THE POWER QUALITY MONITORING OF THE MV NETWORK PROMOTED BY THE ITALIAN REGULATOR. OBJECTIVES, ORGANISATION ISSUES, 2006 STATISTICS.

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INTRODUCTION

With reference to Power Quality (PQ) issues, the only standard in force in Italy is EN 50160: it provides reference values encompassing characteristics of distribution networks up to 35kV of the whole Europe. In 2005 the Italian Regulatory Authority for Electricity and Gas (Autorità per l'energia elettrica e il gas, AEEG) promoted a PQ monitoring campaign with the main objective of knowing the actual performance of the MV distribution networks in terms of PQ parameters. This monitoring campaign, that will last two years, is forming part of a regulatory framework which has focused at first on continuity of supply and which is now facing issues relevant to the voltage waveform as well.

INSTITUTIONAL AND REGULATORY BACKGROUND

In Italy AEEG is responsible for the regulation and control of quality of supply. The Law that instituted AEEG pays close attention to quality regulation. Customers protection and quality improvement are among the main goals pursued by AEEG, which has the legal powers for setting compulsory quality standards, associated either with individual compensations or with general tariff adjustments related to quality actual achievements.

SAIDI regulation and regulation of the number of interruptions for worst-served customers [1]

In year 2000 AEEG introduced a continuity of supply targeted incentive mechanism assuming the form of financial penalties and rewards for Distribution Network Operators (DNOs) (regulatory orders 202/99 [2] and 4/04 [2]). This mechanism focuses on SAIDI regulation of long unplanned interruptions and devises a link with the distribution tariff which is adjusted using a parameter Q in the price-cap formula $\Delta P[\%]=RPI-X\pm Q$. The effects of this regulation show, from 1999 to 2005, a 58% reduction of SAIDI at country level and at the same time a benefit in terms of reduction in SAIFI (39% in the same period). In 2006 the regulation of the number of interruptions for worst-served customers has come into force (regulatory orders 4/04, 247/04 [2] and 246/06 [2]). Guaranteed continuity standards have been determined for HV and MV customers and refer to the maximum number of long unplanned interruptions over the year.

Power quality contracts

To the aim of allowing customers with very high level need for quality to reveal their willingness to pay and to accept compensation, DNOs and HV or MV customers can agree upon specific quality conditions which are better or further than those represented by the guaranteed standard of continuity of supply determined by AEEG (regulatory order 4/04). Only few general rules must be observed by DNOs:

- the parties must define the agreed standard of quality to be observed by the DNO, the premium price to be paid by the customer and the penalty clause in the event of non-compliance on the part of the DNO, specifying cases of exclusion;
- the standard of quality shall be expressed as a threshold applied to one or more indicators of continuity of supply or of PQ. With reference to those indicators for which there is no obligation for individual measurement, the parties shall arrange for measurement during a period of at least one year prior to the stipulation of the PQ contract.

The measurement costs shall be borne by the party which intends to benefit from the higher standards of continuity of supply or PQ, and which is entitled to install its own monitoring device. PQ contracts may not be stipulated for standards of quality which are lower than those defined by AEEG. They may be extended to all parameters of PQ identified by EN 50160, provided that they are recorded in compliance with EN 61000-4-30 procedures.

Power quality individual measurements

Upon request of the customer, the DNO has the obligation of installing an interruptions' recorder compliant with EN 50160 and EN 61000-4-30. Recordings can be extended as well to PQ parameters (e. g. dips), to the aim of subscribing PQ contracts. Costs are charged to the customer who applies. The customer can install his own PQ monitor, on the condition that it is compliant with EN 50160 and EN 61000-4-30.

REASONS AND OBJECTIVES BEHIND THE MONITORING CAMPAIGN

Importance of the power quality issues

In spite of the importance of the matter, in Italy an adequate monitoring of PQ parameters was not available until 2005. In the past few DNOs performed some measurements, but limited to small portions of distribution networks and within a short period of time, therefore not sufficient to give a good estimate of the most critical phenomena like dips. AEEG believes that the reference values provided by EN 50160, in particular those referred to short interruptions and dips, are inadequate for many customers and thinks that actions finalized to the reduction of the number of transient interruptions (< 1s) and dips and to limit voltage variations should be developed. The Italian Trade Associations have stated that a poor PQ can reduce in a considerable way the competitiveness of the represented enterprises in their specific marketplaces: dips and voltage variations seem to be the main causes of damages.

Objectives of the monitoring campaign

The project is financed by the tariff, through R&D levy, and has been realized by CESI and CESI RICERCA. The objectives of this monitoring campaign, that will last two years, can be summarized as follows:

- knowledge of the performances of the MV distribution networks in terms of PQ parameters and their publication;
- correlation of the measured parameters to the type of the networks and to its structure, power of HV/MV transformers, short circuit power etc.;
- promote individual measurements and PQ contracts through a voluntary participation of customers to the campaign;
- verify the possibility to introduce measurement obligations for DNOs and then a financial regulation of some PQ indicators;
- confirm or revise limit values of PQ indicators so that they can reflect the characteristics of the Italian electrical system.

Monitoring campaigns on EHV and HV networks

AEEG introduced obligations of PQ measurements also for the Transmission System Operator (regulatory order 250/04 [2]) and for DNOs (regulatory order 210/05 [2]) as far as the transmission network and the HV distribution networks are concerned.

POWER QUALITY INDICES AND MONITORING SITE SELECTION

Power quality indices

The PQ parameters chosen for monitoring are:
1) supply voltage variations;
2) supply voltage dips and swells;
3) short voltage interruptions;
4) voltage harmonics;
5) flicker;
6) supply voltage unbalance;
7) rapid voltage changes.

In addition to the above voltage parameters, also currents and current harmonics are monitored in MV/LV substations (points of common coupling, PCCs).

Selection of the monitoring sites

The MV distribution network in Italy is characterized by the following figures.

- Around 1800 HV/MV substations whose majority has two MV bus-bars. Under normal operation, bus-bars are separated and fed each one trough a HV/MV transformer. The total number of MV bus-bars is around 3700. They feed as many independent networks radially operated.
- Around 360.000 km of lines at rated voltage 10 kV, 15 kV or 20 kV. 40% of the lines are in cable while 60% are aerial with bare conductors.
- The system feeds approximately 330.000 MV/LV substations; 100.000 of them are dedicated to MV customers. Other 140.000 pole mounted MV/LV transformers are installed for rural LV distribution.

A total of 600 measuring units were installed in as many sites of the MV networks chosen with the following criteria. 400 MV bus-bars in HV/MV substations (corresponding to 11% of the MV networks) chosen to represent as far as possible the complete Italian territory and its environmental conditions. A map of the installations is given hereafter.

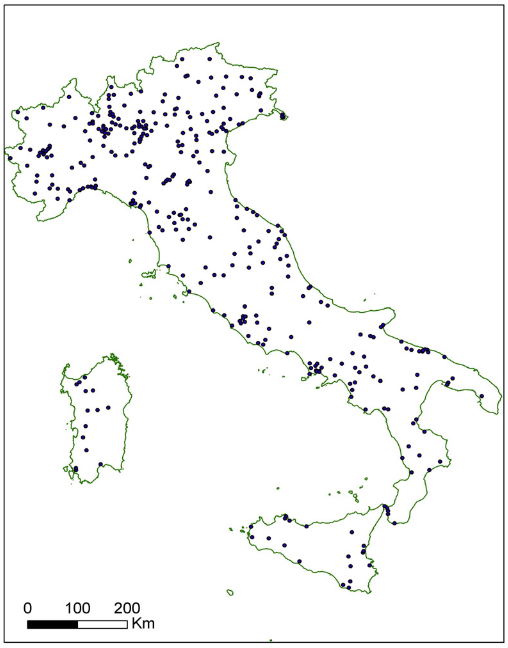

Figure 1 - Map of the sites where measurement units are installed on MV bus-bars of HV/MV substations.

In each region the MV networks were chosen to be statistically representative of the following parameters that were judged as the most relevant from the PQ point of view:

- total length of the lines connected to the MV bus-bar;
- type of MV lines (aerial with bare conductors, cable, mixed);
- type of neutral operation of the MV network (isolated neutral, compensated neutral);
- number of MV customers;
- density, per square kilometre, of LV customers fed by the MV network.

200 MV PCCs along the MV lines freely chosen by MV customers (73 installations) and by DNOs (127 installations), giving priority to the options of the customers.

MONITORING SYSTEM ARCHITECTURE

The Italian system for PQ monitoring of MV distribution networks is fully described in [3]. It is made up of four main parts.

A - 600 measurement units (MU).
B - Voltage and current transducers.
C - The Central System for data collection and storage.
D -The system, named QUEEN, for the final processing and web-reporting of the PQ parameters.

Measurement Units. The performance of the MUs corresponds to the new class S proposed in the Committee draft 77A/539/CD for revision of 61000-4-30 "Testing and measuring techniques – Power quality measurement methods".

Voltage and current transducers. MUs are connected to LV side of voltage and current transformers and measure line to line voltage and line current. In fact, in the Italian three-phase MV distribution system, the electricity is supplied as three line to line voltages. No special voltage transformers have been installed as transducers, but the existing voltage transformers utilised for metering purposes have been used to comply with the budget available.

Central system for data collection and storage. It is made up of two communication servers that administrate the communication with the MUs every day. The communication is mainly used to import the data collected by the units and also to check their set-up or to install new releases of the resident software. The Central System has also a database server where the raw data are recorded. Another database server is used for back-up.

QUEEN – Web system for the final processing and reporting of the PQ parameters. The access to QUEEN (http://QUEEN.ricercadisistema.it) is available to two different categories of users:

- The owners of the MUs have access to the detailed measurement results (time of occurrence and characteristics of any single disturbance) and to statistics of disturbances recorded by their MUs over selected intervals of time. The access is made through a password that allows the non disclosure of proprietary information.
- The public may access the QUEEN and request the processing and reporting of the data collected by the monitoring system aggregating the results in groups of MUs.

<u>Detailed results</u> available to the MU owners are organized in tables that report the list of the characteristics of the given PQ parameter as a function of time (in case of parameters continuously recorded as voltage variations, harmonics, flicker etc.) or as sequence of events (in case of dips, interruptions, rapid voltage changes etc.). For parameters continuously recorded, the user can obtain graphs representing them as a function of time. In case of events, the user can download original wave-shapes recorded by the MU in an interval of time triggered by the event occurrence.

<u>Aggregated results</u> may be obtained by the public over groups of MUs chosen on a spatial criterion (the Italian regions or the entire country) and groups of MUs chosen on the basis of electrical characteristics (rated voltage level, isolated neutral or compensated neutral networks, rated power of the HV/MV transformer etc.). The results are organized in tables that report the statistics of the PQ parameters over time intervals.

Both in cases of detailed and aggregated results, the PQ parameters exceeding the limits indicated by EN 50160 are put into evidence by colour flags.

STATISTICS AFTER THE FIRST YEAR OF MONITORING

A sample of the main results are reported in the following.

<u>Voltage dips in MV bus-bars of HV/MV substations</u>

Monitoring started in February 2006 and thus the data have been extrapolated to one year (from 47 to 52 weeks) to give a one year estimation of the number of dips for each class of duration and residual voltage (see Table 1).

Residual voltage [%]	20-100 [ms]	100-500 [ms]	0.5-1 [s]	1-3 [s]	3-60 [s]	Total
90>u≥85	14.6	5.6	0.4	0.2	0.1	21
85>u≥70	17.7	17.0	0.8	0.3	0.1	35.9
70>u≥40	15.0	28.8	0.5	0.1	0.1	44.5
40>u≥10	3.2	13.8	0.3	0.1	0.0	17.4
10>u≥1	0.3	1.2	0.0	0.0	0.0	1.5
Total	50.8	66.4	2	0.7	0.3	120.

Table 1 - Average number of dips on MV bus-bars in one year (UNIPEDE classification).

As the number of dips experienced in the different measuring points is strongly dispersed, the number of dips exceeded for the 5% of the points monitored is also given. It gives an idea of the worst situations (see Table 2).

Residual voltage [%]	20-100 [ms]	100-500 [ms]	0.5-1 [s]	1-3 [s]	3-60 [s]	Total
90>u≥85	42.9	18.7	2.4	1.0	0.6	65.6
85>u≥70	47.3	57.0	3.4	1.0	0.4	109.
70>u≥40	56.8	105.5	2.4	1.0	0.4	166.
40>u≥10	8.4	43.8	1.0	0.5	0.1	53.8
10>u≥1	1.0	7.4	0.0	0.0	0.0	8.4
Total	156.4	232.	9.2	3.5	1.5	403.

Table 2 - Number of dips exceeded in one year by the 5% of the MV bus-bars.

To give a better view of the distribution of dips, Figure 2 shows the histogram of the number of sites characterized by the shown classes of number of dips during the 47 weeks monitored in 2006.

The density of lightning to ground gives a strong contribution to the high dispersion of the number of dips shown in Figure 2. This is confirmed in Figure 3 where the correlation between the average number of dips measured in each week and the average stroke density in Italy in the same weeks is reported.

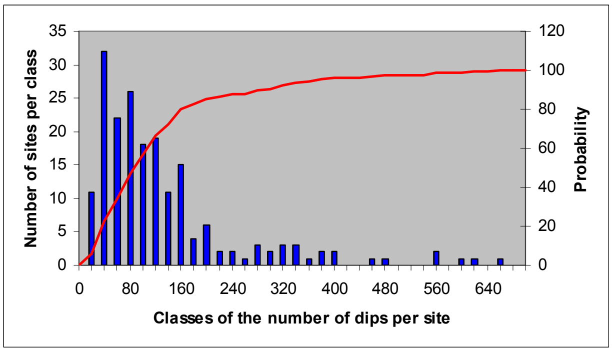

Figure 2 – Histogram of the number of sites characterized by the shown classes of number of dips (47 weeks, 189 MV bus-bars of HV/MV substations, networks with compensated neutral).

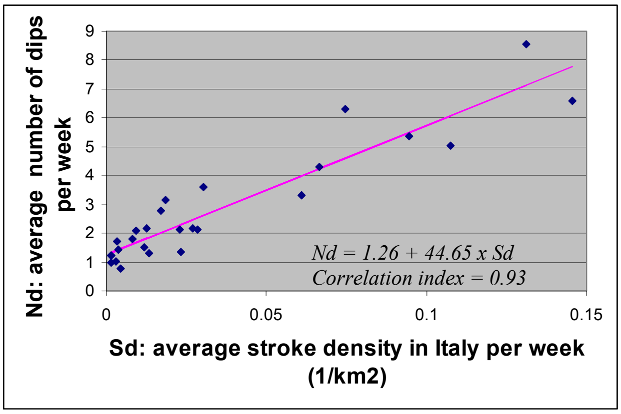

Figure 3 – Correlation between the average number of dips per week (Nd) and average stroke density in Italy (Sd) in the same week (20 March - 17 September, 189 MV bus-bars of HV/MV substations, networks with compensated neutral).

The prevailing type of MV lines has also an influence on the number of dips to be expected. Table 3 gives the total number of dips measured for each duration class on cable, mixed and aerial networks. A network is classified as "cable" or "aerial" if more than 90% of the line lengths are in cable or aerial with bare conductors. In the other cases it is classified as "mixed".

	20-100 [ms]	100-500 [ms]	0.5-1 [s]	1-3 [s]	3-60 [s]	Total
cable	51	53.2	1.3	0.3	0.2	106
mixed	46	66.4	2.3	0.7	0.4	116
aerial	93.0	120	4.3	3.9	0.4	222

Table 3 - Total number of dips, in one year for each duration class, in MV bus-bars feeding cable, mixed and aerial networks.

Voltage dips in PCCs along MV lines

The voltage dips monitored along the lines cannot statistically represent the behaviour of the entire Italian MV network as the sites have not been chosen to be statistically representative. Nevertheless, the results of monitoring in PCCs demonstrate that the statistics gathered on MV bus-bars of HV/MV stations constitute a good view of the dips to be expected in Italy in the 470.000 MV/LV stations.

Table 4 shows, as an example, the number of voltage dips and short interruptions (up to three minutes) in a network where measurement units have been installed on the MV bus-bar of the HV/MV substation and on seven MV PCCs along lines fed by the same MV bus-bar. This example shows that the number of dips along a line is lower or equal to that measured on the MV bus-bar. The difference is constituted by interruptions (only short interruptions are shown in the table).

	MV bar	pcc_1	pcc_2	pcc_3	pcc_4	pcc_5	pcc_6	pcc_7
dips	59	42	40	59	59	40	54	57
int.	0	14	10	0	0	9	1	0

Table 4 - Number of dips and short interruptions (up to three minutes) monitored on a MV bus-bar and on seven MV PCCs along lines fed by the same MV bus-bar.

Besides the number of dips, another important parameter is the residual voltage. In Figure 4 it is plotted, for the same network of Table 4, the distribution of the ratios between the residual voltage measured on the PCCs (Ures-c) along the feeders and that measured on the MV bus-bar (Ures-b) for the same events. On average, the residual voltage of dips measured along a feeder is slightly lower (less than 1%) than that measured on the MV bus-bar. 82% of the ratios (Ures-c/ Ures-b) are within ± 2%.

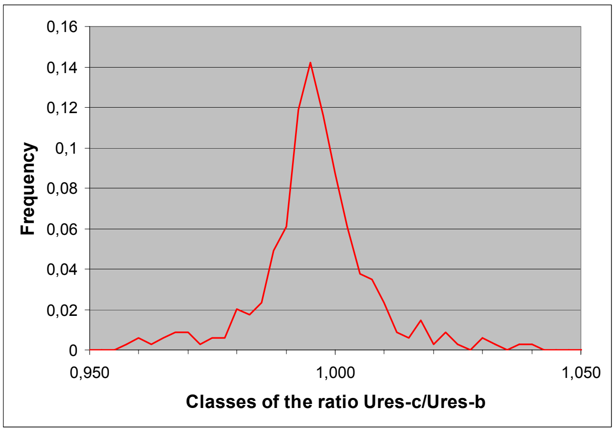

Figure 4 - Ratio between residual voltage on the PCCs (Ures-c) along the feeders and residual voltage (Ures-b) on the MV bus-bar of the HV/MV substation for the same events.

The results shown above confirm that:
- the number of voltage dips measured on MV bus-bars of HV/MV substations gives an over-estimation of the number of dips to be expected in the points along the lines;
- the residual voltages measured on MV bus-bars of HV/MV substations are a good estimation of the residual voltages to be expected in the PCCs along the lines fed by that substation.

Flicker

Figure 5 plots the histogram of the number of sites characterised by a PLT having the shown class of amplitudes. The results of the monitoring confirm that the highest level of flicker are experienced in very few sites. The large majority of the sites (more than 90%) are characterised by a value of PLT 95% lower than 1).

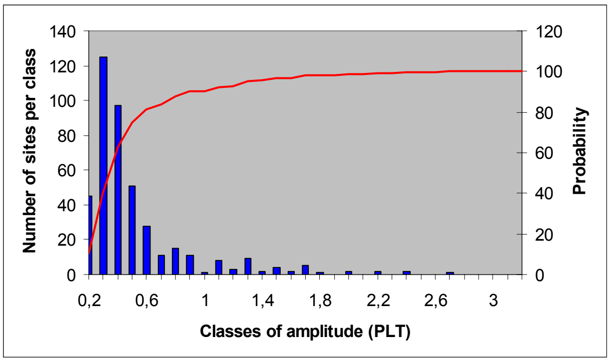

Figure 5 - Distribution of the level of flicker (PLT 95% measured on MV bus-bars of HV/MV substations (400 measuring points) during a week.

Voltage unbalance

Figure 6 plots the histogram of the number of sites characterised by Voltage Unbalances having the shown class of amplitudes. The distribution of voltage unbalances has a low dispersion. In addition all measured values are lower than 2%.

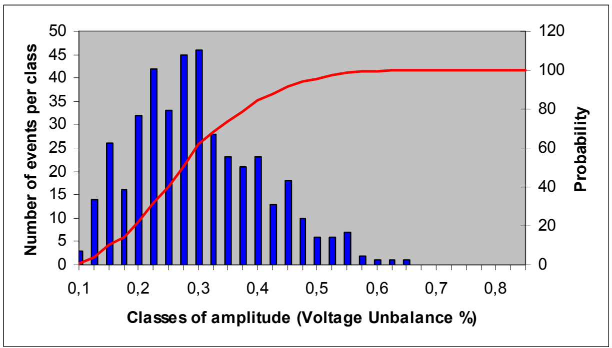

Figure 6 - Distribution of the Voltage Unbalance level measured on MV bus-bars of HV/MV substations (400 measuring points) during a week.

Supply voltage variations

	Number of sites (among 174) with voltage amplitude exceeding the limit for more than 5% of the time		
Week number	**Un ± 10%**	**Un ± 7.5%**	**Un ± 5%**
44	0	3	19
45	0	2	19
46	0	2	19
47	0	3	20
48	0	3	26
49	0	4	20
50	0	3	20
51	0	2	21
52	0	2	23

Table 5 – Number of sites per week with voltage amplitude exceeding the limit for more than 5% of the time.

In Tables 5 and 6 it is reported an example of elaboration of Supply Voltage Variations (SVV) obtainable by QUEEN.

The SVV are elaborated over a sample of 174 PCCs along MV lines during the weeks 44 to 52 of year 2006 (from 30 October to 31 December). Table 5 reports, for each week, the number of sites where the supply voltage exceeds, for more than 5% of the time, the limits Un ± 10%, Un ± 7,5%, Un ± 5% respectively. Table 6 reports, for the entire period of observation, the number of sites where the supply voltage exceeds the limits for at least 1, 2, 3 or 4 weeks. The two ways to present the results allow to estimate whether the actual situation is far from the current limits (Un ± 10%) or from possible more severe limits.

	Number of sites (among 174) with voltage amplitude exceeding the limit for more than 5% of the time		
	Un ± 10%	**Un ± 7.5%**	**Un ± 5%**
at least 1 week	0	5	39
at least 2 weeks	0	3	26
at least 3 weeks	0	3	19
at least 4 weeks	0	3	19

Table 6 – Number of sites, in the period 30 October to 31 December, with voltage amplitude exceeding the limit for more than 5% of the time.

CONCLUSIONS

AEEG confers great importance to PQ issues because of the sensitivity of the end-use equipment and the increasing concern of DNOs and customers. Nevertheless any kind of regulatory intervention should be based on a good knowledge of the actual situation: this preliminary step in considered fundamental by AEEG. The monitoring system described in this paper is recording, day after day, a huge amount of data. The study of them has already begun and will continue during 2007 and the following years. In spite of the complexity of the matter, the pursuance of the objectives at the base of this monitoring campaign is considered essential by AEEG, even in the light of the ERGEG (European Regulators' Group for Electricity and Gas) position on PQ standards [4].

REFERENCES

[1] L. Lo Schiavo, R. Malaman, F. Villa, 2005, "Continuity of electricity supply regulation driven by economic incentives: does it work? The Italian experience", *Proceedings of CIRED 2005*, Turin, Italy, Session 2, Paper 152.

[2] Autorità per l'energia elettrica e il gas, *Delibere n. 202/99, n. 4/04, n. 247/04, n. 250/04, n. 210/05, n. 246/06*. Available, in Italian, on the web site: www.autorita.energia.it.

[3] R. Chiumeo, L. Garbero, I. Mastandrea, O. Ornago, A. Porrino, 2006, "The Italian system for power quality monitoring of MV distribution networks" *IEEE ICHQP conference 2006*.

[4] ERGEG, 2006, "Towards Voltage Quality Regulation in Europe", *Ref: E06-EQS-09-03*. Available on the web site: www.ergeg.org