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DEVELOPMENT OF THE SIGNAL GENERATOR APPLIED TO TESTING OF INSTRUMENTS FOR ELECTRICAL POWER QUALITY MEASUREMENT*

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Abstract. *Procedure for the development of the software supported acquisition system for generating signals applied to testing of instruments for measurement and analysis of the standard electrical power quality (PQ) parameters is presented in this paper. Described solution performs generating standard three-phase voltage waveforms, including possibility for simulation of the various PQ disturbances typical for real electrical power distribution networks. This generator is functionally based on virtual instrumentation concept, including control software application in graphical package LabVIEW and data acquisition board NI PCI 6713. Software support of this generator provides definition and graphical presentation of the reference voltage waveforms for testing. Number of the control functions and switches implemented on the front panel of the developed signal generator enables adjustment of the basic parameters for definition, presentation and signal generating. The presented solution is capable to generate long-time and short-time signal test sequences, including all types of the PQ disturbances defined according to European quality standard EN 50160.*

Key words: *signal generator, testing procedure, electrical power quality measurement*

1. INTRODUCTION

Degradation of electrical power quality (PQ) level is caused by various problems and current/voltage disturbances in electrical power distribution networks. PQ disturbances, present in the form of the RMS voltage value variations or high-order harmonic components, directly affect decreasing of energy efficiency level in electrical power production, distribution and consumption process. Increased concern for PQ assurance problems in the recent years is primarily caused by limitations of the natural resources for energy production and widespread use of the alternative energy resources. Electrical power distribution companies are forced to provide efficient monitoring of the distribution networks,

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in order to reduce possibilities for potential network disturbances and to prevent failures of the customer equipment, highly sensitive to the PQ degradation and problems. This monitoring procedure involves measurement and analysis of the basic PQ parameters and typical disturbances, defined by relevant international documents and quality standards [1,2]. PQ level is determined by acceptable limit values of the standard quality parameters and network disturbances. Relevant and valid information, necessary for assessment of the optimal quality level, can be provided by measurement of the basic quality parameters at specific locations in power distribution networks, including detailed statistical processing and analysis of the measurement results. Different classes of the commercial devices and equipment developed for measurement and software processing of the standard PQ parameters are available. These instruments are capable to perform continuous monitoring of the power supply quality at selected locations in single or three-phase power distribution networks. Measurement of the quality parameters and statistical processing of the measurement results must be performed in order to verify compliance of the quality parameters with demands of the relevant PQ standards [3,4]. In order to satisfy the desired level of the measurement accuracy and some basic parameters, instruments for measurement of the PQ parameters must be followed by an appropriate metrological traceability chain. Metrological verification and testing of these devices must be performed in appropriate metrological laboratories. Reference devices, such as voltage and current calibrators, are available in various functional and constructive variations. Such calibrators are sources of reference signals with high accuracy levels, which correspond to the secondary standards, laboratory and industrial standards in metrological traceability chain. Also, there are specially designed calibration instruments for specific classes of the PQ meters, such as multifunctional calibrators Fluke 5520A and 6100B, supported by some special functions for testing of the PQ measurement instruments [5].

Solution of the experimental acquisition system described in this paper is developed for software supported generating of the standard three-phase signal waveforms, including certain levels of the various PQ disturbances. Generating procedure is based on 8-channel D/A data acquisition board NI 6713 [6] and virtual instrumentation software. Real-time generating of the test voltage waveforms with selected categories of the PQ disturbances, previously defined and simulated in LabVIEW software environment [7], is provided by three analog output channels of the D/A data acquisition board. This solution for signal generating can be applied in processes of the metrological verification, calibration and testing of the measurement instruments and equipment for PQ monitoring and analysis.

2. Hardware Configuration of the Signal Generator

Basic hardware configuration of the software controlled experimental procedure for generating of the standard three-phase voltage signals, including simulation of the various classes of the typical PQ disturbances is presented in Figure 1. This procedure includes standard computer, supported by control software application developed in LabVIEW programming environment and D/A data acquisition board NI PCI 6713, equipped with corresponding connector block SCB 68. Complete generating procedure includes two connected functional segments. First segment of this procedure provides definition and simulation of the standard three-phase voltage waveforms, with the required categories of the typical PQ disturbances for generating. Definition of the basic parameters for different types of the PQ disturbances can be performed directly on the front control panel and block diagram of the LabVIEW virtual instrument. Front control panel gives possibility for fast and simple corrections of the basic signal parameters, according to specific users demands and purpose. Second functional segment of the process is focused on real-time generating of the previously defined and selected types of the PQ disturbances, using three analog output channels of the D/A data acquisition board NI 6713. This 8-channel PCI data acquisition board is capable for D/A signal conversion, designed for output voltage range of ±10V and 12-bit resolution. Generating process is based on predetermined values of the signal samples, previously recorded in internal buffer. Significant characteristic of this data acquisition board is possibility for double data buffering, which enables replacement of the signal samples without interruption of the signal generating process [6]. Estimated nominal accuracy level of the voltage signals generated on data acquisition board outputs is within a range 0,05 to 0,06 %.

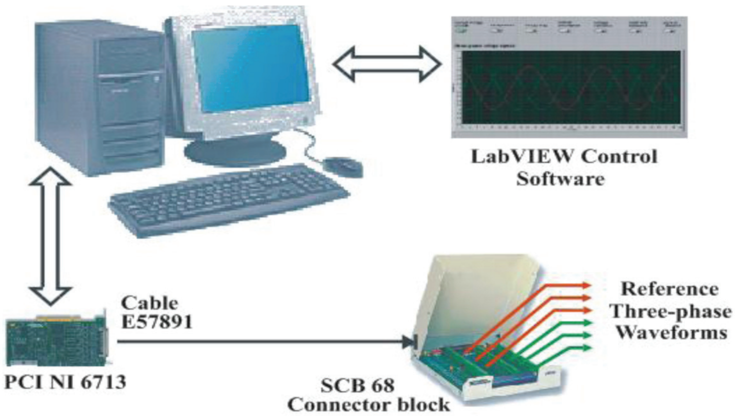


Fig. 1 Basic hardware configuration of the procedure for signal generating

Developed solution is capable to generate long-time and short-time test sequences, including various types of the PQ disturbances defined by European quality standard EN 50160, such as: slow voltage variations, voltage swell, voltage sag, spikes, interruptions, high-order harmonics, voltage swell with high-order harmonics and voltage sag with high-order signal harmonics [8]. Some basic functions provided by this signal generator are:

- definition of the nominal amplitude and frequency values,
- definition of the signal sample rate and duration of the final test sequence,
- possibility for generation of the Gaussian noise,
- variation of the signal frequency nominal value,
- slow variation of the signal amplitude value with defined variation frequency,
- definition of the signal DC offset,
- definition of the voltage swells and sags,
- definition of the high-order signal harmonics components.

In order to be more realistic, for individual PQ disturbances there is enabled definition of the rising and falling times, when disturbance changes value from zero to maximum level. For this purpose in LabVIEW software code is developed trapezoidal function as one common functional segment with time and level of the disturbance variables in input cluster. For each individual PQ disturbance start and stop times can be separately defined. Using this software application it is very easy to perform generation of the signal waveform with different signal disturbances in sequential combinations. Some additional categories of the disturbances can be also generated as a subset of the developed generator, such as: flicker as slow variation of the signal amplitude level, pulse interference caused by lightning as high level of the voltage swell, voltage interruption defined as a type of the voltage sag and voltage signal oscillation in short time caused by influence of the some high-order voltage harmonic components.

3. Software Support of the Signal Generator

The described solution of the signal generator is functionally based on LabVIEW virtual instrumentation software. Front panel of the virtual instrument, developed in LabVIEW software environment, for simulation and graphical presentation of the reference three-phase voltage waveforms is presented in Figure 2. Control panel of the virtual instrument includes basic switch for selection of the specific disturbance classes for generating. Also, this software application provides variation and adjustment of the basic signal parameters by number of the control functions and knobs, implemented in block diagram of the virtual instrument.

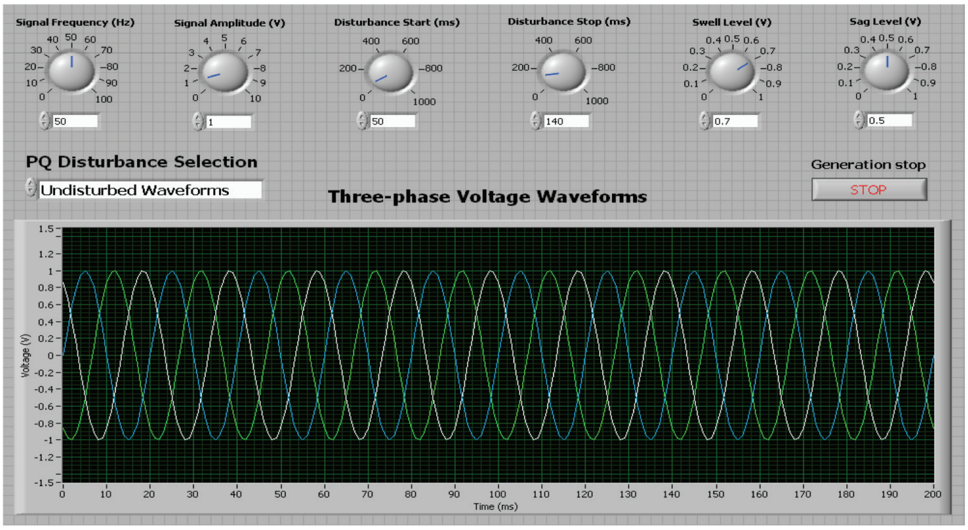


Fig. 2 Front panel of the LabVIEW virtual instrument for generating and presentation of the standard three-phase voltage waveforms

In this figure are shown six control knobs which perform continuous regulation of the signal frequency, amplitude, disturbance start and stop times, voltage swell and voltage sag amplitude levels. Standard voltage waveforms, presented with ten signal periods, are generated with specified nominal frequency value of 50Hz, phase differences between signals of $2\pi/3$ rad and normalized amplitude voltage level of 1V.

One small segment of the LabVIEW block diagram, corresponding to the previously presented virtual instrument for simulation of the standard PQ disturbances, is given in Figure 3.

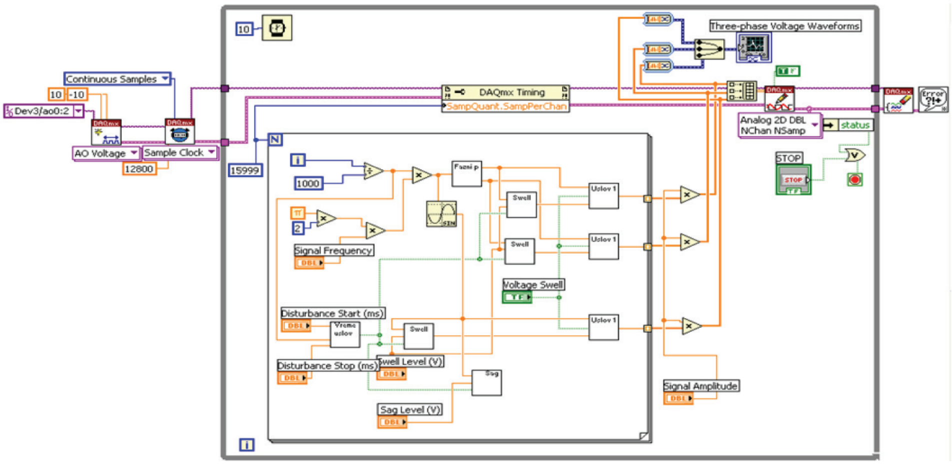


Fig. 3 One segment of the LabVIEW block diagram corresponding to the virtual instrument for signal generating

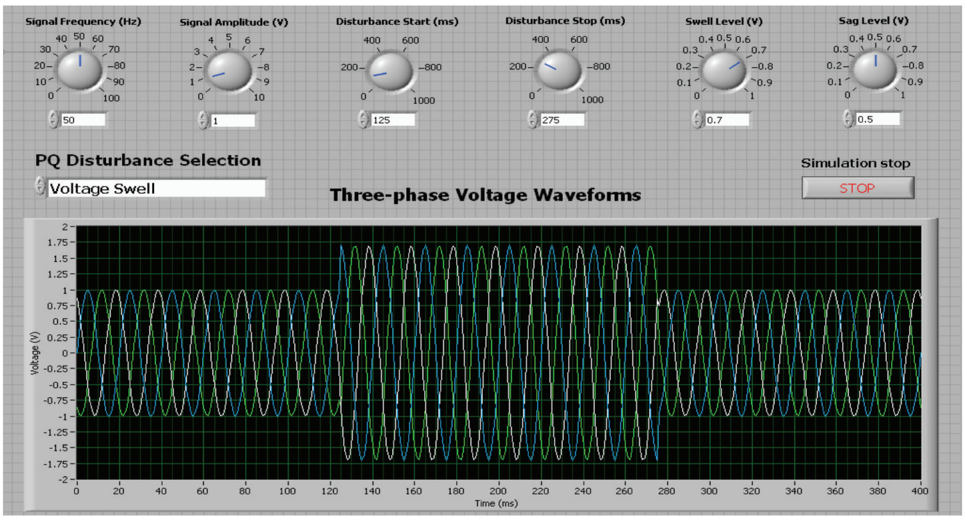


Fig. 4 LabVIEW presentation of the standard three-phase voltage waveforms with simulation of the voltage swell

In this figure is presented only a part of the complete more large software code. Graphical presentation of the reference three-phase voltage waveforms in LabVIEW programming environment, including simulation of the voltage swell, is given in Figure 4. For this specific example of the generator front panel predefined duration of the voltage disturbance is 150ms and voltage swell amplitude level is 0,7V.

Separated segment of the control functions is used for selection and adjustment of the amplitude levels regarding to the individual high-order voltage harmonics. Content of the specific high-order voltage harmonics can be precisely defined by number of the control knobs, implemented on generator front panel. Example for simulation of the three-phase voltage waveforms, with combination of the voltage sag and some of the high-order signal harmonic components, is presented in Figure 5. Level of the voltage harmonics is defined by control knobs for continuous regulation of the harmonics from third to eleventh high-order voltage harmonics. These specific three-phase waveforms are presented with thirty signal periods, for predefined duration time of the specific signal disturbances of 300ms.

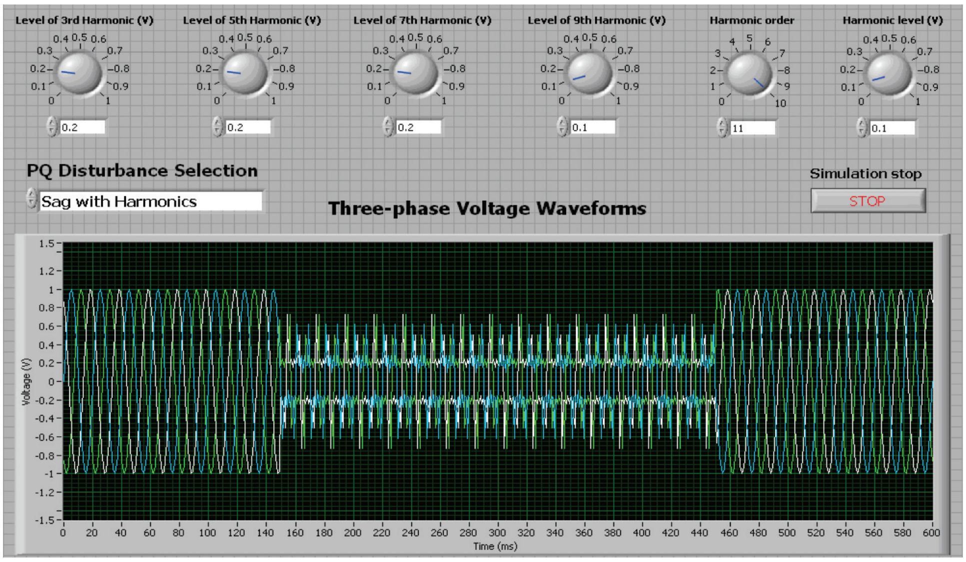


Fig. 5 Presentation of the standard three-phase voltage waveforms with simulation of the voltage sag and high-order signal harmonics

This solution is capable to provide generating of the standard voltage waveforms with different classes of the PQ disturbances in serial combination. In Figure 6 is presented LabVIEW front panel of the signal generator for simulation of the reference waveform with voltage swell and voltage sag in serial combination, followed by certain level of the signal harmonic distortion and slow fluctuations of the signal amplitude value. For these specific signal disturbances is enabled adjustment of the following basic parameters: start and stop times, rising and falling times of the disturbances and percentage amounts of the disturbance amplitude levels. For purpose of the later signal processing, recording of the generated waveforms in specified file locations can be performed using COMTRADE data format. Format of the recorded signal files can be BIN or ASCII. One period of the final composite waveform is always present at separate small front panel of the generator.

LabVIEW front panel for generating and presentation of the voltage waveform with voltage interruption, defined as 100% amount of the voltage sag amplitude level, is shown in Figure 7. Graphical presentation of the standard voltage waveform, generated with short-time voltage transient, caused by influence of the high-order harmonic components, is illustrated in Figure 8. For this specific example of the generated waveform short-time oscillation transient is caused by influence of the 11th order voltage harmonic component.

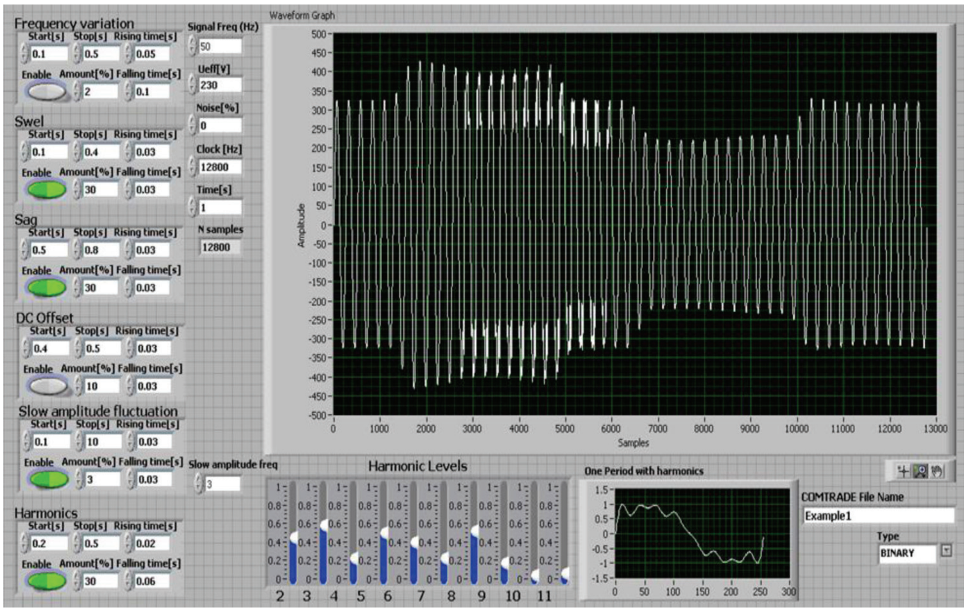


Fig. 6 Front panel of the signal generator for simulation of the various PQ disturbances in serial combination

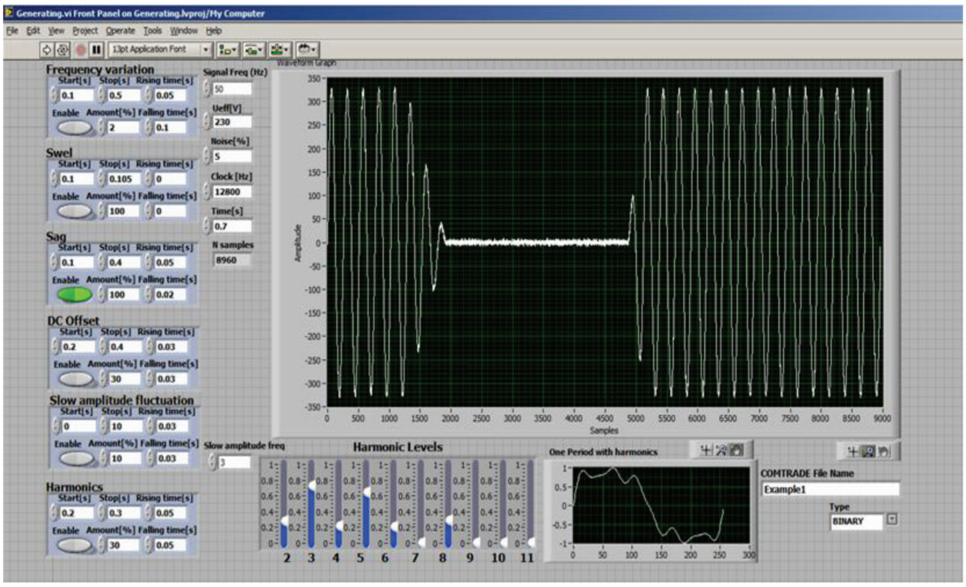


Fig. 7 LabVIEW front panel of the signal generator for simulation of the waveform with voltage interruption

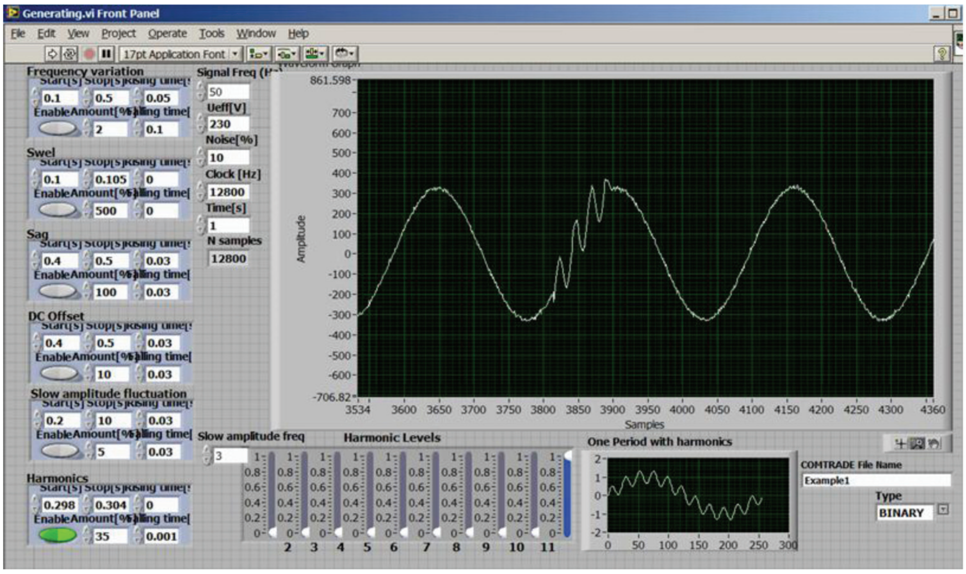
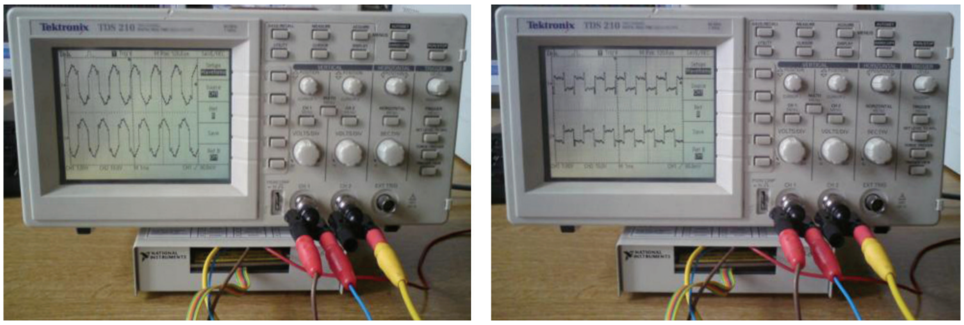


Fig. 8 Generating of the voltage waveform with short-time transient caused by signal harmonic distortion

Graphical illustration of the voltage signals generated in real-time on data acquisition board outputs is given in Figure 9. Here are presented examples of the generated voltage waveforms, recorded on two-channel digital oscilloscope Tektronix TDS 210. Presented signals include combinations of the voltage swell with harmonics and sag with harmonics.



a) voltage swell with harmonics b) voltage sag with harmonics

Fig. 9 Presentation of the generated voltage signals on two-channel digital oscilloscope

4. Conclusion

Signal generator developed in LabVIEW software environment, for simulation of the standard three-phase voltage waveforms with some of the typical PQ disturbances, is presented in this paper. This solution for signal generating includes standard computer, supported by data acquisition board NI PCI 6713 and virtual instrumentation software. Basic front panel of the signal generator includes various control functions for definition and selection of the basic parameters related to signal test sequences for generating, such as: frequency variations, voltage swells, voltage sags, DC offset, amplitude fluctuations and high-order harmonics. Particular disturbances can be finally combined and unified in form of complex waveform sequence, using various command control implemented in LabVIEW programming code. By this signal generator is very easy to perform generating of the voltage waveforms with various types of the disturbances in serial combination. In order to be more realistic, for particular PQ disturbances is enabled definition of the rising and falling times. Real-time generating of the previously defined three-phase voltage waveforms, including certain levels of the various disturbances, is provided by three analog output channels of the data acquisition board. Presented signal generator can be used in procedures for verification, calibration and testing of instruments and equipment for PQ measurement and analysis.

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