Project proposal

Project title:
Power quality measurements using analog to digital converters and digital signal processing techniques

Project acronym: PQM/ADC/DSP

Project Team:

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Project description

Worldwide deregulation of the energy market and the need to produce clean energy without the use of fossil fuels has led to an increase of independent energy producers using solar arrays and wind farms to supply the power grid. The de-centralized power production poses new problems for power companies since they can no longer easily assure power quality. The nonlinear loads characteristic of modern electronic circuits that are used in every household appliance and in all high-power consumption industrial facilities also affect power quality by introducing perturbations that not only affect the user that causes them but also of other users in the vicinity. In addition, many users have become less tolerant to power quality disturbances and demand good quality of service from the power companies [1].

The instruments used to assess power quality are called power quality analyzers. These devices are basically event detectors and data loggers used to accurately measure the power quality delivered to consumers by detecting, recognizing, identifying and recording deviations from the normal conditions. The complexity of these devices can be understood by the variety of anomalies that affect power quality. These anomalies can be either radiated or conducted and are traditionally classified according to their duration which can last anywhere between one millisecond and several minutes or even to be steady state anomalies. As far as the amplitude is concerned, the disturbances variations can reach from as low as 0.1% up to 800% of the power grid nominal voltage [2,3].

Power quality analyzers are complex pieces of electronic instrumentation that must be capable of detecting, classifying, recording and quantifying this wide range of phenomena. Power companies use the devices to settle complaints from customers that question the power quality delivered. The instruments are installed in the customer facilities where they are left to record the quality of the delivered energy. Some instruments transmit the information in near real-time to the power company (typically using phone lines) while others simply record all power quality events for latter processing.

In modern instrumentation, measurement systems are composed of sensors, signal conditioning, translation from the analog to the digital domain with analog to digital converters, data storage and advanced digital signal processing algorithms (Fig. 1). Every component is crucial to the overall instrument accuracy and has to be carefully designed, dimensioned and characterized. Systematic errors introduced by the acquisition channels, can be eliminated by proper calibration procedures [4]. In power quality measurement instruments, another key component necessary to assure reliability is the capability to quickly detect the event in order to record it. This is especially important for transient anomalies that may last only a fraction of the power signal period [5-7].

The objective of this project is to study, develop and implement new digital signal processing techniques to be used in power quality measurement instruments based on analog to digital converters and digital signal processors. Digital signal processing algorithms are fundamental as they can produce very accurate results and are a flexible component of instruments which can be upgraded and improved without the need for expensive and time consuming hardware re-designing.
There is no single algorithm that can detect the variety of power quality anomalies. Instead, a set of algorithms is needed, where each one is responsible for detection of a set of disturbances.

The IT group expertise in analog to digital converters (ADCs) testing/characterization [8-10] and in digital signal processing algorithms [11-13] will be used in the development of power quality analyzers. The use of ADCs and digital signal processing algorithms will enable the development and implementation of instruments with great versatility [14] which can be easily adapted to the anomalies that degrade power quality [15].

The main objectives/milestones of this project are:

- Current and voltage sensor selection
- Study and development of new digital signal processing algorithms for power quality analyzers
- Develop the sensor ADCs interface with signal conditioning electronic circuitry
- Implement a prototype of a power quality analyzer including sensors for power grid interfacing, signal conditioning circuits, twin analog to digital converters, digital signal processor where the developed algorithms will be implemented, DSP external memory modules for data log storage and remote transmission/reception modules
- Metrological characterization of the prototype
- Prototype field tests

The main results obtained with this project will be published in internationally recognized peer-review journals like the IEEE Transactions on Instrumentation and Measurement, Measurement and also on the IEEE Transactions on Power Delivery where power quality related articles are traditionally published.

In addition to these publications, the developed methods, algorithms and results will also be published in international conferences on instrumentation and measurement. These conferences include the IEEE Instrumentation and Measurement Technology Conference, the XVIII IMEKO World Congress, the Conference on Precision Electromagnetic Measurements, the Symposium on New Technologies in Measurement and Instrumentation and the Workshops on ADC Modeling and Testing.
References


State of the art

Power quality (PQ) assessment and measurements are needed due to the perturbations introduced by nonlinear loads, multi source power production and the need to extract the most from existing power systems. A 2001 study estimated losses to the US economy in the ten to twenty billion dollar range due to PQ degradation.

Power quality degradation events range from transient anomalies to steady state variations of the voltage including the presence of harmonics and other undesired frequency components [1]. To assess power quality, utilities companies relied on visual observation of the supplied voltage and current. In recent years, the increased types of perturbations phenomena, the requirements of PQ sensitive energy customers and the commercial challenge of competing power distributors have made it clear to utilities companies the need to use devices to automatically monitor the PQ delivered to customers with power quality analyzers.

The complexity of issues related to PQ make it a cross-disciplinary field which involve power engineering, power electronics, digital signal processing, software engineering and advanced instrumentation. This an important research and development field due to the variety of phenomena to detect and characterize which make these instruments very complex. There is still an urgent need to improve the capabilities, reliabilities and accuracy of current PQ analyzers as better devices are sought by the utilities companies and customers [2].

Advanced modern instrumentation is based on the development of efficient numerical digital signal processing techniques and the design and characterization of the interface between the phenomena to be measured and the digital signal processor (DSP) that executes the numerical algorithms [3]. One main component between the DSP and the measurement system is the analog to digital converter (ADC). A good characterization of the ADC is necessary due to its relevance in the complete system accuracy and precision. With a complete characterization it is possible to develop error correction techniques to improve system performance. The methods to characterize ADCs include static tests, histogram tests, dynamical testing to assess hysteretical behavior and stochastic tests.

Digital signal processing algorithms are another crucial component of instrumentation. In PQ measurements they achieve an even higher importance due to the large variety of events to detect, classify and measure. For PQ, these algorithms include the fast Fourier transform (FFT), wavelet transforms, Kalman filtering and neural networks among others. The FFT is suited for harmonic detection and measurement to determine the total harmonic distortion. Wavelet transforms are ideal to analyze transient disturbances which are very rich in the frequency domain but also very time limited [5]. Kalman filtering is used to accurately determine amplitude phase and frequency in the presence of noise and harmonics [6]. With limited resources and a set of base test recorded anomalies it is possible to train neural networks to identify and quantify PQ events. However, none of these algorithms can by itself classify all PQ voltage and current waveform events. The field of ADC testing to improve accuracy is still not used in PQ instruments as well as the sine-fitting [7] and multi-harmonic fitting algorithms [8]. In particular, with the multi-harmonic fitting algorithms it will be possible to detect the harmonic components present and to accurately determine their amplitudes and phases.

## Deliverables

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<tr>
<th>Deliverable</th>
<th>Timeline</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Project website</strong></td>
<td>3rd month</td>
<td>Project website containing pertinent information regarding the project developments. The website will contain two different areas. In the public area, project description, publications and team information will be available. In the restricted area publications related with power quality and project internal documents will be published.</td>
</tr>
<tr>
<td><strong>Power Quality Monitor Demonstrator</strong></td>
<td>12th month</td>
<td>A fully workable demonstrator including: voltage and current sensors, basic signal conditioning and data acquisition using the DAQs. The algorithms are implemented in the PC either in Matlab or LabVIEW.</td>
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<tr>
<td><strong>Progress Report</strong></td>
<td>12th month</td>
<td>Technical report describing the project progress with special emphasis on the selected sensors, signal conditioning circuit and the algorithms studied and selected for deployment.</td>
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<tr>
<td><strong>Power Quality Monitor Prototype</strong></td>
<td>21st month</td>
<td>Final prototype for power quality monitoring including all the circuitry, sensors and interfaces.</td>
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<tr>
<td><strong>Metrological Characterization of the Prototype</strong></td>
<td>24th month</td>
<td>Technical document containing the complete metrological characterization of the developed prototype.</td>
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<tr>
<td><strong>Final Report</strong></td>
<td>24th month</td>
<td>Final project report describing the project scientific results, publications and financial execution. The scientific results will include a detailed description of the prototype and a discussion of future work in this area describing the advantages of the prototype and possible improvements.</td>
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## Expected output indicators

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<th>1st year</th>
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<td>Papers in international conference</td>
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<td>Internet site</td>
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**Time schedule**

**Task 1**

**Title:** Ground work for power quality measurements and assessment using analog to digital converters in data acquisition systems  
**Duration:** 6 months  
**Description:** The objective of this task is to set the ground work for the project activities, including: (i) gathering and cataloguing of references and books to support the investigation and setup of a database with all the items for the easy referencing and consultation; (ii) purchase of current and voltage sensors the sensors; (iii) analysis, development and implementation of the connection between the sensors and the data acquisition boards; (iv) definition of the data format for the storage of the acquired data for latter processing and analysis; (v) development of two compatible software applications (in Matlab and LabVIEW) for data acquisition and storage of the data using the sensors and data acquisition boards; (vi) development of two software applications to read the storage data for processing.

**Task 2**

**Title:** Development and test of new digital signal processing algorithms for the detection of power quality anomalies  
**Duration:** 12 months  
**Description:** The principle objectives of this task include: (i) study, selection, implementation and test of digital signal processing algorithms for detection and measurement of power quality disturbances; (ii) create, in a laboratory environment, a hardware setup to simulate some of the typical power quality disturbances; (iii) test of the developed digital signal processing algorithms using the hardware setup to broaden the variety of power quality disturbances; (iv) validation and performance improvement of the algorithms based on the results obtained with the experimental data and laboratorial system; (v) publication of the major conclusions and original findings related with the assessment of the algorithms and the development of the laboratorial system for disturbances simulations.
Task 3
Title: Implementation of a DSP based instrument for power quality measurements with interface for personal computers
Duration: 12 months
Description: The metrological characterization of the developed system is a crucial part of this project. With a complete metrological description it is possible to detect and understand the shortcomings and main advantages of the system. To fully characterize the complete system the individual characteristics of the sensors, of the electronic conditioning circuitry, of the input channels of the data acquisition boards, of the analog to digital converters and the characteristics of the digital signal processing algorithms have to be obtained. The prototype will be built with the sensors, signal conditioning circuits, analog to digital converters, DSP, memory modules and interface to communicate with personal computers. The interface will either be based on the universal serial bus (USB) or a wireless interface. After prototype construction and test, it will be metrologically characterized.

Task 4
Title: Laboratorial and field tests of the developed systems
Duration: 6 months
Description: The main objective of this task is to test the prototype in the laboratory and in real power systems. In the laboratory tests the objective is to run a set of complete tests simulating most of the possible conditions of real systems. The field tests will be used for endurance assessment and to detect, record and analyze real anomalies. The obtained will be compared with the results from a commercially available power quality measurement instrument.