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STATIONARY COMPONENTS FOR COMPENSATING RES FLUCTUATIONS IN SMARTGRIDS

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Abstract: This paper describes the application of stationary storages for improving the stability of modern electricity power grids, especially those with a high percentage of infeeds from renewable energy sources (RES). The increasing energy demand in Germany and Europe and the further growing penetration of renewable and mostly fluctuant generators lead to an increasing demand for storage capacity. Battery storages are proposed as a solution. The authors introduce SmartGrids as the vision of the future power supply. Storages play a major role, so the technology of battery storages is presented as well as different application cases such as peak-load shaving and buffering overshoot energy from RES.

Key words: SmartGrids, MicroGrids, Battery Storages, Renewable Energy Sources

1. INTRODUCTION

The reduction of greenhouse gases, particularly carbon dioxide, is an important European goal. Since power generation is causing most of the CO2 emissions, the pollution emitters such as coal power plants are to be replaced by renewable energy sources (RES). Coal power plants are typically blocks with a rated power of some 1000 MW. They operate around the clock and reliably cover the fluctuating consumer demand. However, due to physical reasons, the energy content of coal is transformed to electric power only to a third. The huge amounts of heat can often not be consumed in the surrounding housing or industry area and are wasted into rivers or blown in the atmosphere.

European climate policies claim to replace the traditional power plants by renewable sources. The transition process is aiming up to 30% RES in 2020. Big offshore wind farms are currently built, as well as photovoltaic (PV) and environmental biogas plants. PV and wind farms are evidently volatile, their production is subject to the current weather. They basically do not produce the power when it is demanded. These fluctuations can be compensated by storages .

Which types and capacities are needed? Which advantages do batteries have? And can decentral battery storages, whether stationary or mobile, be a solution? The authors have worked in cooperation with a German distribution company, HSE Energy AG, to find solutions for the SmartGrid technologies and its storages of the future.

2. SUBSTITUTION OF COAL POWER PLANTS

The replacement of traditional coal power plants by renewable energy sources brings several problems, because the substituting generators have to fulfill three tasks equivalently well: Provide the rated power, generate the annual electrical work and be available at times when the power is needed.

In general, it is possible to provide the rated power, but larger areas are needed. For example: A 1000 MW coal power plant takes up about one square kilometer of space. A PV plant of the same rated power would be about 20 times the size. A PV plant of this dimension is currently built in the Quidam desert in northwest China. The rated power for the mid-day load peak is given, but the issues of annual work and availability remain.

A coal fire in the power plant can burn nearly continuously, maintenance times excluded, about 8.300 hours per year. At the same time, sunshine is volatile. In central Germany, the full load hours for a PV plant amount to 1000 h/a, for wind power about 2000 h/a. For the equivalent annual work, about 8 times of the PV power would have to be installed and about 4 times of the wind power. This multiplies the above mentioned demand for space. Better locations, however, make better full load hours: In dry desert zones and offshore wind parks these figures can double.

The availability of RES plants, even of large ones, is always uncertain because of the weather impact. A reliable weather forecast has a significant importance since both customer loads and generation are dependent on the weather. In order to ensure the availability, storages are needed to provide energy in times of weak RES generation.

The realization of the future regenerative power supply regarding the aspects availability, full load hours and rated power is difficult. The solution can only be found in wide distributed and over-dimensioned generating units, and big storage capacity. However, the authors are of the opinion that this task can be solved with contemporary storage technology and the transformation to a stable and environmental friendly power supply is possible.

3. SMARTGRIDS AND MICROGRIDS

How will the future power supply structure look like? The existing three-phase networks will be further used, but some components will be added, others removed. The system will be continuously transformed. The contemporary structure bases on big central power plants, while the new structure is more decentralized. A multitude of smaller, distributed and regenerative generators will be integrated, such as wind turbines, PV panels, smaller gas turbines in CHP operation. Large offshore wind parks are currently installed. All components will be supervised, dispatched and managed from a control center.

In order to be able to use efficiently the fluctuating infeeds and multitude of smaller decentralized generators throughout the grid, new methods of grid operation are necessary. The term "SmartGrids" stands for power supply which is supported by information technology and intelligent load management including storages. A broad range of definitions and approaches can be found here, partially contradictory. The authors define the terms SmartGrids and MicroGrids as follows:

"MicroGrids are small areas, e.g. feed zones of a 110/22kV power transformer in a substation. It is mainly the superior grid´s infeed, but also internal generators close to the consumer, as well as smaller distributed generators and storages, which contribute to the power supply for heating, cooling, industry, commercial and residential areas. Whereas SmartGrids are superior grid cells, e.g. the entire medium-voltage (e.g. 20 kV) network of a DSO." [1],[2]

It is well-known that the sum of partial optimizations in a meshed grid does not necessarily match the total optimum, which is why the area to be optimized should not be chosen too small, neither too large, because the impact of far system components decreases with distance and increases complexity. A number of 100 to 200 SmartGrids for a country like Germany sounds reasonable. Having not only the technical, but also the economical optimum as an aim, the optimization process refers to the SmartGrid as the superior unit. A typical SmartGrid might be a utility for a city. By positioning storages optimally, known bottlenecks in parts of the system can be overcome and the costs for expansion of the distribution grid saved for a certain time. The operational control of the SmartGrid is extended by the management of the internal RES, generators with and without CHP and distributed storages.

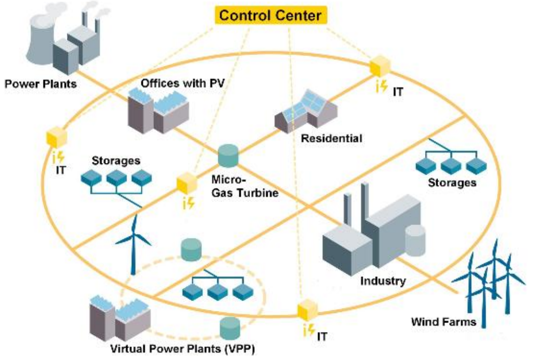

Fig. 1: The Components of the Future Power Supply

4. STABILITY OF SMARTGRIDS

SmartGrids are supposed to guarantee the stable power supply of the future. For stability there are two main criteria: First, the generation has to match the demand at any time and has to hold a reserve for outages. And second, the grid has to provide sufficient transport capacity. Among the RES generators, hydropower and biogas plants can contribute fairly well to the stability since they are flexible and their operation can be planned. Typical wind and PV plants, on the other side, are fluctuating with the weather. A combination of both gives stability: If wind turbines, for instance, are connected with gas turbines and make a so-called combination plant, the fluctuations of the wind can be compensated with the gas turbine.

Storages can compensate the difference between generation and demand. Pump storage plants are the classic approach. But the geographically possible locations are limited and investments costs are rather high. Since the fluctuations of RES and customer loads are emerging locally, a solution with distributed storages, for example batteries, is feasible.

5. DISTRIBUTED ENERGY STORAGES

Batteries are suitable for the distributed storage of electrical energy. They have good properties concerning efficiency, availability and long-term behavior. Though they are still relatively expensive, heavy and have a high specific volume, they offer possibilities which are already proven in emergency power supplies and UPS.

Following locations are possible for the placement of battery packs (see also fig. 2):

- small storages in households (kWh-range)
- mid-sized storages in MV/HV stations (100 kWh-range)
- large storages in substations (MW-range)

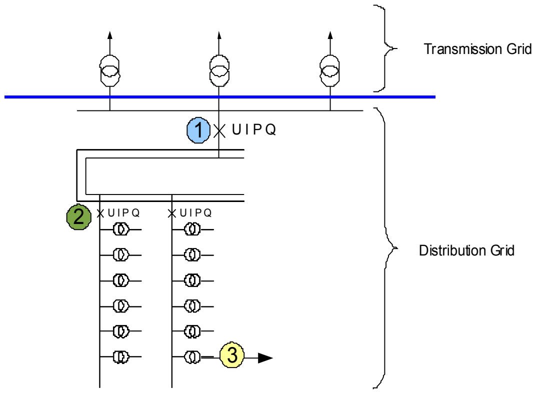

Fig. 2: Possible locations for battery storages in the distribution grid

Battery storages in a suitable location have a couple of applications and positive effects:

- batteries can compensate the fluctuations of RES generators and loads
- the acquisition of high-priced regulating energy can be avoided
- the construction of a new cable or a bigger transformer 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
- the storage can be dimensioned in a sense that a RES plant becomes a 24h plant, also with a reserve of some hours

6. PEAK-LOAD SHAVING

With peak-load shaving, the acquisition of high-priced regulating energy can be avoided, even investment costs for the construction of a new cable or transformer can be postponed. For the calculation of the required storage capacity, the synthetic load profile of a local power supplier has been used. This load profile comprises all domestic, commercial and industrial customers within the distribution grid. It is gained from operating experience and test measurements.

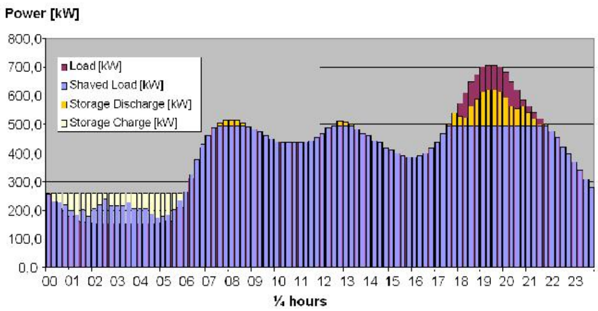

Fig. 3: Shaved load profile

In this below shown example, the peak load of one single customer is assumed with PMax=700W, the average about PAvg=400W and the minimum is Pmin=150W. As mentioned above, the synthetic load curve is an average of many customers. Therefore, the compensation of a single customer is not feasible because there is an equalisation effect over the multitude of single customers. With 100 or more customers, this equalisation can be assumed. Fig. 3 shows the synthetic profile for 1.000 customers in this example.

For a complete shaving of the load curve, all power exceeding 400kW would have to be delivered from the storages. However, this is not feasible, neither technically nor economically. A smaller lowering of the peak load requires much smaller storage capacity.

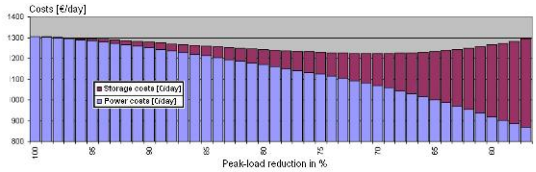

Fig. 4: Peak-load reduction vs. costs

In fig. 4, the costs for a required battery storage (1000€/kWh for Li-Ion batteries) are drawn versus the benefit from the peak-load shaving, resulting from the energy not to be bought from the spot market. The calculation bases on spot market prices of the European Energy Exchange EEX, from a period in October 2009. The minimum in fig. 4 can be found at a reduction of 72%. If the load is shaved to 72% of its original peak value PMax, we obtain a minimum of battery costs and power costs from the energy exchange.

The total energy costs C for one day can be determined by multiplying the load P(t) with the corresponding costs C(t):

$$C_{Day} = \int_0^{24h} P(t) \cdot C(t) \qquad \text{(eq. 1)}$$

In the above shown example, the load peak between the hours 18 and 21 is cut off, the batteries are loaded during night-time between 0 and 6 o'clock. With the load peak missing, the energy acquisition costs for 9760 kWh are reduced from 1305€ (without battery) to 1224€ (including battery costs), which corresponds to a cost reduction of 6%. Obviously, the saving is also dependent of the spread in the EEX prices, the difference between high and low prices in the energy exchange.[4]

The optimal battery size and the charging and discharging times are determined from the load profile and the energy prices.

7. COMPENSATION OF RES FLUCTUATIONS

Battery storages are suitable for compensating the fluctuations of RES generators, such as wind or PV farms. They can reduce the peak currents and increase the number of full load hours. With a battery storage as buffer, a RES plant can even be over-dimensioned in terms of its grid connection. The renewal of cables and corresponding investments can be avoided or postponed.

Below is shown the example of a PV plant. Its peak current is stored in the battery. The required battery size can be determined from the generation curve of the plant:

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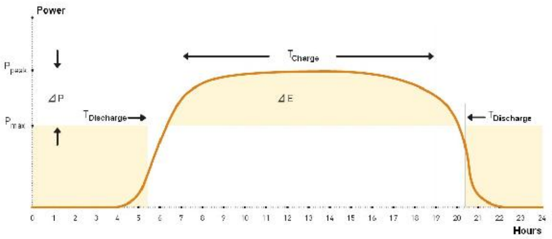

Fig. 5: Power generated by PV panels (cloudless)

Since the cable which connects the installation to the grid is limited to P_{max} , the exceeding power E shall be stored in the battery.

$$\Delta E=\int (P(t)-P_{max})dt \quad \textit{for all generated power } P(t) \textit{ greater than } P_{max} \qquad \text{(eq. 2)}$$

In a simplified way ΔE can be determined with a comparison of areas:

$$\Delta E=T_{Charge}\cdot\Delta P=T_{Charge}\cdot(P_{peak}-P_{max}) \qquad \text{(eq. 3)}$$

T_{Charge} can be assumed as 12 hours. Since the battery cannot be discharged completely (Depth of Discharge – DoD), the capacity of the battery W_B has to be increased correspondingly. With a DoD of k=80%, it can be calculated

$$\Delta E=12h\cdot(P_{peak}-P_{max}) \qquad \text{(eq. 4)}$$

and

$$W_B'-\Delta\frac{E}{k}-\Delta\frac{E}{0.8}-1.25\cdot\Delta E \qquad \text{(eq. 5)}$$

There is one boundary condition to this calculation: The battery must discharge during night time with P_{max}. In summer time, the sun often shines more than 12 hours, so this must happen in less than 12h and is only possible with a PV power smaller than P_{max}. Another comparison of areas gives the time for $T_{Discharge}$. It can be assumed as 9 hours. The discharge happens with a power of P_{max} and an specific efficiency η. The boundary condition is therefore

$$P_{max}\cdot T_{Discharge}>\Delta E\cdot\eta \qquad \text{(eq. 6)}$$

Using eq. 6, the maximum currents for the grid connection and the peak power of the RES plant can be determined:

$$\begin{aligned} P_{max}\cdot T_{Discharge} &= \Delta E\cdot\eta \\ P_{max}\cdot T_{Discharge} &= T_{Charge}\cdot(P_{peak}-P_{max})\cdot\eta \\ P_{max}\cdot(T_{Discharge}+T_{Charge}\cdot\eta) &= T_{Charge}\cdot P_{peak}\cdot\eta \end{aligned} \qquad \text{(eq. 7)}$$

Therefore the maximum power of a RES plant P_{max} with respect to its grid connection is

$$P_{peak}=P_{max}\cdot\frac{T_{Discharge}+T_{Charge}\cdot\eta}{T_{Charge}\cdot\eta}=P_{max}\cdot\frac{\frac{T_{Discharge}}{\eta}+T_{Charge}}{T_{Charge}} \qquad \text{(eq. 8)}$$

Furthermore, the required battery capacity W_B can be determined:

$$\begin{aligned} \frac{P_{max}\cdot T_{Discharge}}{k} &= \frac{\Delta E\cdot\eta}{k} \\ \frac{P_{max}\cdot T_{Discharge}}{k} &= W_B\cdot\eta \end{aligned} \qquad \text{(eq. 9)}$$

resulting in

$$W_B=\frac{(P_{max}\cdot T_{Discharge})}{(k\cdot\eta)} \qquad \text{(eq. 10)}$$

In Europe, solar panel installations on private roofs become more and more popular. Sometimes the peak power of the PV installation exceeds the grid connection, especially when it is farms or houses apart from urban areas. An example illustrates how equations eqs. 8 and 10 can help to decide whether the existing cable is sufficient.

8. MANAGEMENT AND CONTROL OF BATTERY SYSTEMS

A battery system consists of the battery (B), a rectifier/inverter (INV), and a control unit, see fig. 6. The battery is supervised by a battery management system (BMS) to control the depth of discharge and normal operating conditions. The superior unit is the battery control (BC), which controls the power PBatt flowing from/to the battery. The battery control is realised hardware- and software-wise on a PLC.

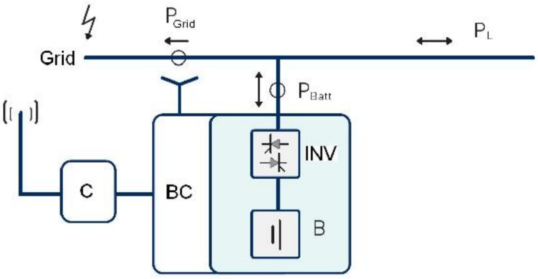

Fig. 6: Battery System for Compensating Fluctuations

The BC can work in three different modes.

1. In a local mode, the PLC operates a fixed schedule and charges/discharges the storage according with preset values, with a 1-hour resolution over 24 hours / 7 days.
2. The BC can run a control loop, in a sense that a desired power PL flows in or out of the network. Here the battery compares the power PGrid with the load PL, which is set locally or remotely via the communication unit (C), and regulates the battery current PBatt.

Certain commands might be ignored by the battery management, for example when the charging level of the battery is too low. The BC can trigger every 10 seconds. A threshold level and hysteresis avoid minimal control actions.

Local control (options (1) and (2)) is only suitable for larger storages. A multitude of small storages in residential areas is controlled by simple on/off commands from the control center. This reduces complexity and also investment costs when setting up the hardware.

3. In a remote mode, the BC receives commands from the control center, using the communication module (C).

A communication system links the decentralised battery packs information-wise to the control center. Measured values, statuses, spontaneous messages and commands for the battery control are transmitted. The transmission has to be safe. Communication units link the battery packs and the control center using IEC standardized transmission protocols, in first instance IEC 60870-5-101, later a conversion to IEC 61850 might be considered.

9. CONCLUSION AND FUTURE PERSPECTIVES

Renewable Energy comes from sources which are unlimited for human dimensions. This includes all plants which use water, wind, sun, geothermal energy and renewable primary products. While water, geothermal and biogas plants deliver constant or controllable energy, wind and PV are rather fluctuating and weather dependent.
This can lead to an excessive energy overshoot during low peak times. In a liberal energy market like Germany, this has big impacts on the electricity price in the energy stock exchange (EEX). A spread from some 100€/MWh during high-load times to nearly zero or even negative prices during low-load times can be observed. When larger offshore wind farms are concentrated in a geographic location, such the Baltic Sea, the transport capacity is hardly sufficient to evacuate the generated power.

It is obvious that storages can contribute to smoothen these effects and countervail the fluctuations of the energy price. In the next couple of years, decentralized battery systems will be installed in the distribution grid of the German Supplier HSE Energy and their functionality will be validated.

The 21st century´s power grids need to be active and intelligent in order to meet the future challenges such as increasing electricity demand and implementation of renewable energies. The idea of SmartGrids as virtually separated, and individually stabilized grid cells within the large continental grid, will contribute significantly to a successful development of the power sector. However, the application of planning, operation and training tools is vital. Grid planning is essential for the dimensioning of the RES installations and storages within the SmartGrid. Demand Side Management can affect the customers´ behaviour in a way the load curve will be smoothed. Finally, control center staff must be trained to cope with the new situations. The Power System Training Competence Centers in Darmstadt and Craiova will further work on this field and implement the SmartGrids functionality in its Dynamic Training Simulator. With these tools, students and professional engineers are enabled to face the challenges of the 21st century's power supply.

Biographies

Thorsten Fiedler, M.Sc., earned his master degree from the University of Applied Sciences Hochschule Darmstadt (Germany) in 2007. Since then, he is research assistant in Darmstadt, developing software tools for SmartGrids and PhD student in a scientific cooperation with the University of Craiova.

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