Requirements for a modern PQ and DFR monitoring system

PQ monitoring case study in Portugal

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Abstract— **There are many manufacturers around the world providing power quality (PQ) monitoring and digital fault recording (DFR) solutions. Different monitoring requirements, monitoring practices, and new standardization make for a diverse range of available solutions. The first section of the paper will summarize the requirements and challenges of a modern PQ and DFR monitoring system. The second section will be a case study about the Qualitrol and Qenergia' systems implemented in Portugal, particularly at EDP and REN; it will show what has been done.**

Until IEC 61000-4-30 [1] was introduced in 2003 many power quality parameters were not well defined leading to situations where different instruments produced different results. In 2008 Edition 2 was introduced and Edition 3 is now in progress.

As well as considering 61000-4-30, this paper will summarize the key requirements of the new upcoming IEC 62586 [2] product standard for power quality monitoring devices.

In the second section of the paper we will present how to manage grid measuring points whose characteristics change over time, rather than just manage a fleet of measuring instruments. We will discuss the way to make compatible different types of measurement devices, access different data sources, handle the standards changes both in the limit values and in the way values are calculated and validate PQ and event data.

Different ways of representing power quality information will also be addressed. Presenting information and not just raw data from the monitoring system is essential for efficient management of reports for regulatory and third party use.

The Qualitrol and Qenergia's systems at EDP and REN have been developed to suit existing communication infra structure, automatic and manual data retrieval and integrate in a single software analysis package, in a multi-vendor way, already existing older PQ devices together with new instruments. Combining PQ and DFR data also leads to efficiencies when collecting and analyzing results.

Keywords- PQ and DFR monitoring devices, multiple-vendor PQ data integration, web based PQ and DFR measuring point management.

I. INTRODUCTION

Power quality (PQ) monitoring and digital fault recording (DFR) solutions present several advantages if they can be combined to share recording instruments, substation cabling, communication infra-structure and IT resources. This combination not only has economic advantages and rationalizes internal human and technical resources but offers an easier access to data and opens integration possibilities for intelligent data mining, particularly for summarizing events coming from multiple data sources, like SCADA, protection relays, PQ and DFR instruments.

II. REQUIREMENTS FOR PQ AND DFR SYSTEM

A. *Standards compliance requirements*

The monitoring of (PQ) Power Quality, might it be for regulatory reasons or in direct response to customer complaints, has lead to a high demand for such PQ measurement devices. PQ parameters are frequency, magnitude of supply voltage, Flicker, events (dips, swells, and interruptions), transients, unbalance, harmonics, interharmonics, and rapid voltage changes.

IEC 61000-4-30 [1] which standardized the measurement technique was introduced in 2003; edition 2.0 in 2008. Before that only Flicker and harmonic measurement were well defined, that has lead to the incompatibility of PQ devices from different manufacturers because different instruments have indicated different results [3]. Nowadays most new installed PQ monitoring systems at network operators are requested to be compliant with class A of this standard. This makes it possible to compare measured data from different measurement points and from different vendors. Edition 3 of this standard is now under development.

Whereas [1] describing the measurement technique as of today no product standard is available. IEC 62586 [2] will close this gap and will cover environmental conditions, ratings, design and construction, marking and operating instructions, tests, environmental and safety type tests, functional type tests, routine tests, certificates and re-calibration and re-verification of the PQ monitoring device. Hence [2] is not conflicting but completing [1] with environmental, safety and performance requirements.

1) Main points of a IEC 62586 device

The new product standard will distinguish between PQI-A and PQI-S devices. PQI-A corresponds to class A of [1], PQI-S to class S of [1]. Next to that fixed installed (F) or portable (P), indoor (I) or outdoor (O), general EMC environment (G) or harsh EMC environment (H) are to be distinguished; the possible combinations are summarized in Table I.

TABLE I. TABLE OF DEVICES

	Fixed installed		Portable	
	Indoor application	Outdoor application	Indoor application	Outdoor application
EMC environment G	PQI-A-FI PQI-S-FI	PQI-A-FO PQI-S-FO	PQI-A-PI PQI-S-PI	PQI-A-PO PQI-S-PO
EMC environment H	PQI-A-FI-H PQI-S-FI-H	PQI-A-FO-H PQI-S-FO-H	PQI-A-PI-H PQI-S-PI-H	PQI-A-PO-H PQI-S-PO-H

General EMC environment (G) devices are aimed for example for power stations, MV and LV substations, extended industrial applications. Harsh EMC environment (H) devices are for example high voltage stations, arc furnaces, welding aluminium plants [2].

New for the devices is the requirement that also the 10/12 cycles values shall be provided by the PQI for testing reasons.

Additional "data marking" is introduced as option to indicate that measured data might be unreliable. This can be considered as a manual data flagging e.g. when device was measuring during a maintenance period of a certain busbar or feeder.

[2] specifies what information and in which way vendors shall provide about the PQI functions. For each of the functions like power frequency measurement or flicker measurement the class the range and additional information shall be provided in form of a table.

Type testing, functional testing procedure, gapless measurements, mixed influence quantities testing is covered in the standard and its partly normative Annex.

B. Requirements about the file format of measured data and protocols

The monitoring system shall be capable to import and export COMTRADE files (COMmon format for Transient Data Exchange for power systems, according IEEE Std C37.111-1999) and PQDIF files (Power Quality Data Interchange Format, according IEEE Std 1159.3-2003).

For the time being no standardization is done in how to connect and directly download PQ and DFR measurement data from different manufacturers into a common database. Systems that are able to provide COMTRADE and PQDIF files make it possible to compare data from multiple vendors via import and export functionality. An automatic import and automatic export function in the analysis software makes it easier for network operators to get data from different vendors into a single data base.

Alternatively a 3rd party software need to get developed, this will be further described in section III.

IEC 61850 is a set of global standards that define information exchange and data-models between independent electronic devices (IEDs) in substations. These standards define protocols and interfaces that allow for inter-operability and integration of IEDs. Built upon a physical Ethernet network, the standards provide a mechanism for open information exchange between IEDs and between IEDs and control centre. Ultimately, this will facilitate substation automation. In present operational terms for a fault-recorder, IEC 61850 may be used to gather real-time values of measured quantities, to retrieve recorded data sets and to have the device initiate recording by detecting messages sent via control-relays. New installed devices should comply with this standard in order to facilitate eventual future upgrades to a full 61850 substation communication.

C. Requirements about the analysis software architecture

PQ and DFR monitoring systems can cover few devices up to several hundreds of devices. The software architecture therefore ranges from a simple single PC installation up to a distributed system with several servers and multiple clients.

1) Multiple users and multiple locations

Small monitoring systems typically are managed from one PC where data base and analysis software are installed. When more than one user wants to look at the measured information at the same time or from a different location such software deployment might not be convenient anymore. In such case a proper client server architecture need to be chosen. Advantage of that is that several clients can access the same data simultaneous; the data is stored at a central data base.

2) Download mechanismn of data

Data download is often done automatically during night, but can also be set up to happen during the day. Especially after faults in the network data will be downloaded manually right after the incident.

Hence it has to be distinguished between the manual data download and the automatic scheduled data download. For the latter it is important that the mechanism behind to download is done as a "service" and not as an "application". The difference is that a service is (optionally) started automatically after the PC or server is rebooted for some reason; often this happens when IT department makes e.g. security updates on the server and hence must reboot it. If the data download mechanism is done via an application it must be manually restarted after each boot up of the PC or server; hence in order to avoid that it is recommended to use a "service".

Big monitoring systems with over hundreds of measuring devices bring also another challenge which is the capability of downloading all the data within the required time. Therefore the monitoring system shall have a flexible structure to share the load of data download across several servers. Like that data can get downloaded from many devices in parallel without derogating the responsiveness of the monitoring system.

Once the monitoring system exceeds a certain size it is important that the system operator gets a quick status overview if all scheduled automatic data download was successful or not. In traditional monitoring systems this information is available but not easy viewable at once. Requirement here is that the information about latest scheduled data download of all devices is summarized into a single screen. Alternatively or additionally the operator in charge shall receive an e-mail notification with the details of the device from which data download was not successfully. Having such functionality communication media problems can get fixed in a timely manner without any risk of losing data or getting data too late to comply with regulatory requirements or internal department requirements.

Figure 1 shows an example of an installation for big monitoring system with decentralized SQL data base, one separate data download server (communication manager), and analysis software server where the clients connect to in order to see and analyze measured information.

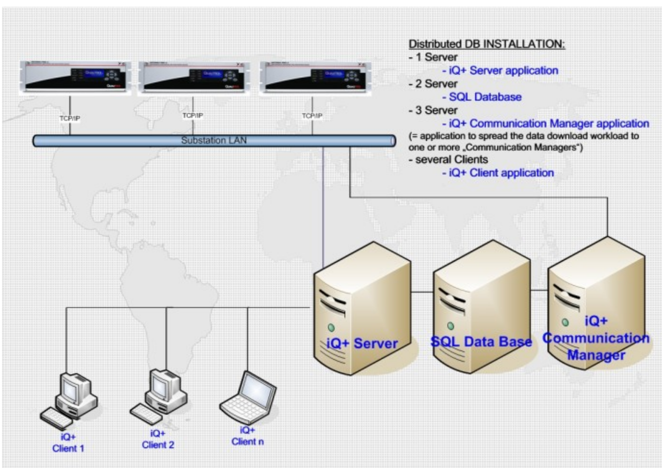

Figure 1. Installation with Coms Manager & distributed Database

3) Decentralized data base and security of data

Different network operators do have different IT security requirements. Some IT departments have stricter requirements than others. A common requirement is to store the measurement data at a from the IT department controlled separate data storage (e.g. clusters SQL server). This has the advantage that the person in charge of DFR and or PQ does not have to make regular data backups as this is taken care of by the IT department.

In case the network operator IT department does not take care about data backups it is important that the monitoring system is capable of automatic backup of measurement data at a user definable periodicity and to a user definable storage location. An integration of the backup and also archiving of the measurement data into the analysis software itself makes the usage of it easy and therefore the PQ and or DFR analysis specialist does not need to be a SQL data base specialsist.

For certain measurement points there might not be any communication media available to download the data, or the communication media might be out of order for some time. Then it is necessary to collect the data on-site and synchronize it later with the central master data base. It therefore is necessary that the monitoring system is capable of handling to import such external data from a different data base into the central master data base.

New device technologies also support the on-site data download via simple usage of any USB memory stick or USB drive. This avoids the need of having PC with special vendors software in the substation, and no special skill set is required in order to do on-site data download from monitoring device.

4) User management and user rights

As monitoring system can be across departments of the network operator the analysis software user management might be important. Monitoring devices can record power quality data, digital fault recording data as well as precise fault location data. As those data types are handled by different departments and the access to certain data must or need to be restricted.

The requirement to monitoring system is that users shall have different user rights (e.g. read only, change device measurement configuration, change device communication settings, delete measurement data, access to certain locations or data types only).

5) Overview screens

Getting the required information in the fastest possible way is needed to reduce the daily workload of PQ and DFR analyzing engineers. Hence it is important that the analysis software does the analysis of raw data automatically in the background and presents the summary of all collected and calculated information into a single screen to the user.

D. Requirements about what to get recorded

Industry trend is going to combine multiple recording functions into one single device or one platform with only one analysis software.

DFR functionality is often added to traditional PQ monitoring devices and vice versa. Often when PQ function is added on DFRs or energy meters it is not compliant to class A or class S of [1], so that should be taken in consideration by network operators when choosing a vendor.

Data types that could be collected are:

- ✓ Power quality
- ✓ Digital fault recording
- ✓ Fault location (FL)
  - o Travelling wave based FL
  - o Impedance based FL
- ✓ Energy

Figure 2 represents details of what measurement types are recorded under which data type. PQ data is split into steady state phenomena (= continuous recordings) and non-steady state phenomena (= triggered recordings / PQ events), whereas DFR data is split into the wavefrom record (DFR) and the dynamic disturbance record (DDR)

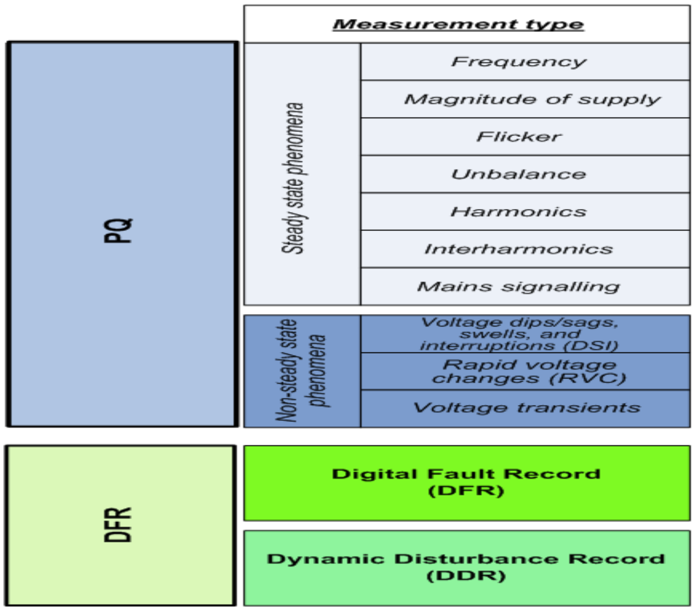

Figure 2. Measurement types

Figure 3 shows the base of each of those measurement types. Steady state phenomena are based on 10 sec values for frequency, special algorithm for flicker and 10/12 cycles for the other parameters. The data outputs of those are 10 sec values for frequency, 10 min intervals or free intervals for magnitude of supply, unbalance, harmonics, 3 sec values for mains signaling voltage, and 10 min (Pst) and 2 hours (Plt) for flicker. The free interval is an adjustable recording aggregation in case a smaller or bigger resolution than the standard 10 min is required; the smallest possible resolution is the raw data which is 10/12 cycles. New monitoring devices can record all of those parameters and therefore record (optionally) more than 1000 different PQ steady state parameters in parallel.

		Measurement type	Data based on
PQ	Steady state phenomena	Frequency	10 sec value (61000-4-30)
		Magnitude of supply	10/12 cycle rms (61000-4-30)
		Flicker	Flicker algorithm (61000-4-15)
		Unbalance	10/12 cycle rms (61000-4-30)
		Harmonics	10/12 cycle rms (61000-4-7)
		Interharmonics	10/12 cycle rms (61000-4-7)
		Mains signalling	10/12 cycle rms (61000-4-30)
	Non-steady state phenomena	Voltage dips/sags, swells, and interruptions (DSI)	rms voltage refreshed each half cycle, Urms (½) (61000-4-30)
		Rapid voltage changes (RVC)	Quick transition in rms between two steady state conditions (61000-4-30)
		Voltage transients	Rate of change, high frequency
DFR		Digital Fault Record (DFR)	Absolute value, power swing, dt/dx, ...
		Dynamic Disturbance Record (DDR)	Rms over one cycle, refreshed every half cycle. For frequency based on 4 cycles refreshed at every cycle.

Figure 3. Measurement types base

Most regulators require data about steady state phenomena and dips, swells, interruptions. RVCs are required in some countries only (e.g. Scandinavian countries, Hungary, Slovakia, Czech Republic). Fast voltage transient are not required to be monitored by regulators and hence are mostly just measured at sites where problems with them occurred or are expected. Fast transient recording is done with a lot higher sampling frequency than normal DFR (DFR e.g. at 25.6 kHz, transient recording e.g. at 20 MHz)

For the DFR it is important that one measuring device is capable of cross-triggering other devices within the same substation. Having this the operator can analyze what happened on other feeders within the substation.

The DDR which is an optional additional record to enhance fault analysis is a slow scan during the fault that can provide operators information about the system behavior up to minutes before and after a fault. It is a record with resolution of half a cycle. DDR helps to understand better the dynamics of system and can be used to analyze system stability during system faults. Next to magnitude for voltage and current it provides also information about frequency, active power, reactive power, apparent power, positive sequence, negative sequence and zero sequence.

III. A CASE STUDY IN PORTUGAL – IQ+ AND QWEBREPORT

A. Regulator requirements

In Portugal the transport and distribution grid operators have to do systematic reporting of power quality data. Since several years that this practice is in place and most of the companies have a legacy fleet of different PQ monitoring devices that are used as fixed as well as mobile instruments and that have to be managed.

At the same time the need to upgrade to IEC 61000-4-30 class A compliant new instruments offered the possibility to evaluate the use of devices combining the functions of a DFR, sharing the analogue acquisition with the class A power quality calculations and thus providing a single measurement source, a single communication channel and a single configuration and data retrieval point.

The requirements at the software level were based in the need to keep automatic and manual data retrieval for the fleet of existing devices, support the new equipments and have the openness for multivendor operation through manual and automatic file import and export based in the standard PQDIF and COMTRADE formats.

The need to distribute information to a large base of users and provide custom reports lead to a web based software able to integrate, manage and make compatible measuring points with time changing characteristics:

- Use of different instruments to record data in different time periods, with different ways of calculating variables and events, providing values in star or in delta and having or not a flagging concept according to [1]
- Change of declared voltage without requiring a configuration change at the measurement level
- Change of standard limit values without requiring a configuration change at the measurement level
- Change of calculation rules keeping the use of the raw data coming from the measurement level

- Change of data source origin from different types of databases and different databases

The requirements mentioned had to be met by the use of two levels of software:

- A data level responsible for the configuration, automatic and manual data retrieval through direct communication and through file transfer using standard formats. At this level different software types from different vendors can be used and multiple databases can co-exist, including both on-line databases and historical data bases.

- An integration level, responsible for access to multiple databases, ensures compatibility between different devices, manage measuring point changes and present the information according to custom specifications, regardless of data origin.

The new software selected to meet the requirements at the data level was the iQ+ software, from Qualitrol, to manage monitoring devices from Qualitrol and Fluke. This software also provides the tools for DFR and PQ data access and visualization using standard views.

The integration software selected was QWebReport IV from QEnergia.

B. *Measurement equipment*

From Qualitrol, EDP Distribuição installed new measurement units in substations, ranging from 8 analogue inputs and 16 digital inputs to 48 analogue inputs and 96 digital inputs. The instruments selected were DFR BEN type that can handle up to 192 analogue inputs and 384 digital inputs with synchronized sampling and gapless measurement. The sampled analogue signals, available in the internal bus, are used by the DFR recording and triggering section and also by the power quality section. The units provide full class A continuous recordings and dips, swells, and interruptions (DSI) detection. PQ and DSI triggers are also available for the DFR recording section. Several busbars with different voltage levels are monitored, HV lines and transformer currents are also measured. Line, busbar and transformer protection status are monitored. The unit uses two sampling frequencies in the DFR section, 12kHz for waveform recordings and 120Hz for RMS recordings.

REN installed new measurement units Informa PMD-A type with 9 analogue channels and 32 digital channels or with 27 analogue channels and 64 digital channels able to perform PQ full class A continuous recordings, DSI and RVC detection, RMS envelope and DFR waveform recordings including PQ and DSI triggers. REN is monitoring only busbar voltages.

Those companies have a legacy fleet that includes namely QWave Power and Premium, Topas 1000 and Fluke 1760 from Qualitrol and Fluke.

C. *Data retrieval*

To support legacy instruments and existing communication infrastructure as well as new equipments, systems at EDP Distribuição and at REN have to support simultaneous modem connections over analogue telephone lines, simultaneous virtual Com Ports over digital PCM communication and Ethernet over enterprise technical WAN, to access fixed instruments. A scheduler takes care that all background automatic communication, using multiple channels, takes place during the night and data is made available in the morning.

Data manually retrieved from mobile equipments is inserted in the database either in a complete manual process or by uploading files to an appropriate shared folder from where data is automatically inserted in the database through a scheduled importer that checks for new files to insert.

D. *Data integration*

For performance purposes on-line databases to where data retrieval takes place have 3 to 5 years of data. Older databases are available in the enterprise WAN, either in the same database server or under other servers.

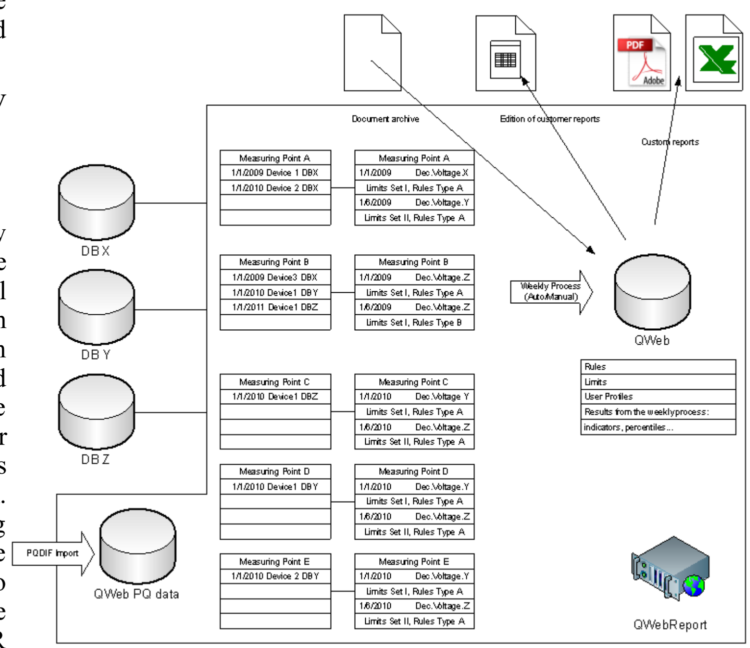

Figure 4. QWebReport IV structure

Historical databases have formats that differ from new iQ+ database. The integration platform enables the definition of the accesses to several databases of different types, providing the abstraction level required to process and present data independently from the its origin.

Whenever there are changes in a measuring point, a new dated entry line is created at the measuring point level:

- different equipment from the same or from a different database,

- change in the declared voltage,

- change in the way the instrument is cabled (delta/star), and how data has to be presented (phase-neutral, phase-phase)
- change in the way events are calculated (fixed reference or sliding voltage),
- use of a validity flag to mark invalid data or reconstruct the validity flag by events or by min/max values
- invalid measurement periods due to malfunction, incorrect cabling or tests
- Changes in the standard limits
- Changes in the calculation rules
- Changes in the event classification

Different sets of standard limits as well as different sets of calculated rules can be created and associated in a dated entry in each measuring point. Different sets can also be available in the user profiles and, if enabled, can be used by the user to see the data according to different rules and/or limits.

E. PQ data presentation

All the administration, configuration and data presentation is web based and reports are directly available as *.pdf or excel type files. The system uses server cached folders, enabling the users to come back to all reports and files requested in the open session. The system only requires a browser with Acrobat Flash player enabled for Flex, all processing and temporary files are server based.

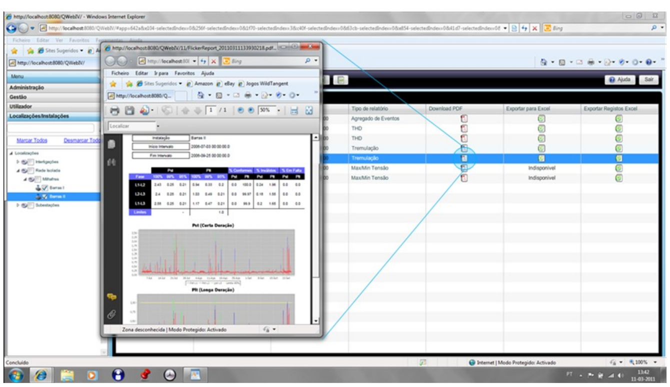

Figure 5. Data presentation (*.pdf or excel type files)

To provide fast access to power quality data, an automatic weekly process pre-calculates the percentiles, data and valid data rate available, aggregated events and single power quality indexes for continuous variables and events according to [4], for every week.

These single indexes provide a way to compress information and enable custom reports searching for representative better and worse weeks, globally or per variable.

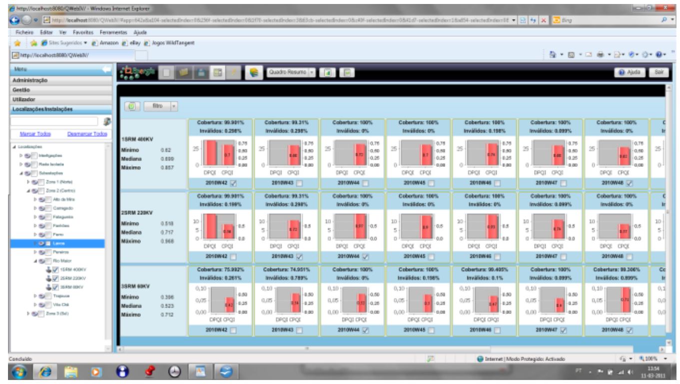

Figure 6. Multiple measuring point weekly analysis using single power quality indexes

Different event classification and aggregation rules provide event aggregation lists, ITIC graphs and access to RMS envelopes and waveform recordings.

Each report or graph in QWebReport is an object that can be re-used to build and edit custom reports.

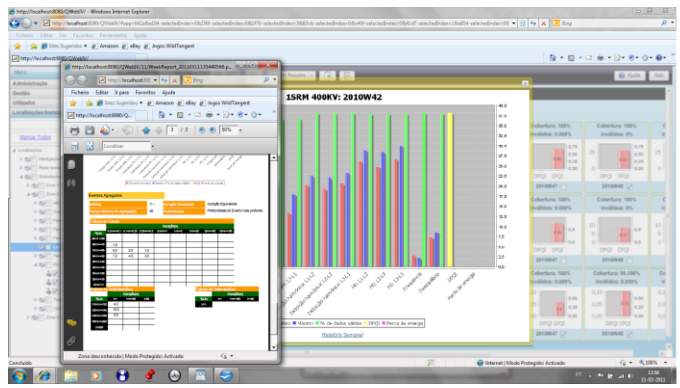

Figure 7. Multiple measuring point weekly analysis using single power quality indexes

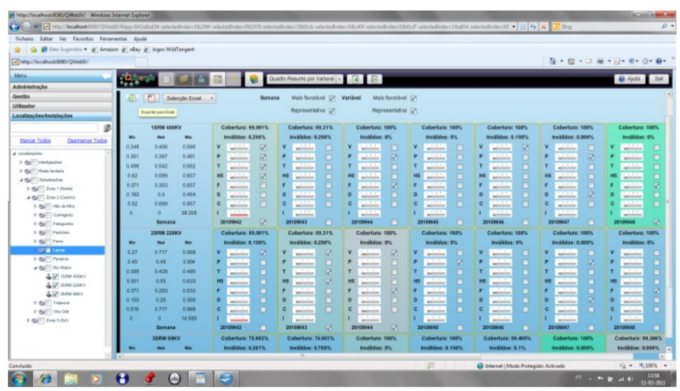

Figure 8. Custom Report Edition Overview

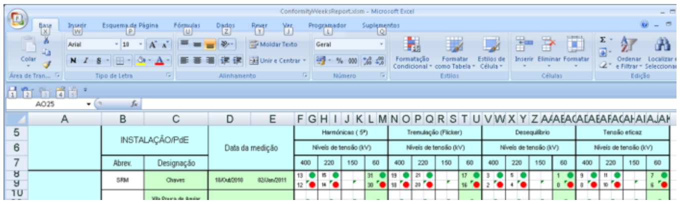

Figure 9. Custom Reports

The system is prepared to associate and classify PQ and DFR events to information coming from SCADA, protection relays and manual entry.

IV. CONCLUSIONS

It is possible to manage a multi-vendor environment of devices, combine PQ and DFR data and distribute information in common way by conformity to standards and use of good integration practices.

PQ and DFR real-time, near-time or historical data are a valuable asset that has to be distributed at the company level in a consistent, common and compressed way.

[1] IEC 61000-4-30 : Ed 2.0, 2008. Part 4-30: Testing and measurement techniques – Power quality measurement methods, International Electrotechnical Commission

[2] CD 62586 : Power Quality Monitoring Devices in power supply systems, International Electrotechnical Commission^

[3] R. Neumann, "The importance of IEC 61000-4-30 Class A for the Coordination of Power Quality Levels", Barcelona, EPQU 2007

[4] F. Pimenta et all, "Web based reporting power quality data", ICHCP 2006 (IEEE)