Analysing the Efficient Use of Energy in a Small Smart Grid System

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Abstract— **Smart grid systems, for being profitably implemented, will have to deliver advantageous results to costumers, investors and operators. This can be realised by providing efficient, secure and reliable systems, connecting distributed renewable energy sources and enabling advanced services. The analysis of those potential benefits should consider all the components of the smart grids from the energy sources to the consumers, including the communication and power flows within the system. This study aims to analyse how to reach an efficient energy use with different means (e.g. better management of the energy consumption rate, consumption forecast, and central energy orientation providing the capabilities of smart homes, communication links and electricity grid management centres. To this end, architecture of a small smart grid system including a novel smart home, communication and energy lines, and a small home energy management centre is studied in this paper. Such architecture is envisaged to have a substantial impact on the operation and management of future electricity network addressing issues such as efficient integration of renewable power sources and emerging consumer behaviour**

Keywords: smart grid, smart home, energy management, analysis of efficient energy use

I. INTRODUCTION

Traditional energy resources have come to the point of exhaustion with rapid increase in energy demand. In order to compensate the extensive energy demand, it is necessary to make efficient use of existing resources and exploit new energy sources. However, the optimal use of new (mainly renewable) energy sources jointly with existing ones will have to surpass diverse difficulties. Some problems might arise when connecting many different (distributed) energy sources at the same time. This could lead to branch overloads and voltage fluctuation in the electricity grid. An intelligent decentralized network management system, as an integral part of the "Smart Grid" concept, appears to be promising solution to such technical problems. Smart grids are enabled by the intense exploitation of communication technologies, empowering the existing power grid, and aiming at maximum energy efficiency, safety and reliability [1]. This approach can help in coping with increasing energy demand while addressing environmental factors [2] and enabling increased energy efficiency through energy losses reduction [3], Advanced communication and control capabilities of the smart grids may also account for: 1) efficient integration of growing potential of renewable energy sources in the network, 2) more efficient use of the electricity network, 3) improving the economics of the end user energy consumption with minimal human intervention and 4) increased power quality and security of supply.

Such control approach enables the end users to manage their own energy consumption in an environmentally sound and cost-effective manner [4]. Finally, this allows for better monitoring and control of the system components, analysis of the system electrical variables such as voltages, currents, harmonics, power factors, phase differences and ultimately to enhanced operation and planning of future electricity networks..

To this extent, a small smart grid system including a smart home, communication and energy lines and an energy management centre have been presented and analysed in this paper. Central to the energy management system is control of the energy consumption of a refrigerator-freezer combination placed in the in the smart home. The cost of the energy consumed by the refrigerator-freezer combination is minimised and monitored, providing communication of variable electricity prices to the consumer.

II. ANALYZING A SMART GRID MODEL

The model of the general smart grid system considered in this study is depicted in Fig. 1 and consists of traditional energy sources (fuel, fossil etc.), renewable energy sources (sun, wind etc.), smart homes, smart buildings and electric vehicles. Communication and power lines interconnect all units among them and with the smart grid management centre. The smart grid communication layer can be divided in three sectors, as shown in Fig. 2 [1], i.e. Home Area Network (HAN), Neighbourhood Area Network (NAN) and Wide Area Network (WAN). With these communication links, different operations can be performed such as control of the energy production from diverse units of the system, continuous monitoring of the energy consumption of all users, adaption of the energy usage rates of each consumer, real-time billing, monitoring of the electricity network variables and tracking

of illegal energy usage. At the same time, the decentralized grid structure aids to enhance the security of supply across the entire grid.

Altogether, this control approach increases the influence the consumers can exercise over the source of their energy, while confronting them with a new level of complexity.

In this context, the paper describes how the smart grid components can contribute to the fulfilment of those objectives, providing the required capabilities of such advanced network structures.
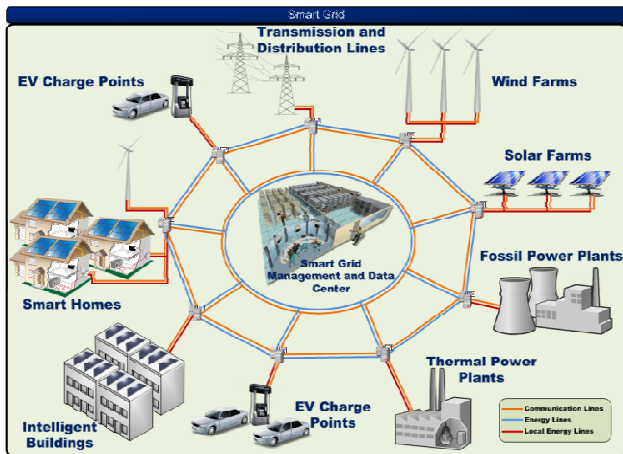
Fig. 1. Block diagram of the designed smart grid management center
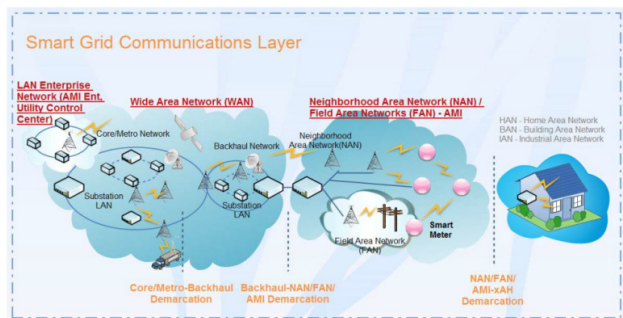
Fig. 2. Smart grid communication layer [1]

III. EXPERIMENTAL STUDY

A model of a small smart grid system illustrated in Fig. 3 includes a smart home, an energy management centre and power and communication lines, as described in chapter II. It is used to experimentally verify some of the simulation and analytic results.

Among the parameters to be measured in this design are the rates of consumption of electrical devices, energy production rates of the various energy sources, interactive connection of the energy sources with the grid etc. In addition, the experiment will follow the real-time billing of energy, and analyse the consumer's energy consumption habits as well as the energy demand forecast. To this end, it will be observed how the consumer follows the energy consumption and monitors retroactively the energy consumption rates.
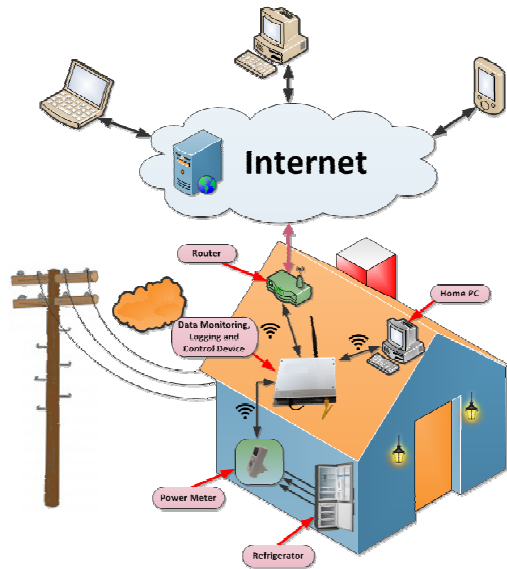
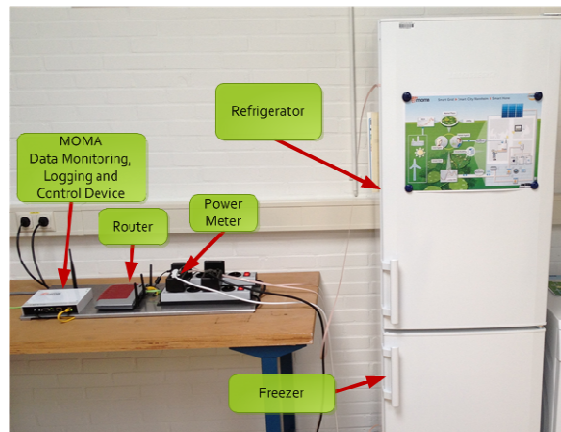Fig. 3. Block diagram of a general smart home energy observing system

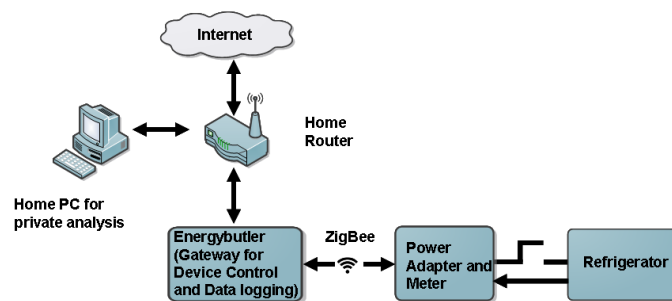Fig. 4. The designed hardware structure

Fig. 5. Hardware structure block diagram

Furthermore, with the Energy-Butler a web interface is provided for tracking the consumer's energy usage status. The designed web interface is illustrated in Fig. 6.
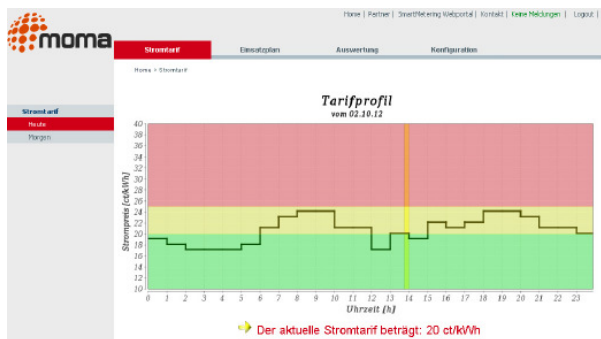
Fig. 6.   The Energy-Butler web interface

Through this interface a set of several actions can be performed, such as monitoring a real-time energy consumption and billing information, remote control of consumers, data analyses and archiving, provision of support, etc.

The power adapter and meter measure temperatures of both freezer and refrigerator and transfer the data to the monitoring, logging and control device via wireless connection using the ZigBee protocol [7]. These data can then be transferred to computer for further analysis. The Energy-Butler receives day-ahead price information via the home network from the Internet (Fig. 6) and optimises the load consumption respecting the temperature set values of both refrigerator and the freezer. In this way, the tendency is to shift the necessary energy consumption from periods of high to low electricity prices thereby obtaining greater economic efficiency and security of supply.

Fig. 7 illustrates the power consumption, temperature and the electricity price for the day of July 1 2012. As shown in the figure, the lowest cost to run the refrigerator-freezer combination was during the time interval 1:10 AM and 2:18 PM. Temperature values of both the freezer and the refrigerator sections are shown in Fig. 7(c). Looking at other time periods during the day in the operating range, the longest operating period of time was achieved during time intervals of low energy cost. When the cost of energy is high the refrigerator-freezer combination operates as short as possible while keeping the temperature of the refrigerator and the freezer below the maximum set value.

The rationale behind this control is minimisation of the operation cost of both the refrigerator and the freezer while maintaining the temperature within the set values during the whole period of operation..

## IV.   EXPERIMENTAL RESULTS AND DISCUSSIONS

Figures 8 and 9 depict the daily average energy consumption and energy cost for several days in July 2012. What can be observed from the figures is that the load consumption of the refrigerator and the freeze tends to shift from days with high to days with low electricity price leading to reduced average consumption cost over the day (e.g. 01.07.2012). Moreover, higher consumption costs are observed during some days of low average power consumption rates (e.g. 03.07.2012) as a result of time variable and daily changing electricity price.

To this end, introducing a smart energy management system allows the energy consumers to manage their consumption more cost-efficiently while enabling easier integration of renewable energy sources into the electricity networks.
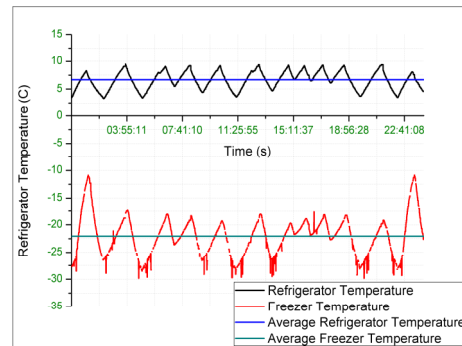
Next steps of our investigations will be to monitor and analyse the power consumption of other household appliances. Also the energy consumption habits of consumers will be analysed by using data obtained at the smart grid simulation centre [8].
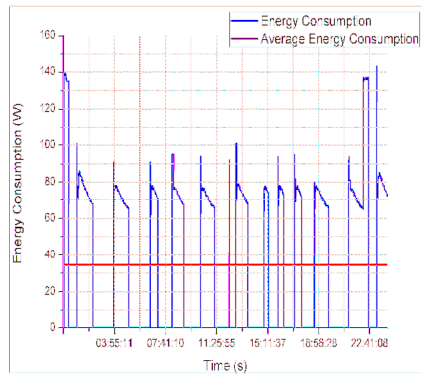
(a)
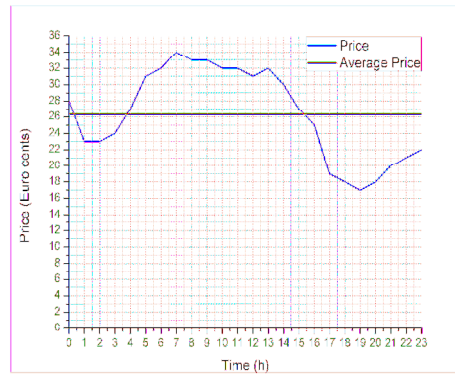
(b)

(c)

Fig. 7. (a) Power consumption of refrigerator-freezer combination, (b) Energy cost, (c)Refrigerator and freezer temperature change on 01 July 2012
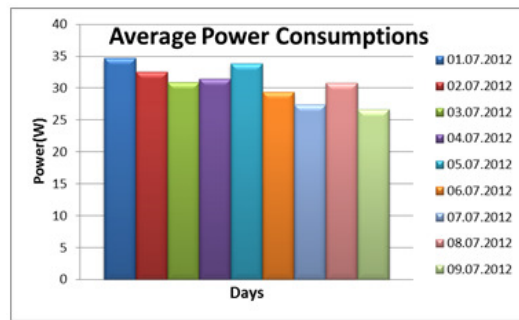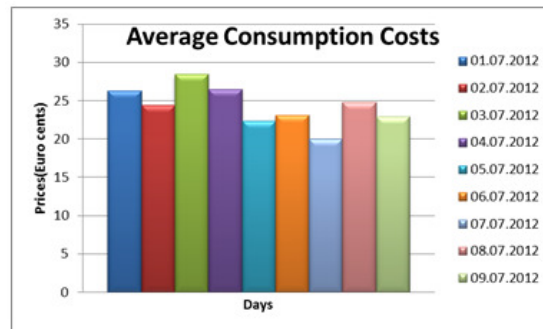
Figure 8.   Average Energy Consumptions from July 01 to 09

Figure 9.   Average Energy Consumption Costs from July 01 to 09

V.   CONCLUSION

This paper aims to study a small smart grid system including a smart home and communication and management centre in an experimental setup. The smart energy management system presented empowers the energy consumers with the ability to closely monitor and control their power consumption and increase their energy use efficiency. Beside the potential of load-shifting the potential of cost savings has been demonstrated.

Also, with such infrastructure the impact of the emerging consumer behaviour on the distribution electricity network can be closely monitored and control allowing the utility companies to better manage and plan the future electricity needs.

Finally, enhanced management of future electricity networks accounts for easier and more efficient integration of distributed energy sources from which to greater extent renewable resources.

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