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Non-Intrusive Hybrid Energy Monitoring System

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Abstract. When the optimization of the manufacturing units is considered, the management usually focus on equipment costs and technology parameters. However, being the rising price of the energy, the energy efficiency has become a sensitive issue. Detailed energy related information should be collected in order to understand the consumption profile of each relevant machine/process and identify potential energy savings. Data gathering is time-consuming and very expensive since individual metering devices have to be used for each consumer. To overcome this inconvenient, several solution have been reported. All of them are making use of a single metering device (monitoring the overall energy consumption) and some Load Signature Identification algorithms, used to disaggregate the overall energy between the identified consumers. Their relatively low detection rate (about 80-90%) hindered the spread of LSI-based architectures. In this context, a new hybrid architecture is proposed in this paper, together with it's hybrid LSI algorithm. Several test performed in an electronic prototyping facility result in a detection rate close to 100%.

Introduction

The idea of using a single smart metering device, empowered with Load Signature Identification algorithms, and thus capable of determine the consumption of each individual appliances is not new. Non-intrusive load monitoring is a method which analyzes changes in voltage and current waveforms in order to identify the characteristics specific to each consumer. These characteristics represent the electric load signature, which can be defined as the electrical behavior of an individual appliance when it is operating. Non-intrusive load monitoring consists of three steps: *feature extraction, event detection and device identification*. During feature extraction, the voltage and current waveform are monitored and different characteristics are extracted, (real or reactive power, admittance, shape of current waveform, harmonics, etc.) [1, 2]. These characteristics are analyzed in the event detection step and when certain variations occur they will be flagged as events, which will be later used for identification. In the final step, an algorithm processes the flagged events and matches them with previously recorded examples [3-5]. In order to obtain conclusive results, different methods of analyzing these features and classification of loads have been used over time.

Considering the analyzed features, these methods can be classified as methods based on:

Steady-state analysis

This method analyzes the changes in steady states of normalized real and reactive power consumptions inside a house, in order to identify electrical consumers [6]. By plotting these changes into a bi-dimensional plane, clusters of points can be observed which relate with devices turning on/off [7]. This algorithm offers good results [8] but has severe limitation in the detection of small appliances, appliances which are continuously turned on or continuously variable appliances, which should not be chosen as targets of this approach.

Transient analysis

Devices with similar steady-states variations may have different turn-on transient currents, which can be used in the process of identifying the electric load signature [9-10]. Being the shortness of the transient regime, a complete analyze of the whole profile of a transient is requesting monitoring systems with capabilities to monitor data at high frequencies over long periods of time hard to implement and requires many resources [11].

Harmonic analysis

Harmonic analysis can also be used to characterize the signature of electric devices [12, 13]. While linear loads draw currents of fundamental frequency, non-linear loads also draw harmonic currents. Analyzing the amplitudes and the values of harmonic real and reactive power,[14] correspondences can be found between a type of device and its harmonic content.

A detailed analysis of all reported achievements [15-17] revealed that the overall detection and disaggregation accuracy is between 80-90%, far from constituting a reliable foundation of an energy management platform. The development bottleneck, yielding this result, consist in the low accuracy of Event Detection component of all LSI algorithms, together with the high computational demand of the Fourier Transform used by Feature extraction component.

Hybrid energy monitoring system

A new architecture is proposed in this paper. Its structure (Fig. 1) is based on developing the new concept of Hybrid LSI, which, besides using the information extracted from the measured voltage and current signals, will also use hardware data, generated by SID, a device attached to the power cord of the appliances and aimed to transmit via PLC the identification code of the powered device.

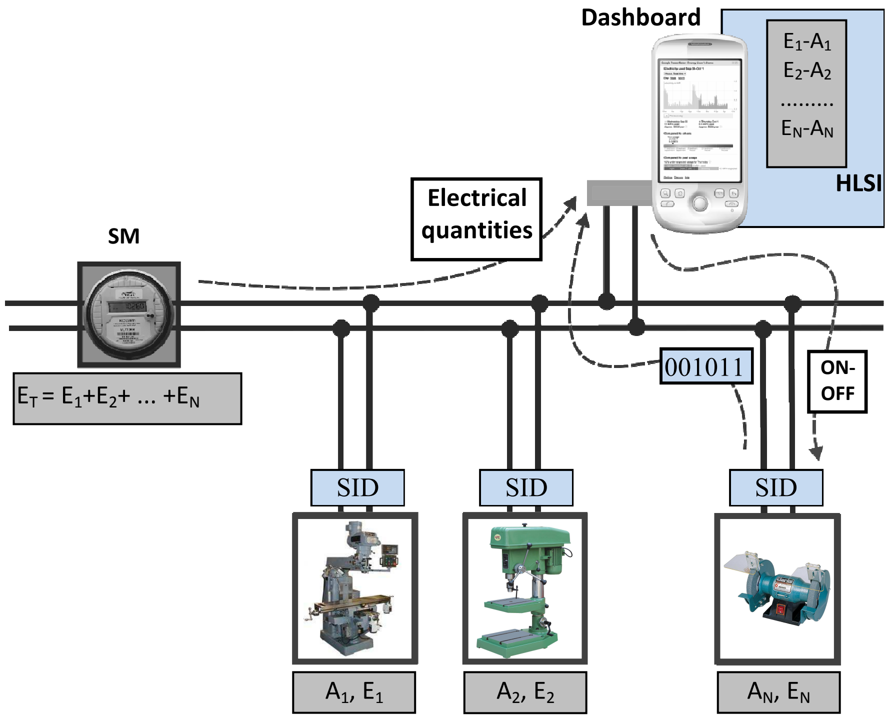

Fig. 1. Hybrid architecture of energy monitoring system

This way, the development bottleneck of *Event detection* is surpassed. A new LSI algorithm, Hybrid LSI (HLSI) (Fig. 2) which will analyze the global current and voltage waveforms, establish the load pattern of the powered appliances and compare this signature with those stored in the household appliances database. A high definition harmonic analyze is performed to identify especially the consumers with a variable load, in conjunction with the event detection and appliance identification provided by SID. It is based on a new type of Fourier Transform, with variable resolution (VDFT) developed and adapted to perform *Feature extraction* and *Disaggregation*. This method, make use of non-integer number of cycles in the DFT kernel's orthogonal signals (argument of DFT), and provide high accuracy evaluation of spectral components with significant reduction of the computational effort [18-21].

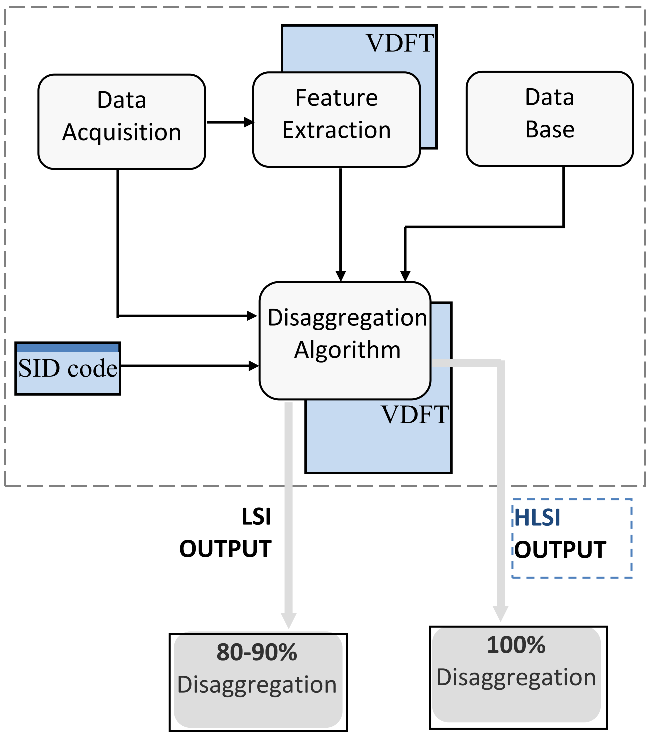

Fig. 2. Hybrid Load Signature Identification algorithm

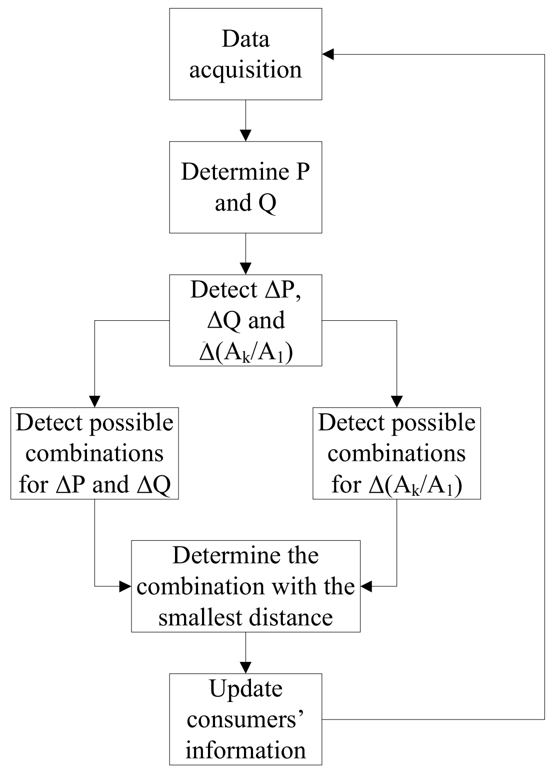

Fig. 3. Block diagram of Hybrid Load Signature Identification algorithm

In Fig. 3, the block diagram of the disaggregation algorithm is presented. The algorithm first acquires continuous data segments of voltage and current which will be used in the next step, to determine the overall values of active (P) and reactive (Q) powers. Next, the algorithm detects the variations of the two powers (ΔP and ΔQ) and first 4 current harmonics ($\Delta(A_k/A_1)$) which correspond with a electrical device transition from one operating state to another. With these values the algorithm detects possible combinations of consumers that could generate those changes. Two detections of combinations are performed, one for the active and reactive powers and the other one for the current's harmonics. Once these combinations are found, the algorithm will determine that combination with the smallest deviation and the information of the corresponding consumers are updated with the measured values.

Under these circumstances, the proposed system will allow a low-cost consumption monitoring of individual appliances, with a detection rate close to 100%.

Experimental results

Test have been made in an electronic prototyping laboratory facility with four working machines: LPKF ProtoMat E33 plotter, Proxxon BFW40/E milling machine, Troy 17150 grinder and Perel 4700 drilling machine.

In the first stage of our experiments, these machines have been monitorized in order to determine their electrical signature. The results, expressed in terms of P-Q diagram and normalized harmonics amplitude spectrum are presented in Fig. 4 and Fig. 5 respectively.

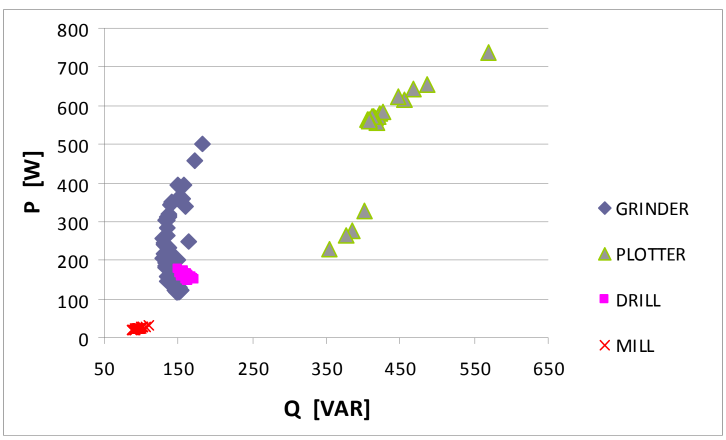

Fig. 4. P-Q Diagram

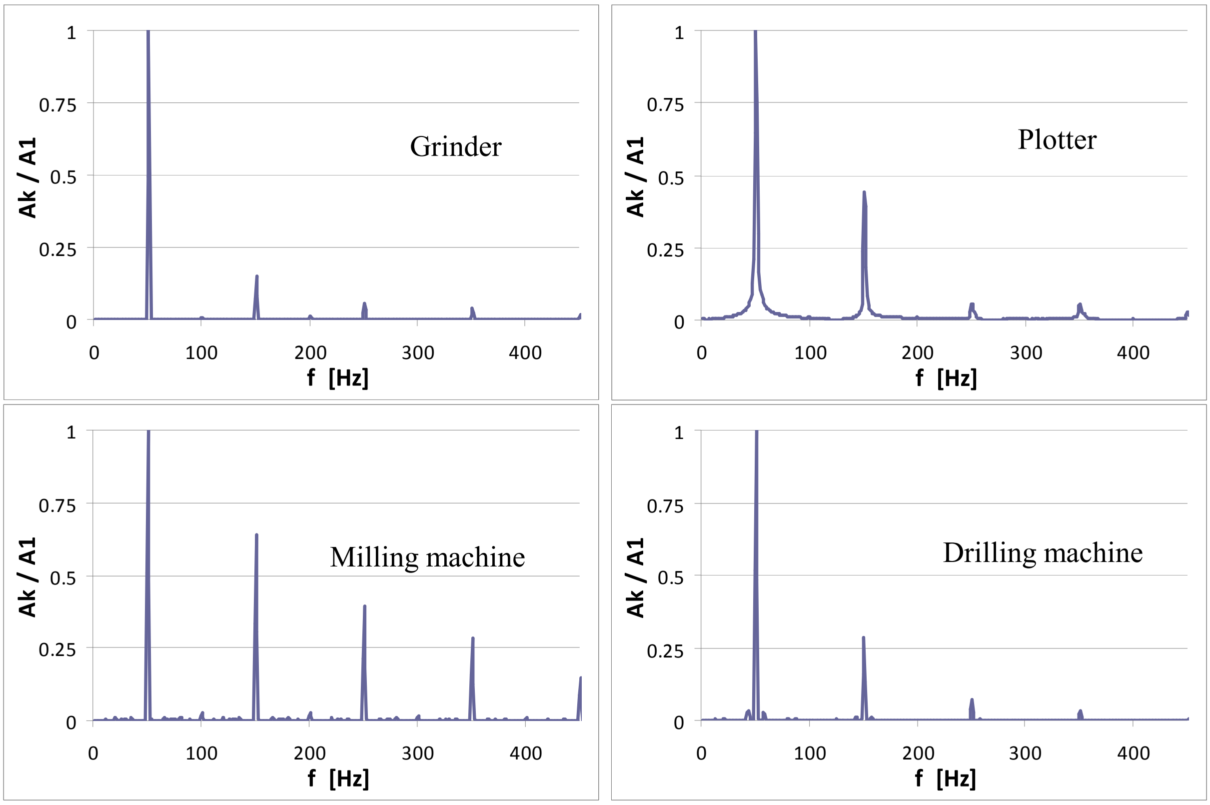

Fig. 5. Normalized harmonics amplitude

In the second stage of our experiments, the hybrid energy monitoring platform was used to monitor the global electrical power consumption and to perform it's breakdown into individual consumptions of the four working machines. The values obtained by using the disaggregation algorithm have been compared with those obtained by direct measurements over an entire working day, the differences being smaller than 3.074%.

Conclusions

A new architecture of electric energy management platform is proposed, making use of both a hybrid hardware architecture and a hybrid load signature identification algorithm. This management platform is able to perform load disaggregation in noisy industrial environments, it's detection accuracy, as tested in an electronic prototyping laboratory facility with four working machines, being close to 100%.

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