HARMONIC ASSESSMENT ON POWER NETWOKS – APPLICATION TO PORTUGUESE DISTRIBUTION GRID

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ABSTRACT

LABELEC has developed a method to identify harmonic content and their origin in power networks which has been extensively and successively applied on Portuguese Distribution Grid in sites where harmonics exceeded the standard limits on EDP Distribuição Annual Power Quality Monitoring Program.

The developed technique is based on the use of Fourier Series for identifying the amplitude and phase of the harmonic components of the signal. It uses the direction of flow of the harmonic real power, calculated using monitored voltage and current, to identify the direction of flow of the harmonic power and therefore establishes its origin.

Three case studies have been selected as an example of the methodology application to Portuguese Distribution Grid: capacitor banks and the 5th harmonic, even harmonics and triplen harmonics in LV systems. In all of them, it has always been clearly identified the harmonics origin.

INTRODUCTION

LABELEC is an EDP Group company created with human and material resources from the ancient EDP Central Laboratory, having has part of its mission to provide specialized technical support to EDP Group.

Accordingly, since 2005, EDP Distribuição requests regularly to LABELEC analysis of sites where harmonics levels have exceeded the national regulatory limits.

LABELEC has developed internally, a method to identify harmonic content and their origin in power networks [1], which has been applied both on Portuguese Transmission Grid and on Portuguese Distribution Grid.

On this paper it will be presented the technique itself and also its application on Portuguese Distribution Grid.

METHODOLOGY

The study starts with the identification of an abnormal voltage harmonic content present on a site detected by the Annual Power Quality Monitoring Program (APQMP) carried out by EDP Distribuição.

Afterwards, LABELEC looks into the measurements of the maximum and mean voltage harmonic amplitude during all the monitored period for the harmonics previously identified by EDP Distribuição.

This simple analysis provides a general picture of the problem, as it is usually possible to detect patterns. This information, used with the network configuration and its components, is a good support for preparing the dedicated monitoring campaign conducted by LABELEC which will make possible the detection of harmonic power flow.

This preliminary analysis helps the identification of: the monitoring devices location, the settings to be used on the devices, the number of phases to monitor, the monitoring campaign duration and the period of the year more appropriate to the present harmonic characterization.

As it can be understood, the monitoring campaign is highly customized to the problem in hands, because good and accurate data will be crucial for the success of the analysis. Accordingly, it is also very important to have all the devices synchronized as well as to measure in the same device the corresponding voltages and currents.

The developed technique, which will be detailed on the next point, is based on monitored voltages and currents. On Figure 1 it is shown a monitoring system installed by LABELEC in a HV/MV substation, used to record voltages and currents in the system.

The devices used by LABELEC for these campaigns are all compliant CEI 61000-4-30 class A.

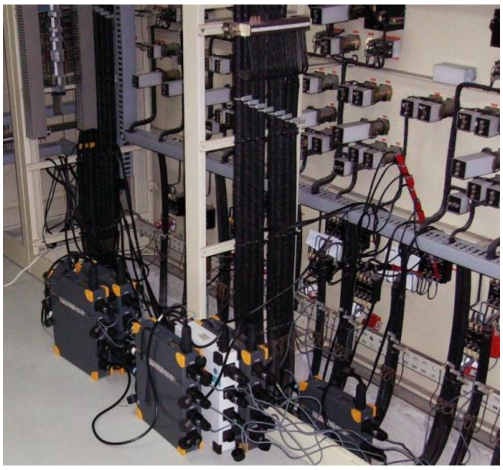

Figure 1 – Example of a monitoring system installed in a HV/MV Substation.

With the recorded voltages and currents obtained, it is possible to identify the harmonic content and their origin in the system, using the developed technique, detailed on the next point.

Depending on the results obtained on each case for the harmonic power flow, additional system operation data is analyzed, for example: capacitor bank switching records, wind farm operating records, customer's power demand curve, etc.

DETECTION OF HARMONIC ORIGIN

The method for detecting the direction of flow of harmonic currents in power networks was detailed presented in [1]. A description of the method and results obtained by its application on synthesized signals and on simple networks (using the ElectroMagnetic Transients Program - EMTP) was given.
The developed method is based on the use of Fourier Series for identifying the amplitude and phase of the harmonic components of the signal. It uses the direction of flow of the harmonic real power to identify the direction of flow of the harmonic power and therefore establishes its origin.
The direction of flow of the harmonic real power is identified by the phase angle between the harmonic voltage at a busbar and the harmonic current flowing out of the bus bar.
The method depends on the accurate identification of the period of the power frequency for the evaluated signal and is based on the following principles:

- The use of Fourier Series to calculate the amplitude and phase angle of each harmonic;
- The use of the signal periodicity for the accurate identification of the fundamental period;
- The use of the direction of flow of the real power of the harmonic to identify the source of the harmonic.

APPLICATION EXAMPLES

Since 2005, the presented technique has been extensively and successively used to analyze cases when harmonics exceed the standard limits on EDP Distribuição APQMP. Three cases have been selected from the experience: capacitor banks and the 5th harmonic, even harmonics and triplen harmonics in LV systems.

Capacitor Banks and 5th Harmonic

When a harmonic characterization is conducted, usually, 5th and, slightly less, 7th are the responsible for worrying power engineers. These harmonics are the highest produced by power electronic devices disseminated on the network and, on some systems, mainly the 5th, is on the resonant frequency between the capacitor bank and the network, producing an increase on the harmonic magnitude.
Portuguese Distribution Grid behaves the same as all the others, and so the 5th and 7th harmonics related with capacitor banks was the first problem analyzed by LABELEC and the one appearing mostly.
With the experience earned in the past with the assembled studies carried out, EDP Distribuição developed its own processes to solve the 5th harmonic due to capacitor bank problem and even to prevent it.
The example presented next is one of the assembled studies developed. On a HV/MV Substation, on the monitoring conducted by EDP Distribuição APQMP, the 5th harmonic went beyond the limits on both the MV busbars. This Substation was supplied at 60 kV by 3 lines and had 2 Power Transformers 60/15 kV, each connected to its busbar, each having a capacitor bank. Busbar I had 4 feeders connected and busbar II had 5.
Following the previously presented methodology, the monitored data obtained by the APQMP carried out by EDP Distribuição was analyzed. For all the monitored period (3 moths) it was identified a habitual behavior on exceeding the 6% standard limit on both busbars, mostly during the night.
Based on the analyzed data a new monitoring campaign conducted by LABELEC, monitoring voltages on HV and MV busbars, as well as currents on every HV lines and MV feeders, Power Transformers and capacitor bank. It was only monitored one phase (line to ground) as it seemed to be similar on the 3 phases.
In order to obtain a weekly pattern, the monitoring period was of almost 2 weeks, and the results are shown on Figure 2 for the 5th harmonic voltage on both the busbars and it can also be identified the periods where both the capacitor banks were connected and disconnected.

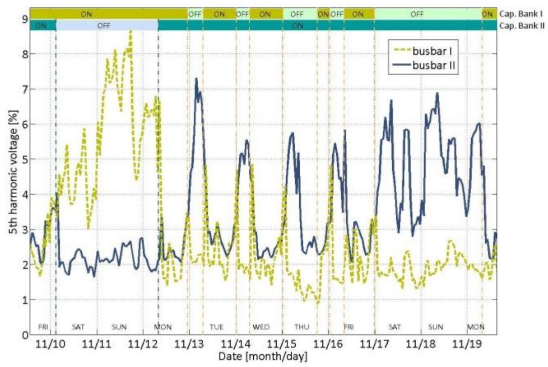

Figure 2 – 5th harmonic voltage obtained during LABELEC's monitoring at MV busbar I and II.

To complete the analysis a harmonic flow in the Substation is presented on Figure 3.

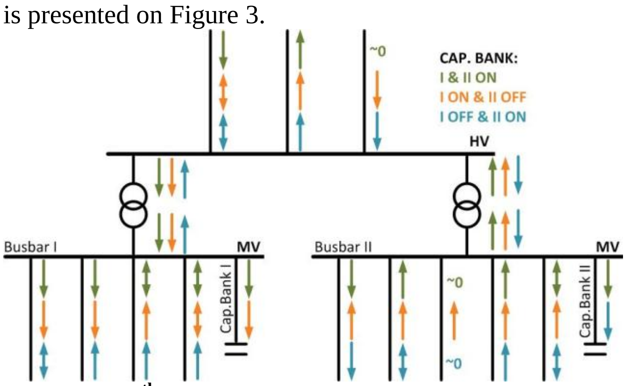

Figure 3 – 5th harmonic current flow at the Substation obtained during LABELEC's monitoring.

It was clearly identified a relation between 5th harmonic and the capacitor bank operation:

- **Both capacitor bank on –** Both the capacitor banks received 5th harmonic, and it was identified a very slightly 5th harmonic circulation on the substation, thus harmonic voltages remained low on both busbars.

- **Just one capacitor bank on –** The working capacitor bank received 5th harmonic, and all the feeders connected to the busbar where the capacitor bank is off injected 5th harmonic, producing a circulating harmonic current from one busbar to the other, thus 5th harmonic voltage raised, sometimes above the limit, on the busbar where the capacitor bank is on.

In this case, the proposal to reduce the 5th harmonic voltage to comply regulatory values, changing the schedule of both capacitor banks, was implemented. Afterwards, an additional monitoring in the HV/MV substation has validated the proposed procedure in order to mitigate the 5th harmonic voltage.

Even Harmonics

As mentioned before, 5th and 7th are the most common and "worrying" harmonics. Meanwhile, other harmonics started to appear, such as 6th and 8th.

Case 1 – Wind farm

On the APQMP, the 6th harmonic went beyond the limits on one phase and the 8th on two phases on a Substation. This Substation was supplied at 60 kV by one line and had one Power Transformer 60/15 kV. There were no capacitor bank installed on the Substation and on the MV side it had just one line connected to a wind farm.

When analyzing APQMP recorded data for the 2 months, it was not possible to identify a daily/weekly pattern on the 6th and 8th harmonic voltages; however it was clearly identified a relation with those harmonics behavior and the wind farm operation.

Based on the analyzed data it was decided to make a new monitoring campaign conducted by LABELEC, monitoring voltages on HV and MV busbars, as well as currents on the HV and MV lines. All the 3 phases were monitored (line to ground) because the behavior was not similar for the 3 phases. The monitoring period was of 2 weeks and the results are shown on Figure 4 for the 8th, just for one week.

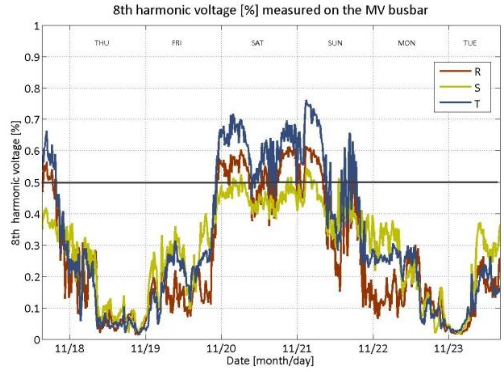

Figure 4 – 8th harmonic voltage obtained during 2nd week LABELEC's monitoring at MV busbar.

To complete the analysis a 8th harmonic flow in the Substation is presented on Figure 5, together with the Power (active and reactive) on the wind farm's line, just for the worst phase. On the left axis, power is represented and on the right axis, harmonic current.

It is clearly identified a relation between the 8th harmonic and the wind farm working regime. 6th harmonic was also analyzed and the behavior and conclusions were quite similar to 8th.

For both cases, harmonic current was always produced by the wind farm and 6th harmonic current clearly followed the active power. For the 6th harmonic this happened for up to 4 MW active power produced by the wind farm; for higher values of power, harmonic current was lower. Consequently 6th harmonic voltage had the same behavior. For the 8th harmonic, power never reached a value for which current did not followed power.

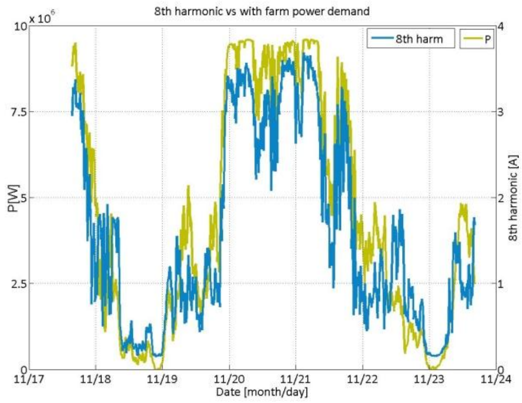

Figure 5 – 8h harmonic current flow at the MV busbar vs. wind farm power demand during 2nd week.

It was clearly identified a relation between 6th and 8th harmonic and the wind farm operating regime. Both harmonics were always produced by the wind farm.

Case 2 – Industrial Unit

On the APQMP, the 6th harmonic went beyond the limits on one phase of the 30 kV busbar on a HV/MV Substation, which was supplied at 60 kV by 2 lines and had 2 Power Transformers each one feeding its own MV busbar (one 30 kV and the other 15 kV). There were no capacitor bank installed on the Substation and both the busbars were feeding just 2 lines.

Following the previously presented methodology, firstly, the monitored data obtained by the APQMP was analyzed. For all the monitored period (3 moths) it is shown on Figure 6 the 6th harmonic voltage on the 30 kV busbar for the 3 phases. On the 15 kV busbar 6th harmonic had low values.

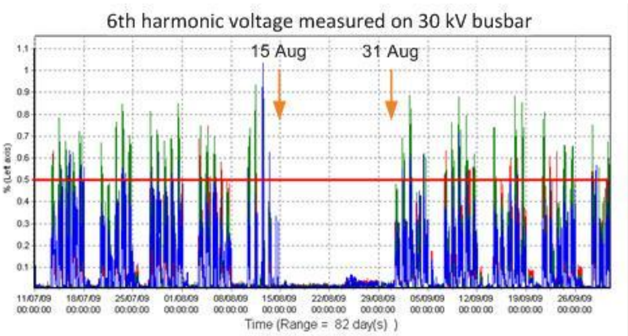

Figure 6 – 6th harmonic voltage monitored during APQMP at 30 kV busbar.

When analyzing the recorded data for the 3 months, it was clear a daily and weekly pattern, with working hours, on the 6th harmonic voltages, as well as the inexistence of 6th harmonic on the 2nd two weeks in August. This preliminary analysis obviously conducted to an industrial unit with 2 shift working regimes per day.
Based on the analyzed data it was decided to make a new monitoring campaign by LABELEC, recording voltages on HV and MV busbars, as well as currents on the HV and MV lines. All the 3 phases were monitored (line to ground) because the behavior was not similar for the 3 phases and the monitoring period was of 2 weeks.
An industrial working regime was identified: high 6th harmonic voltage from 7am to 12pm, and reduced values from 12am to 1 pm and from 8pm to 9pm. The reduced values were also present during the weekend.
To complete the analysis a 6th harmonic flow in the 30 kV busbar is presented on Figure 7, for the worst phase.

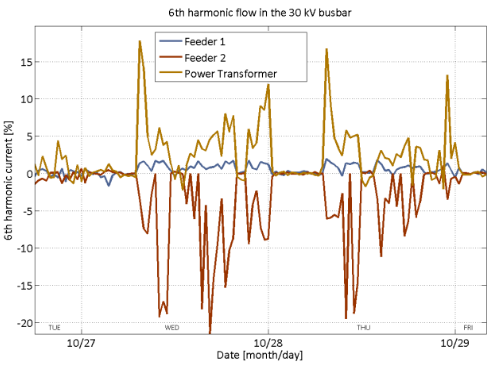

Figure 7 – 6th harmonic current flow at the 30 kV busbar obtained during LABELEC's monitoring.

It is clear the 6th harmonic injection from feeder 2 and its absorption by the Power Transformer, which will block it on its delta winding.
As the feeder was identified, an analysis of the 18 MV/LV transformers power demand curve supplied by this feeder was conducted. The analysis consisted on relating the 6th harmonic and the power demand, hoping to find an unquestionable relation between them in one of the MV/LV Power Transformers. And it was found on one of them, as shown on Figure 8.

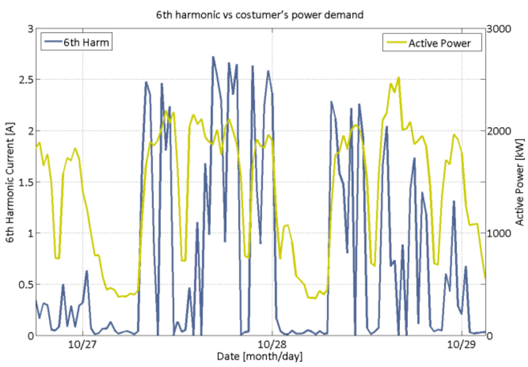

Figure 8 – 6th harmonic current at the polluted feeder and costumer's power demand.

This Power Transformer belonged to a client, supplying an Industrial Unit, confirming thus the entire hypothesis.
Concluding, it was clearly identified a feeder connected to the 30 kV busbar always injecting 6th harmonic. On this feeder it was identified the client (Industrial Unit) with a working regime similar to the 6th harmonic.

Triplen Harmonics in LV Systems

On a MV/LV Power Transformer, on the monitoring conducted by EDP Distribuição APQMP, the 9th harmonic went beyond the limits on the LV 3 phases and also the 3rd, 15th and 21st were high, but within the limits.
Following the methodology, the monitored data obtained by the APQMP was analyzed. When analyzing the recorded data for the 3 months, it was clear a daily pattern, with high harmonic values from 7h00 to 17h30. This preliminary analysis obviously conducted to Public Lighting. On the analysis conducted with LABELEC's monitoring data the results confirmed the suspected relation between triplen harmonics and Public Lighting. This subject is in detail on another paper presented on the conference.

CONCLUSIONS

LABELEC has developed a method to identify harmonic content and their origin in power networks which has been extensively and successively applied on Portuguese Distribution Grid in cases when harmonics exceeded the standard limits on EDP Distribuição APQMP.
Three case studies have been selected: capacitor banks and the 5th harmonic, even harmonics and triplen harmonics in LV systems.
On the example presented for the 5th harmonic and capacitor banks on a HV/MV substation it was clearly identified a relation between 5th harmonic and the capacitor bank operation.
Regarding 6th and 8th harmonics it was clearly identified its injection by a wind farm in one HV/MV substation and on another case it was identified the client (Industrial Unit) responsible for the 6th harmonic injection on the substation.
On the triple harmonic case, the results confirmed the suspected relation between triplen harmonics and Public Lighting.
Based on this assembled studies carried out, EDP Distribuição has been adopting several measures aiming to solve harmonic distortion and even to prevent it. Additional monitoring on the HV/MV substations and on MV/LV power transformers validated the mitigation procedures proposed by the studies in order to prevent harmonic voltage distortion.

REFERENCES

[1] A. Leiria, A. Morched, M.T. Correia de Barros 2003, "Identification of Harmonic Sources in Power Networks", *Power Tech Conference Proceedings, 2003 IEEE Bologna*.