**American Journal of Renewable and Sustainable Energy**
Vol. 4, No. 3, 2018, pp. 56-63
http://www.aiscience.org/journal/ajrse
ISSN: 2381-7437 (Print); ISSN: 2381-7445 (Online)

# Impact Analysis on Power Quality of a Small Distributed Generation

**Talita de Araujo Santos Fernandes Afonso[1], Leonardo de Arruda Bitencourt[1], Marcio Zamboti Fortes[1, *], Sergio Gomes Junior[1], Renan Silva Maciel[2]**

[1]Department of Electrical Engineering, Fluminense Federal University (UFF), Niteroi, Rio de Janeiro, Brazil
[2]Department of Electrical Engineering, Paraná Federal University of Technology (UTFPR), Apucarana, Paraná, Brazil

## Abstract

This paper aims to analyze the harmonics generated in a system when there are different levels of penetration of solar photovoltaic generation. A real system in the city of Buzios (Brazil) was simulated in the program HarmZs with measured values of existent panels. The harmonic total distortion of voltage was evaluated and it was seen that in the scenarios with massive penetration of photovoltaic generators, the limits established were violated, indicating that it will be necessary to make new arrangements in the system, such as in filter allocation, to support the entrance of a great amount of distributed generation. This study shows that the insertion of new (small) renewable sources connected to the grid should be discussed within the context of power quality to prevent major distortions in electrical systems that are adequate and meet the existing regulations for power distribution.

## Keywords

Photovoltaic Systems, Solar Energy, Power System Simulation, Distributed Generation, Power Quality

Received: July 14, 2018 / Accepted: August 1, 2018 / Published online: September 4, 2018



## 1. Introduction

Distributed generation (DG) from renewable sources plays an increasingly important role in the Brazilian energy scenario, contributing to the diversification of energy sources. Due to a lower environmental impact compared to conventional sources and other technical factors, wind and solar generation have been the fastest growing according to the Plan for Expansion Energy 2026 [1]. DG is an alternative not only to reduce losses in distribution systems, but also to supply rural areas with electric energy, as discussed in [2], and this alternative electric power supply can be applied in isolated systems [3]. Several different types of research are being development considering DG systems as islanding detection [4], DG location [5] and grid reconnection detection [6].

The massive application of these intermittent sources can bring many challenges that must be carefully treated. Some of these challenges are difficulty restoring a system after a fault, DG islanding, impacts on protection, and reduction of reliability and power quality (PQ) [7]. Brazil is still developing more detailed regulations for access to these sources to the grid.

Within PQ, the main problems are related to harmonic distortion on the network due to the number of electronic components, voltage rise at the point where the devices are installed, network unbalance and flicker, etc. [8-9]. Some details about the Brazilian experience of photovoltaic system

* Corresponding author
E-mail address: mzf@vm.uff.br (M. Z. Fortes)

connected to the network are described in [10], which comments on some impacts and disturbances and other research focusing harmonic due photovoltaic inverters is presented in [11].

The energy injected by the photovoltaic system must meet the quality requirements in order to avoid disruption of the network. A PQ problem can be defined as any event that can cause an electrical disturbance in voltage, current, or frequency, or that provokes damage or improper operation of equipment [12]. The PQ is analyzed by certain parameters defined by the local power authority. These parameters are usually multiple harmonics of the fundamental component and the power factor [13].

Harmonics are undesirable because they cause overheating of transformers, which shortens the life of motors, transformers, capacitor banks, and other equipment, as well as interference with network communication systems and even trip or malfunction of sensitive equipment [14 -15].

Several studies about PQ have been conducted. Urbanetzet et al. [16] present a PQ analysis in urban feeders in Florianopolis, Brazil, with an integrated photovoltaic system in the network. Varatharajan et al. [17] study the characteristics of low-order harmonics in large photovoltaic systems with drives of varying sizes. Prakash and Lakshminarayana [18] conducted a study that use optimization algorithm to locate capacitor in a radial distribution network avoiding energetic losses and others PQ problems.

The objective of this paper is to analyze the impact on PQ of low voltage distribution networks when there are different penetration scenarios of DG and verify that the electric power quality parameters are maintained in accordance with standard values.

Section II of this article provides the existing requirements in Brazil and the penetration of DG and features the international approach to harmonic voltage distortion. Section III presents a description of the researched system and addresses where we performed the data collection. Section IV describes the system modeling in the HarmZs program and submitted the results. Finally, the conclusions are discussed in Section V.

## 2. Brazilian Regulation

The National Electric Energy Agency (ANEEL) is responsible for regulating and supervising the electrical energy transmitted between different power agents, which are generation, transmission, distribution, energy trading, free consumers, and importers/exporters of energy. In the context of distributed generation, ANEEL published Normative Resolution 482 of April 17, 2012 (later supplemented by resolutions 517/2012 and 687/2015). This document sets out the conditions for access of microgeneration (installed capacity lower than or equal to 75 kW), mini generation (greater than 75 kW and less than or equal to 5 MW), and power compensation systems [19]. In that resolution and the documents which it referenced, it is identified that there is no strict policy in Brazil to access the DG's network in this way is provided to distributor's suit your business systems, and prepare or review technical standards on the subject.

In addition, ANEEL gets the Electricity Distribution Procedures in the National Electricity System (PRODIST) [20], which in its eighth module deals with the quality of electricity. Among the subjects that deal with this document, there is the quality of the product (electric power distribution) and, the PRODIST brings benchmarks related to the voltage in steady state and harmonic distortion.

For the steady-state voltage, proper, precarious and critical limits are defined and shown in Table 1, to the connection point in 220/127 V. These limits correspond to one of the criteria for assessing the PQ at the measured point. This module is also described, as should be the measurements for verification of attendance, in [20]. The complete criteria will not be described here because it does not match the focus of this work.

**Table 1.** Reference Values Voltage.

| Voltage Classified | Classification of Voltage |
|---|---|
| $(202 \leq V_m \leq 231)$ or $(117 \leq V_m \leq 133)$ | Suitable |
| $(191 \leq V_m \leq 202)$ or $(231 \leq V_m \leq 233)$ $(110 \leq V_m \leq 117)$ or $(133 \leq V_m \leq 135)$ | Precarious |
| $(V_m < 191)$ or $(V_m > 233)$ $(V_m < 110)$ or $(V_m > 135)$ | Critical |

$V_m$ is the measured voltage.

Table 2 shows the reference values for total harmonic distortion [20] regarding the fundamental component of voltage.

**Table 2.** Reference Values for Total Harmonic Distortion Voltage.

| Nominal Voltage | Total Harmonic Distortion Voltage ($THD_V$) [%] |
|---|---|
| $V_N \leq 1$ kV | 10 |
| 1 kV $< V_N \leq$ 69 kV | 8 |
| 69 kV $< V_N \leq$ 230 kV | 5 |

The IEEE's recommendations [21], which represent a shared responsibility for the control of harmonics between system operators and users, also follow. The IEEE 519 addresses the measurement of harmonics and presents limits suggested to reduce the negative effects on equipment. The recommended voltage distortion limits are in Table 3 [21].

**Table 3.** Limits of Voltage Distortion.

| Bar Voltage | Individual Distortion Limit [%] | Total Harmonic Distortion THD [%] |
|---|---|---|
| $V_N \leq 1$ kV | 5 | 8 |
| 1 kV < $V_N \leq 69$ kV | 3 | 5 |
| 69 kV < $V_N \leq 161$ kV | 1.5 | 2.5 |
| $V_N > 161$ kV | 1 | 1.5[a] |

[a] High-voltage systems can have THD above 2.0% where the cause is the existence of HVDC terminal.

# 3. Description of the Analyzed System

The data used in this paper were collected in the city of Buzios, a city located in the state of Rio de Janeiro, Brazil. It was the first smart city implemented in Latin America, a project of the Endesa group that covers various technologies such as wind and solar photovoltaic distributed generation, LED public lighting, electric mobility, among others [22].

The energy distribution system has a radial characteristic, originating from a substation located at the city entrance and from there branches off in three directions according to the geographical pattern of the peninsula, shown in Figure 1. This research used real data from photovoltaic panels which are connected at low voltages of this network.

**Figure 1.** Buzios Network.

The load area is mostly residential and concentrated in the first part of the peninsula, where the current installed capacity is 50 [MVA]. Twenty-four thousand, nine-hundred seventy-three customers are served, including 13 industrial and 1,518 commercial in 2012, shown in Table 4. Because the region grew by five percent per year [23], it was possible to estimate the approximate number of customers in each one of the three feeders for future years.

The photovoltaic panels used in the measurements and connected to the feeders are thin film and polycrystalline. Others research are done using similar photovoltaic panel as in [24].

**Table 4.** Total Customers per Feeder [22].

| Feeder | Electrical Set | Customers |
|---|---|---|
| BUZ01 | Buzios | 7,452 |
| BUZ02 | Buzios | 4,080 |
| BUZ03 | Buzios | 2,336 |
| BUZ04 | Buzios | 1,535 |
| BUZ05 | Buzios | 3,015 |
| BUZ06 | Buzios | 4,972 |
| BUZ07 | Buzios | 1,583 |
| Total Costumers (May 2012) | | 24,973 |

# 4. Computer Modeling

The software used for modeling is the HarmZ of Center for Electric Energy Research (Cepel), by which it is possible to perform harmonic behavior studies and modal analysis of electrical networks [25]. Modeling is done at the feeder seven of the distribution network of the city of Buzios. Real data, such as resistance and reactance of cables, as well as their respective lengths and transfer power, are used. Studies done with this software are described in [26-27]. Other software can be applied in studies such as those presented in Chidurala et al. [28], which used PSCAD software.

Three measurements were performed in photovoltaic systems, all of them composed by 20 panels of 250 Wp, totaling 5 kW. The photovoltaic panels measured were the thin-film type and polycrystalline. From these measurements were selected three cases that had the highest rates of total harmonic distortion (THD), according to Table 5. The measurements 1 and 3 were done in thin film panel and the measurement 2 in the polycrystalline panel.

For the purpose of facilitate the analysis, the system that consists in its entirety of 116 bars, was reduced by larger power blocks, totaling a new system with 16 bars, as shown in Figure 2 and its characteristics in Table 6. A 0.9 power factor for all bars was applied to simulate the high level of transformers loading.

Three scenarios were built in order to observe the behavior of the grid with the insertion of harmonics in specific points. In the first scenario, only a single harmonic source is inserting in three different bars ignoring other sources of existing harmonics. The configuration of the photovoltaic systems in the selected bars was as follows:

1. Bar 2: 1 system with the measurement 1
2. Bar 9: 1 system with the measurement 2
3. Bar 16: 1 system with the measurement 3

**Table 5.** Photovoltaic Panels Measurement.

| Harmonic Order | Measurement 1 | | Measurement 2 | | Measurement 3 | |
|---|---|---|---|---|---|---|
| | Current (A) | Angle (°) | Current (A) | Angle (°) | Current (A) | Angle (°) |
| 1 | 7.574 | 5.27 | 15.81 | -7.95 | 6.795 | 226.27 |
| 2 | 0.139 | 216.80 | 0.541 | -4.19 | 0.108 | 341.45 |
| 3 | 0.167 | 214.67 | 0.263 | 3.36 | 0.085 | 181.01 |
| 4 | 0 | 0 | 0.287 | -0.82 | 0 | 0 |
| 5 | 0 | 0 | 0.287 | 2.28 | 0.076 | 280.45 |
| 6 | 0 | 0 | 0.081 | -52.27 | 0 | 0 |
| 7 | 0 | 0 | 0.115 | -3.39 | 0 | 0 |
| 9 | 0.115 | 293.20 | 0.158 | -0.06 | 0.076 | 181.05 |
| 11 | 0.120 | 112.28 | 0.163 | -1.45 | 0.144 | 59.45 |
| 13 | 0.086 | 356.48 | 0.072 | 1.37 | 0.099 | 354.68 |
| 15 | 0.043 | 140.80 | 0.11 | 4.32 | 0.081 | 233.52 |
| 17 | 0.043 | 348.70 | 0 | 0 | 0.027 | 159.69 |
| 19 | 0.029 | 147.56 | 0.081 | 1.36 | 0.04 | 60.732 |

In the second scenario, a 30% penetration factor of the total power of the bar was applied. On the same point analyzed on the scenario 1, totaling 208 harmonic generating sources, represented as follows.

1. Bar 2: 26 systems with the Measurement 1
2. Bar 9: 26 systems with the Measurement 2
3. Bar 16: 156 systems with the Measurement 3

In the third scenario, 30% penetration of total power was again applied, in order to not cause overvoltage problems [29]; however, now the new loads were applied in all of the system bars to observe a massive dissemination of this technology, totaling 555 harmonic sources, represented below:

1. Bar 2: 26 systems with Measurement 1
2. Bar 3: 15 systems with Measurement 2
3. Bar 4: 23 systems with Measurement 3
4. Bar 5: 32 systems with Measurement 1
5. Bar 6: 28 systems with Measurement 2
6. Bar 7: 28 systems with Measurement 3
7. Bar 8: 47 systems with Measurement 1
8. Bar 9: 26 systems with Measurement 2
9. Bar 10: 26 systems with Measurement 3
10. Bar 11: 26 systems with Measurement 1
11. Bar 12: 17 systems with Measurement 2
12. Bar 13: 22 systems with Measurement 3
13. Bar 14: 40 systems with Measurement 1
14. Bar 15: 43 systems with Measurement 2
15. Bar 16: 156 systems with Measurement 3

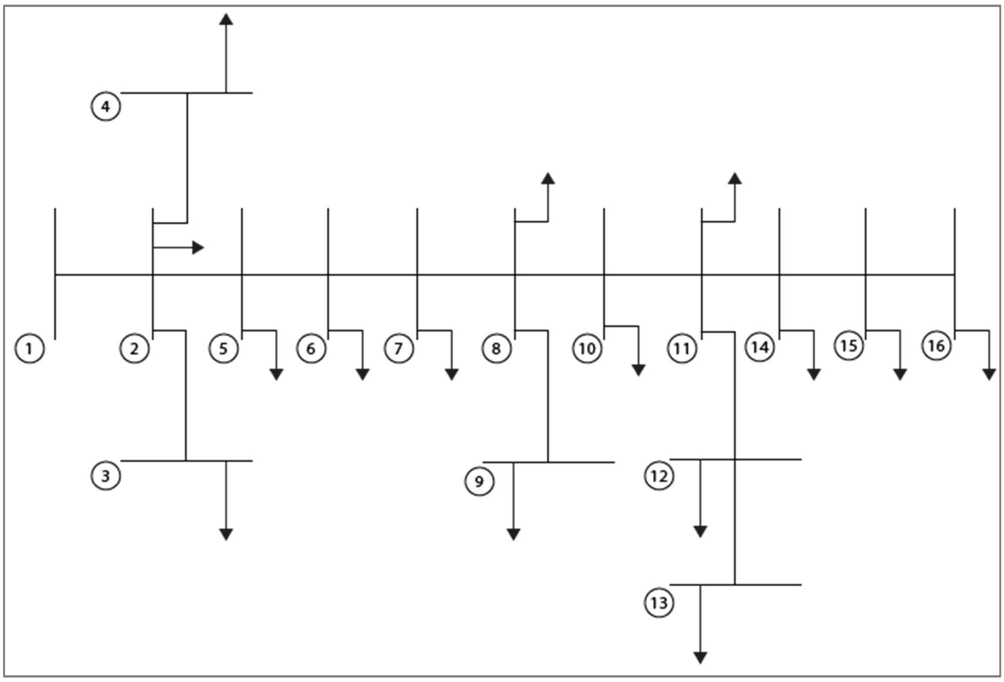


**Figure 2.** Diagram of the Modeled System (Reduced).

**Table 6.** Characteristics of the Grid.

| Bar From | Bar To | R (Ω) | X (Ω) | P (kVA) | Length (m) |
|---|---|---|---|---|---|
| 1 | 2 | 0.23825 | 0.3397 | 412.5 | 1763 |
| 2 | 3 | 0.8695 | 0.403 | 232.5 | 386 |
| 2 | 4 | 0.8695 | 0.403 | 375 | 753 |
| 2 | 5 | 0.2102 | 0.2864 | 517.5 | 554 |
| 5 | 6 | 0.2652 | 0.2908 | 450 | 616 |
| 6 | 7 | 0.2102 | 0.2864 | 450 | 542 |
| 7 | 8 | 0.2102 | 0.2864 | 750 | 1416 |
| 8 | 9 | 0.934 | 0.490 | 420 | 659 |
| 8 | 10 | 0.2641 | 0.2952 | 420 | 1428 |
| 10 | 11 | 0.2641 | 0.2952 | 420 | 1015 |
| 11 | 12 | 0.669 | 0.290 | 277.5 | 1693 |
| 12 | 13 | 1.037 | 0.403 | 345 | 1124 |
| 11 | 14 | 0.2641 | 0.393 | 640 | 4648 |
| 14 | 15 | 0.355 | 0.307 | 682.5 | 2288 |
| 15 | 16 | 0.599 | 0.403 | 2490 | 4607 |

## 5. Results

There is a concern about network's PQ as the number of non-linear loads connected continuously increases, such as inverters in wind and solar photovoltaic systems due to the expansion of renewable energy.

Analysing the harmonic distortion individual and THD of voltage (THDv) in the Buzios network, predicting the massive use of solar systems not only in this network but in the distribution network as a whole, PQ is not a problem when only three bars with one solar system each is connected, as expected.

Figure 3 illustrates frequency spectrum of voltage distortion in scenario 1, whose THDv's maximum value is in order of 0.5%. Those values are presented in Table 7, which summarizes the THDv of all bars. This result indicates that the voltage was not significantly affected in this case.

The voltage harmonic order more significative was the 2$^{nd}$, followed by 4$^{th}$, 5$^{th}$, 9$^{th}$ and 11$^{th}$ as illustrated in the Figure 3.

**Table 7.** THDv in Three Different Scenarios.

| Bar | THD Scenario 1 (%) | THD Scenario 2 (%) | THD Scenario 3 (%) |
|---|---|---|---|
| 1 | 0.5672 | 19.3335 | 69.8388 |
| 2 | 0.5672 | 19.3335 | 69.8388 |
| 3 | 0.5669 | 19.3241 | 69.9115 |
| 4 | 0.5665 | 19.3096 | 69.7369 |
| 5 | 0.5664 | 19.3804 | 69.8366 |
| 6 | 0.5657 | 19.4507 | 69.8356 |
| 7 | 0.5655 | 19.5169 | 69.8035 |
| 8 | 0.5641 | 19.4672 | 69.8011 |
| 9 | 0.566 | 19.7326 | 69.6499 |
| 10 | 0.5527 | 20.1576 | 69.2567 |
| 11 | 0.5519 | 20.1309 | 69.3041 |
| 12 | 0.5509 | 20.0924 | 69.6137 |
| 13 | 0.5363 | 20.7378 | 68.4823 |
| 14 | 0.5137 | 22.4771 | 67.8727 |
| 15 | 0.5022 | 23.4694 | 67.4581 |
| 16 | 0.4744 | 26.4013 | 64.6257 |

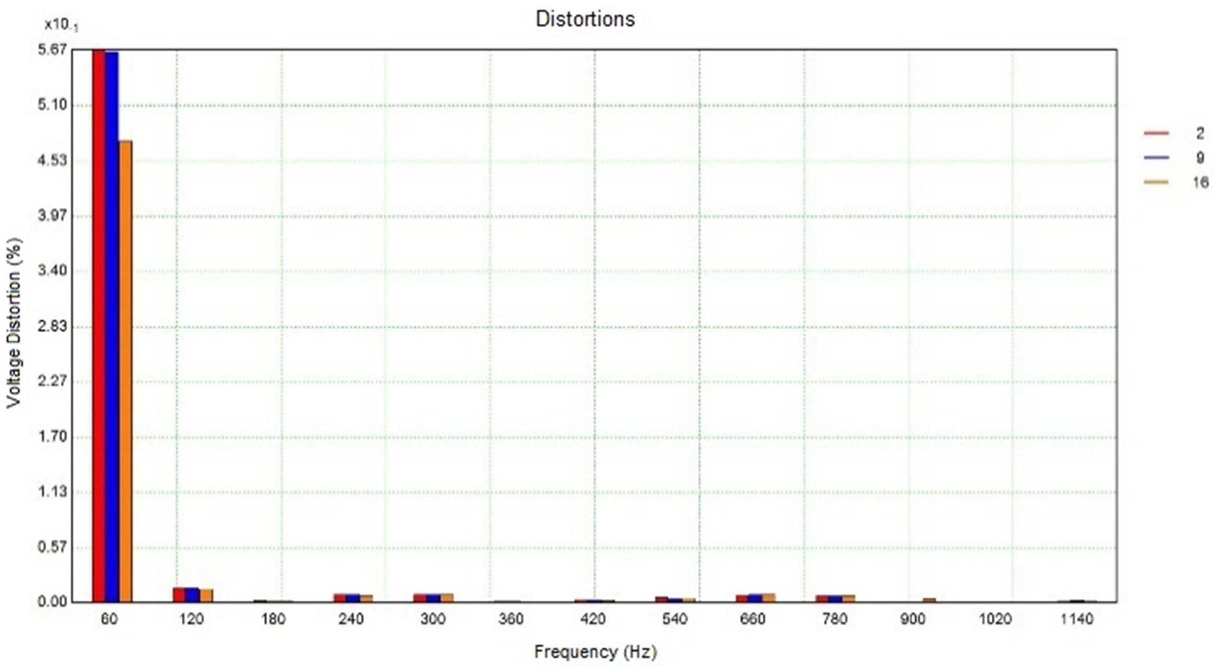


**Figure 3.** Harmonic Distortion of Bars 2, 9, and 16 in the First Scenario.

With the increasing number of systems installed in the second scenario, which represents a 30% penetration in the studied bars (2, 9 and 16), the THDv had an average evolution of 35 times to the previous scenario. In this case, the impact of these inverters on the network will be bigger. Also, through the values displayed in Table 7, it is possible to realize an increase in THDv in the nearby bars of those that have been applied the harmonic sources. This effect shows that the new harmonics sources influence the adjacent bars.

In Figure 4. the frequency spectrum shows a great influence of 2nd and 11th harmonics, other orders also appear as the 13th and 5th, in descending order. In some frequencies, there were only harmonics in bus 16.

It is worth noting that the increase in THDv of bar 16 is almost 56 times greater at the fundamental frequency because it presents the higher network loading.

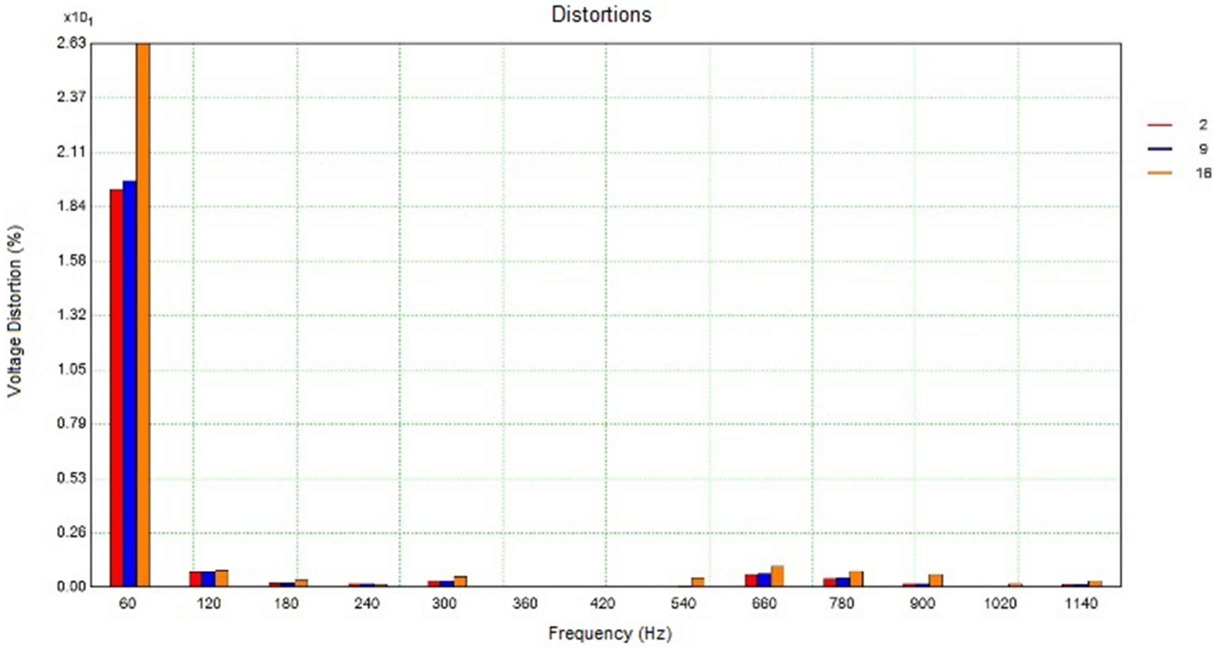


**Figure 4.** Harmonic Distortion of Bars 2, 9, and 16 in the Second Scenario.

The third scenario aims to observe the wide dissemination of technology in the entire distribution network, applying 30% penetration in all bars. With this harmonic source insertion, there was an increase of 3.5 times the value of THDv compared to the second scenario.

The most relevant harmonic frequency in this scenario was the 2nd, closely followed by the 11th and 13th order. This may be seen in Figure 5 and unlike prior scenario, bar 16 had a minor contribution in the fundamental order.

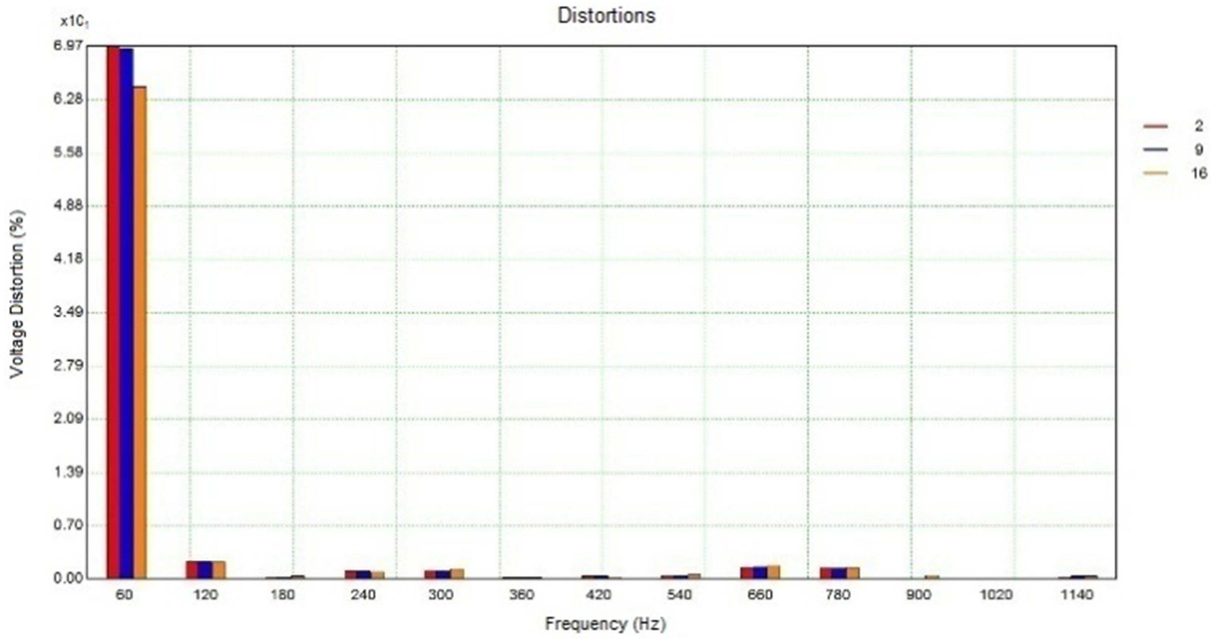


**Figure 5.** Harmonic Distortion of Bars 2, 9, and 16 in the Third Scenario.

In this case, the increase of all bars' THDv was due to the contribution that one bar provides to the neighbouring bar, resulting in an average of 69% in THDv.

## 6. Conclusions

This study aimed to analyze the impacts on power quality caused to the low-voltage distribution networks when there are different penetrations scenarios of DG and, this study verifies if the value of total harmonic distortion of voltage (THDv) are maintained within the desired values. Three cases were created in order to provide current and future scenarios with a wide spread of photovoltaic systems installation.

Although systems have been designed with a penetration in order to maintain the voltage limit, the THDv limit is breached in the two scenarios (2 and 3), because those scenarios showed values higher than 8% (IEEE) and 10% (Brazilian Standard).

Note also that the inclusion of a harmonic source in a bar also affects neighbouring bars, causing problems in THDv across the network. Thus, in the future will be necessary to develop filters and/or other devices capable of framing the harmonic distortion parameters in the network to avoid negative impacts on the grid.

## Acknowledgements

The authors thank Enel (formely Ampla) and its staff that provided support on the measurement at Buzios City, in addition to the data sharing and system information.

## References

[1] EPE, Plano de Desenvolvimento Energético - PDE 2026, 2017 [Online]. Available at: http:// http://antigo.epe.gov.br//pde/Paginas/default.aspx. [Access: 16 feb 2018]. (Portuguese)

[2] T. Lhendup, Rural electrification in Bhutan and a methodology for evaluation of distributed generation system as an alternative option for rural electrification, Energy for Sustainable Development 12 (3) (2008) 13-24. doi: 10.1016/S0973-0826(08)60434-2.

[3] C. W. Shyu, End-users' experiences with electricity supply from stand-alone mini-grid solar PV power stations in rural areas of western China, Energy for Sustainable Development 17 (2013) 391-400. doi: 10.1016/j.esd.2013.02.006.

[4] M. Vatani, M. J. Sanjari, G. B. Gharehpetian, Islanding detection in multiple-DG microgrid by utility side current measurement, International Transactions on Electrical Energy Sytems 25 (2015) 1905-1922. doi: 10.1002/etep.1942.

[5] C. Yammani, S. Maheswarapu, S. K. Matam SK, Optimal placement, and sizing of distributed generations using shuffled bat algorithm with future load enhancement, International Transactions on Electrical Energy Systems 26 (2016) 274-292. doi: 10.1002/etep.2076.

[6] H. Jouybari-Moghaddam, S. H. Hosseinian, B. Vahidi, Grid reconnection detection for synchronous distributed generators in stand-alone operation, International Transactions on Electrical Energy Systems 25 (2015) 138-154. doi: 10.1002/etep.1829.

[7] R. A. Walling, R. Saint, R. C. Dugan, J. Burke, L. A. Kojovic, Summary of Distributed Resources Impact on Power Delivery Systems, IEEE Transactions on Power Delivery 23 (2008) 1636–1644. doi: 10.1109/TPWRD.2007.909115.

[8] M. Karimi, H. Mokhlis, K. Naidu, S. Uddin, A. H. A. Bakar, Photovoltaic penetration issues and impacts in distribution network – A review, Renewable and Sustainable Energy Reviews 53 (2016) 594–605. doi: 10.1016/j.rser.2015.08.042.

[9] P. R. Khatri, V. S. Jape, M. Lokhande, B. S. Motling, Improving power quality by distributed generation, in: 7th International Power Engineering Conference, 2005, pp. 675–678. doi: 10.1109/IPEC.2005.206993.

[10] W. N. Macedo, R. Zilles, Influence of the power contribution of a grid-connected photovoltaic system and its operational particularities, Energy for Sustainable Development 13 (2009) 202-211. doi: 10.1016/j.esd.2009.08.001.

[11] Q. Shi, H. Hu, W. Xu, J. Yong, Low-order harmonic characteristics of photovoltaic inverters, International Transactions on Electrical Energy Systems 26 (2016) 347-364. doi: 10.1002/etep.2085.

[12] J. Rodway, P. Musilek, S. Misak, L. Prokop, P. Bilik, V. Snasel, Towards prediction of photovoltaic power quality, in: 26th Annual IEEE Canadian Conference on Electrical and Computer Engineering, 2013, pp.1–4. doi: 10.1109/CCECE.2013.6567680.

[13] G. A. Rampinelli, F. P. Gasparin, A. J. Bühler, A. Krenzinger, F. C. Romero, Assessment and mathematical modeling of energy quality parameters of grid connected photovoltaic inverters, Renewable and Sustainable Energy Reviews 52 (2015) 133–141. doi: 10.1016/j.rser.2015.07.087.

[14] T. Ackermann, V. Knyazkin, Interaction between distributed generation and the distribution network: operation aspects, in: IEEE/PES Transmission and Distribution Conference and Exhibition, 2002, pp. 1357–1362. doi: 10.1109/TDC.2002.1177677.

[15] P. M. Ivry, M. J. Rawa, D. W. P. Thomas, M. Sumner, Power quality of a voltage source converter in a smart grid, in: IEEE Grenoble Power Tech, 2013, pp. 1–6. doi: 10.1109/PTC.2013.6652457.

[16] J. Urbanetz, P. Braun, R. Rüther, Power quality analysis of grid-connected solar photovoltaic generators in Brazil, Energy Conversion Management 64 (2012) 8–14. doi: 10.1016/j.enconman.2012.05.008.

[17] A. Varatharajan, S. Schoettke, J. Meyer, A. Abart, Harmonic Emission of Large PV Installations - Case Study of a 1 MW Solar Campus, in: International Conference on Renewable Energies and Power Quality, 2014.

[18] D. B. Prakash, C. Lakshminarayana, Optimal siting of capacitors in radial distribution network using Whale Optimization Algorithm, Alexandria Engineering Journal 56 (2017) 499-509. doi: 10.1016/j.aej.2016.10.002.

[19] ANEEL, Resolução Normativa N° 482, Agência Nacional de Energia Elétrica, 2015. [Online]. Available at: http://www.aneel.gov.br/cedoc/ren2012482.pdf. [Access: 16 feb 2018]. (Portuguese)

[20] ANEEL, Prodist - Módulo 8 Revisão 6, Agência Nacional de Energia Elétrica, 2015. [Online]. Available at: http://www.aneel.gov.br/visualizar_texto.cfm?idtxt=1877. [Access: 16 feb 2018]. (Portuguese)

[21] IEEE Power & Energy Society, Transmission and Distribution Committee, Institute of Electrical and Electronics Engineers, IEEE Standards Board. IEEE recommended practice and requirements for harmonic control in electric power systems. 2014.

[22] "Cidade Inteligente Búzios". [Online]. Disponível em: http://www.cidadeinteligentebuzios.com.br/. [Access: 16-jul-2018]. (Portuguese)

[23] Ampla, Levantamento do Perfil Energético de Búzios, Technical Report, 2015. (Portuguese)

[24] S. Yilmaz, H. R. Ozcalik, S. Kesler, F. Dincer, B. Yelmen, The analysis of different PV power systems for the determination of optimal PV panels and system installation - A case study in Kahramanmaras Turkey, Renewable Sustainable Energy Reviews 52 (2015) 1015–1024. doi: 10.1016/j.rser.2015.07.146.

[25] "HarmZs - Estudos de Comportamento Harmônico e Análise Modal de Redes Elétricas". [Online]. Available: http://www.cepel.br/produtos/programas-computacionais/menu/harmzs-estudos-de-comportamento-harmonico-e-analise-modal-de-redes-eletricas.htm. [Access: 27-jul-2018] (Portuguese)

[26] A. R. A. Manito, M. E. L. Tostes, C. C. M. M. Carvalho, K. N. V. Matos et al., Harmonic Analysis of the Electrical System of an Industry of Aluminium at the Connection Point with the Brazilian National Interconnected System, in: IEEE/PES Transmission and Distribution Conference and Exposition Latin America, 2008, pp.1-6. doi: 10.1109/TDC-LA.2008.4641701.

[27] S. L. Varricchio, S. Gomes Jr, R. D. Rangel, Three windings transformer s-domain model for modal analysis of electrical networks, Electrical Power and Energy Systems 33 (2011) 420-429. doi: 10.1016/j.ijepes.2010.10.003.

[28] A. Chidurala, T. K. Saha, N. Mithulananthan, R. C. Basal, Harmonic emissions in grid connected PV systems: A case study on a large-scale rooftop PV site, in: IEEE PES General Meeting, 2014, pp. 1-5. doi: 10.1109/PESGM.2014.6939147.

[29] I. I. Perpinias, N. P. Papanikolaou, E. C. Tatakis, Fault ride through concept in low voltage distributed photovoltaic generators for various dispersion and penetration scenarios, Sustainable Energy Technology and Assessments 12 (2015) 15–25. doi: 10.1016/j.seta.2015.08.004.