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Energy efficiency improvement of the hydroelectric plant Râul Mare Retezat by the use of a compensation reservoir

Claudiu Ștefan Nițescu and Anca Constantin

Abstract – **The hydroelectric plant Râul Mare Retezat is the second largest plant on the inland rivers in Romania. The main adduction gallery has a length of 18km and four water supplies along it. The construction of an additional compensation tank, connected to the protective device, the surge tank, can additionally supply the hydroelectric plant with water, reducing the head losses and resulting in much more efficient utilization of water volumes. Consequently, electricity production can be increased, compared to the initial situation, by up to 6%.**

Keywords – compensation reservoir, energetic efficiency, upper chamber of surge tank.

1. INTRODUCTION

The rational and integral use of the hydropower potential of the rivers in a certain area, entails, in the practice of engineering design of modern hydropower plants, more and more complex hydrotechnical schemes to be conceived. They include several reservoirs, adduction galleries, surge tanks and power plants. Thus, in our country there are hydroelectric plants fed from lakes located at great distances, for example: the Someș Mărișelu hydroelectric plant with the length of the adduction gallery of 8130m, the Lotru hydroelectric plant with a gallery of 13582m in length, and the Râul-Mare Retezat hydroelectric plant with a gallery of 18129m. In such situations, due to long adduction ducts, large longitudinal head losses result.

The paper proposes the use of a compensation tank at the Râul Mare Retezat hydroelectric plant and presents the investigations made on the energy efficiency and the volumes of water saved by the variation of two parameters: the diameter of the tank and the duration of operation.

The tank is located in the close area of the surge tank in order to obtain an improvement of the turbine head value. This additional compensating reservoir can also be introduced by properly arranging a nearby valley. The connection of the compensation reservoir will be made through a pipe of the same diameter as that of the surge tank, located at the bottom of the reservoir. The maximum elevations of the reservoir and the surge tank have to be equal.

The compensation reservoir is similar to the differential chamber in the case of the surge tank with such a differential chamber, except that there will be no discharge from the well into the tank, and the diameter of the chamber is very large. The water level in the tank will be equal to the water level in the reservoir during the non-operating time. The height of the compensation reservoir is considered to be equal to the value of the head losses on the

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adduction gallery, or it can be higher in situations where it is desired to operate the plant for a wide range of water levels in the artificial reservoir. [1], [2], [3].

The emplacement of this reservoir upstream the hydraulic shock protection means does not influence the stability of the hydrotechnical system. The surge tank is dimensioned for the operation of the hydropower system in good conditions and is placed in such a way as to take the hydraulic shock from the forced gallery and transform it into mass oscillation. The diameter of the surge tank should not be changed, this conclusion also being obtained following the determination of the surge tank section in complex schemes.

For a period of a few hours of operation of the hydroelectric plant, the turbine flow will be composed of the flow from the compensation reservoir and the flow from the artificial reservoir, the result being the reduction of the head losses on the adduction gallery and an increase of the turbine head, if we compare with the scheme where there is no compensation reservoir. As a result, the turbine flow rates are lower for constant power operation than in the version without compensation reservoir.

When the hydroelectric plant operates for short periods of time, of about 3 to 6 hours, corresponding to the hourly interval of maximum energy consumption in which these plants are used, large volumes of water are saved. In the case the hydroelectric plant operates for longer periods of time, the hydropower system can operate undisturbed by the presence of the compensation reservoir, but its efficiency decreases with the increase of the operation interval. After the full consumption of the water volume in the compensation reservoir, the hydropower system will work normally as if it didn't have a compensation reservoir.

After the hydroelectric plant shutdown maneuvers and the stabilization of the water level in the surge tank, the process of supplying the compensation reservoir with water begins. The compensation reservoir filling time varies depending on the period of the plant operation, and on the reservoir’s diameter. Thus, as soon as the compensation reservoir is filled, the plant operating cycle can be resumed.

If the hydroelectric plant is put into operation before the reservoir is filled out, the hydropower system can be put into operation, but the efficiency of the compensation reservoir is lower. But, compared to the normal situation, there will be a water volume gained in direct proportion to its degree of filling. Filling the tank to the level of the water in the lake is recommended in order to obtain its operation in the following period, with the most advantageous yield.

The gained water volume can be used for additional energy production by increasing the operating time of the hydroelectric plant. Or we can consider that with the same volume of water, more electricity can be obtained through the turbines.

For hydroelectric plants with long adductions, it will be noted that the additional amount of electricity obtained by using the compensation reservoir can be compared even with the amount produced by medium capacity hydroelectric units.

2. METHOD DESCRIPTION

The hydroelectric plant Râul Mare Retezat, with a power of 320 megawatts, is the second largest plant on the inland rivers, after the Lotru hydroelectric plant. This hydroelectric plant has the main adduction gallery with the length of 18129 m and the diameter of 4.90 m. Its surge tank has an upper and a lower chamber and it is equipped with a hydraulic resistance at the base. The forced gallery has a vertical well, and the underground power plant is equipped with two Francis type turbine groups of 160 Megawatts each, a gallery and escape channel in length of more than 2 km. [4], [6], [7].

The compensation reservoir is located in the immediate vicinity of the surge tank, with the connection placed under the upper chamber. The gallery has 7 m in diameter. The maximum water level in the reservoir should be equal to the maximum level in the artificial reservoir. The calculations to establish the water flows used from the artificial reservoir and from the compensation reservoir are needed to determine the additional energy obtained by the plant. The calculations will be performed for different diameters of the compensation reservoir, spanning between 250 m and 1000 m.

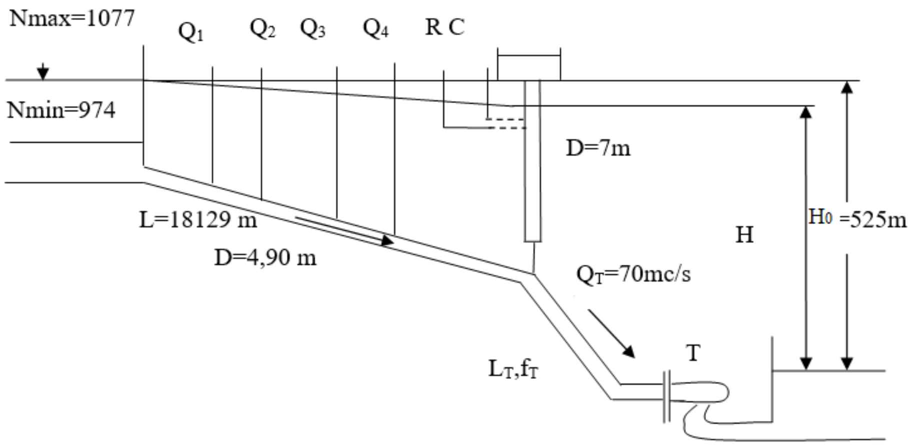

Fig. 1 Scheme of the Râul Mare Retezat hydroelectric plant, with compensation reservoir (RC)

The height of the maximum water level in the artificial reservoir is 1077 m, and the minimum level is at 974 m. We can consider a height of the compensation reservoir of about 30 to 50 m, domain that includes the average exploitation water level. A height of the compensation reservoir, close to the value of the head losses on the intake manifold, can ensure the operation of the hydroelectric plant even for 24 hours with an acceptable efficiency [1].

The turbine flow rate is the sum of the flow rate taken from the artificial reservoir (lake) and the flow rate taken from compensation reservoir [1], [5]:

$$Q_T = Q_L + Q_R \tag{1}$$

Q_T – turbine flow rate, (m^3/s);
Q_L- water flow rate from the artificial reservoir, (m^3/s);
Q_R – water flow rate from the compensation reservoir, (m^3/s).

The head loss slope may be written:

$$J = \frac{h_r}{L} \quad (-) \tag{2}$$

Therefore, the flow rate taken from the artificial reservoir will be:

$$Q_L = \frac{\pi D^2}{4}\sqrt{\frac{2gDJ}{\lambda}} \tag{3}$$

The hydropower plant operates at constant capacity, so the turbine flow rate may be written:

$$Q_T = \frac{P}{\eta \gamma H_R} \tag{4}$$

Where: P – the installed power, (W);

- γ - specific weight of water, $\left(\gamma = 9810\ {}^{N}/_{m^3}\right)$;
- η - plant's operation efficiency, (-);
- H_R - head of the compensation reservoir, (m).,

The installed power is considered to be constant.
The head, H_R, is:

$$H_R = H_0 - h_r \tag{5}$$

Where: H_o -total head, (m);
h_r - head losses, (m).

The volume flow rate taken from the compensation reservoir is:

$$Q_R = Q_T - Q_L \tag{6}$$

Results an efficiency of:

$$\epsilon = 100 - \frac{V_L + V_R}{V} \cdot 100(\%) \tag{7}$$

Where:

ϵ - the efficiency due to the compensation tank ,(%);
V_R, V_L – the water volumes used from the compensation reservoir, respectively from the artificial reservoir, (m^3);
V- the water volume used if there is no compensation reservoir, (m^3);
V_* - the water volume gaind by the use of the compensation reservoir (m^3);

$$V_* = V - V_R - V_L \tag{8}$$

The additional time operation due to the saved water volume is:

$$t_* = \frac{V_*}{Q} \tag{9}$$

Where:

t_* - the additional duration of the plant's operation, (s);
Q – the water flow rate used in the case there is no compensation tank, (m^3).

The relationship for the gained electric energy may be written:

$$E = P \cdot t_* \tag{10}$$

Where:

E – the energy obtained by turbinating the flow rate gained by the use of the compensation reservoir, (MWh)

3. RESULTS AND SIGNIFICANCES

In the case of the hydroelectric plant Râul Mare Retezat, which has a large turbine head and long intake manifold, significant volumes of water are being saved even with a 3-hour operation time and small reservoir sizes.

In Figure 2 there is represented the way the gained volumes increase for different operation periods and different diameters of the compensation reservoir.

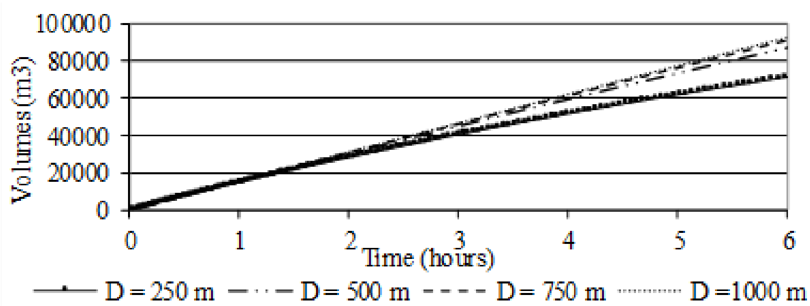

Fig. 2 The water volumes gained due to the compensation reservoir, for different operation time

The additional flow rate taken from the compensation reservoir varies with its diameter, as it may be seen in Figure 3.

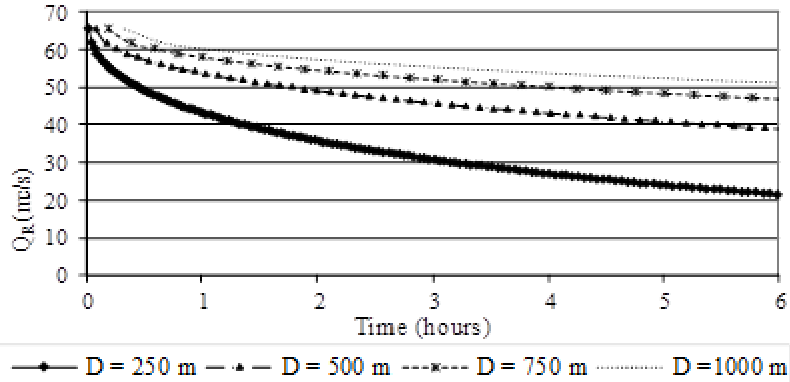

Fig. 3 The flow rate taken from the compensation reservoir, at different values of its diameter

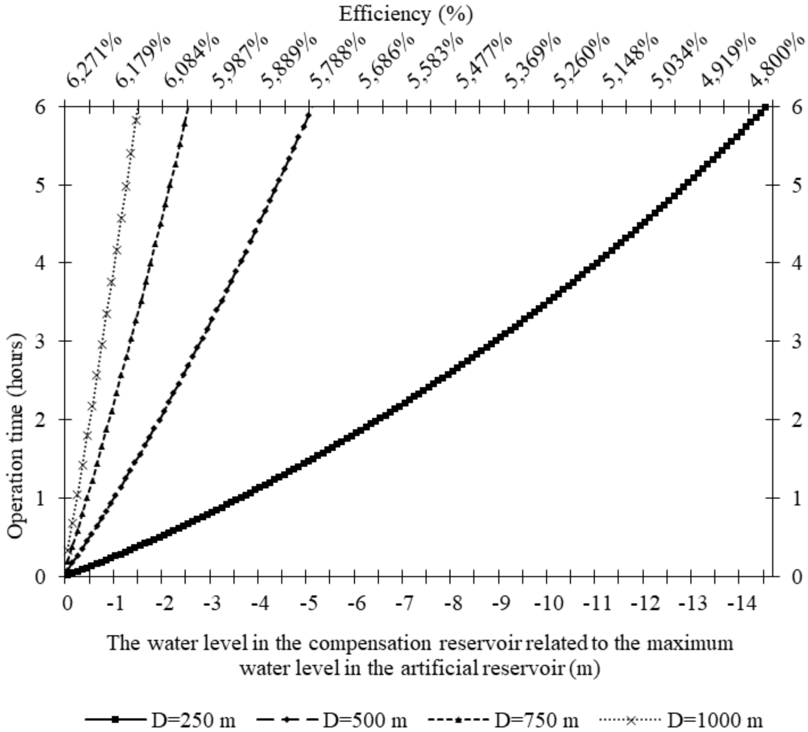

Fig. 4 The water level in the compensation reservoir, for a 6 hours operation time of the hydroelectrical plant

By analysing the saved water volumes (V_*) given in Table 1, for all considered diameter values, at a 3 hours operation time, it is observed that with a 4-times increase in the diameter of the compensation reservoir, the efficiency improves with15.24%. For a 6 hours operation, the efficiency of the compensation reservoir increases more.

Table.1 Energy efficiency gain due to a compensation reservoir of different diameters

D (m)	Timp de funcţionare 3h			Timp de funcţionare 6h		
	V_* (m^3)	E (MWh)	Є (%)	V_* (m^3)	E (MWh)	Є (%)
D_{250}	40692,11	51,67	5,38	71637,61	90,96	4,73
D_{500}	45434,65	57,69	6,00	87395,82	110,97	5,78
D_{750}	46508,14	59,05	6,15	91283,71	115,91	6,03
D_{1000}	46912,39	59,57	6,20	92790,92	117,82	6,13

The results obtained for a 250 m in diameter reservoir show an increase in the produced energy by 29.59%., if compared to those for 1000m in diameter.

The average values Є of the saved energy (due to the compensation reservoir), at a 6 hours operation time, are almost double compared to the values Є obtained during a 3 hours operation period.

Comparing the electricity amounts Є obtained in the case of a 3 hours operation of the hydroelectric plant to those for a 6 hours operation time, it is observed that for the diameter of 500m a significant increase (92.35%) of the energy due to the compensation reservoir is obtained.

4. CONCLUSION

The method of placing a water storage reservoir, close to the surge tank (the means of protection from hydraulic shock), with the role of additionally supplying the hydroelectric plant with water, by reducing the head losses on the long intake manifold leads to a much more efficient utilization of water volumes from the reservoirs with a direct result: the increase of electricity production.

Depending on the hydraulic characteristics of the plant, as well as on its location, the diameter of the compensation reservoir can be chosen so as to obtain maximum efficiency in the use of water volumes.

The operating schedule of the plant is also very important, the maximum values € being obtained if the filling period of the compensation reservoir is achieved.

In the case the height of the compensation reservoir includes the intervals of the average operating levels and for a diameter between 250 and 500m, a large increase in the efficiency of the turbine flows rates is obtained (76-92%).

The electrical energy obtained due to the compensation reservoir represents an additional amount equivalent to 4.7÷6.2% of the energy produced by the Râul Mare Retezat hydroelectric plant.

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Note:

Claudiu Ștefan Nițescu - Ovidius University of Constanta, Bd. Mamaia nr. 124, 900356-Constanta, Romania (corresponding author to provide phone: +40-241-619040; fax: +40-241-618372; e-mail: claudiu.nitescu@365.univ-ovidius.ro)

Anca Constantin - Ovidius University of Constanta, Bd. Mamaia nr. 124, 900356-Constanta, Romania (e-mail: aconstantina@univ-ovidius.ro)