

## A STRUCTURED APPROACH FOR SMART GRID IMPLEMENTATION

Wolfram H. WELLSSOW  
 Technical University Kaiserslautern - Germany  
 wellssow@eit.uni-kl.de

Theodor CONNOR  
 Siemens AG - Germany  
 theodor.connor@siemens.com

Christine SCHWAEGERL  
 Siemens AG - Germany  
 christine.schwaegerl@siemens.com

Reinhard BREHMER  
 WIEN ENERGIE Stromnetz GmbH - Austria  
 reinhard.brehmer@wienenergie-stromnetz.at

Thomas SCHUSTER  
 WIEN ENERGIE Stromnetz GmbH - Austria  
 thomas.schuster@wienenergie-stromnetz.at  
 public infrastructures. In addition to the well known system

### ABSTRACT

*The paper addresses the transition from the existing power distribution infrastructure to a future "smart grid" architecture. Solutions and functionalities needed under the assumption of a further increasing share of distributed generation and bulk fluctuating generation from wind and big solar power plants are discussed. The paper aims at providing a structured approach on the objectives of system improvement, the related smart grid technologies, the players involved as well as a rough cost-benefit analysis.*

### TRENDS IN DISTRIBUTION SYSTEM DESIGN

#### Typical system design as of today

Electricity supply started with islanded systems where generation and load were very close. Due to the benefits of electricity it started to be used frequently and the demand rose in cities as well as in industrial complexes and rural areas. It ended up in the large interconnected AC systems which we experience today with large scale generation at suitable locations based on primary energy, transmission and distribution into the load centres or rural areas.

In this framework distribution system design and operation were driven by cost optimization. This resulted in a top down power flow through radial medium voltage networks with hardly any visibility of the network status. For LV radial as well as meshed structures were applied but also hardly any visibility of system status was given.

Driven by environmental constraints with increasing shares of local and renewable generation and the progress in communication technologies a conversion from top down, "blind" distribution systems towards active, interactive, "intelligent" and transparent MV and LV networks is at the horizon.

#### Challenges

The challenge is to identify the technical feasibility, to analyse the benefits and to develop the road map to convert existing systems into future oriented systems. In contrast to transmission systems distribution systems have an enormous installed base of equipment of different brands and age and these are located in close proximity to other

operators new players try to offer their services. Therefore it is essential to show business cases to solve the "Trilema" of investment/operation costs, quality of supply, and the prize of electricity to end customers.

### THE FUTURE OF DISTRIBUTION SYSTEMS

#### Targets and solutions

Table 1 gives an overview on targets, players, concepts and solutions, many but not all of them usually being referred to as "Smart Grid" solutions.

All considerations should start from the objectives to be met rather than from technologies applied even though some of these objectives are in contradiction to each other. Also investors and beneficiaries are not necessarily the same. To overcome these hurdles incentive schemes or market models must be developed and implemented.

#### Retaining reliability of supply

The best way to keep the high European reliability of supply despite of increasing shares of intermittent generation and aging infrastructure is to increase the level of automation by using state-of-the-art SCADA technology in ring main units. Smart Meters don't help as meter data origin from the LV level and can't help to localize a fault. Even more, these data are usually not available in due time. Certainly new grid concepts offer great opportunities, see below. However, in European systems equipment monitoring in general will have a minor impact.

#### Improvement of voltage quality

The active participation of distributed generators in voltage control shall be the preferred solution as it follows the polluter-pays principle. Today's DC/AC converters have the ability to control the power factor. However, self-governed control schemes need to be defined and the grid codes must be adjusted accordingly and/or attractive incentives must be offered.

As grid-side alternatives LV-transformers with on-load tap changers (OLTC), grid-side power electronics or new grid concepts as closed ring structures can be applied, see the example below with implementation at WES GmbH.

**Table 1: Objectives of Distribution System Development**

Objective	Investor	Beneficiary	Concept and Technology
Securement of supply reliability	Grid operator	Power consumer Grid operator (in case of quality regulation)	<ul style="list-style-type: none"> <li>• Distribution grid automation</li> <li>• New grid concepts</li> <li>• Equipment monitoring</li> </ul>
Improvement of voltage quality	Grid operator	Power consumer  Grid operator (in case of quality regulation)	<ul style="list-style-type: none"> <li>• Participation of distributed generators in voltage control</li> <li>• DSM (based on smart metering)</li> <li>• LV-transformers with on-load tap changers (OLTC)</li> <li>• Reactive power control by power electronics at grid side</li> <li>• New grid concepts</li> </ul>
Reduction of / equal low grid loading	Grid operator Metering service provider	Grid operator	<ul style="list-style-type: none"> <li>• Distribution grid automation</li> <li>• DSM (based on smart metering)</li> <li>• Storage</li> </ul>
Loss reduction - technical - non technical	Grid operator Metering service provider	Grid operator Power consumer (reduced bill)	<ul style="list-style-type: none"> <li>• New grid concepts</li> <li>• Participation of distributed generators in voltage control</li> <li>• DSM (smart metering)</li> </ul>
Simplified grid operation	Grid operator	Grid operator	<ul style="list-style-type: none"> <li>• Distribution grid automation</li> <li>• New grid concepts</li> </ul>
Active power balancing	Metering service provider Energy supplier	Energy trader Energy supplier Balancing responsible party	<ul style="list-style-type: none"> <li>• Participation of distributed generators in active power balancing</li> <li>• DSM (based on smart metering)</li> <li>• Virtual power plants</li> <li>• Storage</li> </ul>

**Active power balancing**

Active power balancing in principle can be done at generation side, load side or by using storage units. In the past generation side balancing was utilized almost exclusively. With growing intermittent generation this will become impossible in the near future. As storage is still expensive and has limited efficiency a significant share of balancing needs to be done by loads.

In principle different technologies for demand side management (DSM) are available. It is questionable whether a sufficient amount of control power can be sustainably mobilized by incentive schemes only. In fact a closed-loop control will be necessary and the appliances must be equipped with storage capabilities in order to allow DSM for longer periods without compromising the comfort of the users.

The most prominent example is the electric vehicle (EV). In future, it will be necessary to introduce controlled charging in order to avoid grid overload and high peaks in active power demand regardless of any incentive scheme.

Studies performed with existing distribution networks have shown that by intelligent charging control voltage deviations, line overloads and network losses can be significantly reduced [1]. In theory vehicle to grid services can be provided by using car batteries for feeding power back to the grid. However, current battery technology and driver's expectations concerning availability and convenience provide technical and socio-economic limitations. Under the given conditions in Germany an aggregation of EVs to participate on reserve markets is economically not attractive; it yields only minimum earnings per car compared to high technical efforts [2]. In any case this vehicle to grid services will not be available in the near future.

Heating and air conditioning of buildings promise a much higher storage capacity at far lower prices.

It is important to notice that the "load follows generation" approach contradicts the objectives of DSOs, who are interested in an equal low grid loading. DSM may cause loads being artificially correlated in time resulting in a worse utilization factor and higher load peaks the grids need to be designed for. In any case it must be avoided that the end customer is exposed to contradicting incentives. The future will show which of the conflicting targets will be accomplished.

Storage at grid-side is always much more expensive compared to storage of primary energy (gas, coal) and storage at load side (in particular thermal) [3]. It is therefore highly questionable whether incentives for grid-side storage, e.g. batteries at wind parks, are reasonable from a gross economic point of view.

Contributions from virtual power plants (VPP) may be very promising. Even though the prime intention is to take economic benefits from participating in power markets the technology offers options for grid support and active power balancing.

While the participating units of VPP can be spread over large regions, the concept of Microgrids comprises distribution systems with different micro-generation units, storage devices and controllable loads that can be operated coordinately. A Microgrid can typically operate grid-connected, whereby it can exchange electricity with the upstream grid [4]. However, in case of failures in the upstream network a Microgrid may also operate autonomously like an islanded network, in which case it would solely rely upon its own resources to maintain demand/supply balance with adequate level of reliability and power quality [5]. In principle, this is a proven concept in case of sensitive loads as e.g. chemical plants and the associated efforts and costs are well known. Therefore, except from these special cases, in the presence of highly reliable

interconnected systems the idea of autonomous islanded Microgrids has its source in a more political intention. An increase in quality of supply is for sure not achievable and the relative size of installed capacity and necessary storage grows dramatically with smaller systems, as can be studied with geographical islands, some industrial sites, ships, oil-drilling platforms etc. It is for good reasons that systems have been interconnected in the past century and are getting even tighter knitted together today.

### **Future requirements**

It is important to understand that “Smart Grid“ solutions will neither make obsolete the optimization of grid concepts nor a solid “classical“ grid planning. The attempt to solve issues in grid structure by “Smart Metering“ or other IT solutions only will fail. In fact a long term development strategy of transmission and distribution systems is mandatory taking into account the rapidly changing framework conditions and technologies for primary equipment and automation solutions. The result is a target concept for the individual distribution system defining the optimum grid structure and the most important key technologies including IT and automation.

## **IMPLEMENTATION AT WIEN ENERGIE STROMNETZ**

### **Starting point and targets**

Wien Energie Stromnetz GmbH (WES) is the biggest distribution system operator of Austria. The supply area is about 2,000 km<sup>2</sup> with 2 million customers. The network of WES covers about 1.5 million meters, 46 substations (380 kV/110 kV to 20 kV and 10 kV), more than 10,000 transformer stations from MV to LV and a line length of 22,000 km. In 2009 the demand exceeded 11 TWh.

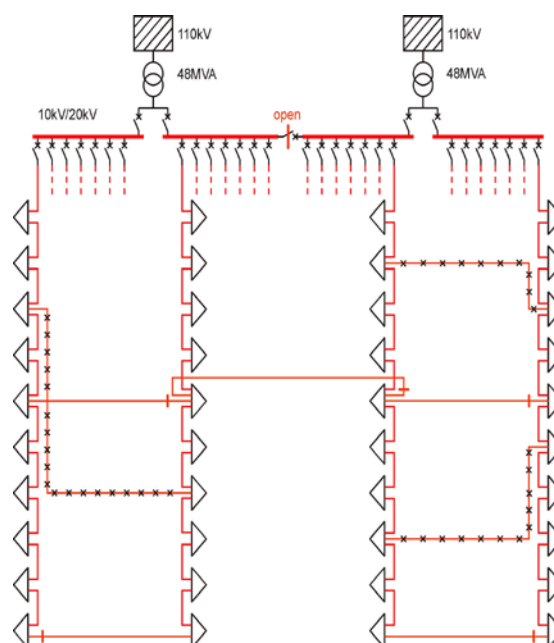
At HV level, i.e. 380-kV- and 110-kV-systems, WES has already implemented a “Smart Grid” in the sense that the system is fully automated. All information for operation (voltages, currents, also faults), including the dispatch at MV level in the substations, is directly reported via SCADA to the system operator in real time. At MV and LV level there is no such information available in real time so far.

The dispersed generation, in majority wind power, is mostly connected to the MV grids, but more and more photovoltaic generation will be connected to the LV grids. The main goal for the future is to upgrade the distribution grids into new well monitored grids to cover all new requirements coming from regulator, consumers and suppliers.

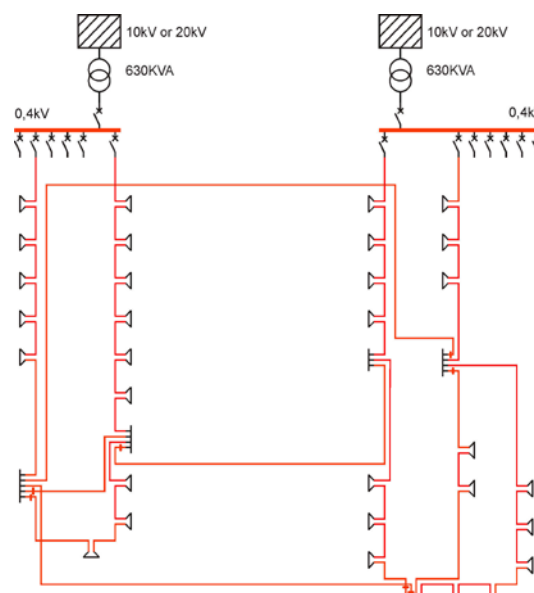
### **The way to a future-proof distribution grid**

The historical requirements for DSOs were completely different from today and the future. In fact the DSO only had to operate the grid with a high quality and security of supply, the load flow was in one direction only; from cen-

tralized generation to the customers. So the MV grid is built as an open ring feeder system with open connections to other feeders (Figure 1). The main advantage is, that fault handling and planned switching e.g. for maintenance is simple and fast. The LV grid is built as an “open meshed network with loop-through technique” with a lot of open connections to other lines (Figure 2).



**Figure 1: Ring feeder system with open connections to other feeders at MV level**



**Figure 2: Open meshed network with loop-through technique at LV level**

Following the concept given in Table 1, with the connection of higher numbers of small dispersed generation and EVs new requirements mainly on MV and LV levels be-

come relevant now:

- Securing the power quality (e.g. voltage control)
- Reduction of grid losses

The following measures will be taken:

- Definition and implementation of new target structures for the MV- and LV-grid
- Implementation of communication between all grid users to maintain high quality of supply

All this becomes increasingly challenging due to the pressure to reduce investment and maintenance cost set by the regulator.

### **Technology choice and road map**

Primary target for WES is to optimize the MV grid. No longer needed connections will be eliminated. The average number of transformer stations for a 10 kV feeder will be reduced to ten; every fifth station will have a connection to another feeder. At 20 kV the average will be twenty with every tenth station having a connection to another feeder. In general, the operation as an open ring feeder system will not be changed. In WES the internally authorised maximum current for each line is 60 % of its rated current. So, during faults there is the possibility to switch the entire line to the next feeder to reduce customer minutes lost (CML). Important nodes will be identified (about 15-30 % of all) and adapted for monitoring in the SCADA-System. At present transformer stations are neither equipped with suitable meters nor capable measurements or communications. In the future they should have a fibre optic cable connection.

The adaptation of the LV grids is much more complex compared to MV grids as the grid is designed as "open meshed with loop-through technique" without any monitoring and control. Faults are cut off only by fuses. In the future each LV feeder has to be measured in the transformer station and the relevant information will be transferred to a LV control system, preferably via optical fibres. Now there are two ways for operating the grid. On-line calculated power flow will automatically lead to

1. Transformers with on-load tap changers (OLTC)
2. Opened switches

The first point requires MV/LV transformers with OLTC. As up to now transformers have to be switched off to adjust their transformation ratio all transformers would need to be exchanged. This is not practicable due to very high costs of new transformers and their difficult replacement, as most of them are placed in cellars.

For the second point a stepwise implementation is possible. After installing measurements and communications, additional switches are placed in important nodes. This will convert "open meshed network with loop-through technique" into a "meshed network with loop-through technique".

Advantages are the reduction of grid losses at LV level, the easier implementation compared to transformer exchange,

and the knowledge of the load flow at LV level helping to control dispersed generation and charging of EV.

In the future more and more dispersed generation and EV charging stations will be built and in addition also energy storages will be implemented. The control of all this new equipment must be highly secure and integrated in the DSO information network. Dispersed generation has to be bundled into virtual power plants in a way that a MV/LV dispatcher can control the volatile input of e.g. photovoltaic generation. Also charging of EV has to be controlled automatically.

In any case there will be a stepwise transition from today's grid structure to an advanced smart grid which will take at least two decades. As outlined this will comprise much more than only ICT measures.

The most important prerequisite is to secure the substantial investment needed for so many measures over such a long period.

### **First experiences**

WES has already started with an optimization program to eliminate feeders that are not needed any longer, e.g. parallel lines and connection lines before or after each 5<sup>th</sup> (10 kV) or 10<sup>th</sup> (20 kV) substation. These lines are taken out of operation after faults, rebuilding of transformer stations or re-allocation of lines.

In all transformer stations that are added or renewed short circuit and earth fault indicators are being installed.

Furthermore to increase selectivity in case of faults, additional circuit-breakers and earth fault indicators (flash lights) are installed, preferably in feeders with overhead lines.

All these measures help to reduce an affected zone in case of faults.

### **REFERENCES**

- [1] M. Hable, C. Schwaegerl., et. al., 2010, "Requirements on electrical power infrastructure by Electric Vehicles", *Internationaler ETG-Kongress Leipzig*, Germany
- [2] C. Rehtanz, J. Rolink, 2010, Evaluation of the Application of Electric Vehicles for the Provision of Ancillary Services, *Internationaler ETG-Kongress Leipzig*, Germany
- [3] VDE, 2009, *Studie Energiespeicher in Stromversorgungssystemen mit hohem Anteil erneuerbarer Energieträger (Study on energy storage systems with high shares of renewables)*, Germany, www.vde.com
- [4] C. Schwaegerl, L. Tao, P. Mancarella, G. Strbac, "A multi-objective optimization approach for assessment of technical, commercial and environmental performance of Microgrids", ETEP 2010
- [5] Schwaegerl C., Tao, L. Mancarella, P., Strbac, G., "European Roadmap for Microgrids", CIGRE 2010, paper C6\_306\_2010