

## DESIGN OF VERSATILE WAVEFORM PLATFORM FOR SUPRAHARMONIC TESTING AND CALIBRATION

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### ABSTRACT

*This paper describes the design of a generic waveform platform for the testing and calibration of power quality analyzers in the frequency range of 2 to 150 kHz. In the electrical grids, the waveform platform can be used to measure the emissions in the frequency range of 2 to 150 kHz. The software architecture of the waveform platform is specified here. In addition, the paper explains the hardware design of the waveform platform. It also includes the applications of the waveform platform. The laboratory setup for the calibration of power quality analyzers and the measurement schema for the real grid waveforms are also depicted here.*

### INTRODUCTION

Supraharmonic emissions are on the rise due to the increasing integration of power electronic interfaces, e.g., for photovoltaic (PV) panels and batteries in the existing grid network [1]. Increased integration of these non-linear loads results in power quality deterioration [2]. Some of the effects of these emissions include capacitor overheating, energy meter inaccuracy, electromagnetic incompatibility, and interference in power line communication (PLC) [1, 3, 4, 5, 6].

Even though the grid equipment is designed to have limited harmonic emissions, which are integer multiples of fundamental component in the frequency range of 100 Hz to 2 kHz, they can still have higher emissions in the frequency range of 2 to 150 kHz [3, 7]. The existing literature [8, 9] outlines the measurement techniques for supraharmonic emissions. It also specifies the challenges in the measurement of supraharmonic emissions like accuracy, sensitivity, bandwidth, and dynamics. Supraharmonic emissions are low amplitude emissions at high frequencies. A recent report from Energiforsk indicates that the methods for accurate and reproducible

measurements at higher frequencies as one of the important research challenges in the study of supraharmonics [10].

Currently, there are no generic waveform platforms that can perform multiple functions in the frequency range of 2 to 150 kHz. Commercial waveform generators available in the market generate only one disturbance in the frequency range of 2 to 150 kHz per test, whereas the proposed system can generate multiple disturbances per test. The design and construction of the proposed platform will contribute to a flexible system for the characterization and testing of power quality (PQ) analyzers and smart meters in the frequency range of 2 to 150 kHz. The platform will be used for both laboratory and real grid applications. For the laboratory applications like calibration of PQ analyzers, the platform will be used as a waveform generator. For the real grid applications like the measurement of supraharmonic emissions, the platform will be used exclusively as a waveform acquisition unit.

### SOFTWARE ARCHITECTURE

The proposed platform will create both standard and user defined waveforms. LabVIEW software is used as the user interface to communicate with the hardware system. The waveform platform has two modes of operation, waveform generation and acquisition. These modes of operation are explained below. The software architecture is depicted in Fig. 1.

From Fig. 1, the acquired waveforms are either:

- stored in the external memory;
- processed using signal processing algorithms;
- displayed in real time, or;
- stored, processed, and displayed in real time.

The raw and processed waveforms are stored in an external memory so that if required it could be used for further mathematical processing.

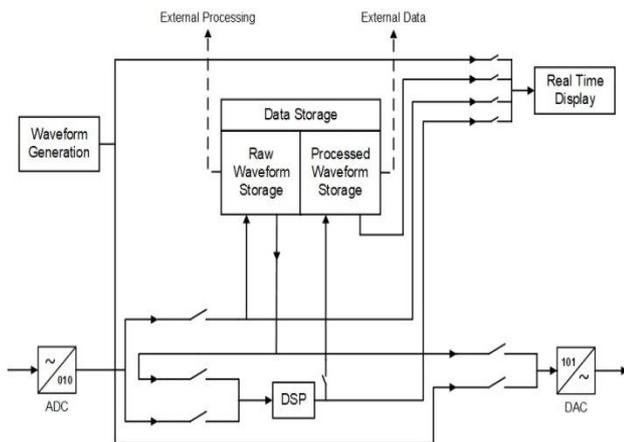


Fig. 1. Waveform platform software architecture.

The platform will generate:

- standard waveform: a fundamental signal without any supharmonic components as shown in Fig. 2. The standard waveforms include sine, square, triangle and sawtooth waveforms;

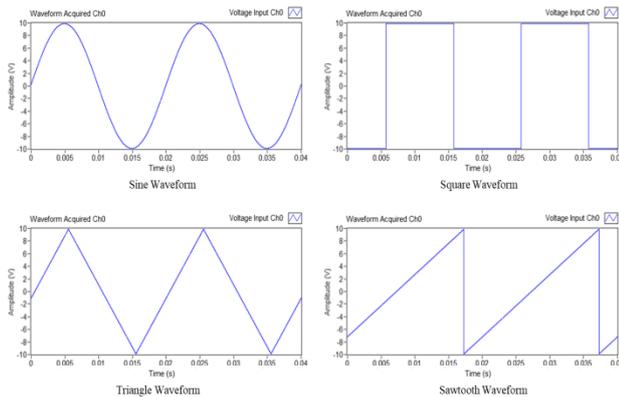


Fig. 2. Standard waveforms.

- complex waveform: a fundamental signal is superimposed with emissions in the frequency range of 2 to 150 kHz as shown in Fig. 3. It is possible to adjust the amplitude and phase of the emissions with respect to the fundamental. In addition, the number of disturbances can be varied from a single to multiple supharmonic emissions;

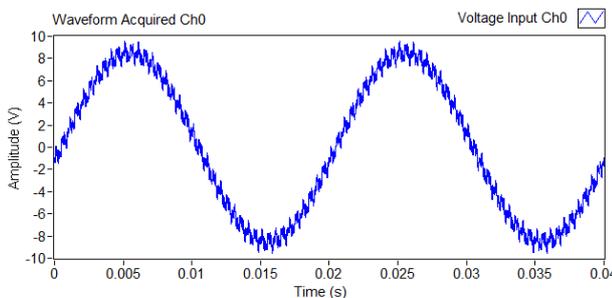


Fig. 3. Complex waveform.

- real grid waveform: analog waveforms are generated from the files, which are acquired during the real grid

measurements. A real grid current waveform from the residential PV inverter is shown in Fig. 4;

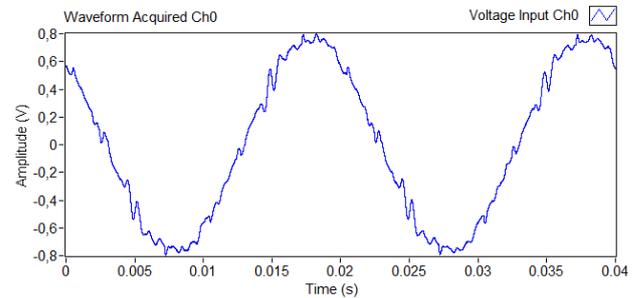


Fig. 4. Current sensor output from residential PV inverter.

- amplitude modulated waveform: generates different forms of amplitude modulated waveforms according to the user definition. Fig. 5 represents square wave modulation of a sine waveform with 50% duty cycle.

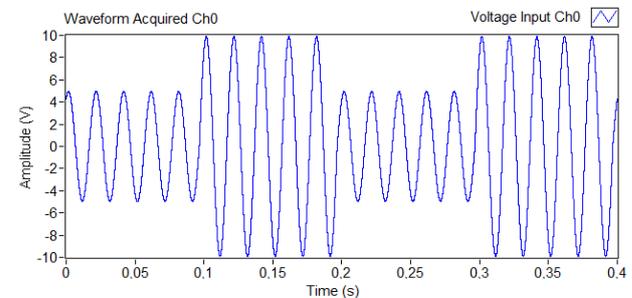


Fig. 5. Amplitude modulated waveform.

The platform will also:

- process the acquired waveform using Fast Fourier Transform (FFT). The results are displayed in real time and saved as file;
- perform Short Time Fourier Transform (STFT) analysis on the acquired waveform in order to display the emissions in time - frequency domain;
- the FFT and STFT parameters, like window function, window length, frequency bins, and time steps can be varied in the platform;

The hardware design of the waveform platform is explained in the next section. In addition, the specifications of the waveform platform and the components, which include the voltage and current sensors, are also described.

## HARDWARE DESIGN

The PXI system is a LabVIEW based measurement and automation system, which consists of both generation and acquisition units [11]. The PXI system with the waveform generator and data acquisition cards (DAQ) are shown in Fig. 6. The PXI chassis is interfaced with the LabVIEW on the computer using a remote controller card with a Thunderbolt 3 connection. The waveform generator has two channels, which can generate two different waveforms. The DAQ has 4 analog input channels, which can be used for waveform acquisitions.



Fig. 6. Waveform platform setup.

The waveforms are generated and acquired at a sampling rate of 2 MS/s. The waveform platform specifications are listed in Table I. The specifications are listed for the laboratory and grid applications.

Table I. Waveform platform specifications.

Function	Parameter	Level	
Generation	Output	$\pm 12$ V	
	Resolution	16 bits	
Amplification	Voltage amplifier	0 – 250 V <sub>RMS</sub>	
	Transconductance amplifier	200 $\mu$ A – 50 A	
Measurement and Sensitivity	Grid	Voltage transformer	230 V <sub>RMS</sub> Ratio: 38:1
		Optoisolator High pass filter	0 – 3.5 V <sub>RMS</sub> Cutoff: 590 Hz
		Rogowski coil	120 A & 0.05 V/A
		Rogowski coil	30 A & 0.2 V/A
Acquisition	Input	$\pm 11$ V	
	Resolution	16 bits	

The platform uses the above mentioned voltage and current sensors for the measurement of supraharmmonic emissions in the grid. The applications of the waveform platform in the frequency range of 2 to 150 kHz are discussed in the next section.

## PLATFORM APPLICATIONS

For the laboratory applications like calibration of PQ analyzer, the system generates waveforms that are closely identical to the real grid waveforms. The front panel of the waveform platform is shown in Fig. 7. The front panel depicts the complex waveform generated and acquired by the platform. A number of supraharmmonic components are superimposed with the fundamental voltage waveform and a disturbed waveform is acquired by the DAQ.

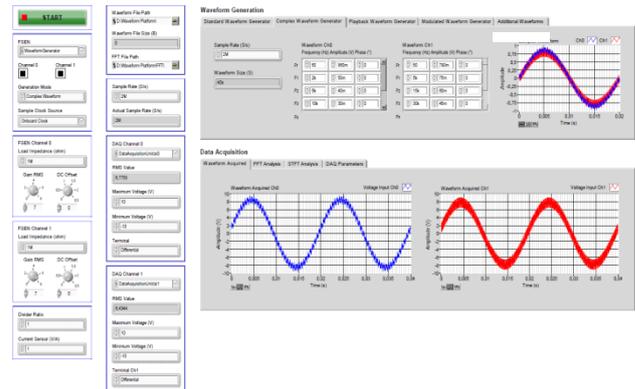


Fig. 7. Waveform platform front panel.

These waveforms are then increased to low voltage grid values using the voltage and transconductance amplifiers. The voltage amplifier increases the generator output to higher voltage levels, whereas the transconductance amplifier converts the generator output to current waveform of required amplitude. These waveforms are applied to the device under test. The block diagram for the calibration of PQ analyzers using the waveform platform is shown in Fig. 8.

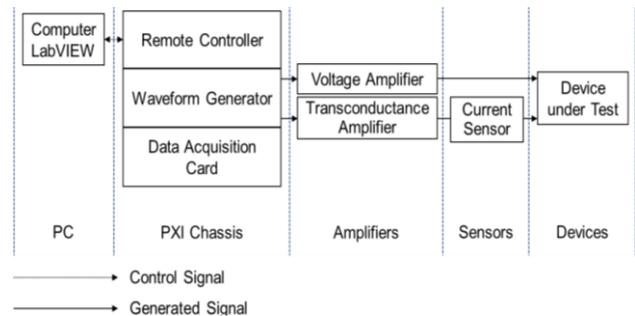


Fig. 8. PQ analyzer calibration setup.

For the real grid applications, the waveforms from the grid are measured through the sensors and acquired by the DAQ. Fig. 9 depicts the platform schema for real grid measurements. The fundamental and supraharmmonic components of voltage and current waveforms are measured separately using different sensors [12].

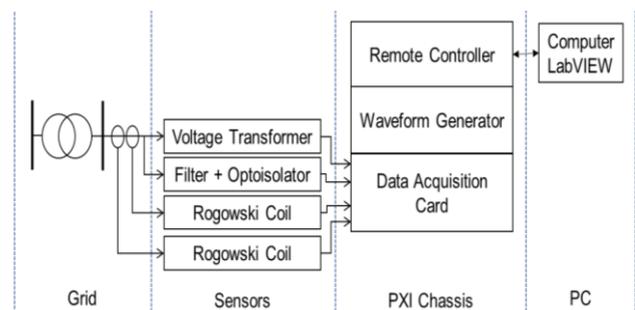


Fig. 9. Real grid measurement setup.

The voltage transformer and optoisolator with a 2<sup>nd</sup> order high pass filter to remove the fundamental component measure the fundamental and supraharmonic voltage

components separately, whereas the Rogowski coils measure the fundamental and supraharmmonic current components separately.

## CONCLUSION

The paper provides detailed insight in to the design and construction of a waveform platform that can be used for laboratory applications like calibration of PQ analyzers and grid applications like measurement of supraharmmonic emissions in the frequency range of 2 to 150 kHz. The platform can generate and acquire supraharmmonic emissions. It can be used for the characterization of PQ analyzers and other equipment like, smart meters in the frequency range of 2 to 150 kHz. Here, the supraharmmonic disturbances are superimposed with a fundamental waveform, thereby creating a highly disturbed signal. The platform can create multiple disturbances per test. Thus, it is more flexible compared to the existing supraharmmonic generators in the market. It can also generate real grid waveforms from files, which are stored during the real grid measurements. The platform specifications make it possible to recreate a real grid scenario in the laboratory. The platform will also function as a standalone waveform acquisition unit for the real grid measurements. The future work includes the characterization of the waveform platform with voltage and current sensors. The characterized waveform platform will be used for the calibration of PQ analyzers and real grid measurements in the frequency range of 2 to 150 kHz.

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