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WEEKLY-TERM OPTIMIZATION FOR LOWER OLT SECTOR, A HYDRO POWER PLANT CASCADE WITH REVERSIBLE UNITS

Radu POPA[1], Florica POPA[2], Bogdan POPA[3], Manuela NICOLESCU[4]

In a previous paper, a mathematical model for the weekly optimal scheduling of a hydropower plant cascade with reversible units was presented. The optimization problem is solved by an evolutionary method based on the genetic algorithms. The performance function take into account the price / cost of the generated consumed power, but the violation of some operational restrictions is also penalized. The operation characteristics of units in both generating and pumping modes were used.

In this article, a numerical case study concerning the Ipotesti-Islaz sector on the Olt River is presented and commented in some details.

Keywords: optimization, hydro power plant cascade, reversible units.

1. Numerical application

Since according to the initial project (and also according with the ongoing refurbishing process) the Ipoteşti – Dunăre sector of the lower Olt system was equipped with reversible units plants, this sector was selected for an illustration by a numeric application. To the existing lakes and hydropower plants (Ipoteşti – Izbiceni), the last estimated plant in the project was added (Islaz), even if it is not functional yet.

Therefore, this is an ensemble of 6 lakes and HPP, each plant being equipped with 4 reversible units. The units in the existing sector are identical and have the same operation characteristics, and, for the final plant, they were assumed different in this respect.

The values for the normal retention level (NRL) and for the minimum operating level (MOL), as well as the corresponding volumes, were taken in accordance with the project data and are included in Table 1. The last column in the table shows the supposed values of the reservoirs levels at the beginning of the study period Z_0.

[1] Prof., Power Engineering Faculty, University "Politehnica" of Bucharest, Romania
[2] Eng., Institute for Hydropower Studies and Design, Romania
[3] Assoc. Prof., Power Engineering Faculty, University "Politehnica" of Bucharest, Romania
[4] Eng., Institute for Hydropower Studies and Design, Romania

Table 1

Characteristic levels and volumes in lakes

Lake	NRL [mdMB]	MOL [mdMB]	V_{NRL} [mil. m^3]	V_{MOL} [mil. m^3]	Z_0 [mdMB]
Ipoteşti	98,00	96,00	112,9	84,88	97,50
Drăgăneşti	84,50	82,50	82,23	62,97	84,00
Frunzaru	71,00	69,00	89,68	71,65	70,50
Rusăneşti	57,50	55,50	86,58	65,82	57,00
Izbiceni	44,00	42,00	64,05	47,00	43,50
Islaz	30,75	28,75	18,44	10,28	30,25

The daily emptying gradient at Ipotesti lakewas accepted as $\Delta Z_1^* = 0.2\,\text{m/day}$ (the filling up gradient in weekend results $\Delta Z_2^* = 0.5\,\text{m/day}$) and the daily level variation was limited at $\Delta Z_3^* = 0.5\,\text{m/day}$ for all lakes.

An extract from the matrix $P(H,Q)$, in MW, in generation for the refurbished units, is included in Table 2. The matrix was shown in the programme at step $\Delta H = 0{,}5\,\text{m}$, for $H \in (8;17)\,\text{m}$ and at step $\Delta Q = 5\,\text{m}^3/\text{s}$, for $Q \in [30;130]\,\text{m}^3/\text{s}$, respectively.

Table 2

Power in MW, for the unit at Ipoteşti – Izbiceni plants, in generation versus *H* and *Q* (partialy)

Q [m^3/s] \ *H* [m]	...	11.5	12	12.5	13	13.5	14	14.5	15	...
...	...	...	...	...	...	...	...	...	...	...
80	...	7.97	8.31	8.68	9.08	9.46	9.83	10.20	10.57	...
85	...	8.46	8.86	9.26	9.69	10.10	10.47	10.87	11.28	...
90	...	9.00	9.44	9.85	10.30	10.72	11.15	11.53	12.00	...
95	...	9.54	10.00	10.43	10.91	11.38	11.80	12.23	12.70	...
100	...	10.05	10.56	11.01	11.52	12.00	12.44	12.87	13.40	...
...	...	...	...	...	...	...	...	...	...	...

The technical minimum flow was approximated as:

$$Q_{th}^{\min}(H) = 135{,}73 - 11{,}917 \cdot H + 0{,}3376 \cdot H^2, \text{ [m}^3\text{/s], for } 8 \le H \le 16.5\,\text{m};$$

and the turbinated maximum flow was restricted through the following relations:

$Q^{\max}(H) = -253 + 42 \cdot H$, [m^3/s], for $8 \le H \le 9$ m;

$Q^{\max}(H) = 125$, [m^3/s], for $9 < H \le 12{,}8$ m;

$Q^{\max}(H) = 225{,}35 - 7{,}84 \cdot H$, [m^3/s], for $12{,}8 < H \le 16{,}5$ m.

In pumping mode the pumped flow and the absorbed power were considered as in the relations:

$Q(H) = 127{,}143 - 5{,}357 \cdot H$, [m^3/s], for $11{,}6 \le H \le 15{,}8$ m;

$P(H) = 11{,}35 - 0{,}1595 \cdot H$, [MW], for the same domain *H*.

For the units at Islaz plant, entry data are fed in a similar manner which is not detailed here.

Head loss in plants at $Q_{inst} = 125$ m^3/s was admitted as $\Delta h_{inst} = 0{,}5$ m.

Downstream head reductions as function of the overall turbinated flow were considered as shown in the left side of Table 3, and the head increases in pumping regime are listed in the right side of the same table.

Table 3

Head reductions / head increases (in m) as functions of the flow

Lake	Flow (m^3/s)				Flow (m^3/s)				
	125	250	375	500	55	110	165	220	260
Ipoteşti	0.01	0.04	0.10	0.17	0.10	0.11	0.12	0.13	0.14
Drăgăneşti	0.01	0.03	0.06	0.10	0.10	0.10	0.11	0.12	0.13
Frunzaru	0.02	0.07	0.15	0.25	0.10	0.11	0.12	0.14	0.16
Rusăneşti	0.03	0.10	0.20	0.33	0.10	0.12	0.14	0.17	0.20
Izbiceni	0.05	0.13	0.25	0.41	0.11	0.14	0.19	0.26	0.33

As about Islaz plant, downstream levels additionally depend on the level of the Danube, and these are specified as data matrixes between which a bidimensional linear interpolation was performed.

It was admitted that the week time horizon starts on Monday at 0:00 hours and it ends on Sunday at 24:00 hours. Time steps Δt of 3 hours each were considered (*m* = 8 steps per day), and thus the optimization problem has 8x7x6 = 336 decision variables. Pumping was allowed in the first 6 hours of the working days and for the weekend 12 hours were accepted on Saturday, and 18 hours were accepted on Sunday. Power value was introduced at market closing prices, monthly average values on working days/non-working days recorded for the year 2008.

Next, the results of a cycle for an October week are presented. The multiannual monthly average flow on Ipoteşti section of 111.23 m^3/s and the values of the monthly average flows on sub-basins of: 9.23; 1.15; 0.56; 0.33 and 0.07 m^3/s, assumed constant in time, were used. Taking into account the location of HPP Slatina upstream the considered sector, the hydrograph flow coming into Ipoteşti lake was schematized in accordance with the position of the day during the week and of the peak/low periods within one day, respectively, as in table 4.

Table 4

Flows coming into Ipoteşti lake , in m^3/s

Step Δt / Days	1	2	3	4	5	6	7	8
Monday Tuesday Friday	0	0	150	320	0	150	320	0
Wednesday, Thursday	0	0	320	320	0	320	320	0
Saturday	0	0	0	250	0	0	250	0
Sunday	0	0	0	174.5	0	0	174.5	0

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The energy market closing prices, as average values on time steps for October, are shown in table 5.

Table 5

Market closing prices for October 2008, used for determinations, in lei/MWh

Step Δt / day	1	2	3	4	5	6	7	8
Monday – Friday	192	180	267	295	276	252	306	274
Saturday Sunday	183	149	176	220	210	212	293	249

A cost of the pumping energy of 21 lei/MWh was assumed; considering it comes from the same producer (therefore only energy transport was taken into account).

AG worked with populations consisting of 78 solutions each, and was stopped after it went through 30.000 generations. Some of the results of the final optimal solution are presented next.

Table 6 contains the weekly power values produced and consumed in the HPP, as well as the distribution of the power produced on the account of the natural incoming flows, and on account of pumping, respectively. For the system as a whole, the ratio between of the powers produced due to pumping and consumed through pumping is 0.692.

Table 6

Power produced / consumed on HPP and on the whole system, in MWh

CHE	Ipoteşti	Drăgăneşti	Frunzaru	Rusăneşti	Izbiceni	Islaz	Total system
Produced power	3069	3432.2	3542	3395.3	3375.7	2990.3	19804.5
- from naturally incoming flows	2100.2	2368.3	2393	2270	2232.9	1998.1	13362.5
- due to pumping	968.8	1063.9	1149	1125.3	1142.8	992.1	6442
Consumed energy	1411.4	1538.8	1650.5	1660.7	1692.2	1350.7	9304.2

The net power (produced – consumed), as a sum on all HPP and on days, have the distribution on the 8 time steps of the average day as in table 7.

Table 7

Distribution of net power on the time steps of the day for the arrangement level in MWh

Pas Δt	1 (1-3)	2 (4-6)	3 (7-9)	4 (10-12)	5 (13-15)	6 (16-18)	7 (19-21)	8 (22-24)
Net power	-3306.1	-3221.6	1750.3	3526.2	2864.4	3046	3584.8	2256.3

With the already-mentioned prices of the produced/consumed power, the value of the turbinated energy is about 5.487.000 lei, and the cost of the energy used for pumping is about 195.000 lei.

The water level variations in the 6 lakes are represented in figures 2 a) ... f). It can be seen that Ipoteşti lake follows the imposed discharging and refilling programme. At the end of the week, levels in all lakes return to the initial values and during the week they do not exceed the allowed maximum or minimum levels.

The energy produced and consumed, respectively, on the time steps of the considered week for each HPP are represented in figures 3 a) ... f).

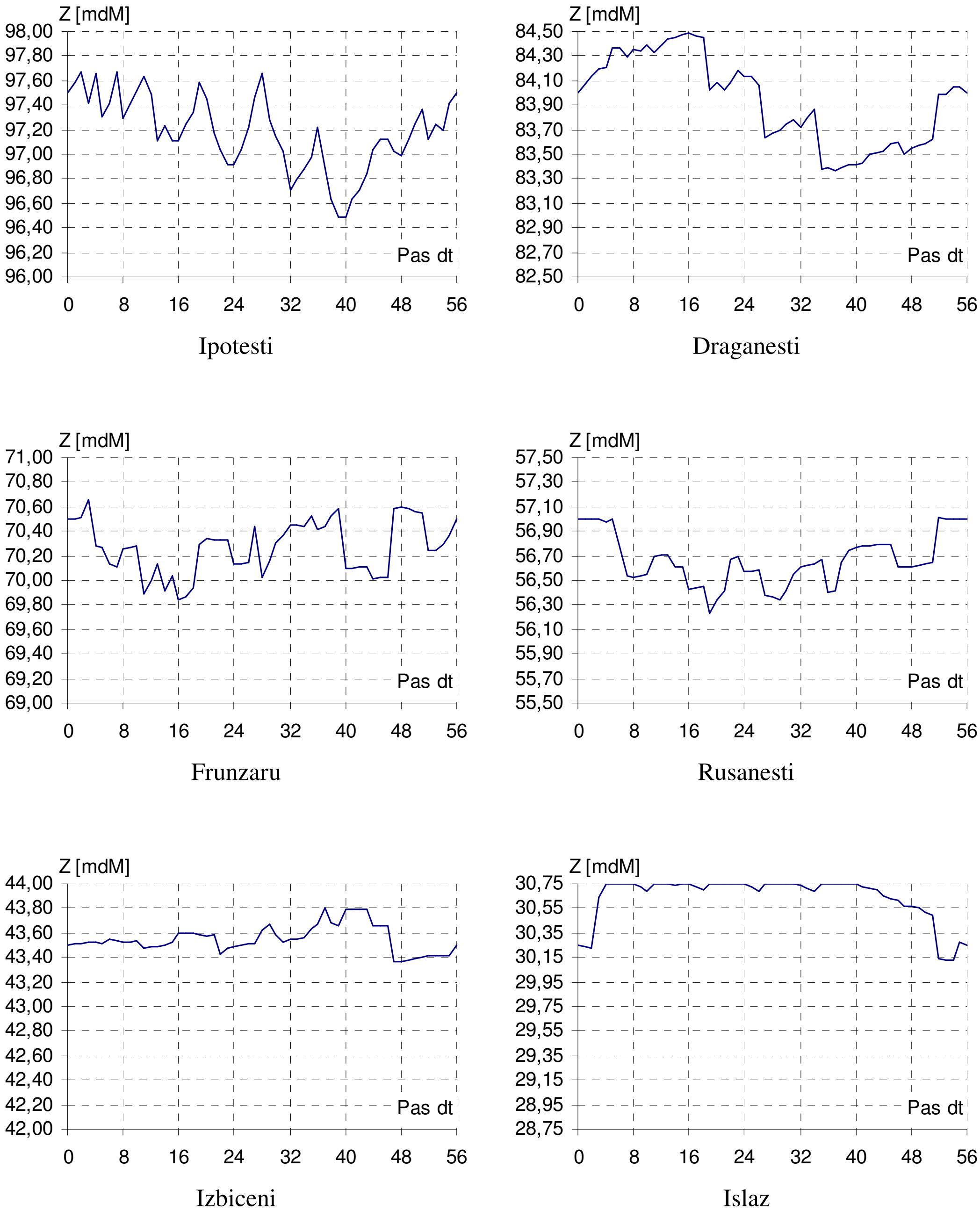

Fig. 2. The water level variations in the 6 lakes.

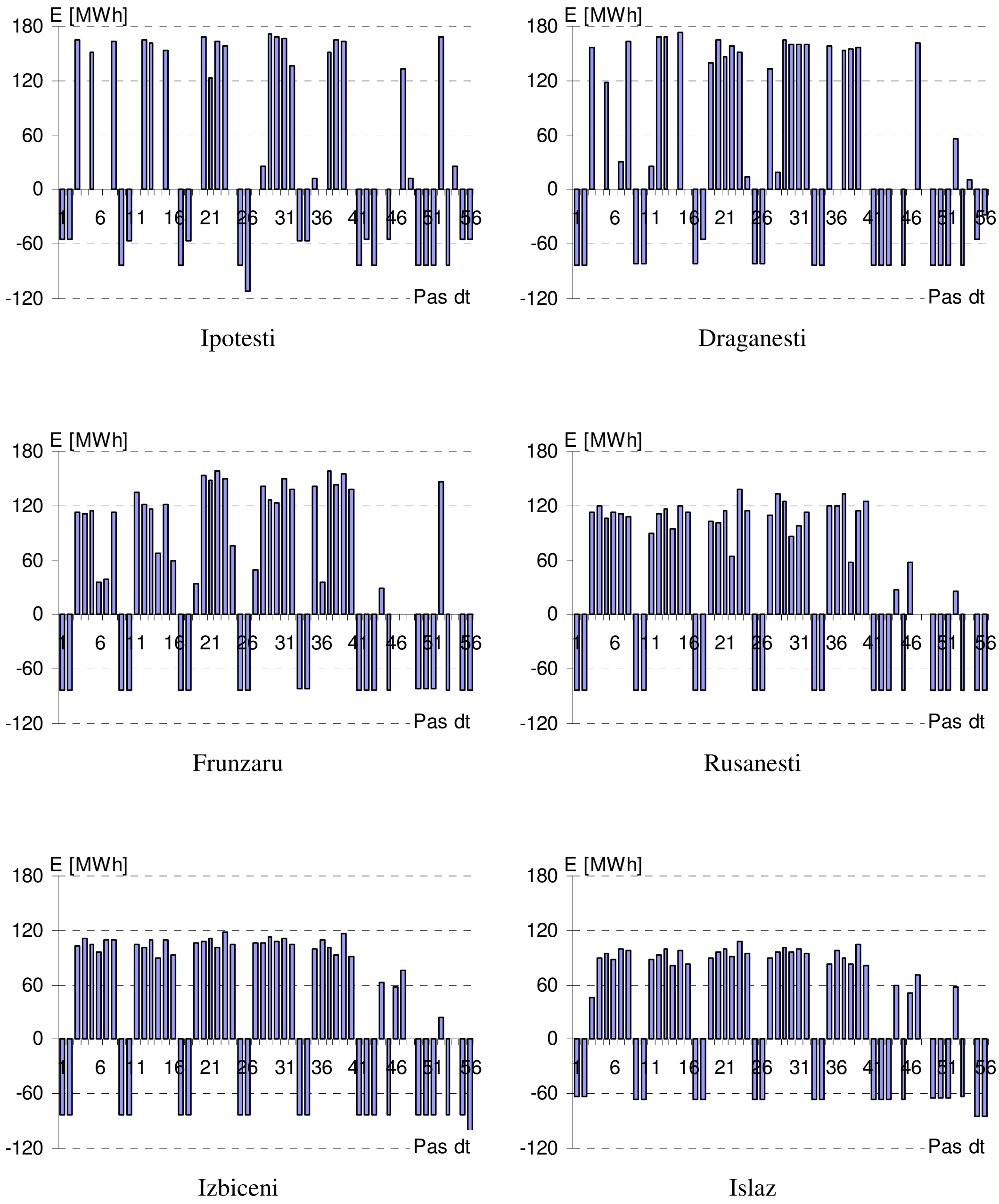

Fig. 3. The energy produced and consumed.

Conclusions

The mathematical model for weekly optimal scheduling of a hydropower plant cascade with reversible units has been illustrated by a numerical case study concerning the Ipotesti-Islaz sector on the lower Olt River. In spite of the large size and non linearity of the system, the optimization model based on a genetic algorithm gave a good solution, according to the input data, operational restrictions and performance function accepted in this paper.

R E F E R E N C E S

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