Decentralized Grid Control

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ABSTRACT

In the near future decentralized small generators must provide grid control. This contribution presents solutions to replace rotating masses for momentary reserve and providing primary reserve power with battery storages. It is proposed to use the intermediate voltage capacitors in power converters to provide energy for the virtual inertia. Decentralized converters must be able to provide power of 5 W and energy of 50 Ws per installed kW of power in the worst case, which can easily be handled by typical battery inverters. Providing primary control power with batteries is limited by the capacity of the battery. Losses and imprecise frequency measurements may soon lead to a depleted or full storage. It is possible to reduce this issue by making use of several parameters of freedom.

Keywords: Grid control, virtual inertia, primary control, power converter, smart grid

1 INTRODUCTION

An electric power supply with 100% renewable energies will be based on decentralized small generators and less large power plants. At certain times, renewable energy sources contribute already up to 80% to the power consumption in Germany and soon shares of 100% for longer periods are expected [6]. Thus, the decentralized small generators must provide grid control. This contribution presents solutions to replace rotating masses for momentary reserve and providing primary reserve power with fluctuating generation as well as with battery storages.

2 PROVIDING VIRTUAL INERTIA

Most power provided by decentralized renewable energy generators is provided by electronic power converters without rotating inertia. Fortunately, Germany’s grid is part of the ENTSO-E, European Network of Transmission System Operators for Electricity, and today the missing inertia can be compensated by the other members, which have less renewable energies [1]. However, in future, this instantaneous reaction on load steps must be covered by the feed-in inverters [2] [3] [4]. These solutions are either costly or not sufficient. Therefore, here a solution for inverters (like e.g. used in Battery storages or PV systems) is investigated. It is proposed to use the intermediate voltage capacitors in the inverters, because they can react much faster than the battery itself. In addition, this concept can be applied to further inverters and even converters of loads, e.g. for LED lamps.

In this chapter, only the instantaneous reaction is considered, while the following primary control is taken over by a further control (see below). To get the power and energy requirements, the methodology and data of reference [1] is used: a worst case event of a lack of 3 GW power in the ENTSO-E grid is assumed. This requires 372 MW in the German grid. Assuming the primary control taking over with a linear increase within 20 s [1], this requires energy of 3720 MWs. Relating this to the peak demand of 80 GW leads to 4.6 W/kW, rounded up to 5 W/kW. Concluding, additional power of 5 W and energy of 50 Ws per installed kW power capacity is needed to cover one event.

Typically, the size of a capacitor relates to its maximum energy content. To determine the interdependence, the capacity, rated voltage, diameter and height of 190 electrolytic capacitors are collected from the website of an electronic components distributor [5]. Rated energy and volume are calculate from this data and shown in Figure 1a. In real circuits, not the maximum rated energy capability E_{max} can be used, because the capacitor is discharged from the maximum voltage U_{max} only by a voltage difference ΔU. Then the usable energy E_{use} is:

$$E_{use} = E_{max} \cdot [1 - (1-\Delta U/U_{max})^2] \tag{1}$$

This equation is used to illustrate in Figure 1b (orange trace), which E_{max} is necessary, if the required energy of 50 Ws is stored. As mentioned before, this relates to an installed power of 1 kW. The blue curve relates to an extrapolation of the volume using the fit function in Figure 1a.

It can be shown that the maximum voltage has no influence on the capacitor size and can thus be freely selected. Only the relative voltage difference, which can be considered as relative voltage ripple, determines the size. If a DC link capacitor is used, the ripple should remain below 10%, requiring least 300 Ws (e.g. 3800 µF/400V), resulting in a capacitor volume of about 100 cm³ (e.g. 4 cm diameter and 8 cm height). A size of this order of magnitude can typically be found in 1 kW single phase converters. The considered voltage step is relevant only for the worst case of an extreme power loss event.

During daily operation, frequency fluctuations are much smaller and thus the expected voltage fluctuations on the capacitor are much smaller. Replacing a virtual inertia, the required control power ΔP is dependent on the time derivative of the frequency deviation Δf from the nominal frequency f_0 (50Hz):

$$\frac{\Delta P(t)}{P_0} = T_a \cdot \frac{d}{dt} \frac{\Delta f(t)}{f_0} \tag{2}$$

P_0 is the nominal power of the system (in this case the rated power of the inverter). T_a is a time constant. In the European power grid this time constant equals typically T_a = 20 s. ΔP is the power, which would be drawn from the grid by the power inverter in addition to the regular power. Figure 2a shows the measured frequency (orange) for one hour on 8.Feb.2014. It is filtered to achieve reasonable results (red). The required additional power (blue) is only a very fraction of the rated power. Compared to the 100 Hz ripple on the capacitor, the additional ripple is an order of magnitude smaller and has thus no influence on the deterioration of the device. The power is used to charge and de-charge a capacitor with maximum energy content of 300 Ws, which relates to charging directly the DC-link capacitor (see above). From this the capacitor voltage can be calculated. The voltage variation ΔU_c is proportional to the integral of the current and thus approximately to the power. Thus, the integral compensates the time derivation *df/dt* leading to the following equation for the voltage variation ΔU_c:

$$\frac{\Delta U_c(t)}{U_0} = T_a \cdot \frac{1}{2} \cdot \frac{P_0}{E_0} \cdot \frac{\Delta f}{f} \tag{3}$$

This equation is applied to the measured frequency in Figure 2b (blue curve). The voltage variation during the investigated time remains between +3.4% and -3.4%. This is a quite small value, which can be handled easily by power electronics.

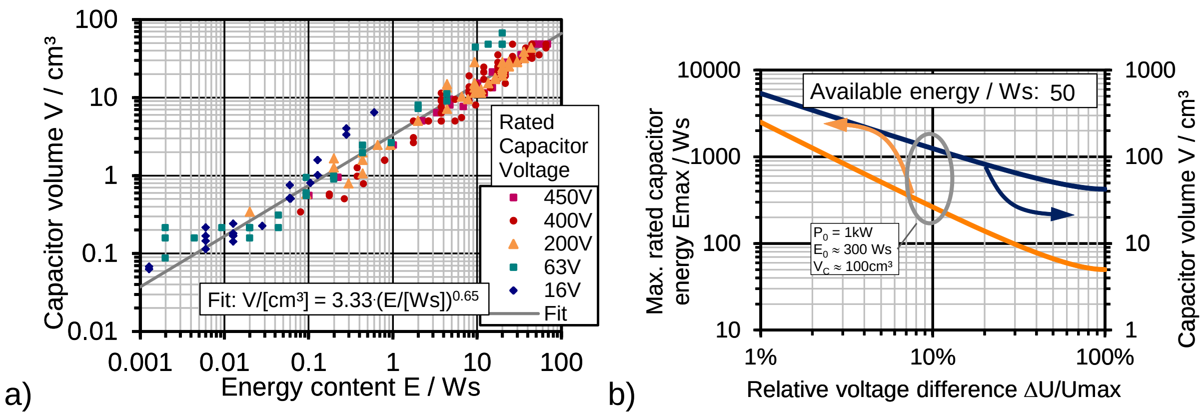

Figure 1: Volume size of electrolytic capacitors. a) Various electrolytic capacitors, data from [5]. b) Needed capacitor energy and volume size to store 50 Ws.

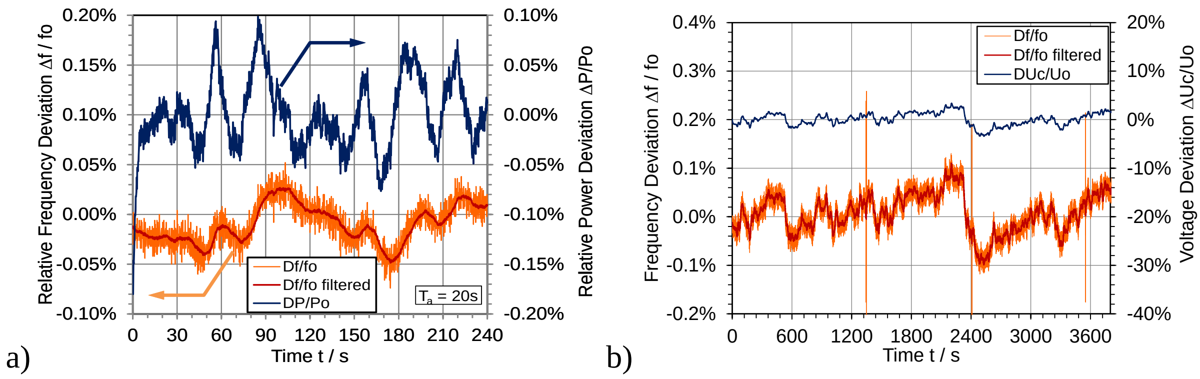

Figure 2: Measured frequency and calculated values on a capacitor with 300 Ws. a) Additional power flow. b) Voltage fluctuation,

3 PRIMARY CONTROL POWER

Providing primary control power with batteries is limited by the capacity of the battery. Positive and negative control power must compensate each other over time to maintain the state of charge. However, losses and imprecise frequency measurements may soon lead to a depleted or full storage. It is possible to reduce this issue by making use of several parameters of freedom. In addition, buying or selling additional energy to maintain the state of charge is possible.

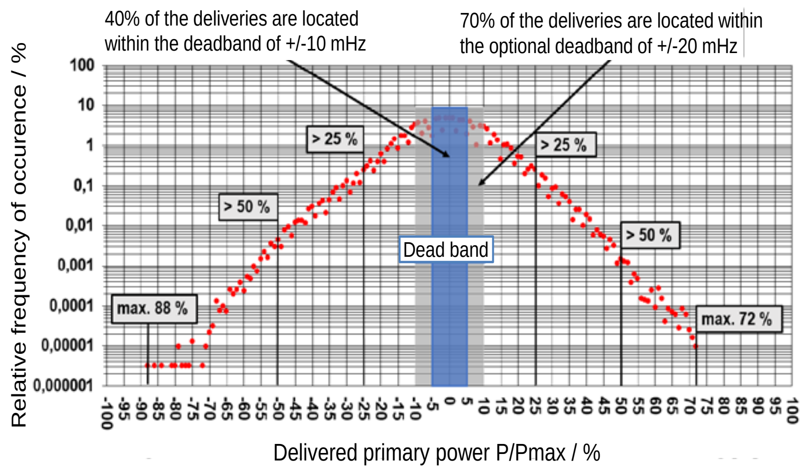

Figure 3: Frequency of occurrence of Primary Control Power in 2013 [14].

To provide primary control power in the ENTSO-E European grid, a system must at any time be able to feed-in or absorb power proportional to the deviation of the grid frequency from the nominal frequency between +/-0.2 Hz [8]. In a worst case, a deviation of +/-50 mHz may last for 30 min. In addition, at any time an amount of energy must be preserved to cover a worst case

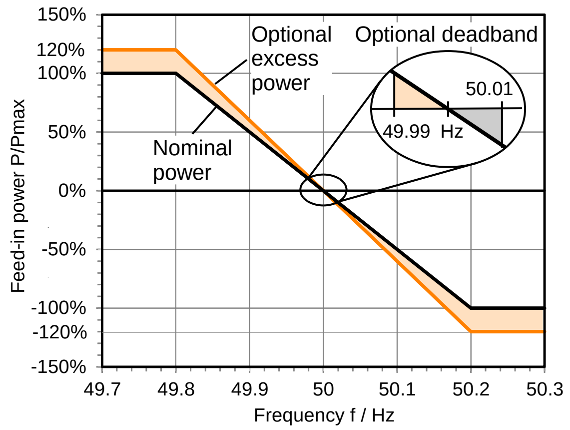

Figure 5: Degrees of freedom of the power delivery curve. According to [12].

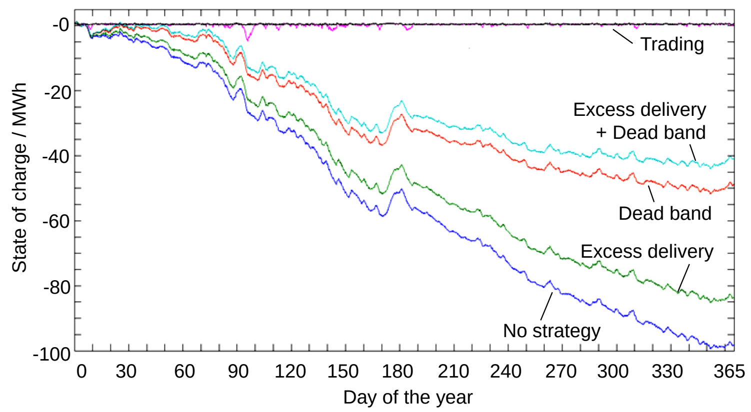

Figure 4: Effect of applying degrees of freedom for a battery storage with 1 MW rated Primary Control Power [14].

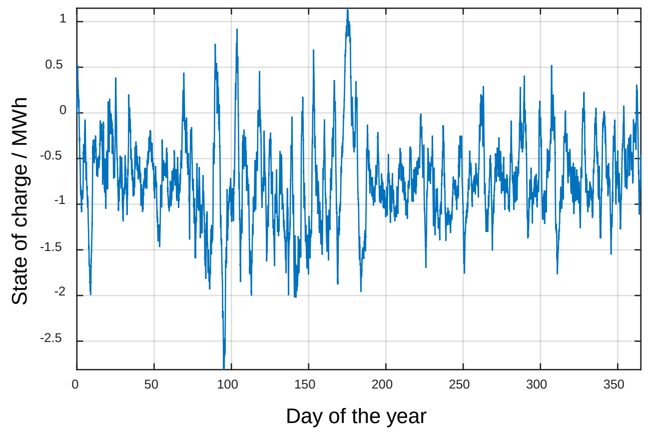

Figure 6: Calculated battery state of charge with frequency compensation using only a running average with an averaging length of one day for a battery storage with 1 MW rated Primary Control Power.

event (near blackout event). This corresponds to providing two times 15 min the full power. These two conditions determine the minimum size of the battery.

Theoretically, positive and negative frequency deviations should average to zero and charging and discharging of the battery should compensate each other. For the further investigations the measured grid frequency with a resolution of 1 s for the year 2013 is used. Further actual frequency data is available at [7]. Figure 3 shows the occurrence of positive and negative frequency deviations. The curve looks rather symmetrical. In addition it shows that more than 40% of the time the grid frequency remains within a dead band (see below) and 70% in an extended dead band, which includes the measurement uncertainty of the frequency [11].

However, an offset may appear due to imprecise measurements and losses of the battery. Then, the state of charge of the battery quickly exceeds any limits. Figure 5 (blue, “no strategy”) shows the simulated state of charge of a battery with an assumed round trip efficiency of 80% and a rated Primary Control Power of 1 MW. At the end of the year a lack of energy corresponding to a delivery of 100 h full power can be observed, which is beyond any technical realization. To avoid this, the following degrees of freedom are allowed [9]: 20% optional excess power delivery during normal operation and optional operation in a dead band between +/-10 mH (both illustrated in Figure 4). In addition, a delay of the reaction and using a gradient of up to 30 s is possible.

The effects of an optional excess power delivery and optional operation in the dead band are simulated and shown in Figure 5. Clearly, the use of the dead band has a much larger effect. Combining both methods reduces the lack of energy to 40 MWh. Further details are available in [11]. To compensate the remaining energy, it is possible to trade energy at the stock exchange market [10]. In addition, the frequency measurement is defined with a precision of +/-10 mH which can be considered as additional degree of freedom. Especially systematic errors in the frequency measurement will lead to a fast runaway of the state of charge. Such errors can be compensated by averaging the measured values and subtracting this value as systematic error. To consider long term effect, a running average can be used, e.g. with an averaging length of one day. Figure 6 shows the effect of applying this method. The state of charge remains within a range of -2.5 MWh to +1 MWh. Such a value is close to a possible realization.

4 CONCLUSION

Virtual inertia can be provided by intermediate voltage capacitors in battery inverters without additional impact on the hardware. Providing primary control power with batteries requires the use of available degrees of freedom. Especially a suitable operation in the dead band and compensation of systematic frequency errors give good results.

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