EXTRACTING EVENTS FROM POWER QUALITY TIME SERIES – PRACTICAL CASE STUDY

Dan APETREI - ELECTRICA[1] S.A., Romania
Claudiu VERMESAN- ELECTRICA Transilvania Nord [2], Romania
Dorel STANESCU - ELECTRICA Transilvania Sud [3], Romania
Alin NICOARA - ELECTRICA Transilvania Nord, RomaniaA Dan APETREI -

SUMMARY

The paper analyzes the voltage and frequency time series. The analysis is based on half cycle survey fulfilled with dedicated IEC 61000-4-30 equipment.
Decision in power network management is based on information. Part of information regarding power system is related to power quality events. It investigates ways to improve the usefulness of power quality data as decision support. Box plot charts were used instead of aggregated values and are explained the benefits coming from this. Fractal behaviour of voltage/frequency time series is tested by calculating Hurst exponent for different periods of time.
Conclusion is that standard time series processing does not produce relevant results for network management because time aggregation hides information related to the process. In order to extract information from the half cycle data, dedicated analysis techniques need to be developed.

Key words: Power quality, box plot, IEC 61000-4-30

[1] SC ELECTRICA SA - Bucuresti strada Grigore Alexandrescu nr. 9, sect.1 cod 010621; telefon +040212085202; fax +040212085204; E-mail: dan.apetrei@electrica.ro
[2] SC ELECTRICA SA – Cluj
[3] SC ELECTRICA SA - Sibiu

INTRODUCTION

Power quality measurement systems aim to support decision. Fig. 1 shows the way PQMS (power quality monitoring system) is gathering and processing data in order to obtain information.

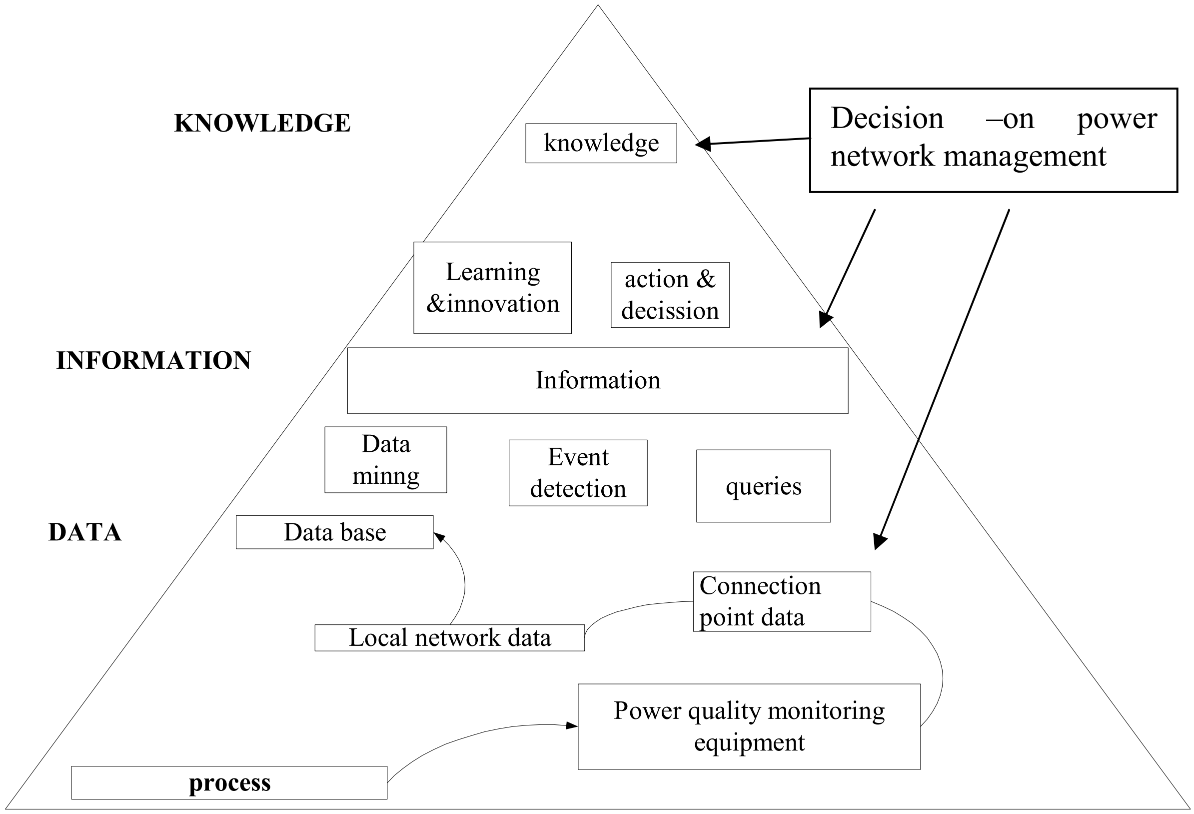

Fig. 1. The data, information, knowledge pyramid.

Our perception of nature is made by stimuli or signals. These are data sources. In technical way the signals after processing could be considered data. For the management systems a data that was processed and leads to a decision could be considered as information and can be seen in figure 1.

The Pyramid model of data, information, and knowledge make possible the analysis of the borders between data and information or between information and knowledge. This paper deals with the transformation of data into information strictly applied to power quality analysis. A data must reflect a fact in order to be considered as information. Information extraction is a process that could be really efficient when it's done by computers.

From the hierarchy data, information, knowledge applied to power quality we can state that:

- the process of energy transfer from producer to the consumer determines specific signals that could be gathered by monitoring (frequency, current, voltage);
- using the metering equipment, the signal could be transformed into data;
  - power quality monitoring uses dedicated metering equipment;
  - modern power meter includes power quality monitoring facilities;

o digital protections and SCADA peripherals are collecting useful data for power quality monitoring

- usually data is organised by the data connection point that generates it and by this structure could give local information;
- in order to establish an innovation/ learning process it is necessary to develop an overall network database;

Without informed decisions there is scarce improvement in Power quality. Information stimulates learning process that determines knowledge. The way data is processed is regulated to some extent. For instance standards [1,2,3] give primary rules used to extract information from data. These methods are used especially to determine power quality related to the customers. The paper tries to make one step further in getting from the data the information that could be useful in PQMS in order to improve the quality. The research is focused on half cycle RMS voltage and frequency measurement. After a short presentation of the processing requirements stated by standard [1] the measurement system used and the main results of the measurement campaign are described. Based on the data that came from the field three families of techniques are exploited: box plots, pattern identification, and Hurst exponent classification. These techniques could be useful in extracting information.

DATA PROCESSING ACCORDING TO STANDARDS

The standard [1] defines the methods for measurement and interpretation of results for power quality parameters. The scope is to obtain reliable, repeatable and comparable results.

A. Voltage data processing

There are three classes of performance for voltage measurement (A, B, and C). This paper refers only to class A, 50Hz, voltage and frequency measurement. Main rules for data processing within class A applications are:

- The measurement shall be the RMS value of the voltage magnitude over a 10-cycle time interval for a 50 Hz power system.
- Every 10-cycle interval shall be contiguous with, and not overlap, adjacent 10-cycle intervals.
- The measurement uncertainty shall not exceed ±0.1 % over the range of influence quantity conditions.
- Aggregated intervals shall be used. Measurement time intervals are aggregated over 3 different time intervals. The aggregation time intervals are: 3s interval (150 cycles for 50 Hz nominal), 10-min interval, and 2-hour interval.

During aggregated intervals, aggregations are performed using the square root of the arithmetic mean of the squared input values. Three categories of aggregation are necessary:

1. Package aggregation: 10 cycle time interval aggregation; this time interval is power system frequency-based.
2. Cycle aggregation: the data for the 150 cycle time interval shall be aggregated from 15, 10-cycle time intervals; this time interval is not a "time clock" interval; it is based on the frequency characteristic.
3. Time-clock aggregation: data for the “2-h interval” shall be aggregated from twelve 10-min intervals.

B. Frequency data processing

The standard [1] states that frequency reading shall be obtained every 10-s. As power frequency may not be exactly 50 Hz within the 10-s time clock interval, the number of cycles may not be an integer number. The fundamental frequency output is the ratio of the number of integral cycles counted during the 10-s time clock interval, divided by the cumulative duration of the integer cycles. Before each assessment, harmonics and inter-harmonics shall be

attenuated to minimize the effects of multiple zero crossings. The measurement time intervals shall be non-overlapping. Individual cycles that overlap the 10-s time clock are discarded. Each 10-s interval shall begin on an absolute 10-s time clock, ±20 ms for 50 Hz. Over the range of influence quantities, and under the conditions described in [3] the measurement uncertainty Δf shall not exceed ±10 mHz.
For frequency determination, measurement time intervals are aggregated over 3 different time intervals. The aggregation time intervals are: 3s interval (150 cycles for 50 Hz nominal), 10-min interval, 2-h interval.

THE MEASUREMENT SYSTEM

MOT-103B/BG equipment [4] was used for the measurements. This is custom designed IEC61000-4-30 class A equipment. Fig. 2 shows the MOT internal the blocks for power supply, input voltage monitoring, RMS value recording, frequency measurement, operator console, processing and storage, clock and synchronization.
The equipment has dedicated inputs for voltage to be monitored, time synchronization and dedicated bidirectional interfaces for communication. Besides voltage monitoring according to the standard EN 50160, the equipment can give on the OSC output the RMS value of the voltage and the duration of the half-cycle, for every half-cycle.

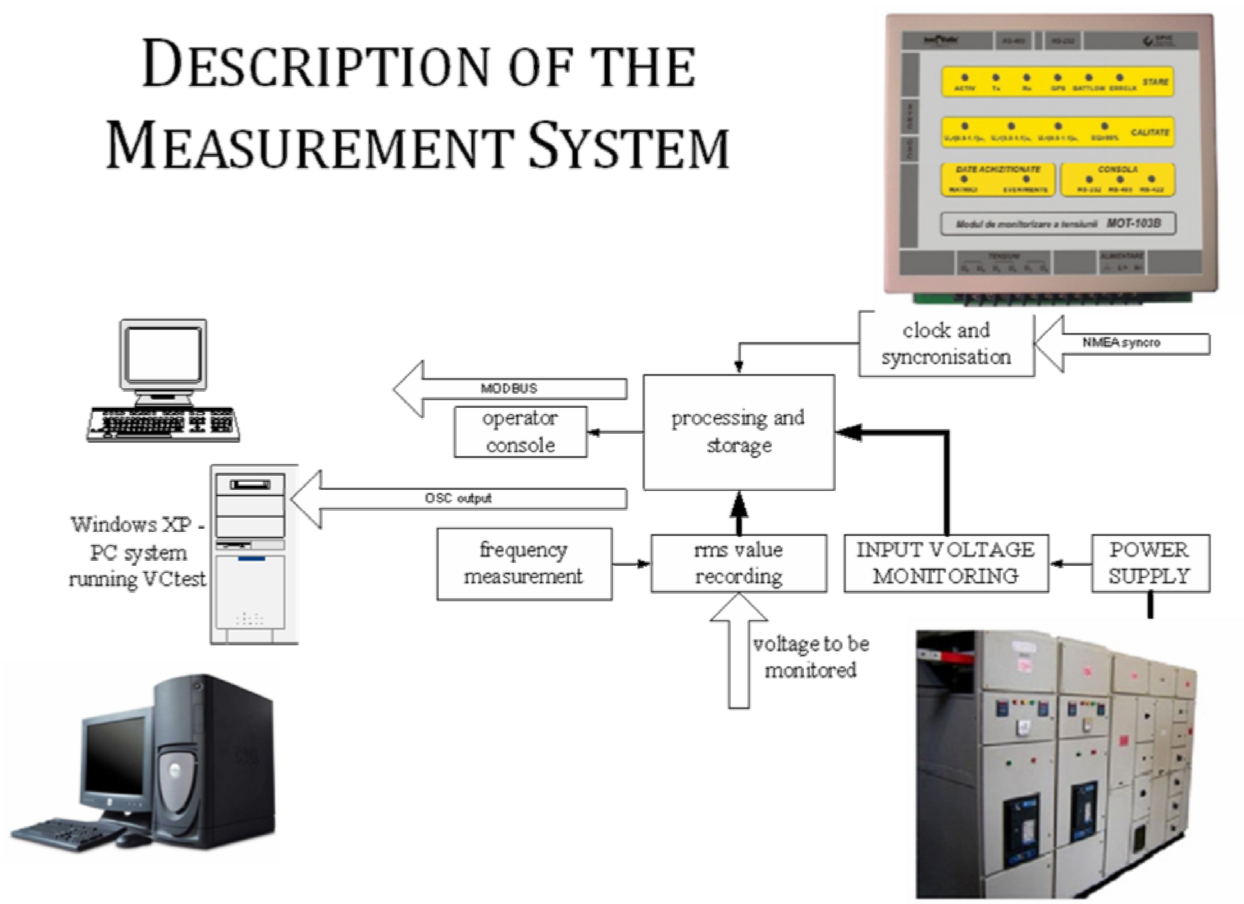

Fig. 2. MOT internal blocks and measurement system

This secondary function is used for the study presented in this paper. As it can be seen in Fig. 2, there is a Windows XP - PC running a dedicated piece of software, called VCtest. This software links the computer and the MOT through a serial interface. Since the equipment has no dedicated memory for half-cycle measurement storage, the processing unit must be continuously connected to the measurement system during the data acquisition process.

DATA PROCESSING

The measurement results obtained according to the standard [1] are meant to support the discussions on power quality between client and network operator. The averaging process will hide some of the information that could be useful to the distributor or supplier in order to improve power quality.

Using box plots

Among the data that describe a time series there are mean, median (or value at the 50th percentile), maximum, minimum, quartiles, and so forth. In 1977, John Tukey published [5] an efficient method to display robust statistics called box plot or box whiskers. Basic features of this kind of plot are:

- central box includes the middle 50% of the data;
- whiskers show range of data;
- symmetry is indicated by box and whiskers and by location of the mean;
- it is easy to compare groups by constructing side-by-side box plots, as shown below.

There are two ways to present data as a box plot: "median-based" or "mean-based". Fig. 3 shows the chart of all the data selected to be analyzed.

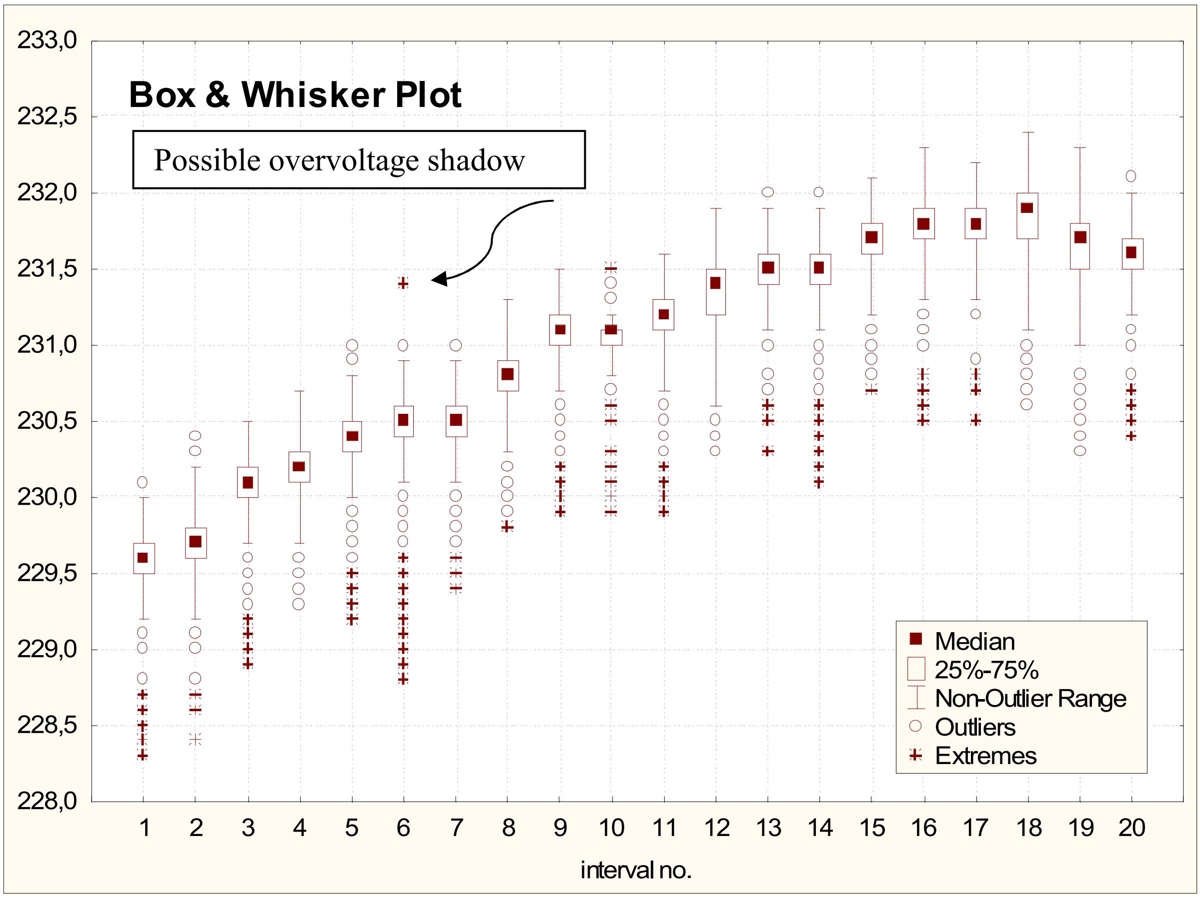

Fig. 3. Box plot of the voltage measurements.

The centred point in a median-based display is the group median, or the middle value. If the number of items in a group is odd, the median is the exact value of the middle number. If the number of items in a group is even, the median is the average of the two middle values.

For instance interval six shows an obvious local overvoltage shadow value. This value despite is within the limits of the standard reflects a totally different behaviour compared to the rest of the group.

The centred point in a mean-based display is the group average. The limits of the box are the 25th and 75th percentiles. The distance between them is also known as inter-quartile range (IQR). The box limits value is the range between the ends of the box, cantered on the 50th percentile.

Real datasets display high maximums or low minimums called outliers. John Tukey [4] has provided a precise definition for two types of outliers:

- outliers are either 3×IQR or more above the third quartile or 3×IQR or more below the first quartile;
- suspected outliers are slightly more central versions of outliers: either 1.5×IQR or more above the third quartile or 1.5×IQR or more below the first quartile.

If either type of outlier is present the whisker on the appropriate side is taken to 1.5×IQR from the quartile (the "inner fence") rather than the max or min, and individual outlying data points are displayed as unfilled circles (for suspected outliers) or filled circles (for outliers). The "outer fence" is 3×IQR from the quartile.

For median-based plots, extremes are typically defined as those individual points which are 3 times the IQR, beyond the end of the box.

Hurst exponent of the time series

With the results obtained from previous paragraph it seems voltage time series is somehow predictable. Fig. 4 shows the Hurst exponent evolution for the time series found by voltage data processing.

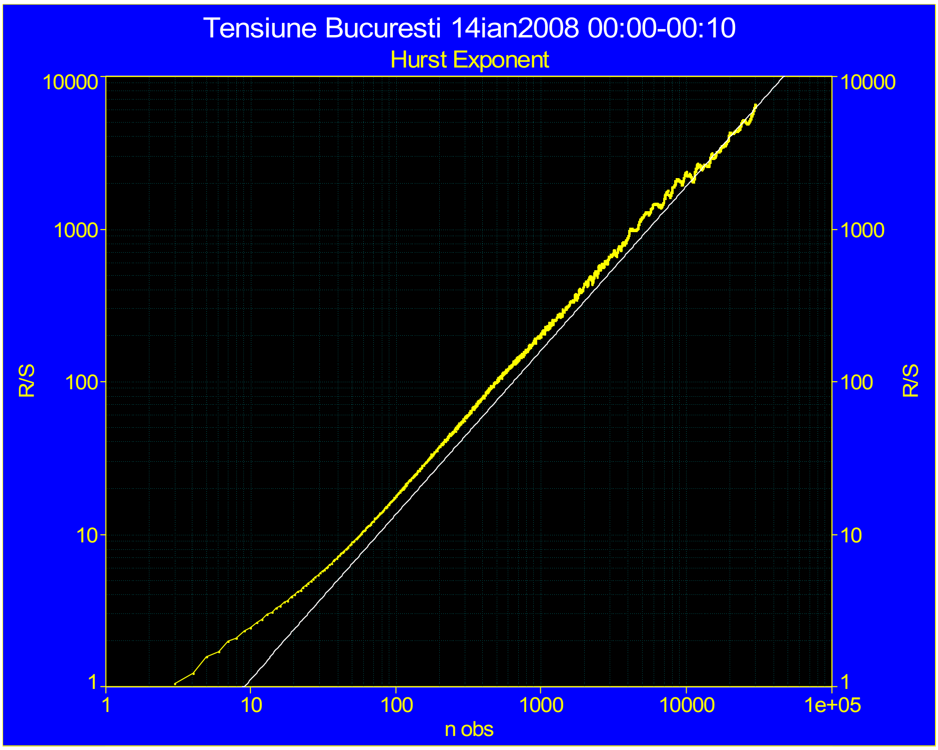

Fig. 4. Hurst exponent evolution for the voltage measurement time series.

The Hurst Exponent is a numerical estimate of the predictability of a time series. It is defined as the relative tendency of a time series to either regress to a longer term mean value or 'cluster' in a direction. Hurst exponent provides means to classify time series in terms of predictability. The Hurst exponent could measure the fractal dimension of a data series.

The value calculated for the whole time interval is $H = 1.07482$. A Hurst exponent of 0.5 indicates no long-term memory effect. Higher values indicate an increasing presence of such an effect. The duration of such a memory effect is often visible in the form of a threshold. This algorithm is useful for determining if a data set is truly distinguishable from Gaussian or white noise. Far more common are values of H above 0.5. These are persistent series which contain a memory effect. Each data value is related to some number of preceding values. These data series reverse signs less frequently than would be true for white noise. Autoregressive (AR) modelling depends on exactly this effect. For a persistent series, the autocorrelation series will have decay to zero. Both the R/S analysis and the autocorrelation map the memory effect.

CONCLUSION

Time series analysis cannot produce relevant results for an efficient network management under the present standard requirements. The process of time aggregation [2] hides information related to the process. In order to extract information form the half cycle data, other dedicated analysis techniques that could better address the data have been investigated.

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