Peter Šulek, Peter Dušička, Marián Ozábal

Planning Of The Ancillary Reserve Provided By Hydropower Plants

A considerable attention has been paid to the optimal utilization of the dynamic characteristics of the hydropower plants in electric power system of Slovakia. For more than 20 years, simplified optimization solutions have been used for the operation planning as well as the real time operative control. The issue of the assuring the support services in the field of the primary, secondary and tertiary reserve of power output has been increasingly occurring by the operation of the hydropower plants in the last years. The article describes suitable methods for the solutions of the problems of the hydropower plant control related to the new tendencies in the planning and the market with electrical energy, while primary taking into account their generality in the aspect of the planning and providing the ancillary reserve.

Keywords: HYDROPOWER PLANT, ANCILLARY RESERVE, GENERATION SCHEDULING, ELECTRIC POWER SYSTEM, HYDROTHERMAL COORDINATION

I. INTRODUCTION

To generate and to supply the electrical power system (EPS) with as much power as is being demanded at the same moment (including transmission losses) is important mainly because the electric power can not be stored in a larger scale and subsequently used in the time of increased power demand. The sources, which are assuring the balance of the energy system between the power generation and the power demand, provide the so-called ancillary reserve (AR) to the electric power system.

The support services can be divided into:

- the primary reserve (PRV),
- the secondary reserve (SRV),
- the tertiary reserve (TRV),
- the quick and the cold dispatch backup.

The power in the EPS which is reserved for the ancillary reserve assuring is called **the regulation (power) backup**.

II. EFFICIENT LOAD DISTRIBUTION IN A HYDROTHERMAL SYSTEM

Whether at the production of the base power or the assuring of the AR, the objective of the power producer should be to maintain the maximum operational effectiveness of the power system. The simplest and the most common criterion for the optimal allocation of the load between the power sources of the system is the achievement of the minimal production costs with the respect to the limiting conditions, which are linked to this criterion in the specific time and space [2]. Based on the previous, for a hydrothermal system, which consists of m thermal and n hydropower plants, can be the total fuel costs N_c in a regulation period T expressed as following:

$$N_c = \sum_{j=1}^{T}\sum_{i=1}^{m}\left\{N_{i,j}({}^{s}P_{i,j}) + {}^{AR}N_{i,j}({}^{s}P_{i,j}, {}^{AR+}P_{i,j}, {}^{AR-}P_{i,j})\right\} \to min \qquad (1)$$

where j is the index of the time interval of the solution within the total regulation time T (j=1 2, .., T), i is the index of the thermal power plant (i=1, 2, .., m), ${}^{s}N_{i,j}$ is the fuel costs of the i thermal power plant during the j hour at the base power generation, ${}^{s}P_{i,j}$ is the power output (base power) of the i thermal power plant (TPP) during the j hour [MW], ${}^{AR}N_{i,j}$ is the fuel costs of the i thermal power plant during the j hour, related to the providing of the AR [costs/hour], ${}^{AR+}P_{i,j}$ is positive regulation power output of the i thermal power plant during the j hour [MW] and ${}^{AR-}P_{i,j}$ is negative regulation power output of the i thermal power plant during the j hour [MW].

For the balance of the power outputs (base power) in the j hour of the regulation period T can be written:

$${}^{s}P_j = \sum_{i=1}^{m} {}^{s}P_{i,j} + \sum_{k=1}^{n} {}^{s}P_{k,j} \qquad (2)$$

where k is the index of the hydropower plant (HPP) (k=1, 2, .., n), ${}^{s}P_j$ is the total required base power during the j hour [MW] and ${}^{s}P_{k,j}$ is the base power of the k hydropower plant during the j hour [MW].

For the balance of the power backup during the j hour stands in the positive or negative course of the deviation following:

$${}^{AR+}P_j = \sum_{i=1}^{m} {}^{AR+}P_{i,j} + \sum_{k=1}^{n} {}^{AR+}P_{k,j} \text{ or } {}^{AR-}P_j = \sum_{i=1}^{m} {}^{AR-}P_{i,j} + \sum_{k=1}^{n} {}^{AR-}P_{k,j} \qquad (3)$$

where ${}^{AR+}P_j$ is the total required positive regulation backup during the j hour [MW], ${}^{AR+}P_{k,j}$ is the positive regulation backup of the k hydropower plant during the j hour [MW], ${}^{AR-}P_j$ the total required negative regulation backup during the j hour [MW] and ${}^{AR-}P_{k,j}$ is the negative regulation backup of the k hydropower plant during the j hour [MW].

The diversion of the load between thermal and hydropower plants with the respect to all of the boundary water management and energetic conditions and fulfilling the criterion (2) will be optimal and the total fuel costs in the energetic system will be minimal.

LOAD DISTRIBUTION BETWEEN THE ENERGY SOURCES OF THE SLOVENSKÉ ELEKTRÁRNE, CO.

The system of the energetic sources of the Slovenské elektrárne company, which operates 2 nuclear, 2 thermal and 34 hydropower plants, can also be considered as a hydrothermal system. Apart from the complicated analytic expression of the costs related to the providing of the ancillary reserve, the complexity of the optimal distribution of the load between the TPPs and the HPPs is caused mostly by the operation of the hydropower plants in the cascade (the Váh Cascade), where the hydropower plants are interconnected between themselves by complicated hydraulic links.

The complexity of the support services distribution is also caused by the fact that the ability of providing ancillary reserve for the EPS depends on the type of the hydropower plant, as well. To express the suitability of the particular types of the hydropower plants for the AR providing is a very complex and complicated task.

In the real process of the planning of the energetic system's operation, the distribution of the ancillary reserve between particular sources is rather based on the experience of the dispatch operators.

In the first step, the percentage of the generation unit's ability to provide power backup with taking into account the backup's use for the providing of the ancillary reserve of a higher rank is specified (e.g., for estimating the ability of the unit to provide the power backup for the tertiary reserve, the backup for the primary and the secondary reserve is taken into account). In the next step, the base power load distribution between the HPP and the TPP is based on the regime efficiency criterion expressed as follows:

$$F = \sum_{j=1}^{T}\sum_{k=1}^{n} b_j \left({}^{s}P_j - \sum_{k=1}^{k-1} {}^{s}P_{k,j} \right) . {}^{s}P_{k,j} \rightarrow max \tag{4}$$

where b_j is the relative increase of the fuel costs during the *j* hour for all of the TPP [costs/MWh].

The values of the ${}^{s}P_{k,j}$ are determined by the maximization of the objective function *F* supplemented by the limiting conditions, which are mostly based on the constraints in the operation manuals of the water structures or given by the constructional and operational parameters of the HPPs.

$$\overset{min}{P}_{k,j} + {}^{AR-}P_{k,j} \leq {}^{s}P_{k,j} \leq \overset{max}{P}_{k,j} - {}^{AR+}P_{k,j} \tag{5}$$

$$\overset{min}{HN}_{k,j} \leq HN_{k,j} \leq \overset{max}{HN}_{k,j} \tag{6}$$

$$HN_{k,T} = {}^{req}HN_{k,T} \tag{7}$$

$$V_{k,j} = V_{k,j-1} + {}^{inflow}V_{k,j} - {}^{outflow}V_{k,j} \tag{8}$$

where $\overset{min}{P}_{k,j}$, $\overset{max}{P}_{k,j}$ are the minimal and the maximal attainable power output of the k HPP during the *j* hour [MW], $\overset{min}{HN}_{k,j}$, $\overset{max}{HN}_{k,j}$ are the minimal and the maximal operational water level in the reservoir of the *k* HPP during the *j* hour [m a.s.l.], $HN_{k,j}$ is the water level in the reservoir of the *k* HPP in the end of the *j* hour [m a.s.l.], $HN_{k,T}$ is the water level in the reservoir of the *k* HPP in the end of the *T* [m a.s.l.], ${}^{req}HN_{k,T}$ is the required water level in the reservoir of the *k* HPP in the end of the *T* [m a.s.l.], $V_{k,j}$ is the storage volume of the reservoir of the *k* HPP in the end of the *j* hour [m^3], ${}^{inflow}V_{k,j}$ is the total volume of inflow into the reservoir of the *k* HPP in the *j* hour reduced by the evaporation losses, leakage and other not energetic withdrawals [m^3] and ${}^{outflow}V_{k,j}$ is the total volume of water withdrawn for energetic purposes from the reservoir of the *k* HPP during the *j* hour [m^3].

THE EFFECT OF PROVIDING THE ANCILLARY RESERVE ON THE BALANCE OF A RESERVOIR'S STORAGE VOLUME

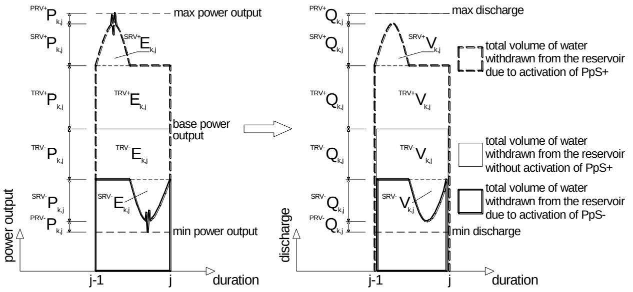

Figure 1. The estimation of the water volume withdrawn for the energetic purposes of the *k* HPP's reservoir during the *j* hour.

The scheme in the fig.1 shows that the value of the ${}^{outflowr}V_{k,j}$ is based on the nature of the provided AR. Based on its nature, for the *primary reserve* is the PRV+ or the PRV- volume equivalent neglected. For its planning, only the assigning of the required power backup is taken into account.

For the *secondary reserve*, the volume of water required for the SRV+ or SRV- can be expressed as follows:

$${}^{SRV+(-)}V_{k,j} = \int_{j-1}^{j} {}^{SRV+(-)}Q_k(t).dt \tag{9}$$

where ${}^{SRV+(-)}Q_k$ is the actual discharge equivalent of the SRV+(-) of the k HPP [m^3.s^{-1}].

For the providing of the *tertiary reserve* is also necessary to take into account the volume change of the water withdrawn from the reservoir. The expression for the TRV+ or TRV- volume equivalent is as follows:

$${}^{TRV+(-)}V_{k,j} = \int_{j-1}^{j} {}^{TRV+(-)}k . {}^{TRV+(-)}Q_k(t).dt \tag{10}$$

where ${}^{TRV+(-)}Q_k$ is the actual TRV+(-) discharge equivalent of the *k* HPP [m^3.s^{-1}], ${}^{TRV+(-)}k$ is the TRV's utilization coefficient, expressing the uncertainity rate of the moment of the tertiary reserve load in the total regulation period *T*. It can acquire values in the range <0~1>. If the ${}^{TRV+(-)}k$ value equals 1, it means that the TRV is assumed to be activated in every hour of the *T* [-].

Then, for the computation of the ${}^{outflow}V_{k,j}$ stand following:

$${}^{outflow}V_{k,j} = {}^{0}V_{k,j} + {}^{SRV+}V_{k,j} - {}^{SRV-}V_{k,j} + {}^{TRV+}V_{k,j} \tag{11}$$

or

$${}^{outflow}V_{k,j} = {}^{0}V_{k,j} + {}^{SRV+}V_{k,j} - {}^{SRV-}V_{k,j} - {}^{TRV-}V_{k,j} \tag{12}$$

The effect of providing the ancillary reserve on a reservoir's operation water level is shown on the scheme in Fig.2. Meeting the (13) and (14) boundary conditions for both limiting water level regimes should maintain a "safety pillow" for providing the planned support services in a range of the total regulation period *T*.

$$\overset{min}{HN}_{k,j} \leq {}^{AR+}HN_{k,j} \leq \overset{max}{HN}_{k,j} \tag{13}$$

$$\overset{min}{HN}_{k,j} \leq {}^{AR-}HN_{k,j} \leq \overset{max}{HN}_{k,j} \tag{14}$$

where ${}^{AR+}HN_{k,j}$ is the water level inf the reservoir of the *k* HPP at the end of the *j* hour when the AR+ is activated [m a.s.l.], ${}^{AR-}HN_{k,j}$ is the water level inf the reservoir of the *k* HPP at the end of the *j* hour when the AR-.

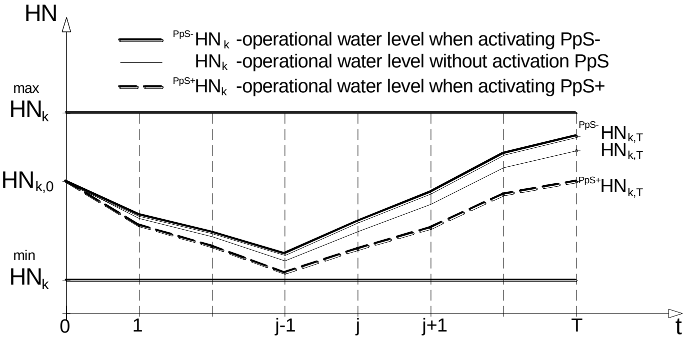

Figure 2. The effect of activating the ancillary reserve on the operation water level regime in a reservoir.

The above shows that an important factor for assessment of the AR planning is the real estimation of the water levels when activating the particular AR. This estimation depends on determination of the ${}^{SRV+(-)}k$ and ${}^{TRV+(-)}k$ coefficients. These have to be determined so that they describe as precisely as possible the share of the particular AR on the changes of the reservoir's available storage volume, guarantee providing the AR during the whole regulation period and at the same time do not restrain the regulation ability of the reservoir.

According to the operators of the Dispatch centre of the hydropower plants in Trenčín, for the estimations of the limiting operational water levels, the values of the ${}^{SRV+(-)}k$ between 0~0,1 and ${}^{TRV+(-)}k$ between 0,2~0,25 give the most real results.

III. CONCLUSION

The described methodology of the planning of the ancillary reserve on the hydropower plants has been implemented into the model of the planning and operative control of the operations of the hydropower plants since 2007. The model is a part of the complex information system of the operations planning of the energetic sources of the Slovenské elektrárne, Co..

In the model, the solution of the optimization objective, which is described by the criterion function (4), is based on the modified simplex method with the corrective algorithm enabling a quick convergence to the optimal result. Although the behaviour of the criterion function is nonlinear, for the selection of this method has been the determining criterion the request of the shortest computational time of the optimization as possible.

The methodology of the optimal load allocation between the thermal and the hydropower plants with the reserving of power backup for the ancillary reserve assuring, which is based on the energy producer so called regime efficiency, is universal only in the case that the EPS operator is identical to the power producer or the case that the power producer's capacity totally covers the demands of the whole ES. In other cases, the conditions of the optimal load allocation much more complicated. It is caused mostly by the fact that the base power and the support services have a substitute character. It means that the increased production of the one product requires the decrease of the production of the second product. Thus a situation may occur that some sources with low marginal costs (e.g. hydropower plants) will be allocated from the base power generation to the providing of the AR. This will decrease the system operator's costs but at the same time it will lead to the increase the prices in the energy market, because these sources will be replaced by the ones with higher costs. The decrease of the AR costs of the system operator would be at the expense of the consumers in the energy market. The situation is complicated also by the facts that the price for the particular types of the ancillary reserve is not defined and the support services market, which would generate their prizes, is not created. The prize for particular types of the ancillary reserve is defied by a temporary apparatus, which is based on the amount of the finances available to the supplier of the AR- the operator of the electric supply system after the confirmation from the regulatory office.

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ADDRESSES OF AUTHORS

Peter Šulek, Ing., PhD., Slovak University of Technology in Bratislava,
Department of Hydraulic Engineering, Radlinského 11, Bratislava, SK 831 68,
Slovak Republic, peter.sulek@stuba.sk
Peter Dušička, Prof. Ing., PhD.Slovak University of Technology in Bratislava,
Department of Hydraulic Engineering, Radlinského 11, Bratislava, SK 831 68,
Slovak Republic, peter.dusicka@stuba.sk
Marián Ozábal, Ing., Slovak University of Technology in Bratislava,
Department of Hydraulic Engineering, Radlinského 11, Bratislava, SK 831 68,
Slovak Republic, marian.ozabal@stuba.sk

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