Dynamic Strategies for Amount and Reliability of Control Reserve in Future Smart Grids

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Abstract

The nuclear phase-out and the increased share of renewable distributed generation implicate new challenges for transforming the electric power system into an environmentally sustainable, reliable and cost-efficient system. An important component in transforming the electric power system is the reliable substitution of large controllable power plants by small generation units (photovoltaic systems, wind energy converters and combined heat and power plants (CHP)) without impairing the overall safety and quality of the energy supply. In particular, the process of control reserve and balancing power to cover power plant or prognosis faults has to be adapted to today´s complex decentralized structure. This complexity both includes the factors of influence on the reserve dimensioning and the certifiable level of reliability for its provision. The aim of this paper is to develop a dynamic strategy for reserve and reliability that factors in these altered circumstances, in particular the provision of ancillary services by decentralized self-organized coalitions of small active units.

1. Introduction

To ensure a constant power frequency and thus a stable quality of supply, the permanent balance of power demand and supply is the most crucial constraint in an electrical power system. Therefore there is a need for reserve and balancing power to cover prognosis faults for example of wind generation and loads or unpredictable events like power plant outtakes. In order of their activation time, the control reserve is differentiated into primary, secondary and tertiary control (also minute reserve). In figure 1 the different forms of control reserve and their factors of influence are shown.

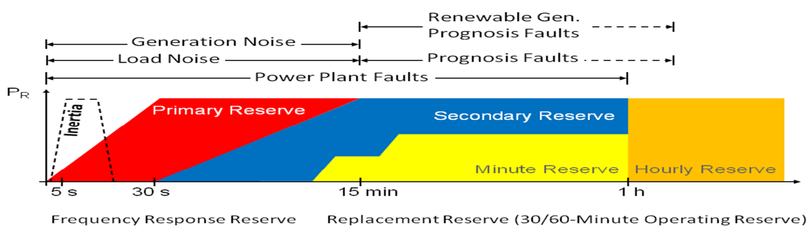

Figure 1
Forms of control reserve and their influencing factors
Source: referring to (Consentec 2008)

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The current design for the dimensioning of necessary reserves and its reliability is based on the strictly hierarchical and centralized structure of the European electricity sector. In contrast, the increase of generation from distributed energy resources (DER) makes the system become more and more decentralized and complex. Thus, the reserve and reliability strategy has to be adapted to today's complex decentralized structure, in which many different agents take part in a free wholesale market. That adaption affects both the control reserve dimensioning and its provision.

In the past the need for reserve control was primarily caused by unpredictable power plant outtakes or load and generation noise. So the design was adapted to the large thermal power plants for instance in respect to the bidding periods, the given loss of load probability (LOLP)[3] or the postulated reliability[4]. Due to the increase of fluctuation renewable energy sources like wind and solar, today both the reserve dimensioning and its activation critically depend on the percentage share of DER generation and within prognosis faults. Whereas the power plant outtakes and noise could be considered as random and stochastically independent the amount of reserve caused by prognosis faults is not stochastically independent or uncorrelated. On the contrary, it is related to the actual state of generation and supply, the current network characteristics and also generation and load forecasts. Even the influence of business management reasons could be accessed in the recent past, e.g. in February 2012 as extraordinary prognosis faults depleted the whole reserve. This event was attended by a price spread between the EEX and the control reserve market, which implies that the load assumption was deliberately underestimated[5] (BNetzA 2012a).

The main fact, that has be regarded is: In the past, frequency control was provided by large "blocks" of high amount with high reliability over long periods of time whilst in the future these services has to be covered from small DER "blocks" with low reliability over short/medium forecasting horizons.

This leads to the main research questions[6]:

- Is it possible to design a dynamic reserve provision which is in line with the demand?
- Is it possible to integrate the systemic characteristics of DER, such as the volatile operational availability into a new method of dimensioning and providing operating power?

These issues are based on the following working hypotheses, which are investigated in this paper:

- The current provision of frequency control is inefficient and does not take into account the altered conditions of an increasing decentralized energy system, that is build on volatile generation
- There is a correlation between the activation of operating power and the influencing parameters so that the dedicated operating power could be reduced by a dynamic method

2. Related Work

A considerable amount of literature has been published on reliability of energy supplies and the required operation reserve to ensure it. One of the pioneers was Prof. Dr. Kurt Edwin, who already examined the demand of power reserve in linked systems of power plants in 1979 (Edwin et al. 1979). Besides the increasing influence of probabilistic DER-generation also the liberalization in the energy sector necessitates a modification of the control reserve market. The main fact is that the responsibility for reserve power was shifted from the energy supply companies (EVU) to the TSO´s with the consequence that the process cannot longer be vertical integrated, but has to be designed with market oriented structure. This led to the creation of the German control reserve market. Hence, the German Federal Network Agency (BNetzA) is-

[3] Usually the LOLP is 0,1%, i.e. that the demand is exceeded ~ 10 hours per year

[4] The actual postulated reliability rate is 100%;which is highly questionable from the technical point of view

[5] The BNetzA resolved this grievance by implementing a pricing mechanism called ReBAP (BNetzA 2012b)

[6] presented in future papers

sued a study on the required secondary and tertiary control power for each German control area (E-Bridge 2006). In this expertise the impact of DER and within the prediction-deviations from wind power were increasingly included. Comparable expertises but with a stronger focus on the common control area network were published two (four) years later (Consentec 2008)(Consentec 2010). The studies determined that the implementation of the common tendering caused a shift from the secondary reserve to the tertiary reserve and reduced the total demand.

Today this so-called method of Graf-Haubrich is still adopted for dimensioning the demand of operating power. This is done by initially analyzing the relevant influencing parameters and then convoluting the individual probability density functions into one common density function[7]. Recently, besides the analytic method also simulative approaches are used. (Brückl 2006) explored a Monte-Carlo-Simulation-based approach for probabilistically dimensioning of the demand of operating reserve by distinguishing the probability density function for each form of control power. Thereupon power outtakes due to power plant outtakes, load- or prediction-deviations were examined with the simulation result that the wind prognosis faults had the biggest influence on the reserve amount, if the current highly dimensioned LOLP-value is kept. So (Brückl 2006) already posed the question, to which extend the actual reliability strategy is economically reasonable. Many of following studies aim at DER integration in the power markets through economic optimizing (Speckmann 2011), (Klobosa 2007), (Burger 2011). One example is the study of (Kurscheid 2009) which aims at integrating decentralized combined heat and power plants (CHP) in the control reserve market for minute reserve.

Besides these studies to integrate single technologies, there is already related work dealing with the overall control reserve market. (Kippelt/Schlüter 2012) actually examine an adaptive control power market with capacitive reserve. The objective of this research is to extent the approach of a flexible tendering for tertiary reserve on the principals of a capacity market. Another research project associated at the Fraunhofer IWES together with Tennet on behalf of the German Ministry of Environment (BMU) seeks to develop a method for a daily dimensioning of reserve power (Speckmann 2013). In contrast of the aforementioned studies, this study will focus on computational intelligence methods to predict the demand for operating reserve dynamically. Whereas other studies still adhere to centralized control architecture, such as in virtual power plants (VPP), this study wants to factor in the increasing impact of self-organized coalitions of small active units based on multi-agent-systems (MAS) as examined in the "Smart Nord" Research Association this work is related to. The Smart Nord approach proposes a distributed control method to launch products of self-organized coalitions of small active units in a power grid at markets for trading power as well as ancillary services (Nieße 2011). One major improvement of this approach is the dynamic proactive and reactive scheduling based on self-organized agent coalitions. The impact of this concept on the reserve control market is one of the facts that should be explored in this study.

3. Methodology

The idea behind this paper is to detect the relevant influencing parameters for reserve dimensioning and to deduce existing correlations between them by a time series analysis and then transfer these results and correlations into a proper model. In time series analysis several methods are used to detect such features, as time correlations for example. These correlations can then be validated by causality functions to guarantee their reliability for forecasting. If the main parameters with the highest impact are found, computational intelligence methods can be applied to learn from several datasets how to predict the demand of operating power for new sets of parameters. So the aim of this paper is a detailed analysis of the reserve activation in the years 2008 and 2012.

[7] Provided the parameters are non correlated; which there aren´t to this extend anymore

4. Results

The analysis is divided into four parts, first the general allocation of the different forms of control reserve is examined, second the activation behaviour of minute reserve is analyzed exemplarily for the year 2012, third the time of day dependency of the minute reserve activation and the activated amount of secondary reserve is reviewed for the years 2008 and 2012 and fourth the occurrence of clusters within the minute reserve activation is examined. With respect to the allocation of the different forms of operating power, the increase of fluctuating renewable energy sources like wind or solar caused a shift towards the tertiary control. Between 2005 and 2008 the number of tertiary reserve activation was relatively constant with 5,325 activations and an average power of 300 MW, in 2009 there was an abrupt rise to 18,206 activations but with almost the same average power. Until 2012 the number of activations is again relatively constant with 17,282 activations per year, but three-times higher than in the period before (BNetzA 06/12).

With respect to secondary reserve it is the exact opposite, the number of activations remained steady whereas the amount of activated reserve decreased in terms of triplication (see figure 3). Today the provided minute reserve is dimensioned analytically based on a-posterior data. The current dimensioning is adapted, if the design deficit-probability, respectively the LOLP, is exceeded or certain generation increased. In the year 2012 the tendered quantities were adapted four-times. In contrast to the dynamic activation of the operation reserve this procedure has to be classified as static. Figure 2 shows exemplarily the activation and provision of minute reserve in the year 2012.

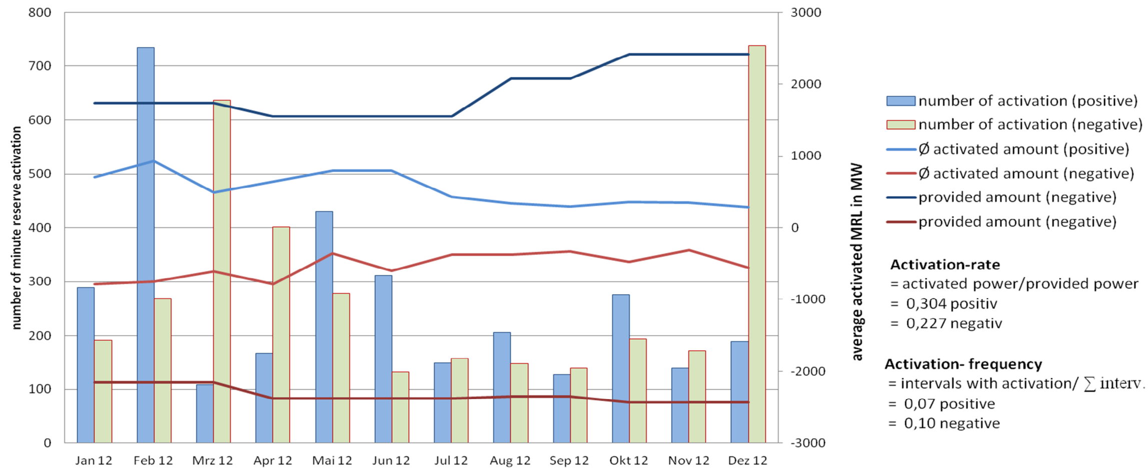

Figure 2
Activation and Provision of Minute Reserve Power in the year 2012

On the right ordinate the average activated power and the provided power (both in MW) are plotted. The quotient of these two values is the so-called activation rate (german Abrufgrad). In 2012 the average activation rate was 0.304 for positive minute reserve and 0.227 for negative minute reserve; that means 70 % of the provided power was held in reserve but not actually needed. This constitutes an obvious and massive inefficiency in the dimensioning of operating reserve. The statically run of the two curves indicates the marginal variance of these values. In contrast, the activation of operation power is highly dynamic due to the influencing parameters like short-term prognosis faults. This data is plotted in a histogram on the left side of the figure. It is measured in the so-called activation frequency (german: Abrufhäufigkeit) and is defined as the quotient of the time intervals[8] with respect to the activation and the given period.

[8] Each interval is 15 minutes

It can be seen that the variance here is much higher; whereas the annual average activation frequency was 0.07 for positive minute reserve (this equates to an average activation of 260 per month), the maximum in February was 734 activations and the minimum in March were only 108 activations. The positive minute reserve it is a similar case; here the annual average frequency was 0.10, with the maximum of 738 activations in December and the minimum of 132 activations in June. This method of reserve provision is very inefficient. So the effective demand has to be analyzed in detail to retrieve correlations, which can be formalized and then transferred into a model. Therefore, the analysis of correlation between minute reserve activation and the time of day, as examined by (Kurscheid 2009) for the years 2006 and 2007, was extended to the years 2008 and 2012 and to the secondary reserve. Figure 3 both shows the activated amount of secondary reserve on the left and the activation of positive minute reserve on the right side respectively for the years 2008 and 2012 summarized over the four German TSO areas.

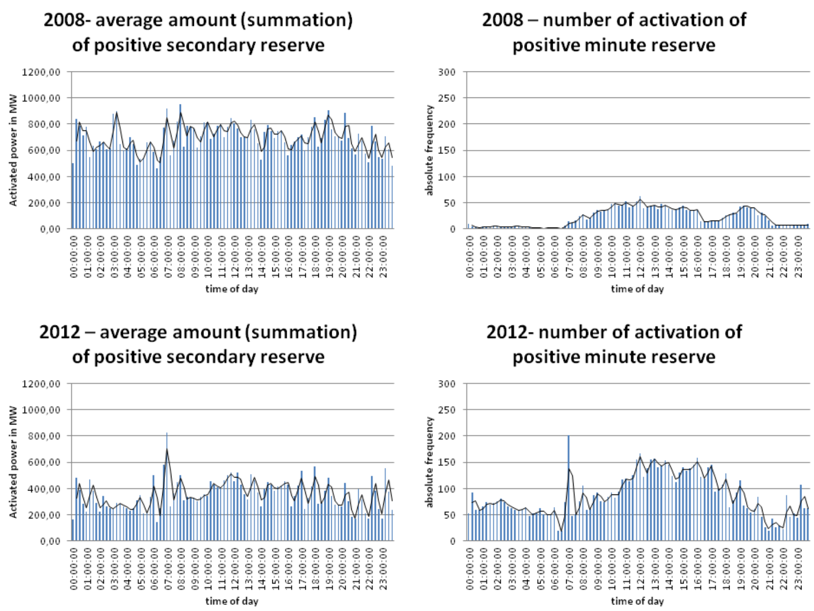

Figure 3
Average amount and number of Activation of Secondary/Tertiary Reserve in the years 2008 and 2012

In general, this figure illustrates that the number of activations of minute reserve increased whereas the amount of activated secondary reserve decreased in terms of a triplication as mentioned before. Noticeable are the peaks at the beginning of each hour in the year 2012, especially at 7:00 pm. Hence, it could conceivably be hypothesized that there is a relationship with the time packages dealt at the EEX, which are divided into hour blocks. That influencing parameter is also called schedule drop (german: Fahrplansprung). In regard to the activation of minute reserve it can be seen, that the curve progressions of the two years are slightly different. Whereas in 2008 at night-time between 0:00 and 07:00 there were almost no activation, in 2012 there were more activation by night then in the daytime in the year 2008. Regarding the turning points it can be seen, that the peaks of the curves remained steady between 12:00 and 16:00 pm, but the lows of the curves shifted from 17:00 pm in 2008 to 21:00 pm in 2012.

In addition, the autocorrelation of the minute reserve is another important feature that has to be considered. (Kurscheid 2009) already posed the fact that minute reserve is rarely activated in periods with the length of a single interval (15 min) but in clusters (german: Büschelabruf). Table 1 shows the percentage share of cluster activation for the summation of the years 2006 and 2007 (Wenzel 2008) and for the year

2012 for positive minute reserve. (Wenzel 2008) related the occurrence of cluster-activation to the total number of intervals with activation. To compare these results with the year 2012 these values are also specified in the table (first number and percentage). But these values do not represent the real distribution, because the activation periods with a big length (over 4 periods) are more weighted than the periods with only one interval. So a better way to describe the percentage share is to take the total number of calls (one call can be over several intervals) as basis. With this data it is also possible to calculate the average length of an activation period, which is ~ 4.5 intervals for 50Hz (f. VET) and Amprion (f. RWE) and ~ 7 intervals Tennet (f. E.ON) and TransnetBW(f. EnBW).

Year	TSO	total number act. Interv.	total number periods	number of activation/calls over several intervals				number of activation from 2 to 4 intervals		number of activation over more than 4 intervals			
2006/2007	VET	187		38	20%			24	13%	14	7%		
	RWE	2631		307	12%			150	6%	157	6%		
	EON	860		156	18%			110	13%	46	5%		
	EnBW	169		40	24%			29	17%	11	7%		
2012	50 Hz	1934	431	1757	91%	254	59%	364	19%	1393	72%	106	25%
	Amprion	2496	545	2246	90%	295	54%	389	16%	1857	74%	135	25%
	Tennet	2292	323	2203	96%	234	72%	263	11%	1940	85%	130	40%
	TransnetBW	1614	222	1558	97%	166	75%	172	11%	1386	86%	100	45%

Table 1
Number of Cluster-Activation of positive Minute Reserve Power in the years 2006/07 and 2012

The percentage share of cluster activation increased in the recent years. In the years 2006 and 2007 the percentage was between 12% and 24%, in 2012 the value lies between 59% and 75%. Especially the cluster with a length over more than 4 periods increased from an average of 6 % up to an average of 34 %.

5. Conclusion

This paper has given an account on the current reserve control market in Germany. The purpose of the current study was to analyze the data from minute reserve activation of the recent years to detect dependencies and correlations. One of the more significant findings to emerge from this paper is that the characteristic of the reserve activation has changed in the recent years. Due to the altered weighting of the influencing parameters the behavior of the activation, in particular of minute reserve, has changed and is still changing. Therefore, it seems that the current analytic statically method to dimension the demand of frequency reserve control is not adequate anymore. The former work should therefore concentrate on the investigation of computational intelligence methods to predict the demand by factoring the dynamic parameters into the dimensioning.

6. Acknowledgements

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[9] http://www.see.uni-oldenburg.de

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