663 Silicon modules with 165 W are connected to the inverter analyzed, organized into strings of 17 modules in series. This represents a total of 109.395 kW. The inverter

is situated in a solar park with a total power of 4.4 MW, located in a rural municipality in the north of the province of Córdoba, Spain.

### III. RESULTS

As an example of the analyzed dataset, Figure 1 shows the daily voltage profiles for each of the three phases and the current produced at the inverter output during March 2021. It can be observed that during this month 70% of the days were cloudy or experienced intermittent cloud cover, which led to significant fluctuations in PV production. It can be observed how the voltage values rise throughout the morning, with the increase in PV production, subsequently decreasing toward sunset. This trend is consistent across all three phases, reflecting a uniform network response to plant production. While voltage levels fluctuate during the night, these variations become more pronounced during the day due to cloud-induced fluctuations in PV generation.

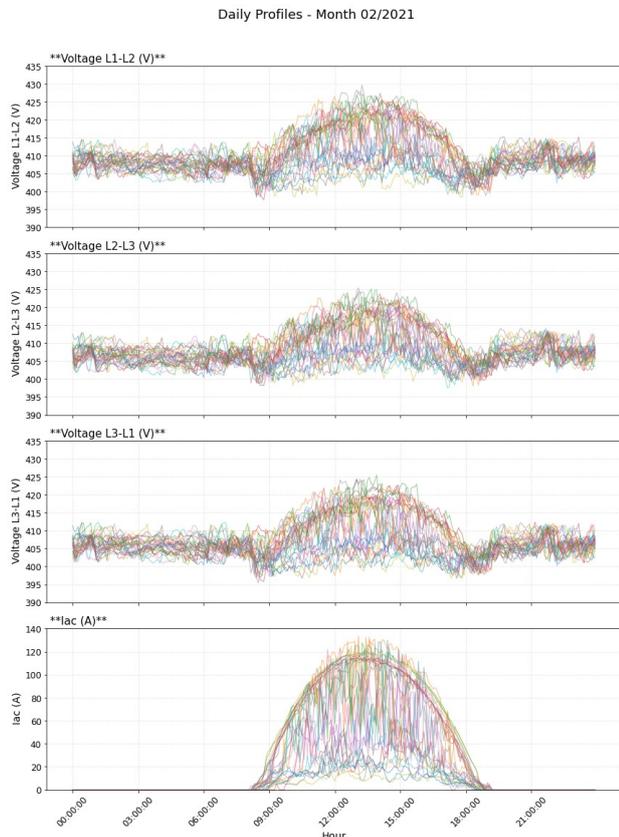


Figure 1. Daily profiles of line voltage in the three phases and the current generated during all days of February 2021.

Figure 2 shows, in this case, the daily voltage and current profiles generated during a summer month, July 2021. In the geographical location where the solar park is located, significantly more frequent during this season.

Figure 3 provides a more detailed example of a fluctuating daily profile for both the current produced and the voltage in one of the phases on a day with unstable

weather conditions and passing clouds, which leads to variations in both production and voltage. Figure 4 provides a detailed view of the daily profiles on a clear-sky day. Once again, a noticeable increase in voltage values can be observed during the peak solar hours, directly related to the period of maximum photovoltaic production.

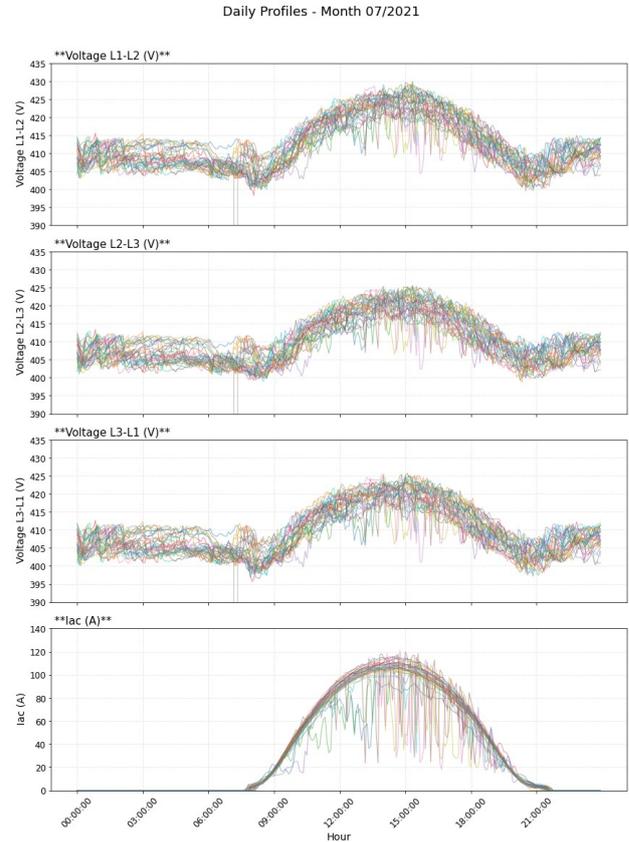


Figure 2. Daily profiles of line voltage in the three phases and the current generated during all days of July 2021.

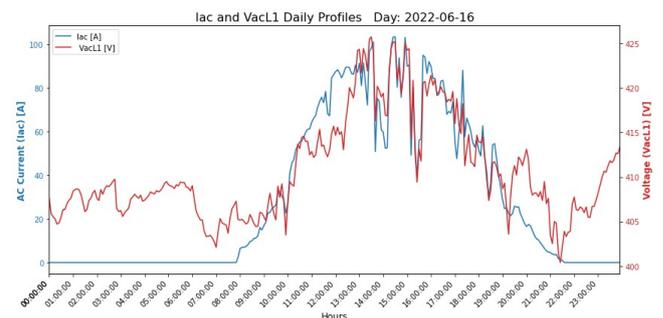


Figure 3. Daily profiles of line voltage in one phase and the current generated during a day of June 2022.

Although clouds are absent and the plant's production follows the solar trajectory, the voltage levels still exhibit fluctuations. These variations are typical of the operational dynamics of the electrical grid where the measurements are recorded and are independent of the photovoltaic plant's power output.

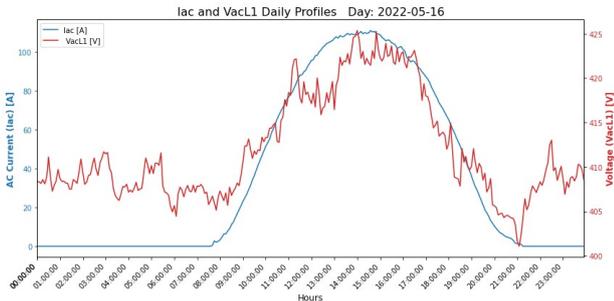


Figure 4. Daily profiles of line voltage in one phase and the current generated during a day of May 2022.

Correlation Voltage and PV current - Month 07/2021

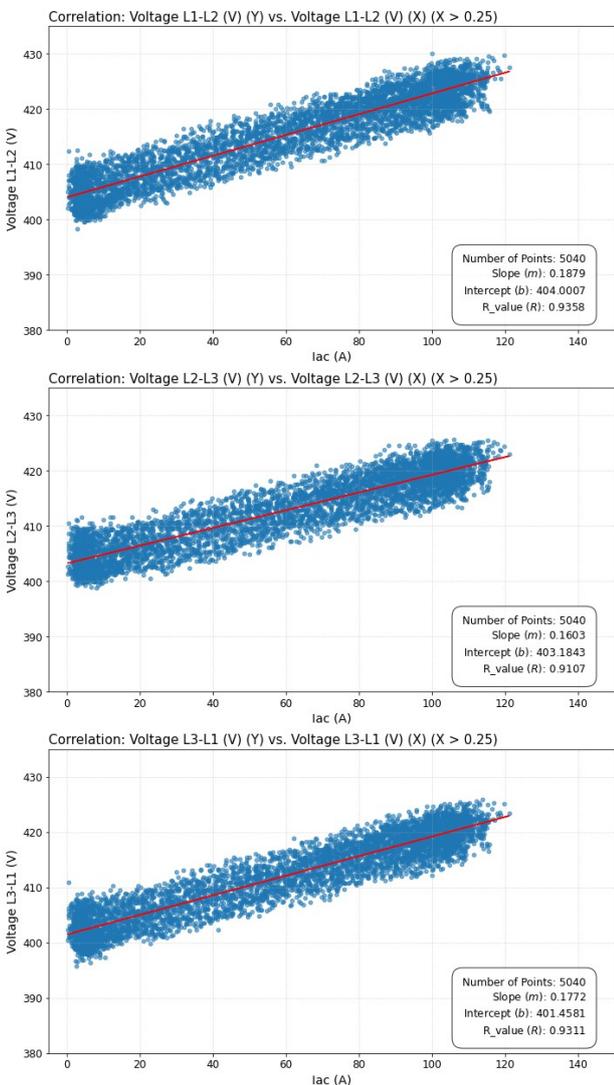


Figure 5. Correlation between the voltage values of the three phases versus the current, when there is PV production, during the month of July 2021.

Figure 5 illustrates the correlation between the current values produced and the corresponding voltage levels during

operating hours in July 2021. A clear linear relationship between these two parameters is evident, indicating that voltage rises with the current injected into the grid.

For each value of the current generated, the voltage may vary by around 10 V, which is a consequence of the operation of the grid and the elements connected to it. Nevertheless, a clear upward trend in voltage is observed as photovoltaic production increases. This trend shows slight differences between phases, which highlights that the sensitivity of the network in PV power output variations will depend on the specific configuration and on the elements connected to each phase [10]. This behavior was consistently observed across all analyzed months.

Although voltage values show an increase, they are not approaching the maximum levels established by standards [11]. However, the calculated slopes suggest that these voltage variations could eventually limit the hosting capacity of the area—restricting the total amount of generation that can be integrated into the local grid [12].

Figure 6 compares the voltage distribution throughout the monitored period, distinguishing between hours with PV production (top green histogram) and hours without generation (bottom red histogram).

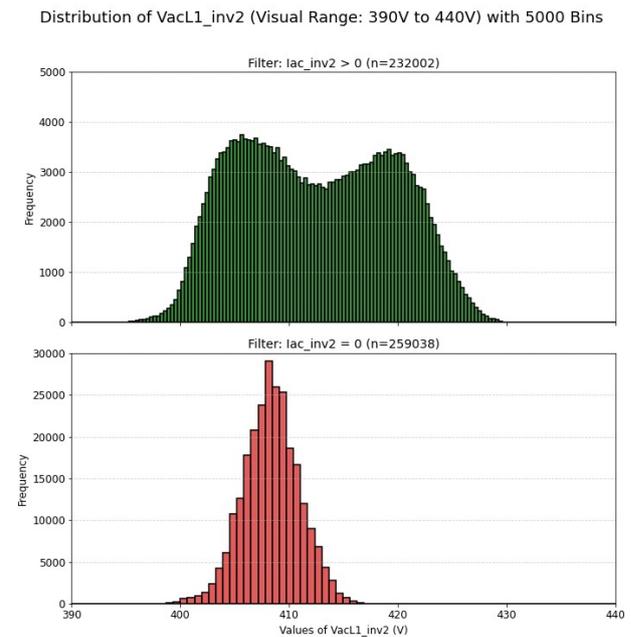


Figure 6. Histogram of the frequency with which voltage values are observed in one of the phases with and without PV power generation (Bins: intervals).

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

grid voltage. However, it should be noted that the inherent variations in grid management and the dynamics of connected loads, typically differ between daylight and nighttime hours.

Distribution of VacL1\_inv2\_delta (Visual Range: -15V to 15V) with 6400 Bins

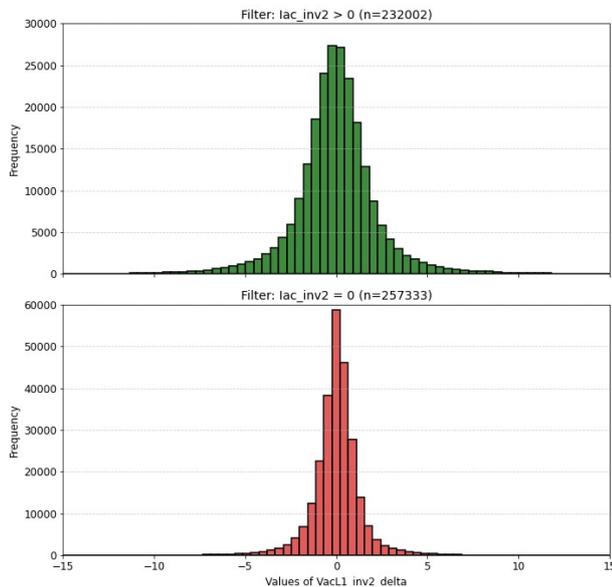


Figure 7. Histogram of the frequency with which voltage variation is observed in one of the phases with and without PV power generation (Bins: intervals).

A comparison of the voltage variations presented in Figure 7 reveals that, 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.

#### IV. CONCLUSIONS

Data recorded by PV inverters provides valuable insights into the impact of solar production on power quality, particularly regarding grid voltage stability. 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. Furthermore, there is a direct link between voltage variation and PV production variability caused by cloud transients. 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.

While data provided by PV inverters typically exhibits lower accuracy and resolution compared to measurements from specialized monitoring systems, it remains a highly valuable resource. However, since this data is usually available at most PV installations, it can be effectively used to analyse grid voltage trends in relation to PV production without the need for additional specialised hardware. Consequently, these inverter data can provide a solid basis

for modelling system behaviour and for developing scalable mechanisms that mitigate the adverse effects of PV output fluctuations, facilitating the integration of renewable energies while maintaining grid stability.

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#### REFERENCES

- [1] European Commission, "European Green Deal." [Online]. Available: [https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en) (last access: 2-12-2025)
- [2] European Council of the European Union, "Fit for 55." [Online]. Available: <https://www.consilium.europa.eu/en/policies/fit-for-55/> (last access: 2-12-2025)
- [3] International Energy Agency (IEA), "Solar PV continues to dominate global renewables growth, though at a slower rate." [Online]. Available: <https://www.iea.org/energy-system/renewables/solar-pv> (last access: 2-12-2025)
- [4] UNEF (Spanish Photovoltaic Association), "Photovoltaic Energy, the Engine of Industrialization, motor de industrialización. Annual Report UNEF 2025," 2025. [Online]. Available: <https://www.unef.es/es/recursos-informes> (last access: 2-12-2025)
- [5] F. H. Malik *et al.*, "A Comprehensive Review on Voltage Stability in Wind-Integrated Power Systems," *Energies*, vol. 17, no. 3, 2024, doi: 10.3390/en17030644.
- [6] M. C. Kocer *et al.*, "Cloud Induced PV Impact on Voltage Profiles for Real Microgrids," in *2018 5th International Symposium on Environment-Friendly Energies and Applications (EFEA)*, 2018, pp. 1–6. doi: 10.1109/EFEA.2018.8617080.
- [7] A. Gawlak and M. Kornatka, "The Impact of Photovoltaic Installations on Changes in Voltage Levels in the Low-Voltage Network," *Energies*, vol. 18, no. 12, 2025, doi: 10.3390/en18123072.
- [8] A. Woyte, V. Van Thong, R. Belmans, and J. Nijs, "Voltage fluctuations on distribution level introduced by photovoltaic systems," *IEEE Trans. Energy Convers.*, 2006, doi: 10.1109/TEC.2005.845454.
- [9] D. Trillo-Montero, S. Cosano-Lucena, M. Gonzalez-Redondo, J. J. Luna-Rodriguez, and I. Santiago, "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," *Appl. Sci.*, vol. 13, no. 3, 2023, doi: 10.3390/app13031357.
- [10] I. Santiago, J. García-Quintero, G. Mengibar-Ariza, D. Trillo-Montero, R. J. Real-Calvo, and M. Gonzalez-Redondo, "Analysis of Some Power Quality Parameters at the Points of Common Coupling of Photovoltaic Plants Based on Data Measured by Inverters," *Appl. Sci.*, vol. 12, no. 3, 2022, doi: 10.3390/app12031138.
- [11] "European Standard EN 50160: 2011. Voltage characteristics of electricity supplied by public electricity networks." 2011. [Online]. Available: <https://en.tienda.aenor.com/norma-din-en-50160-2020-11-327353625>
- [12] L. Freiris and D. Infield, *Renewable Energy in Power Systems*. Wiley, 2008.