CHARACTERIZATION OF VOLTAGE HARMONIC DISTORTION IN THE PORTUGUESE MEDIUM AND LOW VOLTAGE GRIDS

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ABSTRACT

This paper gives an overhaul account of the state of Voltage Harmonic Distortion in the Portuguese Medium and Low Voltage Grids. Some description is made on the problems faced in this area and the measures adopted to tackle them. In particular, some case studies are presented to emphasize the main disturbance found in Voltage Harmonic Distortion in EDP Distribuição (EDP Group), Portugal, MV and LV Grids, namely the 5th and 7th harmonic components. Some explanations will also be given for the existence on the so called non typical harmonics. Conclusions are finally drawn from the Power Quality (PQ) specific campaigns launched to detect Voltage Harmonic Distortion in our grids and an appreciation is also made on the efficiency of the measures taken to deal with this sort of grid pollution.

INTRODUCTION

In recent years the percentage of weeks in accordance with NP EN 50160 in what regards the voltage harmonic distortion measured results in the EDP Distribuição (EDPD) grid – MV busbars of HV/MV substation and at LV side of MV/LV transformer – has been found to be around 99% and 98%, respectively.

EDPD as an operator responsible for the electric distribution networks of HV, MV, and LV, has been systematically monitoring its grids, in particular the MV and LV, since 2001.

Harmonic voltage distortion results (average values) from the HV/MV substations and MV/LV transformers analyzed in the systematic campaigns (3 months PQ monitoring campaigns) during the period from 2008 to third quarter 2012 are presented, as well as Harmonic voltage distortion results (average values) from the HV/MV substations, from continuous monitoring, since 2011 until to third quarter 2012.

The main disturbance in voltage harmonic distortion found in the Portuguese distribution network, in the course of the measurements, lies in the 5th component of voltage harmonic at particular points along the MV and LV grids. It is caused by a phenomenon of resonance created by the interaction of substation capacitor banks (CB) connected to the MV busbar, along with extensive overhead lines and underground cables in the grids and also with the customer's CB, particularly noticed in some network configurations.

However, a few situations of non-typical disturbances have also occurred, namely even harmonics. Occasionally, on the LV side of MV/LV transformers some unusual values have also been detected for triplen harmonics, slightly higher than the normal for the LV grid. Finally, the 15th harmonic case in a city, is addressed.

CHARACTERIZATION OF VOLTAGE HARMONIC DISTORTION

Table 1 presents harmonic voltage distortion results (average 95th percentile values) from almost the whole number of MV busbars from the HV/MV substations of EDPD, based on the representative week of 3 months PQ monitoring campaigns, during the period from 2008 to third quarter 2012.

The 5th harmonic is the largest, followed by the 7th, the 11th, the 3rd and the 13th. THD has presented values lower than 3%. Finally, it may be said that harmonic voltage values have been stable and far from limits in these last years.

		Harmonic voltage (%) - AVERAGE									
		Harmonic order									$THD_{P95\%}$
Year	MV busbars	$2^{nd}_{P95\%}$	$3^{rd}_{P95\%}$	$4^{th}_{P95\%}$	$5^{th}_{P95\%}$	$6^{th}_{P95\%}$	$7^{th}_{P95\%}$	$8^{th}_{P95\%}$	$9^{th}_{P95\%}$	$10^{th}_{P95\%}$	
2008	159	0,04	0,19	0,04	2,32	0,03	1,18	0,02	0,06	0,01	2,55
2009	165	0,03	0,19	0,03	2,20	0,03	1,19	0,03	0,06	0,02	2,46
2010	166	0,03	0,18	0,03	2,26	0,03	1,34	0,02	0,06	0,02	2,59
2011	169	0,04	0,18	0,04	2,24	0,03	1,34	0,02	0,07	0,02	2,57
2012Q3	142	0,03	0,16	0,04	2,00	0,03	1,25	0,02	0,06	0,02	2,32
Limits NP EN 50160		2,00	5,00	1,00	6,00	0,50	5,00	0,50	1,50	0,50	8,00
		Harmonic voltage (%) - AVERAGE									
		Harmonic order									$THD_{P95\%}$
Year	MV busbars	$11^{th}_{P95\%}$	$12^{th}_{P95\%}$	$13^{th}_{P95\%}$	$15^{th}_{P95\%}$	$17^{th}_{P95\%}$	$19^{th}_{P95\%}$	$21^{st}_{P95\%}$	$23^{rd}_{P95\%}$	$25^{th}_{P95\%}$	
2008	159	0,29	0,01	0,16	0,03	0,08	0,05	0,02	0,05	0,04	2,55
2009	165	0,29	0,01	0,17	0,05	0,09	0,05	0,02	0,05	0,04	2,46
2010	166	0,31	0,01	0,18	0,03	0,09	0,05	0,02	0,04	0,03	2,59
2011	169	0,32	0,01	0,19	0,04	0,10	0,05	0,02	0,05	0,03	2,57
2012Q3	142	0,31	0,01	0,18	0,03	0,09	0,05	0,02	0,05	0,04	2,32
Limits NP EN 50160		3,50	0,50	3,00	0,50	2,00	1,50	0,50	1,50	1,50	8,00

Table 1 – Harmonic voltage on MV grid (average values).

In Table 2 are presented harmonic voltage distortion results (average 95th percentile values) from 778 LV busbars in the same period.

The 5th harmonic is the largest, followed by the 7th, the 3rd, the 11th and the 13th. Since 2009, THD has presented values lower than 3%. Finally, it may be said that harmonic voltage values have been stable and far from limits in these last years.

In general, one notices that LV harmonic values are slightly higher than MV harmonic values.

		Harmonic voltage (%) - AVERAGE									
		Harmonic order									THD$_{P95\%}$
Year	LV busbar	2nd$_{P95\%}$	3rd$_{P95\%}$	4th$_{P95\%}$	5th$_{P95\%}$	6th$_{P95\%}$	7th$_{P95\%}$	8th$_{P95\%}$	9th$_{P95\%}$	10th$_{P95\%}$	
2008	153	0,08	0,44	0,10	2,84	0,07	1,38	0,05	0,24	0,04	3,06
2009	166	0,08	0,45	0,08	2,56	0,06	1,44	0,04	0,27	0,04	2,85
2010	167	0,08	0,44	0,09	2,68	0,07	1,51	0,04	0,24	0,04	2,98
2011	167	0,08	0,39	0,08	2,67	0,07	1,49	0,04	0,25	0,04	2,95
2012Q3	125	0,08	0,49	0,09	2,53	0,08	1,56	0,05	0,27	0,04	2,96
Limits NP EN 50160		2,00	5,00	1,00	6,00	0,50	5,00	0,50	1,50	0,50	8,00
		Harmonic voltage (%) - AVERAGE									
		Harmonic order									THD$_{P95\%}$
Year	LV busbar	11th$_{P95\%}$	12th$_{P95\%}$	13th$_{P95\%}$	15th$_{P95\%}$	17th$_{P95\%}$	19th$_{P95\%}$	21st$_{P95\%}$	23rd$_{P95\%}$	25th$_{P95\%}$	
2008	153	0,39	0,04	0,24	0,11	0,13	0,09	0,06	0,08	0,07	3,06
2009	166	0,42	0,03	0,27	0,13	0,16	0,11	0,07	0,08	0,07	2,85
2010	167	0,40	0,03	0,26	0,11	0,15	0,10	0,06	0,08	0,07	2,98
2011	167	0,44	0,03	0,29	0,12	0,16	0,11	0,07	0,08	0,07	2,95
2012Q3	125	0,46	0,03	0,30	0,14	0,17	0,12	0,08	0,09	0,07	2,96
Limits NP EN 50160		3,50	0,50	3,00	0,50	2,00	1,50	0,50	1,50	1,50	8,00

Table 2 – Harmonic voltage on LV grid (average values).

In Figure 1 is presented the evaluation of harmonic voltage distortion results (average 95th percentile values) from 28 MV busbars of HV/MV substations analyzed by continuous monitoring, during the period from 2011 and to third quarter 2012. Also in this case, the 5th harmonic is the largest, followed by the 7th, the 11th, the 3rd and the 13th.

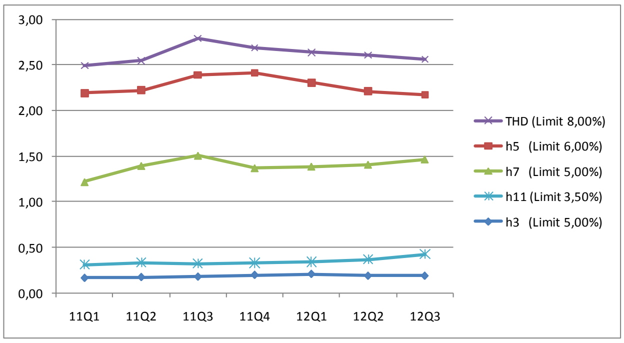

Figure 1 – Evaluation of harmonic voltage distortion results (average values).

Looking at Figure 1, one notices that there was a slight increase of 7th and 11th harmonics, but on the other hand, there was a slight decrease of 5th harmonic, as well as the THD, since the third quarter 2011. THD is mainly due to the 5th harmonic and also presents values lower than 3%.

5TH VOLTAGE HARMONIC

As mentioned in the previous point, the 5th voltage harmonic and, slightly less, the 7th are the main disturbance in voltage harmonic distortion found in the Portuguese distribution network, mainly due by a phenomenon of resonance created by the interaction of substation CB and the network.

DPlan: Harmonic Analysis

In the last few years, in order to characterize some voltage distortion problems found in its grids in the course of these measurements, namely the problems related to the 5th and the 7th voltage harmonics levels, EDPD has been developing harmonic analysis models for simulation of voltage distortion for different network topologies in different load and reactive compensation conditions, with a specialized software tool designated DPlan. The first results on the analysis and simulation of harmonic phenomena in distribution networks were reported in paper [1].

Methodology and some Conclusions

The resonant harmonic, h_r, based on fundamental frequency impedances and ratings is determined by using the following formula [2]:

$$h_r = \sqrt{\frac{MVA_{SC}}{Mvar_{cap}}} \qquad (1)$$

where h_r = resonant harmonic
MVA_{SC} = system short-circuit MVA
$Mvar_{cap}$ = Mvar rating of capacitor bank

When the resonant harmonic is found to be approximately close to the 5th and the 7th harmonic voltage, studies are developed to prevent high voltage distortion based on the identification of potential resonance conditions in most probable network configurations.

Once the non-linear loads have been estimated and the network has been characterized (for the selected frequencies), it is possible to simulate the harmonic behaviour of the system under variations in topology and network parameters. For example, it is possible to simulate the effect of switching-on CB, changing tap positions of transformers, connecting busbars and/or reconfiguring the HV or the MV network.

In this case study, the results of connecting CB can be simulated by running a power-flow for the specific day loads and corresponding network topology.

The impedance curve depicted in the Figure 2 shows the resonance behaviour for the 5th harmonic.

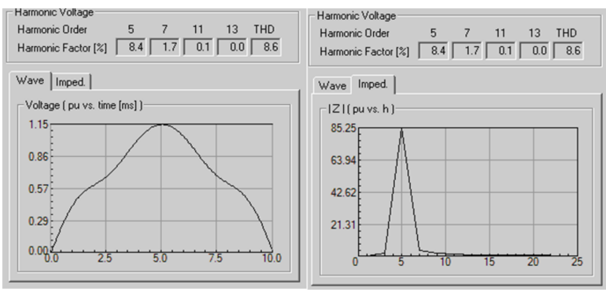

Figure 2 – Harmonic voltage results on MV busbar.

The harmonic distortion problem was being caused by a phenomenon of resonance created by the interaction of substation capacitor banks connected to the MV busbar with the network parameters This resonance was magnifying the 5th harmonic component in the currents from all the customers on this system, producing an increase on the harmonic magnitude. Optimizing the schedule of both CB, together with the management of reactive power in the network, reduces the 5th harmonic voltage to regulatory values. In many cases, it may be more economical to control the voltage distortion experienced by all customers by changing the frequency response of the system. This can be accomplished with carefully planned changes in CB, particularly by changing the switching schedule and/or the capacity level of the CB.

As a conclusion, we present in Figure 3 the 5th harmonic distortion results obtained from the MV busbars monitoring campaigns in the last three years and 3rd quarter of 2012. These results show the number of weeks not in accordance to the NP EN 50160. Looking at them, one notices that the number of weeks not in accordance has been steadily decreasing.

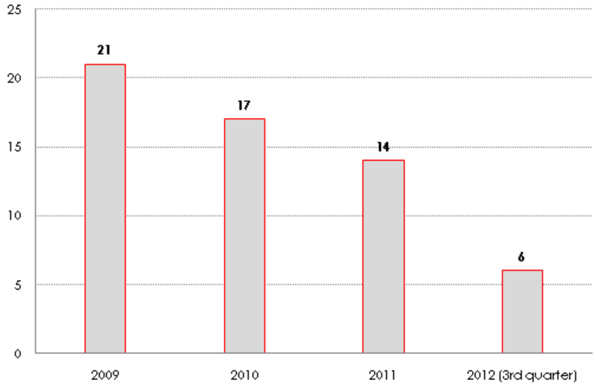

Figure 3 – Weeks not in accordance in 5th harmonic voltage distortion.

NON-TYPICAL HARMONICS

As mentioned before, a few situations of non-typical disturbances have also occurred, namely even harmonics on MV busbars, triplen harmonics on LV busbars, and finally the 15th harmonic case in a city.

In 2009 were recorded the first cases of even harmonics on MV busbars and on the LV side of MV/LV transformers some unusual values have also been detected for triplen harmonics. Considering that was an unusual situation, EDPD was decided to make a harmonic assessment conducted by LABELEC (EDP Group company that operates in the area of laboratory testing and qualification of equipment). On the even harmonics case studies, LABELEC identified its injection by a wind farm and another situation identified an Industrial Unit. On the triplen harmonics case study LABELEC confirmed the relation between triplen harmonics and Public Lighting [3]. These subjects are in detail on another paper presented on the conference.

Based on this assembled studies carried out, EDPD has been identifying some harmonic distortion sources, and therefore, where possible, has been adopting some measures aiming to solve harmonic distortion.

Even Harmonics

One case study is presented as an example of source of even harmonics.

Source: wind farm

The first case study is about the 2sd and 4th harmonic monitored on MV busbar of an HV/MV substation, held between July and September 2011. The period profile for these harmonic voltages and the permissible limits by the standard are shown in Figure 4 and in Figure 5, respectively.

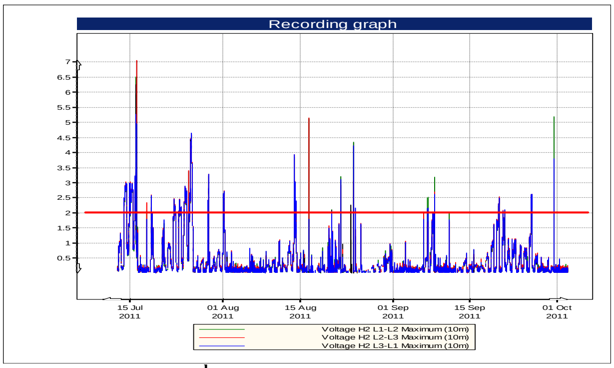

Figure 4 – 2sd harmonic voltage on MV busbar

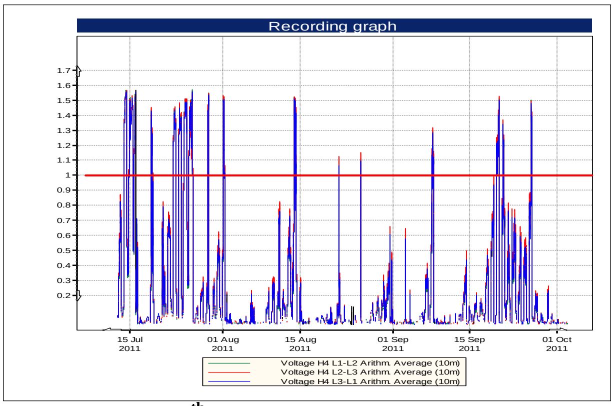

Figure 5 – 4th harmonic voltage on MV busbar.

As on the HV busbar are two lines connected to two wind farms, corresponding to 32,6 MVA of power connected, as well as the harmonic distortion behaviour from MV busbars, it can be expected the source of disturbances is the wind farms. EDPD will continue to follow this situation. Up to now, there is no knowledge of any claims that one can associate with these harmonics.

Triplen Harmonics

As an example of source of triplen harmonics two case studies are presented.

Source: Public Lighting

On the LV 2 phases of MV/LV transformer the 15th harmonic exceeded the limits defined in standard and also the 3rd, 9th and 21st were high, but within the limits. Monitoring held between July and September 2011. The MV/LV transformer is located in an urban area and load profile is clearly a residential one. The Power Transformer is 15000/400V, with 400 kVA of rated power. Transformer winding is Dyn1.

Analyzing all recorded data, it was clear to be in the presence of a daily pattern, with high harmonic values from 6h00 to 19h00, on L2 phase, as is shown in Figure 6.

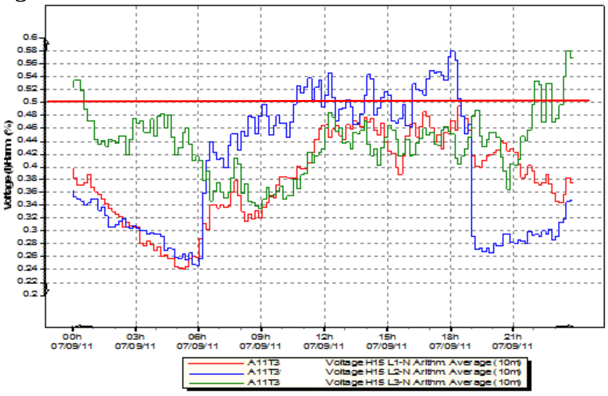

Figure 6 – 15th harmonic voltage on LV busbar (daily).

This analysis conducted to public lighting. The public lighting from this MV/LV Transformer is constituted by 7 feeders, totalizing 52 points of light (sodium vapor lamps).

Considering the LV network was in "head", some LV network build were realized, allowing connected to LV network from an adjacent MV/LV transformer. Thus, some load (customers and public lighting) from the MV/LV transformer was transferred, aiming to decrease the harmonic distortion and improving the robustness of the LV network. An additional monitoring on the MV/LV transformer has validated this measure to mitigate harmonic distortion within regulatory values (15th harmonic on LV 3 phases: 0,26%; 0,41% and 0,31%).

Source: Public lighting control

Finally, it presents the last case study, whose source of harmonic distortion has been known for long time. This case study relates to the 15th harmonic monitored on MV busbar of 8 HV/MV substations, as well as on LV bus of MV/LV transformers, in a city.

This disturbance is due to the public lighting control, based on *ripple control*. *Ripple control* involves superimposing a higher-frequency signal (744 Hz) onto the standard 50 Hz of the main power signal. This city has, since the 1960s, a system based on *ripple control*, allowing remote control of public lighting, decorative lighting (e.g., monuments) and tariff of energy meters.

There are 16 daily emissions, lasting about 3 minutes each, so the signal is present on the electrical network by 2% from 24 hours of the day. It can be expected that InovGrid Project will solve this issue, through the Energy Box of Public Lighting.

CONCLUSIONS

The paper addressed the characterization of voltage harmonic distortion in the Portuguese MV and LV grids, based on EDPD PQ Monitoring Program.

Since 2009, on MV and LV grids, THD has presented average values lower than 3%. The harmonic voltage values have been stable and far from limits in these last years. Based on HV/MV substations continuous monitoring, it can be verified a trend of slight increase of 7th and 11th harmonics and of a slight decrease of 5th and THD.

The main voltage harmonic distortion contribution lies in the 5th voltage harmonic component. It is caused by the phenomenon of resonant frequency between the CB and the network, producing an increase on the harmonic magnitude, in some particular network configurations. However, one can detect a quite effective reduction on the number of weeks not in accordance with NP EN 50160, since 2009. Such reduction is due to the measures undertaken on the grid, as mentioned before.

A few situations of non-typical disturbances have also occurred, namely even harmonics and triplen harmonics. A *Joint venture* between EDPD and LABELEC has allowed the identification of the evens harmonics source. On the triplen harmonic case, the results confirmed the suspected relation between triplen harmonics and Public Lighting.

Finally, it may be said that there is no knowledge of any claims that one can associate with evens harmonics and triplen harmonics, and accordingly it can be expected this sort of disturbances will not be significant.

Acknowledgments

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[3] A. Leiria, F. Bastião, 2013, "Harmonic Assessment on Power Networks - Application to Portuguese Distribution Grid", *CIRED 2013, 0605*.