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INTEGRATION OF DISTRIBUTED BATTERY STORAGES IN MODERN POWER GRIDS

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Abstract **– SmartGrids are the core of the future power supply. They are cell-wise structured, intelligent power grids which are interconnected to exchange both energy and information. In each SmartGrid, control center engineers will supervise the grid and dispatch its distributed, renewable generators (RES), the assigned power plants, the loads and the energy storages. Wind and PV generation, however, is volatile and subject to the weather. Small distributed battery storages in the distribution grid to compensate their fluctuations can be a new approach to solve the problem. This paper presents first the results of a research project between the University of Applied Sciences Darmstadt, Germany, and the regional DSO, HSE Energy. The final goal is to transform the regional distribution grid to a SmartGrid with 30% RES generation till 2020. The authors' calculations have shown that stationary, distributed battery storages in the distribution grid have a couple of positive effects: The peak load can be reduced, investments in grid assets can be postponed and the number of full load hours of RES facilities are increased significantly. In times of a high spread in energy prices, they even reduce energy acquisition costs. The paper shows two of these applications for battery storages and some rules for dimensioning and planning. In this context, the authors also doubt the suitability of unbundled electricity market structures for future tasks in operational control of Smart Grids.**

Keywords: *smartgrids, renewable energy sources, battery, storages, unbundling*

1. INTRODUCTION

According to European climate protection policies the electric power supply in Europe will change significantly. The South-Hessia region in South-West Germany is being supplied by HSE Energy AG in Darmstadt. While maintaining the usual reliability, the power is supposed to come from renewable and environment friendly sources (RES), in the year 2020 about 30% of the annual energy. In order to achieve this goal, concepts are developed with companies and research institutions, RES investments are made inside and outside the HSE grid, pilot projects are launched and the communication and data management is extended. In the seventh framework programme of the European Commission, the research project Web2Energy is sponsored, where HSE Energy has leadership of a European consortium.

In the project, many small generators are coordinated as a virtual power plant, for instance so that the generated power can be planned and matched with the demand. Additionally a battery storage management is realized.

In this project, one issue is the testing of distributed battery storages (accumulators) in the distribution grid. They shall be interconnected as a virtual power plant (VPP) with a communication infrastructure based on IEC 61850 and take over grid energy regulation tasks.

The authors elaborate in particular the question of how much fluctuations can appear, which storage sizes are needed, which storage locations are suitable, which impact they may have and which costs are to be taken into account.

The HSE distribution grid is supposed to be transformed to a SmartGrid, a grid with a high share of RES and intelligent control.

The grid structure as well as the task of operational control will change significantly compared to the past.

This paper will present the tasks, concepts and first experiences with the pilot installations.

2. MICROGRID, SMARTGRID, SUPERGRID – STRUCTURE OF THE FUTURE POWER SUPPLY

The terms MicroGrid, SmartGrid and SuperGrid emerge to describe the new grid structures. Since there are no binding definitions yet, the authors use the terms in a three-level grid structure as follows: The future power grid is structured cell-wise, where

-MicroGrids are small grid cells, e.g. feed zones of a 110/22kV power transformer in a substation with a few 10 MW peak load

-SmartGrids are the superior units, containing the MicroGrids to be supervised, e.g. of a city utility, typically in the power range of some 100 Megawatts.

The existing control centers of the utility can perform the operational control of the SmartGrid.

Important data concerning the current power balance and the forecast is sent to the superior control center of the national area. Power and energy can be balanced at that level, using a trader platform.

-SuperGrids are new planned DC grids (HVDC), superior to the 400kV three-phase grids, which enable a continental energy exchange. They shall be supervised by a new UCTE control center which is yet to be realized. The energy exchange is done through the grids, bidders and buyers work together using a trader platform.

SmartGrids are the core cells of the future power supply. They contain a multitude of distributed RES infeeds, depending on the possibilities in the supply area: wind turbines, PV plants and (biomass-) gas turbines in CHP operation. Shares of large offshore wind farms outside the grid area bring additional energy in the SmartGrid. In a few years, we will be facing a large number of small generating units in combined heat and power operation (CHP) installed in domestic households, an appropriate market model is going to be provided.

Furthermore, storages will be integrated which have to be managed to guarantee the coverage of load at any time. Outages and forecast deviations shall be compensated at least partially with internal resources, to provide further ancillary services.

There are mainly two tasks in the SmartGrid: Load balancing and operational control. First the load balancing: According to the German Energy Industry Act, the power from internal RES generators must be evacuated. For further coverage of 30% RES, contracts for RES outside the grid have been made. Additional conventionally generated power blocks are ordered at the stock exchange.

Eventually an interchange schedule is sent to the transmission operator (TSO) of the regulation control area. However, forecast and reality do not always match, neither on the generation nor on the load side. Nowadays the deviations are compensated using larger regulation plants with primary and secondary control to maintain the grid stability, e.g. hydro storage plants and thermal units.

The instant availability, short operating times and fluctuating power cause high specific costs for regulating energy. Increasing the share of weather dependent, fluctuating RES plants grows, deviations get bigger and the regulation task becomes more difficult.

About operational control of Smart Grids: The control of the grid, its loads and power transport is in charge of the system operator who decides on switching operations, maintenance and repairs. With growing fluctuations, the transported power changes more frequently and faster. Even the flow direction and the station voltages will alter. Operational control becomes more complex, too.

Both tasks, grid control and power balancing, are closely linked, since the power which is generated at different places and times in the grid must be evacuated and transported, and ancillary services must be provided permanently. The unbundled market structure is compounding the problem. Another question of additional grid services comes up, because a SmartGrid can contribute to primary control if, for instance, battery-inverter systems can activate a fast power reserve.

3. THE MAIN TASK: GRID STABILITY

Grid stability requires a fast power reserve (primary and secondary control) to ensure frequency stability and reserve energy. The weather dependent RES fluctuations are a problem for the grid stability. This problem can be reduced by a wide-area exchange of energy, because somewhere in Europe there is (nearly) always wind and sunshine.

However, the existing UCTE transmission grid has a limited transmission capacity and is already being overloaded occasionally in certain areas. This limits the possibilities of equilibration and the free trade. A supplementary HVDC supergrid shall allow long distance transports of solar power from North Africa to Europe.

However, the wide-area expansion of the European grid to meet every possible RES-infeed situation is very costly, apart from socio-political difficulties when realizing new power lines.

But there is an alternative: Costly grid expansion can be avoided when „locality“ is the main stability principle of the future grid cells: The locally emerging fluctuations and deficiencies are compensated – at least partially- locally.

Domestic „energy agents“ communicating with each other and controlling household devices are a recent approach, though they give rise to consumers' doubts regarding data protection and will create enormous need for communication. Further the system reaction of (not) participating or (un-)available customers and end devices is rather unsure.

On the other hand, distributed storage units, for example battery-based, are more reliable and easier to schedule. They can provide both, a fast power reserve and reserve energy. It will be left to market mechanisms whether the assets of the system operator will be used or those of another market player using a trade platform.

Disregarding the unbundled energy market for one moment: The operational task in the SmartGrid is to react to schedule deviations. Decisions must be made, which measures and controls of internal and external components will compensate the deviation and which transports are necessary. The task is visualized in figure 1.

Deviations can be compensated internally by controlling, e.g. virtual power plants (VPP), battery units (B), biogas turbines with/without gas grid connection (BGT) or using Demand Side Management (DSM). Spontaneous deals at a trade platform are possible, too, where available storage energy can be offered. Hydropower and biogas plants can contribute well to stability, they are easy to schedule and flexible. Already a combination of wind power plants, photovoltaic systems and biogas turbines provides higher stability. According to the German Energy Industry Act, biogas plants may buffer purified gas in the high pressure grid, which is another large energy storage.

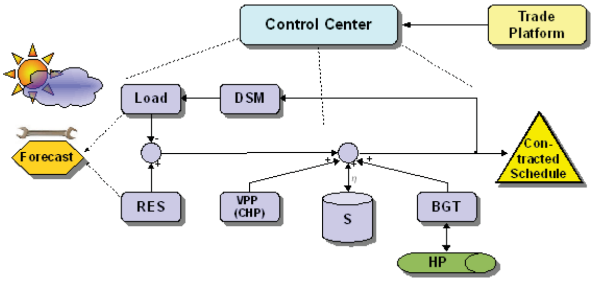

Figure 1: SmartGrid and components for energy regulation

The above described principle of locality requires to compensate missing or overshooting energy locally when deviations from the schedule occur. This can be done using battery storages in the grid (B), a proven technology in UPS systems. They can provide a fast power reserve and, together with modern power electronics, have a voltage stabilizing effect. Distributed battery units stabilize the voltage in a wide area and avoid long-distance transports. Battery capacity, rated inverter power and control logic depend on the corresponding task and reserve energy needed. Today, they are still relatively expensive, so it is favorable to cope with least storage possible, i.e. to optimize their individual application in the grid.

4. DISTRIBUTED BATTERY STORAGES

Different types of distributed battery storages are feasible:

Battery packs are small units in the kWh range (fridge size) at the low-voltage level. They are line-commutated storages which are managed by the control center with off/charge/discharge-commands. Possible installation locations are LV transformer stations, basements of public buildings or residential houses.

Medium-size to large storages are in the range of some 100 kWh to a few MWh and can be installed in substations. They are designed as controllable storages which are able to, for example, regulate a target value of power given by the control center.

Mobile storages in electric vehicles (V2G) are nowadays in the range of 10-20 kWh. Though illustrated differently by the media, traffic simulations show that energy buffering using e-cars is not yet successful due to their relatively small battery capacities and changing recharge locations.

Even additional load peaks are more likely to appear when all cars are downtown and willing to load in the morning. They probably will successfully work with significantly bigger storages, although the business models are yet to be established. In particular the stationary storages in a suitable location have a couple of positive effects:

- compensating the fluctuations of RES generators and loads
- the bills of high-priced regulating energy can be avoided
- the expansion of the grid can be postponed when batteries buffer the overload
- batteries provide an instant reserve
- together with contemporary power electronics, batteries are voltage-stabilizing
- a RES plant can be over dimensioned regarding its grid connection
- increase of full load hours, even transforming a RES plant to a 24h plant

Below, two application cases are looked at more detailed.

4.1. Compensation of load fluctuations with battery storages

A first example: A sample load group of 1000 domestic customers produces a (synthetic) load curve as shown in figure 2, with a load peak of abt. 750 kW. Several groups of distributed battery storages and a large controllable storage are supposed to cover the load peak. The small storage units are activated group-wise. The large unit compensates the remaining power drawn by the load. The set power is given through a RTU unit from the control center. Depending on the available battery capacity the load peak can be shaved (see fig. 2). Which battery capacity is economical? The cost effects of different capacities are shown in figure 3, being total costs as a function of the obtained reduction.

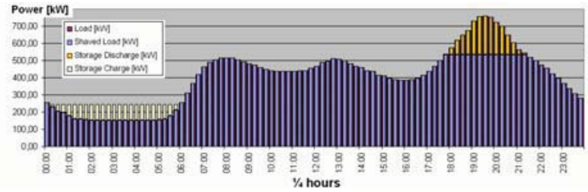

Figure 2: Battery system for peak load shaving, load curve original and shaved

The optimal battery capacity for minimal costs results in a peak load which is about 70% of the original value.

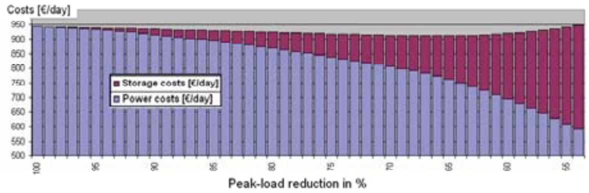

Figure 3: Total costs as a function of the obtained peak load reduction in [%]

For shaving the load peak, several groups of distributed batteries (8 kWh each) and one large controllable storage are used, in total 460kWh at max. 250 kW. With this energy, the load peak between 6 and 9 pm is shaved and the batteries are reloaded in the following night between 12pm and 6 am.

Because of the missing load peak, the energy acquisition costs for 9734 kWh decrease from 942€ (without batteries) to 914€ (including battery costs), usual EEX prices assumed. Whereas the benefit is subject to the spread of prices at the stock exchange. Recent negative prices even increase the benefits.

4.2. Compensation of RES fluctuations

A second example: The full load hours of a RES plant can be increased using battery storages as a buffer. The power of a PV plant P_{peak} can even be over-dimensioned regarding its grid connection with P_{Grid} (see fig. 4). During daytime, a part of the energy is buffered in the battery and discharged during night. Even a 24-hour plant can be designed. A derivation (not shown here) gives the factor K for the over-dimensioning of a PV plant as well as the required capacity WB of the battery.

$$K = \frac{P_{peak}}{P_{Grid}} = \frac{\frac{T_{Discharge}}{\eta} + T_{Charge}}{T_{Charge}}$$

$$W_B = \frac{P_{\max} \cdot T_{Discharge}}{k \cdot \eta}$$

P_{Grid}	Max.power of grid connection
P_{peak}	Max.power of PV plant
K	depth discharge limit
$T_{Discharge}$	Storage charge time
η	Efficiency of storage
T_{Charge}	Storage discharge time

Additional advantages are the lower and smoother grid injection and the possibility to stabilize the voltage by injecting reactive power.

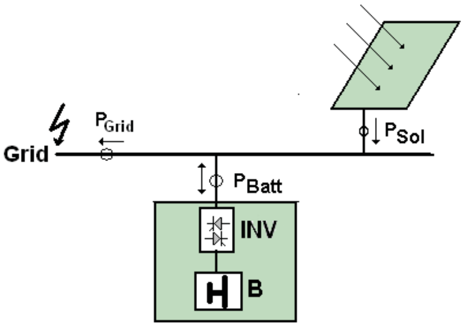

Figure 4: Battery buffer for an over-sized PV plant

4.3. Determining optimal component configurations in the smartgrid

The optimization of matching grid components and storages in the SmartGrid is done in several steps. First, a forecast for the load peak and annual work in the target year is done.

According to the individual RES policy, the required RES annual work is determined. Those target values are compared with the existing and future internal and external RES plants and their respective rated power and full load hours.

In order to achieve the optimization goal, the internal RES production is exploited and the energy drawn from outside is determined so that the RES-energy goals are reached.

An example: For a utility the load peak in 2020 is forecasted as 830 MW and the annual work as 3,1 TWh. The existing and planned mix (from hydro, photovoltaic and wind power) of internal and external RES plants produces in total 990 GWh with the respective full load hours.

The planned 30% RES share of annual work is fully covered.

Subsequently the RES fluctuations have to be taken into account, as well at their possible outages and their forecast errors. An example: Risk calculations show that the above mentioned SmartGrid would require a reserve power of 90 MW for 4 hours, equivalent to a reserve energy of 360 MWh.

This deficiency shall be covered equally by 45 MW (biomass) gas turbines and 45 MW distributed battery storages.

Considering units of 8 kWh and 3,5 kW power, approximately 22,000 small storage units would be needed in the grid, while the reserve energy, not the reserve power determines this figure.

Further background reserves, not taken into account here, are the usage of virtual power plants in combined heat-power (CHP) operation and the demand side management (DSM) with switching on/off of loads (heatimg, cooling etc.), voltage modifications and dynamic tariffs. Investments for the reserve battery units increase the electricity price with less than 1 € Cent per kWh.

5. DOES UNBUNDLING MATCH WITH SMARTGRIDS?

The German Energy Industry Act (EnWG) bases on EU directives, with roots back to the nineties of the last century and the goal of market liberalization. Climate protection goals did not have the significance as they have today.

The authors see a (partial) contradiction between SmartGrids philosophy which takes the grid, the generation, and the storages to be optimized within one cell, and the unbundled market. It already seems that nowadays (too) much staff and IT capacity is spent on finding economic solutions in a complex framework of contracts and market players.

The authors think: The separation is artificial, leads to needless complexity, gives room for egoisms and complicates the tasks in the SmartGrid. However, the non-discrimination claimed by the Energy Industry Act can be ensured by supervision and suitable information and data platforms. Approaches have been realized in the U.S. as independent system operators (ISO). Parts of the Energy Industry Act might be discussed on this background.

Future market models which emerge from technical considerations have to comply with the Energy Industry Act and the entire legal framework.

6. CONCLUSION AND FUTURE PERSPECTIVES

Among the different RES plants, some types offer a relative constant or even controllable injection of power, but the dominating wind turbines are typically heavily fluctuating.

Deficiencies and overshoots regarding the load in the grid have an impact on the electricity price. This is clearly visible in the spread of prices at the EEX stock exchange, where recently negative prices have been traded during times of low load and high wind injection.

In order to protect the grid stability, some generators would have to be throttled which conflicts the Renewable Energy Law.

Facing a significant expansion of fluctuating RES plants, the compensation with conventional methods becomes more and more difficult.

Distributed, battery-based storages can be a solution to compensate overshoots and smoothen fluctuations. They offer a fast power reserve in both directions and reserve energy. Furthermore they stabilize the voltage and electricity price.

An increasing spread would burden all market players with higher risks.

In this paper, two possible applications of battery storages have been presented and guidelines for dimensioning in two cases have been presented. Stationary, distributed battery storages in the distribution grids have a couple of positive effects: They provide reserves for power and work, reduce peak loads, postpone investments in grid expansion and increase significantly the full load hours of a RES plant. Today's mobile storages in electric vehicles with too small battery capacities can hardly provide these advantages yet.

Prototype units of batteries are already working in the labs of the University of Applied Sciences Darmstadt. In 2011, the first stationary battery storages will be installed in the distribution grid of the German supplier HSE Energy AG and their advantages in grid operation will be verified.

A new business model could be created: High negative electricity prices during windy periods would cause short amortization times for battery units.

Furthermore, a high demand would decrease their specific prices.

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