DESIGN AND OPERATION OF SMART GRIDS - TECHNICAL SYSTEM AND MARKET MODEL

Dr. Peter BIRKNER
RWE Rhein-Ruhr Netzservice GmbH – Germany
Peter.Birkner@rwe.com

Yvonne TRAUSCHIES
RWE Rhein-Ruhr Netzservice GmbH – Germany
Yvonne.Trauschies@rwe.com

ABSTRACT

It is unfair to say that today's grids are not designed and operated in a smart way. However, requirements and operational environment are changing substantially. European politics are striving forward to a cleaner, CO_2-free energy future. This will lead to an increasing use of electric power as it can be generated from divers sources and is a clean, flexible as well as a highly efficient energy carrier. Thus our future will be more "green" but also more "electric". Much more volatile generation – small and dispersed as well as big and concentrated – have to be integrated into the grid. New electric applications – characterized by a high and volatile power demand – will determine our daily lives. This requests a new balancing function of the distribution grid and subsequently a new dimension of "smartness" in the grid in order to manage the new requirements in an economic way.

DRIVERS FOR SMART GRIDS

European energy politics will be "stressed" mostly by the challenging 20-20-20 targets: in order to transform Europe into a low-carbon economy Member States shall, compared to 1990 values, cut CO_2 emissions by 20%, improve energy efficiency by 20% and establish a 20% share for renewable energy in the total energy mix, implicating 35% in electric energy, until the year 2020 [1]. By 2050 electricity generation shall be completely CO_2 emission neutral [2].
Increasing the share of electrical energy generated from renewable sources has severe impacts on electrical grids. On the consumption side, use of electrified applications with a high power demand at any position in the grid will increase substantially. Charging e.g. 1,000,000 electric cars in Germany (some 2 % of all cars in Germany) with 44 kW (three phase power of a today's public charging pole) will request already 50 % of Germany's current peak power, which is some 90 GW.
Considering the generation side, renewable energy sources show an intermittent character and a low energy density, thus leading to volatile generation and the necessity of huge generation areas, partially far away from consumption points. Higher grid transportation capacities, increased back-up generation, energy storage and demand side management are needed. Today's consumption driven generation will transform into a generation driven consumption in the future. Combining consumption and generation we can create the model of power sinks and sources with permanently alternating positions in the grid.

BASIC DESIGN OF SMART GRIDS

Intermittent high capacity generators and consumers at different and alternating feeding-in and off-taking points will constitute tomorrow's challenge for transmission and especially distribution grids. They will have to cope with high power and bi-directional load flows as an increasing number of small and dispersed renewable generation will be integrated where in the past a distinct uni-directional top-down load flow was the rule. Additionally, the clear distinction between consumers and producers will eliminate more and more. We will see so-called prosumers who both, **pro**duce and con**sume**.
Electric vehicles as being mobile prosumers having – due to their high need for electric power and at the same time ability to store energy in batteries – have a great impact on the grid infrastructure design and operation. Considering that they are charged synchronously, e.g. in the evenings a consolidation of the overall power request with the grid capacity and the availability of energy is necessary. Additionally, some other "synchronizing" elements in the system have to be consolidated as well. E.g., clouds are "switching on and off" solar generation, external temperature is defining the operation of heat pumps and "happy hours" of suppliers will have an impact on the overall consumption of customers.
Technically, two issues have to be fixed: (1) to avoid overload in the grid, to make maximum use of the available grid capacity and (2) to keep the balance between generation and consumption.

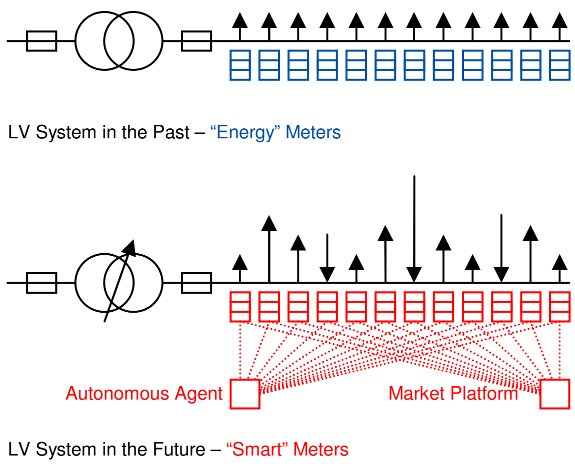

Fig. 1: Two dimensional functionality of smart meters

(1) Avoiding overload: in the past consumers with similar consumption patterns have been dominating LV grids, “energy” meters read once per year have been sufficient and annual energy consumption could be transferred into realistic 15-min-power profiles. Maximum load has always been located at the starting point of the cable (equipped with a fuse).
In the future prosumers will dominate the load flow. The point of maximum load occurs somewhere on the cable and even change its position during the day. Thus a sensor system is needed which is able to identify this point as well as a potential overload and react autonomously in order to protect the cable. Autonomous congestion management in distribution systems becomes necessary. The “smart” meter will enable this function in addition to providing prosumers’ data to a market platform and allow prosumers to participate in the electricity market.

(2) Keeping the power balance: bridging the gap between volatile demand and volatile generation in the future will partially be done on the electricity market platform via bidirectional communication of the smart meter and the market platform. Price signals influence the behaviour of the prosumer and thus contribute to a “rough” power balance. The need to keep 100 % conventional generation capacity as a back-up does not exist any more, leading to a clear financial benefit on the generation side. Additionally, the energetic behaviour of the prosumer has to be controlled in an automated way through a customer specific, transparent, objective and non-discriminatory algorithm in every household (“smart home”). Aggregation of data will be done by the local autonomous agent.
It is also an option to add a power-frequency function P/f to this algorithm and to contribute to the power frequency control as well. A detected reduction in frequency will lead to a reduced power demand of the prosumers and vice versa.

TECHNICAL OPERATION

Smart meters are a decisive source of technical data. However, using the gathered information for an active control of the load flow creates a new kind of “smartness”. In radial LV systems the focus is put on demand side management including vehicle charging infrastructure, generation control and voltage control. In radial operated, however, interconnected designed MV systems the operational structure of the grid (position of open switches) can be changed as well in order to optimize the changing load flow during the day. Remote controlled MV disconnectors have to be installed.
Extended use of the existing primary infrastructure through online load monitoring and active load control forms a smart grid from a technical point of view which has to be operated in a harmonized way. I.e. the time constants of the different control impulses have to be coordinated in order to avoid “oscillations” and thus instability of the system [1]. The detection of an overload needs an immediate reaction in order to avoid damages of assets. Power-frequency control supporting the minute reserve has to react within 1 min. The sample time of data does not necessarily have to be identical with the reaction time. Overload is acceptable for a certain time period defined by the thermal inertia of the asset, a 15 min sample period seems to be sufficient [1].

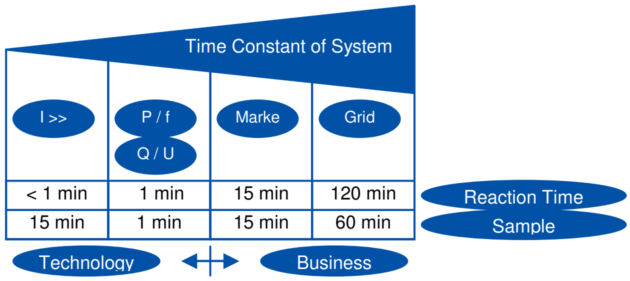

Fig. 2: Order of System Control [1]

Considering data protection, the autonomous agent needs to know only the position of the prosumer in the grid and not his identity. Furthermore, use of data is limited to the supply area of a MV/LV transformer station.

MARKET BASED OPERATION

Smart meters are forming the interface to the technical operation as well as to the market system. Every prosumer becomes a market participant whose identity has to be known to the market platform. His consumption or generation pattern has to be revealed to his market partner (who is acting as an aggregator), who then sends price signals to the prosumer in order to influence his energetic behaviour. As a consequence, identity as well as power data of a prosumer have to be available on a global basis. This requests high standards for data safety but also the ability to handle and manage high data volumes as online transfer of 15-min-power values for every prosumer is the feasible maximum of global data exchange.
With respect to coordination of reaction times there are two elements. The first one is mandatory. The market needs the load or generation data in a 15-min-sequence while there should be the option to change power prices in this time frame as well. Second and optional, grid tariffs can be flexible as well. If applied it has to be made sure that grid fees are changed significantly slower than electricity prices. In order to avoid “oscillations” of the system and to send clear as well as non-contradicting consumption signals the grid tariffs have to be known upfront compared to the electricity prices [1].

REGULATORY SCHEME AND ECONOMIC ENVIRONMENT

The “smart” energy world as described above can be organized in three layers. The basis consists of the electrical infrastructure. Data are collected through smart meters and used for local technical as well as for global business purposes. The second layer is constituted through the data management tools and a third layer is formed by the use of the data for doing business. Here the internet is the connecting element.

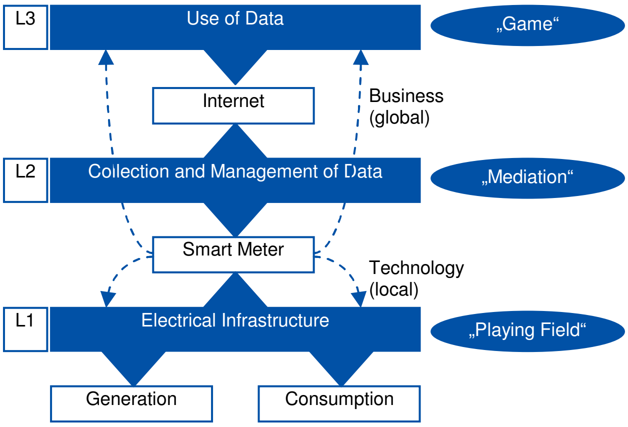

Fig. 3: Layers of the smart energy world

With regard to the regulated infrastructure, there are technically two basic options how to manage future highly volatile and high power load flow situations in distribution grids. Capacity in the primary equipment can be increased (e.g. three cables instead of one) in order to be able to govern all possible situations without the need of more information, or to use smart meters as sensors and to invest in control functionalities. In this scenario the dynamic reserves of the existing primary equipment are used and the load flow is controlled.

The regulatory regime must allow the system operator to find his individual cost optimum (e.g. moderate extension of the primary equipment combined with smart control functionalities) and to implement it. Incentive regulation, so far focussing on the permanent reduction of the operational expenditure and the increase of service as well as technical quality parameters, has to recognize that a substantial increase of (short lifetime) electronics in the system is changing cost structures. The system of grid tariffs and the option of time depending grid tariffs has to be considered by regulators as well. Today's consumption based pricing (generation is not subject to grid fees) might be adapted for future needs. Taking the higher importance of power into account a power based flat rate could be an option. Time depending grid tariffs can impact the energetic behaviour of prosumers, too. Cost and benefit neutrality compared to constant tariffs has to be safeguarded.

Smart metering can be a regulated or a liberalized business, while layers two and three are liberalized. Nevertheless, binding communication and technical standards that are guaranteeing interoperability are indispensable. Also the market needs binding rules that are not only based on voluntary, bilateral contracts.

FIELD TESTS WITH AN ACTIVE INVOLVEMENT OF RWE RHEIN-RUHR NETZSERVICE

RWE Rhein-Ruhr Netzservice GmbH, Siegen, in cooperation with its mother company RWE Deutschland AG is involved in a number of field tests concerning the functionalities of the smart grid as described above.

(1) Mülheim (smart city concept): about 115,000 smart meters are being currently installed in private homes in an urban area. At the moment some 60,000 are already in place. 15,000 are operating with a proprietary meter technology and the others are using the open Multi-Utility Communication (MUC) controller standard. For data exchange a variety of means is tested: Internet (ICP/TP), GPRS and GSM modems but also PLC technology. In order to manage data handling a new data centre has been established. The targets of the field test are to gain experience with reading and transferring huge market data volumes, to develop strategies for handling loss of data, to prepare the data for use on the market platform, to gain experience for the handling of software updates with respect to a huge number of smart meters and last but not least to gain experience about life times as well as operational costs of different smart meters. A smaller sample of customers will be equipped with energy monitoring systems ("energy cockpit") or the energy control tools ("smart home") of RWE Effizienz GmbH [3]. To these customers also a time dependent electricity tariff will be offered. Impact on energy consumption will be monitored and analyzed. By mid of 2012 all the equipment shall be installed and in full operation.

(2) Bitburg-Prüm: in this rural area a high photovoltaic and wind generation capacity has been installed. Despite the fact that we are talking about dispersed generation, load and generation densities clearly show that even within distribution grids the transportation task becomes more important. In this environment a test grid installation with a focus on the MV grid will be performed [4].

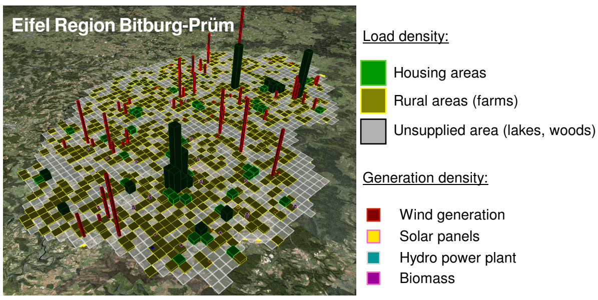

Fig. 4: Dispersed Load and Generation Density

Smart meters in feed-in as well as take-off points together with information and communication technology will allow a detailed monitoring of load flow and voltage. MV/LV stations will be combined with active voltage conditioners in order to guarantee LV quality despite of substantial load flow changes. MV quality will be maintained by the use of wide area voltage regulators in HV/MV substations. These regulators are monitoring several critical nodes via remote control and try to keep the nod voltages within a certain band. This increases flexibility on the generation as well as on the consumption side. The MV grid will be operated as a ring and will be equipped with electronic sectionalizers. This allows self-healing grid features in case of failures. Finally, a biogas power plant with storage will be combined with the solar generation to get a constant generation profile [4].

(3) Laudert, Kisselbach, Wiebelsheim (smart village concept): three villages are being connected to a high speed internet. Customers in two villages will be equipped with smart meters. As metering technology the SYM² concept is used. An algorithm for monitoring the load flow profile on a cable shall be developed and basic functions of an autonomous agent will be tested for a LV grid. Demand side management shall be tested with respect to public charging stations for electric vehicles and energy control tools ("smart home") for private households. Today, smart meter data are just used for market purposes while demand side management tools are operated separately. I.e., control units, monitoring and data management are not connected. For the first time, this field test shall implement an integrated LV smart grid concept.

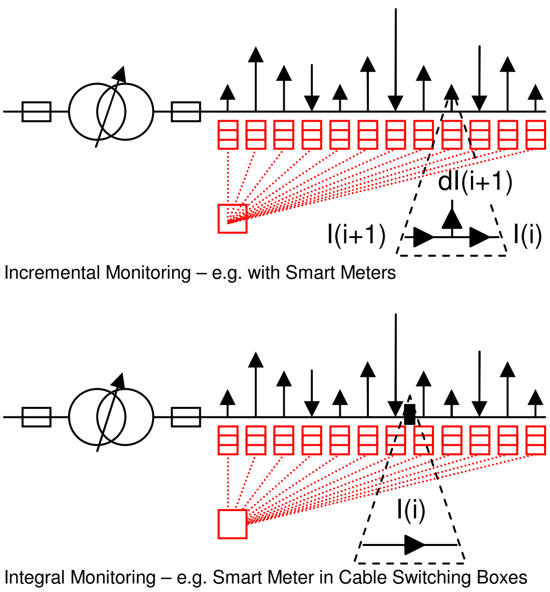

Fig. 5: Monitoring of load flow

Some questions related to the field tests: smart meters are delivering the change of the load flow along the cable. A robust integration algorithm has to be set up. Direct measurement of the load flow on the mains in cable systems is only possible in cable switching boxes. There is roughly one box for 10 to 15 houses. LV overhead systems are allowing an easier access. It is decisive to get all data from all smart meters synchronously. With respect to autonomous agents, MV agents are giving input to LV agents.

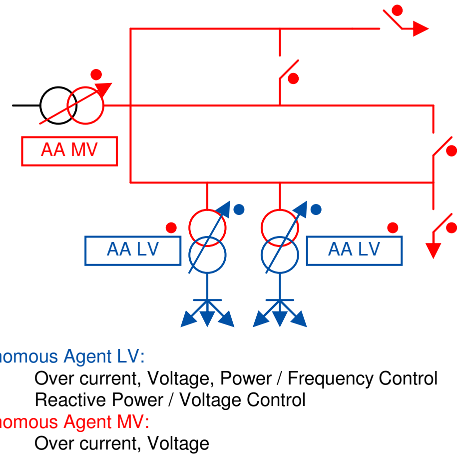

Fig. 6: Hierarchy of voltage levels and autonomous agents

CONCLUSION

The sustainable development of the existing distribution grids to so-called "smart grids" is a solution in order to manage the future tasks in an economic way. The basic concept of a smart grid has been described in a generic way. The requested technology is basically available. As the changes of the generation structure are already visible and the changes on the consumption side (electric vehicles and heat pumps) have already started electric grids have to be adjusted timely. We need standards to guarantee interoperability, a regulation that fosters investments, that distributes expenditure and benefits to all stakeholders in a fair way. Last but not least we have to integrate people into our ideas.

REFERENCES

[1] Birkner Peter, Küppers Stefan, Zdrallek Markus: "Requirements to and Future Need for Smart Grids in Germany" (German language), Proceedings of VDE Kongress 2010, Leipzig, November 2010

[2] EURELECTRIC – Union of the Electricity Industry: "Power Choices – Pathways to Carbon Neutral Electricity in Europe by 2050", Brussels, 2010

[3] RWE Effizienz: "Smart Home Modules", http://www.rwe.com/web/cms/de/468518/effizienz/rwe-smarthome/module/

[4] Hammerschmidt Torsten, Borchard Thorsten, Feldmann Jörg, Petermann Astrid, Rehtanz Christian: "Innovative Concepts for Efficient Electrical Distribution Grids", Proceedings of CIRED Conference 2011, Frankfurt, June 2011