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The Smart Grid – A saucerful of secrets?

Matthias Wissner

WIK Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste GmbH, Rhöndorfer Str. 68, 53604 Bad Honnef, Germany

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ABSTRACT

To many, a lot of secrets are at the bottom of the often-cited catchphrase "Smart Grid". This article gives an overview of the options that information and communication technology (ICT) offers for the restructuring and modernisation of the German power system, in particular with a view towards its development into a Smart Grid and thus tries to reveal these secrets. After a short outline on the development of ICT in terms of technology types and their availability, the further analysis highlights upcoming challenges in all parts of the power value chain and possible solutions for these challenges through the intensified usage of ICT applications. They are examined with regard to their effectiveness and efficiency in the fields of generation, transmission, distribution and supply. Finally, potential obstacles that may defer the introduction of ICT into the power system are shown. The analysis suggests that if certain hurdles are taken, the huge potential of ICT can create additional value in various fields of the whole power value chain. This ranges from increased energy efficiency and the more sophisticated integration of decentralised (renewable) energy plants to a higher security of supply and more efficient organisation of market processes. The results are true for the German power market but can in many areas also be transferred to other industrialised nations with liberalised power markets.

1. Introduction

Smart Grid is currently an often-cited catchphrase within the energy industry. However, it is often unclear what is understood by this phrase and what will be the implications of realising this vague adumbration. While for some, Smart Grids is installing smart meters in peoples' homes, for others it is integrating decentralised energy sources into the grid. For example, the European regulators' group for electricity and gas (ERGEG) defines Smart Grids as follows: "Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety" [1]. The US Department of Energy (DOE), on the other hand, has no comprehensive definition of Smart Grids but defines single aspects of it in a rather sketchy way [2]. Both attempts remain somewhat shallow, however.

This paper wants to reveal the secrets behind the catchword "Smart Grids" and explain what really accounts for it. I do this by showing which possibilities are given to reform the power system in Germany. This is done against the specific German background. The analysis is however in many areas transferable to other industrialised nations.

The German power market has undergone major changes in the past ten years. Liberalisation of energy markets and unbundling of former vertically integrated utilities has led to a huge number of (new) actors at all stages of the energy value chain. Grid operators, for example, have to deal with a multitude of supply companies in their network area. At the same time, the European Energy Exchange (EEX) in Leipzig allows the trading of electricity nationally and internationally. The consequence of these developments is a multiplication of processes and operations compared to an integrated management in pre-liberalisation times. Information must flow across companies' borders and communication between parties involved in the electricity system becomes more and more important.

The second important change is the increase in decentralised energy generation that is mainly driven by the flourishing renewable energy sector. The German Renewable Energy Law (EEG) implemented in the year 2000[1] obligates grid operators to connect renewable energy plants to the grid, take delivery of fed-in power and pay a statutory price to plant operators. The EEG has supported a development that resulted in 16% of all power generation in Germany in 2009 coming from renewable energies [3]. The feed-in of many small distributed sites can lead to a power flow reversion and thus change the original power flow direction, which runs from higher to lower voltage levels. At the same time, there is a high

E-mail address: m.wissner@wik.org

[1] The Renewable Energy Law (EEG) followed the similar feed-in law for power ("Stromeinspeisegesetz") that was enacted in 1990.

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volatility in the feed-in of wind and solar power. This can lead to situations where the grid is no longer efficiently controllable within the limits of its current infrastructure. For example, in times of overload, load rejection may result in a complete cut-off of single wind turbines that deliver carbon-free power. In such moments the grid has to deal with conditions it was not built for. A reasonable steering without the help of information and communication technologies (ICT) is difficult in this situation, especially in distribution grids.

A third issue that presents a new challenge for the power system is the political aim of climate protection and the evolving requirements regarding energy efficiency. The German government has set increased energy efficiency on its agenda in the national "integrated energy and climate programme" [4]. The energy sector as one more or less natural addressee of this goal must find an adequate answer to this issue.

All three above-mentioned developments call for a new approach to operating the power system. A means to do this is to use ICT. This has undergone rapid development in recent years in terms of lower costs and higher availability and offers solutions for optimising all elements of the power value chain. This article therefore focuses on the usage of ICT for increasing energy and economic efficiency. The analysis is mainly of a qualitative character.

The examination starts in Section 2 with an overview of the development of ICT in recent years. Section 3 analyses how these technologies can be applied in different parts of the energy value chain, namely generation, transmission and reserve power, distribution, smart metering and intelligent buildings. Section 4 deals with possible barriers that could hinder the implementation of ICT and hold back the transformation of the energy system in Germany. Section 5 concludes.

2. Development in information and communication technologies (ICT)

The basis for a transformation of the power system is the availability of ICT. The framework for the implementation of new technologies has changed significantly in recent years for several reasons. The complete liberalisation of telecommunication markets in Germany and other industrialised countries has led to the entry not only of new network operators but also of competitors searching for innovative business models and introducing new services in different areas of application [5]. Furthermore, R&D in microelectronics, especially the development of microchips, makes possible ever-increasingly efficient applications at decreasing costs. For example, integrating chips in household appliances (washing machines, refrigerators, etc.) enables these devices to receive commands, influence actors or generate demand data that is sent to a main server via data line [6]. At the same time, the digitalisation of networks and switching centres has not only multiplied available services but also led to a decreasing cost per unit of data transferred. The 'always on' functionality allows data transfers at zero marginal costs, i.e. without dial-up connection, so that energy-related data may be transferred very cost-efficiently [7]. The rapid development of the Internet has made it the crucial backbone of the described data transfers and serves as a global platform for new services that have not been offered in the past. Due to its powerful and cost-efficient infrastructure, the Internet will be the accelerator for future applications of multifunctionality. The introduction of the new Internet protocol IPv6 will expand the current address space so that a higher quantity of applications, for example single devices, can be equipped with their own IP address [8]. This will help realise the idea of an 'ambient intelligence', i.e. the automation of processes and everyday activities through "intelligent" objects [9]. A further push towards a higher penetration of ICT is a result of the development of wireless communication networks (GPRS, WiMAX, UMTS, satellite) [10]. These networks enable mobile activation of processes such as telemetering or steering activities. The mobile phone for example can be used as a mobile remote control to activate room heating or electrical devices in intelligent buildings [11]. All transmission technologies differ in their penetration, availability and data transmission capacity, however. Table 1 gives an overview of these features.

It appears from Table 1 that ICT is principally available to serve for the challenge of restructuring the power network. This means that the great majority of households and enterprises could theoretically be provided with a broadband access of whatever technology (DSM, CATV, etc.).[2] The challenge is to introduce ICT into the energy system, so that each device or appliance can work independently [13].

3. Options of ICT for energy and economic efficiency in single sectors of the energy value chain

How can the described technologies been used for the energy sector? This chapter analyses the options for implementing ICT into the power system in single areas. Fig. 1 shows the structure of a future power system, where the different involved players interact with each other continuously and in all directions.

The idea of an ICT-equipped energy system is that technologies are implemented in such a way that all actors are able to communicate efficiently with their counterparts when necessary. In the long run, the main part of this communication should be carried out automatically, i.e. with as little manual interference as possible. Nevertheless, some progress must be made in single parts of the value chain beforehand, so that the preconditions for establishing a new system are fulfilled. For this reason, the analysis below follows the power value chain to examine the challenges for the application of ICT to solve power related issues. It starts with generation, followed by transmission and reserve power, distribution grids, smart metering and finally smart houses and intelligent buildings.

3.1. Generation

One crucial option that ICT offers in generation is the better integration of renewable power sources like wind and solar power. It is expected that these will be increasingly implemented in distribution grids, i.e. at low and medium voltage levels [15]. The installed capacity of wind energy for example has grown steadily in recent years in Germany. In 2008 the installed capacity amounted to nearly 24 TW and met about 8% of net power consumption [16]. Considering the goal of the German government to reach a proportion of at least 30% renewable energies by 2020 [17] and the high growth rates of previous years (cp. Fig. 2), a strong increase can be expected for the forthcoming years, too.

One crucial challenge is to cope with the intermittent feed-in of these power plants. Although there exist forecast and online models that predict expected power generation with an accuracy of 96% for the four-hour prognosis and 94% for the following day [19] the steady increase in wind energy plants will make it necessary to implement ICT to better integrate these plants into the power grid.

Interesting options like the reliable provision of wind energy through the clustering of wind farms may be a first step and create a new demand for ICT.[3] Furthermore, reliable communication between grid operators and wind plants can be seen as an important element for providing a secure grid management. The more

[2] At the moment it is unclear, whether the realization of a Smart Grid actually needs broadband access for every household or enterprise. However, the theoretical availability shows that this will not be a bottleneck in the future.

[3] An example is the clustering of wind farms within the pilot project "Regenerative Modellregion Harz " in Germany.

Table 1
Comparison of transmission technologies in Germany.

Technology	Penetration of households (%)	Availability	Transmission capacity
Analogue/ ISDN	99	●	◔
DSL	90	●	◕
CATV	52	◑	◕
Powerline	100	◔	◔
GSM/GPRS	90[a]	◕	◔
UMTS	50[a]	◑	◑
WiMAX	–	○	◑

[a] Estimated value.

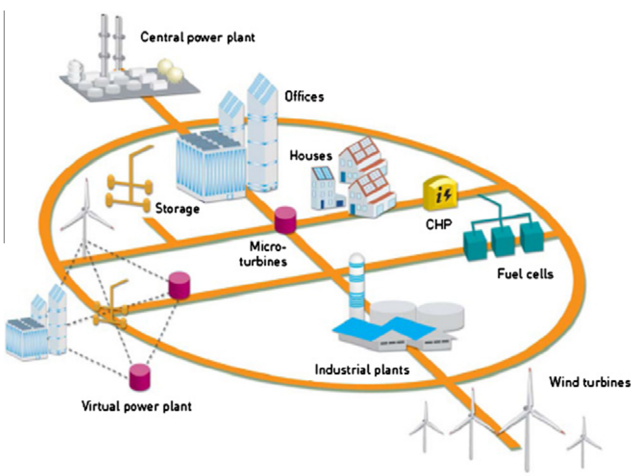

Fig. 1. Smart Grids vision (source: [14]).

information grid operators get from single units the better they are able to cope with the challenge of increasing decentralised power sources with fluctuant feed-in. The maximal economic potential can thus be seen in a crosslinking of all wind plants with real-time analysis of data and forwarding to the responsible actors [12]. In the coming years the focus may lie on the communicative integration of planned offshore wind parks, as maintenance and repair by personnel is much more expensive than for onshore plants. Wireless solutions may play an important role in this field [12].

A related option that is made possible by ICT is the establishing of virtual power plants. A virtual power plant is a pool of small generation units that achieve the characteristic of a big plant through their combination (for different definitions of virtual power plants see [20]). For the realisation of a virtual power plant, communicative crosslinking is a critical issue. Only if single (small) power plants are reliably connected to a central control unit or even among each other is the idea realisable. Besides the communicative connection that transfers measured data or control commands, some more communication infrastructure is necessary. There have to be measuring devices that give information about production and consumption as well as about grid status and potentially also meteorological data (e.g. in the case of wind energy plants). Finally, there must be a central control unit that is able to operate the virtual power plant [21].

Virtual power plants are possibly the application area that best demonstrates how ICT can bring forward certain developments and processes in the power industry. The advantages are obvious: in relation to third parties the virtual plant can act like a large-scale plant with several megawatts of capacity. This increases the likelihood of reaching more recipients in the market than if the single units stood alone [22]. The advantage over single large-scale plants is the higher flexibility in generation. Unpredicted deviations can be cleared within the power pool of the virtual plant. Also, the threshold of 15 MW to take part in the German tertiary reserve energy market is no longer an unreachable hurdle for small units. In terms of ecological aspects, the virtual power plant is a suitable method of linking renewable power plants. Some disadvantages of renewables, like fluctuating feed-in by wind power plants, can be balanced within the pool [23]. In Germany there are two projects installing virtual power plants on a large scale at the moment. Both run on the basis of micro CHP.[4] They show that there is a huge potential for virtual power plants in the market.

3.2. Transmission and reserve power

There are possible new applications for ICT in transmission and reserve power markets as well. The German power system consists of four major transmission companies that are responsible not only for the transmission itself but for reserve power on the high voltage level. These companies auction reserve power to outweigh imbalances within the high voltage and the lower voltage levels.[5] In fact the task is to match generation and demand. In doing this, grid operators fall back on reserve power to equalise all net deviations in the short run. Power plants providing primary reserve power react within seconds automatically and in a decentralised manner to frequency deviations by increasing or decreasing power capacity. Secondary reserve power replaces primary reserve power as quickly as possible to free the former for potential new disturbances. It is triggered automatically by the central network control station and has to be delivered within a few minutes by prequalified power plants. Finally, tertiary reserve power replaces secondary reserve power. It is not activated automatically but requested by telephone call within 7.5–15 min.

The described system was implemented long before the existence of modern ICT, when necessary data and signal transmission was accomplished via "conventional" ways. Therefore, for most players on the power reserve market, modern ICT may play an important but not decisive role today. Primary reserve power gets its steering information directly from the mains frequency. Secondary reserve power was often triggered by ripple control in the past, while tertiary reserve power is activated by telephone.

Secure and available communication is important both for the secondary and the tertiary reserve power, however. The transmission grid operator needs to be sure that his signals reach the person in charge for steering reserve power in the single power plants. The German association of grid operators (VDN) foresees in its guidelines that the transmission grid operator is entitled to request online information from every single technical unit (i.e. power plant) involved. This can be actual data concerning current capacity, planned generation or the current status of the plant (on/off) so that it is possible to check if the earmarked power reserve is actually provided [24].

The communication between transmission grid operator and central contact station is handled by telephone and additionally

[4] One project is the idea of " Schwarmstrom" ("Swarm Power") that is realized by the German power retailer "Lichtblick" and the car manufacturer "Volkswagen (VW)". It is planned to install 100,000 micro CHP units working on a natural gas basis in private homes. The second project is run by the energy company "Vattenfall". 200,000 customers in Berlin are to get micro CHP units that are managed from a central control room and flexibly adapt to power market prices.

[5] At lower voltage levels there exist single balancing groups that try to adjust supply and demand. If after that there is still a difference between forecasted and actual power flow this difference has to be balanced by transmission companies via balancing power.

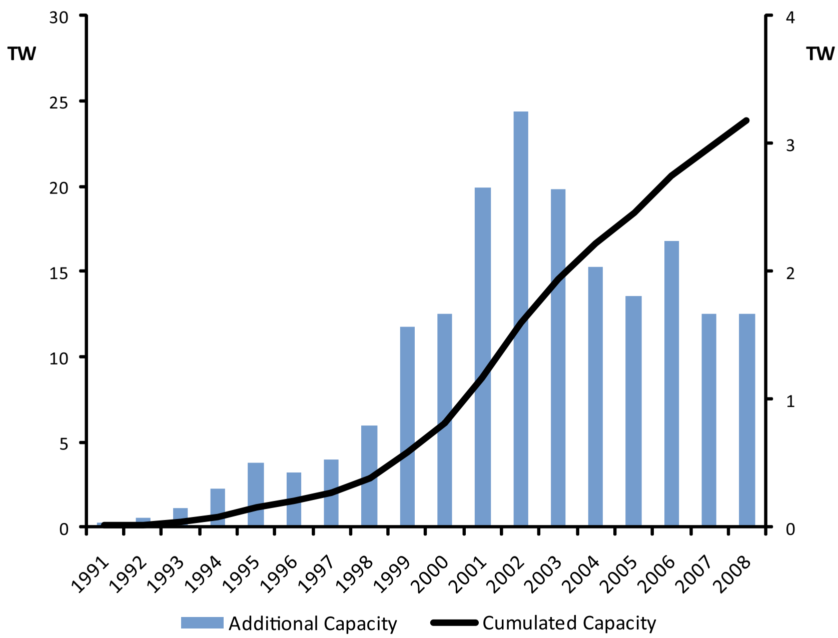

Fig. 2. Development of wind power capacity in Germany (source: [18]).

in written form via email or optionally via control technology or fax. Communication for the registration of the net schedule is carried out electronically and redundantly. Schedules are registered via FTP or ISDN (primary way) and/or redundantly via email [24].

There is of course some leeway for upgrading communication towards broadband technologies in the fields of secondary and tertiary reserve to further automate these processes. Especially when the tertiary reserve markets are to become more competitive by integrating smaller energy units, the above-mentioned threshold of 15 MW should fall. To handle more and smaller providers of reserve energy, ICT is indispensable. It could substitute telephone calls and thus provide for a quicker and more efficient call of tertiary reserve power.

3.3. Distribution grid

A crucial application area for ICT in distribution grids is the fostering of demand-side management (DSM) and demand response programs. It is of vital interest to distribution grid operators to know about the actual grid load and to reshape it if it imperils grid stability. Various price- and incentive-based demand response programmes have been developed in the past. Fig. 3 gives an overview of programme designs, ordered by the time frame of their application.

Price-based programs range between monthly and daily periods. This means that, for example, tariffs that take into account daily or seasonal fluctuations in electricity costs can be fixed months before taking effect. The Italian supplier ENEL has offered such time-of-use rates, for example [12].

In contrast, real-time pricing (RTP) implies notifying tariffs day-ahead or even on the day of demand, so that customers can adapt their behaviour accordingly. Tariffs are then based on spot market prices or marginal costs of electricity acquisition. The economical effect of such pricing regimes is a more elastic demand curve, because actual (generation) price signals are given to the customers. The power price then indicates possible shortages as well as relatively easy availability of electricity [12]. Consumers can be expected to shift at least some of their demand from peak load to base load times so that the load curve flattens. Empirical experience shows that RTP applying critical peak pricing (CPP) can actually help customers save energy [26,27].

Incentive-based programs on the other hand principally involve the right of the grid operator or supplier to cut certain amounts of load [28]. This can, for example, imply direct load control, where suppliers or grid operators can directly access customers' appliances or machines at short notice and drop load thereby. In Germany, such measures are mainly offered to major customers, while in other countries households or small businesses are also involved. The measures can go up to long-term agreements for offering load rejection.

Price-based as well as incentive-based programs need suitable ICT to direct these measures. For price-based programs, smart meters are an essential element, because they are able to communicate bidirectionally (see Section 3.4). Incentive-based programs have been carried out via ripple control in Germany for a long time. Similar to broadcasting services, signals are sent to a large area and can be received by particular receptors only. Disadvantages of cripple control are the unidirectional data transmission and often proprietary systems [12].

New technologies in this field have reached readiness for marketing. Especially developments that make possible so-called grid friendly appliances may be an interesting option. Different institutions have developed computer chips that can be implemented in household devices and can cut them off the grid when system stability is jeopardised. The chips notice frequency deviations and act accordingly and automatically. In the long run they may be part of a comprehensive communication system so that, for example, grid operators are informed about where and when load rejections take place [12]. Similar developments have been made in the field of smart houses (see Section 3.5), where chip technology may interact with or even replace commonly used technologies like KNX.[6]

3.4. Metering

The electricity meter builds the natural link between customers and suppliers. The measured data is the basis for the customers'

[6] KNX is a network communications protocol for intelligent buildings, cp. section 3.5.

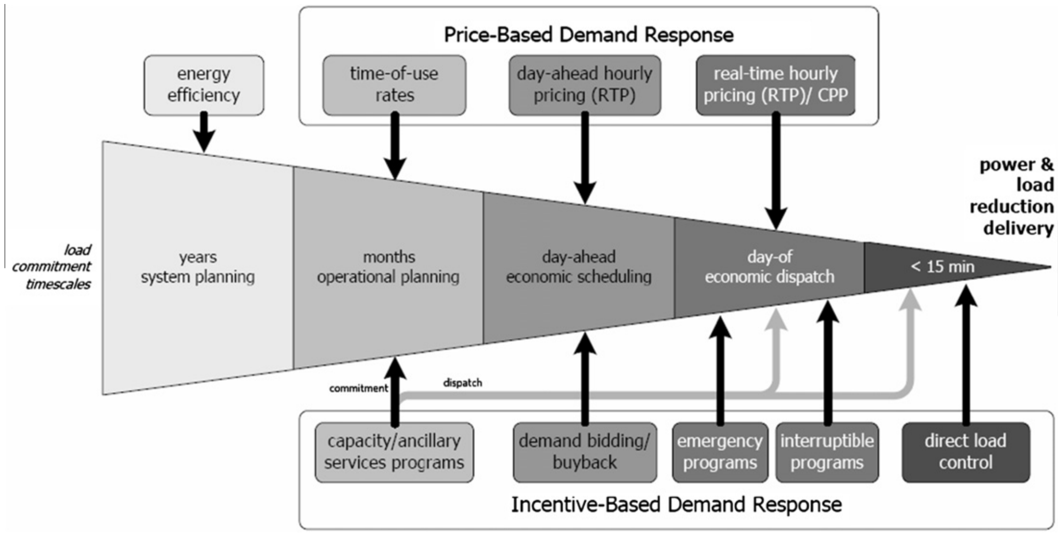

Fig. 3. Role of demand response in electric system planning and operations (source: [25]).

bills, which is often, at least for household customers, the only conscious moment of contact they have with their power supplier. Although meter technology has undergone maybe the most apparent change of all energy system components in recent years, the mechanical Ferraris meter is still in use in most households and small businesses and is blamed for the poor communication between customer and supplier. On the other hand, meter manufacturers already offer a wider range of digital, intelligent meters – so-called smart meters – that have many more features than their mechanical forerunners.[7] The most crucial element of progress is their ability to communicate by means of installed communications interfaces. This enables them to make use of virtually all available transmission technologies (Internet, Powerline, GPRS, etc.) and allows information flows in two directions. The first is from suppliers to customers; this is the traditional way, but is now possible on a higher qualitative and quantitative level.[8] Secondly, information can also flow back from customers to suppliers. Through these newly-gained opportunities, a wide range of benefits is realisable. Remote meter reading can be carried out with a much higher frequency, for example in 15-min intervals, and at the same time provides the supplier or network operator with valuable information. Voltage quality reports can help stabilise the grid and ease grid management for network operators simultaneously. Smart meters can also send warnings of manipulations and thereby help contain power theft. Provided that a common data standard is implemented, smart meters will also significantly ease supplier switch for customers, because an on-site meter reading by the current supplier is no longer necessary. In this way, the new technology will help foster retail competition. Furthermore, because of their capability to measure power flows in two directions, smart meters can help bring forward decentralised energy units. For example, small PV power plants in households not only demand power but also feed into the grid. Both power flows need to be measured.

Considering the objective of increased energy efficiency, smart meters can contribute in many ways. Firstly, power demand is read with a higher frequency. It is possible to save the measured data and provide information about individual power consumption patterns to customers and suppliers. This can build the basis for an individual consumption analysis. If the smart meter is linked with corresponding software, this can be carried out on every home PC. The customer himself can evaluate the data or enlist the assistance of a professional contracting company, which will allow him how to use electricity more efficiently.

Another possible application is the permanent information about current energy consumption on displays, so that customers can check their energy demand in real-time. Pilot programmes of single companies in Germany and abroad have found that energy savings of up to 6.5% are possible in households if energy consumption (and price; see below) are made visible [29]. Customers then are obviously more aware of their power demand and change their behaviour accordingly [30].

The offering of variable tariffs, so that electricity is relatively expensive in times of high overall load on the power grid and relatively cheap in times of low overall load, is therefore another step towards increased energy efficiency (cp. Section 3.3). Different studies show that load shifts up to 30% are possible [12,31]. Smart meters are able to store different tariffs that indicate such scarcities.[9]

Besides a direct effect of load shifting, which reduces the use of spinning reserve, customers may in the long run be more aware of their electricity demand and purchase more efficient electric appliances, which will lower the grid load in general. The effects of visualisation and the choice between different tariffs may provide energy savings of about 7 TW h per year in Germany [32]. For German households, power savings of about 5% basing on feedback measures seem achievable [33].

In the long run, however, smart meters will form a crucial element of an ICT-equipped energy system. They can be considered as a migration technology that helps bring forward upstream and downstream sectors. Upstream, they will be the deliverer of data for distribution grid operators to optimise grid management; downstream they can be the gateway to customers' homes in which further automation is possible (the smart house; see Section 3.5). Smart meters may than directly interact with intelligent appliances in-houses or be the steering unit for network-driven load shift activities.

The introduction of the new infrastructure will be connected with initial and ongoing costs, however. The initial costs of a smart meter, comprising meter production costs, installation and system

[7] From 1 January 2010, smart meters have to be installed in all new buildings or buildings undergoing major reconstruction in Germany.

[8] Downstream communication has been possible before. The principle of ripple control for example (cp. Section 3.2) has been well known for about 80 years in Germany. It only serves simple control commands, however, for example switching between two installed Ferraris meters, of which one measures demand at a day tariff and the other one at a night tariff.

[9] German energy suppliers are obliged to offer such tariffs until 30 December 2010 at the latest.

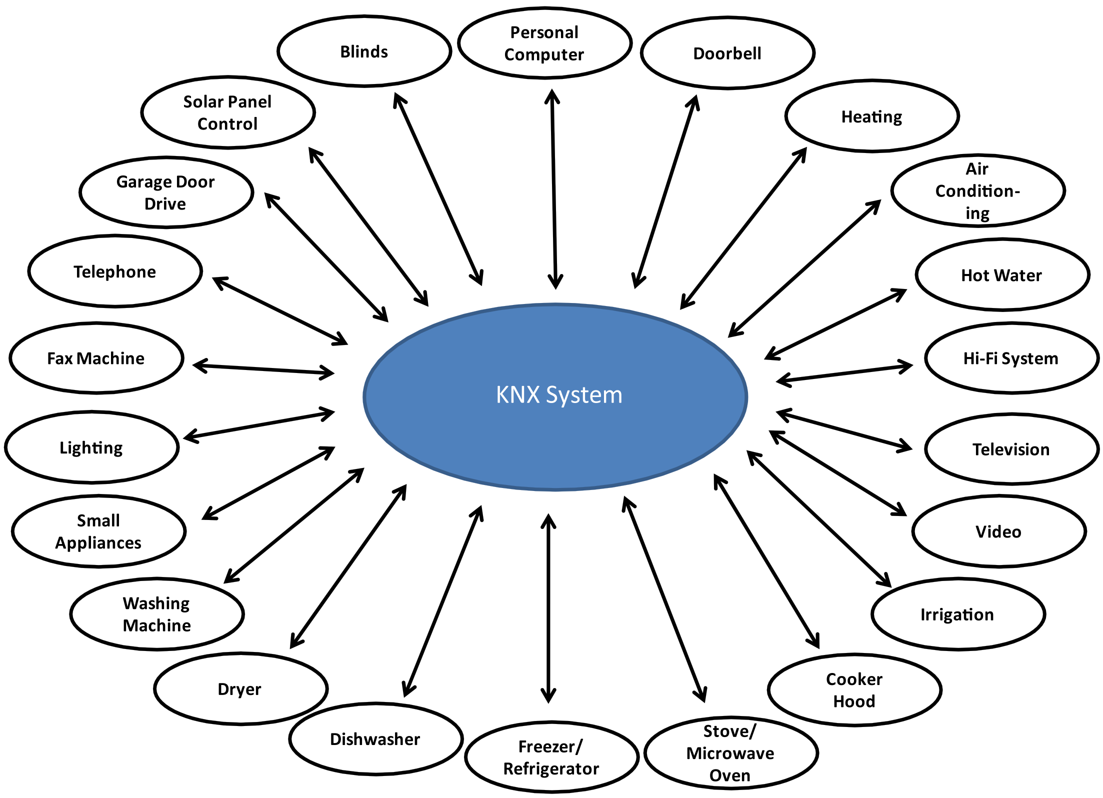

Fig. 4. Integration of applications in buildings through KNX.

integration, are valued between 33 and 253 euros [34,32].[10] Of course, there are differences in functionality that justify such price gaps.[11] On-going costs include data transmission costs, maintenance and training costs as well as billing and electricity costs and range between 11 and 34 euros per year [32]. These costs must be weighed against expected benefits that have been described above. Different international and national studies conclude that benefits will in most cases in the long run compensate for costs [34,35,32,36,37].

Activities concerning the implementation of smart meters in Germany are still of pilot character, however. Many suppliers have already carried out small-scale pilots while others are planning to do so. A further acceleration is expected of a technology competition organised by the German Federal Ministry of Economics and Technology called "e-Energy", where ICT implementation into the power system will be demonstrated in different projects. Smart meters will be one decisive component of integrated strategies and then demonstrate all their positive effects. Besides new regulations in the German Energy Law (see footnotes 7 and 9), the EC Directive 2009/72/EC concerning common rules for the internal market in electricity envisages the implementation of intelligent metering systems in all EU member states. Where the roll-out of smart meters is assessed positively, at least 80% of consumers will be equipped with intelligent metering systems by 2020.

3.5. Smart houses and intelligent buildings

Following the value chain, the last link is houses and buildings where power and energy in general is consumed. In this field, the invention of different new technologies has prepared the ground for the capability of building intelligent (smart) houses. These are characterised by automated operations concerning electricity and heat regulation that need little manual interference. Examples are the control of heating or lighting that depends on the presence or absence of inhabitants or the coordination of processes, e.g. turning down the heating automatically if a window is opened.

The relevant technical components for the realisation of a telecommunicative networking of essential electric appliances in households or industrial premises already exist. A precondition for the realisation of such systems is that all components are equipped with the relevant communication and steering interfaces. The communication of all components (appliances, technical installations, etc.) needs corresponding technologies to transfer metering data or data for controlling purposes to a central control unit, a server or gateway. These units are themselves connected to a telecommunicative network. Such in-house units or technologies can be either cable or radio based.

A widespread cable-based technology in Germany is the European Installation Bus (EIB/KNX). Introduced in 2007, it is the only worldwide acknowledged technology platform for building services engineering [38]. KNX is capable of linking all sensors and actors with uniform standards and interfaces and sending control commands for these components. Fig. 4 illustrates the possibilities.

The system is connected to the outside via IP so that the control of houses and buildings can be carried out from outlying positions via fixed or mobile networks. All processes can then be managed from a central control station that receives all malfunction messages, warning and alerts and can react accordingly.

In Germany, more than 110 companies support the EIB/KNX technology, so that it can be merchandised and installed according to unitary technical guidelines and quality standards. EIB/KNX has set an incentive for manufacturers of brown and white appliances to offer EIB/KNX-compatible household devices (washing

[10] The €33 refers to the UK market and is calculated at a GPB/EUR exchange rate of 1.11, valid on 6 January 2010.

[11] While some meters can only deliver measured data via remote control, others include for example communication with intelligent household appliances.

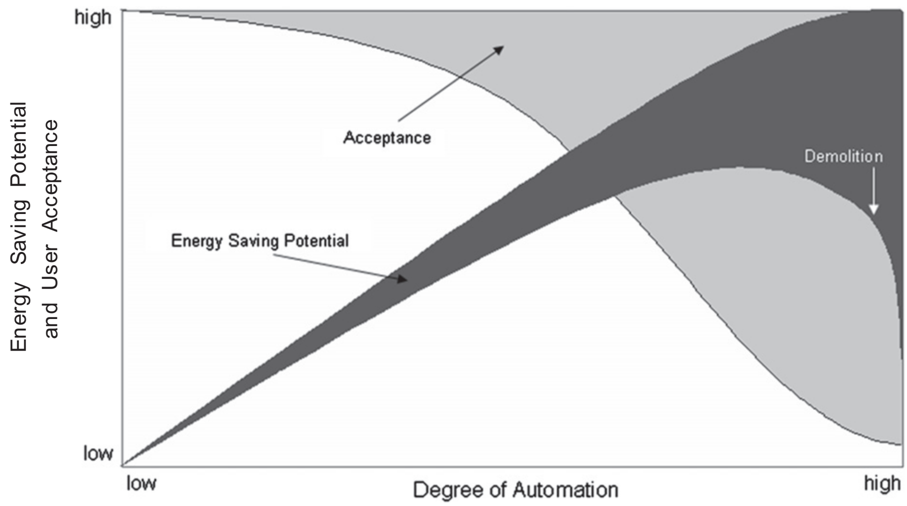

Fig. 5. Energy-saving potential and consumer acceptance vs. degree of automation (source: based on [40]).

machines, tumble dryers, refrigerators, dishwashers, ovens) so that the idea of intelligent homes can be realised today already.

A relatively new approach stems from the Swiss Federal Institute of Technology in Zurich. It is based on a high-voltage chip that is installed directly on 230 V or 100 V power lines without any additional electronics [39]. According to its creators, the chip technology is fitted with the following features [39]:

- Differentiated measurement of use per electrical circuit without significant added cost.
- Controlled stand-by operation under 0.3 W of any electrical device.
- Monitoring of defective electrical devices (pre-maintenance).
- Remote access to individual electrical devices.
- User feedback.

Possible are thus:

- Differentiated load management.
- Avoidance of peak loads and expensive purchase.
- New, differentiated tariff systems enabling user feedback.

It is also possible to implement the new technology into smart meters, so that customers know exactly which device consumes how much power at what time. This makes clear that there is a smooth transition between smart metering, intelligent devices and smart houses and that new services and products for energy saving can be an opportunity for new and established players in Germany.

In the case of smart houses, customers must decide which technology fits best to their needs and is available at affordable costs. An important aspect here is that customers must not be overburdened with technology that at some point they don't understand or simply can't handle anymore. If automation leads to manual interference by its users it no longer makes sense and leads to a decrease in energy savings (cp. Fig. 5).

Nevertheless, smart houses can contribute significantly to increased energy efficiency. Including heat applications, smart houses can reduce energy costs by more than 30% [41]. Investment costs depend heavily on the chosen system, however. It is therefore important that the different standards are compatible so that it is easy to install new technical add-ons in the future. It should be noted, however, that home automation brings with it some other important advantages for users, like improved comfort and higher security.

3.6. Intermediate results

For all fields examined in Section 3, one common conclusion can be drawn: ICT is used in all of these or is expected to play a major role in the near future. Both economic and energy efficiency can be increased through the introduction of new technologies. Between all fields there is a smooth transition, which confirms the idea of a comprehensive approach. Smart meters, for example, can be utilised in interaction with smart house technologies as well as for transferring data and receiving control commands from grid operators. To realise this interplay in all fields of energy industry, some preconditions must be fulfilled and some obstacles must be overcome. Thereafter, new options for action can follow. These aspects are analysed in the following section.

4. Implementing ICT – obstacles and options for action

The final objective of implementing ICT in the whole energy value chain is an integrated information and communication infrastructure, where most processes run automatically and information flow between single sectors is efficient and easy. Moreover, there are clear signs that positive effects for energy efficiency will also arise from such a renewed architecture of the energy system [42]. Nevertheless, some obstacles must be overcome, both in the interplay between value creation levels and within these levels themselves. These are ICT-inherent issues on the one hand, and non-ICT-bound obstacles on the other.

Interoperability, protection of data privacy and encryption are problems that have to be solved within the ICT context. *Interoperability* is crucial for the implementation of an ICT-equipped network. Only if all participants and system components are able to communicate with each other is an integrated optimisation of power flow over all stages of the value chain possible. This can only be realised by defining common data types, so that information, e.g. metering data, topological data, etc., can be transported and evaluated without additional expense [43]. The German Federal Network Agency defined some data types in 2006 already, mainly to provide for an easier supplier switch [44]. Secondly, the implementation of ICT implicates a great amount of data that is generated from millions of intelligent units. This data needs to be *protected* to guarantee that all actors, particularly electricity customers, agree to participate in the new system [45]. It seems to make sense to follow the solutions installed in the German telecommunication's sector. Personal data there is allowed to be generated, processed and saved as long as this is necessary for

Table 2
The Smart Grid: Features and obstacles.

	Today's Grid	Smart Grid	Obstacles
Generation	Large scale power plants	Distributed, mainly renewable and small-scale power plants	No reward for grid-friendly feed-in
		Virtual power plants, connected via ICT	High hurdle (15 MW) for participating in the reserve power market
Transmission and Reserve Power	Tertiary power requested by telephone	International balancing of power flows	Current incentive regulation may hinder smart grid investments
		Request of tertiary reserve via broadband connection	
		Automatic steering of requests with intelligent software	
Distribution	Feed-in follows demand	Demand adjusts to generation status (DSM, Direct Load Control)	Current incentive regulation may hinder smart grid investments
	Distribution grid is a black box	Much better knowledge on grid status and potential location of low power quality	Grid operators not interested in promoting technology because of split incentives
Smart Metering	Dumb meters	Two-way communication	Insufficient knowledge or lack of financial means of consumers on new possibilities through ICT
		Enabling a range of new activities	Missing standardisation and interoperability
		Energy saving	
		Gateway to smart houses	
Smart House	Manual control of heating and devices	Intelligent control of heating and devices	Insufficient knowledge or lack of financial means of consumers on new possibilities through ICT
		Energy saving	
Overall System	No continuous information flow from generation to demand	Continuous information flow from generation to demand	No common standards
		Permanent access to relevant information	Data protection must be guaranteed

the completion or changing of a customer agreement or the fulfilling of a duty by the supplier by reason of this agreement. The generating, processing and saving of personal data for other purposes needs an explicit affirmation by the customer. These principles can be transferred to the power sector [12].

Finally, data *encryption* must be ensured because at least some of the data generated in the energy system is highly sensitive, for example times when certain applications are in use. Therefore it must be protected from leakage, manipulation or loss of availability through hardware- or software-based techniques [46].

On the other hand, non-ICT-bound obstacles must also be tackled. One issue is the (informational) unbundling of former integrated companies and the appearance of newcomers in the course of the liberalisation of markets. In pre-liberalisation times it was possible for the monopolists to carry out an integrated resource planning (IRP) from generation to supply. This eased information flows as well as, for example, DSM programs that built an alternative to the construction of new power plants because reshaped load curves directly affected generation patterns. An independent player in a liberalised market is no longer interested in such considerations. His interest is mainly profit maximisation; the implication of his actions on the upstream levels of value creation is more or less irrelevant to him [12]. To (re)arrange efficient processes that affect the whole value creation chain, an informational and communicational integration in the sense of common data flows and standards in the whole industry is necessary. Only if all players "speak the same language" will the system prove successful as a whole. Therefore, proprietary systems must be overcome and interoperability must be provided for (see above).

Within the single parts of the power value chain, different obstacles exist. In generation, operators of virtual power plants consisting of renewable power sources do not profit from their grid-friendly feed-in because the German Renewable Energy Law (EEG) sets a fixed tariff for the feed-in regardless of the current grid status. The transmission system operator (and thus ultimately the consumer) has to bear the costs for the emerging balancing power originating from intermittent generation and forecast deviation. If grid-friendly feed-in was rewarded, this would be a much greater incentive to build virtual power plants including renewable energy plants [47].[12]

In other parts of the value chain (distribution, smart meters and home automation), insufficiently informed customers can be another barrier that needs to be overcome. These information deficits can appear in different facets, however. Firstly, customers often simply do not know about possibilities that exist and what benefits arise from them, for example energy and cost reductions through DSM activities [48]. Even if customers are conscious of the advantages, the latter must be substantial in comparison to the disadvantages or reckoned costs so that customers choose these offers and technologies. Finally, there may be a willingness to accept new offers, but customers do not have the financial means to invest in new technologies even though they may pay off in the long run [48]. It is therefore necessary that policy creates a framework that brings forward innovative solutions. This can be accomplished by providing customers with appropriate information or by stimulating the implementation of ICT both monetarily and legally [48].

Obstacles concerning grid operators may lie in their reservation regarding necessary investments in ICT because of the incentive regulation in Germany that started in 2009. For example, cost of smart meters with additional functionalities are not fully accredited by the regulator but may only be charged to the amount of a "basic" smart meter. If grid companies nevertheless invest in such smart meters, their costs increase more than their allowed revenues (which base on accredited costs). This may deter companies from investing in smart infrastructure because it may result in not reaching their individual efficiency targets under the revenue cap scheme [49]. It is the task of the German Regulatory Authority to provide incentives that such investments are not postponed or cancelled. Special investment accounts for every grid operator may be an appropriate way to avoid such misleading developments.

[12] In the long run this will also give an incentive to invest in power storage technologies or build up an infrastructure for integrating electric vehicles into the power system.

5. Conclusions

This paper has tried to reveal the secrets inherent in a Smart Grid. The potential of ICT in terms of economic and energy efficiency for the complex requirements in the field of power generation, transmission, distribution and supply has been described. The Smart Grid therefore comprises all parts of the power value chain. The German power market, as well as power markets of many other countries, has undergone fundamental changes in recent years that makes it necessary to fall back on the use of ICT. Three issues played a main role: firstly, the liberalisation of power markets, connected with the unbundling of formerly vertically integrated structures and emerging competition; secondly, the strong growth of decentralised energy generation, particularly in the field of renewable energies; and thirdly the need for efficient energy use to reduce greenhouse gas emissions. In addition, progress in information and telecommunications technology (ICT) was rapid. The Internet and wireless transmission technologies such as GSM and related applications have become standard. The growing and often area-wide coverage with broadband solutions enables new forms of information and communication, summarised under the slogan "ambient intelligence". To tap this potential, appropriate investments need to be carried out and some barriers must be eliminated in all examined fields. Table 2 gives an overview of how a Smart Grid could look and what barriers exist to realising it.

If obstacles can be overcome, it is expected that processes in the energy sector will become more efficient in terms of both economic[13] as well as energy efficiency. Procedures will also be more permeable, meaning that formerly passive groups such as domestic customers can become active players through the integration in a comprehensive energy system based on ICT. The increase in players as well as their better access to relevant information will foster competition in generation and supply and make the energy system smarter and cleaner at the same time. The process towards a Smart Grid can only proceed stepwise, however. It is therefore important to implement new solutions in such a way that they allow upgrading in the future. If this task is managed, the path towards a Smart Grid is wide open.

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[13] So far, there has not been a comprehensive analysis on how much a Smart Grid will cost and benefit customers or society as a whole. This paper showed that a positive net revenue can be expected at least from smart metering. All other parts of the value chain also seem to profit from smart grid solutions. The necessary precondition is that specific circumstances in the single countries or areas are taken into account when implementing a Smart Grid.

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