A Power Quality Signal Generator in LabVIEW Environment

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Abstract – Power quality disturbances is an issue that is gaining the attention of researchers, electrical utilities and customers. For developing tools for power quality (PQ) analysis and diagnosis PQ data is required. Therefore a software controlled scheme for generation of the typical power quality disturbances, is presented in this paper. PQ disturbance signal generator is based on the LabVIEW and MATLAB integration concept. The developed virtual instrument (VI) can generate five different categories of the PQ disturbances like voltage swells, sags, swells with harmonics and sags with harmonics in addition to the normal voltage waveform of single phase system. Each of simulated PQ disturbances can be predefined and easily changed according to user requirements, using various combinations of the knobs and controls provided on the front panel VI. The simulated PQ data can be applied as a part of the procedures for verification testing and calibration of the instruments and equipment developed for monitoring, measurement and software based processing of the basic PQ parameters, prescribed by the relevant quality standards.

Keywords— Electric Power Quality, Power quality disturbance, MATLAB, LabVIEW application software, and Virtual instrumentation.

I. INTRODUCTION

Development of technology in all its areas is progressing at a faster rate. Power scenario has also changed a lot. The development of electronics, electrical devices and appliances has become more and more sophisticated and they demand uninterrupted and conditioned power. In this ever changing power scenario, quality assurance of electric power has also been affected. EPQ (Electric Power Quality) has captured increasing attention in power engineering in recent years. EPQ is often used to express voltage quality, current quality, reliability of service, quality of power supply, etc. [1] [2].

End user intelligent electronic devices and equipment applied in the industrial and various commercial or domestic facilities, such as computers and different automated electronic equipment, are sensitive to many types of the power quality disturbances, caused by influence of the possible power distribution system problems and network disturbances. To reduce possibilities of various disturbances and customer equipment failures, power distribution companies are obligated to perform continuous monitoring and analysis of the delivery network quality. Normally, due to complexity and

importance, PQ problems require combinations of the many disciplines and activities, such as digital signal processing, power engineering, software engineering, supported by advanced measurement instruments and methods. Relevant and valid information regarding to the power distribution network quality level can be provided only by measurement and detailed software based processing of the measurement results related to the standardized power quality parameters [3][4][5]. Nominal reference values of these parameters including acceptable limit values and measurement intervals are prescribed with recommendations of the relevant national and international normative documents and PQ standards. The IEEE Std. 1159-2009[6], "Recommended Practice for Monitoring Electric Power Quality", prescribes voltage characteristics of electricity supplied by the public distribution systems in normal operating conditions encompasses the monitoring of electrical characteristics of single-phase and poly-phase ac power systems. It includes consistent descriptions of conducted electromagnetic phenomena occurring on power systems and definitions of nominal conditions and deviations from these nominal conditions that may originate within the source of supply or load equipment or may originate from interactions between the source and the load. Also, it recommends measurement techniques, application techniques, and the interpretation of monitoring results regarding to values of the typical PQ disturbances as given in Table I.

In this paper Section II discusses the mathematical model of generation of Power quality disturbance signals (PQD) in MATLAB environment. Section III presents the simulation technique of generating signals using LabVIEW application software. Although LabVIEW form National Instruments (NI) is well known as a development environment built around a graphical programming language, it also offers options for working with text-based math programming using .m file (MATLAB) scripts. LabVIEW and MathScript is the newest option for working with .m files in LabVIEW. In Section IV data generated and simulation results are given for verifying the proposed system. Finally, Section V draws the conclusion.

TABLE I
CATEGORIES AND TYPICAL CHARACTERISTICS OF POWER SYSTEM
ELECTROMAGNETIC PHENOMENA ACCORDING TO IEEE 1159-2009

Categories	Typical spectral content	Typical duration	Typical voltage magnitud

			e
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond			
1.1.2 Microsecond			
1.1.3 Millisecond		< 50 ns	
1.2 Oscillatory	5 ns rise	50 ns – 1 ms	
1.2.1 Low frequency	1 µs rise	> 1 ms	
1.2.2 Medium frequency	0.1 ms rise		
1.2.3 High frequency	< 5 kHz	0.3–50 ms	0–4 pu
	5–500 kHz	20 µs	0–8 pu
	0.5–5 MHz	5 µs	0–4 pu
2.0 Short-duration root-mean-square (rms) variations			
2.1 Instantaneous			
2.1.1 Sag		0.5–30 cycles	0.1–0.9 pu
2.1.2 Swell		0.5–30 cycles	1.1–1.8 pu
2.2 Momentary			
2.2.1 Interruption		0.5 cycles – 3 s	< 0.1 pu
2.2.2 Sag		30 cycles – 3 s	0.1–0.9 pu
2.2.3 Swell		30 cycles – 3 s	1.1–1.4 pu
2.3 Temporary			
2.3.1 Interruption		>3 s – 1 min	< 0.1 pu
2.3.2 Sag		>3 s – 1 min	0.1–0.9 pu
2.3.3 Swell		>3 s – 1 min	1.1–1.2 pu
3.0 Long duration rms variations			
3.1 Interruption, sustained			0.0 pu
3.2 Undervoltages			0.8–0.9 pu
3.3 Overvoltages		> 1 min	1.1–1.2 pu
3.4 Current overload		> 1 min	
		> 1 min	
		> 1 min	
4.0 Imbalance			
4.1 Voltage		steady state	0.5–2%
4.2 Current		steady state	1.0–30%
5.0 Waveform distortion			
5.1 DC offset		steady state	0–0.1%
5.2 Harmonics	0–9 kHz	steady state	0–20%
5.3 Interharmonics	0–9 kHz	steady state	0–2%
5.4 Notching		steady state	
5.5 Noise	broadband	steady state	0–1%
6.0 Voltage fluctuations	< 25 Hz	intermittent	0.1–7%
			0.2–2 Pst
7.0 Power frequency variations		< 10 s	± 0.10 Hz

II. GENERATION OF PQD SIGNALS

The primary objective of the system is to provide reference phase voltage waveforms, including special functions for generation of every possible PQD problem. The system can be applied as a part of the procedures for verification testing and calibration of the instruments and equipment developed for monitoring, measurement and software based processing of the basic PQ parameters, prescribed by the relevant quality standards. Power Quality disturbances (PQD) are studied in comparison to the normal sinusoidal signal. Each type of PQ disturbance is generated in MATLAB software using different parametric equations is shown below [7] [8] [9].

1 – Normal Sinusoidal Signal

The normal signal is generated using the equation:

$$v(t) = A\sin(\omega t) \tag{1}$$

Where ω is power system radial frequency, t is sampling time. The signal magnitude (A) varies from 0.9 to 1.1.

2 – Voltage Sag Disturbance

$$v(t) = A(1 - \alpha(u(t - t_1) - u(t - t_2)))\sin(\omega t) \tag{2}$$

$$t1 < t2, u(t) = 1, \text{ If } t > 0$$
$$= 0, \text{ if } t < 0$$

Where α is the magnitude of sag, u (t) unit step function and α may have any value ranging from 0.1 to 0.89.

3 – Voltage Swell Disturbance

$$v(t) = A(1 + \alpha(u(t - t_1) - u(t - t_2)))\sin(\omega t) \tag{3}$$

Where α is the magnitude of swell and α may have value ranging from 0.1 to 0.8.

4 – Voltage Sag with Harmonics Disturbance

$$v(t) = A(1 - \alpha(u(t - t_1) - u(t - t_2)))(\alpha_1 \sin(wt) + \alpha_3 \sin(3\omega t) + \alpha_5 \sin(5\omega t) + \alpha_7 \sin(7\omega t)) \tag{4}$$

Where α is the magnitude of sag $0.1 < \alpha < 0.8$ and α_i is the magnitude of harmonic order i.

5 – Voltage Swell with Harmonics Disturbance

$$v(t) = A(1 - \alpha(u(t - t1) - u(t - t2)))(\alpha_1 \sin(wt) + \alpha_3 \sin(3\omega t) + \alpha_5 \sin(5\omega t) + \alpha_7 \sin(7\omega t)) \tag{5}$$

Where α is the magnitude of swell and αi is the magnitude of harmonic order i.

III. DESCRIPTION OF PROCEDURE

This simple hardware configuration includes standard PC computer platform, supported by virtual instrumentation software LabVIEW 7 and MATLAB7. These two software products (LabVIEW & MATLAB) can acquire, analyze and pass data through file I/O, particularly in applications where the measurement and automation tasks take place separately from the analysis. The generated .m file is further integrated in LabVIEW using the MATH script code. Therefore disturbance signals are initially generated in MATLAB 7.0 using the parametric equations as described in Section II. These generated signals are then sent to LabVIEW for further processing and displaying on the computer monitor.

The aforementioned five categories of disturbances are simulated for 6 numbers of cycles of voltage waveform. These waveforms are generated at a sampling rate of 256 samples per

12

cycle for a total of 1537 points. Table II provides a detailed summary of controlled parameters of disturbance signal. According to the standard definition of the specific signal, parameters for individual disturbance type can be controlled and selected by user directly from *LabVIEW* front panel *VI* figure 2. The block diagram of the *VI* contains six nos. of *subVIs*.

Besides presentations of the waveforms, on front panel, control switches are shown for performing selection of the specific PQ disturbance category. Single phase voltage waveforms, with six signal periods, are simulated with 60Hz standard nominal frequency value and maximum signal level of 1V. Master control switches for selection of the individual PQ disturbances; developed virtual instrumentation software gives possibilities for variations and adjustments of the basic disturbance parameters. These adjustments are provided using a number of the control buttons and knobs available in the virtual instrument, such as presented in Fig 2 and Fig 3. Front panel also shows control buttons for regulation of the signal periods number, signal frequency, disturbance start and stop times, voltage sag / swell amplitude levels. Illustrated front panel also performs graphical presentation of the single phase voltage waveforms.
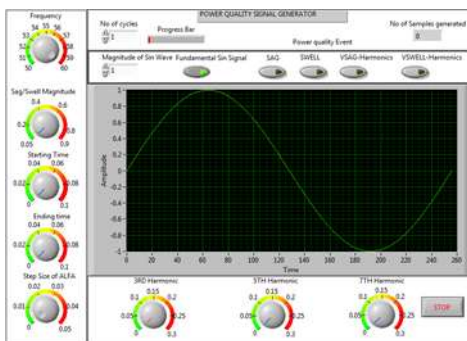

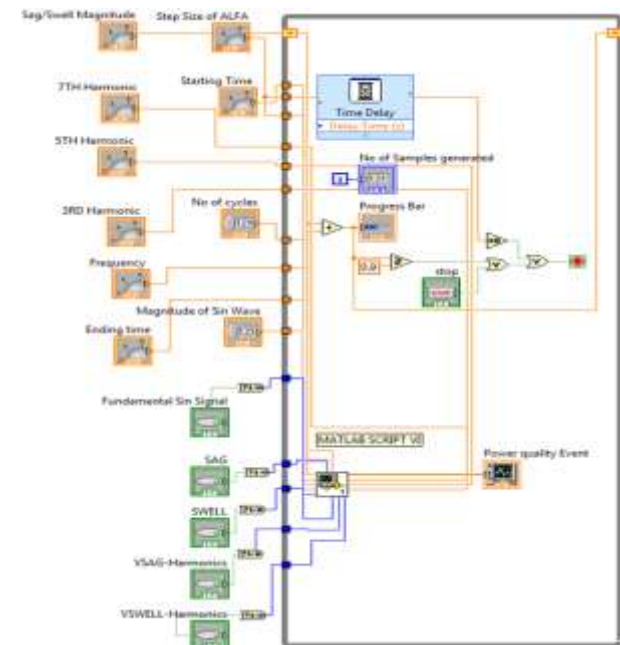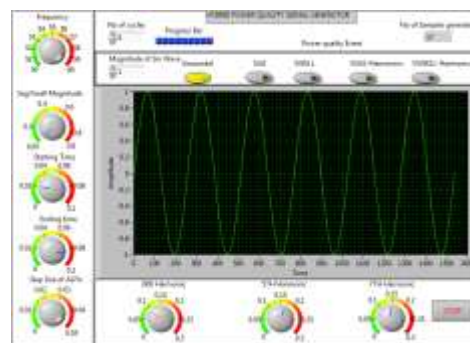Figure 2. Front panel VI of power quality signal generator.

Figure 3. Block diagram of power quality signal generator.

TABLE II CONTROLS ON FRONT PANEL VI

PQ Disturbance	Basic Parameter	Control on Front Panel VI
Pure Sinusoidal Waveform	Signal magnitude(A), f,	Magnitude of sine wave(0.9 ~1.1), frequency (50~60 Hz)
Voltage sag	Start(t_1) and stop time(t_2), α	Starting time and ending time,
Voltage swell	Start(t_1) and stop time(t_2), α	Sag magnitude(0.05~0.9)
Voltage Swell + harmonics	Harmonic levels -3rd,5th and 7th	Starting time and ending time,
Voltage Sag + harmonics	Harmonic levels -3rd,5th and 7th	Swell magnitude(0.05~0.9)

IV. SIMULATION RESULTS

Numbers of signals of each type of PQD are generated according to selected disturbance duration and sag/ swell amplitude level. Simulation of each type of single phase waveforms are performed in hybrid power quality signal generator in LabVIEW environment as illustrated in Fig.3. Figure 3(b) and 3(c) show simulated voltage signals of 1V magnitude of 60 mili-second disturbance duration with variable sag/swell level starting from 0.05 to 0.9. The step size control from 0 to 0.05 is also provided on the front control panel to generate hundreds of signals of different magnitudes automatically. Content of the specific individual high-order harmonic components can also be precisely controlled by number of the control knobs for regulation of the odd voltage harmonic levels, from third to seventh harmonic orders, as shown in the Figure 3(d) and 3(e).
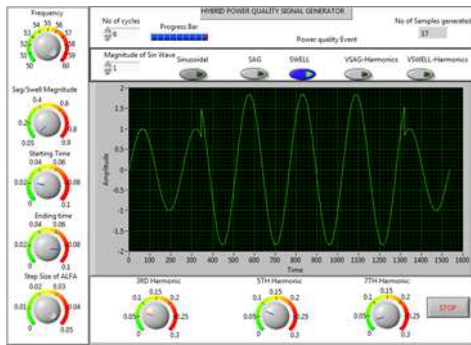

(a)

(b)

(c)

(d)

(e)

Figure 3. Simulated PQD waveforms

     a. Fundamental sine waveform.
     b. Voltage Swell.
     c. Voltage Sag.
     d. Voltage sags with Harmonics.
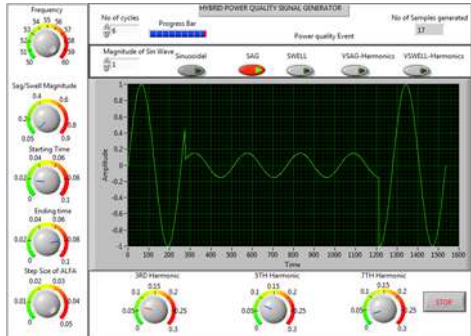   e. Voltage swells with Harmonics.

V. CONCLUSION

A simple power quality signal generator system is developed for simulation and generation of the PQ network disturbances. The system functionality is supported by virtual instrumentation software. Virtual instruments designed in LabVIEW programming environment perform definition and simulation of the basic PQ disturbance classes determined by relevant international quality standards. Selection, regulation and adjustments of the basic parameters for disturbed single phase voltage waveforms are performed by the number of the control switches and knobs, implemented on virtual instrument front panels. The above generation system, which is functionally based on the LabVIEW 7 and MATLAB 7 integration concept, can be used in procedures for developing software tools and techniques to solve the problems of identification and mitigation of PQ in power system.
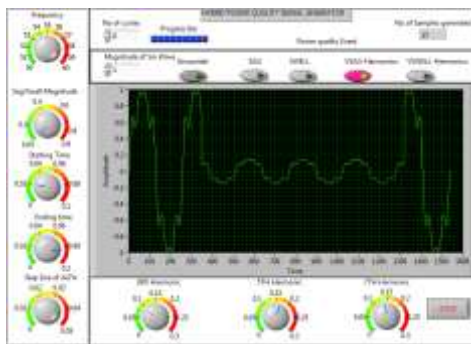
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[9] B.K.Panigrahi, V.R.Pandi,:'Optimal feature selection for classification of power quality disturbances using wavelet packet-based fuzzy k-nearest neighbour algorithm.' IET Gener.Tra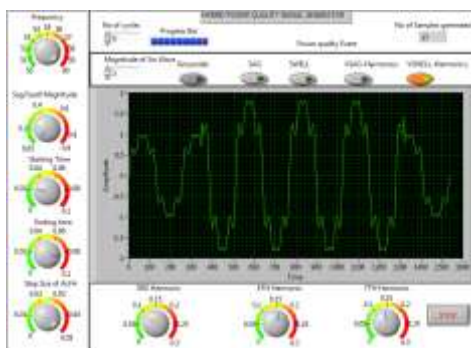nsm. Distrib., 2009,Vol. 3, Issue. 3, pp: 296-306