Impact of Power Ramp Event on Photovoltaic System Voltage Quality Under Different Weather Conditions and Operating Powers

saliha boulahchiche (boulahchiche21@live.com)
Université
Amor HADJ ARAB
CDER
Salim HADDAD
Université
Azzedine BOUTELHIG
Unité de Recherche Appliquée en Energies Renouvelables, URAER, CDER
Salim BOUCHAKOUR
CDER
Ismail BENDAAS
CDER
Abdelhak REZAGUI
CDER

Research Article

Keywords: PV system, distribution power network, Ramp Events, voltage quality, Pst and Plt flicker indices, VSV.

Posted Date: July 5th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1760767/v1

Abstract

This paper presents an experimental voltage quality analysis affected by passing clouds based on results attained from monitoring a 9.5-kWp photovoltaic grid connected. This system is composed of three 3.2 kWp subsystems installed on the flat roof of the Renewable Energy Development Institute (CDER) in Algeria. In this paper we analyzed and evaluated Short-term and long-term voltage flicker indexes (Pst,Plt), power ramp event on voltage quality, harmonics caused by inverter and by the loads connected to the PCC, and very short voltage variation (VSV). The power quality parameters at the inverter output side have been measured using CA8335 power quality analyzer. The results show that the change in the density of the passing clouds has a linear relationship with the change in the intensity of the ramp event on the power generated by the PVS. Moreover, in the case of a bidirectional electrical network and with the presence of non-linear loads, the flicker recorded has exceeded the legal limits, due the second-order harmonics effects generated by non-linear loads and the level impedances at the grid and the PV system connection point. The concluded results obtained can be an additional profit of for the electricity distribution networks in Algeria, upon in the light of the diffusion of promoting photovoltaic systems.

1 Introduction

According to the (International Energy Agency report (IEA), 2020), during the period from 2023 to 2025, the average annual PV capacity is expected to be increased between 130 GW and 165 GW, aiming for a total rate of 107 GW, which consists 60% of the total predictable renewable energy capacity [1]. The IEA report also predict that the cost of large-scale production of PV systems will be reduced by 36% over the next five years, with the aim of installing the cheapest PV systems, in almost all countries [1].

Nowadays, increasing attention has been paid on PV systems that have evolved with the opening up of electricity production to competition and therefore the possibility for consumers to choose their supplier. In this context, Electricity Company's competitiveness is linked to the rate and cost of the energy that can be provided. Nevertheless, any poor electrical power performance may affect a mal system function which generally led to unexpected standby. In addition, the fluctuation in the yearly cost can therefore be a significant impact on the energy production loss, and main cause in components' reset. Moreover, the electronic equipment such as computers, battery chargers, electronic ballasts, variable-frequency drives, and switched-mode power supplies generate perilous harmonics may cause enormous economic loss, annually. Accordingly, both power suppliers and consumers are concerned about these technical. In fact, the electronic equipment's could be affected by power quality problems that are not detectable with voltage/ generators disturbances. The main disturbances likely to impair the proper functioning of equipment and industrial processes are voltage dips, voltage fluctuations, harmonics, inter-harmonics, or flicker, overvoltage, temporary overvoltage, as well as transient overvoltage [2, 3].

Regarding the growth of electronic inverters-based PV systems, the distribution network tested through two-way energy flow can create a new set of power quality challenges such as voltage quality and harmonics in the systems PV connected to the distribution network with the presence of loads at the common connection point (PCC) [4,5–8,9,10]. The photovoltaic systems efficiency is related to the fluctuation of solar radiation, caused by the weather conditions variation which includes, the passing-clouds through the various seasons, the characteristics of the PV erection sites and the PV array erection types (fixed or tracked). The intermittent nature of PV generation is the main source of power quality issues. The main power quality problems associated with rapid power fluctuations are voltage fluctuations or flickering of light, induced by voltage fluctuations less than 10% [5–8,11–14,15–17]. It depends on the weather conditions, the season and the location of the PV system in the grid, which also depends on the size of the PV generator, the output power fluctuations [18, 16]. Rapid changes in solar radiation due to transient clouds can cause large and frequent fluctuations in PV output power, which in turn could cause voltage fluctuations in the PV system integration node. The assessment of short- and long-term flicker has been presented in the literature [5]. [7], based on the relative grid voltage, time of day and date of the year. Hanaa Karawia et al. [15] studied the relationship between PVs of different capacities, different types of 'inverters (single-phase and three-phase) and flicker in the distribution network at the common coupling point. global irradiation gradients and clear sky index in an area. Additional constraint on electrical equipment and the malfunction of sensitive network equipment are presented in Ref. [19]. An appropriate rationale for how the second harmonic can cause an immediate impact and directly increase the severity of the voltage flicker has been discussed in [20, 21].

Considering the large number of passing clouds through- above a site, the incident solar radiation is therefore much dispersed and fluctuating that results the output power of the PV systems very intermittent. The cloud cover affects the performance of solar panels by reducing their lower power production. The partial cloudy sky has a minimum impact on the PV array energy production which can drop by medium average rate between 10–25% [8, 16] The very intermittent power output of PV systems causes sudden and frequent fluctuations in voltage at the PCC, thus generating a large number of voltage fluctuations and flickers to low voltage distribution networks.

This problem has been analyzed through the current attempt, following a deep analysis of voltage quality of a PV system connected to low distribution grid, erected at our research center CDER, Algiers, taking into account different PV production penetrations by inserting non-linear loads at the PCC. Moreover, the contribution of the flicker level associated with solar PV production on the energy quality at the PCC were studied Furthermore, high power ramp rate analyzes were performed. The correlation between the flicker level and the grid voltage and meteorological parameters were studied. The interaction between the grid and the PV system was also presented. The measurement data done with the flicker indices for the observation period were recorded and analyzed. Accordingly, the field measurements of the power quality of the PV system were carried out, for various operating conditions. Hence, the method used to calculate the flicker indices is different from the common method defined in IEC 61000-4 -15 Standard, was then assessed and deemed appropriate during the study.

This paper is organized as follows. Section **1.** presents the introduction. Section 2. Locationcharacteristics, material and methodology. Section 3. Passing-clouds effects on different PV system connected network. **4**. Result and discussions. The findings are presented in section 5.

2 Location Characteristics, Material And Methodology

2.1 *Location Characteristics*

Algeria is one of the sunniest regions in the world. Indeed, following the satellite assessment, the German Aerospace Center (DLR) concluded that Algeria has the greatest solar potential in the Mediterranean basin: 169,440 TWh / year [22, 1, 23, 24, 25]. The average duration of sunshine over almost the entire national territory exceeds 2000 hours per year, and an annual average daily sunshine of between 5 and 6 kWh / m2 / day, received on a horizontal surface, The daily energy obtained on a surface horizontal of 1m2 is around 5 kWh over most of the national territory, i.e. around 1,700 kWh / m2 / year for the North and 2,650 kWh / m2 / year for the South of the country, as it is illustrated in Table1. Adding to the huge “albian” underground water reservoir, in the southern part, the area is characterized by cold weather, in winter, and an extreme heat, in summer when, around 10.7 ° C, is the minimum average temperature level recorded in January (the coldest month), and around 34 ° C as the high average level temperature, recorded in July (hottest month). [22].The Algerian government has launched a national program to install various stations of renewable source supply with a total capacity of 22 GW by 2030. This program aims to reduce around 193 million tonnes of CO_2 emissions [23, 26]. Figure 1. (a) illustrates the map of global solar irradiation at optimum tilt, showing that more than 3.58 kWh / m2 / day can be affected in northern regions. Figure 1. illustrates the Algerian maps; (a) global solar irradiation at optimal inclination, (b) the cloud cover. The cloud covering the Northeast region produces less than 0.41 kWh / m^2 / day. Compared to clear weather a significant loss of 3.17 kWh / m2 / day.

The grid-connected PV system considered in this study is installed on the roof of the Renewable Energy Center (CDER) in Bouzareaha, Algeria. The research center building is located at (L36.80 N, LE of 3.03E and Al.347 m), installed in 2004. The system's location near the sea has given it characteristics of the Mediterranean climate that affect the performance of the system, where the solar radiation number reaches about 12 hours per day. The average temperatures are on the whole moderate due to the temperature of the Mediterranean Sea. This location is also characterized by high humidity, which reaches 90% in winter and 80% in summer. There are also frequent passages of cloudy systems in winter and clear sky situations in summer with stormy systems in the off-season periods, namely winter-spring and summer-autumn. The wind is generally calm except in the winter period when average values of around 30 km/hour can be recorded in situations where meteorological disturbances come from the North [27].

Table 1
Solar potential Algeria[23]

Regions	**Coastal Region**	**High Plains**	**Sahara**	**Total**
Surface (%)	4	10	86	100
Area (km^2)	95270	238174	2048 297	2 381 741
Mean daily sunshine duration(h)	7.26	8.22	9.59	-
Average Sunshine duration(h/year)	2650	3000	3500	-
Received average energy (kWh/m^2/year)	1700	1900	2650	-
Solar daily energy density (kWh/m^2)	4.66	5.21	7.26	-
Potential daily energy (TWh)	443.96	1240.89	14 870.63	16 555.48

2.2 Description of the Experimental System

The Fig. 2. shows the different parts of the PV system connected to the low voltage distribution grid and composed of 90 PV modules with a total installed capacity of 9.45 kW;of Isofoton type with a nominal value (Peak power: 106 Wp and a nominal voltage: 12 V. The PV system splits into three sub-systems of 30 PV modules, each. The three identical fields are connected to the three-phase through three single-phase transformers less inverters of the SMA Sunny Boy 3000TLST-21 type with a nominal power of 3 kW. The collected data in the PV plant is recorded at five minutes time step and saved on a daily basis in SMA Sunny WebBox data logger. The metrological data is collected through the Sunny Sensor Box installed on the PV module which houses various instruments to measure climatic data (wind speed, irradiance, ambient and panel temperatures). Our plant is equipped with a protection system at two locations. The first is DC protection located between the PV array and the inverter, and the second is AC protection found between the inverter and grid injection phases for the safety of personnel and easy manipulation of the system [27]

Table 2
PV Module Specifications

Symbol	Parameter	Value	Units
T	Cell temperature	47	°C
V	Nominal voltage	12	V
P_{max}	maximum power	106 ± 5%	Wp
I_{sc}.ref	Short-circuit current	6,54	A
V_{oc}.ref	Short-circuit voltage	21,6	V
I_{mpp}.ref	MPP current	6,1	A
V_{mpp}.ref	MPP voltage	17,4	V

Table 3
Inverter Specifications (at Rate Conditions)

	Symbol	Parameter	Value	Units
Input	P_{DC}	Nominal Power	3200	W
	I_{DC}	The max input current	15	A
	V_{DC}	Input Voltage max	750	V
	V_{DC}	Input Voltage Min	125	V
Output	P_{AC}	The nominal power	3000	W
	CosØ	Factor of nominal power	1	
	f	The frequency	50	Hz
	V	Rated mains voltage	230	V
	[illegible]	Efficiency	96	%

2.3 Method of Measurements

The measurements were taken at the research laboratory (grid connected PV system). The test bench consists of a Chauvin Arnoux C.A8335 power analyzer and a computer to acquire all the data. Electrical parameters such as voltage, active power, short-term flicker (Pst), long-term flicker (Plt), harmonic distortion rate THD of current and voltage were measured at the outputs of the three inverters of the PV system and at the PCC in the presence of nonlinear loads with a resolution of 1munite. Solar radiation is collected through the Sunny Sensor Box installed on the PV module every 5 min. Measurements in real conditions were carried out over several periods from April 23 to 29, 2021, March 11, 2021, April 5, 2021, and April 6, 2021.

2.3.1 Chauvin Arnoux C.A8335

The Chauvin Arnoux C.A8335 network analyzer consists of nine input channels (voltage and current), four MN 93 current sensors (200 A) and five voltage sensors up to 1000 V, the data transfer carried out by the Power Analyzer software. Transfer (PAT2). The device complies with IEC 61010-1 standards. Harmonic calculations are performed by FFT (16 bits), 1024 points over four cycles.

2.3.2 IEC 61000-4-15 Standard

Generally,flickermeters must be tested with different types of voltage according to the 61000-4-15 IEC standard [28–34]. The International Electrotechnical Commission (IEC) has developed a set of standards which systematically account for many difficulties of the "flicker curve" methods [28]

Several authors have proposed to use the CEI flickermeter as a universal flicker quantification method [29, 34]. The IEC 61000-4-15 standard is becoming the most widely used method for measuring flicker.The architecture of the flickermeter can be divided into two parts, each part performing one of two tasks; simulations of the brain lamp-eye chain response and on-line statistical analysis of the flicker signal and presentation of the results. A Digital Implementation of the 61000-4-15 Flickermeter describes the structure and operation according to the standard whose flickermeter consists of five blocks [29–34].

The voltage flickers were measured by the power grid analyzer according to the IEC 61000-4-15 standard which defines the severity of the voltage fluctuation by two indices, namely the short-term flicker severity index (Pst), and the long-term flicker severity index (Plt) **[**29,34**].** According to IEC 61000-4-15 standard, the Psts are the values measured for ten minutes. Flicker severity indices are statistically calculated from this data in the fifth block of the flicker-meter. The flicker index at Pst is given by the formula (1) **[12, 35]**:

$$P_{st} = \sqrt{aP_{0.1} + bP_{1s} + cP_{3s} + dP_{10s} + eP_{50s}}$$

1

Where

a = 0.0314, b = 0.0525, c = 0.0657, d = 0.28, e = 0.08

$$P_{3s} = \frac{P_{2.2} + P_3 + P_4}{3}$$

$$P_{10s} = \frac{P_6 + P_8 + P_{10} + P_{13} + P_{17}}{3}$$

$$P_{50s} = \frac{P_{30} + P_{50} + P_{80}}{3}$$

While; $P_{0.1}$, P_{1s}, P_{3s}, P_{10s}, and P_{50s} are the instantaneous values of Pst for 10 minutes respectively for 0.1, 1, 3, 10, and 50% of time.

The Plt is a moving average of the Pst values over a two hour period according to the following formula (2):

$$\text{Plt} = \sqrt[3]{\frac{\sum_{i=1}^{12} P_{st,i}^3}{12}} \quad (2)$$

Table 4. gives the values of Pst and Plts according to the IEC 61000-4-15 standard

Table 4
Pst and Plts According to the IEC 61000-4-15 Standard .

Voltage level	Absolute severity of Pst	Absolute severity of Plt
LV System	1	0.8
11kV to 33kV	0.9	0.7
> 33kV	0.8	0.6

3 Passing-clouds Effects On Different Pv System Connected Network

3.1 Impact the Second Harmonic Order on the Flicker Level

The second harmonic order causes waveform distortions characterized by asymmetries between the positive and negative half cycles. Some single phase converter topologies, when supplied with asymmetrically distorted voltage waveforms [36, 37, 20, and 21]. A very strict limit for controlling the second harmonic order is set by international power quality standards [37], the second harmonic order greater than 3% may occur due to possible faults in some of devices and operations of electrical electronic that may cause a slight of different voltage drops on their internal impedances [37].

3.2 PV Power Ramp Event

A ramp event occurs when the magnitude of the increase or decrease in the power signal in the interval Δt is greater than a predefined threshold value. Many researchers should hold a definition for ramp events by the following variables: ramp start time, ramp time, ramp rate, ramp swing, and ramp end time.

According to the ref. [38, 40], a ramp event occurs when the difference between the maximum and minimum output power measured in an interval Δt is greater than a threshold value. As well as Abrupt power change is usually calculated by the percentage of installed capacity.

Equations (3) and (4) give the models used to calculate the lengths of the ramps [38]. The ramps can generally be divided into two basic types: ascending ramp and descending ramp. In meanwhile the ramp event of solar radiation can be calculated.

$$(P(t+\Delta t)-P(t))>P_{val}$$

3

$$(maxP(t+\Delta t)-minP(t+\Delta t))>P_{val}$$

4

Figure 3. illustrates the variations of solar radiation incident on the PV system connected to the CDER building network, during the year 2021, it can be observed that the high lengths ramps event are highlighted during the period from January until December.

at maximum value with the presence of clouds in relation to the summer where large incident radiation and high temperature too. This, in turn, affects the amount of power produced and low presence of clouds. the maximum event ramp lengths reaching 1000 W / m^2 in March and more than 800 in April and May, while in summer the event ramp lengths of low radiation which does not exceed 400 W / m^2 due to low presence of clouds. in Autumn and winter the lengths of the ramps remain between (600 and 800) W / m^2 because the amount of incident radiation is medium although the passage of clouds is dense in these seasons.

The study of the timing and extent of the effect of changing the effects of solar radiation on the quality of electrical energy in grid-connected photovoltaic network, requires deep investigation of its fluctuations through the year. Figure 4. shows the probabilities of the solar radiation ramp events by months of the seasons in the year 2021. It can be seen that the solar radiation ramp events can be occurred during all the months of the year. Within distinction in depths according to months and seasons, the shading, and the clouds number of that pass during each month. These changes are minor in summer, while, their depth reaches between (400 and 500) W / m^2 with the effect of shading. These ramp events increase in winter and fall between (600 and 700) W / m^2, due to the presence of clouds during these months, while they reach their highest level in February and March, and this is due to the increase in solar radiation number and clouds passing together, where it reaches 800 W / m^2.

3.3 Very Short Voltage Variation (VSV*)*

The IEC-61000-4-15 standard for power quality measurements defines two aggregated time intervals for changes in RMS voltage: very short duration for 3 seconds intervals and short duration for 10 min interval [19, 39]. The 10-minute values are used to quantify the performance of the system, where, the 3s values used to quantify the effects of sensitive equipment such as short-term voltage fluctuations(U_{sh}) calculated as follows [39] : $U_{sh}(t_k)$ = $\sqrt{\frac{1}{N}\sum_{i=k-N+1}^{k} U_{us}^2\left(t_i\right)}$ (5)

Where:

N: Number of 3 s values in the 10 min interval.

t_k: Sample time corresponding to the end of a 10 min clock interval

In order to analyze the impact of power fluctuation on the characteristics of the loads at the PCC, we used the techniques of voltage variations($\Delta \mathrm{U}_{\mathrm{sh}}$) at 10 min intervals [39]. $\Delta \mathrm{U}_{\mathrm{sh}}$defines the difference between values of 3s and values of 10 min on the one hand, and the very short variations $\Delta \mathrm{U}_{\mathrm{us}}$of 3s on the other hand is defined as the difference between the rms voltage of 3 s and the rms value of the values 3 s in the previous 10 min.

$\Delta U_{us}(t_k)$ = $U_{us}\left(t_k\right) - U_{sh}(t_k)$ (6)

$\Delta U_{sh}(t_k)$ = $\sqrt{\frac{1}{N}\sum_{i=k-N+1}^{k} \Delta U_{us}^2\left(t_i\right)}$ *(7)*

$\Delta U_{us}\left(t_k\right)$: Voltage variation for 10 min

$\Delta U_{sh}(t_k)$: very short voltage variation during 3s

4 Result And Discussions

Aims to study the effect of fluctuations caused by clouds on the voltage quality with the possible reasons of the PV system connected to the low voltage distribution grid in Algiers.

Figure 5. shows the daily voltage on the three phases of the PV system. These days were chosen because most of the out-of-range voltages occurred during this period (effect of radiation and clouds), and the

different scenarios of the loads at PCC on each phase versus the days of operation of the 23, 24, 25 26, and 29 April 2021 (working days in the laboratory), and the days without use of loads corresponding to the weekend on April 27 and 28, 2021.

A comparison between the daily voltage profiles of the three single-phase phases during the seven days of testing shows that the voltage decreases during the hours of PV production and peak load usage at the PCC between 8:00 am and 5:00 pm, where, the voltage varies between the three phases according to the loads connected. The maximum voltage variation is seen during the five working days, from Sunday to Thursday, compared to the two weekend days.

Figure 6. to Fig. 8. illustrate the active power produced by the PV system, the Pst and the Plt flicker indices of the three PV systems, respectively.

A significant correlation was shown between the active power and the flicker indices. However, a slight effect of PV systems on the flicker level during the hours of PV production with fluctuations in power produced by the PV system is observed, due to the absence of the clouds during those days. However, the low impedances and loads connected at the PCC make the Pst and the Plt flickers very significant. The values are initialized from different initial values that dependent on the connection impedance of each phase, loads connected at PCCs, and the THD of the network at PCC.

Figure 6. is showing the variations of the Pst and the Plt for the first PV subsystem, with respect to the power produced vary between 0.5 and 2 in the most of the time, due to the load fluctuation. In addition, a slight effect of the fluctuating power due to the clouds passing over the system compared to the very high Pst level observed in the duration of the PV production. The Plt level during the entire measurement period is greater than one, and a slight effect of the PV production on the Plt level is observed.

Figure 7. is showing the Pst level of the second PV subsystem varies between 0.4 and 1.6, where these values started at an initial value of 0.4, that represents the Pst of the network, which depends on the connection impedance of this phase and the load connected at the PCC. The effect of PV production is well observed; where the Pst level follows the active power variation. The same effect is observed for the Plt, whose range of variation is 0.4 to 1.2 at low cost.

For the third PV subsystem (Fig. 8.), the level of the initial Pst is low compared to the other PV subsystems from which it starts at an initial value of 0.2, and the same for the calculated Plt from which it increases by a value of 0.2 up to 1.

4.1 Impact of PV System Penetration on Pst and Plt flicker indices

A case study is performed to investigate the severity of the flicker caused by varying PV penetration levels of the three PV systems when the power grid is used as a power source. This study is carried out for two selected days. In order to reveal the penetration effect of PV production in the three subsystems, the first day is a reference day of April 27, 2021, which represents a weekend, is considered as a reference day where, the effect network and loads at the PCC can be neglected. The second day of April 24, 2021, is selected to reveal the the Pst and Plt flicker indices variations caused by the PV system with the presence of the loads connected to the PCC.

Figure 9. illustrates interaction impact between the network and the power penetration of the PV system on the Pst and Plt indices of the first subsystem. As can be seen that for the reference day when the PV system is not connected to the grid (0% of the production capacity), the flicker indices Pst and Plt are respectively 1.28 and 1.05. These values represent the flicker indices of the loads connected to the PCC which exceed the normalized values (see table). The variations of these indices at PCC may depend on the impedance connection between the PV system and the grid, in addition to the loads connected and the problems of harmonics on this phase. When the PV production penetration increases from 25%, 50% and from the maximum capacity the Pst vary respectively 1.28, 1.3,1.3, and the Plt vary respectively (1.05,1.07,1.13,1.15). During the second day the flicker at the PCC is combined with the flickers introduced by the power fluctuations and solar radiation. It is also observed that the Pst indices become almost the same values as on the reference day, due to the very high indices levels of the indices produced by the loads and the grid at the PCC for all the PV power levels where the Pst varies respectively (1.28, 1.3,1.3,1.98), and the Plt vary respectively (1.05,1.16,1.26,1.54)

Figure 10. illustrates the indices Pst and Plt of the second PV subsystem. When the PV subsystem is not connected to the grid during the two days, the Pst and Plt are respectively 0.5 and 0.44. For the reference day, the results show a significant increase in Pst and Plt on the second phase, when the PV capacity gradually increases from 25% to the maximum production capacity. Pst increases from 0.55 to 0.58 for 50% of the capacity, and from 0.78 for the maximum capacity. Plt increases from 0.49 to 0.51 for 50% of production, and 0.7 for maximum capacity. For the second day we can observe a slight effect of the power fluctuations in the indices levels or these indices increase compared to the penetration level of the PV system, and the activities of this phase, otherwise the values of the flicker indices in short and long term are respectively (0,5,0.92, 1.18,1.18) and (0.44,0.82,0.94,0.92).

For the third PV subsystem, the effect of fluctuations appears when the effect of the dominance of the loads and the grid are weak; Fig. 11. shows that the Pst and the Plt are respectively 0.3 and 0.29 when the PV system is not connected to the grid for the two days. A significant increase in Pst and Plt on the third phase, when the PV capacity gradually increases from 25% to the maximum production capacity. Pst goes from 0.36 to 0.37 for 50% of the capacity, and from 0.55 for the maximum capacity. Plt increases from 0.35 to 0.36 for 50% of production, and 0.52 for maximum capacity. For the second day we can observe that the power fluctuations effect on the indices levels, these indices increase compared to the level of penetration of the PV system, and the activities on this phase. The values of the short and long flicker indices term are respectively (0.3,0.36, 0.46,1.34) and (0.29,0.33,0.36,0.81). In this phase, the effect of loads and the network are weak but the effect of power fluctuations is also weak and has no significant impact on the flicker indices.

4.2 Impact of Second Order Current Harmonic Rate

Harmonic currents are due to the presence of non-linear electrical loads at the PCC. The circulation current is greater than the arm current of the non-linear loads static converters is dominated by the second order harmonic. the second harmonic current causes fluctuations voltage on the load capacitor at the connection point between the load, the PV system, and the grid. These fluctuations depend on the number of non-linear loads connected and the impedance of each phase, otherwise these voltage fluctuations affects the level of flickers at the integration point. Figure 12. shows the variation of the second order harmonics on each phase in the test period where the harmonics effect appears in three phases with different values except the photovoltaic production period resulting from the loads connected in each phase

4.3 Impact variations in radiation on waveform and voltage quality

In order to assess the relationship between the flicker indices and the current waveform which directly depends on the solar radiations, the analysis is carried out on three typical weather conditions: an overcast day (April 24, 2021), a cloudy day (April 26, 2021) and a sunny day (April 28, 2021). Figure 13, Fig. 14, Fig. 15, and Fig. 16 show the current, voltage fluctuations, and flicker indices during the three weather scenarios. According to the results there is some correlation between the weather conditions. flicker level, and voltage waveform

According to Fig. 13, the variations in voltage observed mainly depend on solar radiation and the current produced by the photovoltaic system, Fig. 14 and Fig. 15 show the short-term and long-term flicker propagation during a cloudy day, a rainy day, and a sunny day, respectively. The flicker emission during the cloudy day is higher than the emission. Offlickerin during a sunny day and a day with overcast sky

4.4 Impact of the Power Ramp Rate On The Voltage Variations

Figure 17. is showing the voltage ramp is linked to changes in radiation and the cloud passage, otherwise the quality of the energevent versus the power ramp event for the three PV subsystems at the PCC. To find out the impact of the power ramp according to the solar radiation ramp event on the voltage quality, we applied the two models (3) and (4) by a resolution with an accuracy of 5 min. In contrast, the results showed that voltage fluctuations in the three subsystems are produced at the output of the inverters.The results confirm that the two models give different results, furthermore the second model shows the clouds effect as the first takes into account the effect of connected loads which are related to the number and load type, voltage variations do not exceed 4% according to model (03) for the three PV subsystems, in contrast and according to the second model (04) the voltage variations 10% for the first subsystem, 9% for the second sub -system, and 7% for the third.

4.5 Impact the location of the PV system

The powers at the output of the PV system, at the PCC and the powers of the loads for a period on March 11, 2020 are shown in Fig. 18. When many fluctuations in radiation were observed. To show the relationship between the power fluctuation caused by the fluctuations in solar radiation at the output of PV inverters and at PCC at the level of THDi and THDv. Table 5shows the total THDi and THDv for different power ramps on the three locations (inverter, PCC, load). According to the results, the THDi is very sensitive to changes in the power ramp and varies depending on the location of the integration of the PV system in the grid and with respect to the load types connected to the PCC. The THDi has an almost inverse relationship with the actual inverter output power, which in turn affects the level of THDi at the PCC. On the other hand, the total voltage THDv is not sensitive by changes in solar radiation but it is sensitive to the loads type connected.

Table 5 Total THD_i and THDv for different PV capacity production

Case	P_{PV}	P_{PCC}	P_{Load}	$PV_{Penetration}$	THD_i			THD_v		
	W			%	PV	PCC	Load	PV	PCC	load
					% f	% f	% f	%f	% f	% f
01	2623	2309	336.3	87.43	5.3	11.2	37.9	6.4	6.4	6.4
02	1884	1566	334.9	62.8	9	30.3	37.6	6.4	6.4	6.4
03	307.6	-32.1	334.4	10.25	24	95.6	39.3	6.5	6.5	6.5
04	292.7	-50.4	334.9	9.75	24.9	95.7	41.4	6.5	6.6	6.5
05	425.4	92.7	335.7	14.18	20	92	43.2	6.6	6.6	6.6
06	696.3	367.8	336.6	23.21	15.3	67.7	43.3	6.6	6.6	6.6
07	2263	1947	336.8	75.43	6.4	16.7	41.3	6.5	6.5	6.5
08	2698	2385	336	89.93	5.2	11.1	38.8	6.4	6.4	6.4
09	2189	1871	336.7	72.96	7.2	21.7	40.8	6.5	6.5	6.5
10	2399	2083	337.7	79.96	5.7	13.5	42.6	6.5	6.5	6.5
11	2462	2146	337.6	82.06	5.5	12.8	42.6	6.4	6.4	6.4
12	2450	2135	337.2	81.66	5.5	12.7	42.2	6.4	6.4	6.4
13	2472	2159	336.8	82.4	5.4	12.4	41.9	6.4	6.4	6.4

4.7 Impact of fluctuations on rapid variations in very short voltage

Strong correlation has been observed between the power fluctuations, caused by clouds and the values of Pst and VSV. In order to illustrate the impact of these fluctuations on electronic equipment and on the malfunctions of sensitive network equipment, a cloudy day of April 5, 2021 and sunny day of April 6, 2021 s chosen. Figure 19.is showing the power at the output of a PV inverter. According to Fig. 20, Fig. 21,

Fig. 22, Fig. 23, Fig. 24, and Fig. 25 ,the relatively slow current changes caused by passing clouds on a partially cloudy day have a weak effect on the flicker induces, but have a distinct effect on the VSV value. During the sunny day, the only relevant VSV peaks are related to the gradual changes in voltage levels at the PCC caused either by abrupt changes in load or by the type and number of loads at the common connection point.

5 Conclusion

This paper presented a detailed analysis of the relationship between changes in solar irradiance and voltage quality at PCC. The energy quality analysis was carried out on three single-phase photovoltaic sub-systems of the first photovoltaic system connected to the CDER network, through a specific high-resolution electrical energy quality analyzer (seconds and up) according to IEC 61000-3-15 standard. The obtained results concluded that, the power changes due to the clouds passing over the PV system produce the short-term flicker (Pst) and the long term flicker (Plt) that exceed the legal limits and are increased with the PV production penetration, the length of the power ramp, the location of the PV system. The impedance of the network between the PV system and the second order harmonic network, for the production hours with the presence of non-linear loads. Cloud-induced PV power changes only had no significant effect on the flicker except with the presence of non-leniary loads connected to the PCC. Although these variations have a very important effect on the little voltage level which affects the lifespan and fault of sensitive electronic equipment and the protection system.

As perspectives, we will continue the different smoothing technique studies in the way to contribute in adapting the PV grid-connected systems.

Declarations

Author Contributions Statement

Saliha. Boulahchiche : Conceptualization, Methology, Software, Data curation, Visualization.

Amar. Hadj. Arab : Supervision, Investigation, Project administration,

Salim Haddad : Supervision, Investigation

Azzeddine Boutelhig: Supervision, Investigation,

Salim. Bouchakour : Investigation, Supervision.

Ismail. Bendaas: Visualization, Software.

Abdelhak. Razagui : Software.

References

1. International Energy Agency (IEA), Renewable energy 2020 - Analysis and forecast to 2025, pp. 29–38
2. Vladimir N. Tulsky, Artem S. Vanin, Mohamed A. Tolba, Sharova, A.Y., Zaki,A.A Diab,"Study and Analysis of Power Quality for an Electric Power Distribution System –Case Study : 'Moscow Region ," IEEE NW Russia Young Researchers in Electrical and Electroni,2016,DOI:10.1109/EIConRusNW.2016.7448281
3. Patrick Espel,"Power quality analysis:mesurment of flicker,"rnational metrology and testing laboratory (LNE), 2009.
4. Chidurala, A,. Kumar Saha, T,. Mithulananthan,N, "Harmonic impact of high penetration photovoltaic system on unbalanced distribution networks – learning from an urban photovoltaic network," IET Renewable Power Generation, 2015, pp. 1–10. https://doi.org/10.1016/j.ijepes.2019.105780
5. Shenglong Yu and all, "A DSE-Based Power System Frequency Restoration Strategy for PV-Integrated Power Systems Considering Solar Irradiance Variation," IEEE, 2017. **DOI**: **10.1109/TII.2017.2694865**
6. Shivashankar, S., Mekhilef, S., Mokhlis,n, H,. M. Karimic, M, "Mitigating methods of power fluctuation of photovoltaic (PV) sources–A review," Renewable and Sustainable Energy Reviews,2016, p1170–1184. https://doi.org/10.1016/j.rser.2016.01.059
7. Spring,A.,Wirthgerd,G., Pardatscher,B., Witzmann,R., Brantl,J., Schmidt.S,,"Effects of Flicker in a Distribution Grid with high PV Penetration,"28th European Photovoltaic Solar Energy Conference and Exhibition (28th EU PVSEC),2013. https://mediatum.ub.tum.de/doc/1191470/1191470.pdf
8. Cheiw Yaun Lau et al,"A review on the impacts of passing-clouds on distribution Network connected with solar photovoltaic system," International review of electrical engineering. IREE Vol.10, N 03, June 2015, ISN 4827–6660. DOI: 10.15866/iree.v10i3.5817
9. Arash Anzalchi, Aditya Sundararajan, Amir Moghadasi, and Arif Sarwat,"High-Penetration Grid-Tied Photovoltaics: Analysis of Power Quality and Feeder Voltage Profile," IEEE Industry Applications Magazine,2019, pp. 83–94. **DOI**: **10.1109/MIAS**.2019.**2923104**
10. Arangarajan Vinayagam and all,"Harmonics assessment and mitigation in a photovoltaic integrated network," Sustainable Energy, Grids and Networks, 2019. https://doi.org/10.1016/j.segan.2019.100264.
11. Faranadia A. H., A. M. Omar, S. Z. Noor, " Voltage Flicker Assessment of 15.3kWp Grid Connected Photovoltaic Systems," 2017 IEEE 8th Control and System Graduate Research Colloquium (ICSGRC 2017), 4–5 August 2017, Shah Alam, Malaysia. **DOI**: **10.1109/ICSGRC**.2017.**8070578**
12. Nuruddin Hama, Weerawoot Kanokbannakorn, Siriroj Sirisukprasert, "An Evaluation of Voltage Variation and Flicker Severity in Micro Grid," 5th international electrical engineering congress, pattaya,thailand 8–10 march 2017. DOI: 10.1109/IEECON.2017.8075791
13. Dong Wei, Huang Jingsheng, Zheng Fei, Zhang Xiaolin, " A Flicker Assessment Method for PV Plants Considering Solar Radiation Condition,"2016 China International Conference on Electricity Distribution (CICED 2016) Xi'an, 10–13 Aug, 2016. **DOI**: **10.1109/CICED**.2016.**7576197**

14. Brinkela, N.B.G., Gerritsmaa, M.K., AlSkaifa, T.A., Lampropoulosa, I., van oordenb, Fidderb, A.M. H.A., van Sark, W.G.J.H.M, “ Impact of rapid PV fluctuations on power quality in the low-voltage grid and mitigation strategies using electric vehicles,” Electrical Power and EnergySystems,2020.https://doi.org/10.1016/j.ijepes.2019.105741
15. Karawia,H., Mahmoud, M., Sami, M., “Flicker in distribution networks due photovoltaic systems,”24th International Conference & Exhibition on Electricity Distribution (CIRED)12–15 June 2017. DOI: 10.1049/oap-cired.2017.0492
16. Yun Seng, Y., Lim, and Jun Huat Tang,”Experimental study on flicker emissions by photovoltaic systems on highly cloudy region: A case study in Malaysia,”.Renewable Energy 64, 2014, pp.61–70. https://doi.org/10.1016/j.renene.2013.10.043
17. N.B.G. (Nico)Brinkel and all,”Impact of rapid PV fluctuations on power quality in the low-voltage grid and mitigation strategies using electric vehicles,” 2020. https://doi.org/10.1016/j.ijepes.2019.105741
18. Annapoorna Chidurala and all,”Field Investigation of Voltage Quality Issues in Distribution Network with PV Penetration,”IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC),2015.DOI:10.1109/APPEEC.2015.7380959
19. Pakonen, P., Hilden, A., untio, T., Verho, P., “ Grid-Connected PV Power Plant Induced Power Quality Problems –Experimental EvidenceI,”EEE.2016. **DOI**: **10**.**1109**/**EPE7695656**
20. John, A. Orr and Alexander, E. Emanuel,”On the Need for Strict Second HarmonicLimits,”IEEE, 2000, pp. 967–971. **DOI**: **10**.**1109**/**61**.**871360**
21. Barros, J., de Apráiz, M., Diego, R.I and all,”Analysis of second order harmonic voltages in power systems,”Int. Conf. On Renewable Energy and Power Quality, 2007, pp. 1–5. https://doi.org/10.24084/repqj05.243
22. Boutelhig. A, Hanini. S, Hadj Arab. A, “Geospatial characteristics investigation of suitable areas for photovoltaic water pumping erections, in the southern region of Ghardaia, Algeria,” Energy 165, 2018, pp.235–245. https://doi.org/10.1016/j.energy.2018.09.036
23. Stambouli. A. B, Khiat. Z, Flazi.S,and Kitamura.Y, “A review on the renewable energy development in Algeria : Current perspective, energy scenario and sustainability issues,” Renew. Sustain. Energy Rev., vol. 16, no. 7, 2012, pp. 4445–4460. https://doi.org/10.1016/j.rser.2012.04.031
24. Abdeladim. K, Bouchakour.S, and H. Arab. A, “Renewable Energies In Algeria Current Situation And Perspectives,” no. November, 2014
25. Sahouane. N, Ziane, R.D.A, Neçaibia. A,. Bouraiou. A,Rouabhia.A,. Blal. M, “Energy and economic efficiency performance assessment of a 28 1 kWp photovoltaic grid- connected system under desertic weather conditions in Algerian Sahara,” Renewable Energy, December 2019, pp. 1318–1330. https://doi.org/10.1016/j.renene.2019.05.086
26. Algerian Ministry of Energy and Mines, 2018 Renewable Energy and Energy Efficiency Program. Algerian Ministry of Energy and Mines, Algiers, Algeria
27. S. Bouacha,Malek,O. Benkraouda, A. Hadj Arab, A. Razagui, S. Boulahchiche, S. Semaoui, “Performance analysis of the first photovoltaic grid-connected system in Algeria,” Energy for

Sustainable Development, 2020. https://doi.org/10.1016/j.esd.2020.04.002

28. InternationalElectrotechnicalCommission(IEC),"IEC 61000-4-15Testing and measurement techniques-Flickermeter-Functional and Design Specificatiion, Flectromagnetic Compatibility-Part 4–15," Geneva, Switzerland, 2010
29. Silsüpür, M.,.And Türkay, B. E.,"Flicker Source Detection Methods Based on IEC 61000-4-15 and signal Processing Techniques – A review," Balkan Journal of Electrical and Computer Engineering Vol.3, No.2, September 2015, pp.93–97. http://dx.doi.org/10.17694/bajece.83624
30. ClarksonP., Wright.Sensitivity, P.S, "analysis of flickermeter implementations to waveforms for testing to the requirements of IEC 61000-4-15.2010". IET Science, Measurement and Technology
31. Clarkson, P., Wright, P.S.,"Sensitivity analysis of flickermeter implementations to waveforms for testing to the requirements of IEC61000-4-15,"IET Sci. Meas. Technol., 2010, 4, pp. 125–135. https://doi.org/10.1049/iet-smt.2009.0036
32. Electromagnetic compatibility (EMC) part 4–15, "testing and measurement techniques flickermeter functional and design specifications in IEC 61000-4-15,".ed, 2011
33. Balouji, E., Salor, O,"Digital realisation of the IEC flickermeter using root mean square of the voltage waveform," IET. Gener. Transm. Distrib., 2016,10, pp. 1663–1670. http://dx.doi.org/10.1049/iet-gtd.2015.0952
34. Cho, S.H., Jang, G., Kwon, S.H., et al., "Measurement and testing specifications of voltage flicker in 220 V/60 Hz power systems,"IET Sci.Meas. Technol., 2009, 3, pp. 113–122. https://doi.org/10.1049/iet-smt:20080105
35. Arshad.A,Lehtonen.M,"InstantaneousActive/Reactive Power Control Strategy for Flicker Mitigation under High PV Penetration,"IEEE, 2018.DOI: 10.1109/ISGTEurope.2018.8571855
36. Damith B. Wickramasinghe Abeywardana, Branislav Hredzak,and Vassilios G. Agelidis, "A Rule-Based Controller to Mitigate DC-SideSecond-Order Harmonic Currentin a Single-Phase Boost Inverter," IEEE TRANSACTIONS ON POWER ELECTRONICS, Vol. 31, No. 2, 2016, pp. 1665–1679. DOI: 10.1109/TPEL.2015.2421494
37. Zai Peng Goh and all, "Investigation of severity of voltage flicker caused by second harmonic," IET Science, Measurement & Technology, 2017,pp. 363–370. https://doi.org/10.1049/iet-smt.2016.0369
38. Mingjian CUI (&)., Deping, KE., Di GAN,Yuanzhang, SUN, "Statistical scenarios forecasting method for wind power Ramp events using modified neural networks,"Springer, 2015.DOI 10.1007/s40565-015-0138-7
39. Bollen, M.H.J, Gu I.Y.H.,"Characterization of Voltage Variations in the Very-Short Time-Scale," IEEE Trans. Power Del, 2005, pp. 1198–1199. DOI: 10.1109/TPWRD.2005.844253
40. Mohamed Abuella and Badrul Chowdhury, " Forecasting of solar power ramp events: A post-processing approach," RenewableEnergy,2018,https://doi.org/10.1016/j.renene.2018.09.005

Figures

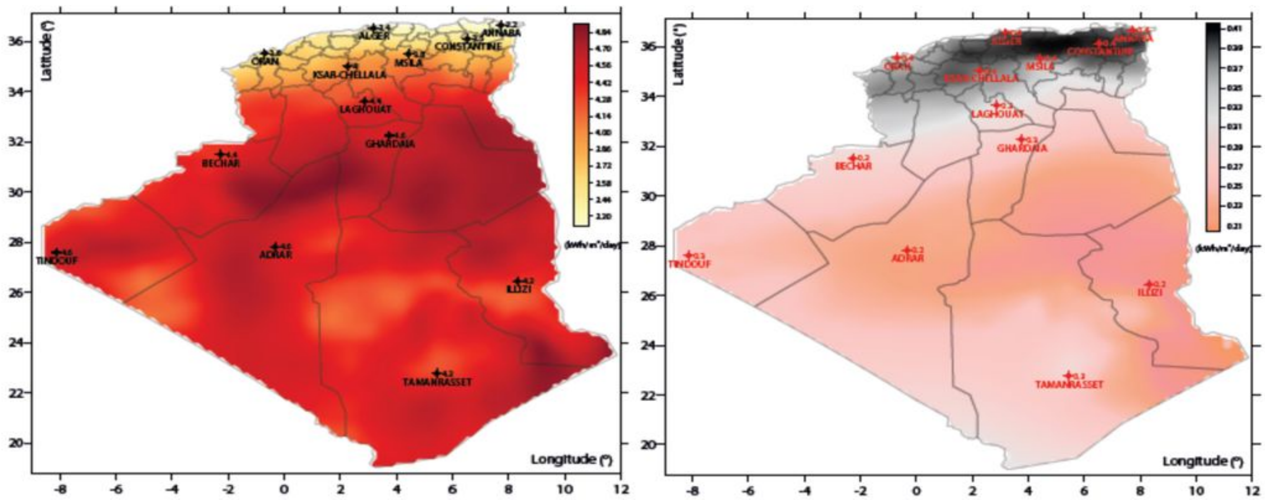

Figure 1

a) Map of the global solar irradiation at optimal inclination, **b)** map of cloud cover

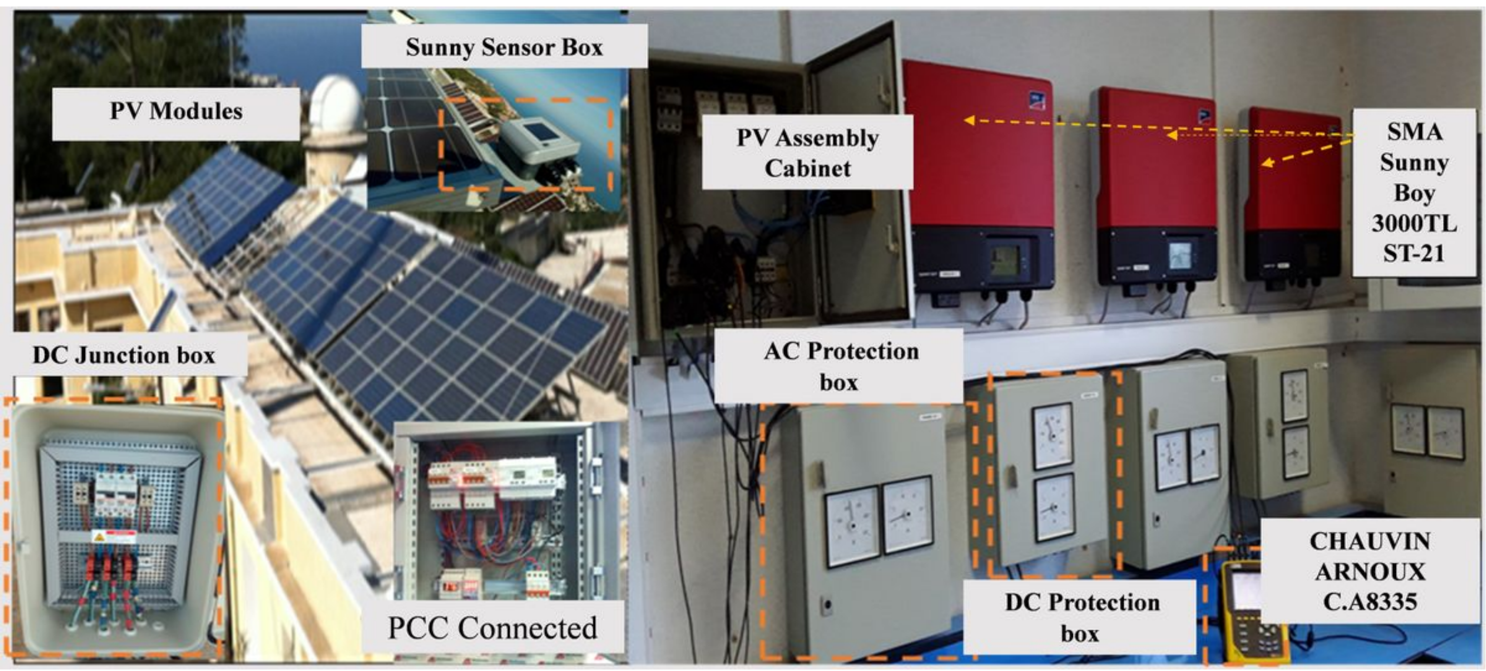

Figure 2

PV system connected to the Algiers's very low voltage distribution network

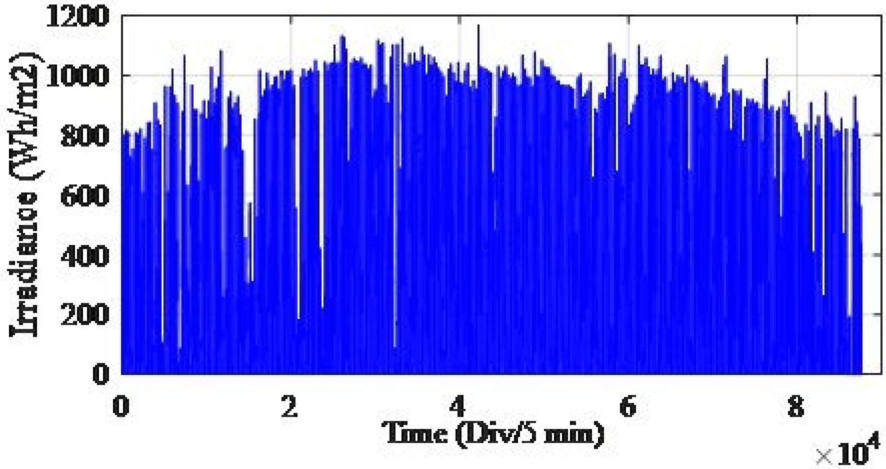

Figure 3

Yearly solar radiation

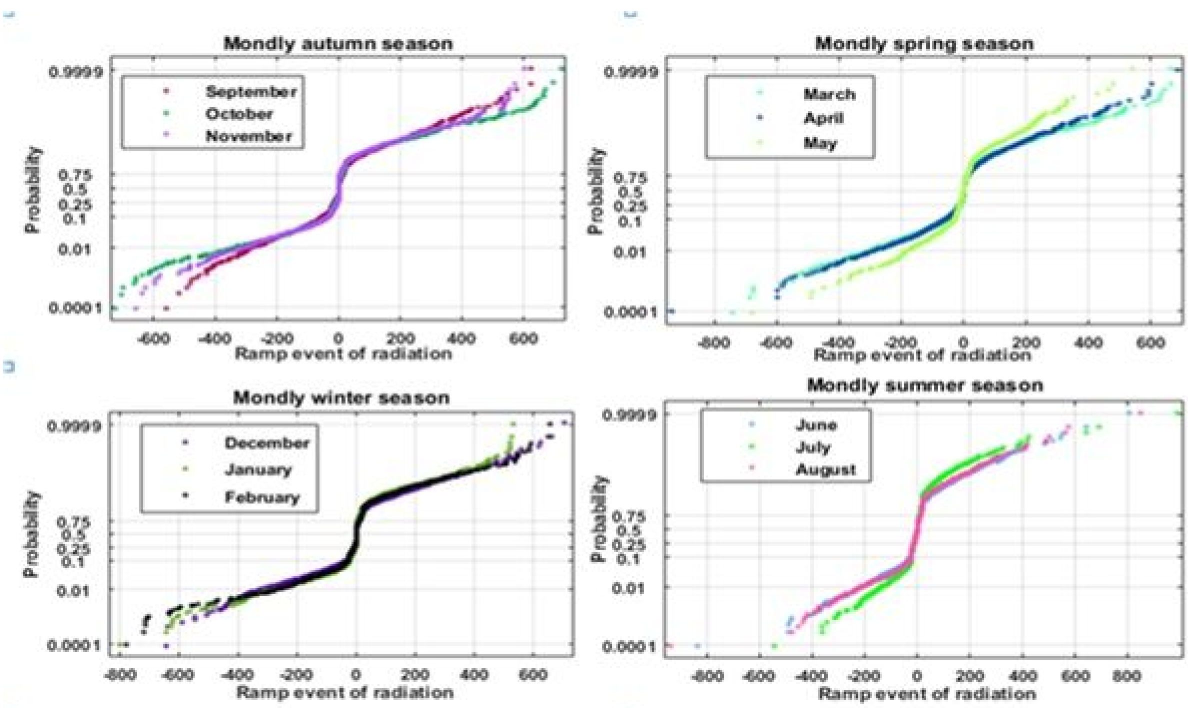

Figure 4

Mondly seasons ramp events of solar radiation

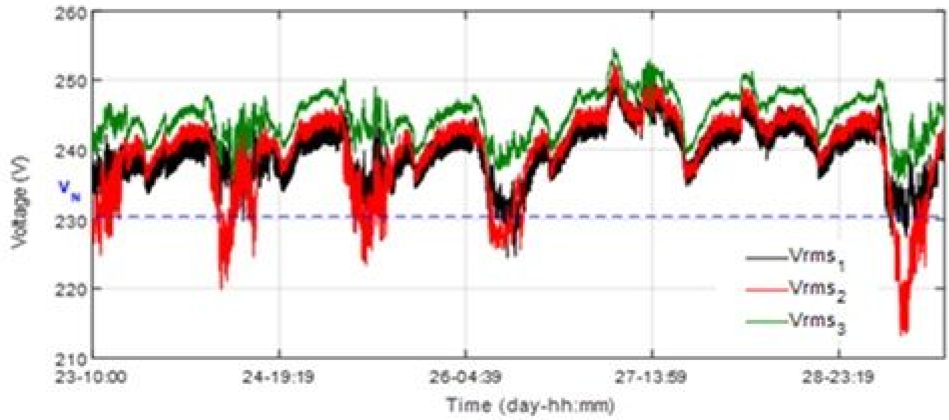

Figure 5

Voltage variation of the three phases at the PCC.

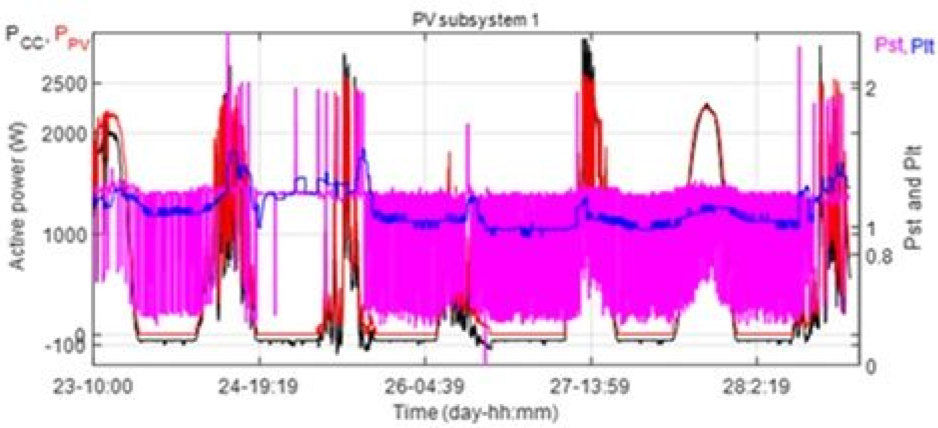

Figure 6

Active power produced by PV and the Pst and Plt flicker indices of the first subsystem

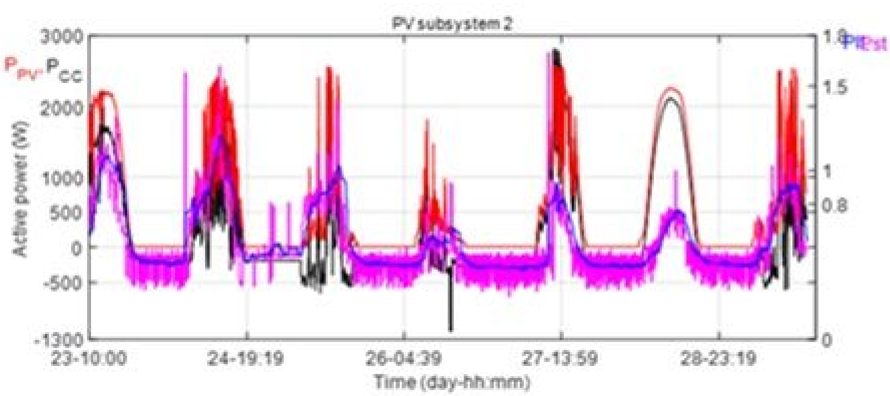

Figure 7

Active power produced by PV and the Pst and Plt flicker indices of the second subsystem

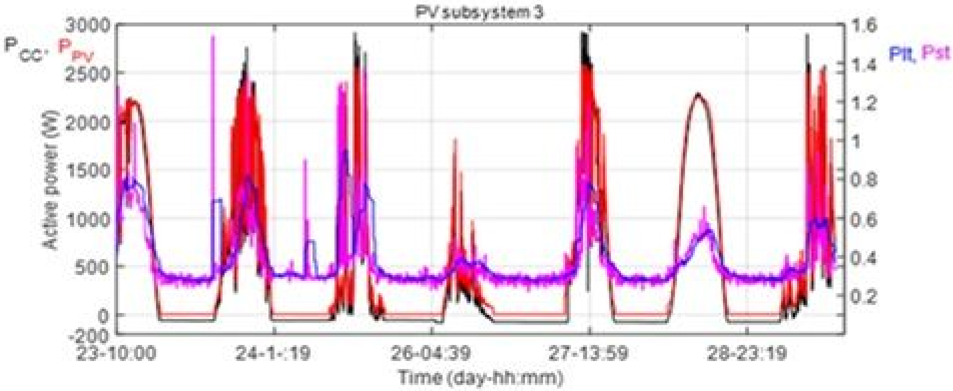

Figure 8

Active power produced by PV and the Pst and Plt flicker indices of the thirth subsystem

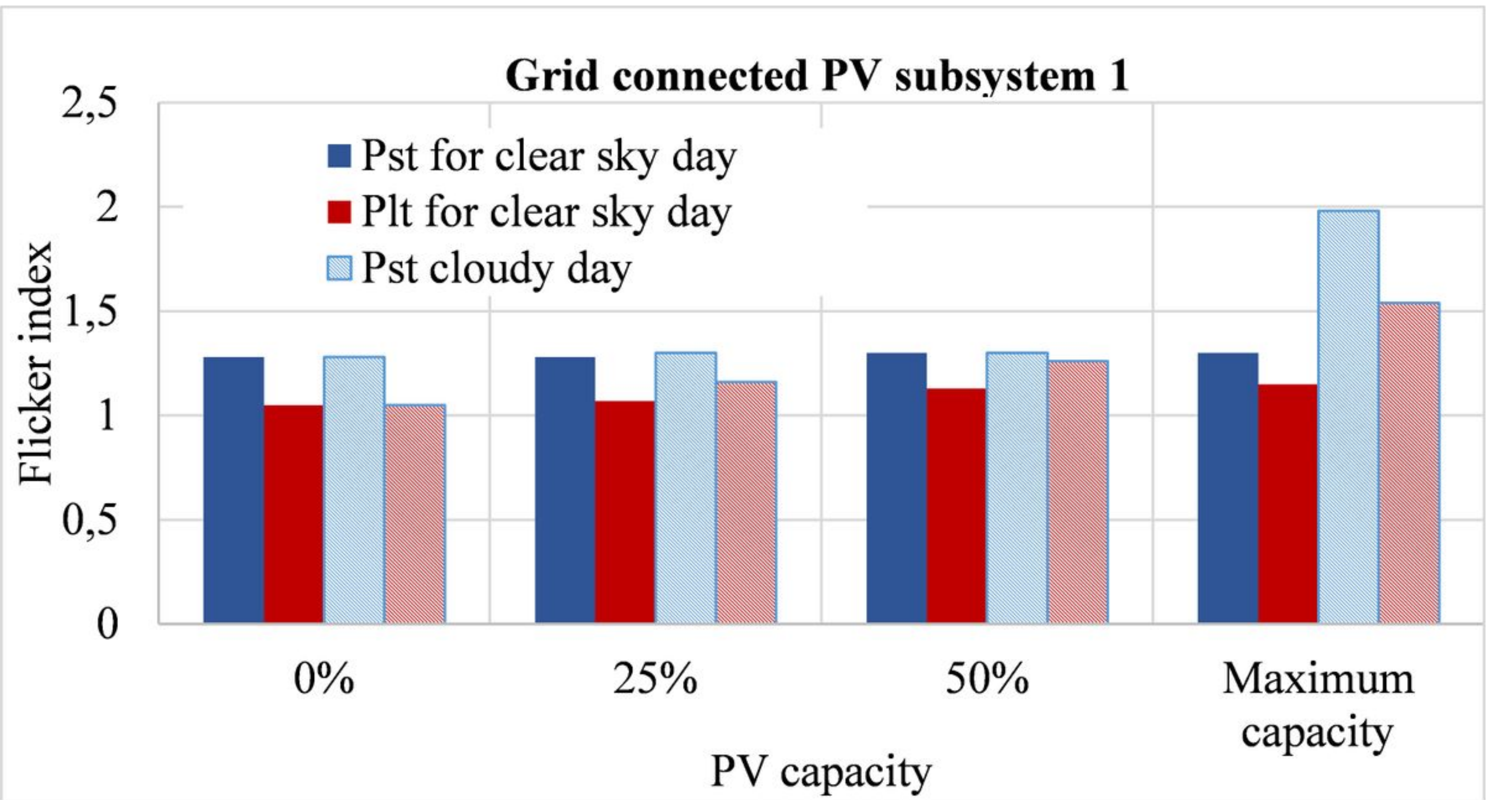

Figure 9

Pst and Plt flicker indices for different capacities production of the first PV subsystem

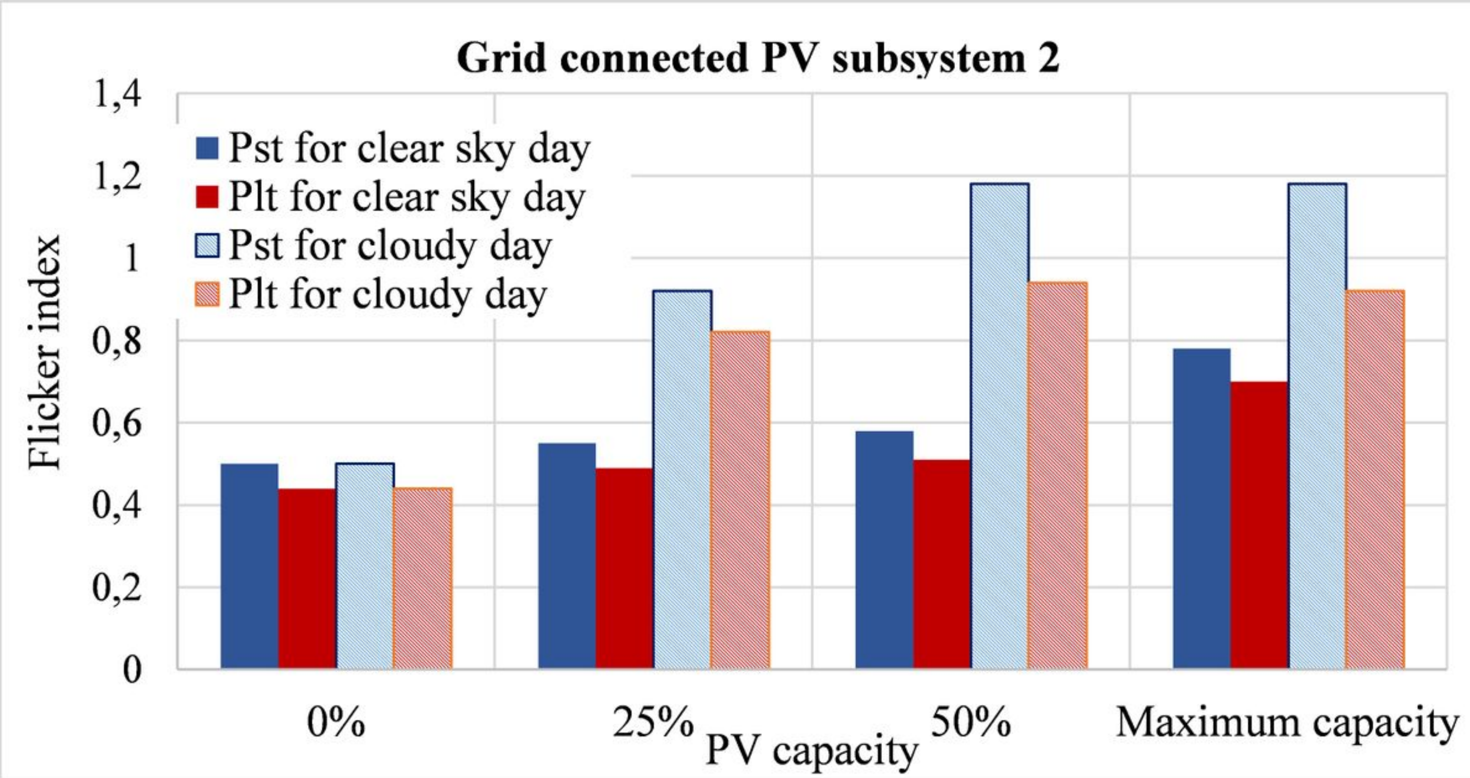

Figure 10

Pst and Plt flicker indices for different capacities production of the second PV subsystem

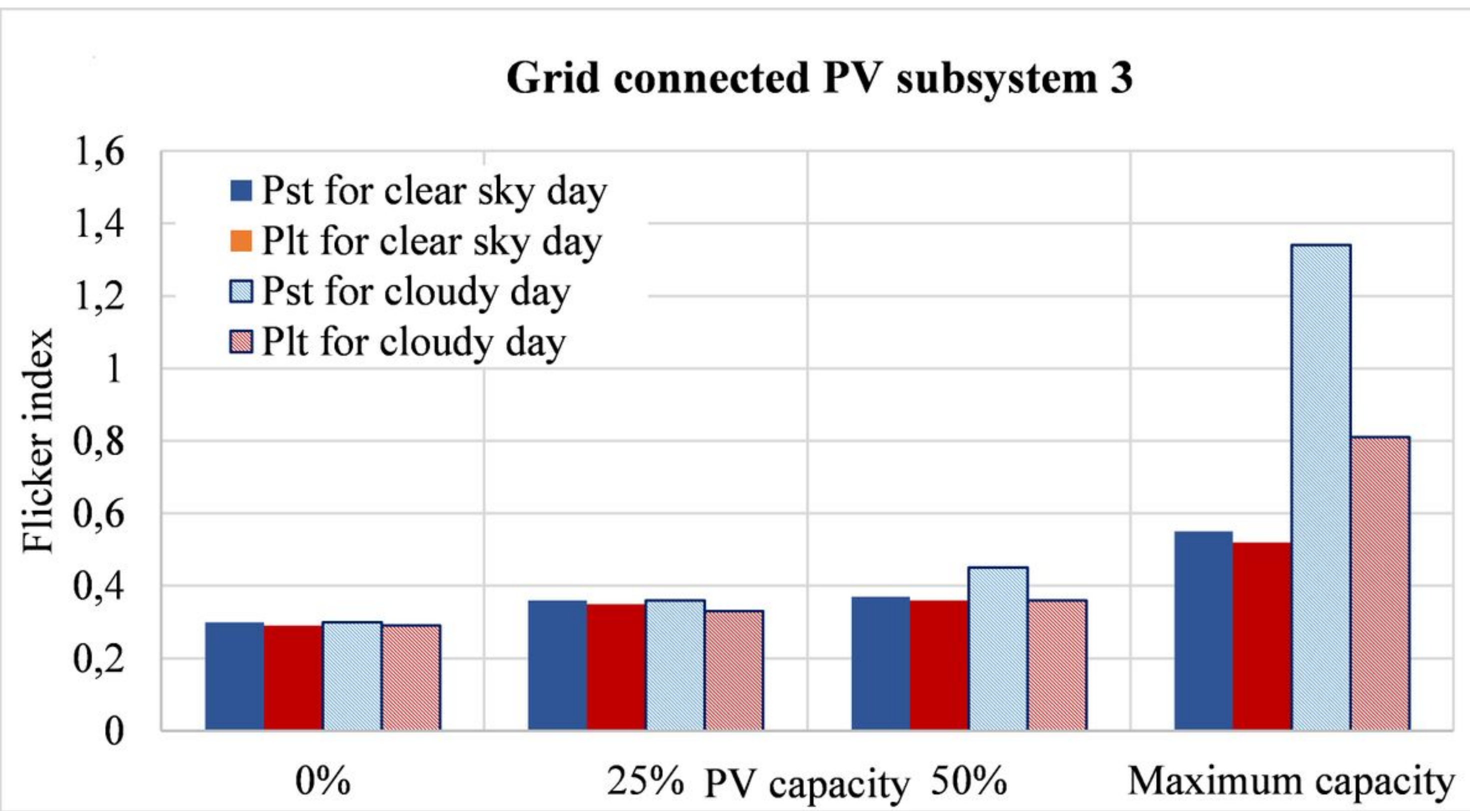

Figure 11

Pst and Plt flicker indices for different capacities production of the third PV subsystem

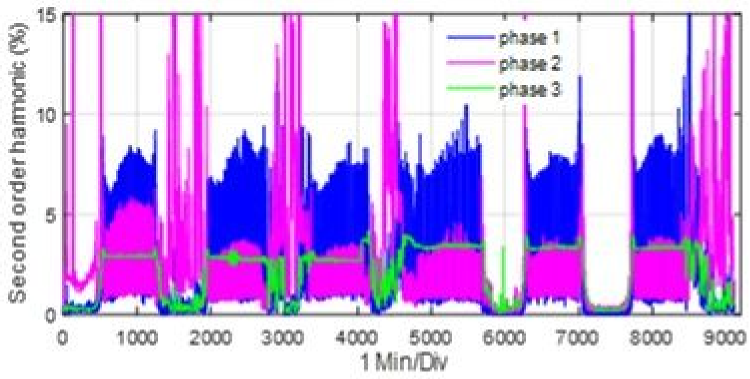

Figure 12

Second harmonic order of current on the flicker

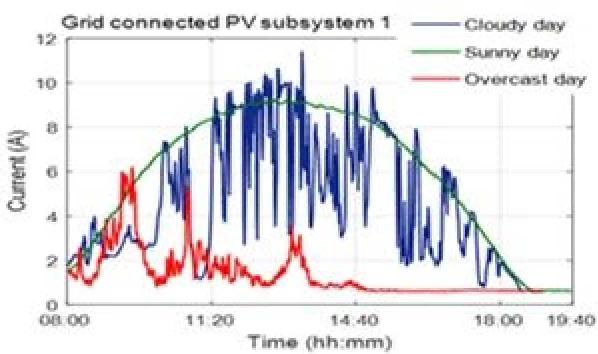

Figure 13

Current injected during a clear sky day, a cloudy day, and an overcast day.

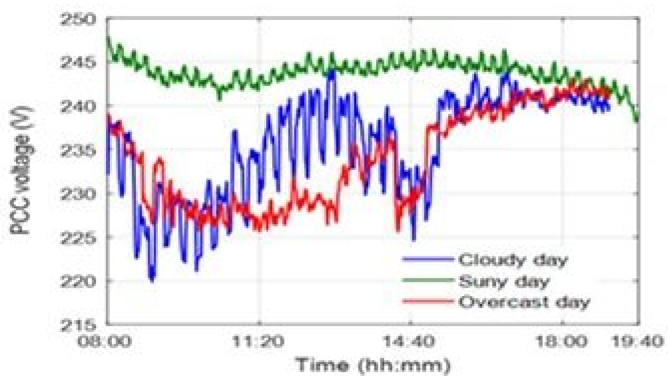

Figure 14

Voltage fluctuations during a clear sky day, a cloudy day, and an overcast day

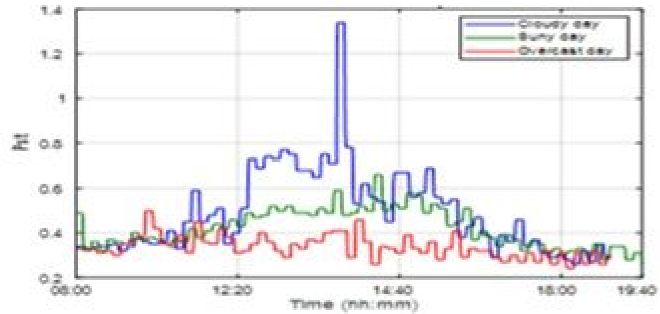

Figure 15

Pst flickers on a clear sky day, a cloudy day, and an overcast day.

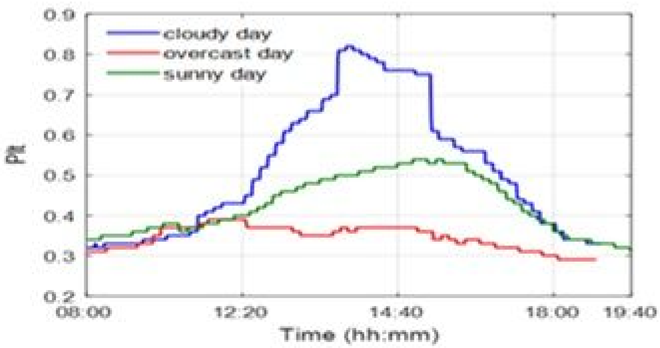

Figure 16

Plt flickers on a clear sky day, a cloudy day, and an overcast day

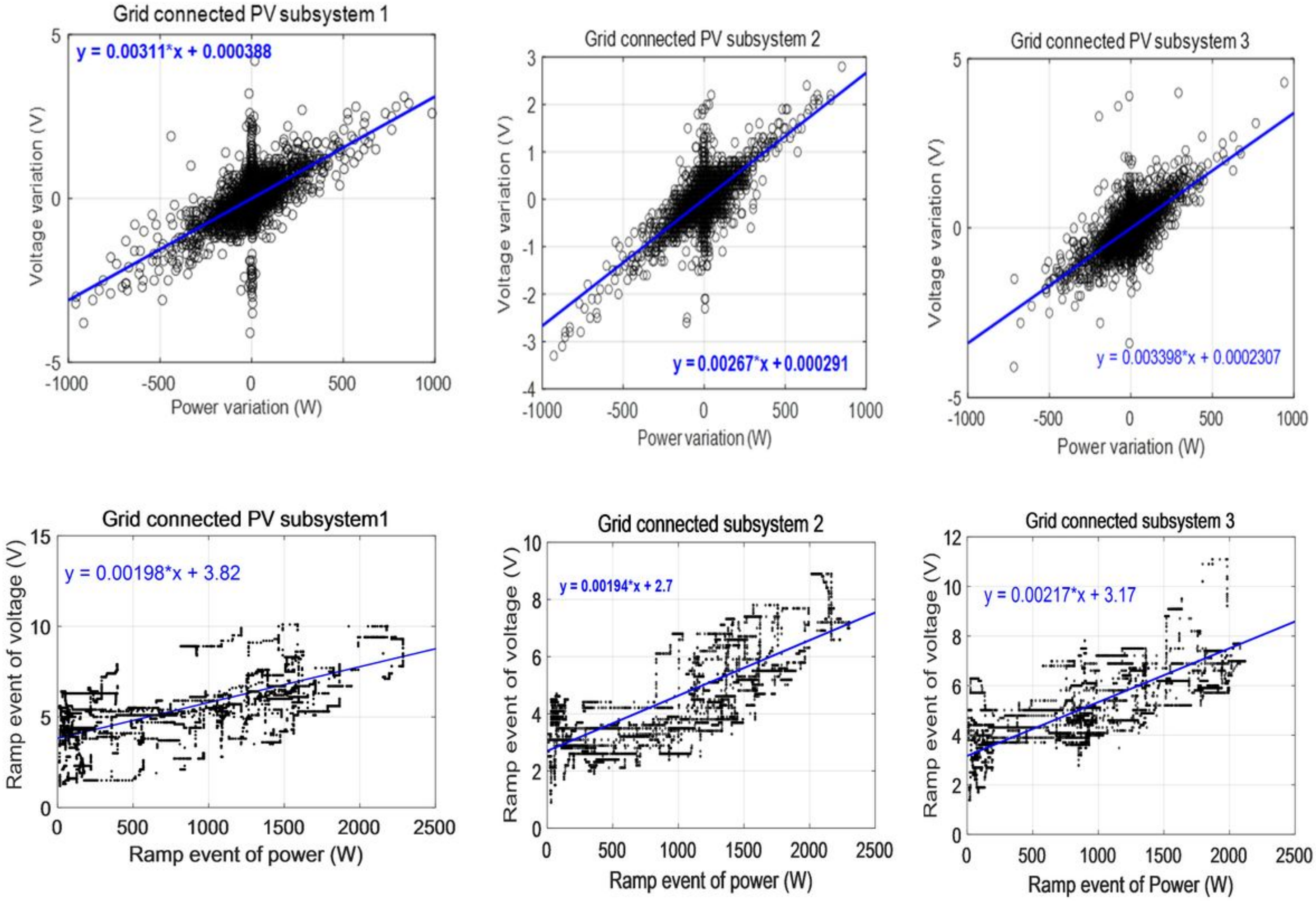

Figure 17

Correlation between voltage variation and power variation

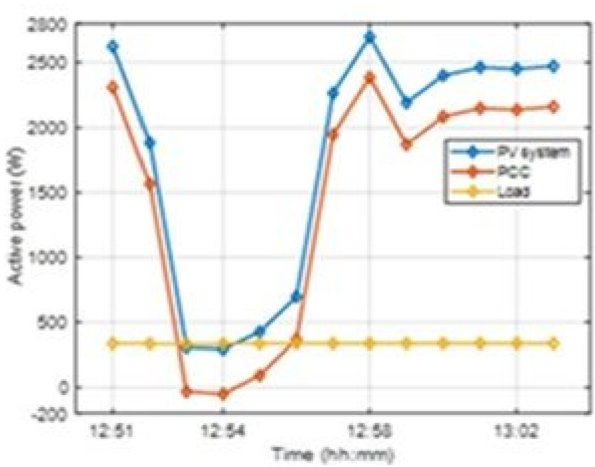

Figure 18

Power ramp for a cloudy day

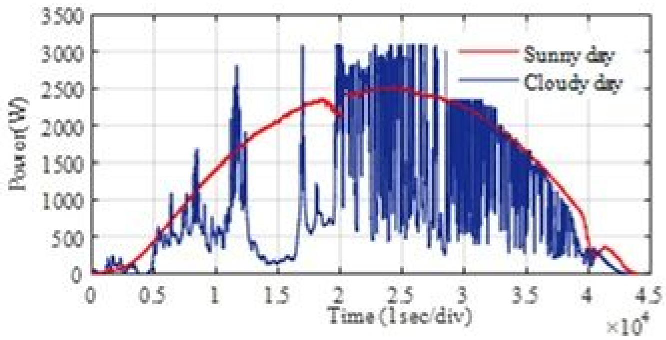

Figure 19

Ramp event of Power for a cloudy day

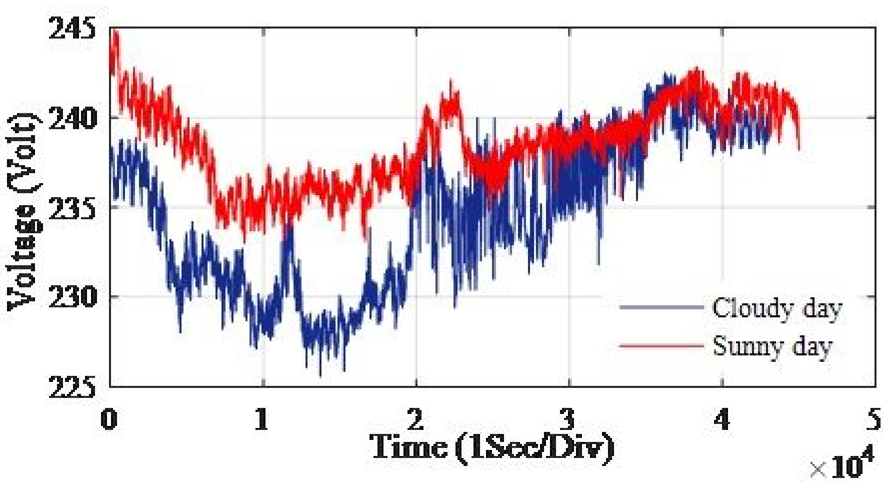

Figure 20

Voltage variation for cloudy day and sunny day

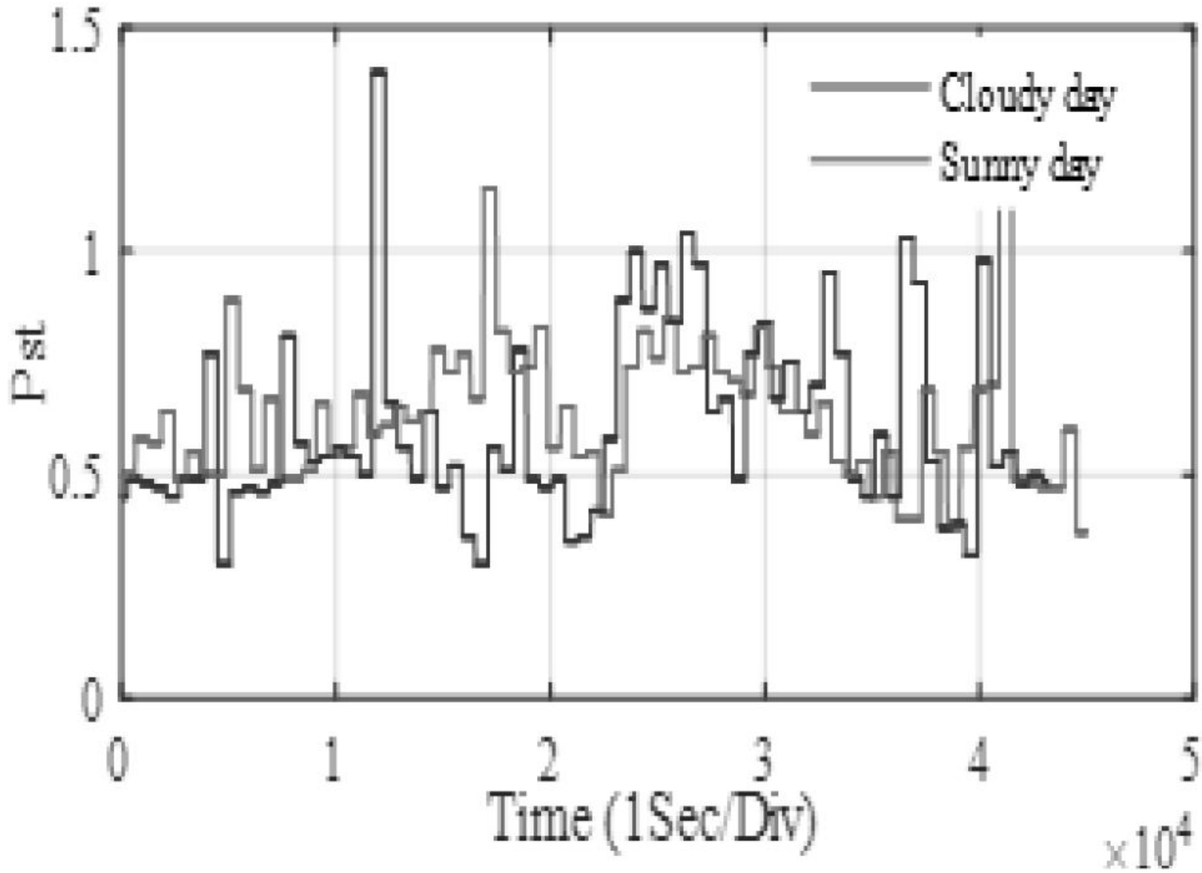

Figure 21

Plt flickers on a clear sky day, a cloudy day

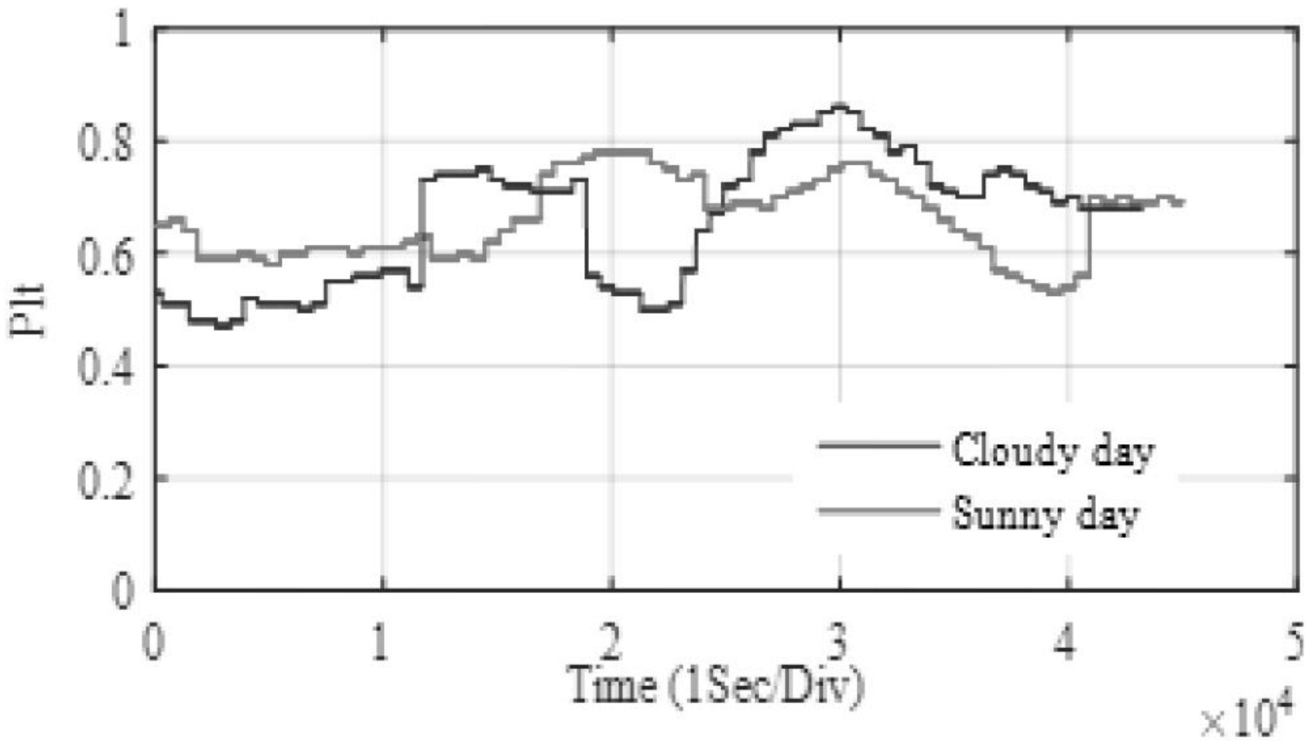

Figure 22

Plt flickers on a clear sky day, a cloudy day, and an overcast day

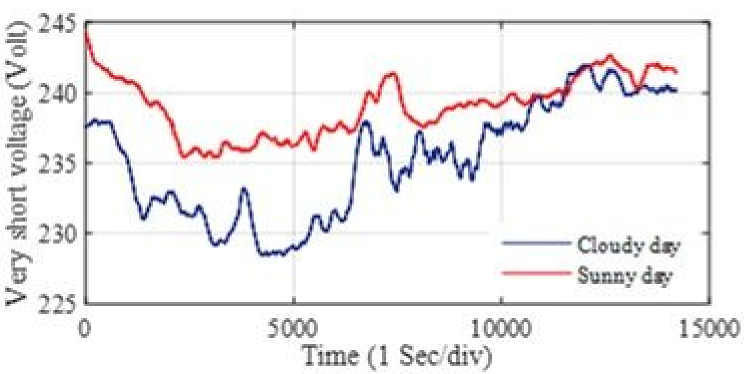

Figure 23

daily 3 second of the rms voltage

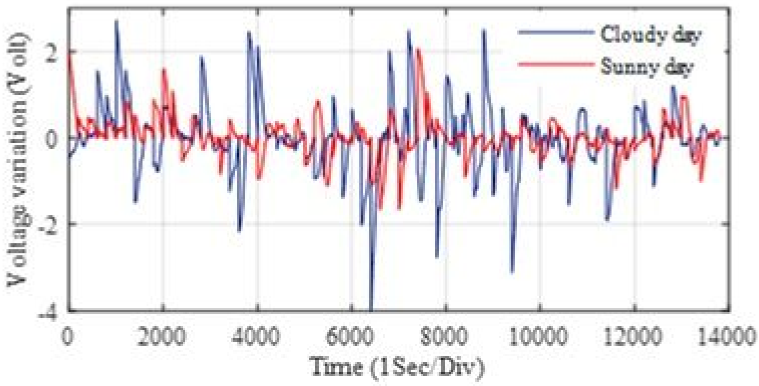

Figure 24

Daily very-short variations: 3 second values versus time of day

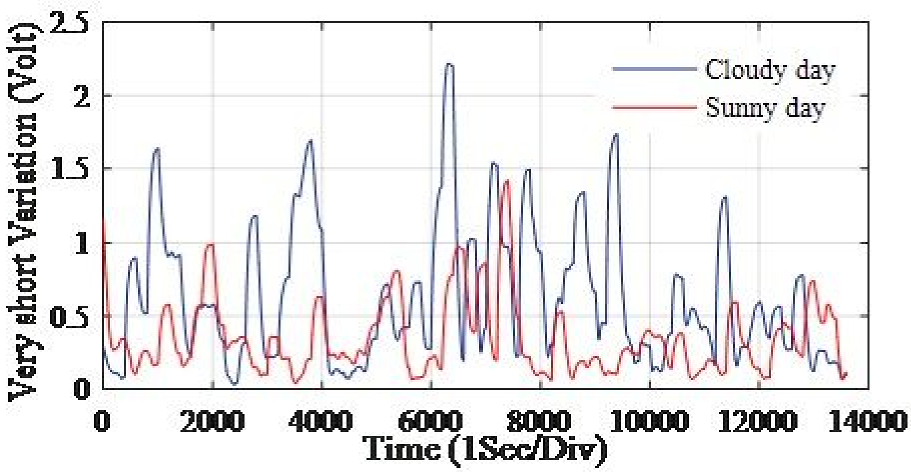

Figure 25

Daily in very-short variations: 10-min values versus time of day