Smart Grids: Real Case Experiences and Regional Perspectives in Mannheim and Salzburg

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***Abstract* -** The transformation of the energy system based on renewable energy resources requires flexible energy exchange mechanisms where smart grids are the basis for new grid and market functions with close inclusion of customers‘ needs and characteristics. In this article real case experiences and regional perspectives are described on the basis of the E-Energy project “Model city Mannheim” (moma) and several projects in Salzburg with an integrated approach. Especially the moma system is put in relation to the architecture of the EU-smart grid mandate 490 as well as to moma flexibilization functions. Common experiences in both countries and the next steps in Baden-Wuerttemberg are discussed.

***Keywords* -** *energy management, smart energy, distributed generation, renewable energy, smart grid, ICT, distributed automation, agent, system architecture, electrical vehicle*

I. Introduction

The transformation of the complex energy infrastructure and the accepted need of a sustainable energy economy puts pressure on today’s decision makers of energy infrastructure investments. On the other hand this radical change offers chances for economic growth, broad participation and a substantial reduction of primary energy resources.

Subsidiarity and connectivity are the keywords which lead to a sustainable energy infrastructure. It integrates decentralized generation, a variety of storage devices and diverse balancing mechanisms for electricity, gas, heat and the mobility sectors. The future energy system requires the balancing of local, regional and national interests as well as interconnection to the European energy system. This historic integration process will be successful, if active participation of a broad part of the population leads to regional market activities and a strong interconnectivity with the European system at the same time. A high level of participation and increased decentral generation facilities improve the supply stability of the system as a whole.

The basis for developing new infrastructure services is a market design with flexibility options and energy efficiency components as well as a thorough digitalization of the infrastructure and new grid code.

For that purpose the cellular system architecture combined with local energy management in the building environment, regional aggregation as well as distributed automation have been the design guidelines in the project “Model city of Mannheim” (moma) within the German Smart Grid program E-Energy.

In the Smart Grids Model Region Salzburg (SGMS) a variety of research and development projects were systematically put together in order to serve one purpose: system integration. The integration process covers all sectors, fuels, applications and players - across technological barriers, local regions, fuels and even political parties.

Now we see the necessity to implement in a next step country-wide smart grids on the basis of the historic infrastructure as well as on the recently built renewable technologies. The planned pilot zone “Smart Grids c/sells” will form the nucleus of such a smart infrastructure.

II. Real case Mannheim

The main feature of the moma project was the generation oriented load control based on variable energy prices especially using thermal flexibilities as well as the distributed and automated grid control in the distribution grid. These processes are combined with high connectivity to customer premises controlling the bidirectional energy flow. The new needs require the automation of market and grid processes as well as the management of energy generation, optimization within grid cells and interconnection of the grids [1], [2].

A. System Archtitecture and cellular Topology

The concept of distributed automation in grid cells in interaction with components in customer premises is the cornerstone of the system architecture and the communication requirements in the project moma.

The grid operation in the grid cells has been realized by grid automata (GA) whereas the market automata (MA) act as agents for aggregators, virtual power plant operators or energy providers. The automata were installed at the common infrastructure "alphaCELL" on a distribution grid cell server (DGC). They communicate directly with flexible loads and generators in the case of bottle neck situations. When grid problems are forecasted the grid automata interact with market automata demanding flexibilities.

The customer automaton called Energiebutler™ is responsible for the automated management of energy processes in its premise. Therefore, the Energy Butler acts as an energy management gateway (EMG) and at the same time as platform for the energy manager (EM) functionalities. It interacts within the premise with measurement devices (smart meters) and with energy resources (generators, storages, loads) of the prosumer (producer and consumer). It is also equipped with sensors and actuators as well as a machine interface for the end-customer (moma app). The described system is a bidirectional energy management interface (BEMI) [3] that forms the basis for communication with the environment, as well as for the decentral energy management within the local environment.

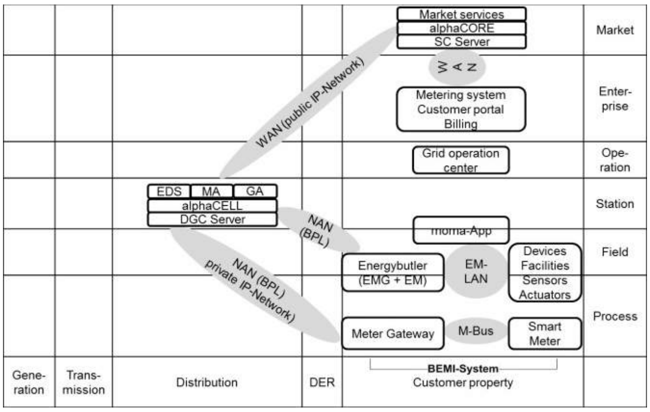

Fig. 1. Application of the smart grid architecture model (SGAM) onto the moma system architecture.

The grid and market automata communicate in so-called system cells that coordinate the grid management and services within the distribution grid as well as the utility systems and higher level markets. The integration infrastructure "alphaCORE" can handle real time and mass data. This forms the platform for services within a market cell. Figure 1 depicts the described components of the moma system architecture overlapped with the EU Smart Grid-Architecture (SGAM).

In moma, methods of distributed automation in distribution grids were developed on the basis of grid cells with interconnected control circuits. Therefore each premise can form an autonomous area within a grid cell. In doing so all grid cells interact as a connected grid region in hierarchical coordination with overlay grids. The instrument for the implementation of this approach is process automation.

B. Functions

In order to comply with the regulatory requirements with respect to the unbundling of grids and markets on the one side, but to simultaneously ensure the well managed coordination between grid and market on the other hand, as defined in the so called traffic light model [4] and [5], the concept of flexibility has been introduced.

Normally, anticipatory monitoring and forecasts should prevent failure. In case of a predicted constraint violation (yellow light), a mechanism is implemented as part of the moma simulation model that allows to acquire flexibilities within the local region via the market automation. The market mechanism can acquire these flexibilities either through an agreed-upon schedule or an incentive mechanism based on variable tariffs.

During normal operation without acute, as well as without predicted boundary impingement (green light), the market mechanisms works without any interaction by the grid operator. In this case, communication primarily takes place amongst market automata, overlying markets and energy managers within the customers' premises. The grid automation only receives the planned schedule from the market automation and otherwise works mainly in a monitoring mode. Should the grid automation recognize a overload situation, the yellow light mechanism is started, which allows the grid management to implement variable grid tariffs in order to change to a more flexible consumption. The field test runs within moma focused on the control of voltage and the limitation of peak loads.

In consequence, the project model city of Mannheim demonstrated an agent based decentralized control strategy as a major means to reduce the line loading, transformer overload and voltage overrun problems. The moma grid automata were modeled to increase the capacity of the grid lines by correlating day-ahead forecasts of generation and load curves. In real time, forecast discrepancies and voltage violations have been reduced through an auction trade model for flexibilities. The major result of the decentralized, distributed automation is that it could allow the increasing of the installed decentralized generation capacity to up to the double of the initial value without requiring additional grid reinforcement.

The testing of the method on a 15 nodes CIGRé benchmark grid has shown a 14% reduction of reactive power compensation from the TSO compared with the inverter based Q (U) method. Another effect was the increasing of the capacity of the benchmark grid for up to 200% without grid reinforcement.

III. Smart Grids Salzburg

The Salzburg AG and its partners have started their researches of Smart Grids with an integrated view following the philosophy "the whole is more than the sum of its parts". Smart Grids are enablers for the so called "Energiewende", as a system they serve their purpose.

Therefore is important to examine all the areas that relate to smart grids for identifying synergies. The Smart Grids Model Region Salzburg (SGMS) is EEGI labeled and comprises today of 23 projects, which are summarized into five smart grids areas of application:

1. The integration of renewables in distribution networks
2. The integration of E-mobility
3. The integration of residential customers
4. The integration of buildings
5. Load management in commercial and industrial enterprises

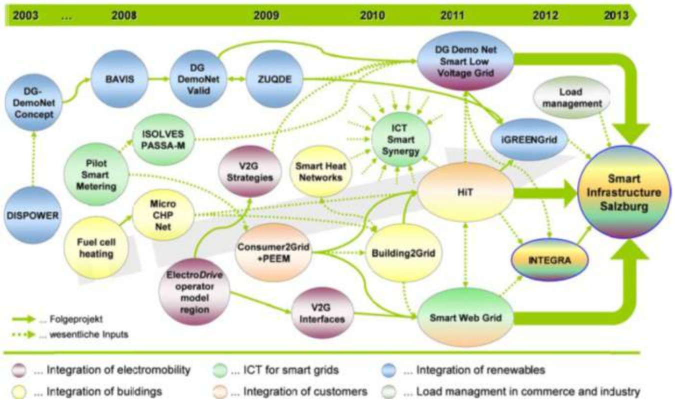

Fig. 2. The “big picture” of SGMS projects

The big picture shows all projects and smart grids application areas and their impacts to each other over the past decade of research. SGMS compares the economic benefits of various technologies like WiMAX[1], PLC[2], fibre optics (FO), coax, UMTS and microwaves. A potential of savings of approx. 30% was investigated compared to the worst case, where all applications need a separate technology – especially the multiple using of ICT connections contribute to the positive result. The connectivity of the last mile to the households via smart metering based on narrowband power line communication (PLC) shows little synergies to other smart grid applications except location synergies [6].

1. The integration of renewables in distribution networks

In a world of almost 100 % renewables there will be a very large number of decentralized and fluctuating energy generation infeeds mainly in the distribution networks. This development causes a great challenge for the distributed networks, which originally were built for supplying the consumers with one-directional electricity. The target of applications in that area is to increase the capacity of the existing grid by using intelligent planning, management, monitoring and voltage control, so that the costs remain at affordable levels.

2. Integration of E-Cars

If properly planned, E-Cars can serve as mobile storage devices. But there is also the danger of causing congestions in the local electricity network, if all electric vehicles charge at the same time. Therefore an intelligent integration of electric mobility into the electricity network which fulfills the market requirements and makes use of the existing network infrastructure is required. The research focus is on intelligent charging, ICT infrastructure and the development of business models.

3. The integration of residential customers

The target of this research area is to decrease the energy consumption and analyzing behavioral changes of residential customers. Intelligent technologies enable customers to play an active role and to contribute to optimizing of the energy system. The investigations here cover feedback systems with information about the actual consumption, automatic shifting of the load pattern within given boundaries and peak limit management.

4. The integration of smart buildings

Energy consumption in buildings reaches nearly 40%. So there is a substantial potential to reduce CO_2 emissions by integrating smart buildings into the intelligent grid. The future buildings contain intelligent storage management; at the same time they will produce their own energy. Future buildings will shift automatically the consumption without loose of comfort if they are well insulated. Demand side management and demand response as well as flexible load management will be established.

5. Load management in commercial & industrial enterprises

This area of application examines the load shifting potential of commerce and industrial companies additionally to the researches in residential and buildings.

IV. Common Experiences

The research results in the five investigated areas of the SGMS are impressive: The first area of application developed an intelligent network control solutions for the medium voltage network. This solution enables producers and consumers to use the existing infrastructure more efficiently and at the same time the capacity of the network can be enlarged for the infeed of much more decentralized renewable energy into the grid. The SGMS have come to the result, that an increase of approx. 20% is realistic in generating capacity in the critical sections of the network. The SGMS also has developed a solution for the management of the low voltage network and implemented it in Köstendorf, a small village at the vicinity of Salzburg. At this complex level, the active participation of all stakeholders is a must. For this purpose an application interface for mobile phones or iPads has been developed which interacts with the power system directly, because an increase of 20% - 40% can cause widespread congestions depending on the charging strategy. Therefore an adaptive charging was implemented.

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[1] WiMAX (Worldwide Interoperability for Microwave Access)
[2] Power Line Carrier

Vehicle-to-grid delivery of electricity is not economically under current market conditions. In a field test, various energy feedback methods produced average electricity savings of 6.7 % (but the variance was very high and cannot be directly attributed to a particular feedback method). Feedback on electricity consumption is a valuable source of information for residential customers but they are losing interest over time. Added values can be generated with the integration of services, but it was found that consumers basically expect monetary benefits for shifting their loads. The integration of buildings is more effective and easy to realize by expanding the building automation system. If buildings are well insulated, electricity use from the heating system can be shifted by up to 12 hours without loss of comfort. A Building Energy Agent (BEA) is a new developed energy management system which is integrated in Köstendorf, where approximately 50% PV and 50% E-Cars are integrated. The BEA manages all process information plus weather forecasts. BEA bundles all the shiftable loads in the building blocks so that it optimizes generation, Storage and consumption.

In the last area of research an investigation of one single enterprise showed that more than 4 MW capacities could be shifted with little efforts.

V. NEXT STEPS IN BADEN-WUERTTEMBERG

The various challenges shown in this article lead to the development of a roadmap of smart grids implementation in Baden-Württemberg [7]. The roadmap process followed a participative approach which resulted in a consensus paper signed by the 144 participants. The major findings of the smart grids roadmap are:

- Most of the required technologies are already available today or are making fast progress.
- The key challenge is to develop market frameworks which allow to exchange of flexibilities of all kinds as well as energy efficiency services - across sectors, actors, companies and individuals.
- The technological basis is an effective ICT infrastructure for the fast interaction between market players, grid operations and the smart building sector. Develop real-time machine-machine operation and system integration.
- The local and regional collaboration is supported by the European backbone.
- The key proposal of the smart grids roadmap is to develop a pilot zone with implementations of all components of an interlinked and highly performant smart grid: smart grids c/sells. As we expect a complete decarbonization of the energy sector, it should carry more than 100% of renewable generation from any kind of renewable source, primarily PV in Baden-Württemberg.
- This case “Smart Grids c/sells” will serve a show room for smart grids technologies made in Baden-Württemberg. “C”ells stands for the cellular approach, “sells” means that smart grids must be economic in the long run.
- Interaction with the transmission grid in Germany as well as cooperative models with the neighbor countries Bavaria, as well as Switzerland and Austria are important success elements in the concept.
- Focus areas are PV generation, cogeneration, use of flexibilities and the energy management of densely populated areas in partly autonomous energy cells.

Fig 3. Shows a possible system architecture for such a Smart Grids c/sells solution in the Smart Grid Architecture Model (SGAM) format of the European Mandate M/490. The components of the various technology providers are in the bottom layer. The energy integration system is responsible for the safe and secure interlinkage and integration. Here is also the devices registry, the information exchange room, the administration etc. The top one is the business layer, where flexibility exchanges take place within the infrastructure “cells”.

Our key approach consists of an economic framework, which enables a digitized market of flexibilities for all fuels and parties. This will require an integrative mass data processing in real time and secure way. Thus, there are still challenges ahead!

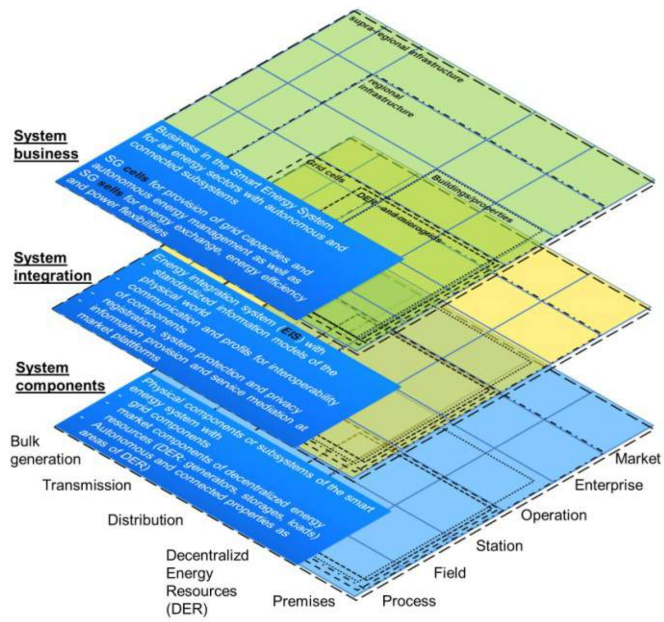

Fig. 3. Architecture model of Smart Grids c/sells.

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