NEW TRENDS FOR POWER QUALITY MONITORING: TOWARDS A FAST RESPONSE ANALYSIS.

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ABSTRACT

Power quality has been traditionally associated with measuring campaigns and detailed reports comprising lots of indexes and analyses. Nevertheless, we have always believed that power quality could be a powerful tool in the same way as SCADAs play their important role in daily operation. Therefore, in ENDESA we began to develop a new approach to the study of power quality focused on rapid solutions, not just on papers.

INTRODUCTION

The philosophy involved in this project, started in 2003, comprises:

- Permanently installed equipment with low delay data transmissions (less than 1 hour).
- Huge, but extremely fast and robust database where data is collected, analyzed and stored.
- Web and end-user oriented application, suitable not only for power quality experts.
- Fully automated, due to the large amount of installed analyzers.
- Use and development of software subject to GPL and BSD licenses (thus avoiding paying for expensive licenses) and fully customized to specific needs.

The result is an evolving system which covers at this moment roughly 45% of our distribution network in the south of Spain (330 sites), employs the most modern communication techniques such as GPRS, and gathers information not only from power quality analyzers, but also from weather stations, SCADAs and lightning recordings. In hands of operators, it allows them to explore, almost instantaneously, the source of customers complaints, i.e. due to dips/sags, and their possible match to electrical faults or severe weather conditions. Moreover, detailed past analysis and future weak points discovery is also performed by automated methods, being less prone to errors and oversights.

This report intends to describe the main parts of the architecture, as well as the most important straightforward data analysis tools.

ON-SITE INFRASTRUCTURE

Based on our own experience with power quality monitors, we decided to focus our efforts on permanently installed equipment in HV/MV substations. Due to the fact that most customers are fed at the MV level, this seems to be a quite reasonable option. Since equipment should be installed mainly on ready-made substations, in order to keep installation simplicity no currents were included in the metering plan. Even though the distance to customers is sometimes high, each monitor covers a quite wide area and the effect on any of them is quite approximate. This fact is even truer regarding dips/sags, since we are seldom interested in very exact magnitudes. Nevertheless, permanent equipment do not intend to replace portable units, but to work in close cooperation. The main fact is that workforce for both types of monitoring installations is quite similar, while portable equipment usefulness is found in many occasions quite constrained. The overall quality of our distribution and transmission network can also be addressed and improved by monitoring substation's busbars. As it is explained all along this document, this last issue is quite important from the utility point of view, since many hidden and spurious problems can be detected and solved. In this sense, monitors have not only been installed in MV busbars, but also at the HV and EHV levels.

With regard to the class of equipment, it was chosen of A type according to IEC 61000-4-30. This decision was mainly supported by flicker measurement, since our goal was to be able to compare this variable across geography with high reproducibility.

Telecommunication facilities at substations played also an important role. Even though there are recent plans to improve the bandwidth by enlarging the use of fiber optics, at the beginning of this project this kind of infrastructure was not widely spread. Therefore, we decided to rely on existing public GPRS/GSM wireless access.

Due to the expected high number of monitoring units that we were going to need in the nearby years, a specific new development was accepted by a leading manufacturer. This equipment was able to monitor the voltage of 2 busbars at the same time and send records periodically by GPRS. It had also an important advantage compared to single busbar equipment, since both measurements could be absolutely synchronized without the need of complex GPS facilities.

Nevertheless, several of these constraints do not matter when talking about new substations and refurbishments. For instance, while writing this document there were 18 new single busbar equipment already installed, able to monitor both voltage and transformer's current.

DATA CENTER

Data center design is another core component of the power quality system. Since the beginning we felt that with such a huge amount of recorders and data, we should follow an overall and robust technology. Our perception of the state of the art about power quality information systems was quite negative, mainly due to its constraint on single user computers and to the very reduced amount of data. We did want to gather all the information, store it and be able to present it to final users quickly. It was not acceptable to be waiting several minutes for simple queries. It was not admissible either to backup and delete ready stored data periodically. We did want to be able to compare data across different sources and not to delete information for at least 10 years.

By the end of year 2006 the main database comprised around 3000 million single phase-to-phase recordings, being just at 10% of its full capacity. In fact this database contained roughly 23 million complex 10-minute recordings and more than 2 million single phase-to-phase dips, swells or interruptions. Each complex 10-minute recordings comprises around 100 variables, such as harmonics up to 25th, flicker and unbalance for each phase-to-phase voltage. Therefore, the overall size of data easily reaches 3000 million single phase-to-phase variables. Meanwhile, data intensive queries do not take more than 3 or 4 seconds at most.

System architecture is depicted below. It consists of the following boxes:

- Public internet access (ADSL) router.
- Router, firewall and NAT unit.
- FTP server, lightning and weather data collector.
- Extra support unit, in charge of backups and system supervision.
- Main server, running the SQL database (PostgreSQL), web application server (Zope) and several scripts for data analysis and insertion (Python).
- Backup server, able to fully replace the main server in case of disaster or maintenance.

All these boxes run FreeBSD operating system (32 or 64 bits x86 architectures) and are equipped with redundant hard disk arrays (RAID).

END-USER INTERFACE

Human interaction is provided through a web page, thus changes are widely spread to all users with no need of installation programs. It also let us listen to final users and change fast enough in order to cope with their recommendations.

READY-MADE TOOLS

Instead of designing a very configurable tool only suitable for very expert people, we decided to set up many but simple straightforward features. The following paragraphs will show up the most important types of tools and how they are useful when finding failure sources.

Voltage related

First of all, three phase-to-phase RMS voltages can be directly plotted for each measurement point. It is also possible to plot such data as a fraction of rated voltage (%), letting the final user check whether voltage tolerances are fulfilled or not. It is also possible to average the 3 measured voltages in order to get just a simplified voltage value.

It is also essential to check whether automatic voltage regulators at MV are working properly. Strange behaviors are not always easy to find, but several ways of checking the way voltages vary during each day may help. The easiest way of checking it is to plot maximum and minimum voltage in sliding windows of 2 hours, since it is a much higher time than the time an automatic voltage regulator needs for correcting voltages. If these two values follow each other up and down and the distance between them is small, it seems that regulator does not work at all. The next chart shows this abnormal working mode during several central days, being the rest of the time period absolutely correct:

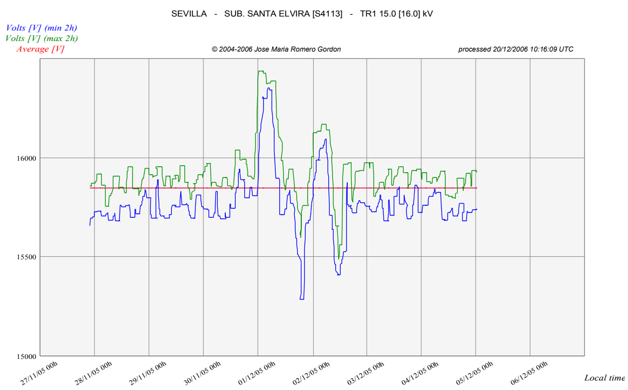

fig. 1 Evolving 2-hours voltage chart.

Harmonics

Maybe *harmonics* is one of the most widely pronounced words in the electrical industry, even though their effects and ways of mitigation are rarely known. Due to the widespread use of our power quality analyzers and to the fact that they are permanently recording data, we are able to check almost in real-time if a special case of resonance has been created due to the switching of capacitor banks. In this sense, the past 4 hours alarms for excessive THD values are visible to operators, as well as an automatic graphical report which comprises the overall harmonic distortion and coupling of capacitor banks at the MV level. Therefore, it is quite easy and straightforward to give advice to disconnect such capacitors or to change the busbar couplings in order to lower the overall resonance phenomena. An example of this synthetic chart is shown below:

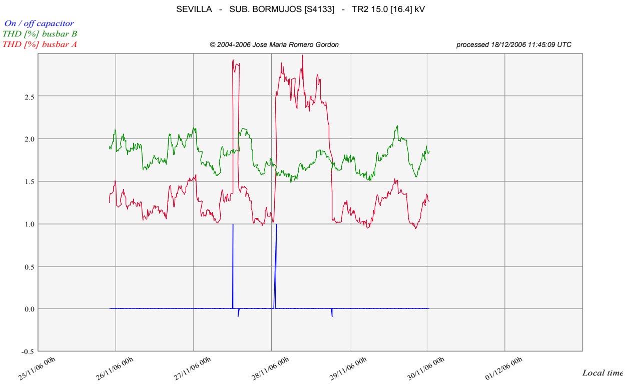

fig. 2 Combined harmonics and capacitor chart.

Another important problem regarding harmonics is created by transformer de-rating. Since harmonic currents may lead to very high values, it is important to check how much transformer losses reduce their effective power. Certain formulas, such as *factor-K*, can be applied more or less precisely. Since power quality analyzers only record voltages, current is approximated by using a 10% pure inductive short circuit reactance and neglecting harmonics at the HV side of HV/MV transformer. Next follows an automatic graphical report including the power and energy loss (this latter expressed as equivalent hours at full load):

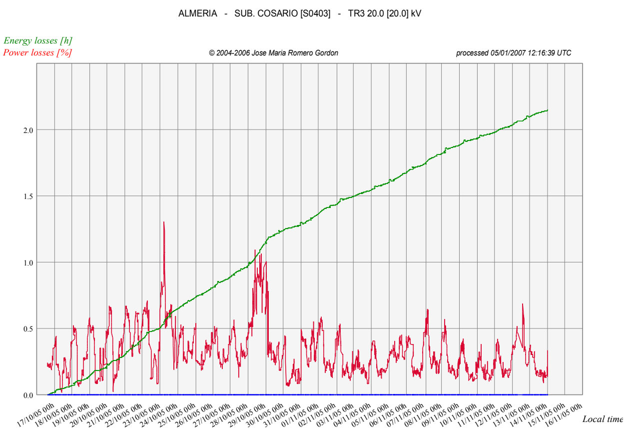

fig. 3 Transformer power and energy losses.

Other electrical variables

Among others, useful electrical variables such as flicker, unbalance and frequency can also be plotted and numerically exported.

Weather indexes

Weather conditions build up a rather useful tool of this system. By means of public data available on internet, it is possible for us to approximate certain meteorological variables close to any substation at any time. Therefore, we use but do not maintain weather automatic stations spread all over our geography. As it will be shown further on, this data is used for matching any event to any specific weather conditions which could lead to electrical faults. Time resolution ranges from 30 minutes up to 1 day.

Lightning

Lightning activity is automatically recorded by direct connection to the Spanish Meteorological National Institute (INM.es). Each lightning is recorded just a few seconds or minutes after its time of occurrence. Each lightning spark is defined by a certain current magnitude and by an elliptical area of influence. Its location will be used afterwards for finding the most likely source of a dip or interruption. The intersection of these ellipses and electrical lines, which is calculated on a daily basis by other company departments, is also used for matching the sources of faults.

SCADA

All breaker trippings are stored in the central database. This is an essential tool since it is fully used to match any dip with the most likely source. Updating frequency reaches 30 minutes. It also provides certain quality indexes for each substation as a whole, such as the number of breaker trippings per week and overall changes during a certain period of time. These functionalities are useful for checking if a circuit breaker is working too often and the overall quality perception of any substation.

Dips, swells and interruptions

This is one of most powerful tools of this system. It intends to match many sources of information within the same snapshot, by freeing the user from rudimentarily gathering many sources of information.

Dips and swells may be graphically shown in a voltage versus duration chart and compared, among others, to ITIC and SEMI F47 curves. They are also classified within certain voltage tolerances (10% increases) and cumulative percentile 95% is calculated for each of those voltage ranges. Altogether, these graphics give the end user an overall view of dips and swells behavior at any measuring location.

On the other hand, it is also possible to check whether the source of any dip has been at the MV or HV level. It is also possible to know whether its source has been one of the MV feeders or an upstream circuit breaker by automatic comparison of events depth and duration of adjacent MV busbars. *Figure 4* shows the dips coming from upper voltage levels compared to the aforementioned immunity curves.

As stated above, every dip, interruption and swell is matched against the following sources:

- Breaker trippings: faults within a certain time and distance interval are listed. Sort criteria are based on distance in between the substation dip and substation fault, as well as their voltage. The most likely source of such dip must be within the list, although correlated trippings are also included. Therefore, the operator must decide the most likely primer source.

- For each of the trippings above, it is checked if there has been any lightning whose area of influence is over output lines of substation. There is shown the amount of lines affected and lightning current.
- Close lightning, showing up its magnitude and distance to the substation. This result sometimes collides with the previous one, although it is maintained since it does not depend on bulky and batched cartographic calculations.
- Weather conditions at the nearest weather station, showing up its distance to the substation (i.e. Daily rain).

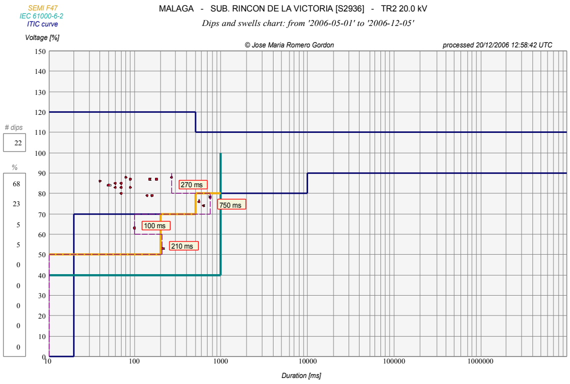

fig. 4 Calculated HV dips and swells.

Therefore, the operator is able to perform an almost on-line study of dips, swells and interruptions finding out the most likely source and approximate weather conditions. Let's take a look on an example:

Start (local time)	End (local time)	Duration [ms]	Type	Phases	vmin/max [%]	vavg [%]	Small/Large	Severity	Severity index [%]
2006-11-02 20:09:40.050	2006-11-02 20:09:40.140	90	dip	B	73	92	small	low	90%

Spark [kA]	Proximity [km]	Map	Substation	Element/Line	Matching error [secs]	kV	Distance [km]	Lines affected by lightning	kA
-48	3	Mapa	SUB. LEPE	AGUA_LEPE	-28	15.0	0.0	1	48.0
			SUB. MACHOS	PIEDRAS	-26	66.0	7.0		

Weather:	Distance [km]	how old	Precipitations [l/m2/day]	Distance [km]	how old
haze	22	0:20:00	26	4	0:00:00
haze	24	0:20:00	26	9	0:00:00

Table 1 Dips matched against several sources.

The above situation means:

- There has been a dip during 90 ms whose minimum voltage was 73%, only phase-to-phase voltage B was affected and average voltage reached 92%. Moreover, compared to the Spanish Energy Board it must be classified as small. Comparison against the ITIC curve reveals that it is within its tolerance area (remaining voltage is just 90% of the gap between 100% and ITIC curve).
- The most likely breaker tripping source is located at the same substation (SUB. LEPE) on a line called AGUA_LEPE (distance 0.0 km). There is also 1 line affected by a 45 kA lightning spark. This event took place 3 km far away from the substation.
- Another simultaneous breaker tripping is located at substation MACHOS line PIEDRAS. This means that maybe the initial lightning source has been propagated to this adjacent substation through the 66 kV line, leading to its tripping.
- Weather conditions where recorded by an automatic weather station located 22 km far away the substation and just 30 minutes before the event. Daily rain was recorded little closer (4 km) by another station.

Standards and Regulations compliance

Even though on-line analysis is a very powerful and straightforward functionality, sometimes the scope must be enlarged in order to cover events not seen by the operator. This type of reports reveal bad voltage regulation, excessive level of harmonics or human negative light perception due to flicker. Therefore, a more detailed analysis can be done on the most affected nodes and specific measures can be taken. In essence, it compares each measurement point to the EN 50160 standard as well as some still drafts indexes from the Spanish Energy National Board (CNE.es).

The following table shows up the aforementioned indexes for a given measurement point on a weekly basis. It must be noticed that voltages outside admissible tolerances are colored in red.

	Dips/swells				Voltage [%]				
Week begins	Dips	Interruptions	Small	Within ITIC	CP95%	MIN	MAX	Average	Time outside ±7
2006-05-01	1	0	1	1	96.51	92.24	96.99	94.83	490
2006-05-08	4	0	4	4	96.37	92.29	96.89	94.76	530
2006-05-15	9	0	8	8	96.49	92.27	97.08	95	520
2006-05-22	4	0	3	4	96.29	92.17	97.09	94.61	660
2006-05-29	1	0	1	1	96.44	92.29	97.02	94.99	380
2006-06-05	5	0	5	5	96.12	92.2	96.76	94.58	880

THD [%]					Unbalance [%]				
CP95%	MIN	MAX	Average	Time > 8% [min	CP95%	MIN	MAX	Average	Time > 2% [min
1.62	0.48	1.93	1.03	0	0.47	0.26	0.59	0.38	0
1.81	0.54	2.24	1	0	0.47	0.29	0.54	0.39	0
1.5	0.44	1.87	0.97	0	0.56	0.27	0.64	0.41	0
1.92	0.52	2.32	1.02	0	0.5	0.28	0.59	0.39	0
1.52	0.49	2.01	0.92	0	0.48	0.29	0.54	0.4	0
1.18	0.51	1.46	0.81	0	0.48	0.31	0.56	0.4	0

Flicker (Plt)				
CP95%	MIN	MAX	Average	Time Plt>1 [h]
0.34	0.17	0.46	0.24	0
0.3	0.17	0.66	0.25	0
0.39	0.18	1.72	0.3	4
0.34	0.17	1.23	0.27	2
0.34	0.17	0.51	0.25	0
0.35	0.16	0.99	0.23	0

Table 2 Overall weekly indexes.

Snapshot alarms

Snapshots alarms are the first entry to the web page, giving the operator a rough view of the system status. This entry page includes lightning activity by province during the previous day, excessive harmonic distortion during the last 4 hours (maybe due to any resonance), dips and interruptions by substation during the last 48 hours and substations sorted by THD during the last 3 weeks. This information is a starting point for a deeper analysis by using all the rest of tools provided by the system.

ACKNOWLEDGMENTS

Special thanks to my wife, due to her infinite patience while making this project and her listening to my boring *speeches*.