Open Source Tool for Energy Saving and Efficient System Management

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ABSTRACT

In order to improve power quality (PQ) techniques, efforts are made to develop smart sensors that can report near real-time data. Proprietary software and hardware on dedicated computers or servers processes these data and shows relevant information through tables or graphics. In this situation, interoperability, compatibility and scalability are not possible because of the lack of open protocols. This paper presents a new open source solution focused on optimization of power quality and monitoring for low voltage power systems. For that, an open source platform has been developed for computing, storing and managing all of the information generated from smart sensors. We apply the most up-to-date algorithms developed for PQ, event detection, and harmonic analysis or power metering. A plugin implementing the S-transform is being developed for the system. To obtain the best input values to this plugin we are developing optimization algorithms to detect the most of well-known disturbances. Our system makes use of cutting-edge web technologies such as HTML5, CSS3 and Javascript to provide user-friendly interaction and powerful capabilities for the analysis, measurement and monitoring of power systems.

Categories and Subject Descriptors

C.3. [**Computer Systems Organization**]: Special-purpose and application-based systems—*Real-time and embedded systems*

General Terms

Management, Measurement

Keywords

power quality optimization, energy saving optimization, embedded systems, ARM architecture

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1. INTRODUCTION

According to the development of our knowledge society and Internet, it is more and more notorious the wide deployment of electrical and electronic devices connected to the Grid. Not only academic or industrial but also home environments are places where those devices are becoming critical in order to deploy daily tasks: electrical appliances, computers, SoC[4] or automated processes are examples of this kind of devices. This strong dependency forces us to maintain electrical devices in order to extend their lifespan.

Today, improve energy efficiency is a key aspect. An efficient use can reduce energy costs, resulting in financial savings to consumers. On the other hand, society has become aware that the energy used to produce goods creates large amounts of pollution by greenhouse gases, which have impact to the environment[5].

Power quality phenomena are very well known and described in literature [2, 7]: sags, dips, swells, surges, outages, impulses, harmonics, transients, etc. A complete and detailed list can be found in [2]. All of these problems have been widely explained and almost solved using different techniques from the signal-processing field [1, 9, 13, 24, 26, 8, 14], so there is a lot of well-known algorithms that allow us to manage, identify, analyze and show large amounts of data for every transient, perturbation or event that occurs in a power network. All of these techniques, though published and readily available separately, are not usually available together in any software package for free and/or open use. Furthermore, they are neither affordable nor easy to understand for basic technical or general audiences. Today, there are several moderately powerful hardware-based commercial solutions from different companies (Fluke, Dranetz-

BMI, etc), that can do the job locally. Web based solutions are being deployed to collect sensor information and send it to central servers in datacenters for processing and analysis [3, 6, 10, 28, 15], and other tools for displaying data generated by sensor equipment[22]. Present and future trends indicate that interconnected sensors through WAN, PAN, LAN, 3G networks and Smartgrid projects will be the focus of more and more efforts in the scientific community.

The creation of near real-time interconnected smart sensor networks along with server processing hardware has clear advantages over traditional solutions for controlling and metering power systems. On one hand, this approach allows an exhaustive control over facilities because it is now possible to know what is happening at every moment. On the other hand, planning and maintenance are made easier thanks to the huge amount of historical and state data relating to consumption, perturbations, anomalies, etc. The previous statement implies large resource savings and also contributes to energy saving and green strategies, now in high demand by governments and green organizations. These "total control" systems allow us to effectively optimize resources and reduce costs significantly. We can therefore conclude that is a good idea to devote significant energy to developing such systems through universal and widely adopted tools.

Open source systems, being considered very secure, scalable and powerful tools, play a very important role in our society. It is well known that their use in critical and technologically advanced systems, as a core component for reliability, gives clear advantages over proprietary systems [17, 19].

We have focused on providing user-friendly interaction and powerful capabilities using cutting-edge web technologies. Its modular architecture allows adding new functionalities using customized plugins developed by third parties.

2. HARDWARE AND OPERATING SYSTEM

The hardware used for implementing processing and monitoring subsystems is based on ARM architecture (Advanced RISC Machines) [11]. ARM is a 32 bits ISA RISC focused on simplicity and designed to allow small and high-performance implementations with very low power consumption. Hence, these features provide great advantages in this kind of systems. In fact, ARM architecture is widely used in smartphones, PDAs and netbooks, competing directly with Intel Atom architecture.

The device used to implement the system was Kirkwood 88F6281 model from Marvell. This model is ARMv5TE compliant, without FPU. The main features of the hardware are:

- CPU 1.2 GHz.
- Cache L1: 16KB data + 16KB instructions, associative cache.
- Cache L2: 256KB, associative unified cache.
- RAM: 512MB DDR 400MHz, 16 bits.
- Internal Bus 64 bits.
- Jump prediction unit.
- 2 Gigabit Ethernet ports.
- Interface SD/DIO/MMC.
- USB2.0.
- 2 UART ports.
- NAND Flash 8 bits 512MB.

The dimensions are 110mm (L) x 69.5mm (W) x 48.5mm (H), and power demand is below 5 W, which is a factor of great interest.

This hardware needs a powerful OS and Linux is the perfect choice because it multitasks, prioritizes and performs well with limited space and resource consumption.

After analyzing different options, Debian was chosen. This Linux distribution is one of the most widely used for production systems because of its robustness, wide range of packages and the great experience of developers and the community. A major feature for our system (because of the lack of FPU) is the ARM EABI port (*armel*) which allows us to compute floating-point operations without serious speed penalties.

3. SYSTEM DESIGN AND IMPLEMENTATION

The aim of our work is to minimize the hardware cost and to maximize the functionalities compared with traditional metering systems.

Open source software is used in order to minimize costs and to modify or add new features. Also, flexible hardware will allow greater scalability and higher computing power. The exclusive use of this kind of software, licensed under GPL and BSD among others, is the key for a low cost design but it also allows components to be reused and provides great flexibility. At the same time, open source software allows us to select the most appropriate tools from the wide range on offer by the community.

Thanks to general-purpose flexible hardware, the features of the system are increased significantly. The system must operate efficiently, obtaining and operating with input data in the time specified without delaying or hindering the services offered to the final user.

The system consists of three main subsystems (see Figure 1): acquisition, processing and monitoring.

3.1 Acquisition subsystem

The acquisition subsystem is a dedicated piece of hardware (controlled by a PIC), the mission of which is to capture and digitize voltage and current wave signals. Those data are sampled and delivered to our embedded ARM using RS232, USB, Ethernet, etc. Power signals are sampled at 16 bits precision and 8 kHz sampling frequency (high enough to capture harmonics up to 60 th order). This subsystem is currently being developed and so for these tests, some data are generated using MATLAB for voltage and current.

Sampled data are sent to the processing subsystem using any of the communication methods implemented in 200 ms packets, which represent 10 periods of the fundamental signal when working with 50 Hz systems.

3.2 Processing subsystem

This subsystem processes voltage and current waveforms and shows power values of interest. It is responsible for the execution of the several analysis methods. It implements a plugin architecture, allowing the creation and design, through a programming API, of new analysis methods

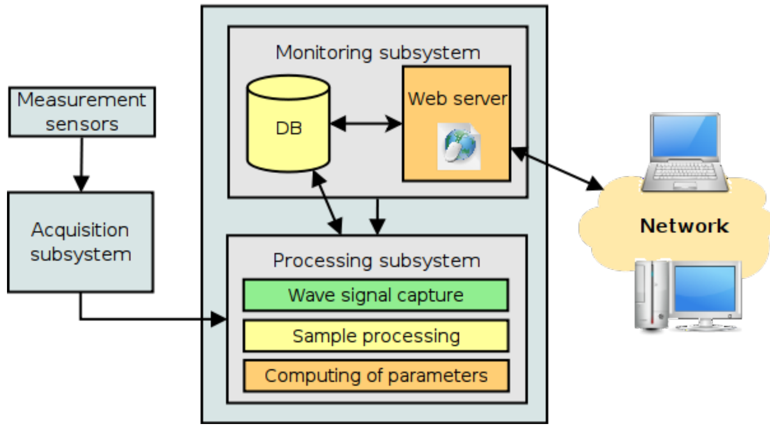

Figure 1: Block diagram of the system

like FFT [27], STFT [25], Wavelet[18] o Kalman filters[21]. Once the signal is processed, the power parameters of interest are calculated using the results computed by the analysis methods.

This subsystem consists of several modules (see Figure 2). The Main module is responsible for the sampling reception and the processing of each specific time interval. When an incidence or event occurs, the Log module records all of them detected during processing. The Calculation module hosts the methods used for calculating the electrical parameters of interest from the coefficients provided by the analysis methods. The XML Handler, which contains methods for accessing and modifying XML files and it is used by the Plugin manager, which executes the loading, registration, initialization and system commissioning of the plugins defined in the configuration file. Finally, the Receptor manager manages loading and data manipulation of the system receptors.

Some of the tasks performed by this module are the system's most critical. It must always be online, obtaining input data from the acquisition module for processing and storage. Therefore, it is very important that its components should be efficient enough to allow it to execute other tasks at the same time.

3.3 Monitoring subsystem

The monitoring subsystem is designed for storing the processed signals and power parameters of interest, real time monitoring [16] and visualization of historic data and managing of events and alarms.

Using cutting-edge web technologies, such as HTML5, CSS3, AJAX and Javascript, the information is shown in a friendly and intuitive web interface (see Figure 3) where the user can search for any power variable. Historical trends, power deviances and data series can be accessed for detailed analysis and diagnosis.

All the information is stored in a SQL database as an advanced management system for the information generated by the processing subsystem. This database is the data source for the monitoring subsystem.

4. OPTIMIZED S-TRANSFORM

S-Transform[23] is a new and effective technique for power quality analysis and event detection (see Figure 4). Extends the features of Wavelet transform, using a moving and scalable Gaussian windows along the signal. ST provides high time resolution at high frequencies and high frequency resolution at low frequencies. However, the analysis of waveforms in power systems requires improve this windows to obtain high frequency resolution at frequencies of interest for harmonic detection. To solve this inconvenience, generalized S-Transform (GST)[12] is used, which adjust the change speed of the window, defined as (eq. 1):

$$w(t, f) = \frac{|f|^p}{k\sqrt{2\pi}} e^{\frac{-f^{2p}t^2}{2k^2}} \tag{1}$$

Where k and p are variable parameters which define the width of the Gaussian window. Optimal values for these parameters can give a practical time-frequency representation for signal analysis. These values have effect on the successful detection of harmonic components.

An analysis plugin implementing this technique is being developed for the system, whose input are the above parameters. To obtain the best values in order to detect most of the well-known power quality phenomena, we are developing optimization algorithms using different and combined test cases.

5. RESULTS

In order to test the system, several test cases were made to demonstrate the event detection, using simulated power signals generated with MATLAB (see Figures 5 and 6). These waveforms for current and voltage were generated with a fundamental frequency of 50 Hz for a sampling frequency of 8000 Hz, and were attached to the system simulating a single-phased receptor with a nominal voltage of 220 V.

First of all, a voltage sag lasting half a second produced at 30 seconds was monitored, which produced 30% reduction of the voltage signal values (see Figure 5). The system correctly detected the sag as shown in the analysis of 3 seconds aggregation intervals (see Figure 7).

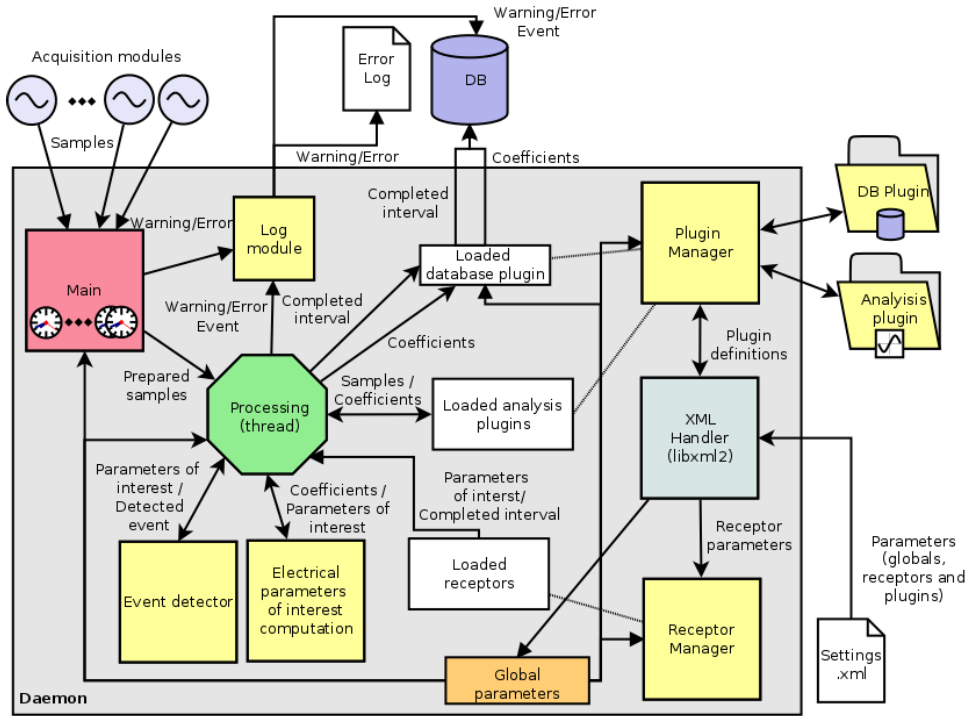

Figure 2: Block diagram of the processing subsystem.

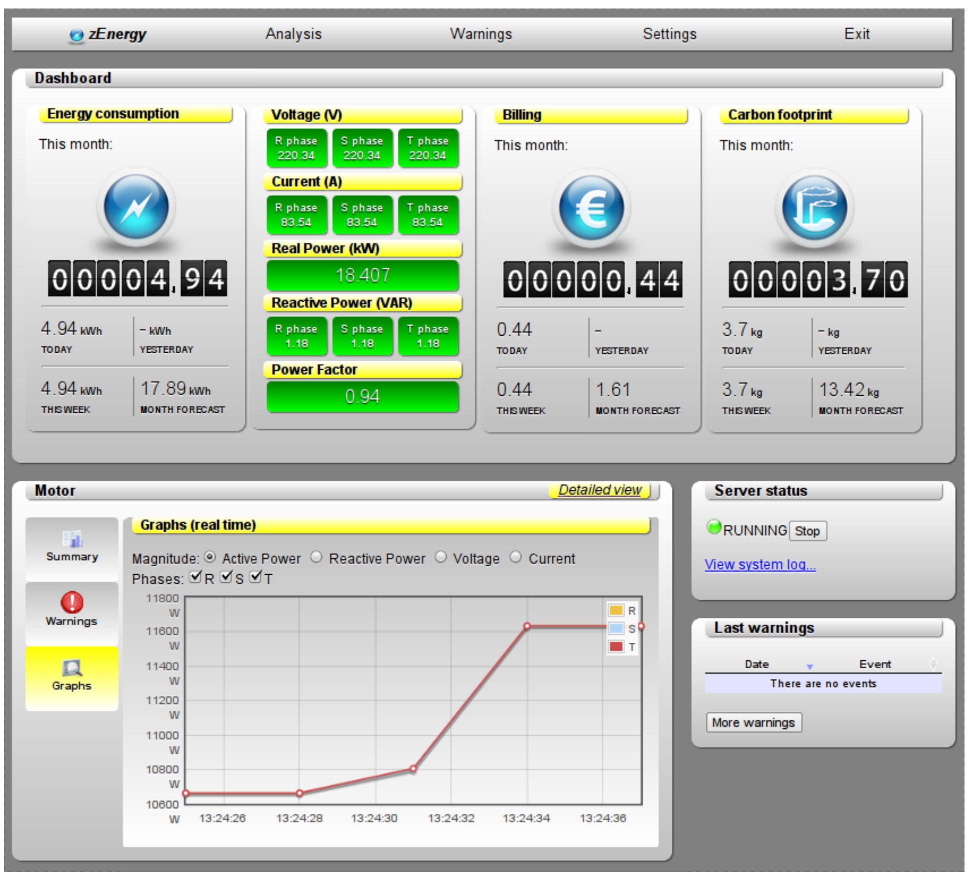

Figure 3: Screen snapshot of the web application.

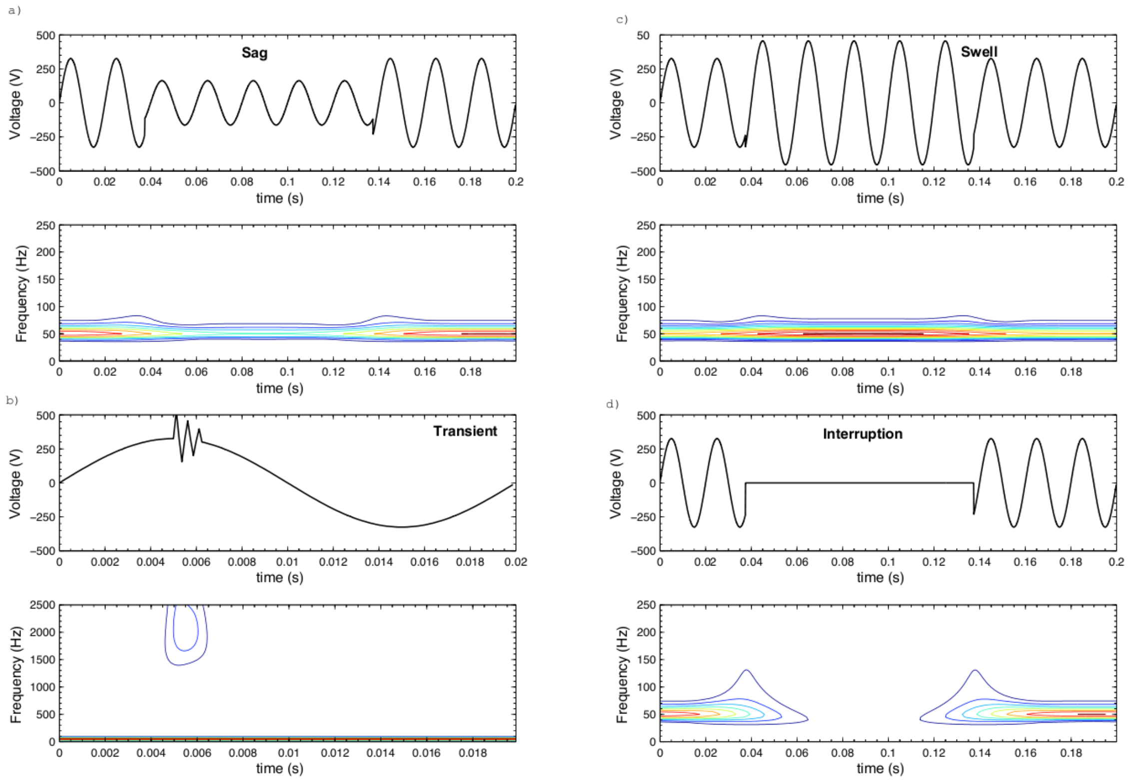

Figure 4: Application of S-transform to different power quality phenomena: (a) Sag. (b) Swell. (c) Transient. (d) Interruption.

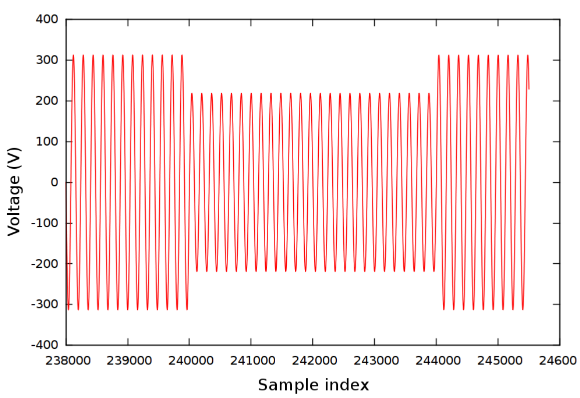

Figure 5: Generated voltage sag at 30 seconds.

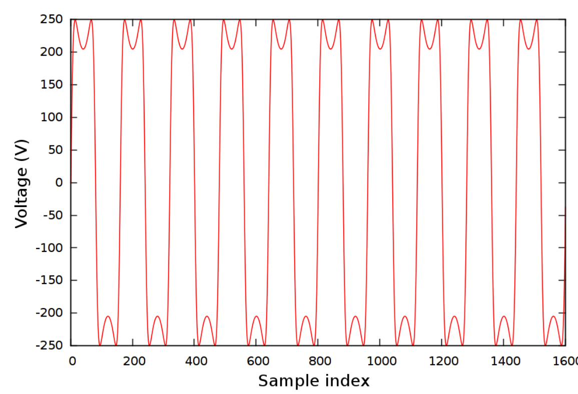

Figure 6: Generated voltage signal with harmonic components.

Finally, 10 harmonic components (odd indexes) were included in the waveforms with amplitudes generated by the expression $e^i \cdot 0,9$ (see Figure 6). The system was able to correctly detect the harmonic components, providing their amplitude values and frequencies (see Figure 8).

6. CONCLUSIONS AND FUTURE WORK

We have developed a new open source tool for the study and analysis of power quality and energy saving in low voltage electrical facilities. Using the latest web technologies, the system offers a user-friendly interface to effectively take advantage of the system capabilities. Moreover, it is also possible to build monitoring tools with metering and billing capabilities. Therefore, our system becomes a low cost (about 200 USD) and consumption solution with high performance and extensible capabilities compared over most commercial systems.

The system has been successfully tested on several test cases, checking the viability and proper operation of the system[20]. Also, its modularity and extension capabilities open a promising future on this work line.

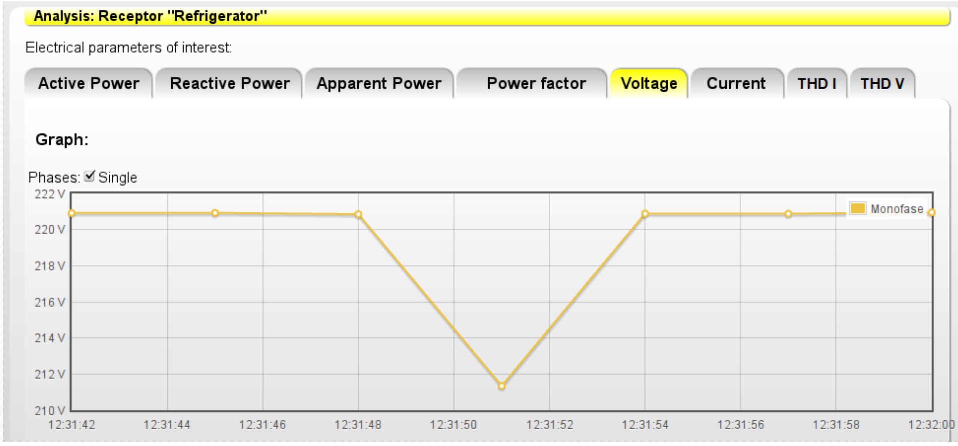

Figure 7: Screen snapshot of the generated voltage graph for aggregation intervals of 3 seconds.

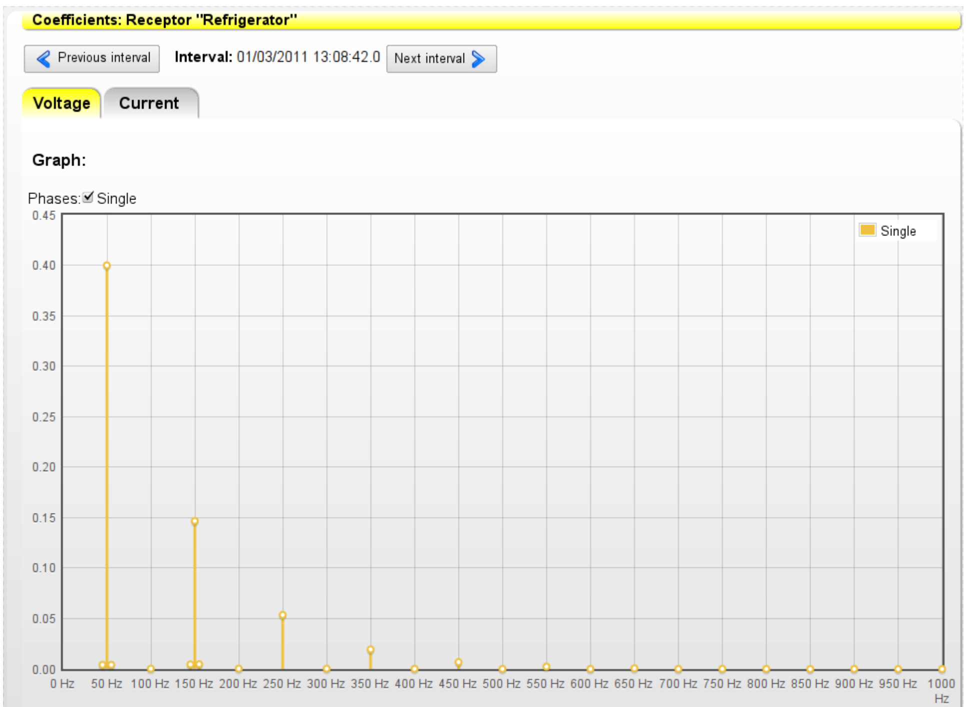

Figure 8: Screen snapshot of the generated voltage graph of the generated Fourier coefficients.

From the viewpoint of multi-objective optimization, the electrical parameters of interest generated can be used by a multiobjective optimizer based on evolutionary algorithms to aid decision making, offering several alternatives and settings based on the characteristics of an electrical facility in order to achieve energy saving.

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