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Analysis of Impact of One Unit of Distributed Photovoltaic Generation in Power Quality of a Rural Property

Santos, E. A dos[1], Ferreira, L. R. A[2], Almeida, A. B[1], Otto, R. B[2], Vendrame, M. G[3]
[1]Centro de Engenharias e Ciências Exatas (CECE)
UNIOESTE, State University of Western Paraná
Av. Tancredo Neves, 6731. Foz do Iguaçu – Paraná (Brazil)
Phone/Fax number:+55 45 3576.8100, e-mail: eduardo.as@pti.org.br; adbaal@yahoo.com.br

[2] Automation and Simulation of Electrical Systems Laboratory (Lasse)
Itaipu Technological Park (PTI)
Av. Tancredo Neves, 6731. Foz do Iguaçu – Paraná (Brazil)
Phone/Fax number: +55 45 3576.7089, e-mail: liz.ferreira@pti.org.br; rodrigobueno@pti.org.br;
[3]Renewable Energy Advice
Itaipu Binational (ITAIPU)
Av. Tancredo Neves, 6731. Foz do Iguaçu – Paraná (Brazil)
Phone/Fax number: +55 45 3520.6411, e-mail:vendrame@itaipu.gov.br;

Abstract.

This paper presents the analysis of the power quality before and after the installation of distributed photovoltaic generation units at the delivery point (distributor/consumer) of a rural property dedicated to milk production in the city of Medianeira, located in the western region of the state of Paraná. Measurements of the aspects that describe the energy quality of the property in question, such as steady state voltage, power factor, frequency, fluctuation, unbalance and voltage harmonics, and short duration voltage variation were performed. The values obtained in these measurements were then compared to the limits considered adequate, according to the procedures of distribution of electric energy in the national electrical system. To carry out these measurements an IMS power quality analyzer model PowerNET PQ - 700 G4 was used. It was found that the limits of three aspects related to the quality of electric power were violated prior to the installation of the photovoltaic panels, which are the power factor, voltage fluctuation and short voltage variations. After the installation of the system, there were improvements in the steady state voltage levels. In addition, a reduction of power factor and fluctuation, imbalance and harmonic distortions of voltage were obtained. The work is finished suggesting solutions to the most relevant problems related to product quality.

Key words
Power Quality, Distributed Generation, Photo-voltaic Solar Energy.

1. Introduction

The concern with the Power Quality (PQ) is due in part to the reformulation that the sector has been facing in order to make feasible the implementation of a consumer market in which the product is the electric power itself. The absence or low quality of electrical energy worries immediately final consumers. We can remember the difficulties when there are interruptions in the electrical power, which causes machines to shut down and operation standstill. Also relevant effects may occur, for example, by the overheating of electric machines due to harmonics, engine vibrations due to imbalances; lighting variations due to fluctuations in tension; sustained power oscillations between the loads and the network during the operation of loads, among many others [1] .

In order to increase reliability and PQ, the Distributed Generation (DG) emerges as a possible solution to problems linked to PQ itself.

Since April 17, 2012, when it came into force Normative Resolution 482/2012 of the National Agency of Electric Energy (ANEEL), the Brazilian consumer can generate your energy energy from renewable sources and provide provide the surplus back to the power grid [2] .

In Brazil, photovoltaic systems have grown especially in rural areas because of the tax incentives provided by the government. Only on the second half of the 1990s, Brazil began its first experiences with the application of Photovoltaic Systems Connected to the low voltage power Grid (PSCG). Since then, demonstrative and experimental applications have been implemented each year in the country, aiming to study and disseminate such an application [3] .

Therefore, it is necessary to carry out an accurate analysis about insertion of photovoltaic panels, in order to assess the on-site gains in PQ parameters with DG before and after the installation of the photovoltaic generation system

2. Power Quality Indicators

In Brazil, the National Electric Energy Agency (ANEEL) is responsible for supervise and regulate production, transmission, distribution and electricity commercialization. The Electrical Energy Distribution Procedures for National Electric Systems (PRODIST) are documents prepared by ANEEL. In module 8, procedures are established for the PQ, the section 8.1 refers to the quality of the product. The aspects that characterize the PQ will be explained below:

A. Steady State Voltage

To carry out the analysis of the steady state voltage, a total of 1008 voltage values must be recorded measured over 7 days, obtained at intervals of 10 minutes between each reading. The voltage between all phases and between all phases and neutral should be measured. For each reference voltage, there is an appropriate reading, precarious and critical voltage range, based on the distance of the reading voltage value in relation to the reference voltage. The individual Relative Duration of the Precarious Voltage Transgression (DRP) and Relative Duration of the Critical Voltage Transgression (DRC) indicators are calculated and expressed by percentage of readings performed in precarious and critical bands respectively, in relation to the total of readings taken during the measurement period. The maximum limits regarding DRP and DRC are set at 3% and 0.5% respectively.

B. Power Factor

The Power Factor (PF) is the ratio between the active power and the square root of the sum of squares of the active and reactive powers. The limit should fall between 0.92 and 1.

C. Harmonic Distortions of Voltage

Harmonic distortions are phenomena associated with deformations in the waveforms of the voltages and currents in relation to the sine wave whose frequency is multiple of the fundamental frequency. The distortions caused in the voltage due to the harmonics are measured through the total harmonic voltage distortion (DTT), total harmonic voltage distortion for even components (DTTp), for the odd components (DTTi) and for the components multiple of 3 (DTT3).

For consumers served at rated voltage equal to or less than 1kV, the limits for DTT, DTTp, DTTi and DTT3, are 10%, 2.5%, 7.5% and 6.5%, respectively. Those limits correspond to the maximum desirable value to be observed in the distribution system.

D. Voltage Unbalance

The voltage unbalance is the phenomenon characterized by any difference found in the amplitudes between the three phase voltages of a given three-phase system, and / or in the electrical gaps of 120 degrees between the phase voltages of the same system. The limit corresponding to the maximum desirable value to be observed in the distribution system is 3%.

E. Voltage Fluctuation

The measurement of the voltage quality of the distribution system in terms of Voltage fluctuation objectives assessing the discomfort caused by the light flickering to the consumer which has in its consumer unit lighting points powered in low voltage. The calculation shall be carried out following the procedure established by the International Electrotechnical Commission IEC 61000-4-15 – Flickmeter – Functional and Design Specifications.

The voltage fluctuation is quantified using the lights scintillation´s analysis and measures through algorithms that simulate the humans' eye reaction to luminosity
´s flow variation through Pst (short-term probability) and Plt (long-therm probability) indicators.
For rated voltage less than or equal to 1 kV, the limit to be used for evaluate performance of the distribution system regarding voltage fluctuation Pst is equal to 1 p.u.

F. Frequency Variation

The variation of the frequency in a system is the deviation in value of the fundamental frequency, 60 Hz in the case of Brazil. The distribution system and the generation facilities connected to it, considering normal operation conditions and permanent basis, shall operate within the frequencies between 59.9 Hz and 60.1 Hz. The table I points the values and the maximum time allowed which the electric system can operate at each frequency.

Table I. - Time that the frequency can remain with the value different from the nominal frequency of the system.

Frequency	Time
59,9 Hz ≤ F ≤ 60,1 Hz	Steady State
F > 66Hz	Not allowed
62 Hz ≤ F < 63,5 Hz	30 s
63,5 Hz < F ≤ 66 Hz	10 s
57,5 Hz ≤ F < 58,5 Hz	10 s
F < 57,5 Hz	5 s
F < 56,5 Hz	Not allowed

Fonte: PRODIST, 2018

G. Short Duration Voltage Variation

Short Duration Voltage Variation (SDVV) can be subdivided into momentary or temporary changes, depending only on the amplitude of voltage in relation to the reference and the period it takes. The voltage variation is rated as momentary when the persistence time is less than or equal to 3 seconds, and as temporary when the persistence time is greater than 3 seconds and less than 3 minutes. It is rated as elevation when amplitude of the voltage in relation to the reference voltage exceeds 1.1 p.u. If the value of the voltage amplitude in relation to the reference voltage is reduced by 0.1 to 0.9 p.u. then it is rated as voltage sag. And, in the case of this voltage value is reduced to less than 0.1 p.u., the voltage is rated as interruption.

3. Case Study

This chapter will present the case study of a rural property dedicated to milk production, located in the city of Medianeira, western region of the state of Paraná, Brazil, which has an average annual electricity consumption of approximately 34.3 MWh and is powered with voltage between phases equal to 220 V at 60 Hz.

A. Cargo Survey of the Property

It was verified through a survey of cargo, that the equipment installed in the property are: milk cooler, water pumps, suction pump, condensers, industrial size fans, water heater, crusher, mixer, and a residential area.

The milking process is performed daily between 5 and 6 o'clock in the morning and in a few days in the afternoon and until the collection, it requires the simultaneous use of many equipment, requiring a great amount of energy during that period.

B. Photovoltaic System Installed in the Property

The PSCG, has 20 kWp of power and is installed on the roof of the shed for the rest of the animals. The photovoltaic system has as main equipment; 80 modules, an inverter, control panel, protection and the bidirectional measuring system. The inverter, control panel and guards are installed in another shed near the shed where the panels are installed, sheltered from rain and direct exposure to the sun.

C. Photovoltaic Panel

Eight modules of the Jinko Solar solution were installed, each module containing 60 multicrystalline silicon solar cells, of 270 Wp and efficiency equal to 19.2%.

D. Inverter

In order to convert the electric energy generated by the photovoltaic panel, the PHB 20K-DT inverter was used. This inverter has the maximum input power equal to 270 kW and the operating range between 260 VDC and 850 VDC. And in the output, it has a maximum nominal level of 20kW with a voltage of 380 VAC or 220 VAC at 60Hz and a efficiency of 98.4%.

E. Installed PQ Meter on Property

In order to evaluate the impact of the photovoltaic distributed generation unit's connection to the property's PQ, the Powernet PQ-700 G4 [7] was installed in the property's Low Voltage General Table (LVGT), which is capable of measuring the seven aspects of the PQ under current PRODIST regulations. Installing this meter made it possible to perform data collections before and after the installation of the photovoltaic distributed generation unit.

4. Analysis of the Results Obtained

In all the figures that are going to be presented in this section, the blue line corresponds to the data before the installation of the PSCG and the dashed pink line corresponds to the data after the installation of the PSCG.

A. Analysis of the Tension in Permanent Regime

Considering that the nominal system line voltage is 220V, to have a proper line voltage at the property, this measure must not be greater than 231V or be less than 202V. In Fig 1 it is possible to observe the graph of the magnitude of the line voltages. In the graph the precarious voltage limit is represented by the black line and the critical voltage limit is represented by the red line, so if the voltage crosses the black line, it will be considered precarious or if the voltage crosses the red line, it will be considered critical voltage.

Fig. 1: Line voltages analyzed between 10/07 and 17/07 of the years 2017 and 2018.

Problems with the voltage had not been registered before the installation of the DG as can be seen in the graph above. However, after its installation it is possible to observe that in general there was an increase in line voltages Vbc and Vca, which is not harmful to the power grid, since it has remained within the limits established by current regulations. However, this increase was not observed in line voltage Vab, so it is possible to conclude that there is a higher load between phases a and b, causing a voltage drop in relation to Vbc and Vca.

B. Power Factor Analysis

In Fig. 2 the graph of three-phase average PF values is presented. The dashed lines in red represent the reference range, the upper half of the graph, indicates inductive PF, the lower half of the graph indicates capacitive PF of capacitors where needed (preferably close to the load).

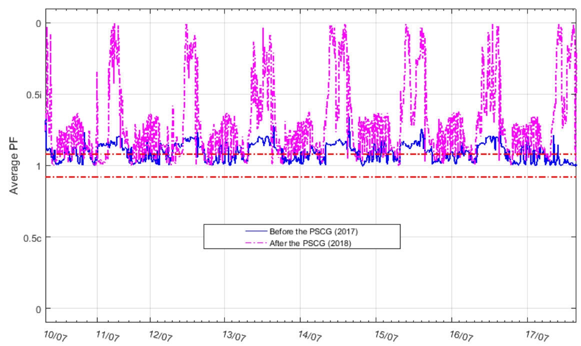

Fig. 2: Average power factor analyzed between 10/07 and 17/07 of the years of 2017 e 2018.

Even before the PSCG was installed, PF was not kept within the limits required by the standard. After the installation of the photovoltaic panels, there was a reduction in the amount of active consumed of the grid and as the panel works with constant PF, there was a reduction in the relation between the active and reactive power seen by the grid, which led to the reduction of PF.

The Fig. 3 shows the graph only of the 12 of July discretized every hour, and in it it is possible to be observed that the period in which the PF is close to zero, coincides with the hour in which the Sun is the pin, that is to say, when there is greater luminous intensity. At this time the panels will be generating energy close to their maximum limit, causing the load to demand less active energy from the grid, while maintaining the reactive energy consumed. This will reduce the relation between the active and reactive power seen by the network, causing a low PF value.

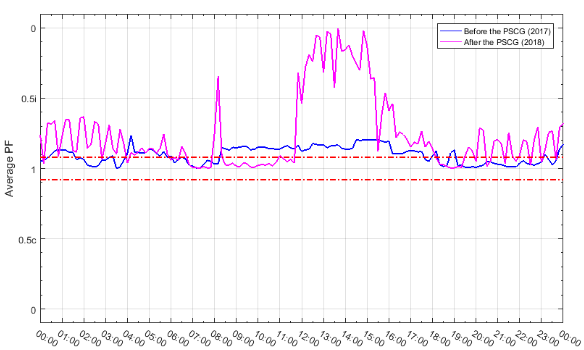

Fig. 3: Power factor three-phase discretized every hour on 07/07 in the years 2017 and 2018.

Most of the installed loads on the property are induction motors of old models, in addition fluorescent type discharge lamps also present themselves in large numbers, such loads contribute to a low PF. The correction of the PF bass is one of the solutions to reduce the losses of electric power, to reduce the risks with electrical accidents due to overheating. Low PF can be corrected by correct sizing of motors and equipment, correct use and operation of motors and electrical equipment in general, and installation of capacitors or capacitor bank where necessary (preferably near load).

However, the consumer is not penalized for not keeping the PF within the limits, since the property belongs to the group B of consumers, which is the group composed of consumer units with a supply voltage of less than 2.3 kV. Not causing an increase in the tax by the low PF.

C. Analysis of Harmonic Distortions of Voltage

The harmonic distortions of voltage are measured through the DTT, DTTP, DTTi and DTT3 indices, with the maximum limit being 10%, 2.5%, 7.5% and 6.5%, respectively. In Fig. 4 the valid DTT records of each of the corresponding phases can be seen. The distortion reaches values just above 2.5%, which is not even close to the limit of 10%

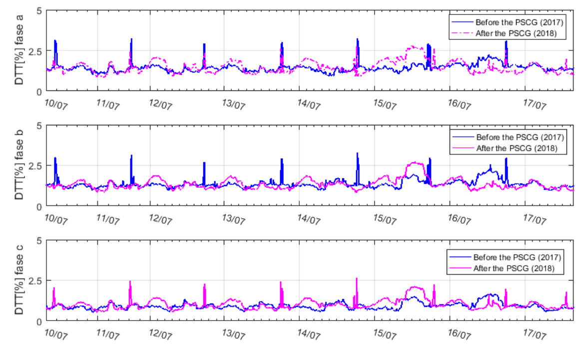

Fig. 4: DTT corresponding to phases a, b and c between days 10/07 and 17/07 of the years of 2017 e 2018.

In Fig. 5 the valid DTTp records of each of the phases can be observed. It can be observed that the distortion reaches values lower than 1.25%, not exceeding the limit of 2.5%.

Fig. 5: DTTp corresponding to phases a, b and c between 10/07 and 17/07 of the years of 2017 e 2018.

In Fig. 6, the valid DTTi records of each of the phases corresponding to the analyzed week can be observed. The distortion reaches values close to 2.5%, not exceeding the limit of 7.5%.

Fig. 6: DTTi corresponding to phases a, b and c between 10/07 and 17/07 of the years of 2017 e 2018.

Finally, in Fig. 7, the valid DTT3 records of each of the phases corresponding to the analyzed week can be observed. The distortion reaches values little more than 2%, not exceeding the limit of 6.5%.

Fig. 7: DTT3 corresponding to phases a, b and c between 10/07 and 17/07 of the years of 2017 e 2018.

Low harmonic distortion values were observed even before the PSCG was installed since the number of linear loads on the property is greater than the nonlinear loads, which are one of the major sources of harmonics.

In general, a reduction in the harmonic distortions was observed, such reduction is given from the passive filter that the frequency inverter has. According to [5] passive filters are the classical solution for the reduction of voltage harmonic contamination in electrical systems, the filter action allows reducing the harmonic content of the network voltage in relation to the load. Therefore, the harmonics present on the property before the installation of the PSCG, which were already low, were filtered and reduced due to the presence of the passive filter that the frequency inverter installed in the property has.

D. Voltage Imbalance Analysis

The Factor of Voltage Imbalance (FU) must be less than 3% so that it is considered adequate. In Fig. 8 it is possible to observe the values of FU corresponding to the analyzed week, where the blue line corresponds to the values of FU before the installation of the PSCG and the dashed pink line corresponds to the values of FU after the installation of the PSCG.

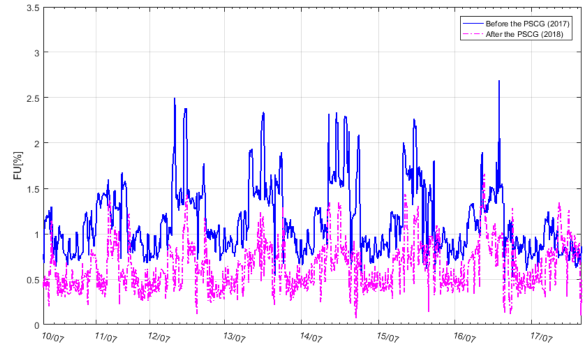

Fig. 8: Unbalance of tension in days 10/07 and 17/07 of the years of 2017 e 2018.

The unbalance factor remained below 3% limit even before the installation of PSCG. Second [4] current imbalance leads to voltage imbalance and irregular heating of cables and lines. This also leads to increased losses in cables and lines. After insertion of the PSCG, a reduction of the FU was obtained, because now part of the current required by the load is taken care of by the photovoltaic panels, thus reducing the required power of the grid and the voltage drop in the line, causing an incensement of the voltage between the phases, and this leads to decreasement of FU.

E. Voltage Fluctuation Analysis

For the nominal voltage less than or equal to 1kV (which is the case of the analyzed property), the value of the Pst indicator is considered adequate when it remains less than 1.0 p.u. Fig. 9 shows the Pst values measured in the "a", "b" and "c" phases of the LVGT.

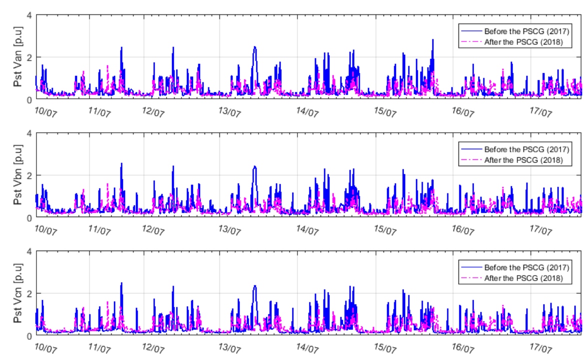

Fig. 9: Pst indicators corresponding to each phase between 10/07 and 17/07 of the years of 2017 e 2018.

Problems with voltage fluctuation had been recorded prior to the installation of the DG, as can be seen in the graphs above. After the installation of the photovoltaic panels it was possible to notice the decrease of the values of the Pst indicators.

In a technical visit to the property under study, it was possible to note that most installed loads are biphasic and single phase induction motors. According to [4] , loads as electric motors are the major contributors to a high Pst value because the motors require a high starting current every time they are triggered, and with heating and cooling loads that usually have a duty cycle Very short.

As the main loads of the property are characterized as electric motors, industrial refrigerators and water heaters, it is possible to affirm that as the load increases, the current in the line increases, thus increasing the voltage drop causing the voltage fluctuation.

Note that after the installation of the photovoltaic system, the values of the Pst indicators for the three phases have decreased, because now part of the power required by the load is taken care of by the photovoltaic panels, thus reducing the required power of the grid and the voltage drop in the line. However, even with the reduction of Pst values these still remained above the value considered adequate according to the norm.

F. Frequency Analysis

The nominal frequency of the measured system is 60 Hz. Therefore, according to the norm, this frequency must be between 59.9 and 60.1 Hz. Fig. 10 shows the frequency values corresponding to the analyzed week.

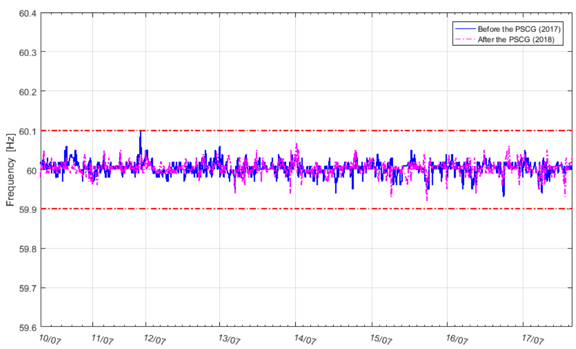

Fig. 10: Frequency indicators between 10/07 and 17/07 of the years of 2017 e 2018.

Photovoltaic systems such as the one installed in the property in question do not participate in the frequency regulation of the Brazilian electrical system. Frequency regulation is inherent in the installation of the panels given the dimensions of the system to which it is connected, so the frequency has remained within the limits in force in the standard.

G. Analysis of Short-Term Transitional Variations

The SDVV be divided into six types, according to duration, magnitude and, in addition, between sinking or elevation. In the analyzed period, interruptions occurred only on 08/04 in 2018 and 08/06 in 2018. It is important to remember that the Momentary Interruption of Voltage (MIV) lasts less than or equal to 3 seconds and Temporary Interruption of Voltage (TIV) lasts longer than 3 seconds and less than 3 minutes. The SDVV are inherent to the installation of PSCG, since the installed DG does not work isolated from the network. Therefore, the shortages, MIV and TIV recorded in the periods analyzed come from COPEL's distribution network

5. Conclusion

From the analyzes that were made, it was possible to verify that the insertion of microgeneration generated steady state voltage rise, not exceeding the maximum limits stipulated by PRODIST. In addition, it was observed that the power factor decreased due to the reduction of the network asset consumption, thus increasing the ratio between active and reactive power consumption. Other important aspects analyzed that underwent changes were the fluctuation and the voltage unbalance, which reduced their values of the indicators Pst and FU respectively. However even with the reduction of the Pst indicators these still remained above the value considered appropriate according to the norm. Together with the harmonics present in the property, they were filtered and reduced due to the presence of the passive filter of the frequency inverter.

Aspects such as SDVV and frequency, are inherent to the insertion of the photovoltaic system connected to the network, since it does not work in an islanded way, that is, without being connected to the network.

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