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# Virtual Instrument for Electromagnetic Disturbances Classification and Analysis

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*Abstract* — **In the recent years, the number of events that affect the power quality has grown. Consequently, the power quality issue has become more and more a key concern for the power engineers as it needs a permanent attention and survey. On the other hand, the development of computer science has encouraged the implication of computers in solving different problems related to power systems: protections, control, measurements, processes control etc. Considering these aspects, a virtual instrument was created to classify and analyze the electromagnetic disturbances (harmonics and interharmonics, voltage dips and unbalance) that appear in power distribution networks. The paper presents the virtual instrument description, working principle, and analysis algorithms; several numeric examples show how it can be operated.**

*Index Terms*—**power quality, electromagnetic disturbances, PQ indices, analysis, virtual instrumentation**

## I. Nomenclature

PQ - power quality
VI – virtual instrument
FP – frontal panel
BD – bloc diagram
ESA – electrical signals analyzer
DAB – data acquisition board
ANN – artificial neural network

## II. Introduction

Power quality is a term often used today for describing a major aspect of the electrical energy supply and utilization. A PQ problem refers any event manifested in voltage, current or frequency variation that results in malfunction of end-user equipment. Taking into account these aspects, the PQ issue requires a permanent attention.

Power system is supplying a growing number of domestic and industrial consumers that use non-linear and unbalanced loads. This fact determinates a permanent non-sinusoidal and unbalanced operating state of electric networks. Then again, short-circuits and faults that occur in the distribution and transmission networks cause voltage dips and interruptions that deteriorate much more the poor power quality level.

On the other hand, in the recent years, the number of loads sensitive to power quality has grown considerable. Conversely, most of these loads become themselves important sources of the degradation of power quality. For the user, problems of new equipment sensitivity to PQ and of the supplying services have become an unpleasant surprise. Indeed, many electronic devices, such as computers, process control and communication equipment are sensitive to power system disturbances. For instance, voltage dips of a few cycles can cause tripping of drives while voltage dips of a few milliseconds can result in loss of computer data and computer errors. A permanent non-sinusoidal and unbalanced operating state can cause malfunctions of industrial equipment based on power electronics.

Diminution of power quality not only has an effect on customer apparatus but is also harmful for the power utility equipment. The negative impacts of disturbances on power system components include the following [1]:

- malfunction of remote control;
- overheating of cables due to existence of harmonic currents;
- increased eddy losses in transformers;
- incorrect operation of protective devices;
- errors in energy measuring;
- growing of power losses in the electric lines and transformers windings;
- overheating of electric motors;
- diminution of capacitor banks efficiency etc.

In the recent years, the development of computer science has encouraged the implication of computers in solving different problems related to power systems: protections, control, measurements, processes control etc. Thus, dedicated software products were created to facilitate and to improve the engineers work: LabVIEW, AutoCAD, MathCAD, EDSA etc.

Taking into consideration all aspects presented above about electromagnetic disturbances, a permanent attention and evaluation of the power quality is necessary. Normally, for power engineers, this task involves the studying of a wide range of norms and many experimental measurements, which is time consumer. Another way, less expensive and time saver, to solve this problem is the use of dedicated software. In this paper, a virtual instrument (electrical signals analyzer) is proposed for classification and analysis of electromagnetic disturbances (harmonics, dips and unbalance). It accepts data acquired in electrical distribution grids, from existing files (of-

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line) or through a data acquisition board (on-line), and processes them. First, a classification of the electrical signals contained in the read data is obtained; supplementary, an analysis of the acquired three-phase electrical signal is performed and all power quality indices imposed by existing norms are calculated and displayed for the user.

Further on, the VI and its working principle is presented; details on proper utilization and some examples are also underlined. The paper ends with a section of conclusions.

## III. Description and Working Principle

The electrical signal analyzer can identify and analyze electromagnetic disturbances that generate non-sinusoidal, unbalanced with/without dips three-phase electrical signals. The electrical signals must be sampled with a frequency of 6.4 kHz, that is, 128 samples per cycle (this frequency can be changed if the user requires other value).

The ESA, as a VI, contains two main parts: the frontal panel and the block diagram.

### *A. Frontal Panel*

The frontal panel is the VI component that user comes in contact with (the graphic user interface) [2], [3]. Fig. 1 and 2 present the VI's GUI when the ESA is in on and off operating state, respectively. The GUI of the ESA was build so that to be easy to use and to suggest a real instrument. So, the FP is made of a „carcass", command buttons (e.g. On/Off, On-line/Off-line) and display windows. In LabVIEW programming environment these elements are the controls and the indicators. Controls are used to introduce the input data, and indicators to visualize the results.


Fig. 1. Frontal panel of the electrical signal analyzer virtual instrument in shut down state. 1- On-line/Off-line button, 2- On/Off button

The VI in "On" operating state is composed of the following elements:

- Controls – command buttons (Fig. 1, 1 and 2), main menu (Fig. 2, 2) and file's path (Fig. 2, 3);
- Indicators – signal display window (Fig. 2, 1), signal characterization display window, numeric arrays (Fig. 9, 1), and simple numeric indicators (Fig. 9, 2).

The main menu is made of three fields: Acquired signal, Signal analysis and Help. The "Acquired signal" field contains information about the measured signals (waveform, classification on each phase). The analysis results can be visualized by accessing field "Signal analysis" where the power quality indicators are presents.

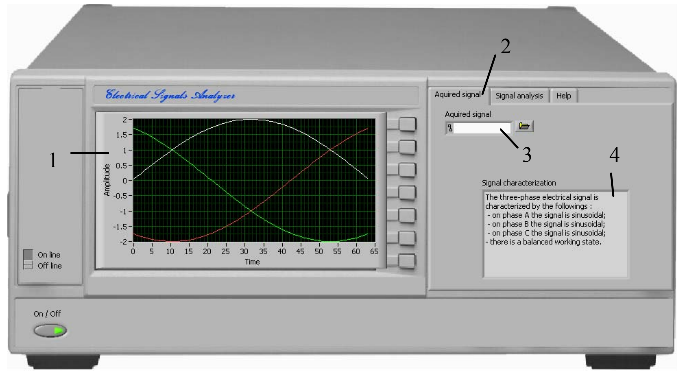


Fig. 2. Electrical signal analyzer's frontal panel during working state. 1 - Signal display window, 2 - Main menu, 3 - File's path control, 4 - Signal characterization display window.

The "Signal display window" is a numeric indicator that helps displaying different output data: signals waveform and harmonics amplitudes.

The "Signal characterization display window" is a string indicator through which the user can see the signals classification for each phase.

### *B. Block Diagram*

The block diagram represents the VI's element that includes its working principle. It contains the appeal icons (signatures) of the used sub-VI, arithmetic functions, logic and repetitive structures and terminals. In Fig. 3 is shown the hierarchy tree of the VI; it contains the signatures of all VI that build up the software. To the main VI (in red borders) are attached all sub-VIs that are direct subordinated to it.

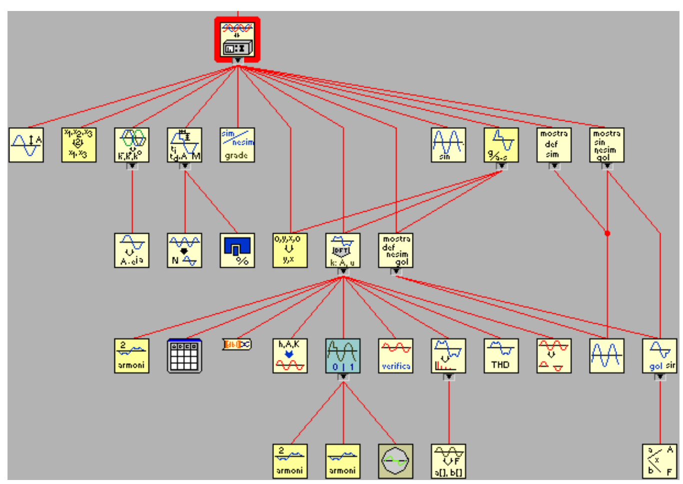

Fig. 3. Hierarchy tree in vertical format of the VI electrical signal analyzer.

Fig. 4 presents the working principle diagram of the ESA. The signals classification and analysis is made in four steps:

1. Identification of voltage dips. In the case that dips do exist, the signal is analyzed and dip parameters are calculated. Then, the signal is rebuild and the dips are

eliminated;

2. Identification of harmonics. In the case of non-sinusoidal signals, an analysis based on Fourier transform is performed and the harmonic characteristics are calculated;
3. Using the results from the former steps, the three phase signals are analyzed to identify a possible unbalance, and if it exists any, its indices are calculated;
4. Considering the results from the previous steps, a characterization of the signal is displayed along with the PQ indices.

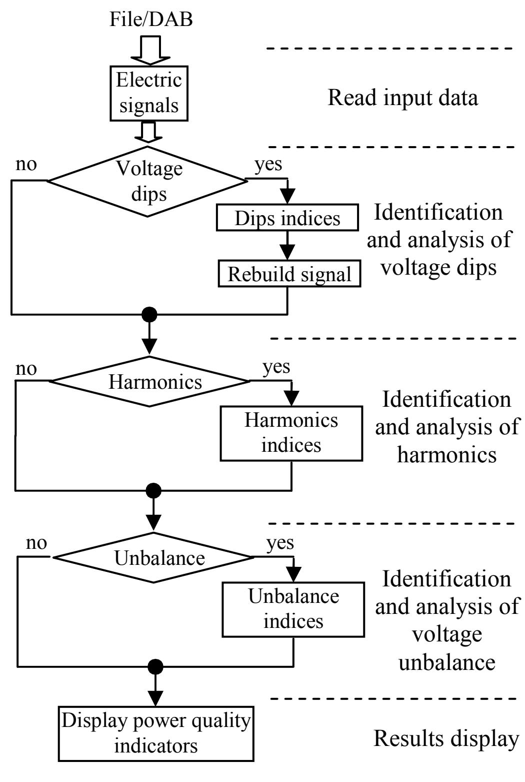


Fig. 4. Working principle's logic diagram of ESA

Input data are the sampled electrical signals that need to be analyzed. This information can be obtained from an existing file (*.txt, *.xls), when the ESA is working in off-line way or directly from the measurement equipment through an acquisition data board, when it is functioning in on-line way.

The obtained results refer to the following:

- Classification of the acquired three-phase electrical signals;
- Power quality indicators for the identified disturbances (harmonics, voltage dips and voltage unbalance).

Considering the classification of acquired signals, the results can show a balanced sinusoidal with no dips (the ideal case that is not usually found in practice) or an unbalanced non-sinusoidal signal with voltage dips on each phase (the worse scenario that often happens in practice).

The calculated power quality indices are the following:

- Voltage dips (for each phase – A, B, C):
  - Amplitude [p.u.] from the rms value;
  - Duration [ms];
  - Start time [hh:mm:ss, mm/dd/yyyy];
- Harmonics (for each phase – A, B, C):
  - Rang;
  - Rms [units];
  - Angle [degrees];
  - Level [p.u.] as a ratio of the fundamental rms;
  - THD (Total harmonic distortion);
- Unbalance (for the three-phase signal):
  - Negative unbalance factor [%];
  - Zero unbalance factor [%];
  - Total unbalance factor [%].

As it was former presented, the working principle of the ESA is based on the identification of the mentioned disturbances followed by the analysis of the signal. Considering the complexity of this step, a section was dedicated to present the way of identification and analysis of harmonics, voltage dips and unbalance.

### *C. Identification and analysis algorithms*

A first identification algorithm refers to voltage dips. It is based on the wavelet transform that can be very easy used to identify if any transient event exists [4] – [9]. The wavelet transform for a sampled signal can be calculated by using the following relationship:

$$DWT(\nu,\tau) = \frac{1}{\sqrt{2^{\nu}}} \sum_{j=1}^{N} f(j) \cdot \psi\left(\frac{j - 2^{\nu}\tau}{2^{\nu}}\right) \quad (1)$$

A second algorithm, used to identify non-sinusoidal waveforms [10] – [18], exploits the artificial neural network presented in Fig. 5. The used ANN is a back-propagation network with 64 neurons on the first layer, 32 neurons on the hidden layer and a single neuron that builds up the last layer. The ANN was learned with the help of 8 sample signals.

Both algorithms were implemented in LabVIEW and used as sub-VIs.

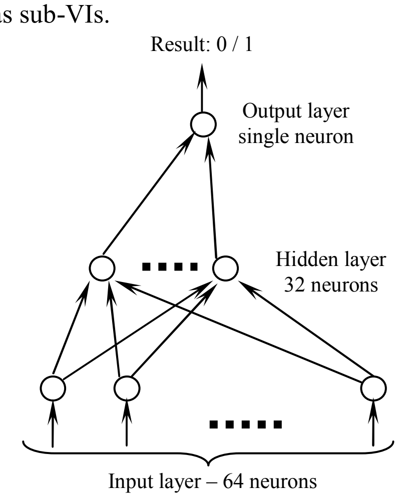


Fig. 5. ANN's structure for identification of non-sinusoidal signals

The calculus of PQ parameters in the case of voltage unbalance is based on the following mathematical relationships proposed by existing norms [19], [20]:

- Negative unbalance factor $$k_U^- = \frac{U^-}{U^+} \qquad (2)$$

- Zero unbalance factor $$k_U^0 = \frac{U^0}{U^+} \qquad (3)$$

- Total unbalance factor $$k_U = k_U^0 + k_U^- \qquad (4)$$

where $U^+$ is the positive sequence component voltage;

$U^-$ - the negative sequence component voltage,

$U^0$ - the zero sequence component voltage.

In the case of non-sinusoidal waveforms, the signals are analyzed with the help of Fourier transform [1], [21] – [24]. To identify the possible interharmonics, the Fourier analysis is performed on a 10 cycles window (0.2 ms period of time). In this case, harmonics having frequencies multiple of 5 Hz can be identified.

By using the Fourier analysis, a non-sinusoidal sampled signal can be seen as a sum of sinusoidal signals (harmonics and/or interharmonics):

$$y = Y_0 + \sum_{n=1}^{\infty} \sqrt{2} \cdot Y_n \cdot \sin(n \cdot \omega_1 \cdot t + \gamma_n) \qquad (5)$$

where $Y_0$ is the continuous signal component, $Y_n$ is the rms value of the $n^{th}$ harmonic, and $\gamma_n$ is its initial phase.

For current, the total harmonic distortion factor can be calculated as:

$$\delta_I = \frac{I_d}{I_1} \cdot 100 = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_1} \cdot 100\,[\%] \qquad (6)$$

where $\delta_I$ is the current THD ,

$I_d$ - current harmonic residue;

$I_1$ - fundamental current rms value;

$I_n$ - $n^{th}$ harmonic's rms value.

## IV. OPERATION

The operation of the ESA is easy and does not require special programming knowledge. This is due to the fact that it looks like a real instrument with a friendly graphic interface [25] – [27]. The first step is the turning on of the analyzer by pressing button "On/Off"; then, the way of acquiring data must be selected by accessing button 2 (Fig. 1): the file path for existing data or the DAB, in the case of "On-line" analysis state.

For an easier understanding of the way of operating with the ESA, some sample signals were analyzed. These signals can be accessed from field "Help" of the main menu. Figure 6 illustrates the "Analyzed signal" field in the case of a three phase non-sinusoidal balanced electrical signal. It can be seen that a characterization of the signal is presented for each phase: "The three-phase signal is characterized by the followings:

- Phase A is working under non-sinusoidal conditions;
- Phase B is working under non-sinusoidal conditions;
- Phase C is working under non-sinusoidal conditions;
- There is a balanced working state."

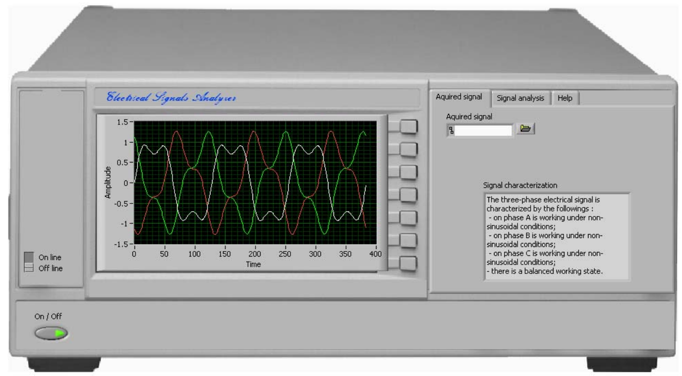


Fig. 6. ESA's FP in the case of a non-sinusoidal balanced signal

Fig. 7 shows a non-sinusoidal unbalanced signal with voltage dips on phases A and C.

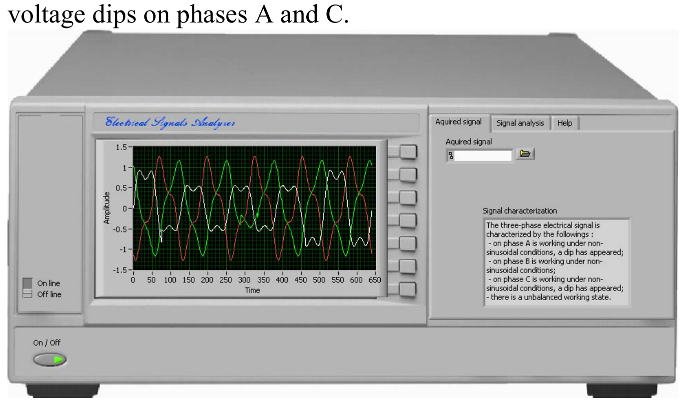


Fig. 7. ESA's PF in the case of a non-sinusoidal unbalanced with dips signal

In Fig. 8, the power quality indicators in the case of an unbalanced three phase signal are presented. They can be obtained by accessing the field "Signal analysis"- "Unbalance state"; the values of unbalance factors (relationships 2-4) and the rms values for each phase are provided.

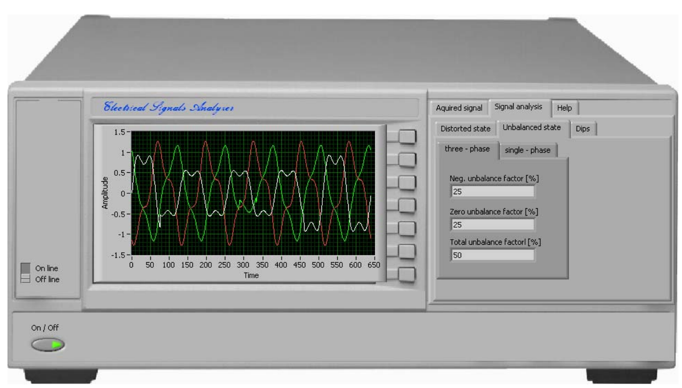


Fig. 8. ESA's PF in the case of unbalance operating regime indicators display

In order to achieve the parameters for harmonic distortion, the sub-field “Distorted state” from the “Signal analysis” has to be accessed; for each phase, the harmonic characteristics and the THD are displayed. In the case of the analyzed signal, two harmonics ($3^{rd}$ and $5^{th}$ rang) and the fundamental were identified; the signal spectrum is represented in the display window on the left – Fig.9.

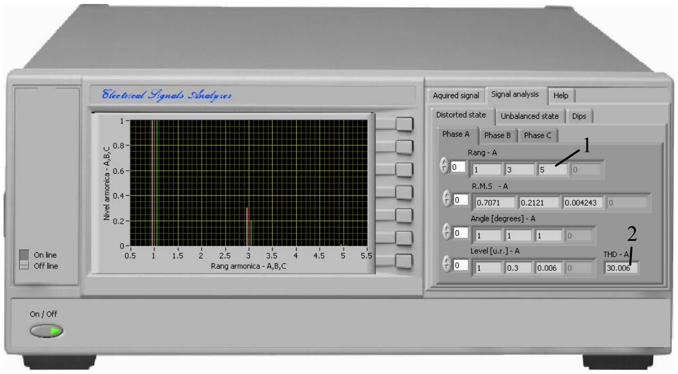


Fig. 9. ESA’s PF in the case of harmonics characteristics display

Fig. 10 presents the characteristics of the identified voltage dips. For each phase, they are displayed in the sub-field “Dips” from “Signal analysis”. It can be seen that the voltage dip on phase “A” began at 12:54:19 PM and lasted 0.06 ms from the beginning of the sample window. The amplitude of the electrical signal during the voltage dip was 0.6 from the rms signal before the dip.

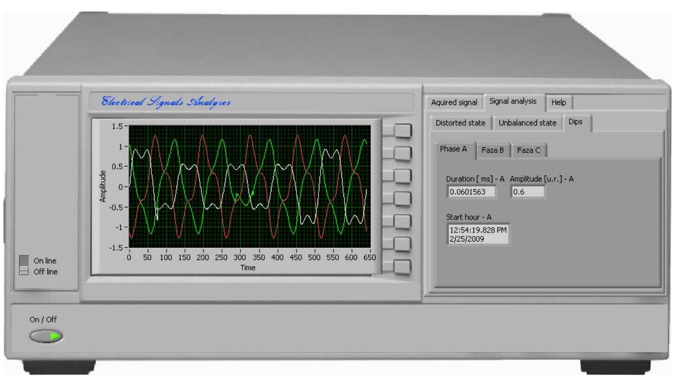


Fig. 10. ESA’s PF in the case of voltage dips parameters display

## V. Conclusion

The paper presents a software tool dedicated to the identification, classification and analysis of electromagnetic disturbances (harmonics, unbalance and dips) that may appear in the electrical signals from the distribution grids. The software tool represents in fact a virtual instrument, named electrical signal analyzer, developed in the LabVIEW graphic programming environment.

The ESA reads the electrical signals, representing the input data, from a file or directly from a data acquisition board, and further processes them according to the existing PQ norms. The instrument performs the signal classification and calculates the power quality indicators that characterize analyzed the signals and all identified distortions.

The advantages of the VI are as follows:

- Friendly graphic user interface;
- Easy to introduce signals from a txt or xls file or directly from the measurement equipment;
- The analysis is made for each phase in the case of voltage dips and harmonics;
- The accurate determination of power quality indicators in the case of distorted, unbalanced signals;
- On-line analysis that gives the opportunity of a permanent survey of power system;
- Quicker results as for traditional power system analyzers.

As any instrument, this analyzer has its limits and disadvantages:

- It can not identify a dip that may appear in the first 10 ms of the read signal;
- The calculus error of start moment of a dip is $\pm 2$ ms.

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## VII. Biographies

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