Operation characteristic analysis of a high head hydropower plant

Georgiana DUNCA[1], Mihaela CONSTANTINESCU[2], Eugen Constantin ISBASOIU[3]

[1] Assistant Prof., Hydraulics and Hydraulic Machinery Department, University "Politehnica" of Bucharest, Romania, georgianadunca@yahoo.co.uk
[2] Eng., OPCOM, Bucharest, mconstantinescu@opcom.ro
[3] Prof., Hydraulics and Hydraulic Machinery Department, University "Politehnica" of Bucharest, ecisbasoiu@yahoo.com

Abstract: *An application was realized for a national hydropower plant. Taking into account the hydraulic turbine exploiting characteristic and the site hydraulic efficiency, a program was developed in order to obtain the turbine efficiency as a function of the capacity and the lake elevation* $\eta_T = \eta_T(P, Z_{lac})$ *and the product between the turbine efficiency and the hydraulic efficiency as a function of capacity and lake elevation* $\eta_T \cdot \eta_h = \eta_T \cdot \eta_h(P, Z_{lac})$, *when only one hydro unit is operating or when multiple units are operating. Similar, the dependency of the efficiency on the turbine load and the lake elevation can be obtained. Using the electric generator efficiency as a function of the electric power, the dependency of the site's global efficiency on the turbine load and the lake elevation can be obtained, as well as its dependency on the generator electric load and the lake elevation. The economic operation, energetically speaking, is obtained when the power plant global efficiency reaches the biggest value in the given conditions (the lake elevation and the required electric load). In order to solve this problem the exploiting characteristic was obtained as a function of lake elevation and power plant load (or flow rate). This exploiting characteristic is useful for establishing the operating loads schedule in order to obtain a minimum value for water consumption.*

1. Introduction

The energy sector is of great importance, being the base of country economic development. In Romania, the installed capacity in electric power plants is about 19000 MW of which 6200 MW in hydro power plants and 1400 MW installed in the nuclear power plant. The annual electric energy production of the hydro power plants is situated between 14 TWh and 17 TWh (taking into account the hydrologic character of the year) which represents 25 – 34 percent of the country annual electric energy production.

Besides the energy produced annually, the hydro power plants provide support for most of the so called "ancillary services", required in order to obtain an adequate electric system operation. Thus is important for hydro power plants to operate as efficient as possible.

Hydro power plants equipped with Francis turbines with big storage lakes (having a very elastic operation) must operate in regimes for which the water consumption is minimum, meaning a maximum energy obtained from the turbined water volume.

Taking into account the exploiting characteristic of the hydraulic turbines $\eta_T = \eta_T(H, P)$, the electric generator efficiency variation $\eta_g = \eta_g(P_e)$ and evaluating the energetic dissipations (hydraulic head loss) for the entire hydraulic circuit, the hydraulic efficiency was obtained as a function of the discharged flow and storage lake elevation $\eta_h = \eta_h(Q, Z_{lake})$.

Using these characteristic efficiency diagrams (turbine's characteristic efficiency $\eta_T = \eta_T(P)$, generator's characteristic efficiency $\eta_g = \eta_g(P_e)$ and plant's hydraulic characteristic $\eta_h = \eta_h(Q, Z_{lake})$), the plant's exploiting characteristic $\eta = \eta(P_e, Z_{lake})$ was obtained, when only one unit is operating and when both units are operating.

2. Plant scheme

An application of this method was realized for the hydro power station Galceag which is included in Sebes river hydrologic basin. The Sebes complex hydro energetic scheme is presented in figure 1.

Fig. 1 – Sebes complex hydro energetic scheme

Galceag hydro power station (fig. 2) is equipped with two Francis turbines, FVM 80-430 type, having a speed of 600 rpm and operating into a head domain of H_{max} = 456 m (corresponding to the maximum upper storage lake elevation of $Z_{lake}^{max} = 1255$ m a.s.l (meters above sea level) and H_{min} = 379 m (corresponding to the minimum upper storage lake elevation of $Z_{lake}^{min} = 1206$ m a.s.l.). Thereby, Galceag hydro power station can operate into a gross head domain of 379 m – 456 m.

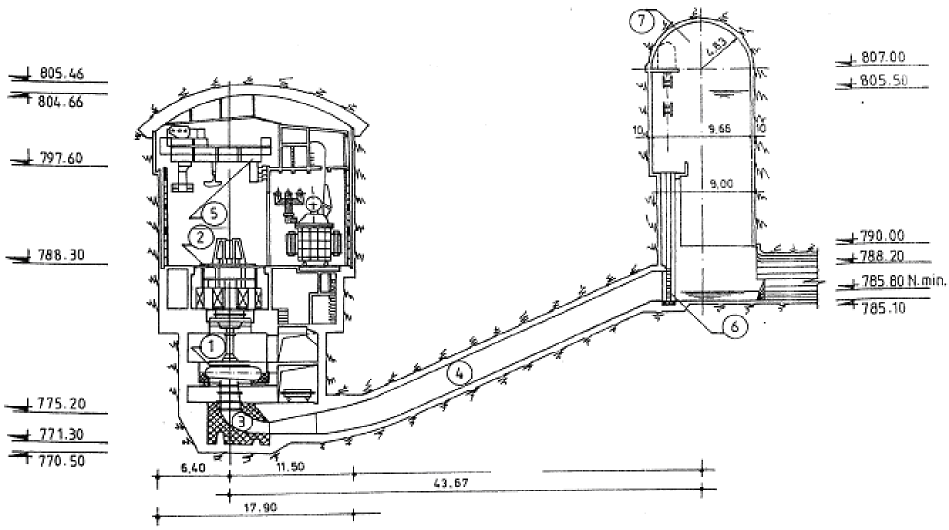


Fig. 2 – Galceag hydro power station

3. Plant efficiencies

The first step in the presented calculus is analyzing the hydro power plant efficiencies.

The power capacity of a hydro power plant at a certain moment is given by

$$P = \rho\, g\, Q(t) H(t)\, \eta\,,$$

and the corresponding electric energy is

$$E = \int_0^T P(t)\, dt$$

In these general equations, η represents the global plant efficiency,

$$\eta = \eta_h \cdot \eta_{tb} \cdot \eta_g\,,$$

which contains: η_h – hydraulic plant efficiency $\eta_h = \eta_h(Q)$, η_T – turbine efficiency, given by the exploiting characteristic curve of the turbine, as a function of the net head H_{net} and the discharge or the turbine mechanic capacity, η_g – generator efficiency, given as a function of its active capacity.

Plant hydraulic efficiency is given by the ratio between the net head and the available gross head:

$$\eta_h = \frac{H_{net}}{H_{brut}} = \frac{H_{brut} - \sum h_r}{H_{brut}} = 1 - \frac{\sum h_r}{H_{brut}}\,,$$

where $\sum h_r$ represents the hydraulic head loss for the entire hydraulic circuit, from the storage lake to the return of the discharged flow.

For high head power station, such as Galceag power station, the admission ducts are mostly under pressure and it can be considered that $\sum h_r = f(Q^2)$.

The linear hydraulic head losses, representing over 90 percent of the total hydraulic losses, can be obtained using the Chezy equation

$$h_{r\,lin} = \frac{Q^2}{K^2} \cdot L\,.$$

where

$$K = A\, C \sqrt{R_h}$$

and the Chezy coefficient

$$C = \frac{1}{n} R_h^{1/6}\,,$$

results in

$$h_{r\,lin} = \frac{L\, n^2}{A^2 R_h^{3/4}} \cdot Q^2\,,$$

where L is the duct length for the analyzed sector [m], C – is the Chezy coefficient, R_h – hydraulic radius [m], A – plan area [m], K – discharge flow modulus, n – roughness factor.

The roughness factor is the single parameter that can vary in hydraulic head linear losses equation, n. Thus, it can be assumed that $Q \cdot n$ is constant or that for a constant discharge Q, the head loss rise with n^2.

In figure 2 there is presented the hydraulic efficiency variation for admission duct roughness factor of 0.012, 0.014, 0.016 and 0.018. The curves were obtained for two values of upstream lake elevation: 1255 m a.s.l. and 1206 m a.s.l.

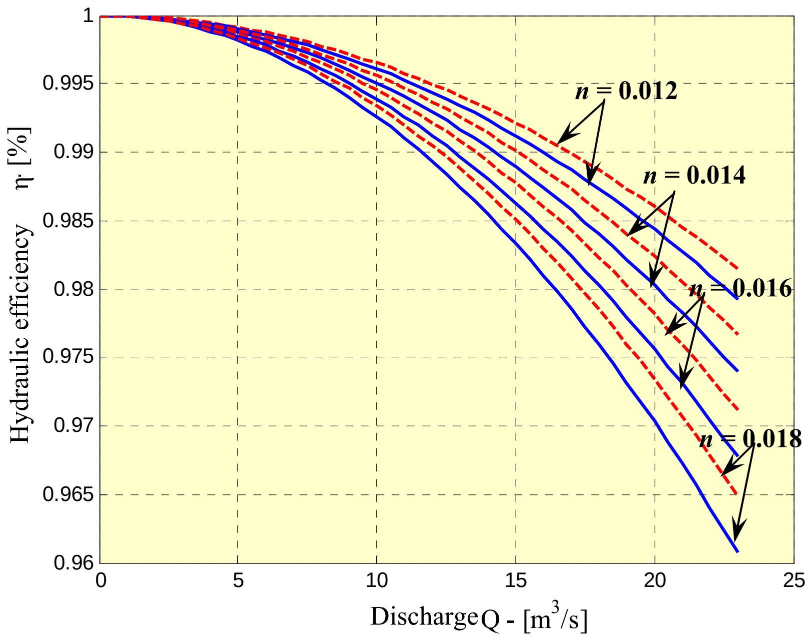


Fig. 3 – Hydraulic efficiency of the Galceag hydro power plant

It can be seen that the plant hydraulic efficiency decreases from 98 % to 96% with the decrease of the roughness factor.

The roughness factor time evolution can be due to the wetted perimeter roughness factor degradation or to some technical incidents on the hydraulic circuit. Also, local modification of the flow cross section produces additional local head losses.

Thereby, it is necessary to realize a general inspection of the hydraulic circuit every 4 or 5 years.

Turbine efficiency is given by the exploiting characteristic curve. In order to obtain it for Galceag power station, the model F90 exploiting characteristic (figure 4) was used, mainly because the FVM 83.5 – 430 type turbines that equip the hydro power station derive from it.

Using the model efficiency (η_M), the prototype efficiency (η) can be obtained using Moody equation

$$\eta = 1 - \left(1 - \eta_{\mathrm{M}}\right)\left(\frac{D_{\mathrm{M}}}{D}\right)^{0,2}$$

which can be applied for Francis turbines with $H \geq 150$ m, as well as for centrifugal pumps.

Using this diagram the turbine exploiting characteristic was obtained. From the entire head and discharge domain of the exploiting characteristic, the interest area was considered, the resulted diagram being defined on the operating head and discharge domain (H = 379 ÷ 456 m, Q = 10 ÷ 22,8 m^3/s).

Generator efficiency can be obtained using the efficiency variation as a function of electric capacity given by the generator manufacturer

$$\eta_g = \frac{P}{P + \Delta P},$$

where P is the electric capacity, and ΔP is the sum of the generator losses.

The global efficiency is obtained using the three efficiency diagrams. In order to compute the hydraulic efficiency, a value for the admission duct roughness factor of n = 0.014 is considered and used for different lake elevation.

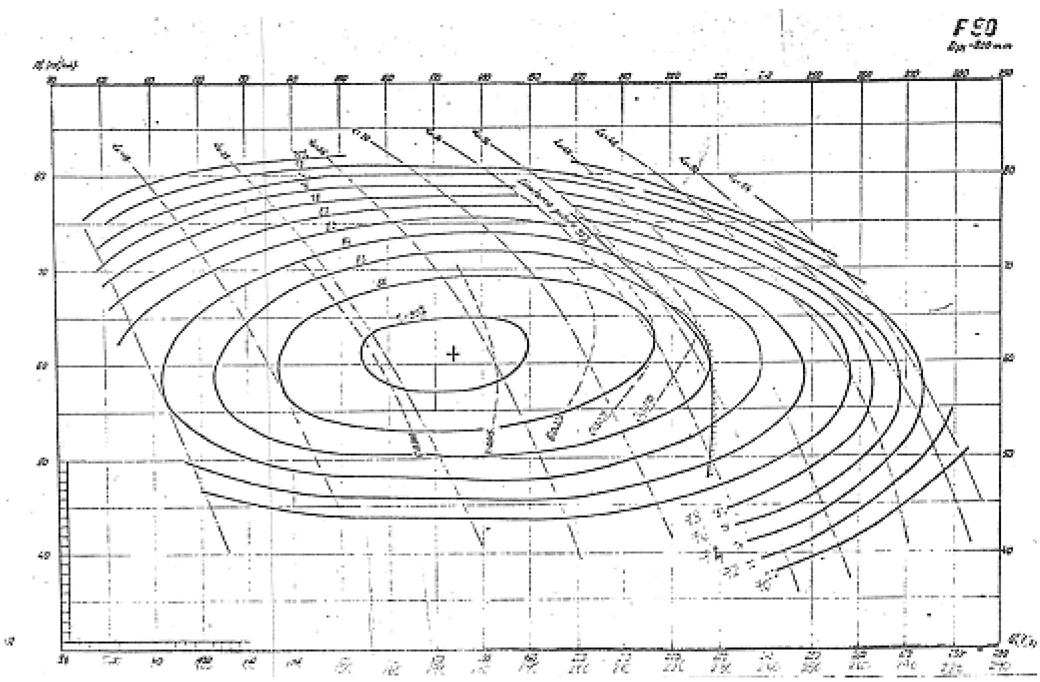


Fig. 4 – Model F90 operating characteristic curve

4. Recommended operating domains

Introducing the upper lake elevation (the Oasa lake elevation), the efficiency variations were obtained for different units operating configurations for Galceag hydro power station. The global efficiencies as a function of the plant power capacity are presented in figure 5 for two lower lake elevations (794.5 m a.s.l. – red curve and of 790 m a.s.l. – blue curve).

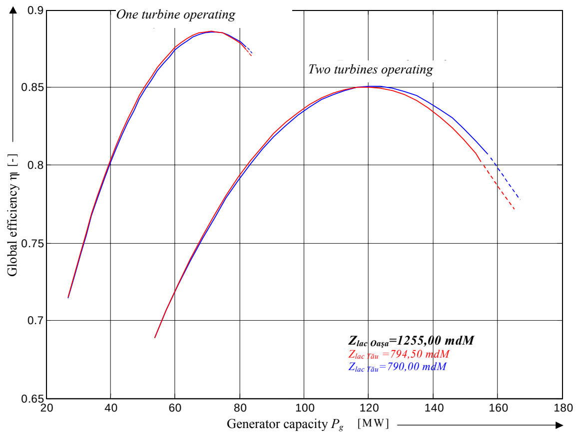
It can be seen that the best global efficiency is obtained for one turbine operation. The best global efficiency for both units decreases due to the increase of the hydraulic head loss on the hydraulic circuit upstream the turbines. Also, it can be seen that there are important efficiency losses for the passage domain between single turbine operating or both turbines in operational state.

It can be seen that for a power capacity of 80 MW – 100 MW the efficiency loss is 4 to 8 percent. These losses are due to the hydraulic head losses on the turbine hydraulic circuit and to the decrease of the turbine efficiency (the turbine is operating outside the optimal).

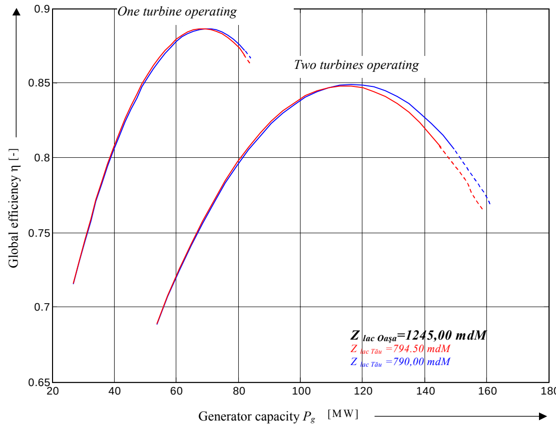
The relative important efficiency loss at the maximum turbine capacity, comparing to the best efficiency is due to the fact that the turbines were chosen in order to obtain the best efficiency around 0.8 of Q_{max}.

Important efficiency losses have been observed on power domain when changing the single turbine operating to both turbines in operational state.

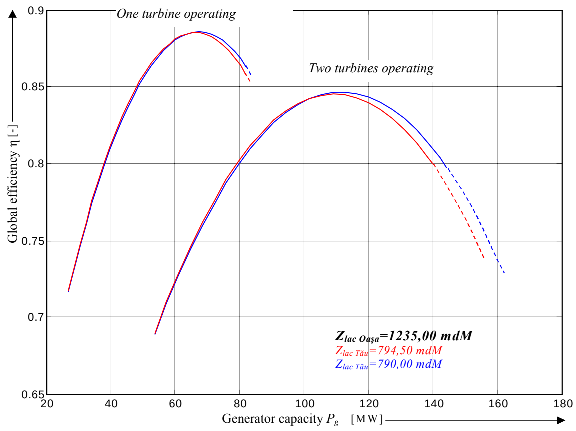
Those results show that the best operation must be realized for capacity values corresponding to the best global efficiencies and the between capacity domains, where the efficiency values are very low, must be avoided.



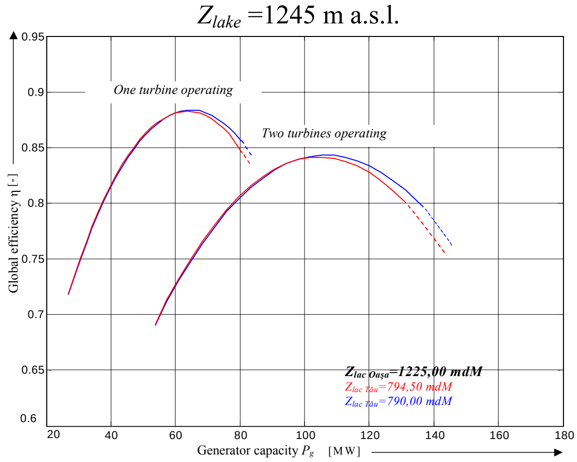
Z_{lake} = 1255 m a.s.l.



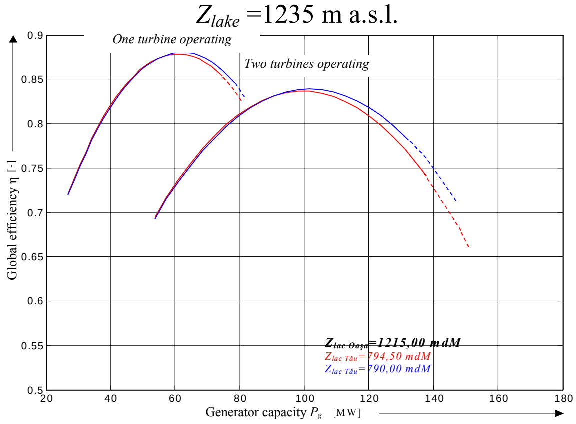
Z_{lake} =1245 m a.s.l.



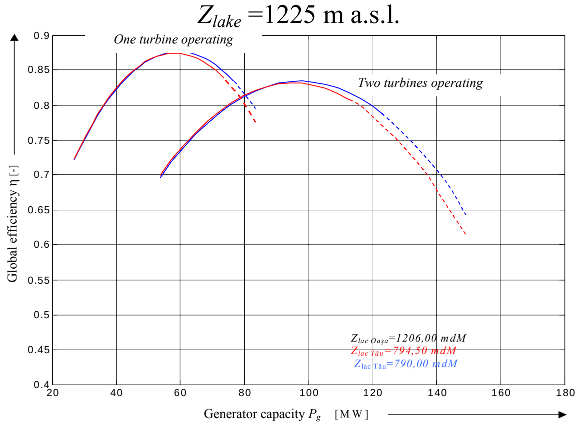
Z_{lake} =1235 m a.s.l.



Z_{lake} =1225 m a.s.l.



Z_{lake}=1215 m a.s.l.



Z_{lake} =1206 m a.s.l.

Figure 5 Global efficiencies as a function of the plant power capacity for two lower lake elevations for single turbine operation and for both units operating

In figure 6 is presented the plant global exploiting characteristic obtained for single turbine operating and for both turbines in operational state. There are shown the capacities and gross heads domains where Galceag hydro power station can operate with only one hydro unit, with both hydro units or where it can't operate because the maximum discharge is exceeded or because of an exaggerate efficiency decrease, for a requested load.

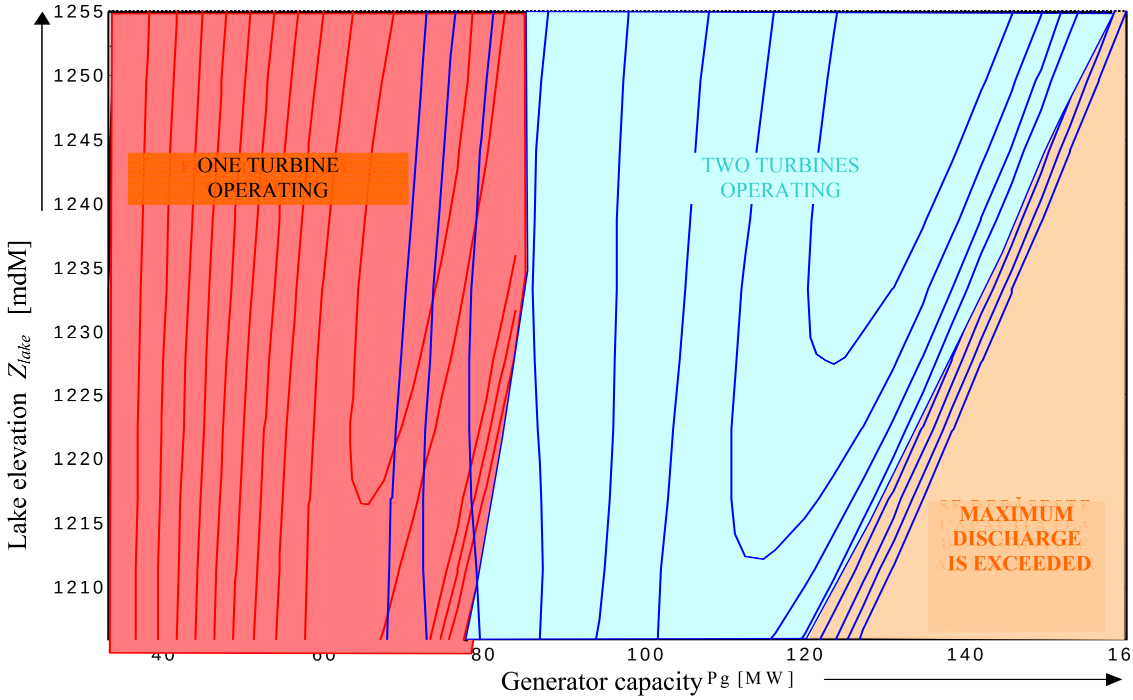


Figure 6 – Station global exploiting characteristic $\eta_{global} = \eta_{global}(P_g, Z_{lake})$

5. Conclusions

Hydro power plants operating regimes must be maintained only in the best global efficiencies domain, with an admissible deviation of 5 percent under this value. The difference between the capacity corresponding to the best global efficiency and the maximum capacity of a hydro power plant must be preserved as spinning reserve in order to assure the system's frequency secundary adjustment.

The transit from single hydro unit operation to both hydro units in operational state is rational to be performed swift, thus avoiding long periods of operation at low global efficiencies. Thereby it is important to know the recommended load domains for both cases of operation.

Hydro power plants, such as Galceag, with under pressure admission ducts have short operation periods of time (about 2000 hours per year). If it is requested to operate for larger periods (1 – 2 days) in order to replace the energy production of a thermo power plant or nuclear power plant it is recommended to distribute the amount of the requested energy to two or three hydro power plants. In this way the hydro power plants can operate with only one hydro unit at the best efficiency point, this being more rational then operating with multiple hydro units at a lower global efficiency.

Taking into account the electrical power market conditions, it is possible for a hydro power plant to operate outside best efficiency areas, if it is necessary, but the corresponding energy production must be tendered at a higher selling price than the energy obtained in the best global efficiency point.

BIBLIOGRAFIE

[1]. ISBĂŞOIU E.C., GEORGESCU, C.S., *Bazele hidraulicii,* partea a treia, Editura Institutului Politehnic Bucureşti, 1994;

[2]. ISBĂŞOIU E.C., GEORGESCU, C.S., *Mecanica Fluidelor,* Editura Tehnică Bucureşti, 1995;

[3]. KISELEV, P.G., *Îndrumar pentru calcule hidraulice* Editura Tehnică Bucureşti, 1989;

[4]. IDELCIK, I., A., *Îndrumar pentru calculul rezistenţelor hidraulice,* Editura Tehnică Bucureşti, 1984;

[5]. LEVIN L., *Formulaire des conduits,* Dunod, Paris, 1968;

[6]. BÂLĂ, M., *Construcții hidrotehnice,* Editura Didactică şi Pedagogică, Bucureşti, 1967;
[7]. VIVIER, L., *Turbines hydrauliques et leur regulation,* Edition Albin Michel, Paris, 1966;
[8]. ANTON, I., *Turbine hidraulice,* Editura Facla, Timişoara, 1979;
[9]. PAVEL, D., *Turbine hidraulice şi echipamente hidroenergetice,* Editura Didactică şi Pedagogică, Bucureşti, 1965;
[10]. Planul național de dezvoltare 2007-2013