Virtual Instrumentation Applied to Electrical Power Quality Measurement

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Abstract – **This paper describes advances in electrical power quality monitoring equipment and virtual instrumentation software tools for metrological support and analyzing power quality measurement results. Different types of power quality variations are described and the methods of characterizing each type are presented. Instruments for electrical power quality measurements are based on complex digital processing of input signals, whose waveforms are highly variable. The flicker and harmonics generated by network disturbances present a problem that is well known to both the manufacturing industry and electrical utilities. Virtual instrumentation tools can be used to record the voltage quality at various points in the system and save the data to a central database. By correlating the relevant variables and analyzing the time of events, the cause for a disturbance can be localized and eventually eliminated. Virtual instrument described in this paper, provides parameters of voltages, currents and phases, defined by electrical power quality protocols, by means of 8 channels DAQ card PCI NI 6713, comparing generated and measured values of voltage and current parameters, and automatically correcting generated values until the desired accuracy class is achieved.**

Keywords - **virtual instrumentation, electrical power quality measurement, LabVIEW**

I. Introduction

Electrical power quality, in recent years, has become an important issue and is receiving increasing attention by utility, facility, and consulting engineers. Present equipment setups and devices used in commercial and industrial facilities, such as digital computers, power electronic devices, and automated equipment, are sensitive to many types of power disturbances. The threatened limitations of conventional electrical power sources have focused a great deal of attention on power, its application, monitoring and correction [1].

Over the last twenty years, power quality has become an increasingly important issue. This is due to a number of reasons: the increased use of non-linear and pulsed loads, can leads to mains interference feedback; a growing number of electronically controlled devices, which require a supply voltage of a certain quality, respond very sensitively to mains pollution; with energy supply companies operating in a highly competitive market, the relationship between supplier and customer has become more important than ever [2]. Power economics now play a critical role in industry as never before. As the use of power electronics and other devices that put a strain on the network is on the increase, electricity suppliers need detailed data on the quality of their network. With the high cost of power generation, transmission, and distribution, it is of paramount concern to effectively monitor and control the use of energy. The increased concern for power quality has resulted in significant advances in monitoring equipment that can be used to characterize disturbances and power quality variations [3].

In the past, voltage quality measurements were only carried out when required, for example after a complaint by a customer who had experienced problems. In such cases, the quality was measured and the results were analyzed. If no special events such as a power failure occurred during the time of measurement, it was basically impossible to establish what had caused the problem in the first place. Today, the market and general good practice of continued quality control require electricity suppliers to permanently monitor the voltage quality in their networks [2]. Computer substations, and manufacturing or process plants now have the tools to monitor power quality and consumption to aid in achieving reliable and cost effective operations. Results from power quality monitoring allow for electrical power supplier selection and electronic load balancing within a plant.

II. Electrical power quality variations

It is important first to understand the kinds of power quality variations that can cause problems with sensitive loads. There is a standard: BS EN 50160:2000 Voltage characteristics of electricity supplied by public distribution systems [4], that provides the limits and tolerances of various phenomena that can occur on the mains. A summary of the criteria for the low voltage side of the supply network is given in Table 1.

TABLE I
A summary of the electrical power quality criteria

Supply voltage phenomenon	Acceptable limits
Grid frequency	47Hz to 52Hz
Slow voltage changes	230V ± 10%
Voltage Sags or Dips (≤1min)	10 to 1000 times per year (under 85% of nominal)
Short Interruptions (≤3min)	10 to 100 times per year (under 1% of nominal)
Accidental, long interruptions (>3min)	10 to 50 times per year (under 1% of nominal)
Temporary over-voltages (line-to-ground)	Mostly < 1.5 kV
Transient over-voltages (line-to-ground)	Mostly < 6kV
Voltage unbalance	Mostly 2% but occasionally 3%
Harmonic Voltages	8% Total Harmonic Distortion (THD)

Some practical conclusions can be made from this data: the limits are wide, perhaps more than one would expect; it

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important to check that safety interlocks and relays can reset after a sag or dip, because such incidents can occur quite frequently; control and process equipment that is voltage sensitive should be applied with caution because the allowable voltage tolerance is very wide and can drift outside ±10% for 5% of the time; the transient tolerances are high and so the use of surge-protection devices should be carefully considered, especially where manufacturing of high-cost components or processes involving lengthy and expensive restart times are concerned.

Categories of these variations must be developed with a consistent set of definitions so that measurement equipment can be designed in a consistent manner and so that information can be shared between different groups performing measurements and evaluations. A voltage dip is defined as a sudden drop of the voltage to a level below 90% of the nominal voltage, followed by an increase to a level above 90% within a period of 10ms to 60s. Most dips in medium or high voltage networks are over within less than 0.2s. Short dips can lead to serious problems such as failure of machine control systems (loss of production) or damage to motors caused by the sudden torque change. Most dips are caused by faults in the insulation in medium and high voltage networks [2]. Other relatively frequent causes are snow, thunderstorms, frost or branches of trees touching lines. If such an event occurs, all customers in the network are equally affected. Many dips are however caused by the consumers themselves. Voltage dips can for example occur when a great load is switched on where there is insufficient short circuit capacity at the point of common coupling. While short circuits are a common cause, voltage dips can also be caused by the start-up of large machines or capacitor banks.

Transient voltages may be detected when the peak magnitude exceeds a specified threshold. RMS voltage variations may be detected when the RMS variation exceeds a specified level. Steady state variations include normal RMS voltage variations and harmonic distortion. These variations must be measured by sampling the voltage and/or current over time. Harmonic distortion of the voltage and current results from the operation of nonlinear loads and devices on the power system. The nonlinear loads that cause harmonics can often be represented as current sources of harmonics. The system voltage appears stiff to individual loads and the loads draw distorted current waveforms. Harmonic voltage distortion results from the interaction of these harmonic currents with the system Harmonic distortion levels can be characterized by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. It is also common to use a single quantity, the Total Harmonic Distortion - THD, as a measure of the magnitude of harmonic distortion [1,2].

III. Electrical power quality monitoring system with virtual instrumentation

To understand the power quality problem better requires a comprehensive monitoring and data capturing system that is used to characterize disturbances and power quality variations. Power quality monitoring and power metering will allow plants to perform predictive maintenance, energy management, cost management, and quality control. We need a configurable and programmable high-performance PC with high-speed data acquisition units and software to perform the required task [3]. The power line monitoring system based on high-performance software and hardware, acquires and displays the voltage and current waveforms. It monitors waveforms for distortion, glitches, and frequency deviations. Such system provides a range of valuable data [2]:

- Overview of the voltage quality, showing types and levels of disturbances experienced in the network.
- Quality reports.
- Detailed, time-related recording of disturbances. Based on the data recorded, the cause of a disturbance can be identified, events can be related to problems or known events and exceptional situations can be distinguished from general seasonal trends.
- The data provides the basis of predictive maintenance. Based on indicators, some disturbances can be predicted at an early stage.

Figure 1 illustrates a typical configuration of an electrical power quality monitoring system based on virtual instrumentation software tools [3].

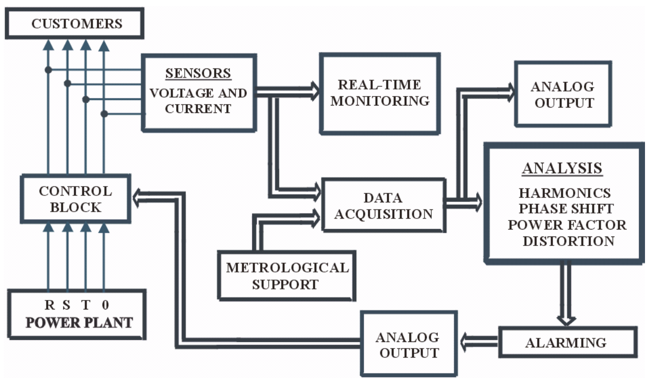

Fig. 1. Configuration of an electrical power quality monitoring system based on virtual instrumentation.

One major development resulting from the widespread adoption of the PC over the past twenty years is the concept of virtual instrumentation. A virtual instrument consists of an industry-standard computer or workstation equipped with application software, cost-effective hardware, such as plug-in boards, and driver software, which together perform the functions of traditional instruments. The development and use of programmable measurement systems have been widely explored. The possibility of modifying the measurement procedure simply by changing the algorithm executed by the computer-based architecture without replacing the hardware components makes the experimental activity easier. Virtual measurement systems have been introduced to simplify the design and implementation of programmable measurement systems by adopting a visual interface [5]. Networking has also been introduced successfully in measurement to interconnect different instruments and data processing sites into a distributed measurement system – DMS.

Currently the most popular way of programming is based on the high-level tool software. With easy to use integrated development tools, design engineers can quickly create, configure and display measurements in a user-friendly form, during product design and verification. Virtual instrumentation software tools are easily applied to electrical power monitoring applications. Control panel of virtual instrument developed in a graphical programming language LabVIEW [6], which provides parameters of voltages, currents and phases, defined by electrical power quality protocols, is shown on figure 2. A virtual instrumentation software tool provides a possibility for changing amplitude and phase of all voltage and current channels.

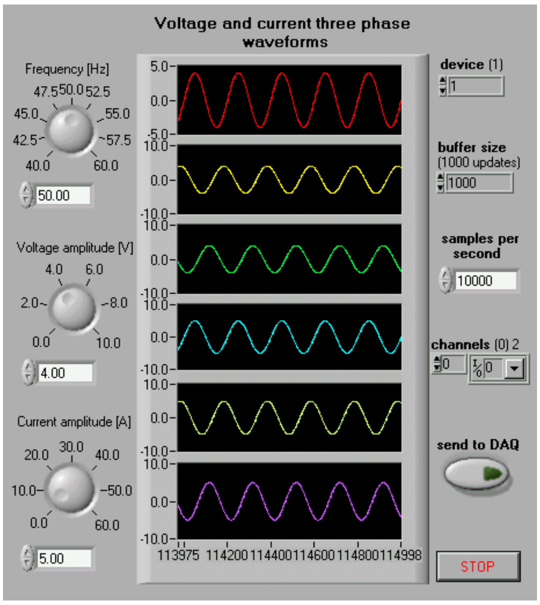

Fig. 2. Virtual instrument for generating voltage and current three phase waveforms.

Using a multi-channel microcomputer card DAQ PCI NI 6713 [7], for referent voltage and current generating, eight digital/analogue output channels are provided.. A program sequence developed using a graphical programming language LabVIEW, is shown on figure 3.

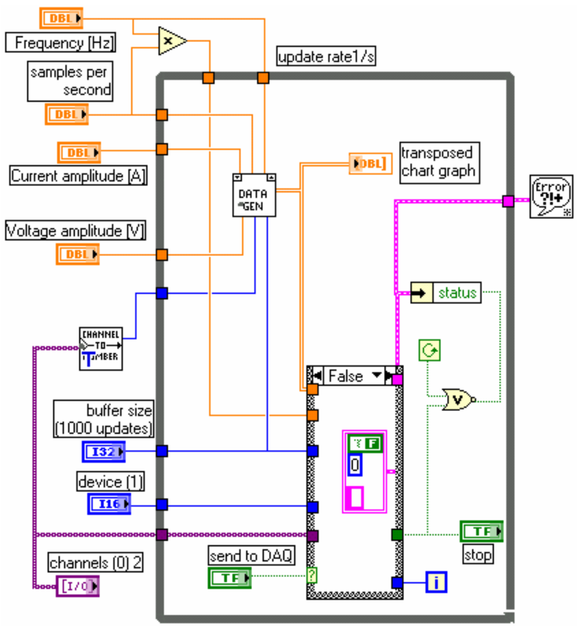

Fig. 3. A program sequence developed using a graphical programming language LabVIEW.

In most practical cases the network voltage variations influence measured quantities and that way increase measuring error. Precise setting of each current or voltage value, as well as the phase shift, requires a substantial time. In addition, most of quantities influence each other, and therefore there is need for multiple corrections. Described virtual instrument can be used as a part of the feedback loop, which in real time compares generated and measured values of voltage and current parameters, in order to correct generated values until the desired accuracy class is achieved.

Multi-channel acquisition card NI PCI 6713, generates voltage and current three phase waveforms. Measuring transducers provide information about momentary values of voltage and current, which are fit to input of acquisition card ADQ ED428. Converted values measured by acquisition card in the feedback loop are corrected for the values of obtained errors based on preset values of measured transducer coefficients [8]. Deviation of effective voltage values in time, that shows reducing of obtained error by feedback loop correction, is shown on figure 4.

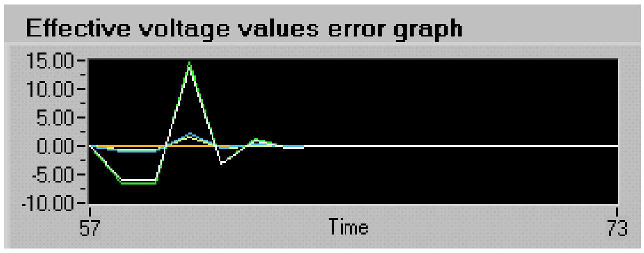

Fig. 4. Time deviation of effective voltage values.

The measurement uncertainty of voltage and current parameters settings depends both on measurement transducers coefficients stability (current shunts and voltage dividers), and the reference voltages stability of the converters in acquisition cards. Experimental measurement results of eighteen successive corrected effective voltage values, together with corresponding reduced error values, are given in table 2.

TABLE II
EXPERIMENTAL MEASUREMENT RESULTS OF CORRECTED EFFECTIVE VOLTAGE VALUES

Ordinal nomber of measurem.	Nominal effect. voltage values (V)	Measured effect. voltage values (V)	Measurement error (V)
1.	220,00	226.62	-6.62
2.	220,00	227.17	-7.17
3.	220,00	227.22	-7.22
4.	220,00	223.92	-3.92
5.	220,00	223.97	-3.97
6.	220,00	223.97	-3.97
7.	220,00	221.63	-1.63
8.	220,00	221.67	-1.67
9	220,00	221.69	-1.69
10.	220,00	219.08	0.92
11.	220,00	219.04	0.96
12.	220,00	219.00	1.00
13.	220,00	219.99	0.01
14.	220,00	220.00	0.00
15.	220,00	219.99	0.01
16.	220,00	220.00	0.00
17.	220,00	220.00	0.00
18.	220,00	220.01	-0.01

IV. CONCLUSION

Electrical power quality has become an important issue and is receiving increasing attention by utility, facility, and consulting engineers in recent years. Power quality problems show up as impacts within the end user facility but may involve interaction between all levels of the system. To understand the power quality problem better requires a comprehensive monitoring and data capturing system that is used to characterize disturbances and power quality variations. Electrical power quality monitoring allows plants to perform predictive maintenance, energy management, cost management, and quality control. The power line monitoring system based on high-performance virtual instrumentation software and additional hardware acquires and displays the voltage and current waveforms. With continuous power quality monitoring, it is very important to be able to summarize variations with time trends and statistics, in addition to characterizing individual events. Virtual instrument described in this paper is developed in a graphical programming language LabVIEW. It provides parameters of voltages, currents and phases, defined by electrical power quality protocols, by means of 8 channels DAQ card PCI NI 6713, comparing generated and measured values of voltage and current parameters, and automatically correcting generated values until the desired accuracy class is achieved.

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