POWER QUALITY ANALYSIS FOR DG IN SMART CITY BÚZIOS

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ABSTRACT

Smart grid projects are being development in Brazil due to the possibility of connecting micro/mini distributed generation to the main electric grid after Resolutions 482/2012 and 517/2012 from Brazilian Electric Energy Agency (ANEEL). The installation of distributed generation and related devices requires the identification and measurement of its power quality characteristics aiming to guarantee the quality of the energy supplied. This paper presents some results of the DG implementation in a Brazilian Smart Grid Project named Smart City Búzios. The impacts in voltage, current and power factor after the installation of photovoltaic systems and wind generator connected directly to the grid are shown along with the respective harmonic analysis.

INTRODUCTION

The increasing number of smart city projects around the world highlights the necessity of measuring and analyzing the impact of the renewable distributed generation in power distribution grids [1]. In this paper, renewable distributed generation is considered as the technology dedicated to the production of electricity near to the consumption place [2], which can be installed as a stand-alone application or a modular grid-connected electric generation device located close to the point of consumption [3]. Details of renewable distributed generation technologies like photovoltaic systems and wind generation, together with the energy management systems applied to this equipment, can be found in [4].
Power quality problems as harmonics, flicker, undervoltage and protection system miscoordination, among others, can be cited as important aspects that should be analyzed in smart grid projects [5]. Some interesting research has been developed in this filed, such as: photovoltaic power generation monitoring using virtual instrumentation [6]; microgrids energy management systems considering power quality aspects [7]; microgrid project and design considering distributed generation and power quality restrictions [8], [9] and [10]; topologies and control strategies for grid-connected inverters [11]; power quality index estimation considering distributed generation and islanding conditions [12].
The smart grid power quality problems originated from distributed generation can be reduced via the installation of energy storage devices. However, this strategy raises considerably the installation and maintenance costs, which can compromise the financial project viability [13].
There are some Brazilian studies reported in the literature about the power quality problem related to distributed generation in smart cities. As an example, reference [14] shows some results about distribution grid power quality implications of a photovoltaic system installed in a car parking. Another example is the work presented in [15].
This paper presents some results related to the power quality impact of the renewable distributed generation installed in the distribution grid of Búzios, a city located in Rio de Janeiro State, Brazil. The installation of this (and other) equipment is part of a smart city pilot named Smart City Búzios. This smart city pilot in Latin America will provide data and experience to develop similar or greater projects like this in other Brazilian cities or Latin America Cities enabling to expand the smart cities concept [16].
The paper is organized as follows. After the first section (Introduction), some data from Smart City Buzios project is presented (Smart City Buzios Project section). The methodology and equipment description is shown in the next section (Methodology and Equipment section). Given this technical introduction, the acquired power quality data is presented and analyzed (Results section). Finally, the main conclusions is presented and discussed in the last section (Conclusions section).

SMART CITY BUZIOS PROJECT

As highlighted in [17], the Smart City Buzios Project aims to serve 10,363 customers, being 13 industrial, 1,518 commercial/public services and 8,832 residential loads. The project includes the installation of 25 distribution automatic switch points, besides the use of 3 medium voltage lines (15 kV) with 67 km of lines, 450 medium/low voltage transformers, and forecasted energy consumption of 55 GWh/year.
The project development was done considering eight technical blocks division. This organization was defined to encompass all the necessary areas for the development and expansion of the whole project. The eight blocks can be listed:

- Communication with Customers and Society;
- Smart Metering;
- Intelligent Energy Storage;
- Telecommunications and Systems;
- Renewable Distributed Generation;
- Electric Vehicles;
- Efficient Public Lighting;
- Intelligent Buildings.

Work teams from different Brazilian Universities and Research Centers was involved in the project. This paper presents some results related to Renewable Distributed Generation technical block.

METHODOLOGY AND EQUIPMENT

The first analyzed equipment was a solar photovoltaic system installed in a public educational institution devoted to children with special needs (APAE in Brazilian acronym). This distributed generation equipment was fixed in an area with considerable solar radiation (Buzios is a well-known Brazilian seaside tourist town famous by its sunny climate and its beautiful beaches). An illustration of the equipment is shown in Figure 1.

This solar photovoltaic generation system presents polycrystalline film panels along with a 220 [V] inverter. The current harmonic content of this equipment was measured and some results are presented in Table 1.

Figure 1. Polycrystalline film panels installed in APAE (a Brazilian public educational institution devoted to children with special needs)

Table 1. Greatest one-phase current harmonic content registered during a fifteen minute measurement interval.

Order	IA (A)	IA (%)
1	14.67	100.00
2	0.543	3.70
3	0.361	2.46
4	0.256	1.74
5	0.219	1.49
6	0.173	1.18
7	0.137	0.93
8	0.132	0.90
9	0.123	0.84
10	0.105	0.71
11	0.096	0.65
12	0.091	0.62
13	0.078	0.52
14	0.078	0.52
15	0.068	0.46
16	0.082	0.56
18	0.078	0.52
20	0.068	0.46

The second analyzed equipment was a solar photovoltaic generation system with thin film panels. This distributed generation equipment was installed in the monitoring and control center also located in Buzios. In this experiment the objective was to analyze the current harmonic content in the inverter output, combining measurements done before and after a LC filter contained in the equipment. This inverter is connected to four solar panels and its electronic circuit is presented in Figure 2.

Figure 2. Electronic circuit of the inverter dedicated to the solar photovoltaic generation system installed in the monitoring and control center in Buzios.

During the measurement period, the greatest total current harmonic distortion (THDi) verified before the LC filter was 4.987 [%]. After the LC filter and for the same measurement instant the THDi was 4.287 [%]. Figures 3 and 4 show the harmonic spectra and current waveform from one phase aiming to illustrate this behavior.

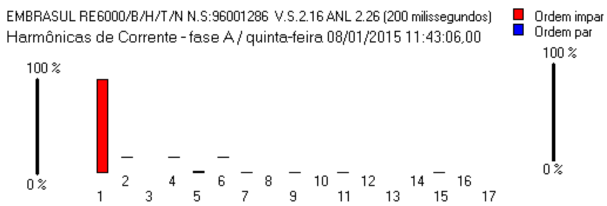

Figure 3. One-phase current harmonic spectrum in the inverter output of the solar photovoltaic system in the monitoring and control center. The legend is presented in Portuguese due to the equipment specification.

The third analyzed equipment was a vertical axis wind generation system directly connected to the distribution grid. An illustration of this installation is presented in Figure 5.

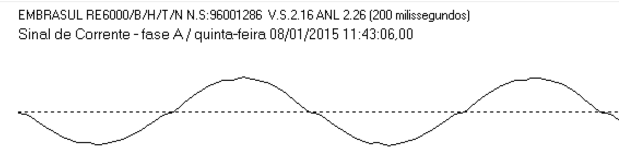

Figure 4. Current waveform in one-phase of the inverter output of the solar photovoltaic system in the monitoring and control center. The legend is presented in Portuguese due to the equipment specification.

Figure 5. Vertical axis wind generators

The current harmonic distortion was analyzed for the wind generation system considering wind velocity variations during the measurement period. The data was collected in the inverter output. The worst harmonic condition occurred for low power condition (46.764 [%]) and the harmonic content is shown in Table 2. Figures 6 and 7 present the harmonic spectrum and the one-phase current waveform, respectively.

The fourth analyzed equipment was another vertical axis wind generation system installed in the monitoring and control center in Buzios. The voltage total harmonic distortion (THDv) in the connection point between the wind system and the distribution grid is evaluated in this case. The greatest harmonic distortion that was measured is presented in Table 3. Figures 8 and 9 show the one-phase voltage harmonic spectrum and the one-phase voltage waveform, respectively.

RESULTS

The IEEE 519-1992 standard establishes current harmonic distortions limits for non-linear loads. Considering the size of the renewable distributed generation studied in this paper, these limits can be applied for harmonic evaluation of these systems. The IEEE 519-1992 limits are presented in Table 4. It is important to highlight that all the generation equipment is limited to this current distortion bounds regardless of the relation I_{cc}/I_1.

Table 2. Greatest one-phase current harmonic content registered during a fifteen minute measurement interval – wind generation system

Order	IA (A)	IA (%)
1	0.507	100.00
2	0.193	38.09
3	0.058	11.42
4	0.072	14.28
5	0.063	12.38
7	0.039	7.61
8	0.058	11.42
9	0.019	3.80
11	0.024	4.76
12	0.014	2.85
14	0.014	2.85
18	0.005	0.95
21	0.005	0.95
23	0.005	0.95
24	0.005	0.95
26	0.005	0.95
27	0.005	0.95

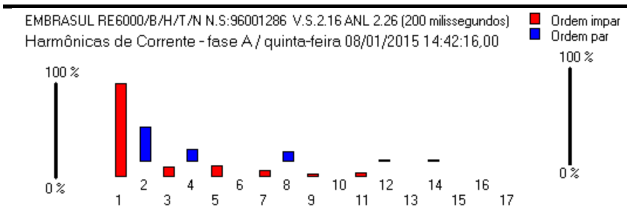

Figure 6. One-phase current harmonic spectrum in the inverter output of wind generation system. The legend is presented in Portuguese due to the equipment specification.

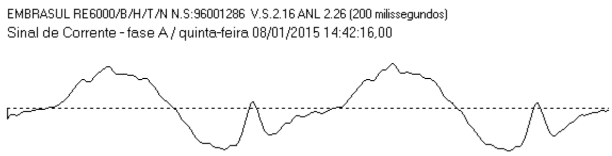

Figure 7. Current waveform in one-phase of the inverter output of the solar photovoltaic system in the monitoring and control center. The legend is presented in Portuguese due to the equipment specification.

Table 3. Greatest one-phase voltage harmonic content registered during a fifteen minute measurement interval – wind generation system in the monitoring and control center

Order	VA (A)	VA (%)
1	124.25	100.00
3	0.459	0.36
11	0.819	0.65

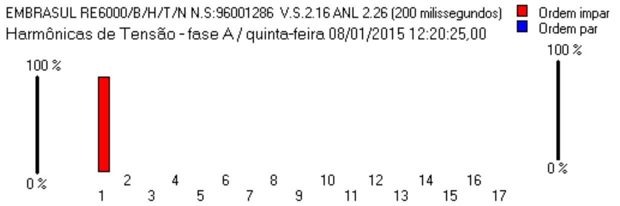

Figure 8. One-phase voltage harmonic spectrum in the connection point between the wind generation system and the distribution grid. The legend is presented in Portuguese due to the equipment specification.

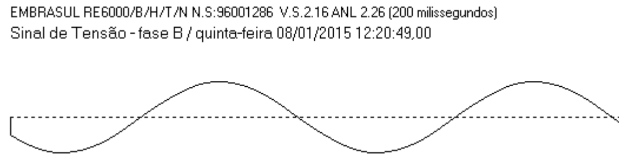

Figure 9. One-phase voltage waveform in the connection point between the wind generation system and the distribution grid. The legend is presented in Portuguese due to the equipment specification.

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Table 4. IEEE 519-1992 harmonics distortion percentage limits (Ih/I1) for non-linear loads with voltage between 120 [V] and 69 [kV]

Odd Harmonics						THDi
I_{cc}/I_1	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h	(%)
< 20*	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100< 1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

The data in Table I (solar photovoltaic system with polycrystalline film) shows that the greatest odd harmonic percentage measured was the 3rd order with 2.46% and the maximum THDi for all measurements was 5.637%. This value is higher than the minimum standard reference and it means that new research related to optimize system must be implemented on the controller.
The idea for the new optimize controller is to get the power quality with limit value less than the international standard. For each harmonic order analyzed separately the individual value is on the limit recommended.
In the case of the solar photovoltaic system with thin film panels (Figures 2, 3 and 4) the measured harmonic distortions is within the IEEE 519-1992 bounds (Table 4). The inverters technology (with or without the LC filter installation) provides small harmonic levels that do not impact the distribution grid.
The wind generation measurements (Table 2 and Figures 6 and 7) show that the oversizing of small wind generators can produce current distortions that are injected in the grid when operating in slow wind velocity conditions. This evaluation is confirmed by the high THDi of 46.674 [%] and by the IEEE 519-1992 bounds passing for various orders (Table 2). Along with the insertion of harmonic filters, this condition can be minimized through the control parameter optimization aiming to disconnect from the grid (or braking) the wind generator when the wind velocity conditions are below some minimum threshold.
In terms of voltage distortion, the data presented in Table 3 is within the bounds considered in the literature. These limits are shown in Table 5 [18].

Table 5. Distortion limits for low voltage grids [Leão 2014]

	Special Applications	Generic Systems	Dedicated Systems
THDv	3%	5%	10%

CONCLUSIONS

This paper presented some results of a Brazilian smart city pilot named Smart City Buzios. Smart city pilot projects like Smart City Buzios are important for the practical evaluation of the new renewable distributed generation technologies that will be connected to the distribution grid. This model of project allows the comparison between technologies from different companies in a real environment, where the equipment are subjected to worse conditions than the ones controlled in the labs.
This activity is complementary to the tests performed in manufactures laboratories and the data produced can be used to support the development of new solutions to answer the questions raised by the different stakeholders (engineers, utilities, academy and end-users). Along with the technology development objective, pilot projects that include university research groups present also an aspect related to professional development. This is an important feature because the technical staff should be trained with new skills and expertise in order to design, project, operate and maintain the smart grid of the future. The promotion of renewable energy to the society is another important aspect of the smart city pilot projects. In the case of a tourist city like Buzios, the spread of the information is even broader.
The power quality of energy produced by the small renewable distributed generation technology installed in Smart City Buzios can be improved. Although the obtained results are not so critical, some improvements should be considered especially about the current.
Another important aspect is the proper distributed generation system sizing. As highlighted for the wind generation system, the oversizing of the equipment brought considerable power quality problems for low velocity conditions. This is not a huge limitation in pilot projects where the technological evaluation is the one of the main objectives. However, in future scenarios considering the installation of a fleet of wind generation

in a microgrid, the huge number of harmonic sources can compromise the power quality indexes of the distribution grid as a whole. In this context, simulation studies using real wind (and solar radiation) data should be carried out for correct renewable distributed generation systems design.

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