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POWER QUALITY ISSUES IN ELECTRICAL POWER DISTRIBUTION SYSTEMS

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Abstract: *The paper intends to present some voltage power quality issues in low voltage electrical power distribution systems. In the introductory part, some of the main specific events are addressed, namely sags, swells, transients and harmonics. The following section is dedicated to the monitoring process. The power quality analyser used is briefly presented, respectively the Dranetz-BMI PowerXplorer PX5. The third section is devoted to the measurements performed at the secondary busbars of a transformer substation. Finally, the conclusions reveal the importance of a rigorous power quality survey and also some of the drawbacks of the power quality standard EN 50160.*

Key words: *sags, swells, transients, harmonics*

1. Introduction

In the last decade mainly, the interest in power quality became more and more important both for suppliers and equipment manufacturers. Suppliers are interested in the quality of their service, manufacturers have to build equipments compliant to a sum of standards and regulations with respect to power quality. Last but not least customers want in their turn reliability in using electrically powered products [1].

As a common rule, electric power is generated in large power stations in a relatively small number of locations. The transmission system allows the sharing of the resources from the various generator stations over large areas. However, the distributed generation plays a more important role in the electric power generation process. The deregulation (liberalization, privatization) of the electricity industry has led to an increased need for power quality and quality indicators.

Any transmission system is at the same time an important contributing factor to high reliability of electric power enabling the deregulation of the electrical energy market.

Distribution networks transport electrical energy from the transmission substations to various loads. Distribution networks are typically operated radially and power is transported from the transmission substation to the end users [2].

There are many causes of faults in distribution circuits: lightning strokes, tree contact, equipment failure, wind, ice/snow, vehicle accident, birds, etc. Single-phase faults (one phase on the ground) are the most common, followed in order by phase to phase faults. Fault location is the

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primary factor that determines the disturbance severity to customers [3].

High speed semiconductor devices with fast switching capability and the emerging digital era in control and signal processing became also main enemies of electrical power quality.

In literature one can find plenty and sometimes conflicting definitions of power quality, related more or less to the performance of equipment or to the possibility of measuring and quantifying the performance of the power system (see the IEEE Standards and the IEC and EN Standards).

Standards have identified and defined also several power quality events.

Sustained (or long) interruptions are most severe. In such interruptions voltage drops to zero and it does not return automatically. According to the IEC definition, the duration of sustained interruptions overcomes 3 min.

Alternatively, short-duration interruption includes: short interruption, momentary interruption, instantaneous interruption and transient interruption.

Voltage dips cause some of the most common quality problems; a voltage dip or a sag (the preferred US term) is defined as a rms reduction to an extent between 0.1 and 0.9 in the magnitude of the ac voltage, at the power frequency, for durations from a half cycle to a few seconds (max 1 minute).

Conversely, the swell is opposite of sag, being a short duration overvoltage phenomenon. During a swell the rms voltage increases in magnitude between 1.1 and 1.8 of the rated voltage; the duration of a swell ranges from 0.5 cycles to 1 min [4].

Harmonics are the most important issue among all issues related to power quality. All transients cause harmonics. To analyze harmonics in power system, different new standards and indices have been introduced, the most common being the harmonic distortion factors of voltage (THDV) and current (THDI) waveform.

Harmonics are analyzed in time domain, in frequency domain or both time-frequency domains [5]:

- Fourier series, that expands continuous, single valued function of time domain in terms of dc component, and series of integer harmonics
- Fourier transform, that makes possible to express a time domain function in frequency domain, being very useful in handling continuous signal in frequency domain. However, the transform method suffers from limitation to handle discrete or discontinuous, multi-valued and undefined signals which are also frequent in electrical applications. Discrete Fourier was able to overcome these drawbacks, but it is a very time consuming method even when a computational method is used, especially for a large number of samples. The fast Fourier transform reduces the multiplication process as well as the time of execution. For this reason, among them, FFT is now extensively used in spectrum analyzer.
- Wavelet Transform**:** Fourier transform fails in the analysis the non-stationary signals in both time and frequency domains. Wavelet transform becomes useful in such cases.

2. Monitoring Power Quality

Monitoring power quality at the distribution end and at the load end has become of major interest. The monitoring process in the low voltage range, namely at the secondary bus bars of a transformer substation and at the load are usually performed using “power-quality meters” or “power quality analyzers,” instruments similar to oscilloscopes, having a number of supplementary, functions particularly suited for power-quality [6].

Power quality measurements are performed for a several number of reasons [7-8]. The two following reasons are in the authors' opinion the most important in analyzing power quality issues:

- Monitoring to characterize system performance, which is a proactive approach to power quality monitoring; by understanding the normal power quality performance of a system, a provider can quickly identify problems and can offer information to its customers to help them match their sensitive equipment's characteristics with realistic power quality characteristics.
- Monitoring to characterize specific problems, which is a short-term monitoring at specific customer sites or at difficult loads. This is a reactive mode of power quality monitoring, but it frequently identifies the cause of equipment incompatibility, which is the first step to a solution.

It is equally important that the monitoring locations would be selected carefully, based on the monitoring objectives. Obviously, one could monitor power quality at virtually all locations throughout the system, to completely understand the overall power quality, which may be prohibitively expensive. Fortunately, taking measurements from all possible locations is usually not necessary since measurements taken from one or several strategic locations can be used to determine characteristics of the overall system as it will be seen further.

Measurements were performed using the Dranetz-BMI PowerXplorer PX5, a portable, hand-held, eight-channel power quality meter/monitor, which can survey, record and display data on four voltage channels and four current channels simultaneously [9].

It can do PQ-optimized acquisition of power quality related disturbances and events. It is designed with a statistical package called Quality of Supply (QOS), with monitoring and setup protocols set to determine voltage measurement compliance required for EN50160 monitoring [10].

The PX5 firmware can monitor power quality phenomena for troubleshooting and/or compliance purposes. It can record inrush conditions, carry out long-term statistical studies to establish performance baselines, and perform field-based equipment testing and evaluation for commissioning and maintenance. The firmware integrates an intuitive instrument setup procedure to ensure the capture of all relevant data for additional post process analysis, report writing, and data archiving using other compatible Dranetz-BMI software applications such as NodeLink and DranView.

All PX5 functions are operable using a color LCD touch screen technology:

Meter mode functions as a true rms voltmeter and a true rms clamp-on ammeter. Voltage and current measurements, along with other calculated and advanced power parameters, are displayed on the Meter mode screens in both textual and graphical format.

- Harmonics mode display the amplitude and phase of each harmonic to the 63rd harmonic in both graphical and textual format.
- The phasor screen displays a graph that indicates phase relations between voltage and current based upon the angles at the fundamental frequency, as determined by Fourier analysis. Phasor diagram displays voltage and current phasors for all channels. Functioning as a phase angle meter, the unit can display system imbalance conditions and provides such information in textual form also. The phase angle display can also verify if monitoring connections have been made correctly.
- An event occurs when a programmed threshold limit is crossed. An event

consists of the pre-trigger cycle(s), trigger cycle(s), and post-trigger cycle(s).

PX5 can monitor the following power configurations:

- Single Phase
- 3 Phase 2-Watt Meter Delta
- Split Phase
- Generic
- 3 Phase Delta
- 2 1/2 Element without V_B
- 3 Phase Wye
- 2 1/2 Element without V_C

Direct connection of all voltage measurement cables are rated at 600Vrms max.

The survey focused on the supply system performance. So, the first measurement points were chosen on the secondary busbars of the transformer substation (10/0.4 kV, 100kVA) in Δ-Y connection.

3. Measurements and Discussions

Fig. 1 depicts a timeplot survey of the secondary voltage of the transformer substation from 6 to 9 p.m. in the evening peak.

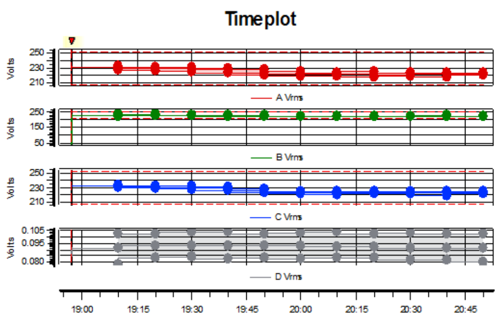


Fig. 1. *Timeplot survey of the secondary voltage of the transformer substation*

One can see the rms voltage of the three lines (A-red, B-green, C blue) and the neutral (0-grey), solidly grounded. At the same time the ITIC curve (issued by the Information Technology Industry Council), which represents a modified version of the CBEMA power acceptability curve for power quality evaluation is available too.

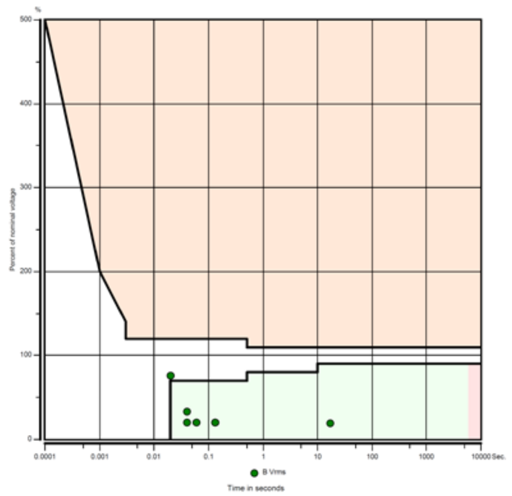


Fig. 2. *The ITIC curve of the survey*

Even if in Fig. 1 the three rms voltages are close around 230 Vac, the ITIC curve (see Fig. 2) reveals six points (the green dots) in which the rms voltage of line B is below the tolerance curve, which means that in the survey interval some severe power quality events occurred. One of these events, i.e. a mild bipolar negative transient is depicted in Fig. 3.

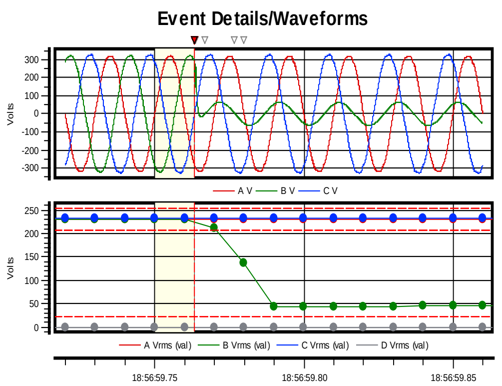


Fig. 3. *Waveform of a mild bipolar negative transient*

The fast Fourier transform is also available in the survey, being depicted in

Fig. 5. From Fig. 5 and from Fig. 6 which depicts the main features of the event, one can see that the magnitude of the fundamental drops to 192.35 V, being associated with a DC component of 10.49 V.

BV Mild Bipol Trans Neg 1/16 Cyc
CATEGORY: Impulsive Transient (microsec duration)

Phase	372.0 Deg
10% Ampl	259.9
50% Ampl	149.7
90% Ampl	36.43
10% Offset (usec)	13672
50% Offset (usec)	13906
Rise time 10-90% (usec)	695.9
Worst Peak-to-Peak	101.3

	A	B	C	D	A-B	B-C	C-A
Vrms	230.1	231.1	233.0	0.09363	399.7	401.4	401.3
VPeak	320.1	321.0	326.5	0.2054			

Fig. 4. *Event description*

The total harmonic distortion of the voltage in line B exceeds almost eleven times the standard limit of max. 8%. The THDV value in line B is 87.25%. Even if the other two lines are "healthy", the THDV between the lines A-B and B-C have also large values around 88%.

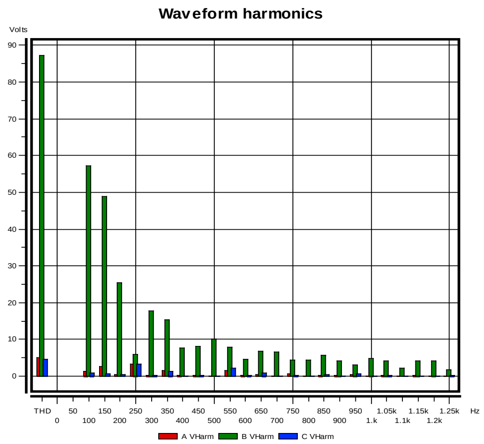
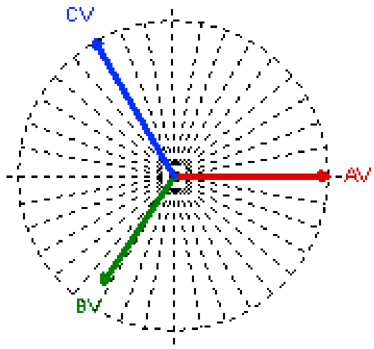


Fig. 5. *The fast Fourier transform*

	AV	BV	CV	A-BV	B-CV	C-AV
RMS	230.53	211.74	232.79	382.40	373.62	401.66
FND	230.47	192.35	232.74	371.61	363.13	401.56
DC	-0.10	10.49	-1.23	-10.59	11.72	-1.13
THD	5.06	87.25	4.60	88.87	86.46	8.46

Fig. 6. *The detailed feature of the event*

The voltage imbalance between the three lines is also available both for the fundamental and for each harmonic component (see a sample in Fig. 7).



Phase

	A	B	C
V	0°	237°	120°

Magnitude

	A	B	C
V	230.5	192.3	232.7

Fig. 7. *Voltages imbalance of the fundamental*

4. Conclusions

From the previous section, it is obvious that the power analyzer has the capability to highlight the various features of the power quality events.

In the three hours of survey performed at the busbars of the transformer substation, 47 power quality events occurred (mainly sags and transients). These power quality events can easily determine the tripping of the protective devices and/or damage the equipment connected to the supply grid.

However, the overall average result says that the survey was compliant to the standard EN50160 (Voltage characteristics of electricity supplied by public distribution systems). This is the direct consequence of the fact that the standard itself must be understood as representing a compromise between the three parties which exert an influence on the power quality, i.e. network operator, network user, and manufacturer of equipment. Each of these three parties has an interest in playing their part. It is essential that electricity suppliers provide, as a minimum, a nominally adequate quality of supply. If the customer has higher requirements, mitigation measures should be provided by the user, or a separate agreement for a higher supply quality must be negotiated with the supplier [11].

As a proof of the above statements, Fig. 8 presents the average total harmonic distortion in line B. It must be noted that in the vast majority of the power quality events during the 3 hours of survey the instantaneous THDV were huge. However the average THDV recorded in the three hours interval by the power analyzer was within the standard limit of 8%.

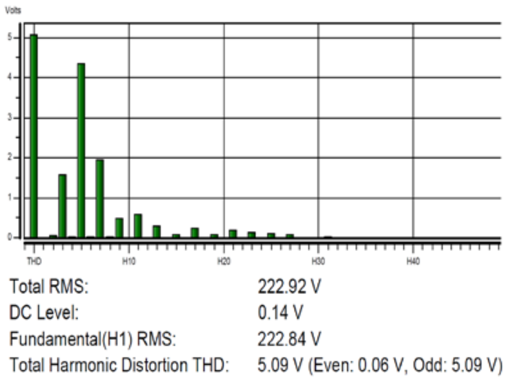


Fig. 8. *The average frequency spectrum of the survey*

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