Smart Grids – the Answer to the New Challenges of Energy Logistics?

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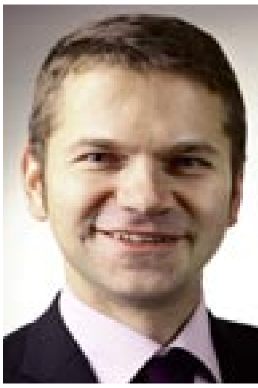

Introduction

The finite quantity of fossil energy resources, as well as global warming due to the greenhouse effect necessitates a massively increased utilization of renewable energies (RE). The shift to RE is a worldwide trend, although there are quite distinct regional differences. According to the IEA Energy World Outlook, the share of RE in the electricity sector, will increase three to fourfold from 2009 to 2020 (IEA 2011, 178), and will increase by a factor of six to 14 by 2035.[1] The EU regards itself as a pioneer in the use of RE and has committed itself to the "20-20-20" initiative in order to improve sustainability and energy safety while reducing the greenhouse effect. The plan is to lower greenhouse gas emissions by 20 percent, increase the share of RE by 20 percent and improve energy efficiency by 20 percent by 2020 (ECEEE 2011). The government of the Federal Republic of Germany has set itself even more ambitious goals of increasing the share of RE from 20 percent (2011) to at least 35 percent in 2020, and to generate over half of its electricity from RE (BMU 2011), increasing the latter's share of overall supply to 80 percent by 2050 (Nitsch et al. 2010). Even although such self-assigned, highly ambitious goals frequently cannot be fully achieved, they are sometimes even realized ahead of schedule. For example, the real expansion of RE in Germany – especially of photovoltaics (PV) – progressed considerably faster than anticipated by serious forecasts (Nitsch 2007) and has far exceeded those forecasts. The PV share, which had been forecast as 25 GW total capacity for the year 2050 in 2007, has already exceeded that level and stands at 28 GW (Bundenetzagentur 2012), higher than the objective at the time of writing, in just five years instead of 43 years. However, this extreme dynamic causes problems of both a technical and financial nature.

Technically, the problem of integrating the RE into the energy system has to be solved; financially, the unplanned high increase of the Renewable Energy Sources Act (EEG) levy is under discussion.

These dramatic changes in the supplier structure in many European countries and especially in Germany are illustrated in Figure 1. The trend is shifting – as illustrated by the example of Germany – away from base load power plants (nuclear power, lignite coal, mineral coal) to less plannable and controllable RE, especially electricity from wind power and photovoltaics. However, since an electric grid – as opposed to other grids (gas, water, etc.) has to be balanced at any given point in time and does not feature any intrinsic storage capabilities, all fluctuations – which had been virtually unheard of on the supplier side previously – now have to be compensated for at any given time.

Beyond this country-specific overall view, the regional disparities that exist between generation and consumption – especially between the North and the South of Germany – still pose a huge problem. The newly added decentralized feeding-in of energy, through decentralized, roof-mounted PV systems or decentralized combined heat and power plants for instance, poses completely new challenges for the previously strictly uni-directional electric grid.

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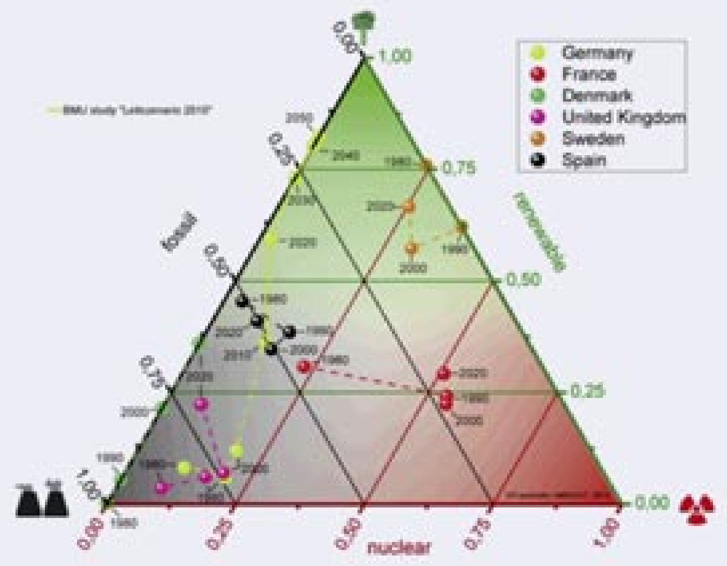
[1] Increase in "Non-Hydro Renewables" from 650 TWh (2009) to 2000–2700 TWh/a in 2020 or to 4000–9000 TWh/a in 2035 – depending on different scenarios.

Figure 1

INSTALLED ELECTRICITY GENERATION POWER
IN DIFFERENT EUROPEAN COUNTRIES



Note: Share of the installed supply load from nuclear power, fossil and renewable energies, their development to date and expansion planning (dotted lines).
In this instance, nuclear power is prototypical of the base load, whereas the fossil energies are primarily for controllable and plannable energy and the RE primarily for uncontrolled, fluctuating energies, although there are exceptions in each of these fields.

Source: Statistics and prospects for the European electricity sector (1980-1990, 2000-2020), 2005, BMWi (1990), BMU Study "Leitszeario 2010" Basiszenario A, and EIA International Energy Outlook 2011.

Spatial energy balancing demand

Unlike with conventional power plants, which are often located near conurbations and thereby near consumers, wind power and photovoltaics systems are predominantly installed at advantageous locations with high yield. Resulting from this is a considerable electricity surplus through onshore and, in the future, offshore wind systems in Northern Germany, as well as a very high feeding-in of electricity into the low voltage grid due to PV system in rural regions in the South of Germany.

In Figure 2 (Fraunhofer 2012), 146 regions and their annual energy balancing needs for the year 2030 are depicted in a map of Germany. Clearly visible are multiple regions in the North with an annualized surplus in electricity, regions with a very high load, e. g., conurbations in the West, as well as in Berlin and Hamburg, although there are also, especially around conurbations, areas with an electricity surplus (also including power plant locations) and where connecting electricity routes affords a balancing, here. This map clearly shows that there is a balancing need between generation (blue) and load centers (red) that cannot be covered by the storage of electricity since storage for more than a year would not make any sense whatsoever. Here, an expansion of the grid is almost the only sensible option.

At the same time there are also more or less balanced regions, in the South of Germany and all over the country. Moreover, a more in-depth review shows that even these areas with a balanced balance sheet are subject to considerable fluctuations within a year and therefore also need to be temporally compensated. These time spans for balancing may amount to minutes, hours, days, or even weeks. Here, grid expansion offers only a very limited potential for balancing.

Energy logistics - energy balancing measurements

In the easiest, but not necessarily cheapest case, the spatial and temporal disparity between generation and consumption can be realized through energy storage systems (temporal disparity) and grid expansion (spatial disparity). However, in reality, there is a much broader bundle of intelligent technical solution options that each can solve part of the grid balancing (Figure 3).

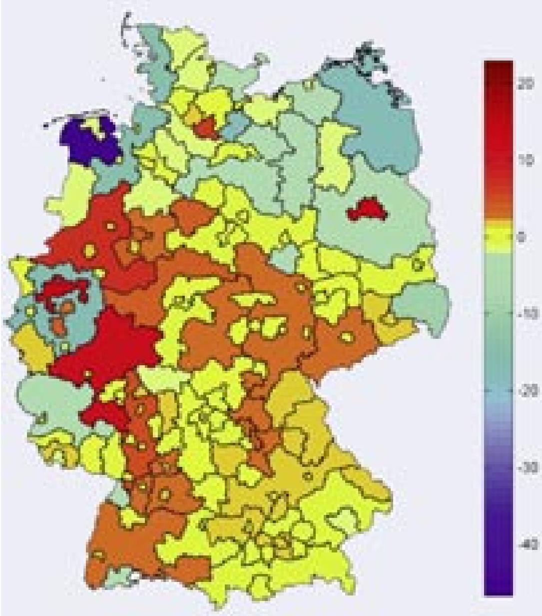
In addition to energy storage systems that balance the temporal disparity and grid expansion, which compensates for the spatial disparity, there are another four options. The first option is producer management, i. e., the curtailment especially of wind power and/or photovoltaic systems; the advantage of this option is the minimal investment required while the disadvantage is that practically free energy is given away. A second option is demand side management whereby dispatchable electric loads are turned on or off on short notice, which also allows for load balancing in the grid. Here, the challenge is primarily in creating these options through additional thermal storage systems that can be intelligently controlled and economically/technically integrated. Further options are controlled decentralized providers (virtual power plants) and additional controllable loads. The virtual power plants allow for grid-oriented operation as long as the generated heat can be stored at the same time. The additional loads may, for instance, be the generation of hydrogen as raw material for further process steps.

Electric energy storages

At present, over 99 percent of electric energy storage worldwide takes place via pump storage power plants (PH - pumped hydro) (Doetsch 2009). In addition, there are currently two large compressed-air energy storage (CAES) plants in operation (Figure 4). Above and beyond these two central storage systems, there are also decentralized battery storage systems under development and/or in being introduced in the market. These electrochemical storage systems are at present in the test phase in the kW to double-digit MW class (NaS battery, redox flow battery, Lithium ion battery) and/or in use (lead acid battery). In this case, the main obstacles remain the investment costs, as well as the service life of the batteries. Other storage systems (e. g. flywheel, double layer capacitor and SMES) do not plan any relevant role for the integration of the RE since the storage capacity is limited to seconds or a maximum of a few minutes (Wietschel et al. 2010).

Figure 2

Energy balancing requirement of the 146 regions in Germany for the 2030 scenario



Source: Fraunhofer-Institute UMSICHT and IOSB-AST.

Electric grid enhancement

To assess the grid expansion required in Germany, the dena Grid Study II (DENA 2010) was conducted. The objective is the complete integration of the RE for 2020 and 2025.

The model calculations show[2], for example, that in 2020 it will not be possible to transfer the necessary output at 70 percent of all connections between neighboring model regions. One of the study variants, in which the non-transferable outputs are fully integrated through grid expansion without using storage systems, shows that an expansion of the transmission grid of 3,600 km will be needed by 2020. In view of the rather slow grid expansion to date (Der Spiegel 2012), and the partly low acceptance level among the population, this objective will not be easy to achieve.

Potentials for Demand Side Management

In urban areas that have a high demand for electricity, the option exists to temporally displace the demand for electricity in order to react to an intermittent feed-in from wind power and photovoltaic. If there is a lot of electricity from wind and solar power in the grid at a given time, the power consumption is then temporally shifted ahead, in case of a power deficit, it is shifted back. This concept – referred to as demand side management – provides a cost-efficient option for load balancing and thereby realizes the system integration of fluctuating RE.

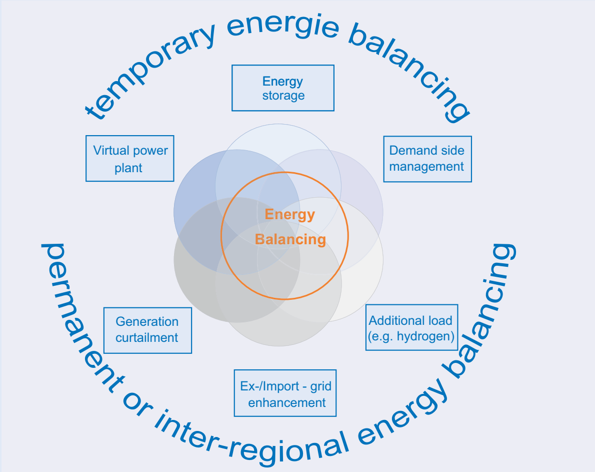
Yet, not all devices consuming electric power are suitable for participation in demand side management (Klobasa 2007). Electric consumers without final thermal energy utilization such as lighting, consumer electronics and kitchen appliances in particular could only be included in load management with a high loss of comfort for the end user. Consumers connected to thermal storage such as hot water heaters, freezers and heat pumps, on the other hand, can be integrated into the load management without

[2] To address the regional differences in consumption and provider potential, Germany was split into 18 regions and the following assumptions were made: exit from nuclear power by 2022, as well as achieving, by 2020, a combined heat and power plant share in electricity generation of 25 percent, a reduction of the power demand by eight percent, and an expansion of photovoltaics to 17.9 GWp by 2020. In fact, today 28.2 GWp has already been installed (Bundenetzagentur 2012). Therefore, it can be assumed that the problems in the integration of RE and the grid expansion derived from it will occur to a considerably greater extent and/or sooner than determined by the study.

a recognizable loss of comfort. Furthermore, thermal storage is comparatively cost-effective. This cost difference makes thermal storage systems highly attractive with respect to the system integration of solar and wind power. However, the utilization of thermal storage systems for load management is not without its challenges. This is primarily due to the dual utilization of the storage system: On the one hand, it is intended to cover fluctuating demand in thermal energy, on the other, it is intended to provide as much flexibility as possible on the electric side. Both objectives are contrary in nature and the effectively usable load shifting potential fluctuates considerably from day to day – depending on consumer behavior.

Figure 3

OPTIONS FOR SPATIAL/TEMPORAL GRID BALANCING THROUGH DIFFERENT, IN PART COMPETING, IN PART COMPLEMENTARY MEASURES



Source: Fraunhofer-Institute UMSICHT.

Smart grids

However, all energy-logistical measures mentioned are only possible if these are acting intelligently coordinated or intelligently controlled, which requires a "Smart Grid". In total, the Smart Grid is a holistic intelligent energy supply system that includes the networking and control of power generation, stationary and mobile storage systems (Schwerdfeger et al. 2011), consumers and grid equipment in transfer and distribution grids with the help of ICT (Westermann and Kratz 2010). Private households are connected via intelligent meters, which present the current usage history via an interface and influence electricity consumption in case of time or load variable tariffs (VDEETG 2012). In case of disruptions, the intelligent networking of all equipment allows for an automatic grid reconfiguration, and the reestablishing of the grid in case of global/local blackouts.

Worldwide research activities are underway to develop the Smart Grid technology. The German E-Energy-Initiative is one of the most important research funding programs which is, in the six model regions eTelligence, RegModHarz, E-DeMa, Smart W@TTS, Model City Mannheim (Nestle, Ringelstein and Waldschmidt 2009) and MeREGIO (Hillemacher, Eßner-Frey and Fichtner 2011), researching the impacts of intelligent power grids and their practical implementation in real energy supply systems (see also http://www.e-energy.de/). The focus of these programs is on economic implementation through market places, for example, (Leprich et al. 2010; Joe Wong et al. 2012), decentralized hardware as well as controlling concepts.

The *eTelligence* project, for example, researches the bringing together of power producers, consumers, energy suppliers and grid operators on a regional energy market place in the model region Cuxhaven (Krause et al. 2009). In the project, the electric power consumption of major consumers of electricity and private households are intelligently coordinated with power generation from decentralized sources.

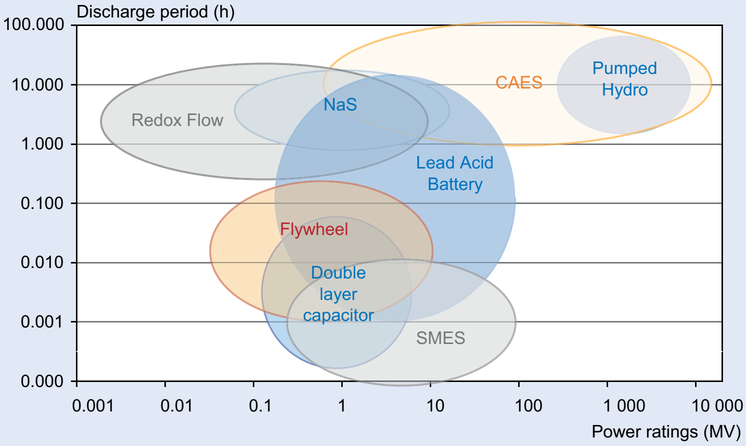
In the *RegModHarz* project "Regenerative Model Region Harz", on the other hand, different renewable energy producers, controllable consumers and energy storage systems are linked into a virtual power plant to demonstrate that through the coordination of generation, storage and consumption, a stable, reliable and consumer-oriented supply with electrical energy is possible – even with a high share of renewable energy producers RE (Hochloff et al. 2011).

The *Smart Watts* project, on the other hand, investigates increasing the self-regulating ability of the energy system. Its objective is to ensure that household appliances primarily consume power when it is available cheaply (e. g. during strong wind or sunshine), without limiting comfort (Quadt 2009).

This short overview shows that the development of the necessary technologies is progressing, but that the energy management system, i. e., the control and operating concept, as well as the economic and legal integration of a Smart Grid, are still unclear.

Figure 4

Types of Energy Storage Systems



Note: Overview, as well as the installed output (MW) and installed storage capacity (GWh) to date.
Source: Doetsch (2011).

Energy management systems

The developments to date regarding energy management can be separated into three categories, based on their application:

1. Virtual power plants / load balancing power plants
2. Virtual marketplaces
3. Grid operations support

A *virtual power plant* represents a multitude of decentralized energy systems. It aggregates their generating capacities and creates an overall load profile for the portfolio. This way, the different systems appear to the outside as a single large power plant (Pudjianto, Ramsay and Strbac 2007). The objective of a virtual power plant is to control decentralized systems such that at any given point in time a specific amount of electricity is produced. Typical of such systems is the use of prognoses for load development and feed-in development of fluctuating energy production systems.

The *virtual marketplace* is pursuing a different approach. Here, future market activity is based on a volatile supply situation in which all stakeholders react flexibly. Market price mechanisms, price signals in particular, are expected to govern the behavioral control of consumers. This approach is mostly based on local markets, with the objective of achieving a regional balancing of electric power supply and demand (Bundenetzagentur 2011). The implementation then takes place in accordance with free market principles, whereby every producer and consumer participates in the market, and the resulting pricing varies over the course of time and is the result of supply and demand. This way, consumers in private households are also intended to be incentivized to shift their power consumption towards times of high renewable energy production. Therefore, generation-oriented consumption is to be promoted.

An objective more strongly pursued recently is *grid operations support* through decentralized energy systems by means of an energy management system. The purpose of such systems is to optimally use the capacity of grids and/or grid sections through the targeted load and generation management of decentralized energy systems. This means that such systems are more suitable for solving local problems and less appropriate for central problems through superordinated planning. They can therefore be organized in a more decentralized way, so that systems at certain points of the grid, for example, are switched automatically when required by the local voltage, without instructions from a superordinated instance. The target function when switching systems and in case of any optimization also differs from the systems mentioned above since economic optimization is not in the foreground in this instance, but solely the locally existing technical restrictions are decisive.

Hybrid urban energy storage

Since not only the creation of large central storage systems, but also grid expansion are both progressing rather slowly, in the short and medium-term, the biggest viable potential for energy balancing is found in cities. These large central storage systems have an enormous, partly indirect, and as yet undeveloped potential available, since they are load centers and often also feature numerous decentralized, controllable producers.

This approach is pursued by the Fraunhofer-Gesellschaft with its future project "Hybrid urban energy storage" (see also www.hybrider-stadtspeicher.de). In the framework of this project, buildings in which electricity is converted into heat (e.g. heat pump, domestic hot water) or in which electricity and heat are produced jointly (mini combined heat and power plant) are operated electricity-controlled through additional thermal storage systems and are used as buffers for the electric grid. Additional components of hybrid urban energy storage are also real electric storage systems. These may consist of larger, centralized batteries or smaller ones at individual homes. What they have in common is the fact that they can be combined, just like the aforementioned options, as balancing systems for the electric grid, and can act as hybrid storage in the grid through intelligent control. For very short consumption or production spikes in the grid, for which the use of storage systems is not economical and/or which time-wise are outside the framework of shiftable production and loads, emergency generators, such as at hospitals and computing centers, may fill in on short notice and/or on the consumer side, the electricity may be used for heating local and district heating grids.

The essential advantage of hybrid urban energy storage in this is that many systems are already installed (e. g. heat pumps, CHP, potable warm water systems), which with small measures (e. g. additional heat storage) and therefore lower costs can be used for the storage of electrical energy.

Conclusions

The addition of renewable, quite often non-plannable energies, which are desirable from a resource protection and CO2 point of view, requires a massive conversion of the energy system. This necessary conversion is well illustrated by the example of Germany since the changes in the energy system here are among the most dynamic in Europe. The focus in this instance has to be on the main problem, namely the spatial and temporal balancing of energy. For economic reasons, this balancing can only occur through synergetic utilization of almost all balancing potentials such as storage systems, grids, intelligent control of decentralized systems, etc. The backbone required to achieve this is an intelligent grid, a Smart Grid, to tap into all options. However, above and beyond the smart grid approaches to date, the energy and IT technologies for this have to be developed, as well as the market and legislative frameworks. It is only this way that all options can be utilized, using optimization algorithms and taking into consideration efficiency, costs and acceptance. The Fraunhofer-Gesellschaft wants to provide its contribution to this concept with its "Hybrid urban energy storage" project.

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