# Planning of Ancillary Services Securing Power System

Ondřej Novák[1)], Tomáš Strnad[1)], Petr Horáček[1)], Josef Fantík[2)]
{novako5,strnat2,horacek}@fel.cvut.cz, fantik@ceps.cz
[1)]Czech Technical University in Prague, Faculty of Electrical Engineering
[2)]ČEPS, a.s., Czech Transmission System Operator

***Abstract*- Procuring sufficient amount of operational reserves used by the Transmission System Operator (TSO) for keeping a balance between generation and load in real-time is a complex task. Extensive balancing power reserves enable keeping the Area Control Error (ACE) close to zero most of the time but the cost of enabling these reserves might be very high. The paper proposes a method of planning sufficient amount of operational reserves or rather Ancillary Services on economical basis. The goal of the presented algorithm is to find AS combination that minimize the cost of AS reservation and at the same time secures transmission system operations. Monte-Carlo simulation scheme of the area operation provides sufficient insight to ACE behavior under different operational reserves. Branch and Bound search scheme is applied to arrive at the best compromise between power security and cost of AS procurement. Short term, one month planning horizon is considered.***[*]

## I. Introduction

Prior to the restructuring and liberalization of the European electricity industry responsibility for security of supply was generally the role of vertically integrated companies with an obligation to supply. Unbundling of the activities has resulted in the establishment of Transmission System Operators (TSO) and changes in roles and responsibilities.

TSO companies from 34 European countries created a new association, the European Network of Transmission System Operators for Electricity (ENTSO-E) in December 2008. The ENTSO-E structure includes three committees for pan-European activities on System Development, System Operation and Market Frameworks being also the main responsibilities of a TSO. TSO is the ultimate instance in the chain of electricity market players participating to active power balancing. Electrical energy market players are economically responsible for meeting their planned individual balances in each settlement time frame. While market players are commercially responsible for their actions in all timescales, after gate closure the TSOs are physically responsible for securing power system operation and maintaining balance between supply and demand by having access to sufficient operational reserves ( Fig.1).

Balancing power is a tool used by TSOs to maintain the instantaneous physical balance. Balancing power is a commodity which is made available on the market in the form of Ancillary Services (AS). One of the tasks of the TSO is to plan and purchase enough AS and activate them timely to meet the grid performance standards and minimize the cost of the AS purchase taking into consideration all physical and market constraints. A TSO might define and use different AS depending on the control area/country specificity of generation sets, however, there are some generic categories present in every control area: Continuous Regulation, Energy Imbalance Management, Replacement Reserves, Voltage Control and Black Start. The paper deals with procurement of all AS categories except voltage control and black start as these do not contribute to power balancing directly.

Performance standards are specified and set for a control area of the UCTE following general requests for all interconnected areas defined in the UCTE's Operation Handbook [1]. An important aspect, which influences the choice and volume of AS, is the cost of the purchase which should be kept low. Simulated operation of the control area under the TSO's Automatic Generation Control and Energy Management System dispatching balancing power in real time, as shown in Fig.1, will be used for generating time series of

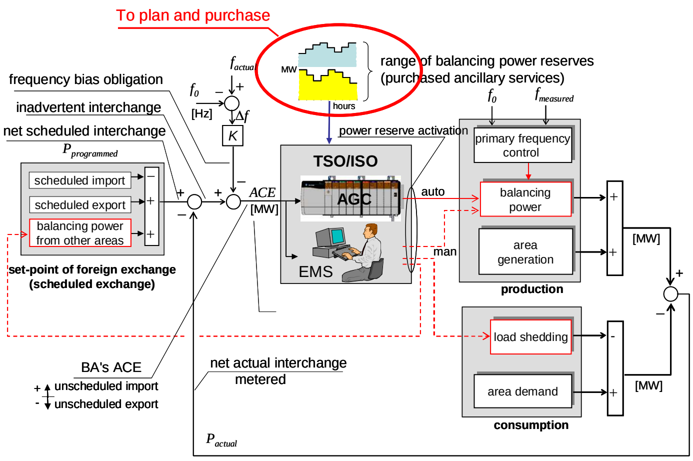


Figure 1 Power balancing in the area as a feedback control system

Area Control Error (ACE) for one year area's operation.

Every TSO might adopt different AS planning procedures depending on interconnection and control area specificity. What make the problem more difficult are recent changes in market structures so there is a lack of long term experience in effective AS planning. The principles presented in the paper

[*] This work was supported by the Ministry of Education of the Czech Republic under the project 1M0567 and by the Czech TSO under the project "Reliability and economy of system services"

might serve as a basis for a general platform adopting various criteria and constraints despite the fact that the approach was developed for one control area of the UCTE interconnection.

In chapter II problem definition is introduced. Chapter III describes proposed solution. In chapter IV achieved results are shown. Final chapter deals with conclusions and outlook for future work.

## II. Problem Statement

Goal of presented work is to find AS combination with the least reservation cost that secures reliable transmission system operation. From optimization point of view the problem can be stated as a reservation cost minimization constrained by reliability standards that have to be met.

Reliability standards of the AS combination are evaluated by means of Monte Carlo simulation which incorporates transmission system statistical model parameterized by values obtained from processing of real operational data of the Czech transmission system and dynamic model of the AS activation. The list of AS considered is given in Tab. I as defined by the Grid Code of the Czech TSO [5]. Details of how the Simulator is designed and used in the Monte-Carlo scheme to calculate time series of ACE can be found in [4].

### *A. Ancillary services definition*

In the planning algorithm five types of AS are considered: *RZSR*, $RZTR^{+}$, $RZTR^{-}$, *RZQS* and *RZDZ*. Note that the method allows working with any other AS. AS definition changes from time to time and the algorithm will not be practical is restricted to particular AS only.

TABLE I

Ancillary services

| Ancillary Service | Description | Guaranteed | Response time |
|---|---|---|---|
| RZPR (spinning) | primary control | Yes | ~ 30 sec. |
| RZQS (non-spinning) | quick-start reserve (pumped-storage) | Yes | max. 10 min. |
| RZSR (spinning) | secondary control | Yes | max. 10 min. |
| RZN30+ (non-spinning) | stand-by reserve | Yes | max. 30 min. |
| | load change | Yes | |
| | emergency assistance from abroad | No | |
| RZTR+ (spinning) | tertiary control | Yes | |
| RZN30- (non-spinning) | load change | Yes | |
| | emergency assistance from abroad | No | |
| RZTR- (spinning) | tertiary control | Yes | |
| RZDZ (non-spinning) | stand-by reserve | Yes | more than 30 min. |
| EregZ (non-spinning) | balancing energy | No | |

### *B. Reliability standards*

Result of Monte-Carlo simulation and control performance of used AS combination is expressed by area control error which is given:

$$ACE = \Delta P + K\Delta f \, , \qquad (1)$$

where $\Delta P$ is an inadvertent interchange (measured difference between actual and scheduled interchange with neighboring areas), $\Delta f$ is a frequency error (difference between measured frequency $f_{actual}$ and the frequency set-point $f_0$) and $K$ is a frequency bias of the control area. Formula (1) matches Fig.1 except for sign (polarity) of ACE. Fig.1 respects the way how $\Delta P$ is calculated by Czech TSO. By statistical processing of ACE reliability indices are obtained. Definitions and descriptions of reliability indices used by Czech TSO are shown in Tab. II.

TABLE II

Reliability indices

| Index name | Index unit | Description |
|---|---|---|
| $rACE_1$ | % | Probability that the absolute average value of one-minute (clock minute) averages of ACE exceeds 100 MW over given period. |
| $rACE_{60}$ | % | Probability that the absolute average value of one-hour averages of ACE exceeds 20 MW over given period. |
| $nACE_{1t}$ | % | Number of events when ACE remains higher/lower +/- 100MW for time longer than 15 minutes in given period. |
| $E^2_{100}$ | $MWh^2$ | Sum of squared energy of events when ACE remains higher/lower than +/- 100MW for longer than 10 minutes in given period. |
| $\mu_{ACE_1}$ | MW | Average value of one-minute averages of ACE over given period. |
| $\sigma_{ACE_1}$ | MW | Standard deviation of one minute averages of ACE over given period. |
| $\sigma_{ACE_{60}}$ | MW | Standard deviation of one hour averages of ACE over given period. |
| $E_{100}$ | MWh | Sum of absolute values of energy of events when ACE remain higher/lower than +/- 100MW for time longer than 10 minutes in given period. |

### *C. Reservation cost evaluation*

AS reservations cost evaluation is modeled by elasticity curves which respect relation between price and AS bids so that mean unit price for reservation is increasing with increasing amount of AS. Total reservation cost is given by

$$TC = \sum_{\forall RZxx} C_{RZxx}(RZxx) \cdot RZxx \, , \qquad (2)$$

where RZxx stands for ancillary services RZSR, RZTR+, RZTR-, RZQS and RZDZ respectively and CRZxx denotes unit mean reservation cost of RZxx given by its elasticity curve.

### *D. Reliability indices computation*

Reliability indices for selected AS combination are generated by means of Monte-Carlo simulation [4]. Two hundreds of simulation runs were simulated for each AS combination to arrive at statistically better conditioned results. The core of the proposed method is the way how AS combination is selected.

## III. BRANCH AND BOUND ALGORITHM DESCRIPTION

In this chapter a branch and bound algorithm used in the procedure of generating and selecting prospective combination of ACE is be described. Principal scheme of the proposed algorithm is shown in (Fig. 2).

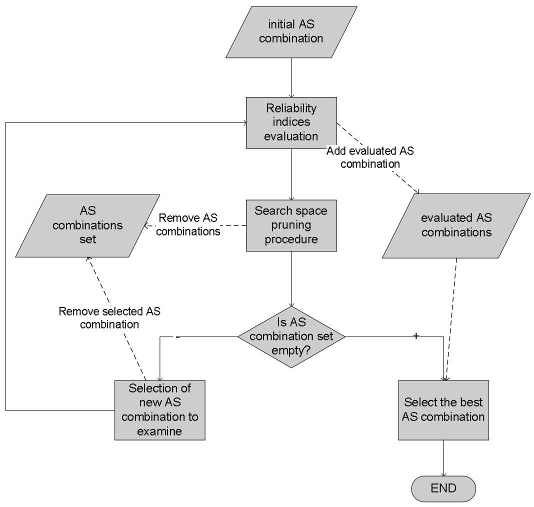


Figure 2 Principal scheme of the algorithm

Before starting the search algorithm several initialisation steps have to be completed. The search space of all AS combinations to examine is defined first. As only discrete values of reservation are expected, all AS reservations are separated into distinct values. Other constraints on reservation may be applied, e.g. minimum recommended volume of secondary regulation specified in [1] or maximum volume of AS certifications in regulation area. Step size and limits used in our studies are show in Tab. III.

TABLE III
Reliability indices

| Ancillary service | Lower bound [MW] | Upper bound [MW] | Step size [MW] |
|---|---|---|---|
| *RZSR* | 200 | 700 | 50 |
| $RZTR^+$ | 0 | 700 | 50 |
| $RZTR^-$ | 0 | 400 | 50 |
| *RZQS* | 300 | 1000 | 100 |
| *RZDZ* | 0 | 200 | 50 |

The next step is to specify reference value of reliability indices as a minimum requirement we would like to achieve. Reliability indices can be given directly or by means of reference AS combination. In that case reliability indices are determined by Monte-Carlo simulation with the reference AS combination.

Final step of initialization is to choose initial AS combination. If the reference combination is used then it is also taken as initial AS combination otherwise random selection applies.

### A. *Reliability indices evaluation*

Next step after initialisation is generating ACE in Monte-Carlo simulation scheme of the control area operation and getting the expected values of reliability indices from statistical processing of ACE time series.

### B. *Search space pruning procedure*

Search space pruning depends on whether or not reliability standards are satisfied. In the first case we obtain upper cost estimation of optimal solution and hence every AS combination with reservation cost equivalent or greater than current upper bound can be removed from search space.

In latter case pruning algorithm is based on presumption of lower amount AS reservation, that is needed to assure reliable control area operation.that if the actual AS combination does not satisfy reliability standards, it is natural to expect that any combination with less reserves will not satisfy reliability standarts either, and can be deleted from the search space. To show that previous idea is correct the concept of monotonicity needs to be introduced. A reliability index is monotone in some AS if lower amount of the AS reservation implies higher value of the index and consequently less reliable control area operation. If monotonicity holds for all reliability indices the pruning method described above can be used. Due to the complexity of the modeled control area and the indices definition, the relation between the amount of AS and the value of indices is difficult to express analytically. Therefore simulation approach was employed to find index–service combinations where monotonicity does not hold:

$rACE_1$ index does not preserve monotonicity in $RZTR^+$ and $RZTR^-$, (3)

$rACE_{60}$ index does not preserve monotonicity in *RZSR*, (4)

$E^2_{100}$ and $E_{100}$ do not preserve monotonicity in any AS, (5)

for the rest of reliability indices monotonicity holds. (6)

Therefore any AS combination for which monotonicity holds, and volume of AS is lower then the actual AS combination, can be remove from the search space.

### C. *Selection of new AS combination to examine*

The cheapest AS combination found so far is returned as a solution when the search space is empty the search algorithm stops, otherwise we are looking for the new AS combination which will be examined in the next iteration. As in the previous step of algorithm, the AS selection depends on whether or not reliability standards are satisfied. First of all the next AS combination with lower amount of reserves in less utilized service is selected. If such combination does not exist in search space, AS combination with lower amount of the most expensive service is selected. If such combination does not exist the next AS combination is selected randomly. In the case when the reliability indices are not satisfied AS combination with higher amount of the most utilized service is selected. If such combination does not exist the next AS combination to examine is selected randomly.

By selecting the next AS combination the algorithm continues in next iteration as described in the paragraph A.

## IV. Simulations Results

In this chapter simulation results are presented. The algorithm was used in month-ahead AS planning. AS combination from year-ahead plan was taken as a reference. Reference reliability indices were computed by means of Monte-Carlo simulation of the control area with two hundreds of monthly runs using reference AS combination.

The algorithm performance is shown in two case studies.

### A. *Case study #1*

The control area simulator is fed with three average monthly time series of $ACE_O$, where $ACE_O$ is the expected area control error as would be without TSO's regulation reserve activations. Selected $ACE_O$ are average in sence of indices values calculated from ACE after TSO's regulation using the reference AC combination.Test inputs were chosen from 200 randomly generated $ACE_O$ that respect statistical behavior of the Czech control area.

### B. *Case study #2*

Seven monthly $ACE_O$ time series equidistantly chosen from the same 200 time series as in the case #1, ordered by reliability indices computed with reference AS combination, were used.

Resulting reserves and the relative cost of their procurement in relation to the reference is shown in Tab. IV and Tab. V respectively. Reliability indices of the solutions are given in Tab. VI and Fig. 3.

TABLE IV

Found AS combinations

| | Ancillary services combination | | | | |
|---|---|---|---|---|---|
| | RZSR | RZTR+ | RZTR- | RZSQ | RZDZ |
| | [MW] | [MW] | [MW] | [MW] | [MW] |
| Reference | 290 | 260 | 100 | 570 | 160 |
| **Case #1** | **340** | **200** | **100** | **600** | **0** |
| **Case #2** | **280** | **100** | **150** | **700** | **100** |

TABLE V

Relative cost of the found AS combinations

| | Reference | Case #1 | Case #2 |
|---|---|---|---|
| Relative cost of reservation [%] | **100,00** | **99,59** | **97,75** |

## V. Conclusion

Developed algorithm was tested on month-ahead ancillary services planning problem. Ability of presended method was proven by two case studies show the ability of the algorithm of finding better solution than was the reference. However, not all indices were satisfied as can be seen (Fig. 3) that is because of difference in accuracy between indices evaluation during planning procedure and in evaluation of the found solution by means of two hunders of Monte-Carlo simulation runs. Minimalisation of this difference is main goal of the future development of the method.

TABLE VI

Reliability indices of the found AS combinations

| | | | **Reference** | **Case #1** | **Case #2** |
|---|---|---|---|---|---|
| **Reliability indices** | $rACE_1$ | % | 2,65 | 2,61 | 2,68 |
| | $rACE_{60}$ | % | 2,86 | 2,49 | 2,80 |
| | $nACE_{1t}$ | - | 0,07 | 0,05 | 0,06 |
| | $E^2_{100}$ | [MWh²] | 523 265 | 1 225 797 | 1 619 786 |
| | $\mu_{ACE_1}$ | [MW] | -0,63 | 0,15 | 0,42 |
| | $\sigma_{ACE_1}$ | [MW] | 45,39 | 46,17 | 46,88 |
| | $\sigma_{ACE_{60}}$ | [MW] | 11,69 | 13,04 | 14,12 |
| | $E_{100}$ | [MWh] | 25 715 | 25 766 | 25 930 |

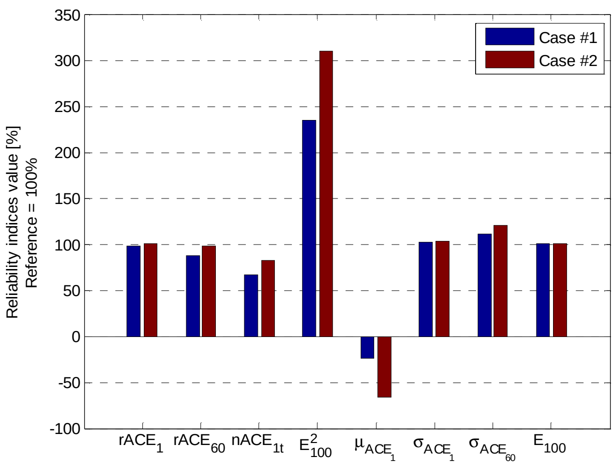


Figure 3 Relative values of reliability indices

## References

[1] *UCTE Operation Handbook*, v2.2/20.07.04, Union for the Co-ordination of Transmission of Electricity, Brussels (2004)

[2] *Reliability Standards for the Bulk Electric Systems of North America*, North American Electric Reliability Corporation, Princeton, NJ (2008)

[3] P. Havel, P. Horáček, V. Černý, J. Fantík: Optimal Planning of Ancillary Services for Reliable Power Balance Control, *IEEE Trans. on Power Systems*, Vol. 23, No. 3, 1375-1382 (2008)

[4] V. Černý, , P. Janeček, A. Fialová, J. Fantík: Monte-Carlo simulation of electricity transmission system operation, in *Proc. 17th IFAC World Congress*, Seoul, Korea, 2008.

[5] Rules for the Transmission System Operation Extract from the Grid Code, Revision 09, ČEPS a.s., (January 2009) , [online], http://www.ceps.cz/doc/kodex/part_I_II_III_an_rev09.pdf