Dynamic Sizing of automatic and manual Frequency Restoration Reserves for different Product Lengths

Dominik Jost, Axel Braun, Rafael Fritz and Scott Otterson
R&D Department Energy Economy and Grid Operation
Fraunhofer Institute for Wind Energy and Energy System Technology
Kassel, Germany
dominik.jost@iwes.fraunhofer.de

***Abstract* — On last year's EEM conference a method for the dynamic sizing of frequency restoration reserve capacity based on quantile regression was presented. Further research has improved the method and has made it ready for use. It contains the following new features, which will be presented in this paper: an adaptive bias correction function, the allocation of frequency restoration reserves (FRR) to automatic FRR (aFRR) and manual FRR (mFRR) and the calculation of needed reserve capacity for different product lengths. The results will show the advantages of the adaptive bias correction, estimate the needed reserves for aFRR and mFRR, and demonstrate the influence of different product lengths on the needed reserve capacities.**

***Index Terms* - Dynamic reserve sizing, frequency restoration reserve, quantile regression, secondary control, tertiary control**

I. INTRODUCTION

The conversion of the energy system from continuous conventional generation to intermittent renewable generation leads to higher dynamics in the system, also regarding the need for balancing. Therefore static reserve sizing should be replaced by dynamic methods in the long run.

In [1] influencing factors on the imbalances respectively the need for FRR within the German balancing area were identified, initially. Afterwards a basic method was introduced which allows sizing the needed total FRR capacities dynamically, depending on the above mentioned influencing factors. This is done by training artificial neural networks with historical data using quantile regression to find the quantiles which represent the share of time during that the exceedance of the sized FRR is allowed. These quantiles are derived from a certain security level. As input for the training of the neural networks historical time series of the influencing factors are used. The target variable is the corresponding time series of the actual imbalance within the balancing area. After applying those artificial neural networks to the forecasted influencing factors of the sizing period a simple bias correction is used to improve the results.

It was shown that the proposed method has a significant added value compared to static approaches regarding the reduction of average FRR capacity and the provided security in terms of meeting the required security level and reducing the height of exceedance in those cases.

The advantage of this method over other approaches is that it uses the target variable directly. Approaches that are based on the convolution of single error distributions like load forecast errors and power plant failures to estimate the total imbalance distribution (e.g. [2], [3] and [4]) need very exact data for setting up those single error distributions, which is not available in most cases. Additionally, possible correlations have to be considered. Problems are similar for other methods that are for example based on Monte Carlo simulations [5]. Furthermore the artificial neural networks allow for finding dependencies between combinations of influencing factors and the target variable which hardly can be found by other approaches.

In this paper a further development of this basic method is presented which enables it to be used in real grid operation by TSOs. First the method of the extension will be presented in chapter II before the added value is evaluated in chapter III.

II. METHODOLOGY

In this section the new features of the dynamic sizing approach are introduced, starting with the adaptive bias correction function, continuing with the allocation of total FRR to aFRR and mFRR and the sizing of those reserves for different product lengths with constant reserve capacity.

A. Adaptive bias correction function

In [1] a bias correction function was introduced which is able to compensate for the weaknesses of the neural network to meet the required quantiles better. It calculates the bias to the results from the quantile regression that would have been needed during the validation period. This bias is than added to the results of the neural networks. This static correction function was applied once for the whole sizing period. However, due to changing market conditions, the behavior of market participants, and technological developments, the balancing demand fluctuates highly over time. Figure 1. shows that for example in 2012 and 2013 a long term trend of decreasing imbalances can be observed. Starting with a standard deviation of about 1200 MW in the first months of 2012 the standard deviation decreases to 700 MW in the last months of 2013. Those long term trends can be considered by the adaptive bias correction function. The idea behind this is that certain patterns of imbalances remain over time but can

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change in height. This can be compensated by the adaptive bias correction function by considering not the training period for the neural networks (e.g. total 2012) but the last days and months (e.g. 1 January till 30 June 2013) right before the day of sizing (e.g. 1 July 2013). Using this approach enables the sizing method to use longer periods (e.g. one year) to identify the patterns of imbalances and using shorter, more up-to-date periods (e.g. the last 6 months) to calculate the bias.

Additionally to the above mentioned long-term trends there are also short-term fluctuations which are due to normal changes between critical and uncritical situations. Therefore it is important to choose the right period length to consider for the calculation of the bias correction. This period should contain all kinds of situations, if possible. Test have shown that six months seem to be a good choice for the period length allowing to consider long term trends, but helping not to overestimate the influence of short-term events (Results of tests are not shown here).

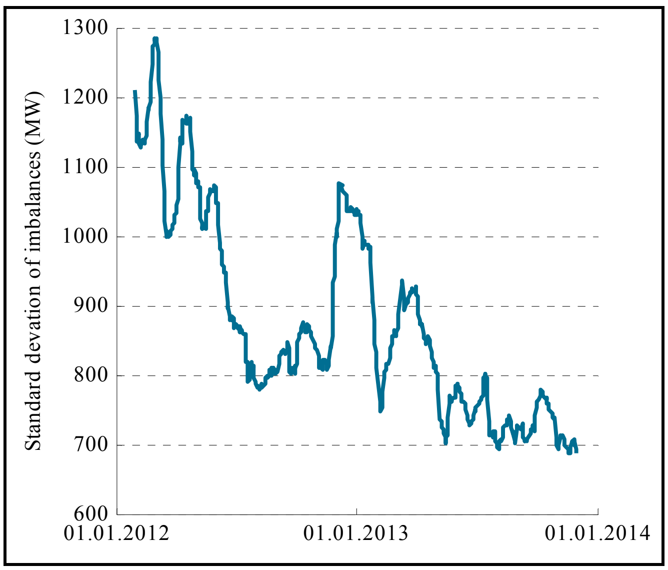

Figure 1. 30 days moving standard deviation of total imbalance in the German balancing area

B. *Allocation of FRR to aFRR and mFRR*

In Germany, as in most European countries, two types of Frequency Restoration Reserve (FRR) exist: Automatic FRR (aFRR) with an activation time of 5 minutes and the slower manual FRR (mFRR) with an activation time of 15 minutes. aFRR is activated automatically by a load-frequency-controller whereas mFRR is activated manually by the control room staff. Some reserve sizing approaches, like the German Graf-Haubrich method, assume that some kinds of errors (like load forecast errors) can be balanced entirely by mFRR, whereas others (e.g. fluctuations) have to be balanced by aFRR [6]. This approach leads to nearly equal aFRR and mFRR capacity tendering.

In reality aFRR (including substituting IGCC exchange [7]) is much more often activated than mFRR (Figure 2. . The reason for this much higher activation of aFRR is that mFRR often is activated only during very high imbalances, which allow the assumption that this imbalance will persist at least for the next quarter hour. Consequently, aFRR is often not replaced by mFRR and is activated more often than assumed. Additionally, the above mentioned errors never occur as an isolated event. They always occur jointly with other errors since several events happen simultaneously. This leads to mutual neutralization or accumulation, depending on the errors' sign. For this reason, we need to consider a different approach: For the sizing of aFRR, we use the same method as for the sizing of the total FRR. The target variable used here is the historical need for aFRR. The difference between total FRR and aFRR is then the needed mFRR. In some cases the needed aFRR is higher than the total FRR. In these cases the FRR is adjusted to the value of aFRR while mFRR is zero.

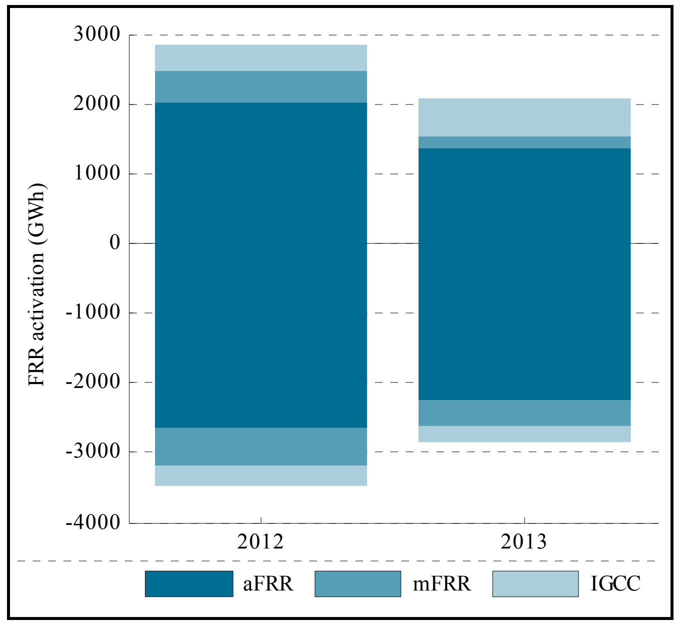

Figure 2. Activated aFRR and mFRR as well as IGCC exchange which substitus aFRR activation

German TSOs strive for a security level where in 99.995 % of the time enough aFRR should be available [6]. However, analyzes show that the striven security level is much too high compared to reality and would lead to sole aFRR and no mFRR capacities. For this reason here a security level of 99.98 % is used which roughly reflects today's situation.

C. *Different product lengths*

The dynamic sizing of reserves is based on the idea that there is an optimal reserve capacity for every time interval. For practical reasons it is not possible to procure different capacities for arbitrary time intervals like e.g. one minute. In reality the procurement will be carried out for longer product lengths like hours.

Training the neural networks on shorter time intervals has the advantage of more information that can be obtained. One year for example contains 525,600 data points if using minute values. Using hour values would decrease the amount of information by a factor of 60 to 8760 data points. Another reason for using one minute data is that there should be enough reserve capacity in average during every minute.

Mean values over longer periods would underestimate the needed reserves. For these reasons the training is done with one-minute-data. For the calculation of needed reserve capacities for longer product lengths the results of the neural networks are averaged over the product length. Subsequently the dynamic bias correction is applied which ensures to meet the striven security levels.

D. Whole dynamic sizing process of aFRR and mFRR

Figure 3. shows the whole extended dynamic sizing process. It starts by training the neural networks for total FRR and aFRR with historical data by quantile regression. In the next step the trained neural networks are used to compute the needed FRR and aFRR capacities for the sizing period with the according forecast data.

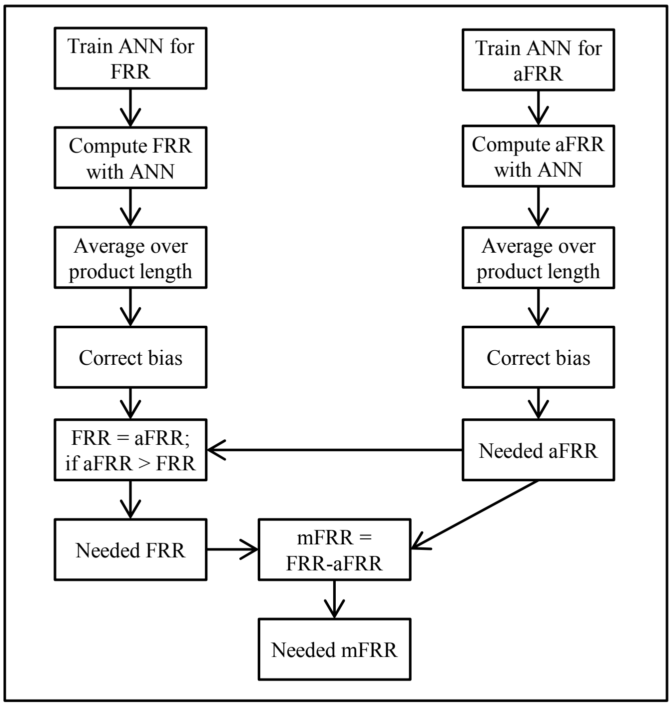

Figure 3. Flowchart of dynamic sizing of aFRR and mFRR

Afterwards the results are averaged over the target product length, before the adaptive bias correction takes place. Then the FRR capacity is corrected to the aFRR capacity in times where the result for aFRR is higher than for total FRR such that always enough aFRR is available. Finally the needed mFRR capacities are calculated by subtracting the aFRR capacities from the total FRR capacities.

III. Evaluation

For the evaluation the same data as for last year's paper is used here (see [1]). As influencing factors time series of the load, the day-ahead forecast of the generation from photovoltaic and wind, the residual load and the temporal gradients of all of these time series as well as the temperature forecast and the time of the day and the day of the week are considered.

As target variable for FRR the total imbalance (mFRR activation, aFRR activation signal plus the IGCC exchange and further reserve activation) is used. Whereas for aFRR only the aFRR activation and the substituting IGCC exchange are considered.

As security levels 99.955 % for total FRR and 99.98 % for aFRR are chosen which results in a total security level of 99.9935 %.

For each type of reserve 24 artificial neural networks are trained with quantile regression backpropagation. Each of these neural networks was designed with 5 neurons in the hidden layer. The sizing is done for 2013 and the training is done on data from 2012. The time around Christmas 2012 (23 till 31 December 2012) is neglected for the bias correction because of very high imbalances that are unlikely to occur again (see [1]).

For evaluation four criteria are taken into account:

- The *needed reserve capacity* which should be as low as possible
- The *loss of time* which represents the exceedance of available reserve capacity and should comply with the symmetric quantiles (0.0225 % for FRR and 0.01% for aFRR, derived from the striven security levels)
- The *loss of power* which corresponds to the height of exceedance and should be as low as possible
- The *loss of energy* which represents the imbalances that could not be covered by the available reserves over one year

A. Adaptive bias correction function

For the comparison of the static and the adaptive bias correction function the last 183 days are taken for the bias calculation. The results for total FRR can be seen in Figure 4. labeled with "Dynamic" on the left side of each subplot. The main advantage of the adaptive bias correction is that the striven quantiles (*loss of time*) of 0.0225 % are hit much better (0.0280 % or 0.1905 % compared to 0.0080 % or 0.0063 %). This is due to the fact that the trend of decreasing balancing demand could be considered which is not possible with the static bias correction function, which here leads to an overestimation of reserve capacity. Consequently, the needed reserve capacities in average (middle point) are lower (3,940 MW or 3,807 MW) compared to the static bias correction (4,327 MW or 4,240). The highest aFRR need (upper point) also decreases. The *loss of power* as well as the *loss of energy* gets higher for the adaptive bias correction. However, this is a logical consequence of the higher loss of time and lower reserve capacities.

In this example a long-term trend of decreasing imbalances can be observed. That is why the static bias correction overestimates the needed reserve capacities. In the case of increasing imbalances the static approach would underestimate the needed reserves. Here the dynamic bias correction would size more reserve capacity and guarantee the required security level.

Furthermore, it can be observed that the dynamic sizing approach in general has great advantages compared to static sizing approaches. The results of a static ex-post sizing approach (needed constant reserve capacities over the whole year are determined with the actual imbalances) can be seen on the right side of each subplot. Compared to these the dynamic sizing method is able to reduce the average reserve capacity significantly while meeting the striven security level and reducing the height of the exceedances of the available reserves (*loss of power*), which even increases security.

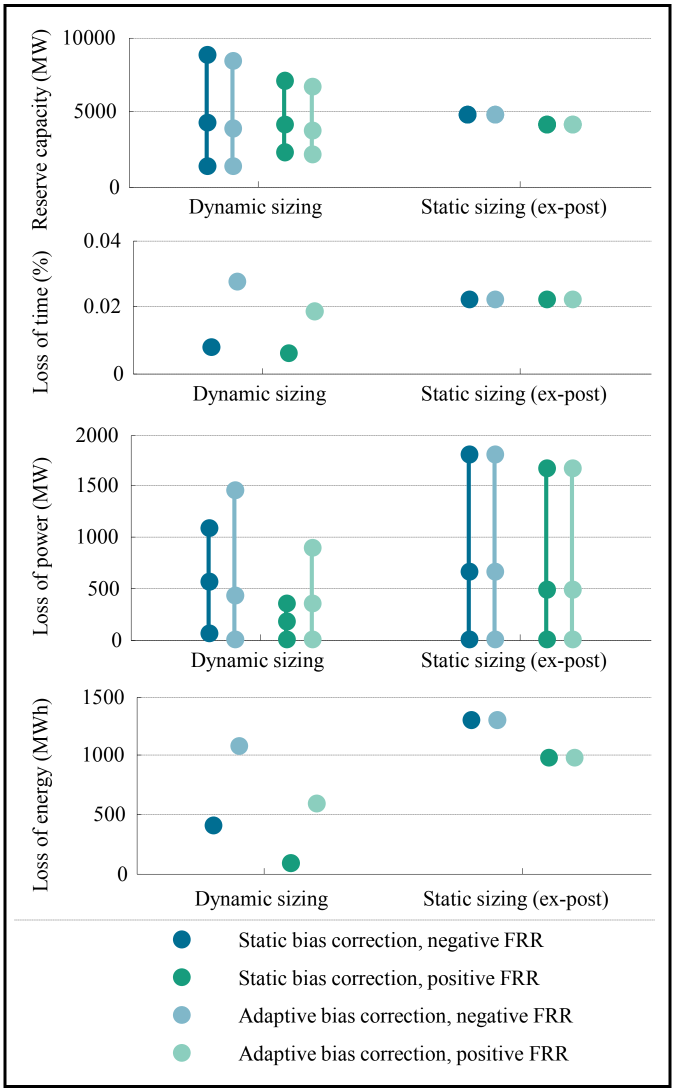

Figure 4. Evaluation results of dynamic sizing approach with static and adaptive bias correction function

B. *Allocation of total FRR to aFRR and mFRR*

The curves in Figure 5. depict the annual capacities for aFRR, mFRR and total FRR. One can see that in about 2,000 hours per year no mFRR is procured. During those hours only aFRR is tendered. This result takes account to the fact that in several quarter hours no mFRR can be activated as this would lead to counteracting reserve activation. On the other hand significantly more aFRR has to be procured, up to about 5,000 MW in a few hours per year. Compared to actual reserve activation (Figure 2.) this result is much more reasonable than today's practice where the capacities of both reserve types are nearly similar.

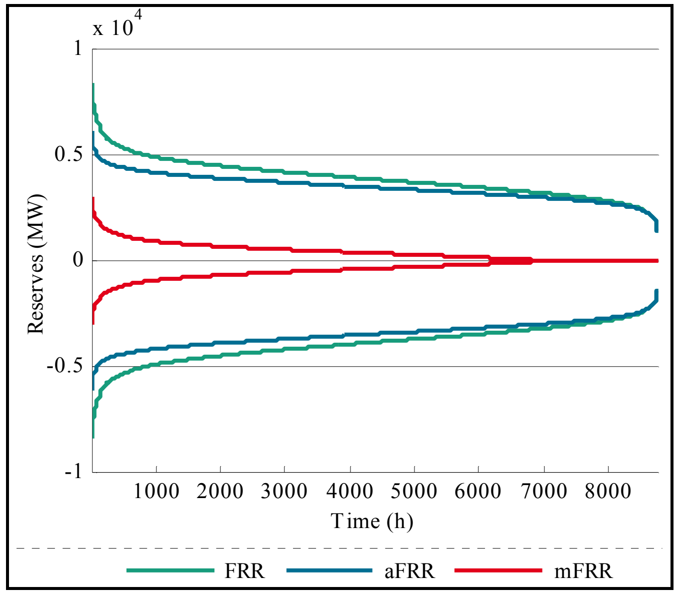

Figure 5. Annual curve of needed FRR, aFRR and mFRR

C. *Different product lengths*

Figure 6. shows the time series of FRR capacities sized for product lengths of 1 hour and 4 hours for two days in October. It is a good example for the advantage of shorter product lengths. In the evening of October 28th a very high demand for positive FRR occurs that exceeds the FRR capacity for 4-hours product length by almost 1,000 MW, whereas it could be covered much better with the 1-hour product length capacity. Although the average capacity over 4 hours is almost equal to the sizing for the shorter product length, it is not fully capable of forecasting short-term events.

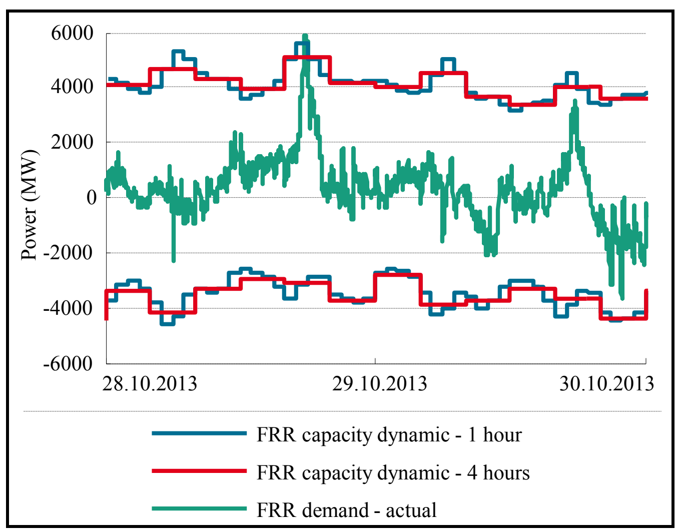

Figure 6. Example for different product lengths

This impression can be confirmed by analyzing longer observation periods. Figure 7. illustrates the influences of different product lengths on the loss of time and the needed average reserve capacity for one year. The first observation is that shorter product lengths (1 minute to 4 hours) seem to work better with the proposed method compared to longer product lengths (1 day to 1 year) regarding the achieved *loss of time*, which is 0.0225 % here. Longer product lengths seem to cause problems especially for negative FRR in this example.

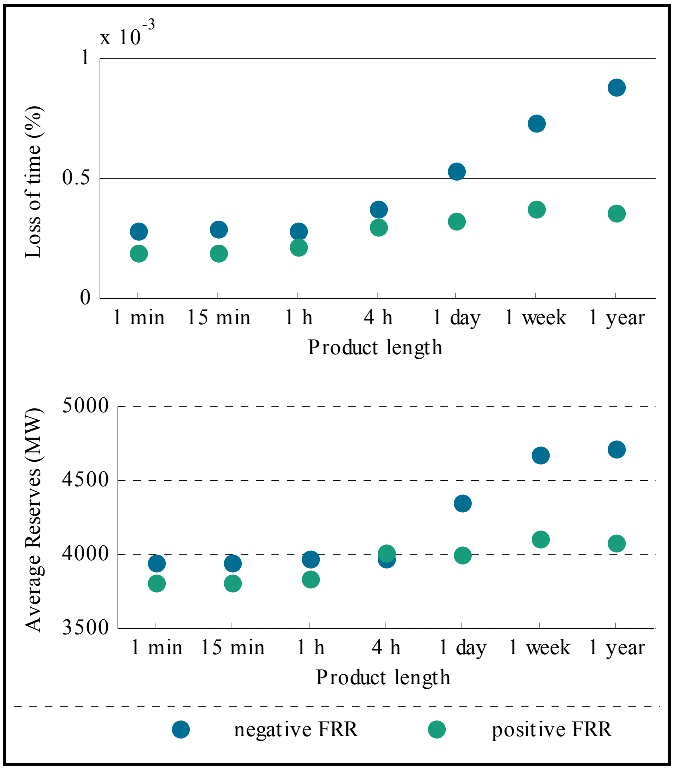

Figure 7. Influence of product length on loss of time and the needed average aFRR capacity

Furthermore, it can be observed that longer product lengths require higher reserve capacities. For negative FRR the average reserve capacity increases from 3,940 MW to 4,711 MW although the loss of time triples. This effect can also be observed for positive FRR, but less pronounced. It is due to the fact that the above mentioned flexibility of short product lengths has to be compensated by higher reserve capacities for long product lengths.

IV. Conclusion

In this paper an extension of the dynamic sizing method from last year's EEM conference [1] was presented. It enables the approach to be utilized for actual reserve sizing by TSOs.

The first improvement is the adaptive bias correction function. Making the bias correction function adaptive allows covering the latest events and helps considering long-term trends regarding the balancing needs. So the right amounts of reserve capacity can be procured to meet the striven security levels more exactly. In the case of long-term changing balancing need (like the decreasing trend in Germany in 2012 and 2013) the adaptive bias correction function leads to more appropriate capacities.

With the second new feature the allocation of total FRR to aFRR and mFRR is realized. For the allocation the sizing of total FRR and aFRR is done separately. The difference between FRR and aFRR is than procured as mFRR. Results show that mFRR only plays a minor role compared to aFRR. This result is contrary to today's reserve sizing practice where roughly the same capacities are tendered for aFRR and mFRR, but it is consistent with today's mFRR activation practice. This is due to the fact that mFRR is activated only if the control room staff can assume that there will be a certain imbalance over the whole next quarter hour which is not considered by the today's applied sizing method.

Finally the method was extended to calculate constant reserve capacities for longer product lengths. This is important due to the fact that TSOs cannot tender different amounts of reserve capacity in every minute, but rather for hours. Calculating those reserve needs is possible by averaging the 1-minute results over the product length. To meet the striven security level the bias is corrected afterward. The results show that short product lengths allow more accurate sizing of reserve capacity which is also lower in average. For product lengths up to one hour nearly no difference to one minute can be observed. Longer product lengths lead to significantly more reserve capacity with even lower security levels.

Further research will analyze if lower limits for the reserve capacities are necessary to guarantee a secure grid operation at any time. These limits could defined based on deterministic considerations, e.g. having enough reserve capacity to overcome very rare events like offshore cable failures, which are not covered by the training data.

V. References

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