DOMESTIC ELECTRICITY CONSUMPTION DATA FOR RESEARCH AND SERVICE DEVELOPMENT

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ABSTRACT

During the last few decades, citizens around western countries became more and more sensible to energy saving. However, while home electricity consumption is a source of concern, the means to reduce this consumption are not easy to find and implement for private individuals. Different studies show that displaying the home consumption could lead to a reduction of electricity use. However, the global consumption doesn't provide the consumer with sufficient information about what counts for the main part of their electricity invoice. Systems able to display the energy used by the main appliances would greatly help the consumer to find out which equipment should be replaced and/or which behavior should be modified. Implementing such systems requires the disaggregation of the consumption of the main appliances. One solution consists in measuring the global electricity consumption and extracting the most important information from the general load curve using signal processing methods and detection algorithms.

The HES-SO Valais-Wallis (University of Applied Sciences Western Switzerland) and the CSEM (Swiss Center for Electronics and Microtechnology) are currently working in this direction. To develop recognition algorithms from an aggregated load curve, an acquisition system able to measure the three phases of a standard household has been built. This system has been deployed in seven households and has been acquiring data sampled at 1Hz for over two years for the first deployment site. In two households Ecowizz [1] plugs are used to acquire disaggregated data of the main appliances in parallel to the central measure. In parallel the HES-SO Valais-Wallis is deploying the system in fifty households for one month.

The collected data allow a better understanding of the main contributors to the load curve as well as the useful characteristics to recognize them. To first tackle the complexity of the aggregated load curve, a simulator of the main contributors (washing machine, dishwasher, tumble dryer, oven, stove, etc.) was also created, thus allowing to initially test the disaggregation algorithms with an *a priori* knowledge of the contributors. Both the database of real signals and the simulator are new tools that will allow for new research and development of algorithms for the analysis of aggregated load curves.

Keywords: Electricity Consumption, Energy Management, Non-Intrusive Load Monitoring (NILM), Load Signatures, Household Appliances, Household Appliances Simulator, Disaggregation Algorithms

INTRODUCTION

Since the first energy crisis in the early 1970s, populations of the western countries became progressively aware of the importance of sustainable development and energy saving for preserving the environment but also for reducing their energy bills. In 2010, households in Switzerland have consumed 19 TWh and a typical Swiss household of 4 people consume about 4500 kWh, representing a 1000 USD electricity bill [2]. Although Swiss households could potentially save 40% of their electricity bills by 2035, thanks for example to the optimization of the energy efficiency of appliances [2], efficient tools to reduce this consumption are not easy to find and implement for private individuals. Different studies show that providing pertinent information about the home consumption could lead to a reduction of electricity use between 4 and 15% [3]. However, the general consumption doesn't provide the consumer with sufficient information about what counts for the main part of his electricity invoice.

On another hand, systems able to display the energy used by the main appliances, in other words systems able to disaggregate the global consumption, would greatly help the consumer finding out which equipment should be replaced and/or which behavior should be modified. The disaggregation could be achieved using a measuring unit embedded in each appliance, in a similar way to the Web of Things [4]. This kind of solution is however very difficult to implement, especially with the already existing appliances, and generates high investments and operating costs. Another way to achieve this disaggregation is to measure the global electricity consumption of the household and to extract the most important information from this general load curve. This solution only requires one measuring unit but requires a system able to recognize in real time the main appliances.

The HES-SO Valais-Wallis (University of Applied Sciences Western Switzerland) and the CSEM (Swiss Center for Electronics and Microtechnology) are currently working in this direction. In order to develop recognition algorithms to disaggregate the general load curve, a representative consumption data set was needed. Given the lack of publicly available large data set and the relatively poor precision of already installed measuring systems we had to develop our own acquisition system able to measure the three phases of a standard household. As a example, the data of previously deployed smart meters were at our disposal, but the period (15 min) and the precision (1 kWh) were clearly insufficient for our purpose. The setup is recording values of voltage, current, active power, reactive power, power factor and energy at 1Hz. The system has already been deployed in seven households for up to two years. In two households a series of Ecowizz plugs able to record the electrical "signature" of a single-phased appliance [1] are used to record the electricity consumption of different appliances in parallel to the central measure. The acquisition system together with up to eight Ecowizz plugs are currently deployed in fifty households for one month in order to build a representative database.

The collected data allow a better understanding of the main contributors to the general load curve as well as the useful characteristics to recognize them. To first tackle the complexity of the aggregated load curve, a simulator of the main contributors (electric heating, boiler, washing machine, dishwasher, tumble dryer, oven, stove, etc) has been created. The simulator allows the aggregation of fully generated appliances as well as the aggregation of previously recorded appliances. This simulator is a powerful tool to initially test different disaggregation algorithms as it provides an *a priori* knowledge of the different appliances and therefore allows quantitative evaluations of the performances.

METHOD

The measuring unit is a power meter PowerLogic Series 800 PM810 from Schneider Electric. This power meter is equipped with 40/5 current transformers and with RS485 communications for integration into any power monitoring/control system. The PM810 is a true RMS meter capable of accurate measurement of highly non-linear loads. The sampling frequency is 6.4kHz (128 samples per 50Hz cycles) and the sampling technique enables accurate measurements through the 31^{st} harmonic [5-6]. The data is integrated and finally sampled at 1Hz and values of voltage, current, active power, reactive power and power factor for the three phases are recorded. The system also allows to store the value of the total active energy. The measurement accuracy is 0.325% from 1A to 10A for the current, 0.375% from 50V to 277V for the voltage and 0.2% for the power [5-6].

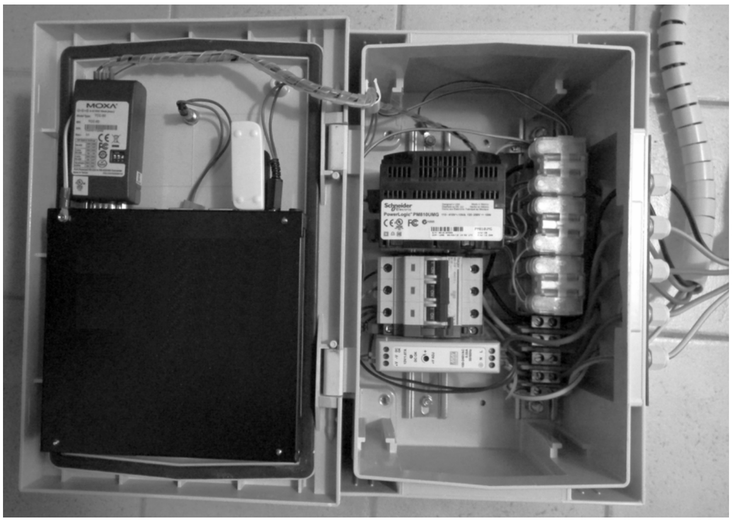

Figure 1: Data acquisition system.
The PC Engine can be seen on the left whereas the PM810 and the electric connections can be seen on the right.

The data is stored through a Modbus connection on a small PC platform (PC Engines [7]) running Voyage Linux [8], a very stripped-down Debian Linux. The data is stored in CSV files (Comma Separated Values) and is saved on two flash drives for redundancy. The data is composed of two timestamps (one from the PM810 and one from the PC Engine), the 3 voltages values, the 3 current values, the 3 active power values, the 3 reactive power values, the 3 power factor values and the cumulated active energy. The system generates one CSV files for every period of 24 hours, each CSV file consists thus of 86400 entries. The recordings are finally synchronized with a data server at the HES-SO Valais-Wallis that provides the final storage location. Figure 1 shows the details of the acquisition system, the PC Engine can be seen on the left whereas the PM810 and the electric connections can be seen on the right.

The simulator aims at producing realistic load curves by combining different electrical appliances. It is written in MATLAB and the format of the generated data is the same as the format of the "real-world" data recorded by the acquisition system. The simulator is based on configuration files defining the setup of the simulations (start and stop times, appliances to be used, phase(s) on which the appliances will appear, etc.) and models of the different appliances. Every electrical appliance used in the simulator is either generated using a statistical model or directly extracted from a database containing different measurements of the specific appliance. Two main aspects are modeled: the occurrence probability and the load curve. The occurrence probability varies during time (e.g. the dishwasher is more likely to be used around 1pm and/or 7pm rather than in the middle of the night). The statistical models contain parameters representing the appliance (number of cycles, duration of the cycle(s), duration of the different functioning states of the cycle, power levels of the different states, etc). The output of the simulation is stored in different files. The global load curves, similar to the "real-world" data, can be used to test different disaggregation algorithms. The particular load curves of every appliance used in the simulation can be used for quantitative evaluations of the disaggregation algorithms.

RESULTS

The acquisition system has been deployed in seven households and has been recording data sampled at 1Hz for over two years at the first deployment site. In two households Ecowizz plugs [1] are used to acquire disaggregated data in parallel to the central measure. In parallel the HES-SO Valais-Wallis is deploying the system in fifty households for one month to increase the statistical relevance of the database. Figure 2 shows a typical 24-hour recording of the active power for the three phases. A washing machine (over phase 1 & 2), a coffee machine, a tumble dryer (over phase 1 & 3), a dish washer and a fridge were used that day.

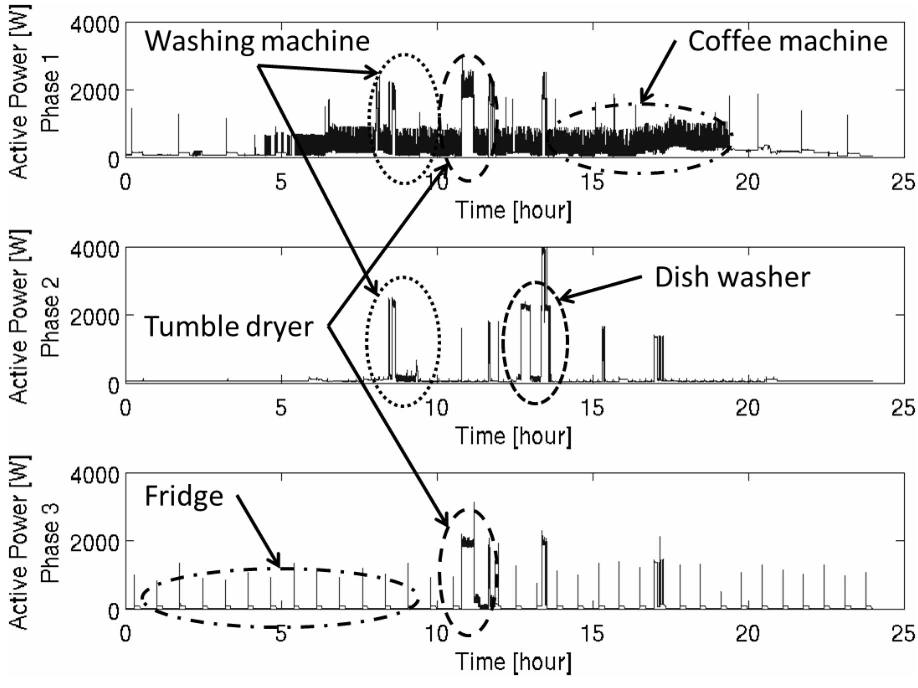

Figure 2: Typical 24 hour recording (active power, three phases).
A washing machine (over phase 1 & 2), a coffee machine, a tumble dryer (over phase 1 & 3), a dish washer and a fridge were used that day.

The simulator allows the aggregation of fully generated signals and/or the aggregation of previously recorded "signatures" of different high-consuming appliances. The user can choose to aggregate an electric heating, a boiler, a dish washer, a fridge, a heat pump a tumble dryer, a washing machine, and cooking appliances. The user can also choose on which phase(s) the selected appliances will appear. Figure 3 shows a typical 24-hour simulation of the active power for the three phases. The simulation includes a heat pump (over phase 1 & 2), a washing machine, a fridge, a dish washer and a tumble dryer.

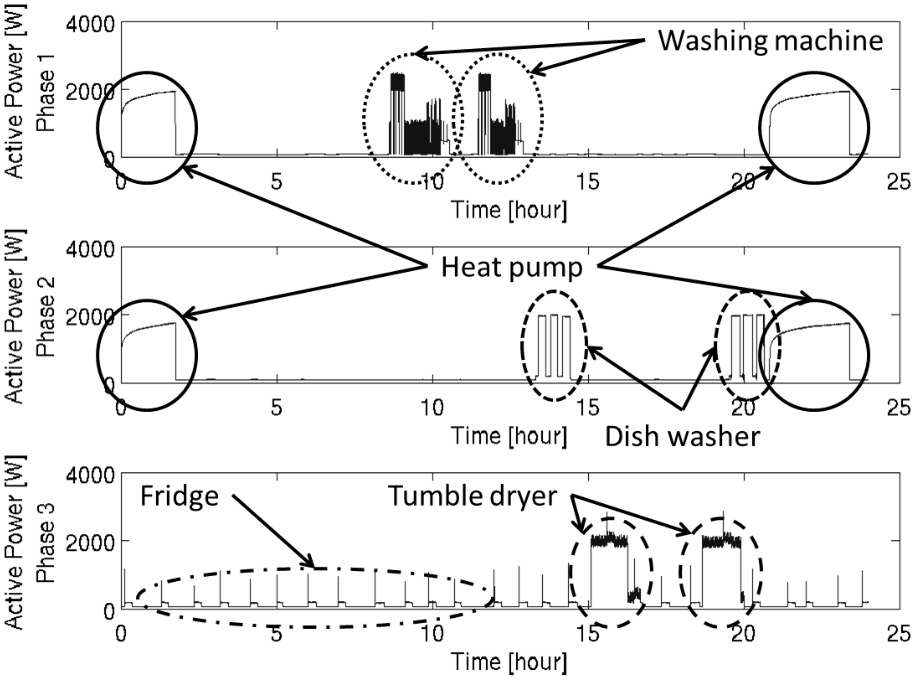

Figure 3: Typical 24 hour simulation (active power, three phases).
The simulation includes a heat pump (over phase 1 & 2), a washing machine, a fridge, a dish washer and a tumble dryer.

DISCUSSION

Research in this field is moving fast. Between our first measurements and the time this article was written (April 2013), a publicly available large data set of households electricity consumption appeared on-line [9]. Likewise, smart meters, which were initially developed for remote monitoring and billing purposes, are becoming more and more efficient, meeting the desired requirements (precision of a few Watts and data accessible each second). Moreover, solution such as the Solo II from Geo [10] counting the pulses from old smart meters should also provide the user with accurate enough data. All those low cost acquisition solutions would make data available for new services such as the analysis of aggregated consumption data.

Qualitative evaluations of different output of the simulator have shown a good match between simulated data and "real-world" measurement. Furthermore, the simulator is a powerful tool to test different disaggregation algorithms as it provides an *a priori* knowledge of the different appliances and therefore allows quantitative evaluations of the performances. This *a priori* knowledge could be obtained for "real-world" measurement using individual meters for each appliances, but generates higher investments and operating costs. Based on the recorded data and the simulator, different approaches for disaggregation algorithms are currently investigated with encouraging initial results.

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