AUTOMATED ELECTRICAL ENERGY ANALYSIS FOR DOMESTIC CONSUMERS BASED ON SMART METERS

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ABSTRACT

The European Union plans a roll out of smart meters to at least 80 % of all households. Consumers should benefit through more frequent billing periods and they should be able to regulate their energy consumption through the total power consumption provided by smart meters. Due to the large number and the individual usage of electrical devices, consumers have to spend a lot of time and effort to distinguish between the influences regarding the total power consumption of each electric device. In an average Austrian household there are 9 major electrical devices that have a total share of 72 % of the total power consumption. To split up the bigger part of the total power consumption additional measurement equipment is necessary. In order to benefit from synergies without causing high costs for the purchase and installation of measuring devices (with high investment and operating costs) and without neglecting ease of operation it is proposed that a mini PC, which gathers and analyses the data from smart meters, has to apply the method of non-intrusive load monitoring and provide consumers with valuable additional information about their power consumption of selected electrical devices.

INTRODUCTION

The European Union set itself the target to reduce the primary energy consumption by 20 % by 2020 compared to projections for 2020. To achieve these reductions the EU's energy efficiency policy relies on five pillars [1]. One of these pillars is the general policy framework to which the Directive 2006/32/EC belongs. Besides other measures member states shall ensure that final customers are provided with "…individual meters that accurately reflect the final customer's actual energy consumption and that provide information on actual time of use." Furthermore "…billing on the basis of actual consumption shall be performed frequently enough to enable customers to regulate their own energy consumption" [2].

Through the "third energy package" of the EU, member states shall ensure "…the implementation of intelligent metering systems that shall assist the active participation of consumers in the electricity supply market". Until 3rd September 2012 an assessment "…of all the long-term costs and benefits to the market and the individual consumer or which form of intelligent metering is economically reasonable and cost-effective and which timeframe is feasible for their distribution…" has to be accomplished by the member states. A positive assessment leads to a roll out of smart meters to at least 80 % of consumers [3].

In most recently published studies and smart grid demo projects the main focus is on how electric utilities can use this new technology to reduce costs and get more information like loading or voltage characteristics about low-voltage grids.

However, all approaches in reducing the energy consumption in households are based on informing consumers about the total power consumption of a selectable period. Due to the increasing number of electrical devices in households, it is not possible for customers to recognize easily which electric devices have a significant share of the total power consumption. Impacts of changes in the user behaviour as well as realized energy efficiency actions are not traceable for them through observing the total power consumption. Due to these reasons customers are not able to identify and monitor the influencing factors on their electrical energy demand or even separate the total power consumption by major electrical devices.

AUTOMATED ENERGY ANALYSIS

Providing consumers with information about their electrical energy consumption during a selectable period like the European Commission is planning is in any case an improvement regarding the status quo. However, information about the total power consumption doesn't give consumers the opportunity to differ between the consumption of single electrical devices. Several currently sold smart meters provide the possibility to log load curves with a home PC. Despite this, manually observing such load curves is a time consuming analysis assuming special expertise about the behaviour of different electrical appliances as well as a diary of the usage of single electrical appliances. Without a handwritten log about the usage of major appliances it is infeasible to reveal which devices have contributed to the monitored total power consumption. Besides this a high number of different electrical devices switched on at the same time make such an analysis more complicated. So an automated analysis of this data would be the only possible and practicable solution for the consumer.

For measuring the electrical power consumption of major electrical devices with traditional energy-monitoring devices, meters for each load are required which cause high investment and operating costs. In order to benefit from synergies without causing high costs for the purchase and installation of measuring devices, in this paper a concept is described for gathering data from smart meters to apply the method of non-intrusive load-monitoring (NILM).

Concept

A mini PC which costs below 100 EUR having a rated power of about 5 W is connected to a smart meter and records active and reactive power as well as the voltage which allows normalizing resistive loads with a high resolution in time. The recorded data is analyzed frequently by an algorithm. Recurring patterns from electrical appliances with high loads are detected and the power consumptions of these devices are calculated. The hourly power consumption of all detectable electrical devices as well as further statistical data about the usage and the detailed electrical costs are provided in diagrams and tables (see figure 1). Measures like the replacement of an electrical device with a significant share to the total power consumption or additional energy consuming electrical devices are traceable for consumers through automated analysis via visualization. Energy-hungry electrical devices can be identified easily and consumers can find out the standby power consumption. Besides this, influences of the user behaviour on the energy consumption of electrical devices are analysed. Each household gets individual information how to save energy and which are the most efficient measures. For a deeper analysis parts of the monitored data can be provided to energy savings consultants who can give more detailed information about further measures and energy savings advices. Through the development of intelligent electrical devices which are equipped with communication chips the optimizations targets of the automated analysis can be varied between load shift and peak clipping to reduce GHG-emissions on its maximum level.

Furthermore the power consumption of selected electrical devices is automatically rated by several inputs of parameters such as energy efficiency grade or size. So consumers can compare their devices with standard devices and the best available technology with the lowest energy consumption on the market. Through an energy savings evaluation tool the amortization time for different electrical appliances as well as provided measures can be calculated. The software for the algorithms is automatically updated over the internet. All the monitored data is only saved on the mini PC which is fixed in the distribution box. Merely consumers have access through LAN or WLAN to this device which is protected by encryption. The results of the automated energy analysis are visually displayed for customers.

Monitoring measures for saving energy

The total power consumption in households rises by time through additional electrical appliances or replacement by bigger devices like large widescreen plasma televisions. Furthermore the total power consumption varies day by day and each electrical device has an individual usage. Influences of a single electrical device on the total power consumption are not traceable for most consumers nowadays. Even when measures to reduce the total electric

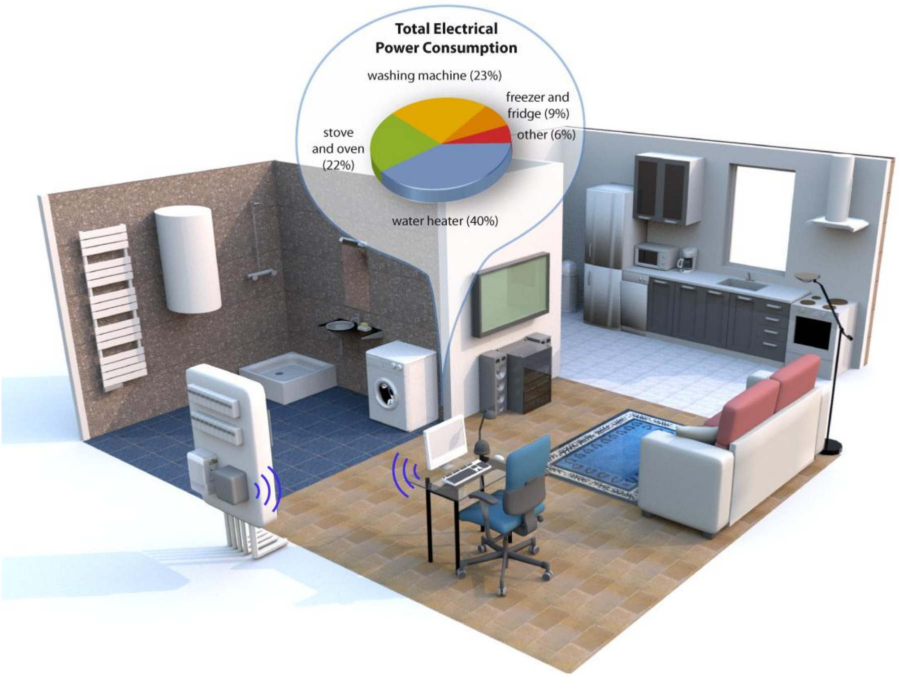

Figure 1: A mini PC which is connected to a smart meter detects and analyzes the power consumption of several electrical devices and provides an interface for consumers.

power consumption are realized, it is not sure that these measures are reflected in the total power consumption. Due to the reason that the total power consumption is dependent on so many parameters such measures are just traceable with special expertise. The total power consumption varies over the year (blue line) and raises yearly (dashed black line) as can be seen in figure 2. Besides this the total power consumption varies day by day what leads to a baseline conflict.

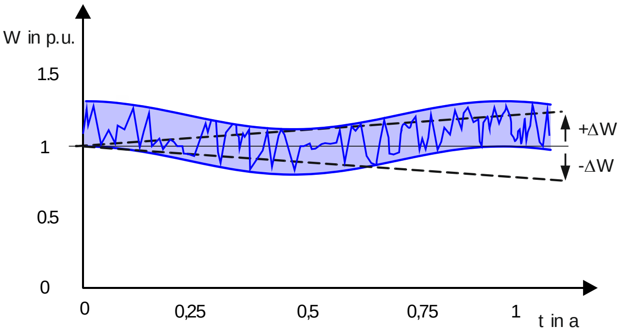

Figure 2: Variation of the average total power consumption during a year

Through the automated energy analysis of the load curve a couple of measures such saving electrical energy for heating of water in electric heaters or washing machines as well as additional consumption can be monitored and analysed. For example the frequency of the usage of electrical devices such as washing machines and the variation of the time for heating up water give information about how energy efficient the users operate electrical devices. A ranking allows consumers to compare their power consumption of a single electrical device with other consumers' devices.

Another example is the observation of the frequency of the cycle time of the heater of a stove. When consumers tend to use the maximum heating level of a stove very often it can be sure that they do not use lids on their pots which can be detected by the automated energy analysis. So, specific advices can be determined.

Non-intrusive Load Monitoring

Hart [4] proposed a NILM system that is based on changes of active and reactive power of electrical appliances. Hart's concept was to represent each electrical appliance by a finite state machine which handles discrete power consumption changes for gathering states.

Since 1992 a lot of papers have been proposed new algorithms such as harmonic pattern recognition, time frequency characterization, using steady-state and turn-on transient energy based on artificial neural networks, hidden markov models or integer programming. While it is nearly impossible to successfully detect all appliances with power consumption below 100 W, the recognition of devices that have a recurring load profile and high loads such as water heaters or refrigerators works with an error in evaluating the energy consumption below 15% [5].

Another recent approach by [6] detected major electrical appliances such as stove, oven, geyser, microwave and kettle by step changes in total active power with a maximum error of 9 % in energy consumption. Considering the power consumption of each phase of a three-phase power system separately and observe the reactive power consumption as well as maximizing the resolution of the measurement data to at least 0.1 seconds would also raise the correct detection rate of appliances. Even an error of 9 % would be enough to give consumers a sufficient overview of their share in total electrical power consumption and provide them information about how much money they spend for each major electrical appliance and the rest (standby,…).

Due to the increasing number of electrical loads and varying electrical power consumption as well as load profile overlapping of electrical appliances it is not possible to detect all devices with an adequate minimal error in energy consumption. Electrical devices with recurring patterns and high loads are easier to detect.

Total electrical energy share

Just a couple of electrical appliances are responsible for the bigger part of the total electrical power consumption. A study carried out by the Statistics Austria come to the conclusion that 72 % of the total electrical energy consumption of an average Austrian household is caused by 9 different major electrical devices as well as standby [7] (see Figure 3). All of these devices have recurring patterns with high loads and can be detected by available NILM algorithms. Dependent on the individual household and the existing equipment of electrical appliances this share can vary and consequently also the detection rate of the NILM algorithms. Nevertheless it can't be neglected that households would benefit through additional information of an automated analysis about their individual electric energy consumption even with a lower share.

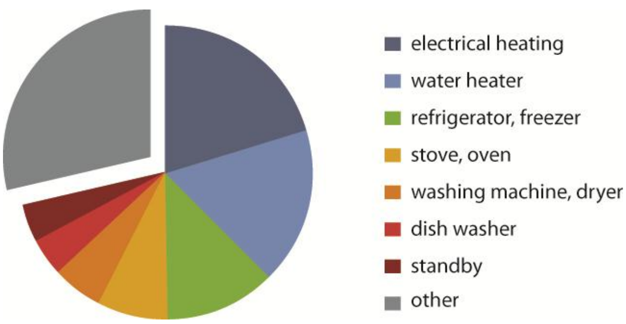

Figure 3: Average total electrical power consumption of an Austrian household [7]

Gathering Measuring Data by Smart Meters

Smart meters measure voltages and currents with a sampling rate of typically 12 to 15 kHz and the active or instantaneous power is processed internally with a high resolution of a couple of milliseconds for all 3 phases.

These data could but currently can't be used to apply the method of nonintrusive load monitoring.
For getting good results and minimum detection errors with NILM algorithms, a load curve with a resolution of at least one second is necessary. The higher the resolution in time of active and reactive power the easier overlaps of load curves from different appliances can be distinguished. Recently published NILM algorithms analyse harmonics as well as turn on transient energy. These algorithms typically process reactive and active power in milliseconds and current harmonics with several kHz. Though such algorithms can raise the detection rate and give the opportunity to detect further electrical appliances, analysing reactive and active power with a resolution of about one second, gives maximum detection errors of 9% in energy consumption [6]. However, to gather the measuring data for NILM algorithms from smart meters the minimum resolution of reactive and active power as well as the voltage for all three phases should go below one second.

Interfaces of smart meters
Currently sold smart meters are equipped with pulse indication, a multipurpose expansion port, a wire-connected PLC interface and an optical service interface. Through expansions for the multipurpose interface radio ZigBee connections and wireless M-Bus connections can be established. Among other things the optical service interface provides the possibility to read out standardized parameters (IEC 62056-21) such as voltage, electrical power consumption per phase or 15-minute-averages of active power. These interfaces are predominantly used for in-home displays and connections to other digital meters. Up to now a few manufacturers provide in collaboration with software developers off-the-shelf solutions for consumers to display the current total power consumption on PCs every second. Table 1 shows an overview of available interfaces of currently sold smart meters in Europe.

INTERFACE	MAX. RESOLUTION P/Q PER PHASE	MAX. RESOLUTION VOLTAGE
Service-Interface (IEC 62056-21)	1-5 seconds	1-5 seconds
pulse indication	up to 60.000 pulses per kWh or kvar	n.a.
Multipurpose Expansion Port	*P:* 2-4 seconds	n.a.
wire-connected (PLC)	*inhouse:* 1 second, *external:* 15-minute-average	*inhouse:* n.a., *external:* 15 minutes

Table 1: Overview of available Interfaces of Smart meters different manufacturers

So far, it is not possible to read out active and reactive power as well as the voltage per phase every second which is necessary for an automated energy analysis. Although the internal data is processed in milliseconds there is no possibility to read out this data with a high resolution including a timestamp.
However, to unfold the full potential for saving energy with the help of smart meters, manufacturers should be aware of these lacks and provide as soon as possible though smart meters.

CONCLUSION

The total power consumption doesn't allow distinguishing between the power consumption of different electrical appliances. Just a daily log of the usage of electrical appliances allows consumers with special expertise to retrace the variations in the total power consumption. The efforts from the EU to reduce GHG emissions through smart meters which provide the total power consumption can only be done with a necessary scale by consumers with special expertise doing great efforts.
With a mini PC, which could also be integrated in the next generation of smart meters, an automated energy analysis can be accomplished that gives consumers detailed information about their individual power consumption. Such an automated energy analysis which gives specific advices for saving energy allows the maximum savings in the total power consumption. Furthermore appropriate optimization targets such as energy saving, load shifting or peak clipping combined with intelligent electrical devices can reduce the GHG emissions to its minimum.

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