Towards Efficient Energy Management: Defining HEMS, AMI and Smart Grid Objectives

Ana Rosselló-Busquet, Georgios Kardaras, José Soler and Lars Dittmann, *IEEE members*
Networks Technology & Service Platforms group, Department of Photonics Engineering,
Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
{*aros, geka, joss, ladit*}*@fotonik.dtu.dk*

***Abstract*—Energy consumption has increased considerably in the recent years. The way to reduce and make energy consumption more efficient has become of great interest for researchers. One of the research areas is the reduction of energy consumption in users' residences. Efficiently managing and distributing electricity in the grid will also help to reduce the increase of energy consumption in the future. In order to reduce energy consumption in home environments, researches have been designing Home Energy Management Systems (HEMS). In addition, Advanced Metering Infrastructure (AMI) and smart grids are also being developed to distribute and produce electricity efficiently. This paper presents the high level goals and requirements of HEMS. Additionally, it gives an overview of Advanced Metering Infrastructure benefits and smart grids objectives.**

I. Introduction

Despite the fact that home appliances have become more energy efficient, electricity consumption in households has increased 30% over the last 30 years [1]. This is due to the fact that the number of appliances that can be found in households is also increasing. According to the International Energy Agency (IEA), European electricity consumption is going to increase 1.4% per year up to 2030 unless countermeasures are taken [2].

Residential buildings can reduce their energy consumption by becoming more energy efficient. This paper will try to identify the objectives that need to be fulfilled in order to deploy an energy efficient infrastructure. This infrastructure will help reduce the electricity consumption in users' residencies and make the electric grid more efficient.

The research areas of efficient energy management have divided into three more specific research areas: energy management in-home environments, consumers and utilities cooperation and energy management in the electrical grid.

In this paper we treat 'utilities' as the parties involved in the production and distribution of electricity through the electrical grid. In addition, we use the term distribution to refer to the process of electricity transport from the generation plants to the users' residences.

As shown in table I, energy consumption in home environments can be reduced by installing Home Energy Management System (HEMS) [3] in users' residences. HEMS will give the users the necessary tools to manage and reduce their consumption. Advanced Metering Information (AMI) will enable two way communication between the households and the utilities. AMI will benefit the users as it will enable the provision of real time rates and billing status through the smart meter. If users take into consideration the price of electricity while consuming and reduce their consumption when the price is high, consumption will be optimized as demand peaks will be reduced. In addition, providing this exchange of information is one of the first steps towards optimization of energy distribution and production as it will provide the utilities with statistics that will help predict energy consumption. In order to reduce losses and optimize energy distribution and production the electrical grid needs to be upgraded. Upgrading the electrical grid will lead to the so called smart grid. The smart grid will include new elements to efficiently manage the electricity distribution and production.

In this paper, the different goals that should be achieved in these areas in order to reduce energy consumption in home environment and make more efficient distribution and production of electricity are presented. When designing such systems, researchers usually focus on one of the goals. However, it is important that when designing these systems, researchers design them in the framework they are going to be deployed and keep in mind all the goals they should achieve to maximize the benefits. This paper summarizes the different objectives of these research areas which can be used as a guideline.

The remainder of this paper is organized as follows: Section II introduces the concept of Home Energy Management System (HEMS) and describes the high level goals and requirements to deploy it successfully. Section III will present the concept of smart meters and AMI. In addition, the possible information exchange between households and utilities will be explained. Finally, section IV will present the concept of smart grid and the objectives that need to be achieved to optimize energy production and distribution.

II. Energy management in home environments

Energy consumption in households should be reduced in order to decrease greenhouse gas emissions. Introducing Information and Communication Technologies (ICT) into home environments can help reduce users' energy consumption. A HEMS is a system that includes all the necessary elements to achieve reduction of electricity consumption in home environments. One of its main elements is the so

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Table I
IMPROVING ENERGY MANAGEMENT

Issues \ Research areas	**Home environments**	**Cooperation**	**Electrical Grid**
Energy Goals	Reduce energy consumption	Optimize energy consumption, distribution and production	Reduce losses and optimize energy distribution and production
Who benefits?	Users	Users and utilities	Utilities
How?	HEMS	AMI	Smart grid

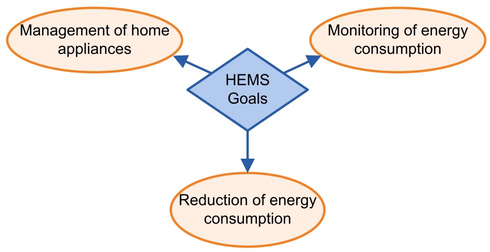

Figure 1. Home Energy Management System Goals

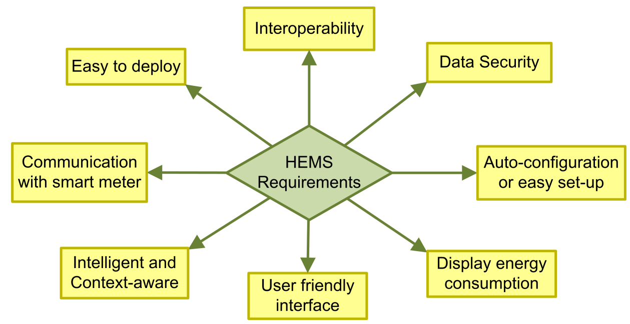

Figure 2. Home Energy Management System Requirements

called home gateway or residential gateway which is able to communicate and manage the rest of the home appliances and offers to users' tools to reduce their consumption. Using context-aware information in HEMS will provide knowledge of the environment which can be used to further decrease energy consumption.

Section II-A will present the goals HEMS should achieve and the high-level requirements it should fulfil. Section II-B will present the major challenges when designing HEMS.

A. *HEMS High-Level Objectives and Requirements*

The main objectives of HEMS are shown in Fig. 1. HEMS main goal is to reduce the energy consumption. However, to achieve this, monitoring energy consumption and managing appliances are needed. In order to reduce energy consumption, first it is necessary to know how energy is consumed. Therefore monitoring is needed. Secondly, it is necessary to manage the appliances to apply energy reduction strategies.

We consider that HEMS has to fulfil the requirements summarized in Fig. 2 to achieve these goals satisfactorily:

- Easy to deploy: It has to be taken into consideration that HEMS should be easy to deploy into users' houses because deploying new cables or infrastructure is not the best solution. This requires using already installed communication systems, such as wireless communication or power line communication which will minimize the costs and gain users' acceptance.
- Interoperability: in order to monitor and manage users' appliances efficiently a home network has to be introduced where devices can exchange information and commands without interoperability conflicts.
- Data security: Security has to be incorporated into HEMS in terms of data encryption and authentication to protect the system against external threats. However, security issues will not be analyzed as they are out of scope of this paper.
- Auto-configuration or easy set-up: HEMS is going to be used by users that may not have enough knowledge to perform difficult network configuration tasks. Taking into consideration that users may add or change their home appliances, HEMS should provide easy to use configuration tools or in the best case the network should be auto-configurable.
- Display energy consumption: One of HEMS goals is to monitor energy consumption. This information should be available to users through the user interface.
- User friendly interface: The user interface should provide information about the current consumption and also previous consumptions, providing daily, monthly and even annual reports. Additionally, it can offer the possibility to compare the electricity consumption between months or even compare it to other sources, such as average neighbourhood consumption or other users' consumption. This option could be a new service provided by the smart grid through the smart meter. This interface should also provide management options, where the users can modify their preferences and control their appliances. User preferences are related to the strategy used to reduce users' energy consumption and can vary from system to system. Providing the possibility of controlling devices is also important as the system may apply undesired configurations and the user has to be able to correct them.
- Intelligent and context-aware: HEMS should have some intelligence to facilitate efficient energy management. This can be achieved by creating a context-aware system. A context-aware system is capable of collecting information from the environment, or context, and react accordingly. We consider that a context aware system can significantly improve the reduction of energy con-

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sumption. There are different ways in which context-aware systems can be implemented in HEMS: by defining energy polices or rules or by creating ubiquitous computing system.

In HEMS, a system that uses energy policies is a context-aware system which collects information from the environment and then uses this information together with the rules to reduce energy consumption.

Ubiquitous computing requires a more complex system. We define that a HEMS using ubiquitous computing reduces energy consumption by using context-aware information to predict users' behaviour and then applies the energy management strategy without compromising the users' comfort. Before being able to predict users' behaviour and apply the energy management strategy, there has to be a learning process. This learning process includes (1) collecting context-aware information, which can include location-aware information, and (2) analyze and process this information to extract the users' routines and patterns. Once the learning process is completed, the system can extract the settings needed to reduce energy consumption.

- Communication with smart meter: Enabling this communication will provide the user with real-time price and billing status, energy consumption information, as well as possible services that may arise. An example of a new service could be comparing the household energy consumption to other users' consumption.

In the next section the challenges found when designing HEMS when trying to comply with the above requirements will presented.

B. Issues and challenges

The main challenge to provide an efficient HEMS is interoperability. HEMS should provide seamless interaction between devices. However, there are a number of different home appliance manufacturers and communication technologies available for the user which makes device interoperability problematic. In addition, devices of the same type, such as washing machines, can have different functionalities depending on the model. Technical incompatibility has limited market possibilities. Users are looking for a 'one size fits all' solution without having to worry about compatibility requirements. An example of how to solve this problem can be found in [4].

Additionally, there are other challenging users' expectations that have to be fulfilled related to the following requirements: auto-configuration or easy set-up, user friendly interface and easy to deploy:

- Easy to use and easy device control: there is diversity in users' preferences and expectations when interacting with HEMS. Some users would like an interface that will give them advanced options while others would just like a simple system but without losing control of their devices [5]. Furthermore, users have different user interface display preferences, some users would like to use their mobile phone or PDA, while others would rather use their computer or a controller. An example of how to deal with this can be found in [6].
- Easy to configure: complex configuration or need of a professional to configure the network is a drawback. HEMS should be easy to configure or even be auto-configurable. However this can be a challenge due to the heterogeneity of home appliances and home technologies.
- Easy software upgrade: home appliances can have software installed, which in some occasions has to be updated. Software update should be easy for users to do. An example of how to deal with this can be found in [7].

Moreover, designing HEMS as an intelligent and context-aware system is not an easy task and presents the following challenges:

- Design of context-aware systems, data collection and interpretation: HEMS may use sensors to collect information about the users' behaviour. The system may have to work with different types of sensors and from different brands. This will force the system to be designed to deal with different sensor details which sets a barrier to interoperability. [8] proposes an infrastructure to support software design and execution of context-aware applications using sensors to collect data.
  Another issue is coping with the amount of data transmitted from home appliances and possible sensors. An example of how to deal with this can be found in [9].
- Policies and rules: There are two main challenges when using policies to implement energy management: coordination and contradiction. As the number of appliances in the house increases so does the number of policies, which can lead to coordination problems and contradictory rules. Tools to identify interactions and detect contradiction between policies should be incorporated into HEMS to manage rules and policies more efficiently. An example of this can be found in [10] and [11].
- Ubiquitous computing: HEMS using ubiquitous computing should include an algorithm which after processing the collected data will be able to learn and predict the users' behaviour . Examples of such algorithms can be found in [12] and [13].
- Multiple-inhabitants: Prediction of users' behaviour when there is more than one user in the home environment adds complexity to the predicting algorithm as each user has his/her own routines and practices.
- Not compromising users' comfort: HEMS should not have undesirable outcomes, it should be an intelligent system that can adapt to different situations and user behaviour.

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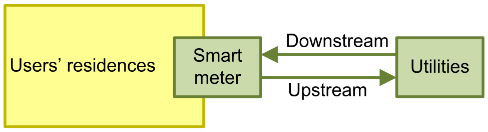

Figure 3. Communication between users' residences and utilities

III. Consumers and Utilities cooperation

Efficient distribution and production of energy requires knowledge about users' energy demand. Collecting data of the energy consumed in households can help built up statistical information about consumption patterns. By providing this knowledge to the utilities, they can foresee the energy needs of their consumers and avoid electricity shortages or blackouts.

Deployment of renewable energies, such as photovoltaic panels or solar thermal panels, is increasing in home environment. These renewable energies help reduce the user electricity consumption from the grid, and, if excess of electricity is produced, they can insert electricity into the grid. Utilities can also use renewable energy production data to foresee the energy demand.

Furthermore, it is expected that electric vehicles will replace fuel vehicles. These new electric vehicles are going to be equipped with a battery that will be charged directly from the grid. When demand peaks occur the users can use the electricity already stored in their vehicles to lower the load in the grid.

In order to collect all these data a cooperation between consumers and utilities has to be established. This cooperation involves incorporating a bidirectional communication system between utilities and users. Users will also benefit from this communication as utilities can provide them real time information about electricity price and billing status. In addition, there will be no need for having utilities employers coming to read the electrical meter as that information will be obtained through this communication system providing Advance Metering Reading (AMR).

As shown in Fig. 3, the upstream communication is define as the transmission of data from the user to the provider and the downstream is defined as the one from provider to user. As stated before, the data transmitted in the upstream will include information about users' electricity patterns taking into consideration their renewable energies. The downstream communication is the transmission of electricity price and billing information from the utilities to the users. Having access to real time price and billing information will make the users become more conscious about their electricity consumption and they may try to reduce the associated costs, by avoiding peak hours, leading to a more distributed and efficient consumption. In addition, the utilities can use this downstream to ask their users to reduce their demand when demand peaks occur. This communication system will enable utilities to be proactive, acting before the problem occurs instead of reacting to it. Furthermore, utilities can offer new service that can be access by the user through this downstream.

This bidirectional communication channel will have benefits for both sides.

A. Requirements

To enable a bidirectional communication between users' and utilities some changes have to be performed in users' residences and in the electrical grid. Traditional electricity meters have to be upgraded to make communication between users and utilities possible. Smart meters are similar to traditional meters, they collect data about the users' consumption, but they additionally support communication between utilities and users. In addition to smart meters, an Advanced Metering Infrastructure (AMI) has to be deployed in the electricity grid. AMI is a system capable of measuring, collecting and analyzing energy usage which is expected to be deployed within the electrical grid. Smart meters comprise a major component of AMI and one of the first necessary steps for bidirectional communication between users and utilities.

B. Issues

AMI is a communication infrastructure that can involve the communication of different utility sectors and companies. The electrical grid is mainly divided into: (1) generation: production of electricity, (2) transmission: transmission of electricity from generators to distribution systems, (3) distribution: connection of power lines to consumers, and (4) consumers. Deploying AMI will require that these parties work together to obtain the maximum benefits. This may require data interfaces between the different parties to deal with interoperability issues. Integrating AMI into the grid may require (1) to deploy a new communication infrastructure in the grid, (2) to use wireless networks such as mobile networks, (3) to use web-based communication. In addition, the communication should be secure to prevent cyber-attacks.

IV. Energy Management in Electric Grids

As stated before, energy consumption in home environments is increasing and consumption patterns have considerably changed in the last years. However, the electrical grids have not changed significantly during the last century, therefore an upgrade is needed to achieve efficient energy distribution and production. This upgrade in the electrical grid will lead to the so called smart grid. [14] defines the smart grid as "electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies". Smart grids will incorporate AMI and agents to fulfil the requirements for energy efficiency. In the next section, the objectives of the smart grid are described.

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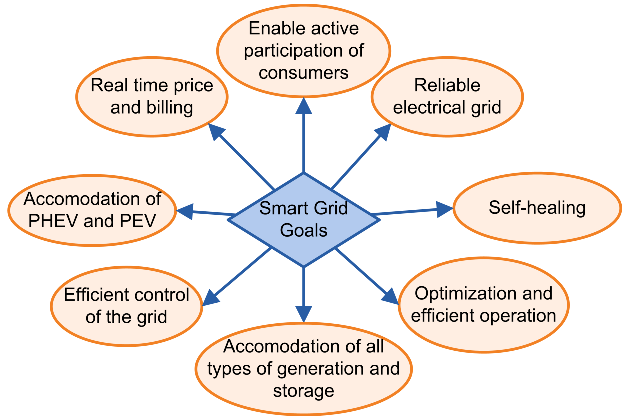

Figure 4. Smart Grid Goals

A. Smart Grid Objectives

Fig. 4 summarizes the main high-level objectives the smart grid should fulfil. When designing the smart grid these goals should be taken into consideration and be integrated together in order to maximize the benefits.

- Enable active participation of consumers: The grid should accept injections from renewable energies installed in the users' residences. In addition, the grid can ask the users to reduce their consumption to avoid demand peaks or shortages and reward them with economical benefits. This process is referred as Demand Response (DR).
- Reliable electrical grid: the smart grid should improve security and quality of supply and reduce the number of blackouts and shortages.
- Self-healing: the smart grid should be more resilient than the electrical grid we have today. Smart grids should be easily reconfigurable and dynamic in order to achieve self-healing which will make the grid more resilient and reliable.
- Optimization and efficient operation: Optimization and efficient operation of the grid implies a reduction of energy losses in power lines. This can be achieved by upgrading the grid components and by using consumption statistics to foresee the electricity usage.
- Accommodation of all types of generation and storage: The smart grid has to accommodate from large centralized power plants to renewable energies installed in the users' premises or distribution systems. In addition, it is foreseen that new storage systems, such as community storages, may be included in the smart grid. To properly manage and control these new elements, the smart grid should be designed as a decentralized and distributed grid.
- Efficient control of the grid: As explained in the previous section, AMI will enable the transmission of energy consumption which can be used by the utilities to forecast users' demands. This information will enable an efficient control of the grid as load scheduling and management can be carried out to avoid blackouts and electricity shortages. In addition, smart grids should enable control information communication among different elements of the grid to achieve an efficient control of the grid.
- Accommodation of PHEV and PEV: Even though Plug-in Hybrid Electric Vehicles (PHEVs) and Plug-in Electric Vehicles (PEVs) are not yet wide-scale adopted, they should be taken into consideration when designing the smart grid. It is foreseen that the amount of PHEV and PEV will increase which will lead to a considerable increase of electricity demand.
- Real time price and billing: AMI will provide the infrastructure to transmit real time price and billing information to the user. The smart grid should incorporate the necessary elements to make this information available such as billing databases.

B. Towards Smart Grid

The electrical grid has to undertake a transformation to reach the smart grids objectives. Introducing AMI into the grid will provide the communication tools to help reach some of the smart grids objectives. However, further changes in the smart grid components have to be done to successfully fulfil these goals. Advanced components, advanced control methods and communication and improved decision support will be introduced in the electrical grid as it moves towards becoming a smart grid. In addition, sensing and measurements technologies should also be incorporated to evaluate the correct functionality of all elements in the grid and enable and efficient control.

V. Conclusion

There is considerable literature on energy management and smart grid. This paper has tried to outline the main goals that have to be fulfilled by the Home Energy Management System, AMI and smart grids. When developing systems to reduce or make energy consumption more efficient, such systems usually focus on one specific capability. It is important that the overall framework and objectives are taken into consideration during the design of such systems to maximize their benefits. This paper can be upstream communication theused as a guideline of the objectives that should be fulfilled by HEMS and smart grids.

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