

Wireless Sensor Networks for a Zero-Energy Home

Rangarao Venkatesha Prasad, Vijay S. Rao, Ignas Niemegeers,
and Sonia Heemstra de Groot

Faculty of EEMCS, Delft University of Technology,
Mekelweg 4, 2628 CD Delft, The Netherlands

{R.R.VenkateshaPrasad, V.SathyanaRayanaRao, I.G.M.M.Niemegeers,
S.M.HeemstradeGroot}@tudelft.nl

Abstract. Energy, especially *Electricity* has become a critical concern of society. The generation and distribution are, to a large extent, not matched with each other. There are many initiatives to balance the load on the Grid vis-à-vis production and consumption. Recently, technology has made it possible to generate small amounts of energy in each household with solar, thermal, wind and other sources. With storage devices, it is possible to use the generated energy at the sources i.e., localized generation and consumption of energy. The system can be made efficient and possibly design a zero or positive--energy home with the use ICT infrastructure, wireless sensor networks, in particular. This paper proposes a three-layered architecture for this system and also lists several associated issues and challenges.

1 Introduction

Electrical energy has become a critical concern of society. The generation and distribution are, to a large extent, not matched with each other. In fact the generation and consumption locations are also geographically isolated and to a large extent these two are always seen in isolation. There are many initiatives to balance the load on the Grid vis-à-vis production and consumption. This is not sufficient in the current age since the centralized production of power implies that we are heavily dependent on fossil fuels, nuclear fuel, windmills and large hydro projects, followed by a complex distribution system that needs to be managed. Thus it is imperative to look beyond this existing system for better solutions [1].

Recently, technology has made it possible to generate small amounts of energy in each household. There are ample opportunities to harvest energy, e.g., solar, thermal, wind, using micro-turbines, photo-voltaic cells, fuel cells etc. There are possibilities of storing the generated small amount of energy and possibly feeding it back to the Grid [2, 6, and 11]. Moreover, if the network is designed well, the generated (even small amounts) could be spent in the neighborhood, thereby avoiding distribution losses. The capability to generate and leverage the small amounts of energy in neighborhoods autonomously provides a subsystem with potential to reduce or avoid the centralized grid and its associated complexity and losses. Having sources closer to loads contributes to enhancement of the voltage profile, reduction of distribution and

transmission bottlenecks, lower losses, exploits wasted heat,. It also allows to avoid or postpones investments in new transmission and large scale generation systems. Therefore, smartgrids and microgrids are being actively researched [2].

Major companies have started developing systems for Smart Metering [8]. As an example, Cisco and IBM [9, 10] started a joint project in which 500 households will have smart metering implemented.

There are few implementations of microgrids and they are complex; however, there is a need for a non-complex model and control methods that take care of the generation, distributed storage and consumption in a localized manner. Such a system should, ideally, realize zero-energy (or even positive-energy) homes and buildings. Information and Communication Technologies (ICT), in particular, Wireless Sensor (and Actuator) Networks (WSNs) have been widely used to increase energy efficiency of systems. We believe this technology could be employed in these microgrids to achieve cooperation and collaboration between the sources and the loads, and facilitate building the zero-energy homes. Moreover, with sensors it is possible to get context information at the loads. Along with the sensors at the sources, it is possible to enhance energy management functionality of the system. In this paper, we present an overview of microgrids and their benefits; we also propose an ICT architecture for realizing zero-energy homes using Wireless Sensor Networks and discuss important issues involving its implementation. Finally we brief about the projects on microgrids.

1.1 Microgrids

There is ample opportunity for small scale energy harvesting in homes, buildings, and public places. The very fact that the living environment is controlled opens many doors to harvest small amount of energy. For example, the thermal difference occurring during severe winters enables us to harvest some amount of the energy spent on heating the living space. Small wind turbines are also part of this in many countries. Energy can also be harvested using solar and thermal gradient systems [11]. With these micro-generators, the reduced energy cost as well as having a clean environment is making people conscious of the opportunity of harvesting energy. At present these initiatives are isolated.

Further to the above description, we observe that energy is not required at a uniform rate during a day. The energy consumption also varies depending on the number of people, their habits and requirements in any particular building or home. Domotics and many recent initiatives are bringing newer ICT technologies to households to save energy. For example, the sleeping rooms are not heated till sometime before the persons go to bed to save energy. The lighting is switched off and intelligent lighting is also used in many buildings and long corridors where it is turned on only when required, or lighting is adapted to the context, e.g., the activities or the mood of people. Thus, the energy load in buildings or houses varies depending on the available technology as well as the habits and context. For example, households use the least amount of energy in the day time but offices and factories use mire energy at that time (see Fig. 1).

The second aspect is that the micro-generators that people use to harvest small amounts of energy are always stored in small storage elements such as batteries, flywheels, and super-capacitors [11]. Since the energy harvesting will not usually yield usable power continuously there must be some devices to store the generated energy and to refine it for later use. Thus wherever there is a generator there would be usually a small battery to store the energy generated. Thus we see that there is a huge potential for storing the generated energy locally and in a distributed way.

The third aspect is that the cost of connecting to the Grid and maintaining the power flow from - and to - the Grid. Energy transportation also introduces heavy losses. When small amounts of energy are generated there is no reason to transport and maintain that energy connecting the generator with the Grid. Thus local storage and consumption of the locally generated energy is the best possible way to minimize the losses and reduce the maintenance overhead.

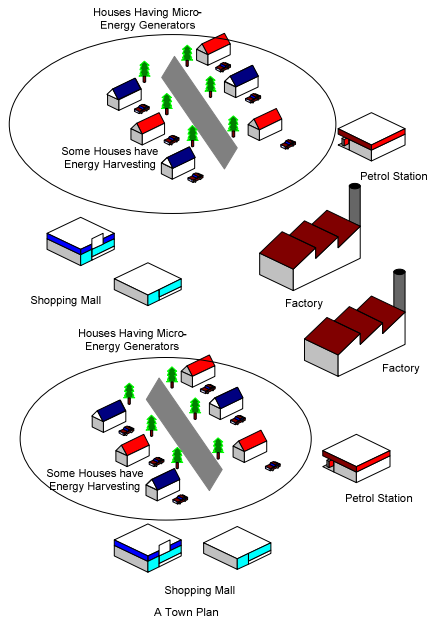


Fig. 1. A view of various energy generation and consumption zones

1.2 Sensors

We envisage that sensors are going to be an important aspect of any ICT enabled architecture or service or applications in the future. As we have seen the applications of sensors in many ICT enabled application, we need to integrate the sensors seamlessly into the design of systems which takes care of balancing generation and consumption. We identify the sensors under three different classes. Please note that sensors here mean an integrated system of sensors that could also accomplish some

computation. Three classes are: (i) source sensing; (ii) load/sink sensing and (iii) context sensing. The distinguishing aspect between many micro grids and the architecture we propose is that the complete system is seen holistically. We explain here each of the sensors we envisage here in this architecture.

(1) *The Source* sensor gives the information on amount of energy generated. The sensors which monitor micro energy generation also give an indication as to the amount of energy that could be generated. We envisage that these sensors are also equipped with prediction algorithms and also they have the capability to learn. For example, a sensor that is attached to photovoltaic panels would also learn and then predict when there would be some energy available (based on day night periodicity).

(2) *The Load* sensor has the information of energy requirement if the load is turned on. In fact the sensing is done in realtime based the amount of load that each equipment has. As in the source sensing this can also predict to an extent how much load would be required. For example, based on the temperature difference between the outside temperature and usually required temperature inside, required amount of load can easily be predicted in case of room heaters.

(3) *The Context* sensor gives or predicts when to turn on or off the load. Basically we group all the sensors that generate the context of the environment including the users' locations, day/night temperature, requirements and usual settings of users, etc. Indeed for the sake of convenience, we also group together some of the max-min settings of users.

The energy manager can consider these parameters, to budget the energy. If any of these three parameters are missing, then accurate budgeting is not possible.

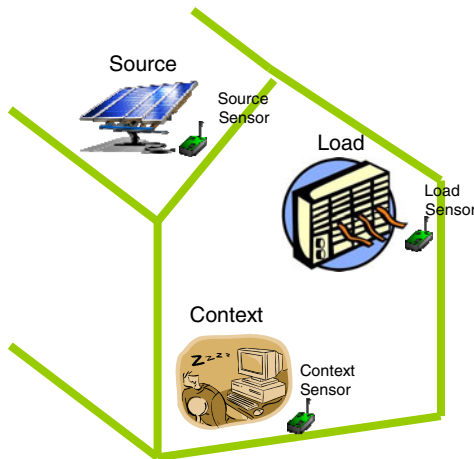


Fig. 2. Schematic of types of sensing

2 Proposed Architecture

An aspect that enhances the efficiency of the whole system is ICT - especially wireless communication has become pervasive and is being used in various domains for different purposes. The purpose of microgrids and ICT is twofold: (1) enabling the generation and storage of (small amount of) energy harvested in homes and buildings; and (2) using the communication and networking technologies to achieve the control and balancing of the micro generation of energy which would ultimately support the large Grids along with efficient usage of the energy.

Wireless sensor and actuator networking (WSAN) has been steadily growing and permeating into many spheres of life. Many techniques such as localization of events, clustering, self organization of the nodes and various other facets of WSANs have been studied in depth. Now the very same methods and the devices could be coupled to the energy generation and consumption modules to derive maximum benefits. Here we list some commonalities and the motivation to bring seemingly different domains together:

1. WSN and WSAN have been studied from the point of view of information generation and consumption (source and sink). In case of energy harvesting too, we can draw analogies for source and the sink i.e., the generation unit to the nearest place of consumption.
2. The generation and consumption areas and points are to be grouped so as to easily manage the energy requirements. This is similar to the clustering in WSNs.
3. There is always a provision of distributed computation and storage in WSNs. Here too the batteries are storage devices which are distributed and one can use them for temporary storage of harvested energy before converting it to usable form.
4. Dynamic self-organization on the fly, based on the requirements and available resources, is a hallmark of ad hoc networks and WSNs. Here too, since energy consumption and generation is varying with time (at micro layers), self-organization plays an important role.
5. Further, WSNs have been used to gather context i.e., movements or activities of people. The context information can be used to increase the efficiency of the system [12].

Therefore, it is but natural to use the techniques that have been addressed in depth in this different domain in the case of balancing and utilizing the harvested energy. Thus we propose the following conceptual 3-layer architecture (see Fig. 3). At the lowest layer, there are instruments, modules and storage equipments in which some are energy generators and others are energy consumers. These equipments are connected to switches, actuators, transducers (current transformers, etc) and sensors. They are grouped in the second layer. These sensors and actuators act as the glue connecting the lowest layer and the highest layer that contains the brain of the system. The top layer has communication and computing devices. The sensed data is actually

sent to this layer. The context of the situation such as, sleep time, office time, someone is present in the building or moving, etc., is given to these computing nodes. They interpret the sensed data collectively and individually to make decisions. A decision is sent across the devices in the neighborhood. The data also contains the energy consumption and generation rates at various places. Since these computing devices, which are equipped with communication capability, can quickly reorganize themselves and collectively decide to take actions. The actions are in the form of triggers to be passed to the actuators/switches. Thus the energy generation, consumption, storage and requirements (using the context) are all addressed holistically in this concept. The localization of the generation and consumption as well as the balancing is to be done in real-time.

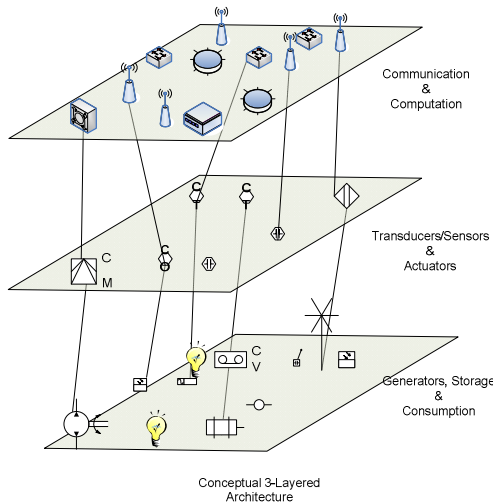


Fig. 3. Three layered architecture

In Layer 2 of the architecture, we can distinguish between three types of sensing operations (see Fig. 2) which have described earlier.

To realize a zero-energy system, the following aspects need to be addressed:

1. Investigating the possible avenues of harvesting energy in homes and other buildings.
2. Localization of energy harvesting and consumption i.e., getting an accurate view of where energy can be generated and where it can be used.
3. Development of a model of energy storage in small quantities for a large group of harvesters (say in each building).
4. Development of simple, reliable, efficient and cost-effective energy balancing methods so that efficient systems could be designed that take into account local energy needs (microgrids).

5. The ICT infrastructure to manage and control the energy system i.e., the communication and computing backbone to support the above activities.
6. Efficiently using the small scale energy storage devices such as batteries stationed in various locations in houses that act as distributed storage devices.

The above issues can further be delved in to gather further set of technical issues such as ensuring stable operation during faults, handling large mismatches between generation and loads (a frequency and voltage control problem), system protection to line faults, [9, 11] etc.

We emphasize that the effective management of the system is the key to efficient system. This effective management can be achieved through ICT. Issues such as coordination of the distributed sources and loads (with possibly conflicting requirements), dispatch control, load-shedding control, dynamic management etc are some issues to be handled by the energy management subsystem. In addition to the above tasks, the system should enable:

1. Analyzing the energy generation, storage and consumption in homes and buildings and in turn in localities and cities.
2. Modeling generation and consumption in small localities and studying its effect on the grids including the prediction of energy generation and usage.
3. Modeling the energy storage in small amounts in a distributed way.
4. Distributed control and management of the complete system. We envisage that the sensors, actuators, source and the load may decide about the actions to be taken to micromanage the complete system. Since this is an ambitious goal, in the initial stages, we can bring in a centralized simple *manager* who does take appropriate actions in real-time.

3 Related Work

The EU funded two major projects “Microgrids: Large Scale Integration of Micro-Generation to Low Voltage Grids” and “More Microgrids: Advanced Architectures and Control Concepts for More Microgrids” [13] for researching, designing and developing microgrids. Several deployment sites were also identified and tested.

In the U.S., the Consortium for Electric Reliability Technology Solutions (CERTS) funded a project CERTS Microgrid. A Microgrid testbed was also developed [14]. An implementation of energy manager design done under CERTS project is given in [5].

In the industry, GE Energy funded a project to develop and demonstrate a microgrid energy management (MEM) [4] framework for a broad set of microgrid applications that provides a unified controls, protection, and energy management platform.

The IEEE Standards Coordinating Committee 21 is supporting the development of IEEE P1547.4, Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems [15]. This covers microgrids connected to both local and area island electric power systems (EPS). This document

provides alternative approaches and good practices for the design, operation, and integration of the microgrid, including the ability to separate and reconnect, while providing power to the island local EPSs.

4 Ongoing Work

There is an ongoing work on which this article is based. It is called as L-BEES -- *Load Balancing and Efficient Energy Sourcing*. This is under the exploration and initial stage at the moment. However, under another Dutch national project IOPGencom-GoGreen, we are investigating the use of energy harvesting sensors that could provide the context as well as sensing to help in reducing the total energy consumption in indoor environment. This work enhances the aspects in GoGreen by looking at the generation, consumption along with intelligent sensing together. We also mention here that the batteries (used for storing energy from micro-generators before conversion) in different houses and buildings act as small energy storage devices. This is another novelty of this proposed architecture. Context of the users and also the environment parameters are another aspects that is being considered in the above projects.

5 Conclusions

Microgrids have been actively pursued and researched for local energy generation and consumption. These systems enable enhancement of the voltage profile, reduction of distribution and transmission bottlenecks, lower losses, exploiting waste heat, and they allow postponing investments in new transmission and large scale generation systems. Three main aspects of microgrids are energy generators, storage of the generated energy and distribution. We propose the use of ICT, in particular, wireless sensor networks for increased efficiency of the system. One recognizes similarities in the WSN applications and microgrids. Further context information can be another useful parameter for the energy management which is made possible by the usage of sensor networks. Issues such as coordination of the distributed sources and loads (with possibly conflicting requirements), dispatch control, load-shedding control, dynamic management etc, can be handled better with wireless sensor network, which increases the overall efficiency of the system. A three-layer architecture comprising of these is also proposed. Finally, recent projects on microgrids have been discussed.

Acknowledgements. The authors would like to deeply thank Hermes Partnership (<http://www.hermes-europe.net/home/>) and Trans research academy (<http://www.trans-research.nl/>) for supporting this work.

References

1. Electric Power Research Institute, Grid 2030: a national vision for electricity's second 100 years,
http://www.oe.energy.gov/DocumentsandMedia/Electric_Vision_Document.pdf
2. Hatzigiargyriou, N., et al.: Microgrids. An overview of ongoing research, development and demonstration projects. *IEEE Power & Energy Magazine*, 78 (2007)
3. Marnay, C., Siddiqui, A.S., Rubio, F.J.: Shape of the microgrid. In: *Proc. IEEE Power Eng. Soc. Winter Meet*, p. 150 (2001)
4. Pogaku, N., Prodanovic, M., Green, T.C.: Modeling, analysis and testing of autonomous operation of an inverter-based microgrid. *IEEE Trans. Power Electron.* 22, 613 (2007)
5. Firestone, R., Marnay, C.: *Energy manager design for microgrids* (2005)
6. Lasseter, R.H.: Microgrids. In: *Proc. Power Eng. Soc. Winter Meeting*, vol. 1, pp. 305–308 (January 2002)
7. Hatzigiargyriou, N., Jenkins, N., Strbac, G., et al.: Microgrids – Large Scale Integration of Microgeneration to Low Voltage Grids. In: *Proc. CIGRE 2006, Paris*, paper C6-309 (August 2006)
8. EURELECTRIC's Position Paper, Building a European Smart Metering Framework suitable for all Retail Electricity Customers (2008)
9. http://www.ibm.com/smarterplanet/us/en/smart_grid/nextsteps/solution/K626033G66635H91.html
10. http://www.cisco.com/web/strategy/docs/energy/aag_c45_539956.pdf
11. Lasseter, R., Akhil, A., Marnay, C., Stevens, J., Dagle, J., Guttromson, R., Meliopoulos, A.S., Yinger, R., Eto, J.: White Paper on Integration of Distributed Energy Resources: The CERTS MicroGrid Concept. Lawrence Berkeley National Laboratory Report LBNL-50829, Berkeley (2002)
12. Taylor, K., Ward, J., Gerasimov, V., James, G.: Sensor/actuator networks supporting agents for distributed energy management. In: *29th Annual IEEE International Conference on Local Computer Networks*, November 16-18, pp. 463–470 (2004)
13. <http://www.microgrids.eu/>
14. <http://certs.lbl.gov/certs-der-micro.html>
15. <http://grouper.ieee.org/groups/scc21/>