Sizing control reserves with a new dynamic method considering wind and photovoltaic power forecasts

Influences on the demand for frequency control

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Abstract—**Control reserves are usually sized statically which means there is a fixed amount of reserves for a long period. In reality the demand for frequency control fluctuates strongly. For this reason a dynamic method for the sizing of control reserves for the following day should be developed that could be used in Germany already today. In this paper all possible imbalances are classified. Afterwards the influences on the probability density functions of the different classes of imbalances are analysed. The identified factors will be the base for the new sizing method as they are crucial for the demand for frequency control. Additionally the stochastic independence of forecast errors and fluctuations around this forecast error is examined which is a prerequisite for the convolution of two probability density functions which will be preferably used for the new method.**

control reserve, dynamic sizing, frequency control, secondary control, tertiary control, wind power forecast, photovoltaics power forecast, power plant outages, forecast error

I. Introduction

For a secure grid operation generation and consumption of electricity always have to be in balance. The Transmission System Operators (TSOs) are responsible to maintain this balance. For this task they procure different types of control reserves. In the UCTE grid primary control is provided solidly by all TSOs connected to the synchronous grid, irrespective whether or not the imbalance was caused within their own control area or not. It is activated locally depending on the grid frequency and has to be activated completely within 30 seconds. Secondary control and minute reserve (tertiary control) are centrally activated by each TSO to minimize the area control error within its own control area. In Germany they have to be activated completely within five and fifteen minutes, respectively.

Whereas the amount of procured primary control for the whole UCTE synchronous area is determined by the maximum instantaneous power deviation which is defined to be 3000 MW, the sizing of secondary control reserve and minute reserve is up to the single TSO [1]. In Germany the probabilistic Graf Haubrich method is used to size these reserves. The sizing is done every three months (in March, June, September and December) for the next three months considering data from the last four quarters. This means that there is always a fixed amount of reserves for three months.

In reality the demand for frequency control fluctuates strongly over time. For this reason there is an increasing effort to size control reserves dynamically, e.g. on a daily basis for single hours of the following day. There are some research projects that have proposed methods for a dynamic sizing of control reserves but most of these projects focus on future situations [2, 3]. In the project *Dynamische Bestimmung des Regelleistungsbedarfs* we are developing a method that focuses on Germany and should be useable already today.

For the sizing of control reserves according to the Graf Haubrich method probability density functions for imbalances due to different reasons (load forecast error, power plant outages, etc.) are convoluted to a probability density function that represents the probabilities for the occurrence of a certain imbalance. Afterwards certain deficit and surplus probabilities are applied to this probability density function to determine the needed reserves [4]. For the static sizing the probability density functions of the whole training period are determining. For a dynamic sizing of control reserves only the periods are interesting that represent situations that are equal or similar to the situation that is expected for the sizing period. Therefore it is crucial to know what the influences on the different imbalances are.

In this paper all occurring imbalances will be classified. Based on this classification the factors influencing the probability density functions of these classes will be identified. Finally the stochastic independence of the different probability density functions, which is a prerequisite for convoluting, is analysed.

II. Classification of Causes for Imbalances

The schedules that are created by the balance responsible parties and sent to the TSOs always have to be balanced. If all balance responsible parties would stick to their schedules there would be no imbalances and no need for control reserves. Obviously this is not the case. Hence, deviations from the schedules are the reason for the activation of

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control reserves. These deviations can be classified by various criteria.

One classification is the period that these deviations cover, respectively which type of control reserve is used to balance them. The first class called forecast errors covers the mean deviation from the schedule respectively the forecast within one quarter hour. As fifteen minutes correspond to the settlement period in Germany most time series of forecasts, measurements etc. are available with this temporal resolution. In the same way minute reserve is activated for quarter hours, so forecast errors should ideally be balanced by the activation of minute reserve. The second class covers fluctuations from the quarter hour mean value. These fluctuations should be balanced by secondary control. Here, fluctuations correspond to the deviation of each minute mean value within a quarter hour from the mean value over the whole quarter hour. Fig. 1 illustrates the concept of forecast errors and fluctuations.

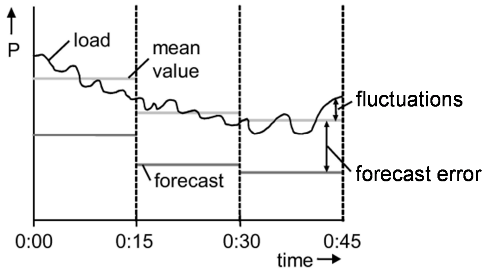

Figure 1. Illustration of forecast errors and fluctuations. (adapted from [4])

Furthermore schedule deviations can be classified according to their origin. They can be caused on the consumption or on the generation side. The consumption side is modelled by the forecast error. The generation side can be subdivided even further according to the type of generation. Wind and photovoltaic (PV) power generation is stochastic due to its fluctuating nature. Here the forecast error of the generation is the decisive factor, in contrast to controllable power plants like thermal or hydro power plants, where predicting the output is usually no problem, apart from power plant outages that occur randomly.

Figure 2. Fig. 2 shows the classification of schedule deviations that is used in this paper.

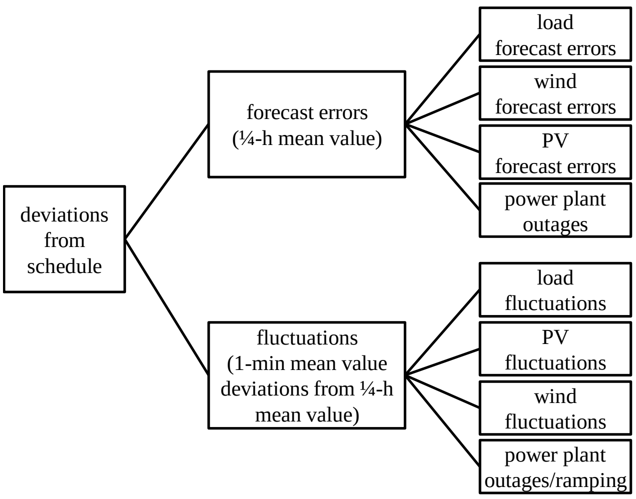

Figure 2. Classification of schedule deviations.

In the following all classes of schedule deviations will be analysed according to the availability of data and factors influencing the occurrence. All data used in this paper is from 2012.

A. *Forecast errors*

The forecast error, which is the sum of all different forecast errors, is represented by the fifteen minute mean value of activated secondary and minute reserve. Fig. 3 shows the probability density function of the forecast errors in 2012. The influences on the forecast errors are analysed for each subclass in the following.

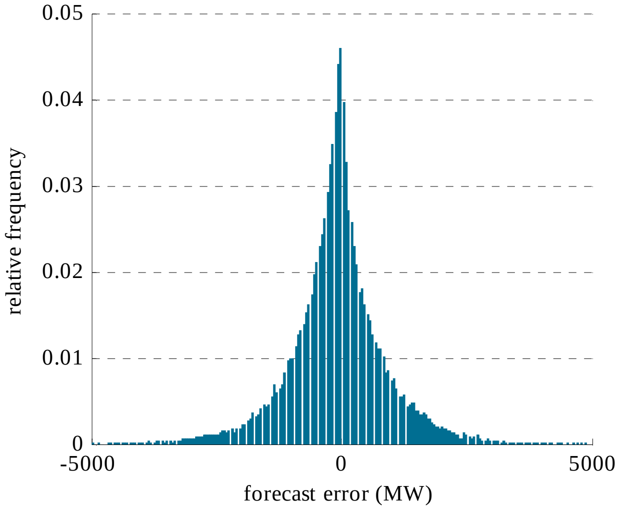

Figure 3. Probability density of forecast errors in 2012.

1) *Load forecast error*

In Germany there is actually no data for the load forecast error available. On the one hand this is due to the fact that for example the consumption of standard load profile customers is usually only measured once a year. On the other hand consumption and decentralised generation e.g. photovoltaic mix up in the distribution grids, so the vertical grid load is also no reliable indicator for the actual consumption. However data of delta balancing groups of distribution grid operators that cover all deviations which cannot be allocated clearly can give a first clue what are the influences on the load forecast error. As an example Fig. 4 shows the deviations of the delta balancing group of bnNETZE grid in the southwest of Germany. Positive deviations indicate a shortage of electrical energy, negative deviations an excess.

It is apparent that on most days there is a shortage of energy during the night hours from 10 p.m. to 6 a.m. whereas during 6 a.m. and about 2 p.m. an excess occurs. This suggests that the used standard load profiles do not exactly reflect the actual consumption of standard load profile costumers. Analyses in [5] support this thesis. For this reason the time of the day and the day of the week probably influence the load forecast error.

In February there are several days that show an extreme shortage of energy during the night hours and in parts even during the day hours. This can be explained by the unusual cold weather during those days as most standard load profiles do not consider the influence of the outside temperature on the electrical energy consumption.

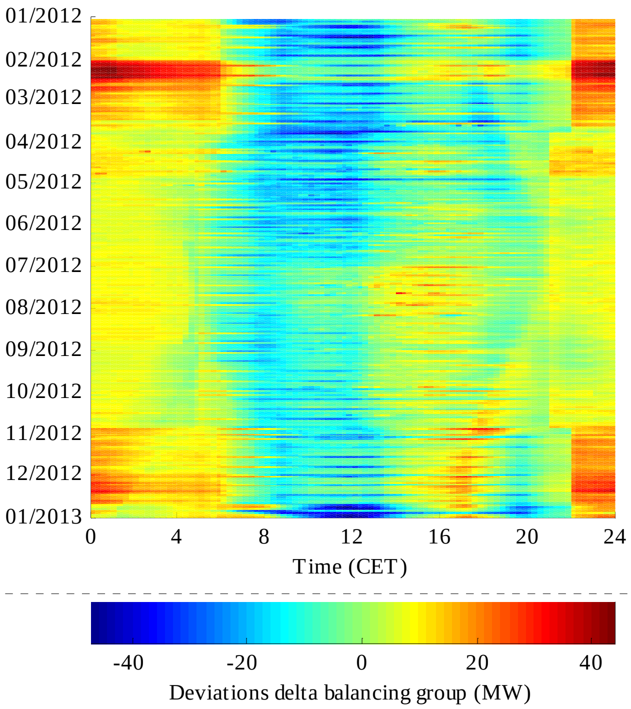

Figure 4. Deviations of delta balancing group of bnNETZE.

Figure 5. Fig. 5 indicates that there is not only a positive forecast error (need for positive control reserves) for low temperatures but also for high temperatures. This is probably due to air conditioning which is also not considered by standard load profiles.

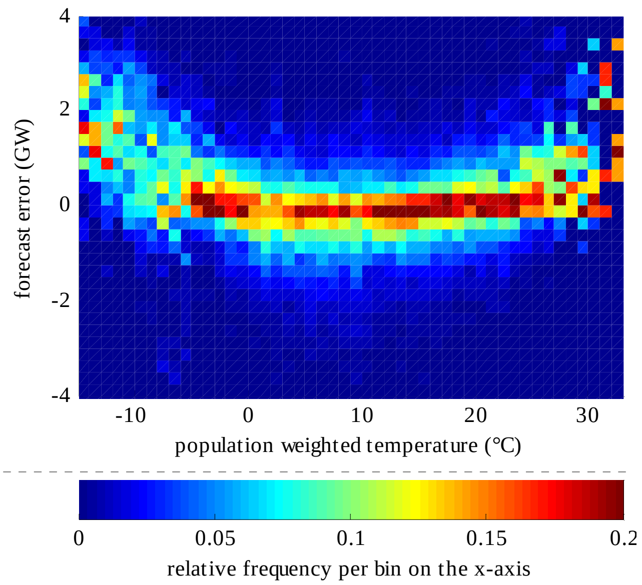

Figure 5. Binned frequency of forecast errors depending on the population weighted tempearature.

Another phenomenon that affects the load forecast error is the so called hour step. Although balance responsible parties have to balance their balancing groups in every quarter hour they often still trade only products with a length of one hour. Controllable power plants are able to follow their schedule quite strictly which results in a staircase-shaped generation whereas the load increases or decreases continuously. This means that e.g. for increasing load in the morning hours an excess of energy occurs to the beginning of each hour which turns to a shortage of energy in the end of the hour. When the hour changes the situation reverses within a few minutes, which is called the hour step. Fig. 6 illustrates this phenomenon for the morning hours of one day. The altitude of the hour steps depends directly on the load gradient. For this reason the highest hour steps occur in the morning and evening hours. As one can see in Fig. 6 hour steps are the dominating factor for the activation of control reserves today. But it can be expected that they will decline in importance as there will be quarter hour products on the day-ahead market and the pressure to balance balancing groups every quarter hour will probably be increased by the TSOs and the Federal Network Agency (Bundesnetzagentur).

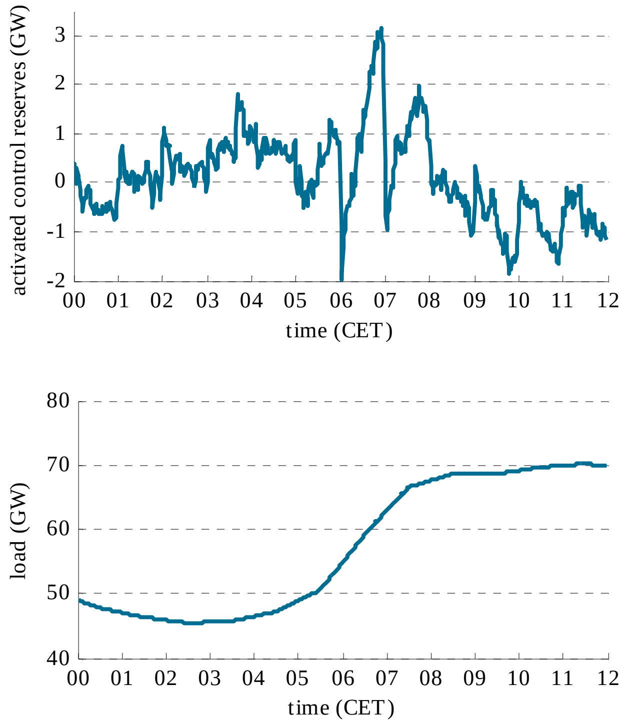

Figure 6. Hour steps and load on 16th January 2012.

2) Wind and PV forecast error

There is no data available for the forecast errors induced by wind and PV power generation in Germany as there are no schedules exclusively for wind and PV. On the other hand it is not known which forecasts for the wind and PV power generation are used by the balance responsible parties. Here the meta short term forecasts for Germany created by TenneT with lead times from 90 to 135 minutes are analysed to identify the factors that are influencing the forecast error.

Fig. 7 shows that the distribution of the summed short term forecast error of the wind and PV power generation highly depends on their current generation.

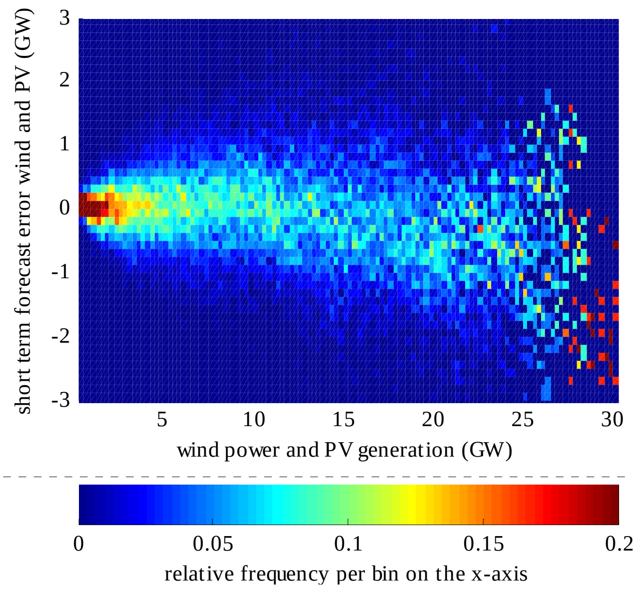

Figure 7. Short term forecast of wind and PV power generation depending on the wind and PV power generation.

But not only the level of generation is decisive also the gradient of the generation influences the distribution of the short term forecast (Fig. 8). As the dynamic sizing of control reserves is done for the following day the equivalent day-ahead forecasts have to be used for this purpose.

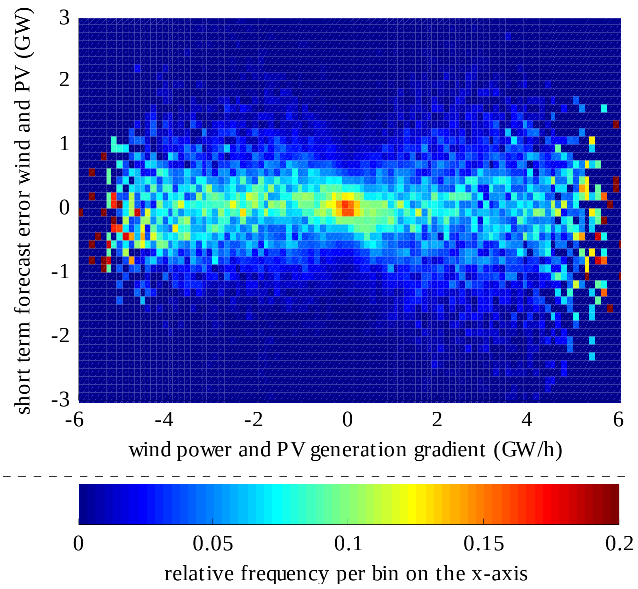

Figure 8. Short term forecast error of wind and PV power generation depending on the wind and PV power generation.

3) Power plant outages

In Germany only data of outages of power plants with a generation capacity of more than 100 MW is available. But the probability density function of forecast errors induced by power plant outages can be assessed theoretically. The occurrence of outages is stochastically distributed. To determine the probability density function for forecast errors induced by power plant outages the outage probability and schedule of every power plant that is online in the specific situation has to be known. This information is only known by the TSO for power plants with a capacity of more than 100 MW. Therefore a probability density function created in this way can only be a rough estimation.

In general the probability density function depends on the residual load (load minus wind and PV power generation). A high residual load means more online power plants and thus also a higher probability for outages. The particular feature of this probability density function is that it covers only positive forecast errors which induce a need for positive control reserves.

B. Fluctuations

The definition of fluctuations used in this paper corresponds to the deviation of the one minute mean value of activated reserves from the fifteen minute mean value. Fig. 9 shows the probability density function of all summed fluctuations in 2012.

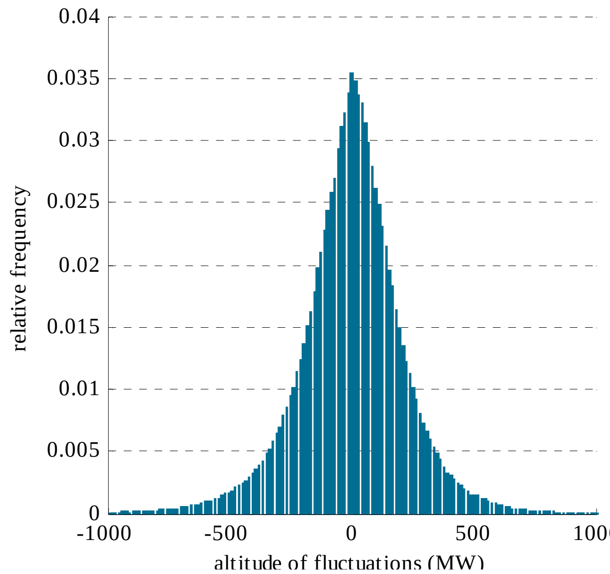

Figure 9. Probability density of fluctuations in 2012.

1) Load, wind and PV power oscallations

There is no data available regarding the fluctuations caused by load, wind and PV power as the settlement is made only quarter-hourly. This means that most measurements are also only mean-values for one quarter hour. For this reason only the influences on the summed fluctuations can be analysed. It can be expected that the fluctuations on the one hand consist of a pure stochastic part which depends on the level of the load or the wind and PV power generation. On the other hand there are fluctuations that result from the same effect like the hour step (chapter II. A. 1)), only adapted to quarter hours as the settlement period in Germany is fifteen minutes. For this reason one can expect that the distribution of fluctuations also depends on the gradients of the load and the wind and PV power generation. If all these gradients have a positive respectively negative value the fluctuations caused by wind and PV act accumulatively whereas the fluctuations caused by the load gradient act contrarily. Fig. 10 shows that the distribution for a sum of all gradients of about zero is quite narrow and spreads significantly for high negative and positive sums of the gradients.

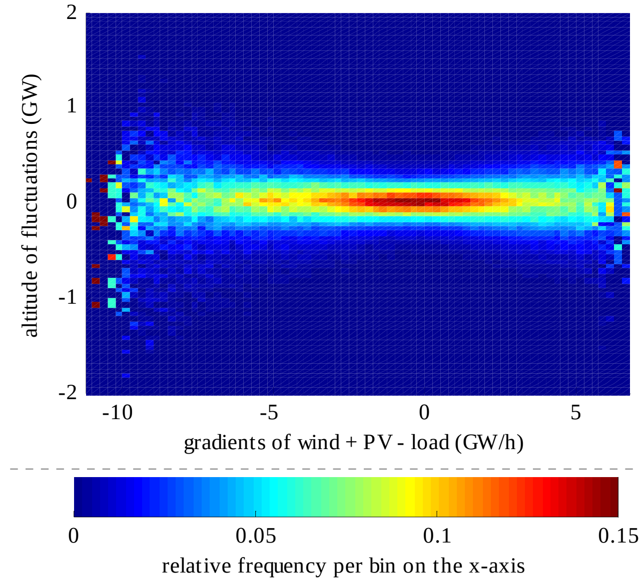

Figure 10. Altitude of fluctuations depending on the gradient of wind and PV power generation minus load.

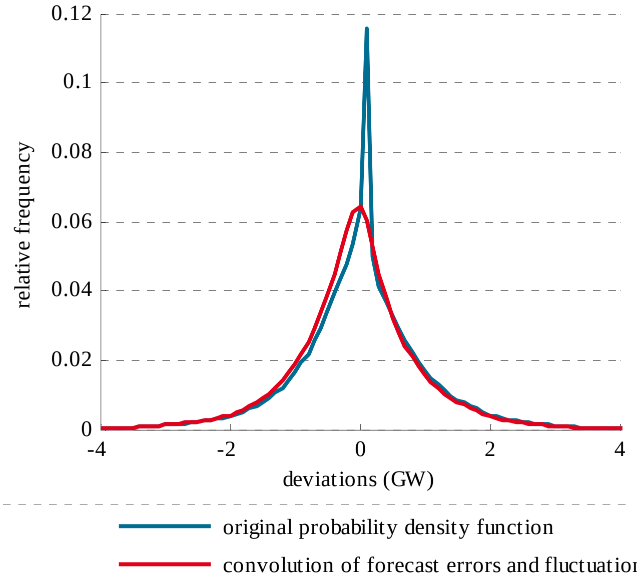

Figure 11. Probability density function of convoluted forecast errors and fluctuations compared to the original probability density function.

2) Power plant outages and ramping

The fluctuations caused by power plants can only be assessed theoretically. Here power plant outages that occur within the considered quarter-hour and fluctuations caused by the ramping of power plants due to a change in the timetable would have to be considered. Therefore we expect the fluctuations induced by power plants to depend on the residual load respectively its gradient. But the influence of power plant outages and ramping on the fluctuations is probably small. Therefore no further analysis is carried out here.

III. STOCHASTIC INDEPENDENCE OF FORECAST ERRORS AND FLUCTUATIONS

A prerequisite for the convolution of probability density functions is their stochastic independence. As there is only reliable data available for the summed forecast errors and the summed fluctuations the following analyses focuses on the stochastic independence of their probability density functions.

For a first check the probability density functions of the convolution of all summed forecast errors and fluctuations and the original probability density function are compared (Fig. 11). In the case of stochastic independence both functions would match perfectly. This is obviously not the case as the original probability density function has got a peak for values slightly greater than zero which cannot be found in the probability density function of the convolution. The Q-Q-plot (Fig. 12) confirms the expression, but it also shows that the main differences occur for the middle quantiles. The low and high quantiles match quite well. This means that the convolution of both probability density functions is strictly speaking not allowed but may be a good approximation when only the low and high quantiles, which are crucial for the sizing of control reserves, are considered.

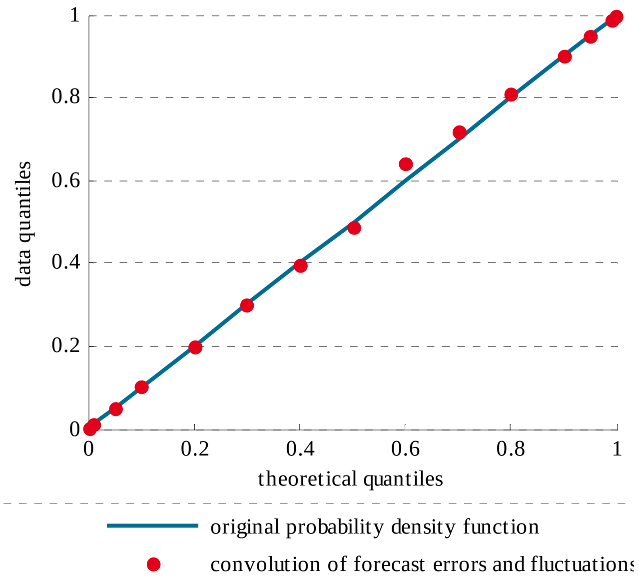

Figure 12. Q-Q-plot of the convolution of forecast errors and fluctuations compared to the original probability density function.

IV. CONCLUSION AND OUTLOOK

All possible schedule deviations that induce a need for control reserve activation have been split into forecast errors and fluctuations. Afterwards they have been classified according to their origin (load, wind power, PV power or power plant generation). It has been found that for most subclasses no reliable data is available. Nevertheless it could be analysed what the influencing factors for the different deviations are. The factors that are influencing the forecast error are:

- Time of the day and day of the week
- Load and its gradient
- Temperature
- Generation of wind and PV power and their gradients
- Residual Load

The main influences on the fluctuations are:

- Load and its gradient
- Generation of wind and PV power and their gradient
- Residual load and its gradient

Stochastic independence of the probability density functions of all summed forecast errors and fluctuations has been analysed and it has been shown that these probability density functions are strictly speaking not stochastically independent and so cannot be convoluted. But the convolution may be a good approach when only low and high quantiles are considered.

For this reason we will develop, implement and test two different approaches. In the first approach probabilistic forecasts for the forecast error and the fluctuations for every quarter hour are made. Then these probability functions are convoluted to one probability density function. In the second approach this probability density function will be the direct result of the probabilistic forecast. Afterwards a deficit and surplus probability will be applied to determine the needed reserves.

V. ACKNOWLEDGEMENT

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