Power Quality Evaluation of a Photovoltaic System on an Electric Grid

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Abstract **— This paper focuses on tests of photovoltaic systems in order to address two case studies with silicon monocrystalline and silicon polycrystalline panels, respectively. The first case is an identification of the three parameters of the single-diode equivalent circuit for modelling photovoltaic systems with conclusion about the inevitably age degradation. A comparison between experimental observed and computed I-V and V-P characteristics curves is carried out at standard test conditions. The second case is an experimental observation on a photovoltaic system connected to an electric grid in what regards the quality of the energy injected into the grid. A measuring of the harmonic content in the voltage and in the current waveforms at the terminals of the photovoltaic system is carried out in order to conclude about the conformity with the Standard EN 50160 and the IEEE 519-1992, respectively.**

Keywords: PV systems, power quality, harmonic distortion, electric grid, experimental results.

I. INTRODUCTION

The increasing integration of distributed power generation systems (PGSs), namely wind systems or photovoltaic (PV) system will change considerably the dynamic behavior of the energy power system in comparison with the forerunner one [1]. Actions have to be envisaged against this change to eventually circumvent the reduction of power system frequency regulation capabilities and to ensure that consumer power quality is not compromised [1]. The harmonic content, as one of the power quality issues, requires that the harmonic distortion is kept as low as possible on the energy flowing through the grid. Some standards, for instance, EN 50160, IEEE Standards 519 and 1547 impose limits on voltage harmonics, on current harmonics and on total harmonic distortion (THD) of the energy injected into electric grid [1].

II. MODELING

For the forward bias cell the I V characteristic is formulated by an implicitly function [2] given by,

$$I_{pv} = I_{ph} - I_0\left(e^{\frac{V_{pv}}{mV_T}} - 1\right), \tag{1}$$

The total harmonic distortion (THD) is given by,

$$\mathrm{THD}\,(\%) = 100\sqrt{\sum_{H=2}^{50} X_H^2}\Big/X_F\ , \tag{2}$$

III. CASE STUDIES

The cases studies are from a PV system [3] situated in LNEG, Lisbon, Portugal, coordinates 38°46'18.50' N, 9°10'38.50' W. For the first case study, the comparison between simulation and experimental results is made for a silicon monocrystalline PV panel Isofotón M-55-L. The data for the silicon monocrystalline solar module Isofotón M-55-L at STC [2] is shown in Table 1.

TABLE 1
DATA FOR ISOFOTON M-55-L MODULE AT STS

V_{MP}^*	I_{MP}^*	V_{oc}^*	I_{sc}^*
17.4 V	3.05 V	21.8 V	3.27 A

The model for the solar cell with single-diode is implemented in Matlab/Simulink. For the experimental results, the I-V characteristic curve of the panel was drawn using the curve tracer PVPM 6020C PVE Photovoltaik Engineering.

The parameters identification of the silicon monocrystalline module tested at STC under IEC 60891, 2009 allows to draw the green curve, while the experimental results gives the blue curve shown for the I-V characteristics plotted in Figure 1.

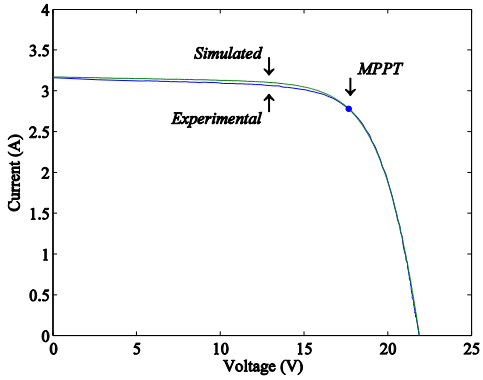

Fig. 1. I-V simulated and experimental curves at STC.

In the second study, under the exploitation of photovoltaic energy, the harmonic content for the voltage and for the current waveforms at the terminals of the photovoltaic system connected to an electric grid is studied by experimentation. The photovoltaic system is composed by silicon polycrystalline modules Solar LDK-225P-20.

The relevant measures are the voltage and current as well as harmonic frequencies at power line. The harmonic content measurement equipment used is the Fluke 41 Power Harmonic Analyzer, which obeys EN 50160. The analyzer automatically calculates power and other measurements useful in determining harmonic distortion levels. This analyzer has a fundamental frequency measurement up to 100 Hz and harmonic frequency measurement up to about 1.5 kHz. Data acquisition harmonic components are up to the 31st order [2]. The harmonic content of the voltage at the terminals of the PV system is shown in Figure 2.

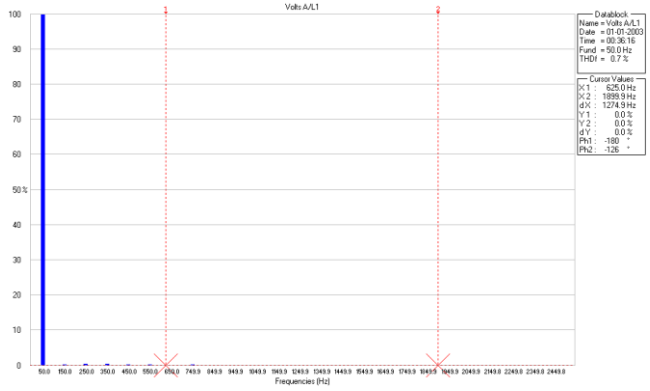

Fig. 2. Harmonic content of the output voltage.

Figure 2 allows to conclude that the dominant harmonic is the fundamental one. Harmonics of higher order with none zero amplitude are of odd order, being the 3rd, 5th, 7th principal ones, but having negligible values. The value of THD is 0.7%. This THD of the voltage is lower than 8% limit imposed by Standard EN 50160 [4]. The harmonic content of the output current at the terminals of the PV system is shown in Figure 3.

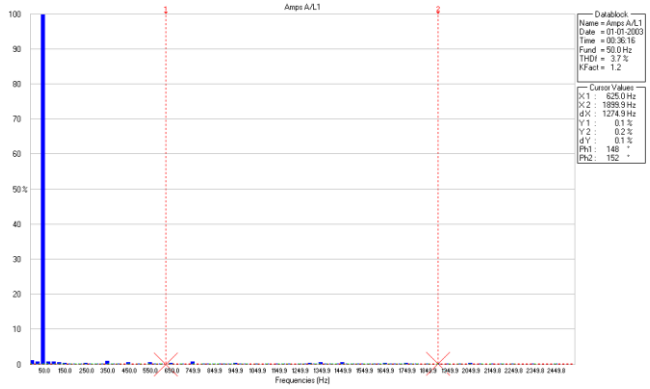

Fig. 3. : Harmonic content of the output current.

Figure 3 allows to conclude that higher order harmonics, the 3rd, 5th, 7th, and inter-harmonics are reveled with negligible amplitudes.

The value of THD is 3.7%. This THD of the is lower than 5% limit imposed by IEEE Standards 519-1992 [4].

The observation of the curves allows concluding that they have a consistent behavior with theoretical studies and knowledge of system behavior leads to predict [2,4-5].

IV. CONCLUSION

The identification of parameters is important in order to consider the change due to the inevitably age degradation, identifying changes on the parameters allows anticipate the performance of the PV system. Silicon monocrystalline panels can be conveniently model by the single diode equivalent circuit as presented in this paper in a case study and conclusions about age degradation can be asserted by comparison with the manufacture data. PV systems connected to the electric grid are equipped with power inverters, converting the electric energy coming as direct current to alternating current, because the electric grid is normally in alternate current. But, even if the voltage of the electric grid has only the fundamental harmonic, inevitable the inverter originates other undesired ones. One of the power quality issues is the harmonic impact on the grid and on the consumer. The harmonic content of a PV system equipped with silicon polycrystalline panels is presented in this paper, reveling a satisfactory power quality of the energy injected into the electric grid.

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