MEASUREMENT SCIENCE REVIEW, **18**, (2018), No. 2, 41-51

DE GRUYTER OPEN

ISSN 1335-8871

MEASUREMENT SCIENCE REVIEW

Journal homepage: http://www.degruyter.com/view/j/msr

Generation of Long-time Complex Signals for Testing the Instruments for Detection of Voltage Quality Disturbances

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Software supported procedure for generation of long-time complex test sentences, suitable for testing the instruments for detection of standard voltage quality (VQ) disturbances is presented in this paper. This solution for test signal generation includes significant improvements of computer-based signal generator presented and described in the previously published paper [1]. The generator is based on virtual instrumentation software for defining the basic signal parameters, data acquisition card NI 6343, and power amplifier for amplification of output voltage level to the nominal RMS voltage value of 230 V. Definition of basic signal parameters in LabVIEW application software is supported using Script files, which allows simple repetition of specific test signals and combination of more different test sequences in the complex composite test waveform. The basic advantage of this generator compared to the similar solutions for signal generation is the possibility for long-time test sequence generation according to predefined complex test scenarios, including various combinations of VQ disturbances defined in accordance with the European standard EN50160. Experimental verification of the presented signal generator capability is performed by testing the commercial power quality analyzer Fluke 435 Series II. In this paper are shown some characteristic complex test signals with various disturbances and logged data obtained from the tested power quality analyzer.

Keywords: Signal generation, instrument testing, voltage quality disturbances, LabVIEW software.

1. Introduction

In recent years, electrical power quality has become a very important and significant topic, foremost due to limitations of natural resources necessary for electrical power production and widespread usage of renewable energy resources. Powerful electronic components and switching devices can directly cause quality level degradation, which affects the production process costs and reduces reliability of customer electrical devices and equipment. In order to provide the required level of energy efficiency in electrical power production, distribution and consumption, including providing final customer protection, the optimal voltage supply level is determined according to relevant international standards and regulations [2], [3]. For example, the European power quality standard EN50160 defines voltage characteristics of the public electrical power distribution systems under normal operating conditions. The required quality level is determined by reference nominal values and acceptable tolerances of basic quality parameters and typical network disturbances. Continuous measurements of voltage quality parameters at carefully selected locations inside the power distribution network, including software processing of the obtained measurement results, are necessary to provide the relevant information for proper assessment of electrical power quality level. Instruments and equipment designed for measurement and software supported processing of standard quality parameters are available on the market in various constructive and functional solutions. Such measurement instruments are designed to perform continuous monitoring of voltage supply quality at selected locations inside electrical power distribution networks. Using continuous measurement of standard quality parameters, including software supported statistical and diagnostic activities in the single and three-phase power distribution systems, these instruments are capable to verify compliance of measured parameters with quality standards requirements. The European standard EN50160 defines reference values, acceptable limits, measurement intervals and monitoring periods for following quality parameters and network disturbances: frequency variations, slow RMS voltage value variations, voltage dips and voltage swells, temporary and transient overvoltages, short and long time voltage interruptions, three-phase signal unbalance and maximum levels of individual high-order signal harmonic components [4].

Having in mind the significant importance of VQ issues and problems, there have been developed various sophisticated and reliable microprocessor-based instruments and complex measurement systems for continuous electrical

DOI: 10.1515/msr-2018-0007

power quality monitoring in recent years. Generally speaking, software based virtual instruments can be very useful and successful in realization of flexible computer-based measurement systems. A number of research and scientific papers related to the use of virtual instrumentation for electrical power quality measurement and reference signal generation have been published so far [5]-[10]. Naturally, in order to satisfy the required measurement accuracy level, instruments and equipment for measurement of quality parameters must be supported by appropriate metrological traceability. Reference instruments, voltage and current calibrators, are sources of reference waveforms with high accuracy parameters, which correspond to the secondary standards, laboratory and industrial standards. Also, there are some commercial calibration instruments developed for testing of specific types of quality meters and analyzers. Closed and not flexible functional architecture, predesigned according to some relevant quality standards, for example EN50160, presents certain limitation of these instruments. Virtual instrument, presented in the paper, is capable of reproducing long-time predefined complex test scenarios, including various combinations of standard VQ disturbances. This solution, easily adaptable to various practical requirements, random test sequence generation and upgrading, includes significant improvements of computer supported signal generator presented and described in the previously published paper [1]. It is suitable for testing the commercial instruments for detection of standard voltage quality disturbances. For the purpose of practical experimental verification, developed complex signal generator is applied for testing three-phase quality analyzer Fluke 435 Series II [11]. Complete test procedure, generated characteristic test waveforms and important results obtained from test procedure are presented and analyzed in the paper.

2. BASIC CONFIGURATION AND DESCRIPTION OF VIRTUAL VQ SIGNAL GENERATOR

Software supported generator of sinusoidal voltage waveforms with standard quality disturbances is based on the virtual instrument programmed in LabVIEW graphical environment, data acquisition card NI PCIe 6343 for output signal generation and external power amplifier.

Signal generation virtual instrument (VI) is divided into two basic functional segments: a graphical user interface (virtual instrument front panel) and executive program code (virtual instrument block diagram), interlinked between each other. At the left sides of the control front panel of LabVIEW virtual instrument (shown in Fig.1.), one can see default values of signal parameters per each of the three signal phases: nominal signal amplitude and frequency, phase angle, signal DC offset, noise level, flicker amplitude, flicker frequency, and overall control of presence of high-order harmonics. Percentage level of the specific high-order harmonics can be precisely determined by an array of the control knobs for harmonic regulation. Using these defined parameters, virtual instrument successively calculates samples for signal generation and sends specific samples to the buffer of data acquisition card for output signal generation. Sample rate, as well as duration of test sequence is also present at the front panel. Shown front panel generates test voltage waveform with nominal frequency value of 50 Hz and normalized RMS voltage value of 5.6 V. This selected RMS voltage value corresponds to the nominal power line voltage level of 230 V, after amplification of generated waveform using the external power amplifier.

In addition to such generation of test signal, similar to the one shown in [1], presented generator includes an array of commands to change any of the enumerated parameters, in defined time, with defined rising time, and goal value of parameter. That array of changes, present at the right side of the front panel in Fig.1., enables a more complex predefined test scenario during the generation process. Each type of signal disturbances, for example voltage swell, voltage dip, interruption, flicker, noise and high-order signal harmonic components, can be combined in serial combination, and unified in the form of final complex sequence, according to the requirements of the European quality standard EN50160 [4]. As an example, graphical presentation of voltage test signal with various quality disturbances, generated using the described LabVIEW based virtual instrument, is given in Fig.2.

Another feature in the presented generator is the possibility to load default parameter values and the list of commands from a textual script file, before starting generation. Such approach with a script file definition of generator working enables easy repetition of several different test scenarios, automatic generation of test files and manual editing or combining test scenarios by using a standard text editor.

Example of the script file including changing of default parameter at the beginning, and then an array of commands to change particular parameters are presented in Fig.3. One command is based on one line of text. Comments can be anywhere after '//' characters. Line which changes one of the default values contains three parameters separated with comma ',' character. Line starts with the name of the voltage phase, then comes the name of parameter, and goal values of that parameter are at the end.

Line with command for dynamic change of parameter in any moment during signal generation contains five parameters, separated with coma character. After the name of the phase, before the parameter name, comes the start time for this change, and the rising time while a particular parameter will linearly change value from previous value to goal value. Short increasing of signal amplitude (defined over parameter Ueff as $\sqrt{2}$ * Ueff) can be set by two commands: first which will increase Ueff, and second which will change Ueff to previous value. It is also possible to put several short transients of voltage in any moment during generation of signal, by command for Transient parameter, where the third parameter "rising time" will present duration of transient.

In the example of script file, presented in Fig.3., one can see definition of start Ueff value of 5.6 V, definition of present flicker with amplitude 5 % of signal amplitude, frequency of flicker as 1 Hz, and amounts of noise in generated signal 1 % of amplitude. Based on such defined signal, level of noise will change after 2.2 s, short swell of voltage will be from 10.7 s to 12 s, and at the end of the file, one transient of voltage is defined to be in 15.2 s from beginning of the signal generation.

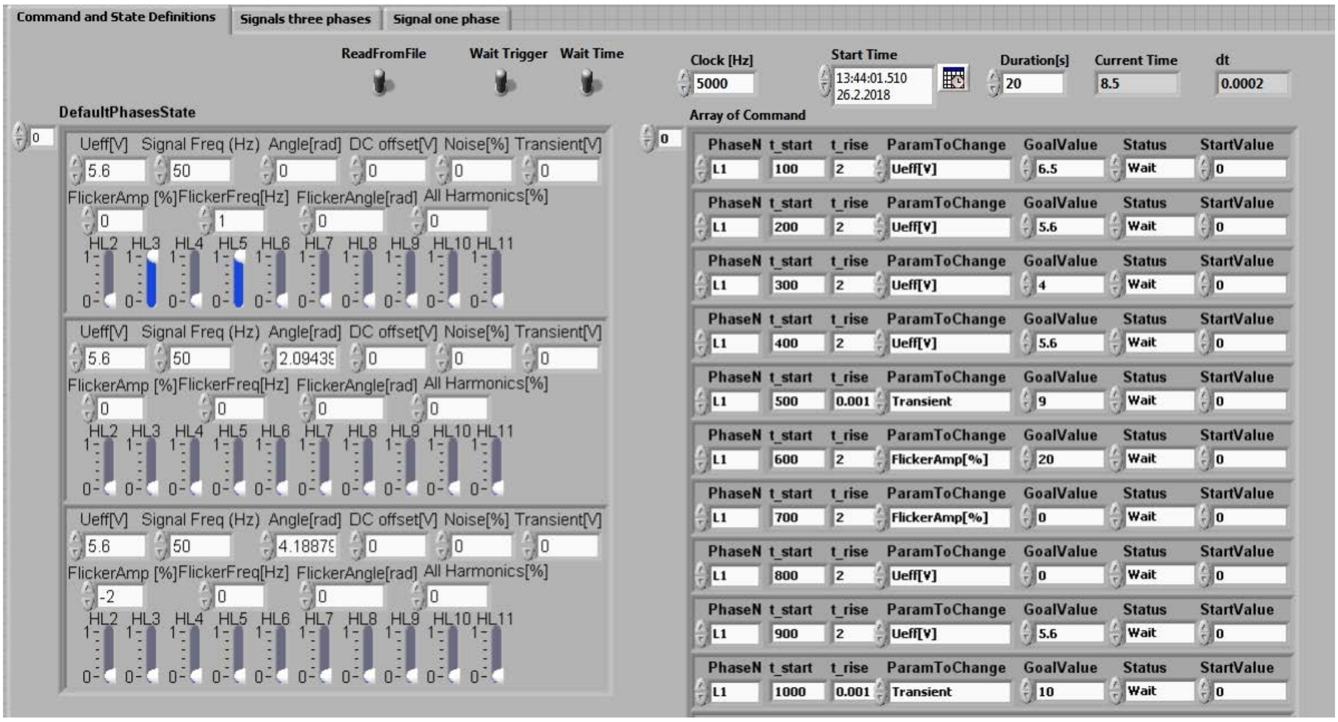


Fig.1. Control front panel of LabVIEW virtual instrument for generation of standard VQ signal disturbances.

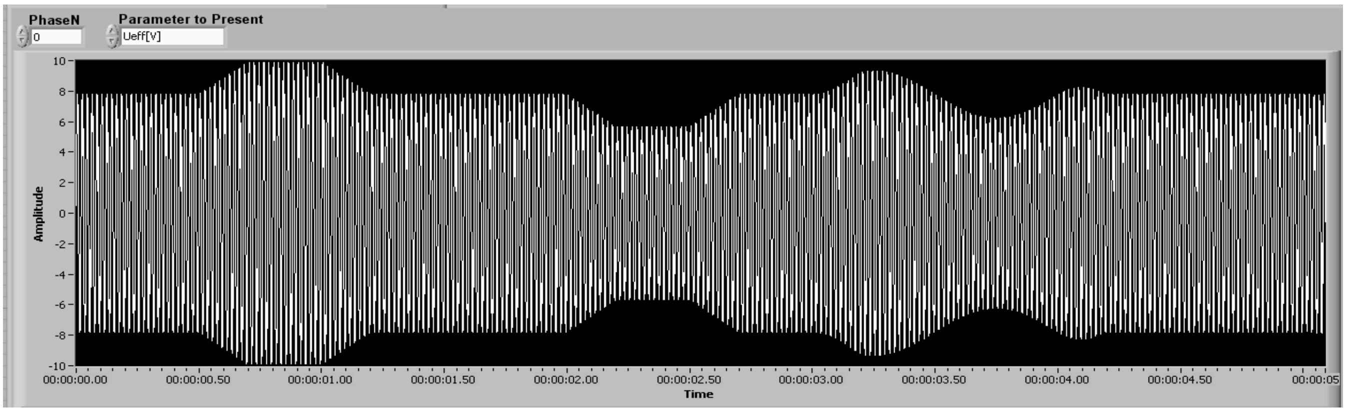
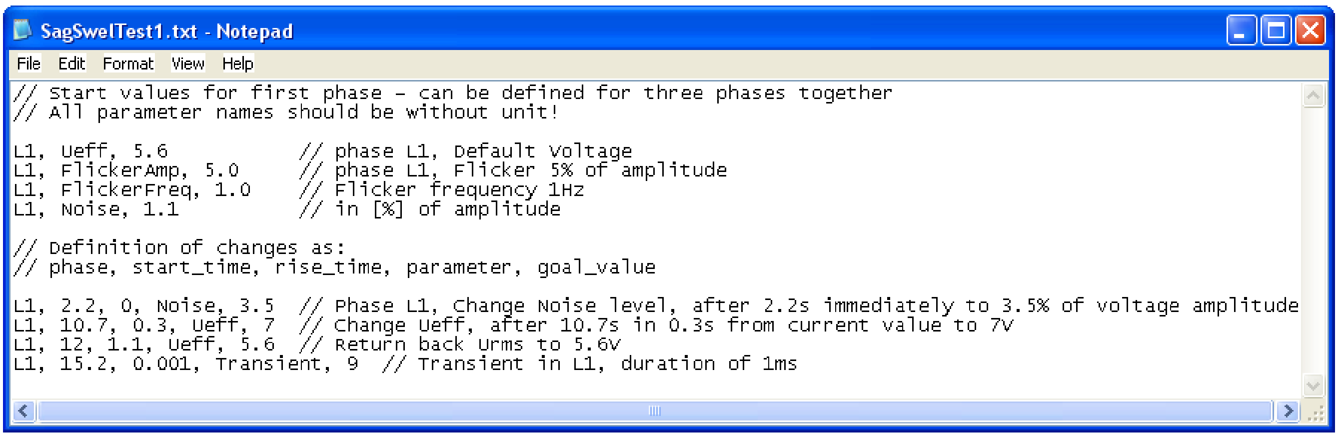


Fig.2. Graphical presentation of voltage test signal with various disturbances generated using LabVIEW based virtual instrument.




```
// Start values for first phase - can be defined for three phases together
// All parameter names should be without unit!

L1, Ueff, 5.6           // phase L1, Default voltage
L1, FlickerAmp, 5.0     // phase L1, Flicker 5% of amplitude
L1, FlickerFreq, 1.0    // Flicker frequency 1Hz
L1, Noise, 1.1          // in [%] of amplitude

// Definition of changes as:
// phase, start_time, rise_time, parameter, goal_value

L1, 2.2, 0, Noise, 3.5  // Phase L1, Change Noise level, after 2.2s immediately to 3.5% of voltage amplitude
L1, 10.7, 0.3, Ueff, 7  // Change Ueff, after 10.7s in 0.3s from current value to 7V
L1, 12, 1.1, Ueff, 5.6  // Return back Urms to 5.6V
L1, 15.2, 0.001, Transient, 9  // Transient in L1, duration of 1ms
```

Fig.3. Example of test voltage waveform with various signal disturbances defined in .txt script file.

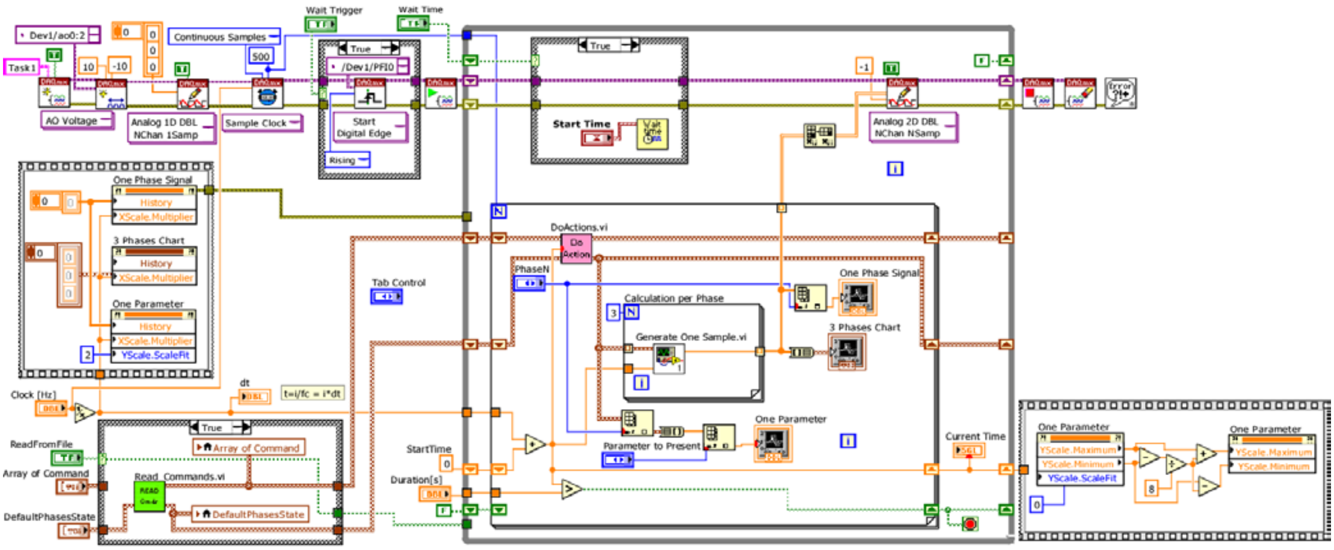


Fig.4. Block diagram (software code) of LabVIEW virtual instrument for generation of VQ signal disturbances.

Block diagram (executive software code) of LabVIEW based virtual instrument for signal generation is shown in Fig.4. In the sub VI called "Read_ Commands.vi", reading of Script file and changes of predefined default parameter values is performed. In the main software loop, during calculation of each individual signal sample, using sub VI "DoActions.vi", program checks through an array of commands if current time is larger than the defined start time. If it is true, this specific parameter needs to be changed linearly in the period of rise time. Then, using changed parameter values (amplitude, frequency, high-order harmonics, noise, etc.), individual signal samples are calculated in the sub VI "Generate_One_Sample.vi". In order to improve the overall virtual instrument performances, 500 samples at once per each phase are calculated and sent to data acquisition card NI PCIe 6343.

Reproduction of time axis during generation is based on a defined sample rate and counting of samples from the beginning of generation. Time reference for start of generation can be chosen at the front panel by two switches: waiting for exact start time (entered by user), and/or waiting for external trigger signal. If both switches are in off position, generation will start instantly when program is started. If exact time for starting generation is chosen, then accuracy of that time reference largely depends on the version of the computer operating system, and its automatic synchronization to the Universal Coordinated Time (UTC). External trigger input enables synchronization in the accuracy of one sample time. Not dependent on selected start of generation, accuracy of time interval between two disturbances will be caused only by accuracy of data acquisition card NI 6343 sample rate generator, specified as 50 ppm. This will produce maximal error of 18 ms after one hour of generation.

Using high performance universal counter HP5316B, time between the appearances of two transients is measured, and the result of 1.0000137 s is obtained. As this time is defined in script file to be one second, it can be calculated that sample rate generator in the used acquisition card has an error of 13.7 ppm.

Generation process will be interrupted when total time of generated signal samples (Current_Time = N*1/f sample) becomes equal to or greater than previously defined "Duration", at the front panel of virtual instrument.

Working with three phases together is possible in realized generator and script file, in order to simulate a three-phase power distribution system. However, in the experiments described in this paper, signal generator is used for generating L1 - one phase voltage waveforms.

Signal calculated using the LabVIEW software can be reproduced by standard data acquisition card with analog output channels. However, this acquisition card must have good-enough resolution (which is defined by the required output signal uncertainty) and must support high-enough sampling frequency. Theoretically, the sampling frequency has to be at least two times higher than the frequency of highest signal harmonic. According to the standard EN50160 (up to 50th harmonic), the minimum sampling frequency is 5 kHz. In practice, the sampling frequency should be higher in order to maintain the accuracy of the higher signal harmonics. For this application, real-time generation of previously defined test voltage waveforms with standard VQ disturbances is performed using analog outputs of the D/A data acquisition card NI PCIe 6343 [12]. This is a 32-channel PCIe acquisition card, with digital to analog signal conversion, output signal range of ±10 V and 16-bit resolution. In order to provide the output signal level required for testing the instruments for VQ measurement, reference signals generated on the data acquisition board analog outputs must be amplified to the nominal power line voltage level of 230 V. For realization of signal amplifier several analog signal processing blocks were used: low pass antialiasing filter (to restrict the input signal bandwidth and eliminate noise), preamplifier (to amplify the input signal to the required given reference level), and power amplifier (to amplify the input signal to the nominal power line voltage level of 230 V). Design and implementation of this specific power quality (PQ) amplifier used for signal amplification are already described in recently published scientific papers [1], [13].

For low-pass antialiasing filter a fourth order Butterworth low-pass filter in Sallen-key configuration realized as the cascade of two two-pole filters was designed. Considering that 50^{th} voltage harmonic (f_{50} = 2.5 kHz) has to be generated, the cut-off filter frequency is 5.45 kHz. Preamplifier has a double function: to amplify the input signal from acquisition card to the standardized reference level and to limit the input voltage level. Power amplifier is designed to amplify input signal to the power line voltage levels. However, in order to be able to generate voltage swells, the power line voltage level should be placed near the middle of the data acquisition card analog output range. The power amplifier was designed by using high voltage operation amplifier APEX PA97 [14]. The amplifier is capable of delivering 10 mA at 500 V (or power of 5 W), which is sufficient to test the commercial quality meters. The amplifier was designed in an inverting configuration with amplification of 40 times. Special attention has to be paid to the power amplifier supply. In this realization, a classical Zener-diode based power supply of ± 430 V was designed.

Table 1. Summary of measurement uncertainty components for signal generator voltage uncertainty budget at 50 Hz.

Voltage uncertainty source	**Uncertainty value [V]**
Standard deviation of measurement results from amplifier	0.0020162
Calibrator uncertainty	0.0267748
Calibrator resolution	0.0000058
Multimeter uncertainty in amplifier range	0.1407124
Multimeter resolution in amplifier range	0.0002887
Combined uncertainty amplifier - u_{CAMP}	0.1432500
Expanded uncertainty amplifier - u_{EAMP}	0.2807700
Standard deviation of measurement results from data acquisition card - DAQ	0.0000235
Multimeter uncertainty in DAQ range	0.0023240
Multimeter resolution in DAQ range	0.0000029
DAQ card uncertainty	0.0000013
DAQ card resolution	0.0000881
Combined uncertainty for DAQ - u_{CDAQ}	0.0023300
Expanded uncertainty for DAQ - u_{EDAQ}	0.0045600
Combined uncertainty - signal generator	0.1432690
Expanded voltage uncertainty of signal generator - u_{EGEN}	**0.28 V**

Metrological performances of applied signal generator are evaluated using the professional instrumentation. Reference input signal was obtained from high quality signal source - calibrator Fluke 5500A and output signal parameters are measured with 6½ digit precision digital multimeter Fluke 8846A, which is described in [1]. For complete assessment extensive measurement uncertainty calculation is performed, according to the recommendations of the document "Guide to the Expression of Uncertainty in Measurement", as defined by the International Organization for Standardization - ISO. Final summary of measurement uncertainty components for signal generator voltage uncertainty budget is shown in Table 1.

This procedure includes calculation of standard, combined and expanded measurement uncertainties and presentation of overall uncertainty budget. Uncertainty calculation is based on three main segments: calculation of amplifier uncertainty, data acquisition card - DAQ uncertainty, and calculation of entire signal generator uncertainty.

Calculation of standard uncertainty involves Type A uncertainty (standard deviation of the measurement results) and Type B uncertainty (calibrator uncertainty, calibrator resolution, multimeter uncertainty, multimeter resolution, DAQ uncertainty, and DAQ resolution). Calculation of the combined voltage uncertainties for amplifier and DAQ card is based on the previously calculated Type A and Type B uncertainties. Considering the values of amplifier combined uncertainty (u_{CAMP}) and DAQ combined uncertainty (u_{CDAQ}), combined voltage uncertainty of signal generator is:

$$u_{CGEN}(V) = \sqrt{u_{CAMP}^2 + u_{CDAQ}^2} \tag{1}$$

Finally, expanded measurement uncertainty is calculated for desired confidence probability level of 95 % (value of coverage factor *k* is 1.96). Using the previously calculated value of combined voltage uncertainty, expanded voltage uncertainty of computer-based signal generator is:

$$u_{EGEN}(V) = 1.96 u_{CGEN} = 1.96\sqrt{u_{CAMP}^2 + u_{CDAQ}^2} \tag{2}$$

Experimental results show that signal generator expanded voltage uncertainty of ± 0.28 V and frequency uncertainty of ± 8 MHz can be achieved [1].

3. Experimental procedure for testing instruments for detection of VQ disturbances

Capability of developed signal generator to generate proper signal for testing commercial quality analyzers is experimentally verified in this chapter by testing quality analyzer Fluke 435 Series II. Block configuration of experimental system is presented in Fig.5. Amplified voltage waveforms, generated by VQ signal generator with various standard disturbances, are sent directly to the voltage inputs of device under test (DUT) - measurement instrument Fluke 435.

The photo of experimental system including computer-based signal generator, acquisition card connector block SCB 68 A, PQ signal amplifier and tested instrument Fluke 435 is shown in Fig.6.

Setup of experimental test procedure includes various tests with generation of reference voltage waveforms with some characteristic variations of standard VQ disturbances. Computer supported testing of instrument Fluke 435 is focused on detection of standard VQ disturbances: voltage swells, voltage dips, transients and voltage interruptions, in accordance with the recommendations of the European standard EN50160. Test scenarios also include certain presence of high-order harmonics, flicker, and noise in defined intervals.

Communication principle between instrument Fluke 435 and computer supported by Power Log application software for processing of previously recorded data is shown in Fig.7.

Instrument Fluke 435 is set to operate in the Data logging mode. Time interval for each measurement cycle in instrument data logger is adjusted to 0.25 s. Duration of data logging is equal to length of reference test signals from generator. Logged signals and data recorded in instrument database are transferred to computer according to the USB communication principle previously presented in Fig.7. Power Log software provides various possibilities for processing and analysis of recorded data and logged signals. In this paper there will be presented the following results of data analysis: time diagrams and histograms of RMS voltage values measured using instrument Fluke 435, diagrams of detected and measured high-order harmonics of reference test signals, diagrams of disturbance events detected using Fluke 435 (swells, dips, rapid voltage changes, transients, interruptions, etc.), including some reports about detected disturbances recorded directly from graphical display of tested instrument. Time diagram of measured RMS voltage values for 1800 s (30 minutes) long voltage test signal, including a large number of various disturbances, recorded using the Power Log application software, is presented in Fig.8. In this diagram are chronologically and clearly indicated detected events (voltage disturbances) with specific measured RMS voltage values related to individual events. Script files with such large number of signal disturbances are produced with the help of additional LabVIEW application software for random generation of various signal disturbances. As the produced script file is written to .txt text file, it is possible to inspect it, and also manually modify with any text editor before using it, and store in database of test scenarios, for repetition of test, or later possible applications.

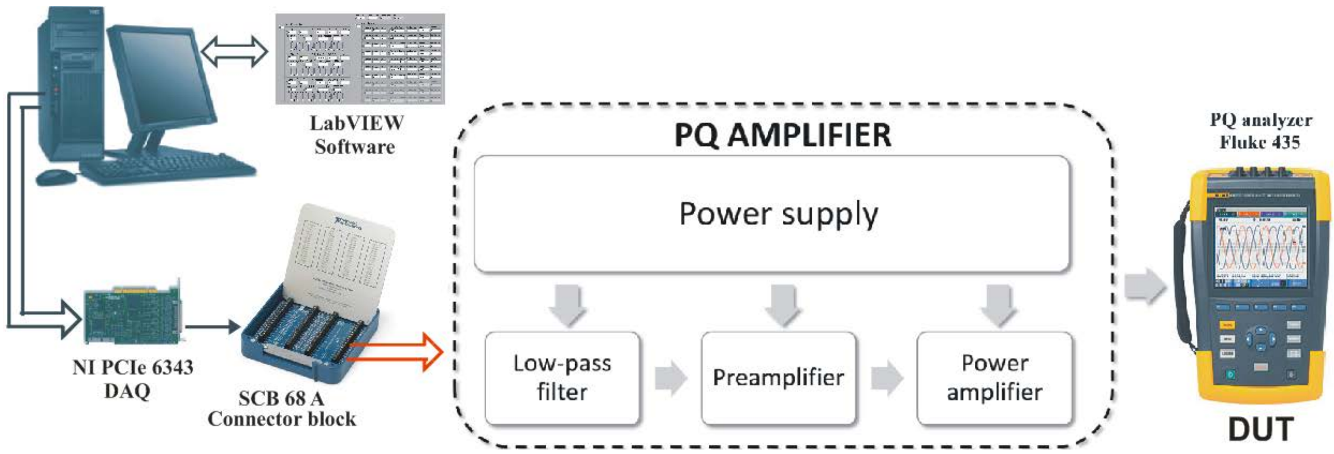


Fig.5. Block diagram of experimental procedure for testing quality analyzer Fluke 435 using LabVIEW based signal generator.

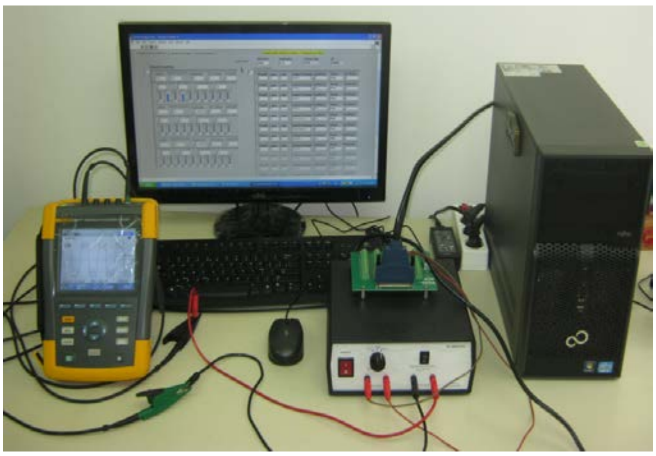


Fig.6. Photo of experimental system for testing instrument Fluke 435 using LabVIEW based signal generator.

Analyzer Fluke 435 detects voltage disturbances according to the standard EN50160. This standard prescribes acceptable limits of nominal RMS voltage value 230 V ± 10 % (207 V to 253 V). Practically, the RMS voltage values larger than 253 V are detected by the instrument as the swell (SWL), while the RMS voltage values smaller than 207 V are detected by the instrument as the dip (DIP). On the other hand, instrument detects voltage interruption (INT) in the cases when measured voltage values are smaller than 1 % of nominal RMS voltage value (1 % of 230 V). This practically means that interruptions will be detected for voltage values smaller than 2.3 V. For voltage levels smaller than 10 % of nominal RMS voltage value (10 % of 230 V) the instrument indicates the rapid voltage change (CHG). Finally, for short-time and very fast rapid voltage rise, in amount greater than 100 V in relation to nominal RMS voltage value, instrument will detect the voltage transient (TRA).

Fig.7. USB communication between instrument Fluke 435 and computer for recording and processing of measurement data.

As an example, for instrument events detection, in Fig.9. is presented a detailed summary of chronologically detected voltage disturbances in test signal, recorded directly from graphical display of tested analyzer. This summary gives just a small part of all detected signal disturbances, due to the space limitations in instrument display. In this report summary are included the following data: types of detected voltage events, exact dates and times for individual detections, voltage amount and time duration for detected individual disturbances and events.

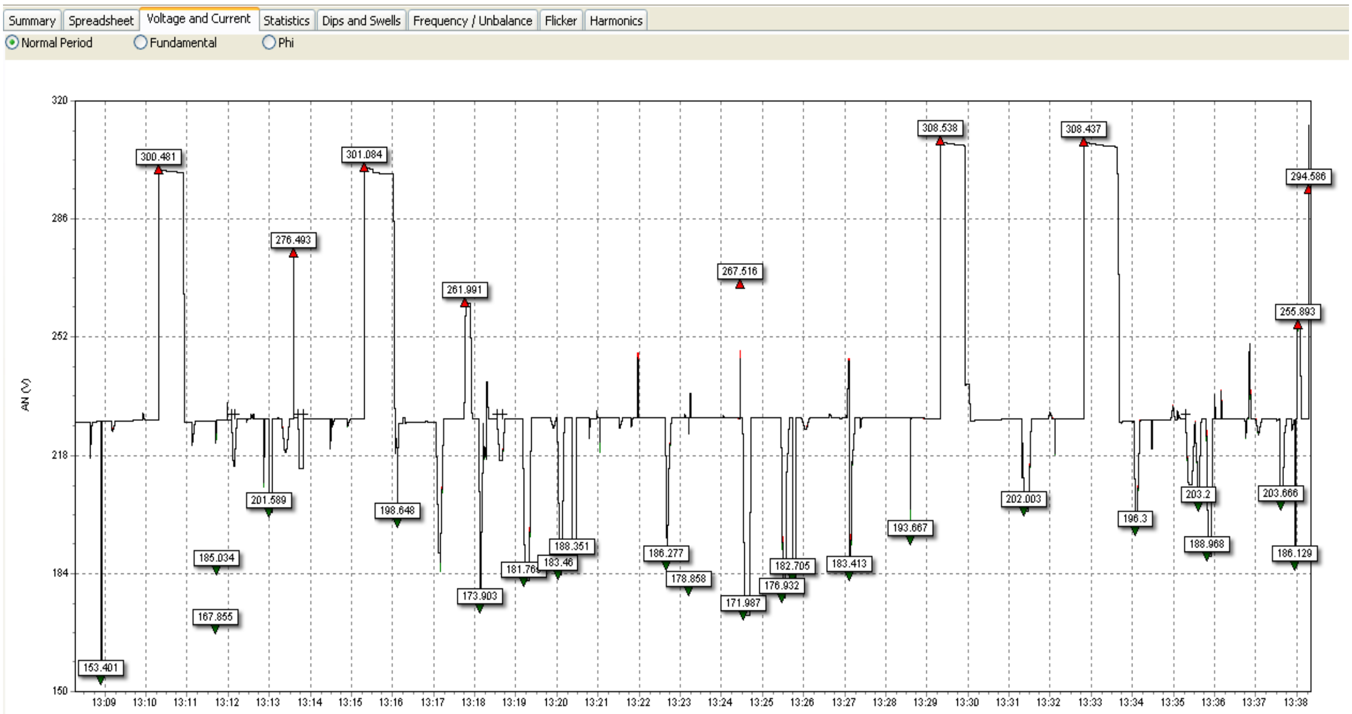


Fig.8. Time diagram of measured RMS voltage values - 30 minutes long test signal with large number of voltage disturbances.

More detailed analysis of detected disturbances is provided using the Power Log application software. Software analysis of detected signal disturbances for previous case according to the standard EN50160 is presented in diagrams in Fig.10. Two curves in this figure, blue and red, indicate general standard power acceptability limits. Blue curve is CBEMA Curve - Power Acceptability Curve for Computer Business Equipment. The CBEMA curve was adapted from IEEE Standard 446 (Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications), which is typically used in the analysis of power quality monitoring results [15]. The CBEMA curve is a susceptibility profile with the abscissa representing the duration of the event, while the ordinate indicates the percent of nominal voltage value. In the center of plot is the so-called acceptable area. Voltage values above the envelope are supposed to cause malfunctions such as insulation failure and over voltages. Voltages below the envelope are assumed to cause the load to drop out due to lack of energy. In other words, the concept is that if the supply voltage stays within the acceptable power area then the sensitive equipment will operate normally.

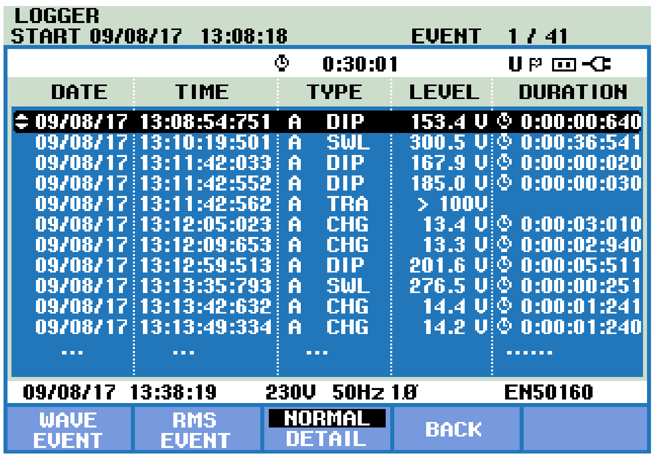


Fig.9. Summary of detected disturbances recorded from graphical display of instrument Fluke 435 - 30 minutes test signal.

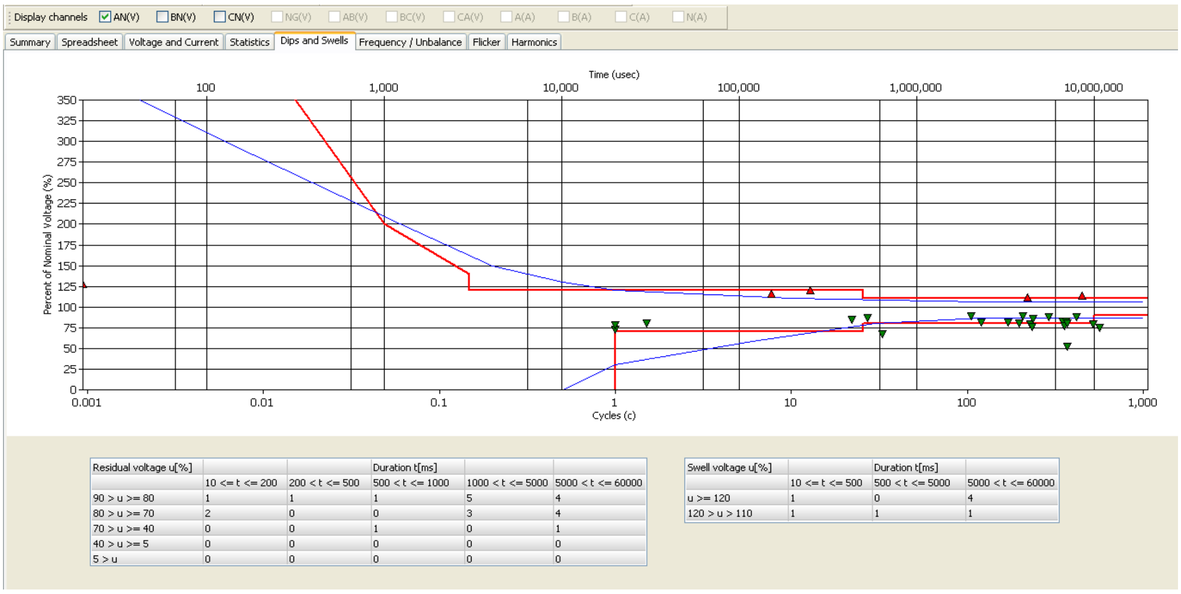


Fig.10. Power Log software analysis of detected signal disturbances according to the quality standard EN50160.

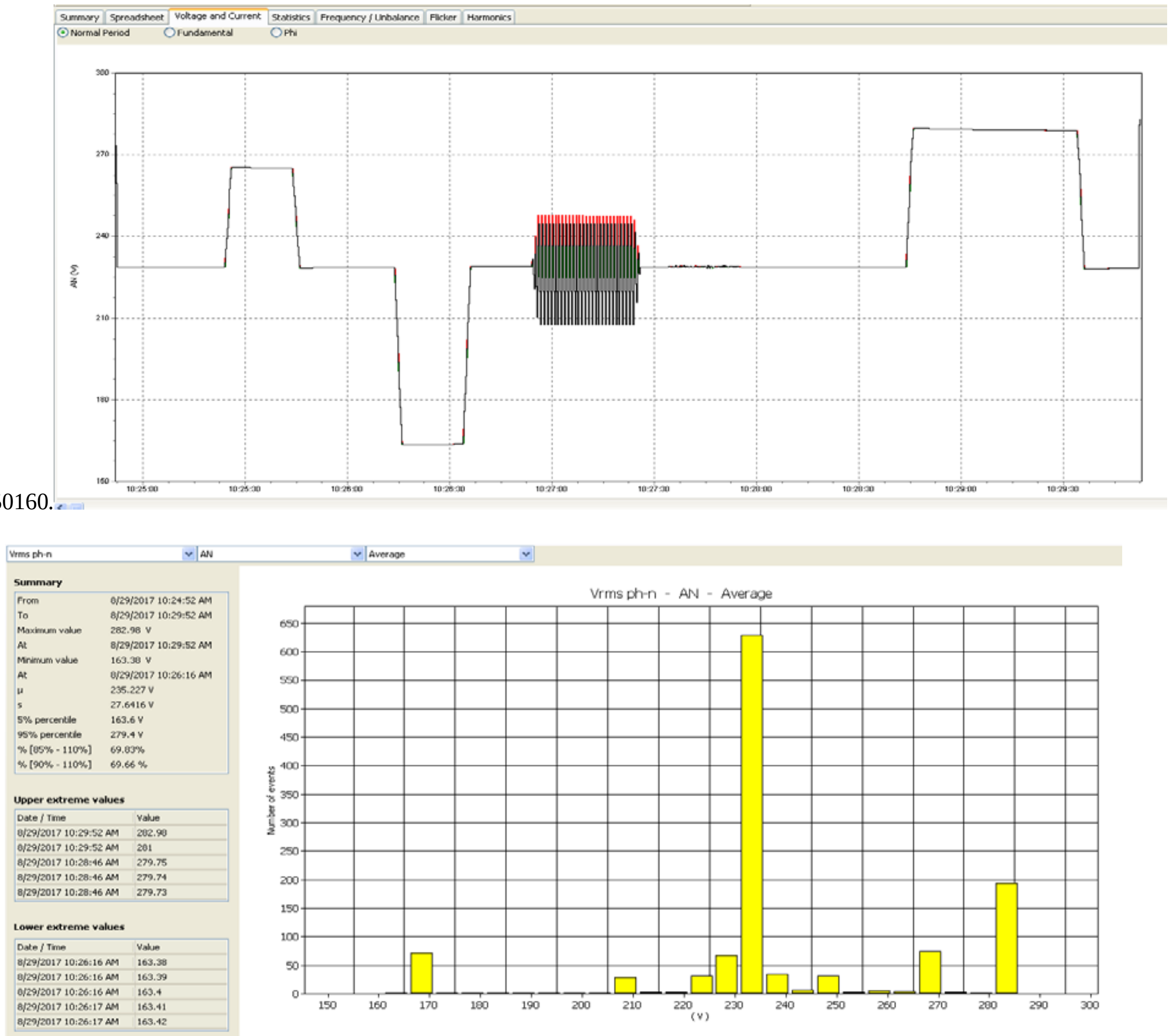


Fig.11. Time diagram (above) and histogram (below) - measured RMS voltage values (300 s long test signal, no harmonics, flicker 10 %).

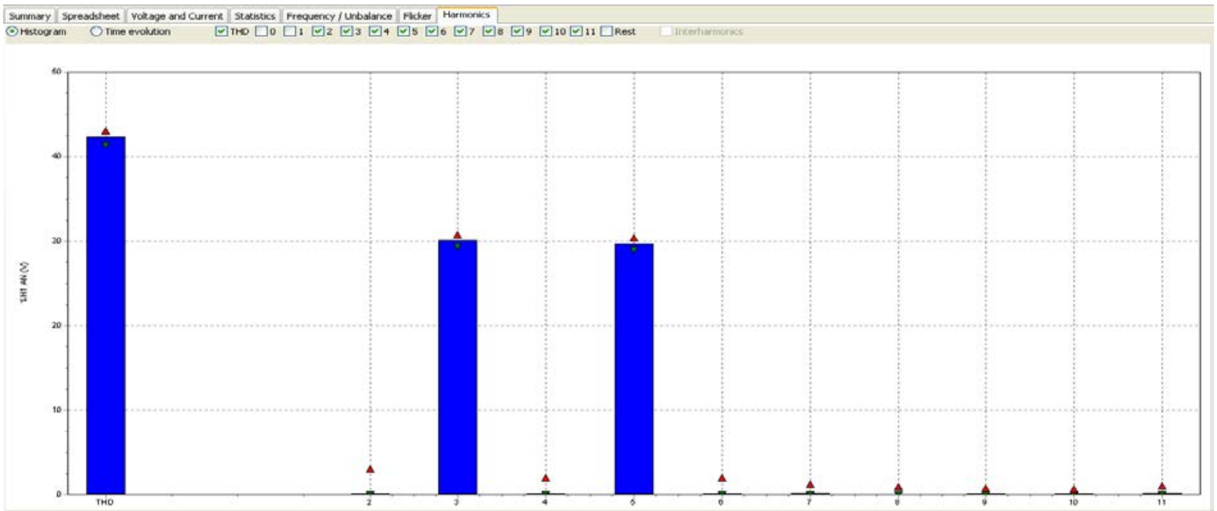
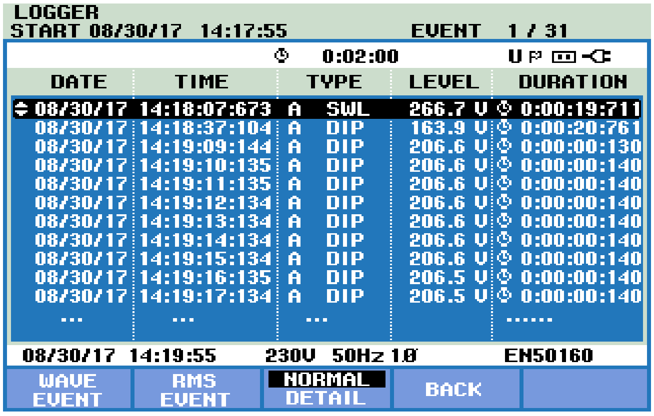
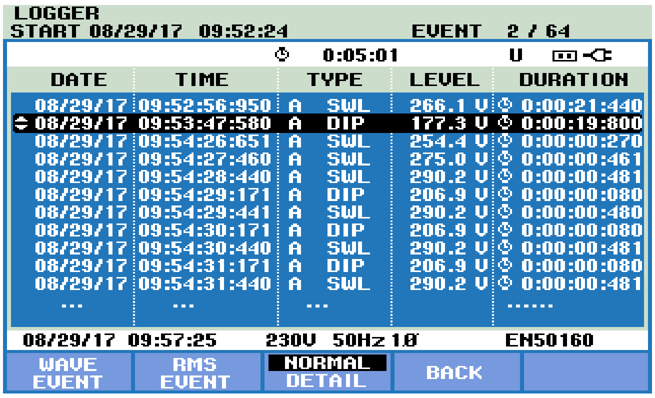


Fig.12. Histogram of measured high-order signal harmonics (total THD value, 30 % of H3 and H5 voltage harmonics).



a) 10 % flicker amplitude, no harmonics



b) 20 % flicker amplitude, 30% H3 and H5 harmonics

Fig.13. Summary of detected VQ disturbances for two different levels of flicker and high-order harmonics in test signals.

Red curve is ITIC Curve - Power Acceptability Curve for Information Technology Equipment. ITIC curve is the modified version of CBEMA power acceptability curve, but the concept remains the same. The intent was to derive a curve that can better reflect the performances of typical single-phase computers and their peripheral units. Besides the described power curves, in Fig.10. there are shown dips, swells and transient classification table according to the standard EN50160. In this figure, detected voltage dips are presented using green arrows, while detected voltage swells are indicated using red arrows in relation to the percentage nominal voltage values shown on the diagram vertical axis.

Second experiment includes 300 s long test signals generated with combination of voltage swell, dip, flicker, noise and certain level of odd high-order harmonics (specifically 3rd and 5th signal harmonics as most dominant odd harmonics). For test purposes are analyzed cases with the various percentage levels of flicker and noise, without high-order harmonics or with the presence of signal harmonics. For each generated disturbance there are defined various start times and the same disturbance rise time of 2 s. Time diagram and histogram of measured RMS voltage values, regarding the disturbed test signal with presence of short-time flicker, are shown in Fig.11. In this case, reference test signal is generated with voltage swell, voltage dip, 10 % amplitude level flicker, short-time noise, without high-order harmonics and with time duration of 300 s. In time diagram are clearly visible specific disturbances in test signal, first swell and dip, then influence of flicker, small noise level and finally again voltage swell.

For test signal with certain level of high-order harmonics, test scenario is performed similar to the previously presented case, with 300 s time duration, voltage swell, voltage dip and small level of noise, but in this test, in the signal are included 3rd and 5th high-order harmonics with amplitude levels of 30 % and flicker with amplitude level of 20 %. In Fig.12. is shown a histogram of measured high-order signal harmonics, recorded using the Power Log software support, including percentage value of total harmonic distortion - THD factor and measured individual high-order harmonic components – 30 % of H3 and H5 signal harmonics.

Table 2. Summary of events detection using instrument Fluke 435 for various amounts of typical disturbances in test signals.

Default voltage parameters of test signal	**Instrument Fluke 435**
Percentage levels	**Detected VQ events**
› 110% of nominal RMS value	voltage swells (SWL)
‹ 90% of nominal RMS value	voltage dips (DIP)
‹ 10% of nominal RMS value	rapid changes (CHG)
‹ 1% of nominal RMS value	interruptions (INT)
› 100 V + nominal RMS value	transients (TRA)
Nominal RMS value + 30% of H3 and H5 signal harmonics	no events, only signal harmonics
20% of flicker amplitude, no signal harmonics	voltage swells (SWL) and dips (DIP)
10% of flicker amplitude, no signal harmonics	voltage dips (DIP)
9% of flicker amplitude, no signal harmonics	no detected events
20% of flicker amplitude + 30% of H3 and H5 harmonics	voltage swells (SWL) and dips (DIP)
3% of flicker amplitude + 30% of H3 and H5 harmonics	voltage swells (SWL)
2% of flicker amplitude + 30% of H3 and H5 harmonics	no detected events
3% of flicker amplitude + 25% of H3 and H5 harmonics	no detected events
100% of noise amplitude	no detected events

An interesting case for analysis is influence of percentage value of flicker amplitude in test signals on disturbance detection. Actually, when flicker occurs in the measured signal, depending on flicker amplitude level, three different cases for events detection are possible: instrument could detect swells, dips, or none of the disturbances. For example, in case of 10 % flicker amplitude the instrument detects combinations of swells and dips. This is clearly confirmed in Fig.13., where are shown detailed summaries of detected disturbances for two examples of voltage test signals, with the different levels of flicker, 10 % flicker amplitude (above) and 20 % flicker amplitude (below). For 10 % flicker amplitude value the instrument detects only dips, while for 20 % flicker amplitude the instrument alternatively detects voltage swells and dips. Generally, detailed software supported analysis of flicker amplitude influence shows that without harmonics for flicker amplitude values greater than 10 % the instrument detects combination of swells and dips, for flicker amplitude value equal to 10 % the instrument will detect only voltage dips, and for flicker percentage amplitude values smaller than 10 % the instrument will not detect presence of voltage disturbances in the test signals. Instrument under test defines Dip and Swell events based on calculated true RMS values within window of a half of each signal period, thus flicker will change detected voltage periodically and generated dip and/or swell each time when limit according to the standard EN50160 is reached. Presence of harmonic in the signal slightly changes the calculated RMS value of measured voltage. Contrary, even high amplitude of noise in test signal is very good suppressed based on this 10 ms period of integration.

Finally, tabular presentation of signal parameter influence on event detection in tested instrument Fluke 435 can be seen in Table 2.

4. CONCLUSION

An improved generator of long-time complex signals with various combinations of standard VQ disturbances is described in this paper. Developed signal generator is based on virtual instrumentation concept and interpretation of script files. Definition of test sequence in text file enables easy and flexible repeatable testing of VQ instruments, especially during the development phase of detection algorithms, when minutely repetition of long and specific test is required. This system enables generation of long-time test sequences according to predefined complex scenarios, including typical VQ disturbances predefined in accordance with the European quality standard EN50160, in combination with presence of noise, harmonic and flicker in the specified time intervals. As the practical experimental verification of developed signal generator, in this paper is shown a procedure for testing the instrument for detection of standard VQ disturbances Fluke 435. In the first test scenario is analyzed a large number of various disturbances. Second test scenario was focused on an influence of various percentage levels of flicker and high-order harmonics in test signals on the VQ disturbance detection using the instrument Fluke 435. Some characteristic time diagrams of measured parameters, detailed reports and most important, conclusions about detected signal disturbances obtained from the experimental procedure are presented and analyzed in the paper.

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Received September 30, 2017.
Accepted March 20, 2018.