Intelligent Home - Smart Grids and their effects

Dren Gashi

University of Luxembourg
2, avenue de l'Université
L-4365 Esch-sur-Alzette (Luxembourg)
dren.gashi@uni.lu

Abstract. Visions of intelligent homes have caught the attention of researchers for a long time and extensive effort has been put towards enabling home automation. With the goals of an eco-friendly environment, electricity costs and rates reduction and a reliable and intelligent energy power system, the idea of a revolutionary electricity grid, the smart grid, has come to life. This paper is a survey for smart grids and their uses and effects. We first give an inside of the history and motivation for smart grids, then highlight the current state-of-the-art technologies, show key features and benefits but we also critically review some side-effects of smart grids. We synthesize the evaluation of smart grid, including requirements and challenges such as complexity, privacy and security for both, consumers and suppliers. We finally conclude with a short summary and a reflection on the realm of smart grids.

Keywords: Intelligent Home, Smart Grids, Evaluation of Smart Grids, Smart Grid Technologies, Requirements and Challenges

1 Introduction

Intelligent Home, also often referred as Smart Home or Smart House, is the term that is being used when it comes to *home automation*, the process of controlling, monitoring and automating home appliances such as washers, dryers, ovens, freezers, lights, etc. in domestic environments. It provides ubiquitous computing technologies that interconnect electronic appliances in homes, thus building a so called *Home Area Network* (HAN). This private network is used as a communication layer between devices in order to achieve a better quality of life. Users can simply control and monitor any device or home appliance that is connected in the network. For instance, an automation of repetitious tasks such as opening and closing window blinds in the morning and evening, respectively, is certainly possible and being done, as one of the first use cases [8]. The market for intelligent homes in general is growing very slowly despite the fact that the idea of smart homes exists since three decades. Many devices such as motion sensors, video cameras or programmable lightning have been available since the 1970s [2]. However, recent studies show that the market growth is predicted to rise to $26 billion in 2019, initially at $40 million in 2012 [11] as shown in figure 1. This clearly indicates hope for the future of intelligent home. Many scientists were

also attracted by the idea of a smart homes, thus more research in the area were spurred. One of the main reason of the growing market value is, however, the awareness about energy consumption, that finally lead to the invention of *Smart Grids*.

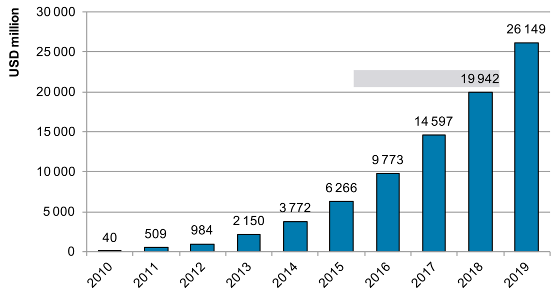

Fig. 1. Smart appliance global market value 2010-19

Source: Intertek, 2011

Since all devices and home appliances are interconnected, activity monitoring is possible and consequently the question that arises is how to use the intelligent home principle to not only improve quality of life but also to reduce electricity costs? This is where Smart Grids come in place. They make it possible to save money by cooperation between electrical energy suppliers and consumers. The main idea is to introduce a *two-way* dialogue as opposed to the traditional *one-way* wired connection, i.e., an additional wire that goes back to the energy supplier. This second wire is used to notify about the current amount of electricity that is being used by the customers at a given time. This enables suppliers to better react to the ever changing energy demands and predict peak hours in electricity usage, thus providing lower prices since the rates of electricity vary throughout the day due of costly secondary power plans in peak times. As a concrete scenario, we can adjust the run schedules of our washers and dryers to start when the electricity rates are lowest, that is, during off-hours as illustrated in figure 4. This will positively impact the control of energy bills and help preventing blackouts at peak hours. Utilities can therefore better communicate with their consumers to help to manage their electricity needs. The intelligent home communicates with the smart grid by frequently measuring homes electricity consumption through *smart meters*, advanced electric meters that identify power consumption in much more detail than a conventional meter and communicate the collected information back to the utility for load monitoring and billing purposes [25].

However, what side effects do smart grids bring with? What about privacy and security of the data of the consumers? How do even smart grids work and are they really an improvement? How easy (or difficult) is the transition to the

smart grid and what are requirements and challenges that come with? These are some research questions this survey tries to answer.

The remainder of this paper is organized as follows. In the next section we present the evolution of the smart grid together with its motivations. In section 3 we elaborate on the current state-of-the-art technologies used in this realm followed by some examples of requirements and issues for both consumer and supplier that are described in section 4. In section 5 we discuss some challenges that arise when dealing with smart grids. Finally we conclude in section 6.

2 History and Background of Smart Grids

The current grid exists unchanged since more than 100 years. It was created at a time where most homes had small energy demands. Local power generators were build around communities to deliver electricity. Mechanical meter readers were installed in houses in order to collect energy consumption data and send it to the utility. Such *automated meter reading* (AMR) systems that make use of *one-way* communication made it hard for suppliers to respond to the erratic and rising energy demand. The problem is that there exists peak times where energy plants cannot produce enough electricity but also there are times where too much energy was produced without being consumed or needed. Other deficiencies are a lack of automated analysis, poor visibility, mechanical switches causing slow response times and lack of situational awareness [23]. These have, among others, caused many blackouts over the past decades. Some additional factors are the growing population, the global climate change, equipment failures, increasing energy demand, energy storage complications, the capacity limitations of electricity generation, decrease in fossil fuels, and resilience problems [15][23]. Due to a centralized network infrastructure, nearly 90% of all power outages and interruptions have their roots in the distribution network [20]. A restoration always involved utility technicians to come and inspect the failure, which is costly and time consuming.

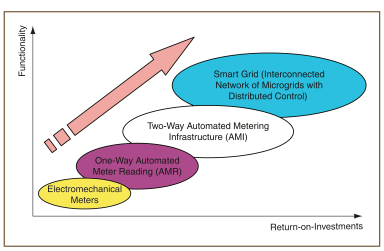

Fig. 2. Evolution of the Smart Grid [20]

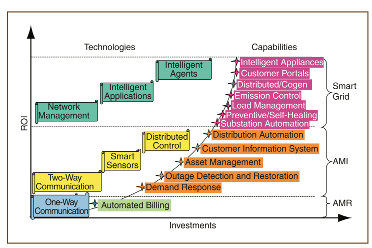

Fig. 3. Evolution of Capabilities [20]

As depicted in figure 2, *advanced metering infrastructures* (AMI) were invented to solve the problem of a one-way communication by simply using a second wire for sending information back to the consumers. AMI meters do not

only measure the electricity consumption alone but also at what times during a day. Thus, suppliers can respond in real-time with pricing and energy information to find best configurations and time slots to be used to efficiently reduce costs. For instance, as we can observe in the figure 4, the off-hours in summertime are between 2-8am and the peak hours are between 3-6pm due to high usage of air conditioners. Hence the energy suppliers can provide cheaper rates during the off-hours.

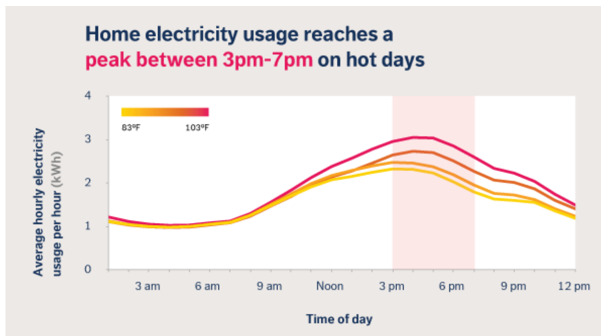

Fig. 4. Electricity usage in summer [6]

In order to avoid the remaining problem of stability, smart grids came into existence. Instead of using the ever aging centralized and producer-controlled energy generation networks, a decentralized, consumer-interactive network is deployed [12]. Whenever an interruption in the energy distribution occurs, for example due to storms, bad weather or failures of energy generators, the utility can simply *re-route* the energy flow. In this way, restorations are being done automatically, making the smart grid *self-maintaining*, *self-healing* and robust against most of the failures.

The re-routing is also being used to feed the consumers' houses with energy from different energy generators such as renewable and alternative energy sources like wind and solar whenever a generator is overloaded. For instance, during summertime, solars will produce electricity at full capacity and power plants will do so as well. The smart grid, however, enables a more balanced and optimal energy flow by simply letting power plants produce less and reroute energy distribution through other alternative energy sources. Less fossil fuel and coal will be burned, resulting in a more eco-friendly environment.

It is clear that the energy demand of the 21st century can no longer be managed by the traditional grid, especially not with the steadily rising trend of increasing energy consumption. A novel system has to be created that faces the problems from the very bottom. In order to address these challenges, a new concept of next generation electric power system, the smart grid, has emerged. The

smart grid is a modern electric power-grid infrastructure for improved efficiency, reliability with smooth integration of renewable and alternative energy sources, through automated control and modern communication technologies [22]. We will discuss reliability in more detail in section 5.

3 Technologies

A communication system is the key component of a smart grid infrastructure [23]. Therefore, many well-known communication technologies are being deployed. Some examples include WiMAX, home area network (HAN), building area network (BAN), neighbor area network (NAN), wide area network (WAN) and ZigBee [14][23]. All come with advantages as well as disadvantages. One of the most interesting and actually used technology is ZigBee since it provides relatively low power usage, data rate, complexity and cost of deployment. It is an ideal technology for smart lightning, home automation, AMI, etc. Some technologies are also combined. For instance ZigBee is used by the smart meters in HAN's and for inter-tower communication, LAN is used for the communication between homes and distribution centers and WAN is used between generators and transmission towers [20] as illustrated in figure 5.

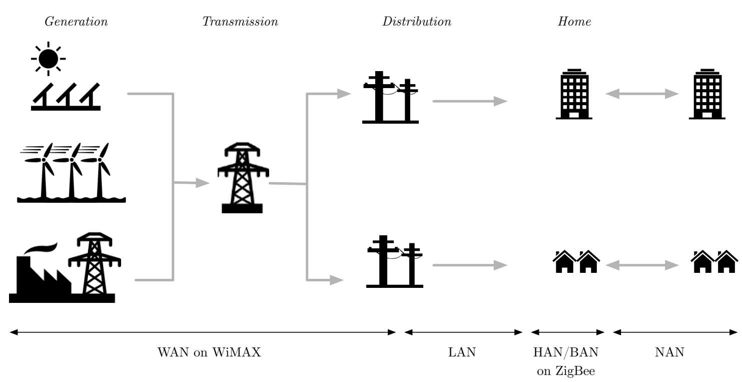

Fig. 5. Smart grid - Technologies usage

The WiMAX standard is used because it can serve as a backhaul or a point-to-multipoint access network. In addition, WiMAX can provide full end-to-end *Quality of Server* that makes it a very suitable for smart grid communication networks [3]. However, WiMAX was proposed a decade ago where 4G/LTE were still in its early development phases. Also, at that time, WiMAX were already part of IEEE standard [3] which resulted in a good candidate for smart grid designs. At this point in time, current state-of-the-art designs should adopt to LTE since it has been shown that LTE aims at gaining advantage over WiMAX in all areas, capacity, coverage and complexity [1][10].

3.1 Smart Meters

Smart meters are digital meters that measure and monitor electricity usage in near real-time. They periodically collect data locally and send it to the utility, consequently the energy suppliers exactly know how much energy is being consumed at what times. This has benefits for both parties. For instance the utilities can better predict peak hours, hence conduct more efficient energy plans which imply lower costs for suppliers and lower rates for consumers. Blackouts can also be avoided by providing more energy generators in advance. Consumers can further lower their bills by running smart appliances such as washers or dryers at off-times.

Smart meters need to be part of the local HAN network in the home where it is installed to be able to gather data from smart appliances. In figure 6, a small overview of the communication between the different networks is illustrated.

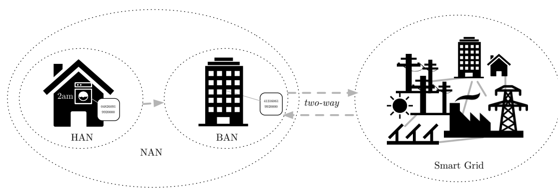

Fig. 6. Smart Grid - Metering

The two-way communication (AMI) is established between the smart meters and the smart grid. They are an integral part of the smart grids, thus being a requirement for consumers at the very first place. The problem with these meters are that there might not be suited for every household. A HAN network is needed and sufficient smart appliances in order to make an investment of up to 500$ [17] for a smart meter worth it.

3.2 Network Infrastructure

The network infrastructure of the smart grid consists of many components. The idea is to maintain a *modular* framework that handles *plug-in* mechanisms to simply add or remove new entities in the grid without human intervention and additional setup. Such components include smart meters of houses/buildings, energy generators such as solar, wind or power plants, energy transmission towers, energy distributors, smart grid units and wireless *sensors*. Smart grid units interconnect several sub-grids and are used to collect data from sensors for control management purposes and further analysis. Sensors are smart agents that are placed on power transmission lines and permanently send information to smart grid units. Such information include the amount of energy needed and/or used within a local area, failure and blackout alerts, routing data, emergency events, etc. As a concrete scenario of how a smart grid works, let us take the

simplified infrastructure of a smart grid in figure 7 as an example. The reddish dots represent sensors. Now we can see that if there happens to be a failure such as a destroyed route (illustrated with a red cross) or an interruption of a power generator, the sensors will hit alarm and by an overall coordination between the sensors, the grid will propose a new route (i.e. depicted in green) in order to further supply the houses and buildings with electricity.

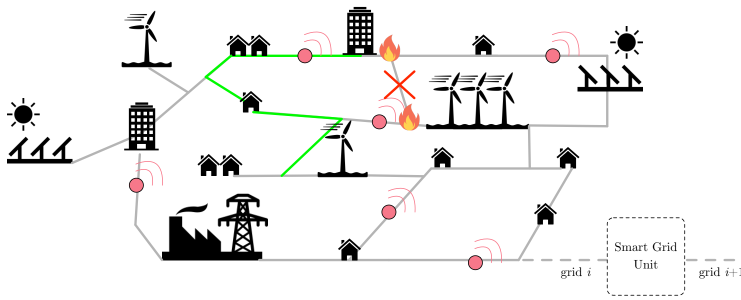

Fig. 7. Simplified Infrastructure of Smart Grids

Another scenario is the following. Suppose the solars are working at full capacity. The smart grid unit can thus decide to partially stop the electricity production in pollution-causing energy plants and to re-route the electricity supply. This has the advantage that costs can be reduced for both consumer and supplier. Another side-effect is that less pollution will be produced. The grid is also self-maintaining, there is no need for human monitoring and intervention that would anyway be very hard to achieve with such a complex and always growing infrastructure of thousands of components (we discuss complexity in more detail in section 5). Therefore, automation is a key feature of smart grids.

Those were some examples why the grid is called smart. This intelligence, the flexibility and scalability of the design of the smart grid has been established through a quantitative analysis of a large example power grid [13].

4 Requirements and Issues

In this section we present some requirements for a transition to a smart grid for both, consumers and suppliers. The main three fundamental building blocks that will convert a power distribution system into a smart grid are monitoring/sensing, communication and control [25]. Additional intelligent sensors need to be bought and installed. Smart grid control units need to be deployed and interconnected between the grids. A modular framework needs to be developed to allow a smooth integration of components. An issue is that every household that needs to be part of the smart grid, also needs to be equipped with a

smart meter, which alone does not suffice since one needs a HAN network deployed. At the same time, two-way communication wires need to be established. The communications infrastructures between energy generation, transmission, distribution and consumption require two-way communications, interoperability between advanced applications and end-to-end reliable and secure communications with low-latencies and sufficient bandwidth [21]. Those are already several requirements that need to be met for utilities that are not directly given with the traditional power distribution grid. Some control protocols and standards have been developed to ensure a common communication vocabulary among system components [20][23][25]. Utilities need to satisfy those protocols and standards to acquire a certain level of quality and safety.

In the other hand, the requirements for consumers are quit small compared to suppliers. One needs a HAN network deployed with a smart meter and a two-way communication wire. Besides an initial installation and setup, this is a summarize for about what consumers need in order to be qualified to be part of smart grids.

We can see that the requirements for consumers should not for prevent an integrating into a smart grid. However, there might be other issues such as installation costs depending on the location. Those usually range up to 500$, which might not be worth for households without sufficient smart appliances. The savings will also not cover the investments directly but rather in the long run. Comparing to the deployment costs of utilities, those numbers are meaningless. For instance, the Australian AMI program reached around 1.6 billion Australian dollar and the deployment of smart electricity meters in the U.K. also cost up to near 11 billion pounds [24]. In the other hand, the deployment of smart electricity meters in the U.K. by 2020 will save energy suppliers more than 300 million pounds a year by alleviating the need of meter readings and decreasing disputes on bills [24], making it a profitable investment in the long run.

5 Challenges

The challenges include the deployment of large-scale embedded systems, legacy power grids, smart appliances, and next-generation communications and collaborations that will provide the foundation for a post-carbon society [25]. In this section we discuss four major challenges that need to be addressed by smart grid utilities.

5.1 Scalability

A smart grid should be scalable enough to facilitate the operation of the power grid [23]. Howevery, scalability is a central issue in the development and deployment of an agent based system [4] and not trivial to achieve. Being a fundamental building block, scalable systems must be capable of handling the contentiously

growing number of interconnected entities such as smart meters, (renewable) energy resources, sensors, etc., thus being capable to be enlarged to accommodate that growth without compensations in functionality.

Scalability was one of the main challenges during the early designing phases of smart grids. This is one of the reasons why a centralized approach cannot work due to several issue where one is *single point of failure*. Modularity has been introduced to cope with simple plug-in mechanisms for new components [13] and several smart grid units have been deployed to process each its own sub-grid, hence making the grid self-controlling.

For consumers, the scalability challenge does not play a role. It is addressed to energy suppliers and it must be fulfilled in an early stage of development. Otherwise, costly bottom-up redesigns are needed, which are also time consuming. That is why non-scalable designs should be avoided in the very first place.

5.2 Complexity

Complexity increases with each interconnected component. However, the communication network has not been designed to carry such amount of information. Consequently, the introduction of the data traffic might undermine the performance of other control operations [7]. Bouhafs *et al.* proposes *data aggregation techniques* to reduce the communication overhead from the introduction of new smart devices and sensors without a costly upgrade of an equipment [7], which is certainly an option to consider.

The complexity yet makes a manual management for utilities practically infeasible. That is also why the grid is being designed to be autonomous, self-maintaining and self-healing using artificial intelligence. However, this implicitly has effects on the labour market. Less jobs for technicians and engineers in power plants and monitoring branches will be available, introducing long-term effects that are not trivially perceivable at the beginning.

5.3 Reliability

Reliability has always been in the leading edge of power grid designs and operations due to the cost of disruptions to customers. For instance, in the US, the annual cost of outages in 2002 was estimated to be about $79B which almost equals a third of the total electricity retail revenue of $249B [13]. Therefore, reliability is another building block to be addressed by electricity utilities. Smart grids improve reliability by intelligent re-routing whenever failures arise. However, there are other side-effects because of the involvement of many diverse components, leading to a production of aggravated grid congestion [13].

Reliability is hard to achieve but in comparison with the traditional grid, smart grids already perform better due to automation procedures [18]. Most

standard outages become transparent to the consumers, which is a clear benefit.

5.4 Security & Privacy

Security and privacy are very important factors for the acceptance of a smart grid by the public. The use of different communication protocols, information transmissions and monitoring systems makes the grid vulnerable to data identification and theft by several hackers or cyber criminals [19]. Access to smart meters by third parties is very unpleasant because they can manipulate the energy costs or change generated meter readings. Also, since the smart meters periodically send information to the utilities, privacy is restricted. This arises the concern related to the collection and use of energy consumption data. Research in this area is already ongoing. There actually exists intruder detection mechanisms in NAN networks [9] to prevent local data theft or anonymization techniques for securing metering data [5]. Note that it is quite unclear as to who will gain access to such data besides the customer's energy provider. The utilities could sell some information of their consumers to electric appliances companies so that they could send advertisement to their homes for attraction purposes and gaining potential new clients. Besides utilities, the Google PowerMeter service for instance, has also potential for privacy abuse since it receives real-time usage statistics from smart meters [16]. Early versions of the privacy policy enable companies to use this information for commercial purposes such as marketing individual or aggregate usage statistics to third parties [16]. These are real world challenges that energy suppliers must face.

6 Conclusions

Ubiquitous home delight with new exciting yet challenging possibilities. Intelligent home is the new trend of the 21st century where smart home appliances and devices are interconnected and remotely accessible to generate a better quality of life, all transparent to the user's experiences. In order to take advantage of the smart home principle with the goal to reduce electricity costs, energy consumers and suppliers corporate together by introducing so called smart meters that monitor the energy consumption. This information is being shared with electricity utilities in order to better predict overloads and prevent blackouts. Thereby, better energy plans can be established that result in lower electricity rates for consumers. Peak hours can be known in advance, resulting in using the electricity more efficiently during off-times. This is the idea of the smart grid, a novel electricity grid, consisting of many interconnected components and intelligent agents that makes the grid self-maintaining, self-healing and smart, making human intervention almost superfluous.

In this paper we conduct a survey for smart grids, from definition, history, functioning to requirements and challenges. We discuss the functionalities and

advantages of smart grids, as well as side-effects in this realm. The evaluation is two-sided. Besides the numerous advantages, the smart grid comes with compromises and side-effects. For instance, the transition for consumers might not be worth it when one considers the initial installations costs that need to be covered after very slowly accumulating savings. Artificial intelligence will replace many humans and reduce jobs on the market. Home area networks (HAN) need to be setup in domestic environments as a requirement for coupling smart meters with electric appliances without a guarantee that the setup will be worth it, especially not with few smart appliances. The requirements and challenges that come with the smart grid are not easy to handle, especially not for energy suppliers. Utilities need to invest millions in beforehand to build such highly reliable systems and consumers are hard to attract due to privacy and security issues that are not trivially clear to the public.

Many researchers across the world are working to ease the transition to the smart grid by developing required next generation technologies. However, for the idea of a novel electric grid to become an essential part of our lives, the described issues need to be resolved, otherwise the smart grid can never reach its full potential. Utilities need to better enlighten their customers, dissolve the obscurities of privacy policies and promote for lower (or no) smart grid installation costs. Working more tightly with the government and local municipalities is certainly a valuable option since both support the goal of a more eco-friendly environment. The transition is slow but it is happening. We are in favour of a more environment friendly world after all, believing in a future with less fossil fuel and coal burning, hence supporting the idea of smart grids.

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