Primary control with batteries

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***Abstract*— In the near future renewable energy decentralized generators must provide grid control. Storages are attractive for grid control and especially for primary reserve power. However, 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. Especially attractive is the compensation of a systematic frequency measurement error by applying a running average correction signal.**

1 Introduction

With a higher share of renewable energies in the generation of electrical power less conventional power plants are needed. At certain times, renewable energy sources contribute already up to 85% to the power consumption in Germany [1] (see Figure 1), and soon shares of 100% for longer periods are expected [2]. Then, also the control of the grid must be organized by renewable energy generators.

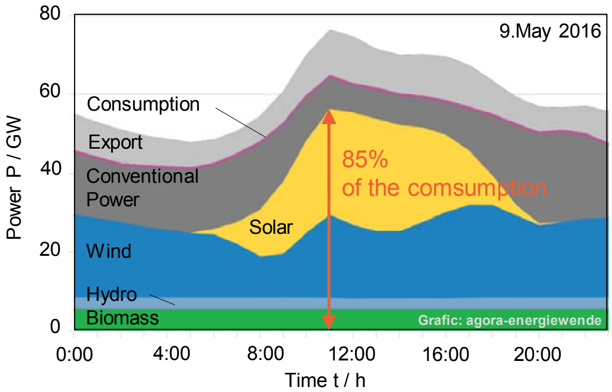

Figure 1: Power generation and demand in Germany in May 2016, graphic based on [1].

Batteries are considered to support grid control in islanding grids since more than 20 years [3] up to now [4] [5]. However, lately storages have become attractive for grid control and especially for primary reserve power [6] [7]. In Europe the market for control power is opened for decentralized power generation and first batteries are qualified to provide primary reserve power. This stimulates research on batteries for primary reserve power connected to mains grid [8] [9] [10] . Especially useful is the combination of the operation as primary power reserve device combined with additional functionality, e.g. photovoltaic storage [11]. Fewer publications consider the state of charge of the battery in their model in detail [12]. While providing primary reserve power, it may easily happen that the state of charge runs against its limits, as explained later in detail. The authors of [13] propose using emergency resistors to prevent over-charging.

However, a more suitable way is to use the allowed degrees of freedom for operation [14] as demonstrated in [15]. This conference contribution gives an overview of the challenges, the rules and regulations and the degrees of freedom using batteries for primary power. Furthermore, an additional degree of freedom, the precision of the frequency measurement, is investigated.

The following considerations are related to a rated battery power of 1 MW. In chapter 2 it is discussed, which size of the battery is at least needed for this specification. For daily operation the storage use can be optimized using allowed degrees of freedom as listed in chapter 3. Chapter 4 shows that systematic measurement errors have a large impact and a solution to overcome this issue.

2 Specifications for worst case

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 [16]. In a worst case, a deviation of +/-50 mHz, corresponding to +/-25% of maximum power, may last for 30 min. This corresponds to a margin of at least 0.25 MWh.

In addition, at any time an amount of energy must be preserved to cover a worst case event (near blackout event). This corresponds to providing two times 15 min the full power in both directions, which equals a capacity of two times 500 kW.

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 (see below). In addition, buying or selling additional energy at the stock exchange market is possible to maintain the state of charge and is proposed in [15]. This requires an announcement before the next trading block of 15 min. Therefore, the time until the energy can be traded can last up to 15 min. Spare capacity for this case must be provided. Assuming a worst case of constantly +/-50 mHz during these 15 min (see above) an additional 0.125 MWh is required. These conditions determine the minimum size of the battery, which sums up to 1.375 MWh. Figure 2 illustrates the usage of this storage, where the lines illustrate the state of charge in case of excess frequency.

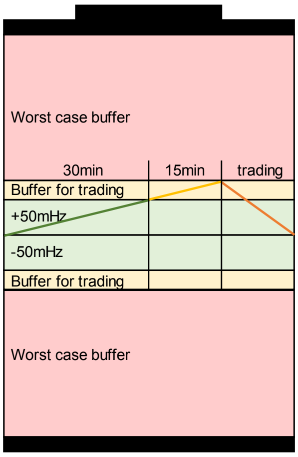

Figure 2: Storage use to provide required energies for worst case and for operation.

3 DEGREES OF FREEDOM FOR DAILY OPERATION

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 [17]. 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 [18].

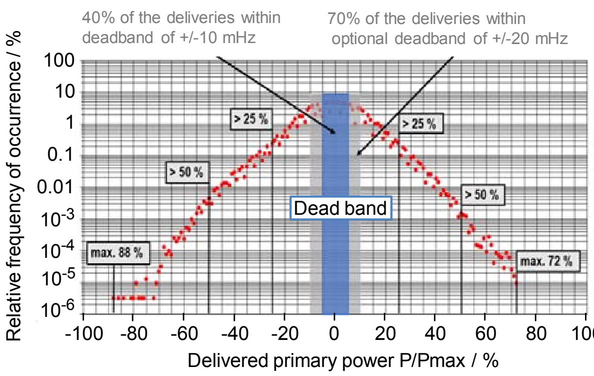

Figure 3: Frequency of occurrence of Primary Control Power in 2013 [18].

Indeed, the grid frequency is controlled such that the average of all deviations approaches zero, and positive and negative values cancel each other. This is ensured by keeping the so called synchronous time within a margin of +/-20 s. If it deviates more, a correction to the grid frequency is applied at the end of each day. With this correction the deviation is cancelled and the average of the grid frequency is set the nominal frequency again [16]. Therefore, the average grid frequency can be considered as a very stable measurement normal.

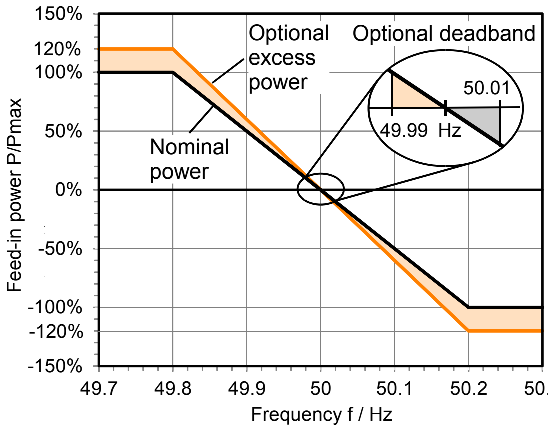

Figure 4: Degrees of freedom of the power delivery curve. According to [14].

According to these considerations the battery state of charge should vary around an average. However, an offset may appear due to imprecise measurements. In addition, losses may deplete the battery and impose an asymmetry. Then, the state of charge of the battery may 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. An infinite battery capacity is assumed in order to investigate which battery size would be required. 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 [14]: 20% optional excess power delivery during normal operation and optional operation in a dead band between +/-10 mHz (both illustrated in Figure 4). In addition, a delay of the reaction and using a gradient of up to 30 s is possible.

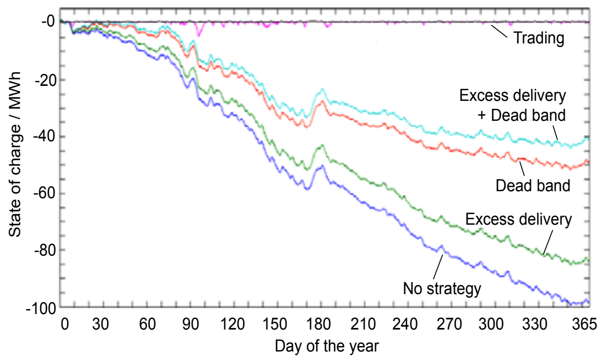

Figure 5: Effect of applying degrees of freedom for a battery storage with 1 MW rated Primary Control Power [18].

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 [18]. To compensate the remaining energy, it is possible to trade energy at the stock exchange market [15]. However, this is costly and should be avoided.

4 COMPENSATION OF A FREQUENCY OFFSET

In addition, the frequency measurement is defined with a precision of +/-10 mHz 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. The missing (or excess) energy can linearly be attributed to the systematic measurement error. The calculation shown in Figure 6 illustrates that a systematic measurement error within the allowed range of +/-10 mHz may lead to a lack of energy of +/-450 MWh, which is far beyond any reasonable technical realization. To bring the lacking energy below 1 MWh a systematic measurement error of less than 0.023 mHz would be required. This is not possible with reasonable technical equipment.

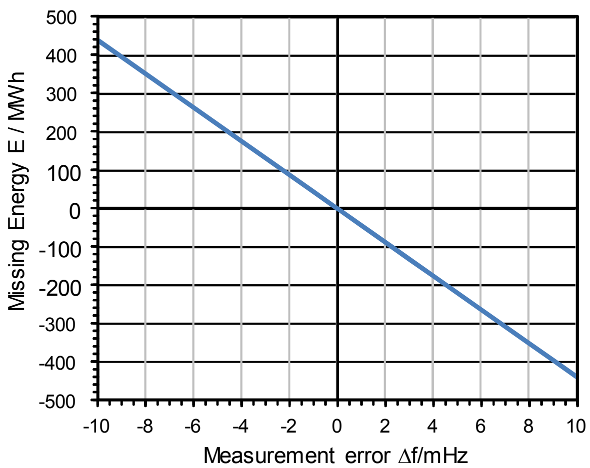

Figure 6: Missing or excess energy at the end of a year due to a systematic frequency measurement error.

However, such errors can be compensated by averaging the measured values and subtracting this value as systematic error. A circuit providing such a function is depicted in Figure 7. A signal corresponding to the actual grid frequency is processed: First a value corresponding to the nominal frequency is subtracted to achieve the frequency deviation. Then the running average is generated by adding the stored previous value, which is multiplied with a weighting factor *n* (see below).

To investigate the impact of this method simulations with frequency data as mentioned before were made for a whole year assuming an ideal storage providing a maximum primary control power of +/-1 MW. This way only the effect of the frequency measurement error is relevant.

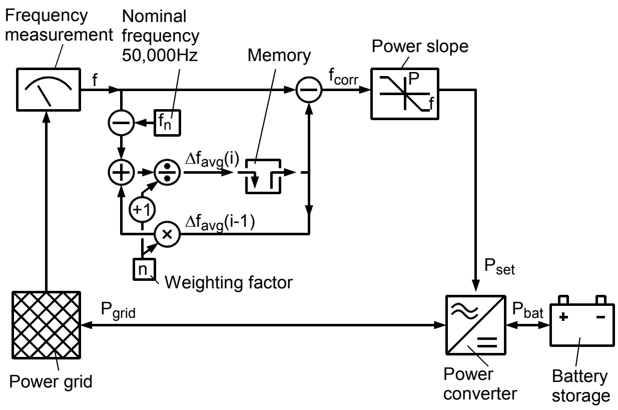

Figure 7: Schematic of the systematic frequency error compensation circuit integrated in the primary reserve power control of a battery.

First, a simulation with a simple cumulative averaging was performed. The average is calculated from all measured values with the same weight. The result is shown in Figure 8. The resulting state of charge still shows a strong deviation, which, however, is reduced at the end of the year. This is not completely satisfying. An investigation of the synchronous time, which is calculated from the corrected frequency values, shows a deviation of significantly more than 20 s (not shown as figure). This indicates that the systematic error of the frequency measurement is not constant over long term. Therefore, the correction signal should be corrected in regular intervalls.

This can be achieved by using a running average. Here, older measurement values are weighted less and less, such that the correction signal is mainly based upon the actual deviations.

In that context the weighing factor *n* describes, how long older values have an influence. Simplified, it determines the grade of averaging and relates more or less to the length of the averaged interval. For example, if the frequency is measured once per second, a weighting factor of $n = 3600 \cdot 24$ corresponds approximately to a daily average.

The larger the weighting factor *n* is, the longer is the interval, which determines the average. A longer interval (e.g. one or more days or even longer) results in changes in the systematic error being detected relatively late. This results in lager missing energies. With a short interval these changes can be corrected faster resulting in less energy lack. However, this also results in larger correction signals, which (as shown below) may exceed the given measurement tolerance. This leads to the question, which interval is most suitable for the measurement.

An interval of one day ($n = 3600 \cdot 24$) seems to be a reasonable compromise. The synchronous time is corrected daily [1], leading to the assumption that the daily average of the actual frequency may well correspond to the nominal frequency. Therefore, this value can reasonably be used as a reference. Calculating the correction signal for the whole year shows that it remains with very few exceptions (reaching +/-15 mHz) within the required measuring tolerance of +/-10 mHz. Therefore, such an operation would be possible within the existing frame conditions.

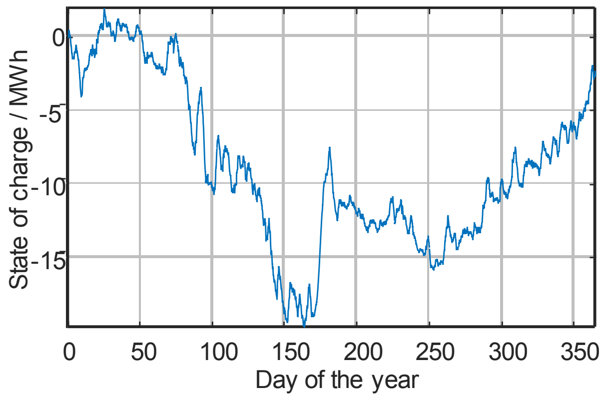

Figure 8: Calculated battery state of charge with frequency compensation using a simple cummulative average.

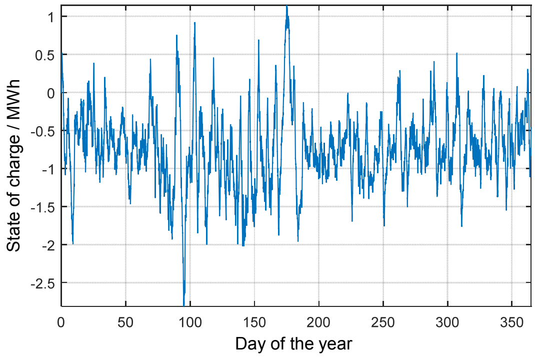

Figure 9: Calculated battery state of charge with frequency compensation using a running average with an averaging length of one day.

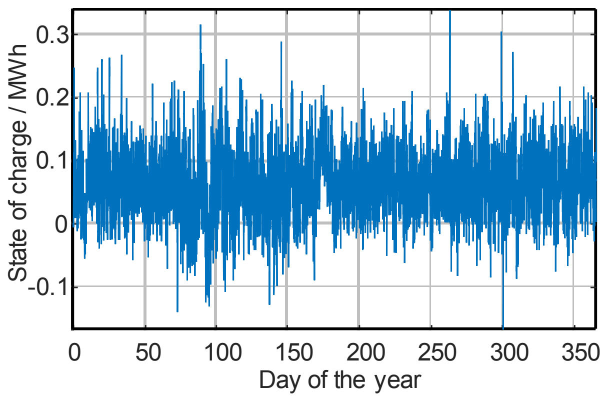

Figure 10: Calculated battery state of charge with frequency compensation using a running average with an averaging length of one hour.

The calculated missing energy is presented in Figure 9. The values are within + 1 MWh and -2.7 MWh. Values of this order of magnitude could be covered by a corresponding dimensioning of the battery, which would be technically feasible.

As a shorter averaging interval 1 h (n = 3600) would be interesting. The following argumentation would justify such an interval: At the energy stock exchange hourly products are common, beside shorter trading intervals. This corresponds approximately to one cycle of control power (Primary, secondary and minute reserve power), which could be used as justification for such an interval. However, the correction signal would have values of up to +/-50 mHz, which exceed the measuring tolerance significantly. For such an operation the frame conditions would be needed to be adapted. However, the missing energy values still improve significantly as shown in Figure 10. They are now within the limits of -0.2 MWh and +035 MWh. Such values can easily be provided by existing battery storages.

5 Conclusion

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. The operation in the dead band has a good impact, but especially attractive is the compensation of a systematic frequency measurement error by applying a running average correction signal. Here, an averaging interval of one day is suggested, which corresponds to the correction interval of the synchronous time of the grid frequency.

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