Optimization of mode of operations of hydropower stations with reservoir

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Abstract: Optimization of work of electric station with reservoirs is even more difficult task. The main criterion of optimization of energy mode of reservoirs is to maximize energy production in that period of year while there is a shortage of water.

For instance, Kayrakkum hydroelectric station, which is the only hydroelectric station of the most developed northern region of the republic this period, continues 6-7 months.

Keywords: Optimization, Hydropower, Kayrakkum reservoir

1. INTRODUCTION

What can be the role of reservoir here? It seems that this task is easy. According to accepted point of view the more works reservoir the more water will go through turbine and as a result hydroelectric station will produce more energy. Then, the most optimal mode should be such at which reservoir will be filled up to the greatest possible mode to the beginning of considered period and is completely worked at the end.

2. MODELS FOR OPTIMIZATION

Let' s consider two variation of mode of hydroelectric station work without any function of reservoir (on transit flow). Appropriate to this variation the work of energy on hydroelectric station will be equal:

$$Э_1 = 9{,}81 \cdot \eta \cdot Q_0 \cdot H_1 \cdot T \cdot 24 \qquad (1)$$

Q_0-the transit charge through reservoir and hydroelectric station provided the tributary of the river, $H_1 = \Delta^{max}$ upp.b. $-\Delta_{low..b.}$ pressure on hydroelectric station, T-Duration considered period in day.

In second variation reservoir in regular intervals works for the considered period up to a mark Δ^t upp.b. Having accepted that the area of water s mirrors in reservoir at all its level is equal S (m^2) we consider that in this variation the additional volume of water passed through turbines of hydroelectric station is equal:

$$V_{add.} = S(\nabla^{max}_{upp.b} - \nabla^{t}_{upp.b}) \qquad (2)$$

and additional average consumption for entire period:

$$Q_{add.} = \frac{V_{add.}}{t} = \frac{S(\nabla^{max}_{upp.b.} - \nabla^{t}_{upp.b.})}{T \cdot 86400} \qquad (3)$$

Having accepted with sufficient for estimated accounts mark of tail-water in all cases constant, $\Delta_{low..b.}$ the equation (3) we write:

$$Q_{add.} = \frac{S(H_1 - H_2)}{86400 \cdot T} \qquad (4)$$

Where: $H_2 = \Delta^{t}_{low.b.} - \Delta_{low..b.}$ - pressure on hydroelectric station, at the end of the work of reservoir.

In evenly work of reservoir it may be accepted that in second variation the hydroelectric station all the time worked with average pressure:

$$H_{aver} = \frac{H_1 + H_2}{2} \qquad (5)$$

And its energy production will be equal to:

$$Э_2 = 9{,}81 \cdot \eta \cdot (Q_0 + Q_{add.})H_{aver} \cdot T \cdot 24 = \\ = 9{,}81 \cdot \eta(Q_0 + \frac{S(H_1 - H_2)}{86400T})\frac{H_1 + H_2}{2} \cdot T \cdot 24. \qquad (6)$$

With consideration Э=9,81ηQHt

Where Э-energy (kW/h), η-efficiency, Q-water consumption (m^3/sek), H-pressure (m), t-time (h) and (6) condition at which the work of reservoir brings to additional effect can be written as:

$$\frac{\text{Э}_2}{\text{Э}_1} = \frac{9{,}81\eta(Q_0 + \frac{S(H_1 - H_2)}{86400T}) \cdot \frac{H_1 + H_2}{2} \cdot T \cdot 24}{9{,}81\eta_0 H_1 T24} \geq 1 \qquad (7)$$

As a result of elementary transformation from equation (7) we can get two following criterion:

$$T \leq \frac{S(H_1 + H_2)}{86400\,Q_0} \qquad \text{and}$$

$$Q_0 \leq \frac{S(H_1 + H_2)}{86400T}. \qquad (8)$$

Kayrakkum hydroelectric station with reservoir has following main parameters and can be served as an example.

$S = 200$ km^2; $H_1 = H_{max} = \nabla^{max}_{upp.b.} - \nabla_{low.b.} = 347{,}5-327{,}5 = 20$ m; 9 m $\leq H_2 \leq 20$ m ; $0 \leq Q_0 \leq 900$ m^3/s; $Q_{aver.\ long.stand.} = 600$ m^3/s.

The appropriate calculation at formulas (7) and (8) are given in the tables 1,2,3. They show that for really having a place for Kayrakkum hydro electric station of range of change ($400 \leq Q_0 \leq 900$) of the average consumption and pressures of work ($9 \leq H_2 \leq 20$) the efficiency of use of reservoir takes place only at it fully draining during no more than 70-120 that is much less shortage of the electric power of the autumn-winter period, which is seven months (October- April).

Thus for representing practical interests of the periods of time (T>180) the efficiency of work of reservoir for real pressures is provided only at average charges 300-400m^3 that is essentially smaller valid.

Concrete sizes of losses of production of the electric power at work of reservoir shows Fig. 1. At usual for today's practice $H_2 \cong 10$ m and T =180 days they comprise 10% or in absolute meanings 70-80mln.kWt/hour a year.

The given analysis even in view of the made simplifications show that the mode of operations of Kayrakkum reservoir accepted today in practice, is not optimum from the point of view of power. The loss of energy is obvious during such mode. Moreover, it is not effective for irrigation because a big work of reservoir would result in additional expenses of energy at pumping station.

3. OPTIMIZATION OF KAYRAKKUM HYDROPOWER

As an example we consider the concrete task of optimization of Kayrakkum hydropower station at Syrdarya River in Tajikistan. Its capacity is 126 MWt; the volume of reservoir is 4,6km^3 and useful-2,6km^3. The reservoir of Kayrakkum hydro electric station is the biggest for all northern zone of republic hydro electric station, which is isolated from its basic energy system and carries out seasonal regulation of flow in the most intense river pool of Aral Sea in the interests of following republics: Kazakhstan, Turkmenistan and Uzbekistan .The additional need in water for these republics in vegetation period comprises 2,2km^3

For the defining of national and regional interests we consider two regimes: for national-power and for regional-irrigation. Thus all accounts in models we shall carry out for time units equal to one month with use of monthly average of parameters.

Basic settlement formula for production of energy on hydroelectric station after transformations shall present as:

$$\text{Э} = 9{,}81\,\eta \frac{H}{3600}(Q3600\,t) = \frac{9{,}81H\eta}{3600}W \qquad (9)$$

Table 1.The maximal meaning of the period of time T/ day ensuring efficiency of work of Kayrakum reservoir at various meanings Q m^3/sec and H,m.

Q\H	9	11	13	15	17	19
400	167.8	179.4	191.0	202.5	214.1	225.7
500	134.3	143.5	152.8	162.0	171.3	180.6
600	111.9	119.6	127.3	135.0	142.7	150.5
700	95.9	102.5	109.1	115.7	122.4	129.0
800	83.9	89.7	95.5	101.3	107.1	112.8
900	74.6	79.7	84.9	90.0	95.2	100.3

Table 2.The maximal meaning of water charge Q m^3/sec and ensuring efficiency of work of Kayrakkum reservoir at various period of time T and H,m.

T\H	9	11	13	15	17	19
10	6713.0	7175.9	7638.9	8101.9	8564.8	9027.8
30	2237.7	2392.0	2546.3	2700.6	2854.9	3009.3
60	1118.8	1196.0	1273.1	1350.3	1427.5	1504.6
90	745.9	797.3	848.8	900.2	951.6	1003.1
120	559.4	598.0	636.6	675.2	713.7	752.3
150	447.5	478.4	509.3	540.1	571.0	601.9
180	372.9	398.7	424.4	450.1	475.8	501.5
210	319.7	341.7	363.8	385.8	407.8	429.9

Table 3.The attitude of production of the electric power at work to pressure H_2 to a maximal pressure H=20m at different time of work/day and Q=const=600m^3/sec.

T\H$_2$	9	11	13	15	17	19
10	3.80	3.47	3.05	2.56	2.00	1.35
30	1.75	1.67	1.57	1.44	1.28	1.10
60	1.24	1.22	1.20	1.16	1.10	1.04
90	1.07	1.07	1.07	1.06	1.04	1.02
120	0.98	1.00	1.01	1.02	1.01	1.01
150	0.93	0.95	0.97	0.99	1.00	1.00
180	0.90	0.92	0.95	0.97	0.98	1.00
210	0.87	0.90	0.93	0.96	0.98	0.99

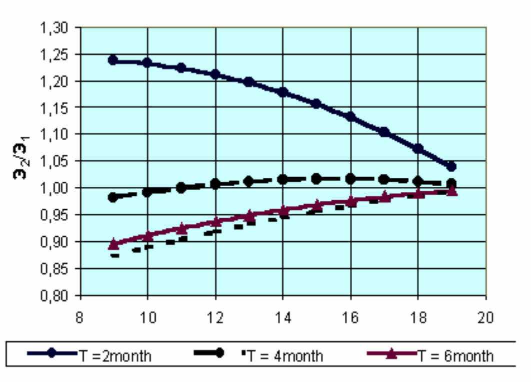

Figure1. Effectiveness of working out of Kayrakkum reservoir for production of power energy in dependence of final pressure and time

From the last formula we get:

$$\frac{W}{Э} = \frac{3600}{9{,}81\eta H} = q \qquad (10)$$

Where: q-water consumption on energy production on hydroelectric station, m^3/kwt/h.

The volume of water through hydroelectric station Wi is calculated by formula:

$$\mathrm{Wi} = Q^{i}_{ch}\ 3600 \cdot N_i \qquad (11)$$

Where: Q^{i}_{ch}-average monthly consumption of water through turbine of hydroelectric station, Ni-quantity of days in 1-month, Wi-volume of water passed through turbine of hydropower station in 1-month.

The main entry condition for our model is an initial volume of reservoir. For this we should define the settlement period. We take it equal to 1 year (12months) not consider it as usual calendar year, but we take it from the start of vegetation period from 1st October till 30 September when the vegetation period is finished. Thus, it makes easy to consider irrigational issues and also the issue of energy so as shortage of energy and vegetation period are coincide.

Both in hydropower and in irrigational models the natural restrictions having clear physical sense are used.

1.The entry conditions on volume of reservoir (on 1October) should be reproduced by the end of the period, considered in models, (by September 30).

2.The consumption of water through turbines of hydroelectric station should be more or equal to 0.

3.The volume of reservoir in any considered period of time should not be less than minimally possible and more than maximally possible

$$W_{\min} \leq W^{i}_{reserv.} \leq W_{\max}$$

4.The consumption of water through turbines of hydroelectric station should not be more as possible allowed on conditions for small pressures.

$$Q_{\mathrm{HPS}} \leq Q^{\text{мах}}_{HPS}$$

As a changing parameters in both models the consumption of water through turbines of hydroelectric station are accepted.

The criterion of optimization of operational regime of Kayrakkum hydroelectric station from a position of national interests of water-power engineering is defined practically unequivocally i.e. maximization of production of energy in winter: from October till April (May) without any other conditions for other period of year.

A criterion of irrigational regional operational mode of Kayrakkum reservoir is defined by need of water in vegetation period required by countries Uzbekistan and Kazakhstan.

Both models were developed with the use of personal computers in framework of programs Microsoft Office1998 or Excel and menu Service.

The algorithms of a simplex method and method ’’branch-and-bound” for the decision of linear and nonlinear tasks with restrictions are developed by Yohn Watson and Dan Fulstra, Frontline Systems, Ync.

For conducting of concrete calculation on mathematic models the fact sheet, which were in use for the last years (1998-2001) have been used.

The results of calculation are shown in Fig. 2.

Comparison of results of these two models allow to define those direct losses of produced energy, which bears Tajikistan rendering service on irrigational regulation of flow for Uzbekistan and Kazakhstan. They are equal to:

719,183-472,334=246,849 mln.kwt.hour

As characteristics of this mode it is possible to note that for maintenance of the maximal production of energy in autumn-winter period there is no necessity of he complete function of reservoir up to its minimal volume 881,1mln.m^3.The minimal volume of reservoir during its energy mode is1600, 7mln.m^3.

Received results allow that by using of market approach to optimize the use of water energy resources of river on international level.

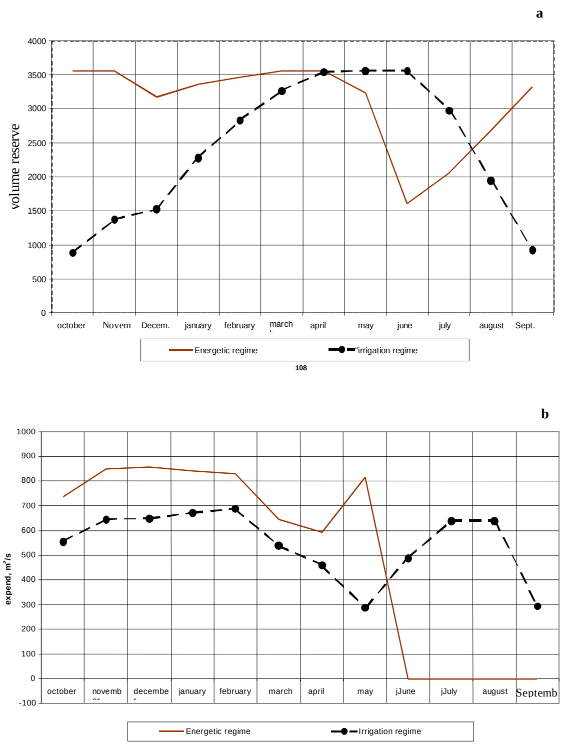

Figure2. Energetic and irrigation scheme of operation and accumulation of Kayrakkum reservoir (a),Monthly average drawn downs from Kayrakkum reservoir in energetic and irrigation regime(b)

4. CONCLUSION

To certain extend it can provide considering by us the maximization of regional benefit but with taking into consideration the social aspects.

It is that: In conditions of priority for life-support of Central Asian Countries and irrigational farming in practice will be implemented irrigational regulation of flow while the criterion will be the maximum provision of water for irrigated agriculture in vegetation period. Countries of lower flow should compensate the loss of energy, which bears the countries of upper flow, getting by result of such scheme the additional water for irrigation.

Such a scheme was implemented in Central Asia for the most intense river pool –Syrdarya of Aral Sea. In 1998 among Kirgizstan, Tajikistan Turkmenistan and Uzbekistan the ”Agreement of using of water-energy recourses of the river pool Syrdarya’’ was signed. This agreement successfully worked during 5 years and in 2003 was prolonged by Central Asian Republics for five years.