Dimensioning of Control Reserves: Approach Based on Probabilistic Methods

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Control reserves are means for establishing and maintaining a balance between produced and consumed electrical energy in a power system even in cases of significant deviations of an actual operation conditions from planned ones. A correct dimensioning of control reserves is a very important task seeking a trade off between security and economy of power system operation. Frequently an approach to this problem is based on probabilistic methods, whose one form is described in this report.

1 Introduction

In power system operation planning electricity production is scheduled to match expected consumption. However, in an actual operation, commonly a mismatch occurs. The sources of mismatch are: outages of power plants, load forecast error, spontaneous load variations and production forecast error of poorly controllable power plants[1].

The structure of control reserves, their characteristics, naming, a way of acquiring etc. differs from system to system. Here we adopt principles of UCTE [1]. UCTE is a multli-area power system, thus it can be accepted that control reserves in one area do not have to cover all situations, since a support from other areas can be provided in case of some extreme emergencies.

2 Methodology

An ability of power plants to supply load is treated in e.g. [2] and [3] applying probabilistic methods. We adopt methodology similar to [4] [5] and [6]. The methodology essentially follows the steps:

[1]Poorly controllable power plants are traditionally run-of-river power plants and recently in some systems in a significant extent distributed generation, mostly wind based.

1. **The influence factors are described by means of probability distributions.** Essentially any type of distribution can be considered within this methodology.

   Outages of generators may have a significant effect on the balance between load an generation. The probability $P(X)$ of a generator outage within the considered time span for the application of control reserves T_c, resulting in the loss of X MW can be determined based on the generator's *Mean Time To Failure* T_{MTTF} and *Mean Time To Repair* T_{MTTR} as follows:

   $$P(X) = \frac{T_c}{T_{MTTF} + T_{MTTR}} \tag{1}$$

   Loads[2] deviate from their scheduled, i.e. expected, or predicted value usually in two ways due to: load forecast error and spontaneous load variations. Load forecast error refers to the deviation of the actual **energy** value from the predicted value for the given time interval T_c. Spontaneous load variations are deviations of instantaneous **power**; frequently experiencing maximum value in morning load pick-up, i.e. gradient. Practice shows that both types of load deviations follow normal distribution with the expected value μ equal to zero:

   $$P(X) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{X-\mu}{\sigma}\right)^2} \tag{2}$$

2. **For the given control reserves category corresponding influence factors are identified and their probability distributions combined.** In UCTE two types of control reserves keeping or establishing balance between load and generation are determined for the control zone by its TSO: secondary control and tertiary control reserves. Secondary control reserves are permanently activated, i.e. it can not happen that only tertiary control reserves would be activated. Therefore when dimensioning control reserves, control reserves are split into these two categories: secondary control reserves and overall control reserves including both secondary and tertiary control reserves. The purpose of secondary reserves is to compensate spontaneous load variations and power plants outages within the time scope of T_c 15 minutes. Overall control reserves compensate power plant outages, spontaneous load variations and load forecast error within a time span T_c of 1 hour.

   For the given control reserves category a joint probability distribution is calculated out of distributions of the corresponding influence factors, e.g. for two independent events such as load deviation from schedule by X MW and simultaneous power plant outage of the size Y MW:

[2] Note, that when speaking about loads in this context, the system load, i.e. the entire sum of all loads in the system, is meant contrary to generators, which have to be in the first stage treated as individual units with their respective reliability characteristics expressed by T_{MTTF} and T_{MTTR}.

$$P(X+Y) = P(X) \times P(Y) \tag{3}$$

Note, that [4] [5] and [6] consider the direction of control reserves already in this stage, i.e. outages of power plants are considered as an influence factor only for dimensioning of positive control reserves. Contrary to this, we believe that outages of power plants shall be included in computations of both directions of control reserves, since they have an effect also on the negative side of unbalance between load and generations.

3. **The combined probability distributions are split into positive and negative part and then reformulated into cumulated distributions.** Cumulated distributions describe which portion of time (i.e. probability P_c) a deviation X from scheduled balance between production and consumption exceeds a certain size X_c, i.e. $P_c(X \geq X_c)$.

4. **The amount of control reserves is identified.** An accepted deficit level of control reserves P_D, in other words a portion of time within which control reserves X_{CR} do not suffice to cover deviations X from power balance, determines control reserves holding the relationship:

$$X_{CR} \in X : \min\{X_{CR}\}; P(X_{CR}) \leq P_D \tag{4}$$

3 Small example

The above described methodology has been applied in form of Matlab programs having a general structure allowing to easily change he scale of the problem, studied system etc. An analysis of a realistically sized power system should be possible. However, here a small system is used for demonstration purposes capturing essential characteristics in a scale allowing an intuitive interpretation of the procedure and results.

3.1 Input data and model parameters

The system is supplied by 4 power plants with an aggregate power rating of 500 MW and characteristics listed in table 1.

The load model data are shown in table 2. The standard deviations of distributions are derived by scaling down [5] a reference case where data is known to the size of this system, i.e. $P_{system} = 500MW$. Assuming $\varepsilon_{ref} = 5\%$ and with a probability of 99.73% quantile of $\chi_{ref} = 3$ shall all load forecast errors lie within the tolerance band and its standard deviation is:

$$\sigma_{lfe} = \frac{\varepsilon_{ref} \times P_{system}}{\chi_{ref}} \tag{5}$$

Power plant	Outage probability	Outage size in MW
1	0.02	100
2	0.01	150
3	0.04	200
4	0.02	50

Table 1: Power plants data. The outage probability defines a probability of an outage within the timeframe of the application of tertiary control reserves, i.e. 1 hour. For the secondary control reserves timeframe, i.e. 15 minutes, 4 times smaller values have been used.

	μ in MW	σ in MW
Load forecast error	0	8.33
Load spontaneous variations	0	37.95

Table 2: Parameters of normal distribution of load deviations.

Contrary to the reference, we combine positive and negative distributions of spontaneous load deviations into one distribution. Since the distribution type is normal, the resulting standard deviation σ_{lsv} can easily be derived as follows:

$$\sigma_{lsv} = \sqrt{\sigma_{lsv+}^2 + \sigma_{lsv-}^2} = \sigma_{ref} \times \sqrt{2 \times \frac{P_{system}}{P_{ref}}} \tag{6}$$

where $\sigma_{ref} = 120$ MW, $P_{ref} = 10000$ MW.

3.2 Results and discussion

Probability distributions of input factors are shown in figure 1. Power plant outages characteristic confirms intuitive expectations: the largest probability is assigned to the state when all power plants are in operation; the second most probable outage size is 200 MW, which can be obtained either by the outage of the plant 3 or by the simultaneous outage of plants 2 and 4; and the largest possible outage is sum of all power plants' ratings, i.e. 500 MW.

Figure 2 shows schedule deviations in time ranges of secondary and tertiary control reserves. Distributions of deviations are quite similar, however the effect of outages of power plants is clearly visible in the bottom part of the figure, indicating a need to keep tertiary control reserves to cover plants' outages.

Splitting the distributions in figure 2 to positive and negative part and constructing cumulative distributions, figure 3 is produced and the amount of control reserves is graphically demonstrated. The accurate amount of control reserves is then listed in table 3.2.

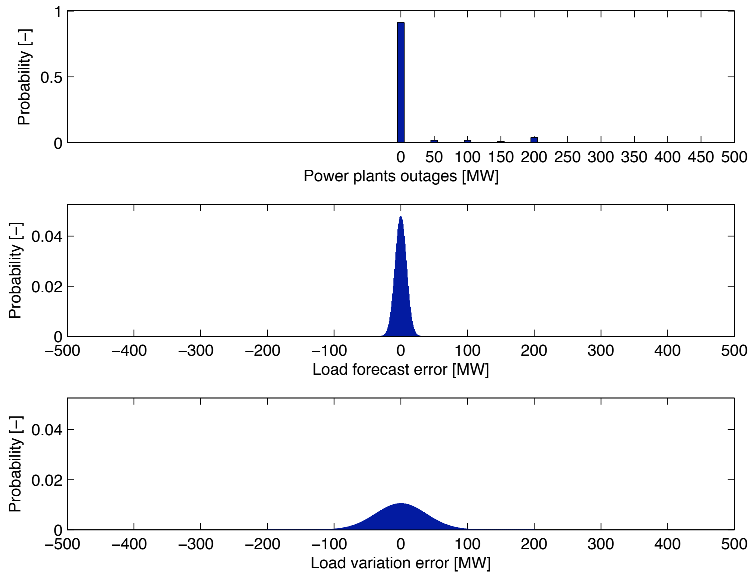

Figure 1: Probability distributions of input factors. The outage probability defines a probability of an outage within the timeframe of the application of tertiary control reserves, i.e. 1 hour.

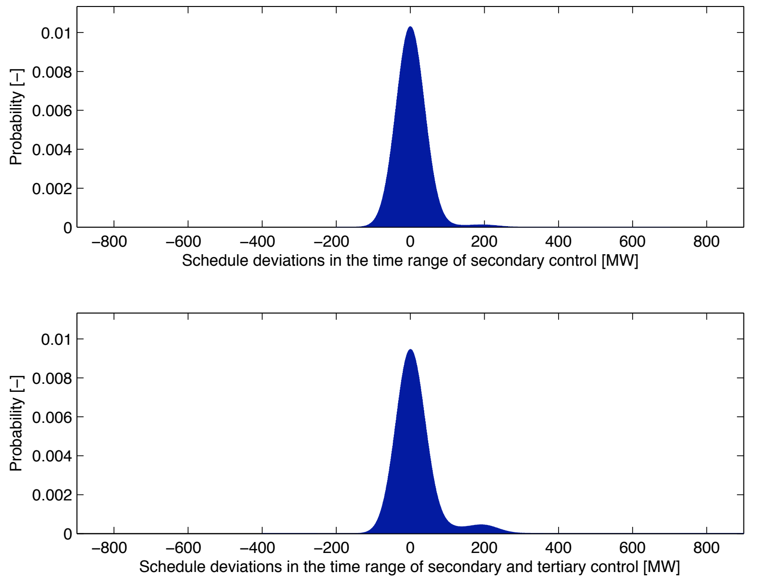

Figure 2: Probability distribution of deviations from scheduled balance between power production and consumption.

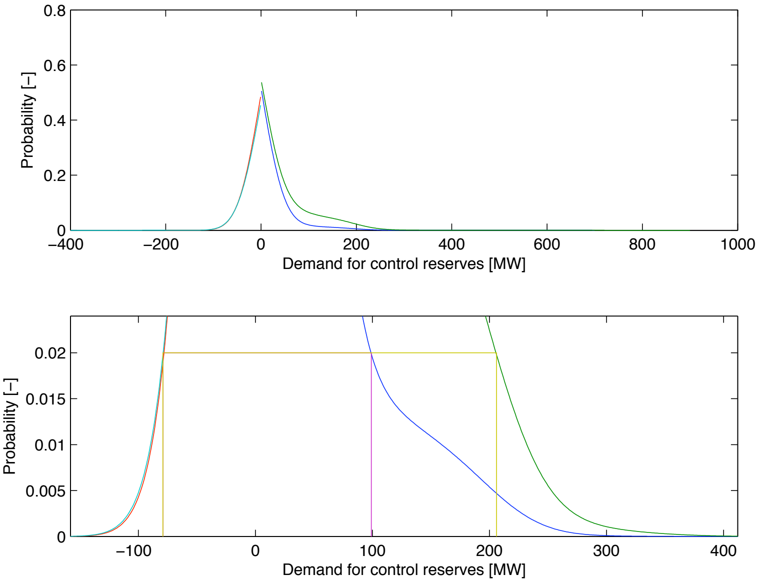

Figure 3: Cumulative distribution of deviations from scheduled balance between power production and consumption intersects with the horizontal line at the deficit probability value of 0.02, determining negative control reserves on left and positive control reserves on right.

Control reserves category	Amount in MW
Positive secondary control	99
Negative secondary control	-79
Positive tertiary control	107
Negative tertiary control	0

Table 3: Control reserves.

References

[1] UCTE. UCTE Operation Hanbook. Available online: http://www.ucte.org/publications/ophandbook/.

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[5] Jens Büchner, Tuncay Türjucar, Wolfgang Nick, Falk-Rüdiger Graf, Edmund Handschin, Willi Horenkamp, Dieter König, Daniel Waniek, and Waldemar Schultz. Gutachten "Bestimmung des regelzoneninternen Regelleistungsbedarfs für Sekundärregelung und Minutenreseve". Technical report, E-Bridge Consulting GmbH, Universität Dortmund, September 2006.

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