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A new method for day-ahead sizing of control reserve in Germany under a 100% renewable energy sources scenario

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ABSTRACT

In Germany, the installed capacity of renewable energy sources, especially that of wind and photovoltaic energy, has increased over the past few years and will continue to increase in the future. Due to errors in forecasting wind and photovoltaic energy, the control reserve needed to balance the electricity system will correspondingly increase if control reserves will be sized statically for several months or one year as it is done in most countries today [1–3]. That is because sizing control reserves this way does not consider the fact that there will be hours with a high penetration of wind and photovoltaic which cause a different demand for control reserves than hours with a lower penetration. Therefore, in this work, we present a new probabilistic *dynamic method* that sizes control reserves for the single hours of the following day making use of forecasts of the power feed-in of wind and photovoltaic. In contrast to similar approaches [2,3] forecast errors of wind and photovoltaic power are not modeled as normal distributions, which does not reflect reality [4–6], but by kernel density estimation to get more realistic distributions. Under a 100% renewable energy scenario for Germany, the control reserve that would be allocated by the *dynamic method* is compared with the control reserve that would be allocated by a *static method*. The *static method* is similar to the probabilistic *Graf-Haubrich method*, which is applied in Germany today, but can, in contrast to this method, be applied to future scenarios. It is shown that the *dynamic method* halves the average required control reserve.

1. Introduction

To guarantee the secure supply with electrical energy load and generation in a power system always have to be in equilibrium. To compensate for imbalances the transmission system operators connected to the UCTE network can perform control actions with different characteristics and qualities. Therefore they contract different types of control reserves. Primary control reserve must be activated within 30 s. The size of the overall primary control reserve for the UCTE network is set with respect to the reference incident to 3000 MW and then distributed amongst the connected transmission system operator [7]. For this reason the sizing of primary control reserves is not considered in this work. In addition secondary and tertiary control reserves are contracted. In Germany, for instance, these reserves have to be activated within 5 min, respectively 15 min. The sizing of these two reserves is done by each control area individually. Currently, both deterministic and probabilistic methods are used for the sizing. An example of such deterministic methods is found in the ENTSO-E Handbook [7]:

$$P_{\text{Secondary\_reserve}} = \sqrt{a \cdot l_{\max} + b^2} - b \tag{1}$$

Here the amount of secondary control reserve is calculated based on the maximum load $l_{\max}$ and two constants a and b, which are determined empirically.

In contrast to deterministic methods, probabilistic methods try to reflect stochastic system behavior [8], ensuring that the risk of an insufficient amount of control reserve is known. One example of a probabilistic method is the so-called *Graf–Haubrich method*, which is used in Germany [9,10] and basically explained in [11]. The method is used to size secondary and tertiary control reserves every quarter for the following three months, without considering subsequent renewable energy sources forecasts.

The *Graf–Haubrich method* is based on the idea that there are different error types that require control reserve. The error types are described in detail in Section 2. For each error type, a distribution is estimated based on historical data, and these error distributions are convolved to produce two summed-error distributions, one for the secondary control reserve and one for the total control reserve. The difference between the distributions for the secondary and total

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control reserves is that different error distributions are considered. From these two distributions – and with fixed targets for surplus and deficit probabilities – the required secondary and tertiary control reserves can be obtained. The demanded tertiary control reserve is the difference between the total and the secondary control reserve. In the following, “control reserve” will be used as a generic term for tertiary, secondary and total control reserves.

To determine the influence of increasing wind penetration levels on control reserves one can use different approaches [12,13]. The *Graf–Haubrich* method does not allow the sizing of control reserves for future scenarios with different wind and photovoltaic production capacities because the distribution of the forecast error, which combines the wind, photovoltaic and load forecast errors (s. Section 2), is based on the required total control reserve of the previous year, which is only valid for the installed capacity of wind and photovoltaic energy of this specific year. To enable the *Graf–Haubrich method* to determine the influence of increasing wind and photovoltaic penetration the wind, photovoltaic and load power forecast errors have to be separated so that forecasts for the period for which the control reserve is sized can be used to calculate the error distributions [14]. The separation of these forecast errors is implemented in the *static method* in this work and has already been discussed, inter alia, in [1–3,14,15]. In any case, these studies concluded that the control reserve requirements will increase with the increasing shares of renewable energy sources and that the increase will depend strongly on the quality of their forecasts.

However there will be a very different demand for control reserve in different hours. Hours with lot of wind and sun will for example lead to a higher demand for control reserve than night hours with little wind where no photovoltaic and only a small wind forecast error can be expected. To benefit from this fact the sizing of control reserves has to be done on a daily or even shorter basis so that forecasts for wind and photovoltaic energy can be used. For reducing the lead time a daily tendering of the control reserves is necessary, which is already the case for the tertiary control reserve and is planned for the secondary control reserve in Germany [16]. Another prerequisite for obtaining the full benefit from renewable energy sources forecasts is reducing the control reserve market product length to, for example, 1 h. In [2,3,17,18] methods for sizing control reserves in day-ahead or shorter time-periods are proposed.

In this work we developed a *dynamic method* which is based on the idea of the *Graf–Haubrich* method and characterized by sizing the control reserve one day before its use for a product length of 1 h. In [2,3] similar approaches have been implemented. However both works model the wind and photovoltaic forecast errors as simple normal distributions which does not reflect reality [4–6], especially for single hours. Here is the main difference to the *dynamic method* presented in this work. For the *dynamic method* the distributions of the wind and photovoltaic forecast errors are created with kernel density estimation depending on the day-ahead forecast and the intraday forecast error to reflect the specific characteristics of wind and photovoltaic forecasts.

In Section 2, the *dynamic method* is described and compared in detail with a modification of the *Graf–Haubrich method* here called the *static method*. In Section 3, the 100% renewable energy sources test scenario is presented followed by a discussion of the results in Section 4 and concluding remarks in Section 5.

2. Comparison of the dynamic and static methods

Because the *Graf–Haubrich method* currently used by the German transmission system operators cannot be applied to a 100% renewable energy sources scenario, a new method that can yield similar results is needed; the *static method*, a modification of the *Graf–Haubrich method*, is one such method. The *static method* is used as a baseline method against which the *dynamic method* will be compared. There are two differences between the static and the *Graf–Haubrich method*. First, in the former, the forecast error is separated into wind, photovoltaic and load forecast errors. Second, the *Graf–Haubrich method* uses historical data from the last 12 months to size the control reserve for the next three months, which cannot be performed for a future scenario because historical data from the year before the future scenario and from the scenario year itself would be needed. Therefore, the control reserve is sized for the whole scenario year, which is the usual approach when the control reserve is sized for future scenarios [1,14,15].

Both the *static* and the *dynamic method* respect the same error distributions types. The load forecast error considers the deviation of the quarter-hourly average of the load from the forecasted load for this period whereas the load noise error describes the deviations of the load from its quarter-hourly average value. The schedule step error represents deviations from the scheduled exchange with other control zones. Failures of conventional power plants are represented by the power station error distribution. The wind and photovoltaic forecast errors correspond to the deviations between the actual feed-in and the forecasted values averaged over 15 min.

To illustrate the differences between the two methods, the error distributions for the whole year (*static method*) and for one single hour (*dynamic method*) of the 100% renewable energy sources scenario are presented in Fig. 1 as an example. The methods require the same type of error distributions, but the estimation of the error distributions varies among the two because forecasts for the period for which the control reserve is sized are used in the case of the *dynamic method*. The *static method* sizes the control reserve for the whole year. The *dynamic method* sizes the control reserve for every hour of the following day. Thus, in the markets for control reserve, a product length of 1 h and a lead time of one day are assumed. Other lead times are also possible, but because the German control reserve is tendered daily for the tertiary control reserve and will presumably be tendered daily for the secondary control reserve [16], a shorter lead time is not plausible. A product length of 15 min is not considered because the resolution of the scenario is 1 h.

In Fig. 1, the Gaussian distributions for the load forecast error and load noise errors are narrower for the *dynamic method* because the load of that particular hour is used as the expected value, which is smaller than the maximum load of the year used for the *static method*. With the *dynamic method*, the power station error has a probability of one for an error of zero because there is no residual load in this particular hour and so no conventional power stations are in operation. This is the same with the schedule step error because there are no changes in the power exchange to neighboring countries during this particular hour and so no schedule steps. The difference between the wind and photovoltaic energy forecast error distributions for the static and *dynamic method* is observed because for the *static method*, all 1-h forecast errors of the last year are used, and for the *dynamic method*, mainly the 1-h forecast errors with day-ahead forecasts similar to those for this particular hour are taken into account (s. Section 2.5). It can be observed that the shape of the wind forecast error distribution for the *dynamic method* is not as symmetric as the error distribution for the *static method*. This discrepancy occurs because a high power feed-in compared to the installed capacity is forecasted for this hour, and in contrast to the *static method*, the *dynamic method* can model the fact that in this case, a negative forecast error is more likely than a positive forecast error. In addition, the photovoltaic error distribution for the *dynamic method* is narrower than the distribution for the *static method* because the sun's altitude is low at this hour, and therefore, the *dynamic method* models the fact that the actual feed-in can only vary between zero and the theoretically maximal feed-in due to the sun's position.