INTEGRATED SMART GRID CONCEPT – EXPERIENCE IN A GERMAN DISTRIBUTION GRID

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ABSTRACT

The new German energy strategy – the so-called Energiewende – is mainly based on the large scale implementation of volatile renewable energy sources, like onshore wind and photovoltaic. As a consequence there are two tasks to be done. The first, time-based one is to keep the power balance between the fluctuating generation and consumption. This has to be managed by the implementation of a smart market which is coordinating flexible conventional power plants, demand side and – in future – storages. The second, location-based task is to manage the new high power and volatile load flows in the grids. The utmost challenge will occur in the distribution grid. By far the most of the new generation units will be connected there. In order to solve this challenge in an economic way the technical reserves of the existing grid have to be used. This means the transition from a static dimensioned grid to a dynamically operated grid. This approach is based on the availability of on-time load flow information and active load flow management. In general such a grid is a so-called "smart grid". A very promising concept – called iNES – with a high strategic potential has been developed and implemented in Frankfurt.

INTRODUCTION

In 2011 Germany decided to redefine its energy supply by implementing the so-called „Energiewende“. Phasing out of nuclear energy, minimizing the use of coal, substantially increasing efficiency, but above all, generating 80% of the overall electricity in 2050 based on renewable energy sources are the main pillars of the new strategy. The target for the year 2020 is a share of 35% of renewable energies in the electricity generation. This amount requests an installed capacity of green power in the range of 100 GW. The current German peak power demand amounts to about 85 GW. To backup such a system, conventional power plants of about 85 GW with significantly reduced annual operational times are necessary.

Beyond 2020 the installation of additional renewable energy sources will further increase the percentage of green power. At that time, the generated power will frequently exceed the maximum consumption. Demand side management, peak shaving and large scale reversible electricity storage are indispensable then. Furthermore, new renewable generation technologies – e.g. organic solar cells – and electrical devices – e.g. electrical vehicles, heat pumps, air condition systems – will be rolled out into the system. This creates numerous technical challenges whose solutions are discussed already today. The utmost challenges will occur in the distribution grid which has been designed and operated as a "one way" system – from source to sink.

In order to focus on the time period until 2020 the priority has to be put on the integration of renewable energy sources into the existing electrical system by two activities:

(1) Keeping the generation-demand balance and managing the generation volatility of renewables (time based issue) and

(2) Connecting the renewables to the grid (mainly on the distribution level), managing the transportation of electricity from new sources to existing sinks as well as the load flow volatility in the grid (time and location based issue).

The first activity means the implementation of a "smart market" that is using price signals as the control tool and "smart meters" as the information and demand side management instrument. The second activity means the implementation of a so-called "smart grid" [1] [2] [3]. Such a system is using the technical reserves of an existing grid, which becomes "smart" by monitoring the load flows and influencing those in case that voltage levels are not maintained or overloads are occurring. The control is based on online load flow information and direct load flow control in case of an infringement of rated values.

CONVENTIONAL SMART GRID CONCEPTS

Currently, there are many so-called smart grid field tests ongoing in which smart meters and demand side management driven by price signals are playing a central role. In line with the logic described those test should be better called smart market tests. With respect to grid centered options **Fig. 1** gives an overview over the "smart components" for low voltage grids available today: Voltage controllable MV/LV-transformers (voltage measured in the transformer station or voltage measured remotely in the grid) are often considered to make a grid “smart”.

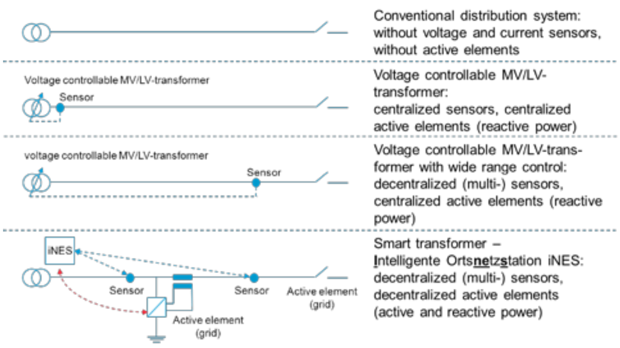

Fig. 1: Systematic of smart grid concepts

INTEGRATED SMART GRID DESIGN FOR LOW VOLTAGE GRIDS

The newly developed system “iNES” – Intelligente Ortsnetzstation – goes far beyond these concepts and offers a huge range of new options (**Fig. 1 and 2**). Decentralized voltage and current sensors are installed in the public grid at sites defined by a specific algorithm upfront. Their number is minimized. The measured data are online transmitted by power line carrier technology to the MV/LV transformer station. An autonomous online state estimation algorithm – running on an autonomous agent called “Smart RTU” – is calculating the load flow and the voltage distribution in the LV grid. In case of voltage problems or overloads – based on physical reasons or triggered by the market – the iNES system reacts automatically. First, grid based actors – e.g. voltage controllable transformers or voltage controllers – are adjusted. Second, the reactive power of loads and generation units is influenced and third – if not avoidable – customer based actors – e.g. reduction of active power of load or generation – are involved. As a rule only the last mentioned intervention is disturbing the customer. Thus, with a minimum impact on the customer it is possible to avoid or at least to postpone up to 50 % of grid investments [1][4][6].

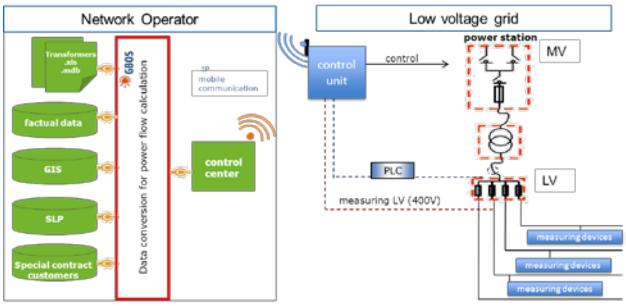

Fig. 2: Basic design of the autonomous agent “Smart RTU” with load monitoring and control functionalities

Fig. 3 gives an overview over the underlying market model and shows the interaction between smart market and smart grid. Given the case, a supplier has a surplus of electricity in his portfolio he reduces the **price globally** and all his consumers – who are connected to many LV grids – increase their consumption. This has an impact on the market but also on the various LV grids. The DSOs are monitoring the situation and only in case of **local problems** they are intervening on a local base with **minimum impact** measures. A limited number of interventions will not distort the market.

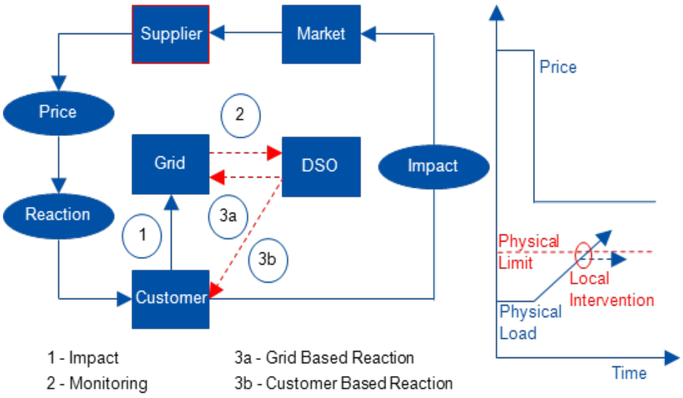

Fig. 3: Interaction of smart markets and smart grids

The smart grid concept iNES gets the information from independent sensors. If available and suitable also smart meters can be used. In order to react, actors are necessary. In case of grid bound measures they are directly connected to the active grid elements. For customer bound measures a direct connection to the customer’s devices is an option as well as the integration into the smart home facilities.

THE FRANKFURT FIELD TESTS

Since mid 2012 two Frankfurt low voltage grid areas – one rural and one urban – are equipped and successfully operated with the iNES technology (**Fig. 4 and 5**) [5][6].

Fig. 4: Field test in the urban quarter Bornheim (three transformer stations and meshed LV grid – screen shot)

Fig. 5: Field test in the rural area Bergen-Enkheim (one transformer station and radial LV grid – screen shot)

Both areas are characterized by a high share of installed photovoltaic capacity. In the rural testing area the length of LV line amounts up to 600m.

EXPERIENCES AND RESULTS

In the last six months the focus of the tests has been put on the demonstration of a robust function of the iNES devices as well as the proof of a well-functioning state estimation algorithm that shows the requested accuracy and sensitivity, i.e. neither an overreaction nor an overlook of a critical situation.

This phase one of the tests clearly has proven that sensors, power line carrier technology and smart RTU have been working without any problems. Also the sensor positioning algorithm and the state estimation algorithm fulfilled all expectations.

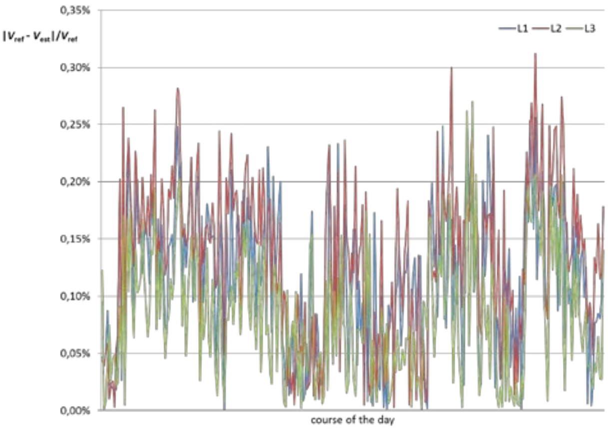

Fig. 6: Difference between the calculated voltage based on the very few sensor data and a consistent set of data for all nodes in the test grid

Fig. 6 shows that the difference between the algorithm based voltage of a node and the "real" voltage is below 0.5% [5]. **Fig. 7** gives an example of a – non-critical – voltage increase based on the current injection of a solar panel.

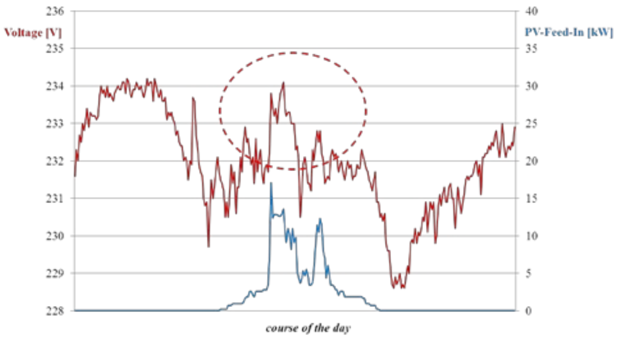

Fig. 7: Three phase voltage diagram in the LV grid

COMPLETION OF THE LOW VOLTAGE SMART GRID

In phase two the focus will be put on actors. Due to this, an electronic voltage controller as an actor will be installed in the rural test area while the urban test area will be equipped with controllable transformers. Fig. 8 shows exemplarily the effect of a voltage controller in extended LV grids with long feeders.

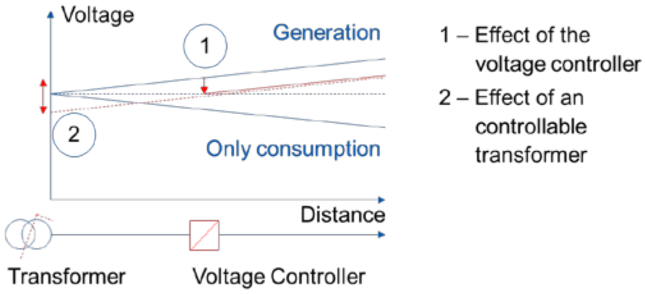

Fig 8: Basic functionality of voltage controller and voltage controllable transformer

In addition – as far as technically feasible – the solar panels of the customers will be equipped with reactive power control units. Active power control – which is and should stay the last option – is already possible today. At the moment the project is in the designing and planning state.

EXTENSION OF THE CONCEPT TO THE MEDIUM VOLTAGE LEVEL

With respect to phase three, the iNES system shall be extended to the medium voltage (MV) level. **Fig. 9** shows the design principle. The LV iNES equipment – above all the smart RTU – is used as a sensor which provides the values of voltage and current in a MV/LV transformer station to the superior smart RTU positioned in the HV/MV substation. In addition, for MV/LV transformer stations without a smart RTU, specific cable terminations with integrated voltage and current sensors are available. Actors are the voltage controlled HV/MV transformer (reactive power), MV switches (active power) and the smart RTUs in the MV/LV transformer stations (active and reactive power). These smart RTUs are directly addressing their actors in the relevant LV grid. Again, grid based measures are taken first and customer based measures last. Data transmission between sensors, actors and smart RTU is managed through GPRS. Whether PLC is an option still has to be analyzed.

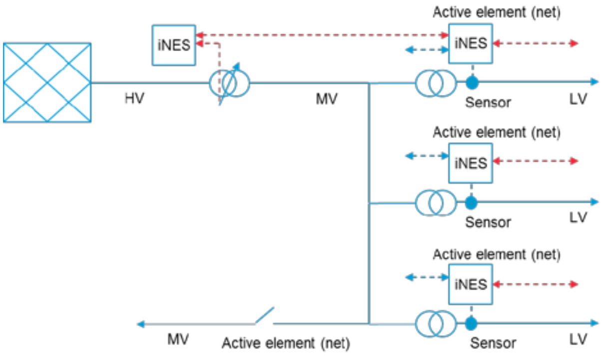

Fig. 9: iNES system in the MV level (red dotted lines are symbolizing the control connections – actors – and blue dotted lines the information paths – sensors)

THE INTEGRATED SMART GRID CONEPT

The iNES system has a modular structure and it is possible to integrate additional elements, like smart meters (sensors) or energy storages (e.g. batteries, actors). However, due to the existing experience the integration of smart meter is quite difficult: the data owner is the customer, the values are incremental and the online availability is limited. The use of smart metering for grid purposes seems to be limited to ex post load flow analysis.

With respect to urban development solar power has a great potential as a future urban energy source. Solar panels can be integrated into buildings and thus provide new options for urban architecture. The combination of silicon solar cells for direct light, organic carbon based solar cells for diffuse light and modern batteries provides an exciting option for architecture and the future energy supply and it is possible to consume most of the energy produced locally.

Finally, the iNES concept can be also used for contributing to the power frequency control: only a frequency dependent load reduction algorithm has to be implemented in the smart RTU of the HV/MV substation.

SUMMARY AND CONCLUSIONS

The iNES concept has proven to provide all the features requested for the establishment of a smart grid. Still two testing phases have to be done, however, from a technical point of view a smart grid has become reality. Regulatory and legal aspects, defining rights and obligations but also liabilities still have to be adjusted to the technological options. From a sociological point of view the customer has to learn that he is no longer still a consumer but an active player with rights and obligations. The more the customer is willing to be an active part of the smart system, the cheaper the costs for the grid of the future will be.

One final aspect, it seems that grids are having sometimes more reserves than supposed. Standardization which uses the same cable type within one grid area creates unexpected reserves above all in low load districts. However, iNES helps to discover also those cost reducing elements in electric systems.

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