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Operating the NPP with Hydro Thermal Coordination in a Complex Power System

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Abstract. The paper presents the model for power plants operation in a complex power system. According the mathematical model, the software tool can be applied for different analyses and needs of the operators of power plants or power system operators. The optimization model takes into account the minimum operating costs of thermal power units in complex power system for all period (one year). The optimization procedure is made according the power balancing between energy demand and supply for each time interval (1 hour) respecting the operating and technical conditions of the units.

The application of the model in this paper is for projected power system of Macedonia for the period after 2020. The input parameters of the thermal units and hydro power plants are from Macedonian power system, with operation of a proposed nuclear power unit in a power system. The energy demand is according projected needs with hourly loads in a year (8760). The results will be presented for selected weeks in winter and summer period of the year for hourly operation of the power plants in the power system.

Keywords: power system, reservoir, reversible, hydro power plant

1 Introduction

The paper presents the model for planning the operation role of the reversible hydro power plant in a complex power system consists of thermal and hydro power plants. The application test example for the Macedonian Power System is a future projection when the hydro power complex of the Crna River will be finished. Hydro power plants Cebren and Galiste are the most significant investments in the Macedonian Energy System planned for the next decade. These two hydro power plants together with the existing HPP Tikves which is downstream of the new ones are enclosing the hydro power complex of Crna River.

This paper gives the analysis for the role of the HPP Cebren and HPP Galiste, together with all other power plants in the Power System of Macedonia. Taking into accounts the technical parameters, the following three scenarios (cases) will be taken into consideration:

- HPP Cebren and HPP Galiste as the ordinary hydro power plants which operate only in turbine-generation regime.
- HPP Cebren as a reversible hydro power plant which can operate in two regimes: pump-motor regime and turbine-generation regime, and HPP Galiste as ordinary hydro power plant.
- Both HPP Cebren and HPP Galiste as the reversible hydro power plants, which operate in two regimes: pump-motor regime and turbine-generation regime.

The analyses are done with the software tool for planning of the complex power system consists of thermal and hydro power capacities. The software tool gives few other results and values as the output of case processing, as the following ones: natural input, reservoir level, pumped water from down to upper reservoir, turbine discharge, power balance and energy balance for each time interval.

2 Model for Operation Role of Reversible HPP

The model for operation planning of the reversible HPP is the upgraded of the existing model [1,2] which is analytical approach of the objective function. The objective function is the total production costs for electricity generated from thermal power units. Also the model includes the constrains and conditions for water balances of the HPPs, covering the electricity demand, taking into accounts for the technical parameters of the hydro and thermal units. The time period, for example one year, can be divided in intervals with a hour duration (8760), or intervals with 24 hours duration (365), intervals with week duration (52), or others.

The modelling of the reversible HPP can be done in two approaches:

1. Fixing the pumping water for the reversible HPP for each time interval.
2. Fixing the electrical energy needed for pumping regime for the whole period.

The first approach with fixing the pumping water follows the power for pumping of the fixed amount of water which is the additional load of the interval

$$\text{fixed pumping water } Q_m^{\text{pump}}(t) \rightarrow$$
$$\rightarrow P_m^{\text{pump}}(t) \rightarrow P_{\text{load}}(t) + P_m^{\text{pump}}(t) \text{ additional load.}$$

The second approach is the opposite of the first one. With fixing the total electrical energy for the whole period needed for pumping, follows the electrical power for pumping in each interval and then follows the water power for pumping:

$$\text{fixed electrical energy } W_{\text{total}} = \sum_{t=1}^{T} P_m^{\text{pump}}(t)\Delta t \rightarrow$$
$$\rightarrow P_m^{\text{pump}}(t) \rightarrow Q_m^{\text{pump}}(t) \text{ pumping water.}$$

The total electricity amount for pumping W_{total} can be the import contract or other previous contract for TPP unit. The $P_m^{\text{pump}}(t)$ in each interval is getting in the optimization procedure for the whole power plants. The relation between power for pumping and water discharge for pumping is given by

$$P_m^{\text{pump}}(t) = \frac{9.81 Q_m^{\text{pump}}(t)(H_{\text{gross}} + \Delta H_{\text{losses}})}{\eta_{\text{pump}}\eta_{\text{motor}}}.$$

The generating regime for the reversible HPP is the same as the others HPP. Also, it is very important to determine the time intervals for pumping and time intervals for generation. Following the optimization procedure for the whole power system of thermal and hydro power units; the solution is approach in the iteration procedure.

3 Existing Power Generation System in Macedonia

The power plants in Macedonia (Figure 1), is dominantly lignite fired thermal power plants (TPP), gas fired TPP, an oil fired TPP, hydro power plants (HPP – Table 1), and in 2014 starts with operation the wind farm.

- Lignite TPP – 820 MW, 4500 GWh, (Bitola, Oslomej)
- Gas TPP – 280 MW, 2000 GWh, (TE TO Skopje, Kogel, Energetika ELEM)
- Oil TPP – 210 MW, 1200 GWh, (Negotino)
- HYDRO – 580 MW, 145 GWh and small ones
- RENEWABLE, Wind Farm Bogandci of 36.8 MW

Figure 1. The existing power plants in Macedonia.

Table 1. Existing Hydro power plants

Basin	W_{annual} [GWh]	W_{share} [%]
Mavrovo HPPs	488	33.66
Crn Drim HPPs	513	35.38
Treska HPPs	190	13.10
Crna HPPs	184	12.69
Small HPPs	75	5.17
TOTAL	**1450**	**100.00**

4 Future Projection of New Power Plants

The planned power plants in Macedonia (Figure 2), are mainly gas fired TPP and HPP (Table 2), and also nuclear power as an option. The renewable is expected to penetrate with more installed power.

- Gas TPP – 500 MW, 3000 GWh, 2 units
- Nuclear – up to 1000 MW, 8000 GWh
- HYDRO – almost 1000 MW, 2300 GWh
- RENEWABLE (up to 400 GWh), Small HPP 60 MW, Wind 150 MW, PV 20 MW

Figure 2. The new planned power plants in Macedonia.

Table 2. New Hydro power plants

	Basin	$P_{\text{inst.}}$ MW	W_{year} GWh	Investment mil €
Boskov Most	Radika	68.2	117	70
Lukovo pole and HPP Crn Kamen	Mavrovo	5	163	45
Galiste	Crna river	193.5	264	200
Cebren	Crna river	333	340	319
Spilje 2	Crn Drim	72	33	35
Gradec	Vardar	54.6	252	157
Veles	Vardar	93.0	300	251
10 HPPs in the Vardar valley	Vardar	176.8	784	486
TOTAL		**1032**	2343	**1563**

5 Simulation of Power System Operation after 2020

The simulation is made for projected power system of Macedonia after 2020, with all existing generating system and the new power plants. The mail input parameters for simulation of the cases are:

- Yearly Demand of 13000 GWh
- Existing TPP Bitola and Gas power plants
- New CHP on gas
- Existing HPP, New HPP, Lukovo pole, Boskov Most, Gradec
- HPP Cebren, HPP Galiste, (conventional or reversible HPP)

For simulation the following scenarios were under investigation:

- Power System operation without Nuclear Power
- Power System operation with Nuclear Power Plant

6 Cascade Hydropower System on Crna River

The cascade hydro power system of Crna River consists of three HPP, Tikves which operates over 30 years, and the planned ones, Galiste and Cebren. Table 3 gives the main technical parameters of all three HPPs, and Figure 3 shows the layout of the cascade.

The simulation cases for analyzing the operation of the cascade in the power system of Macedonia:

Case 1 : Both, Cebren and Galiste are conventional HPP

Case 2 : Cebren is reversible HPP, Galiste is conventional HPP

Case 3 : Both, Cebren and Galiste are reversible HPP

Table 3. Technical parameters of hydro power plants on Crna River

	$Q_{inst.}$ [m^3/s]	H_{gross} [m]	P [MW]	Storage volume [10^6 m^3]
Cebren	3×50	174	225	655
Galiste	3×50	130	165	260
Tikves	4×36	100	116	272
TOTAL		**404**	**506**	**1187**

Table 4 and Figure 4 give the results for yearly energy generation and financial effect of each HPP (Tikves, Galiste and Cebren) for all cases.

Table 4. Comparing the cases operating regimes in a year (GWh)

	CASE 1		CASE 2		CASE 3	
	Gal conv Gen	Ceb conv Pump	Gal conv Gen	Ceb REV Pump	Gal REV Gen	Ceb REV Pump
Tikves	200	0	200	0	198	0
Galiste	280	0	276	0	584	-400
Cebren	319	0	811	-550	810	-550
TOTAL	**799**	**0**	**1287**	**-550**	**1592**	**-950**
ENERGY	799		737		642	
FINANCIAL	799		1012		1117	

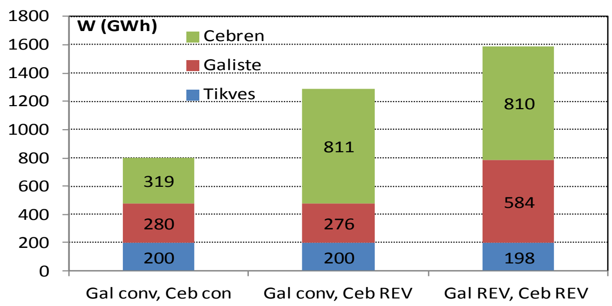


Figure 4. Energy contribution for all cases (GWh).

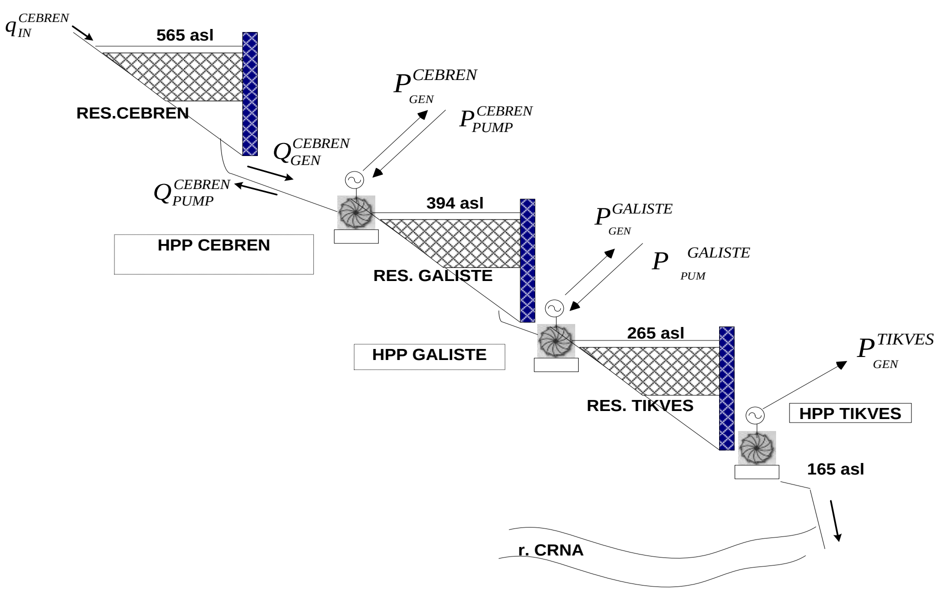


Figure 3. Cascade hydro power plants of Crna River.

Daily Operation of Reversible HPP has two modes:

- **Pumping regime in 7 hours (1-7)**
- **Generation regime in 17 hours (8-24)**

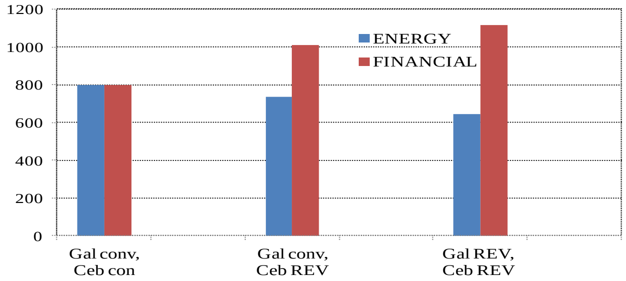


Figure 5. Comparing the energy and financial contribution for all cases (GWh).

The energy contribution calculates as the generation energy reduced for the pumping one (Rev.HPP as a consumer). The financial contribution is the generation energy reduced for half pumping one, because for positive financial balance of operating the reversible HPP, the generating electricity should be at least double price of the electricity for pumping.

- $\text{Energy} = \text{Generation} - |\text{Pumping}|$
- $\text{Financial} = \text{Generation} - 0.5 \times |\text{Pumping}$

Figure 6 and Figure 7 present the covering of the peak demand for a week in case1 and case 3.

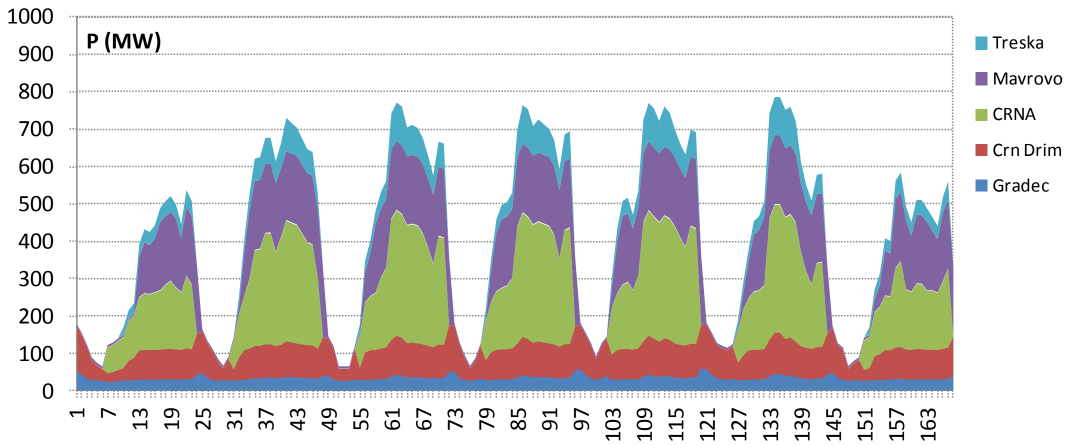


Figure 6. Covering the peak demand for a week in case 1 (Both Cebren and Galiste are conventional HPP).

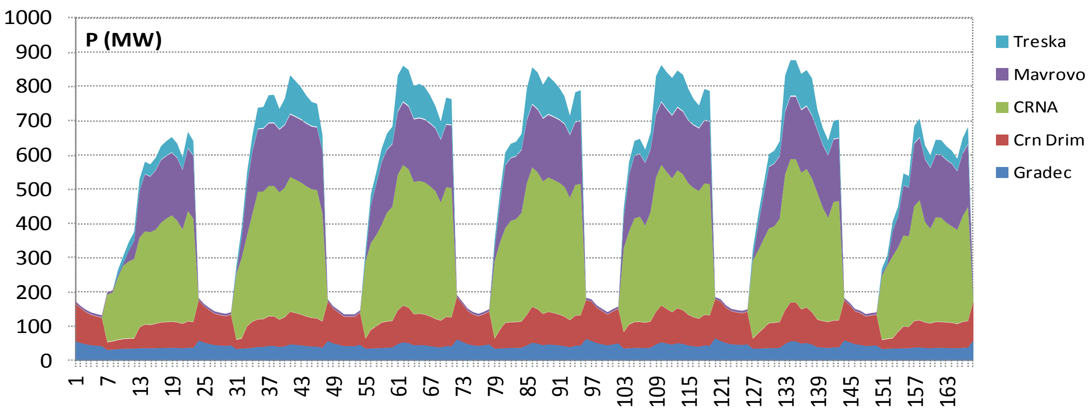


Figure 7. Covering the peak demand for a week in case 3 (Both Cebren and Galiste are Reversible HPP).

7 Simulation of Scenario – No Nuclear and Both Cebren and Galiste Are Reversible HPP

This case presents the operation of the power plants as a no-nuclear option (fossil option); where the base load is covered with lignite TPPs, gas TPPs and import.

- Case – Both, Cebren and Galiste are reversible HPP
- Coal TPP Bitola, Gas CHP and Import (Demand and Pumping)

Figure 9 and Figure 10 give the operation of the power system in a week, covering the demand of the consumers and the needs for pumping.

COAL	Gas	Import Demand	Import PUMP	Pumping	Hydro
4800	3460	1600	750	-950	3346

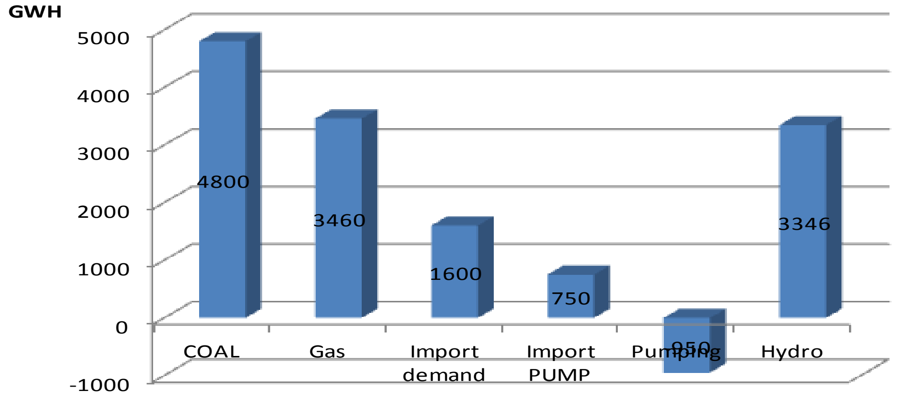


Figure 8. Contribution of the each type of technology for power generation.

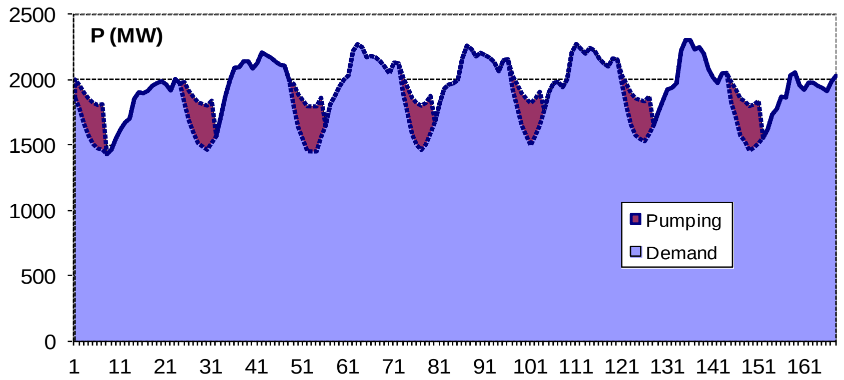


Figure 9. Demand and Pumping for Case of Reversible HPP, both Cebren and Galiste.

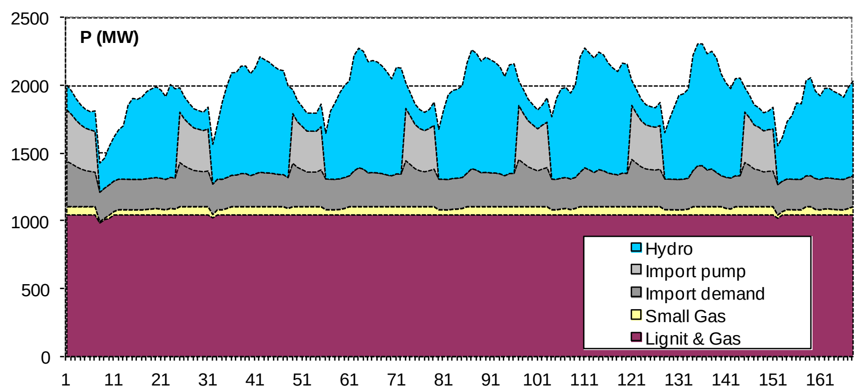
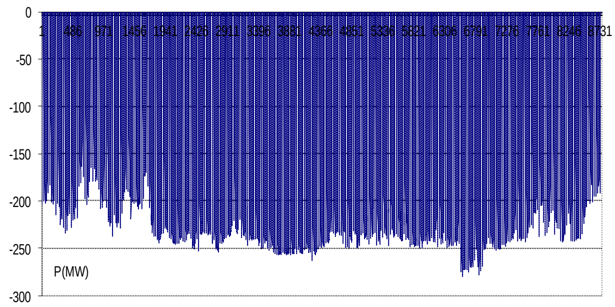
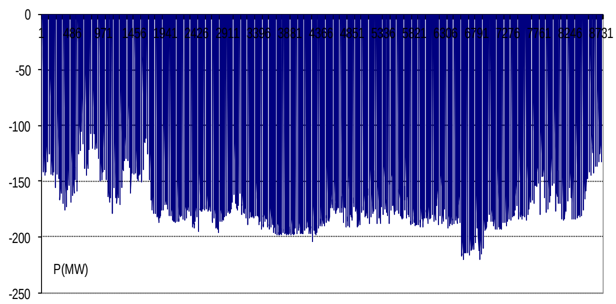


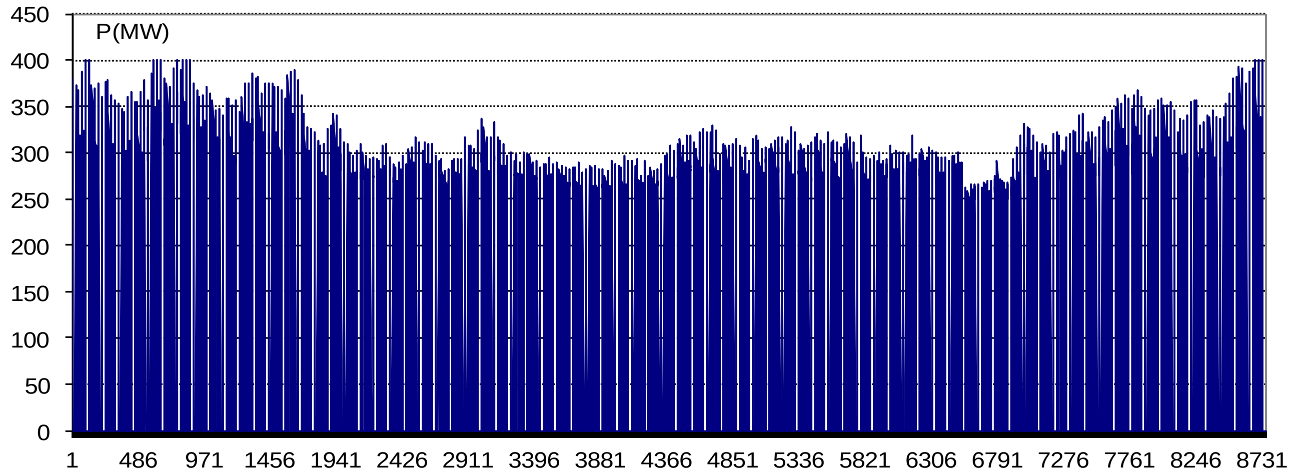
Figure 10. Power Plant Operation in a week of a year.



CEBREN pumping – 550 GWh.



GALISTE pumping – 400 GWh.



Yearly Import for Pumping 750 GWh

NUCLEAR	Gas	Import PUMP	Pumping	Hydro
6800	3460	340	-600	3000

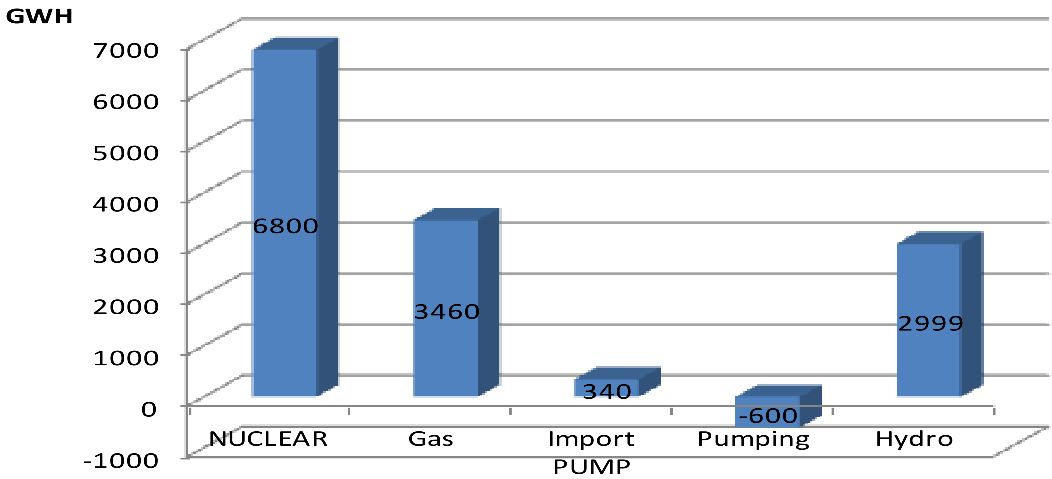


Figure 11. Contribution of the each type of technology for power generation.

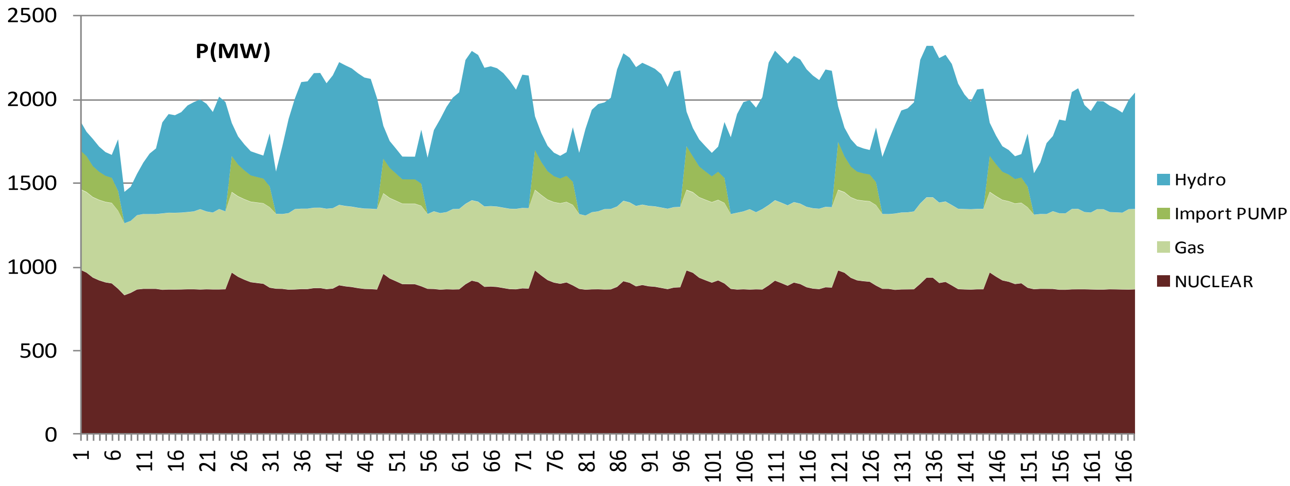


Figure 12. Covering the demand of the power generation system for winter week with NPP.

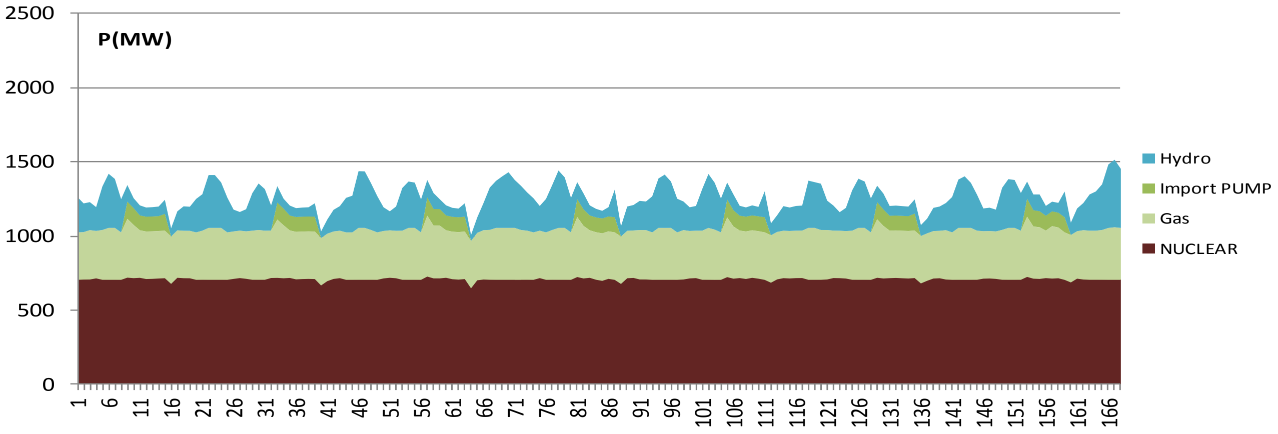


Figure 13. Covering the demand of the power generation system for summer week with NPP.

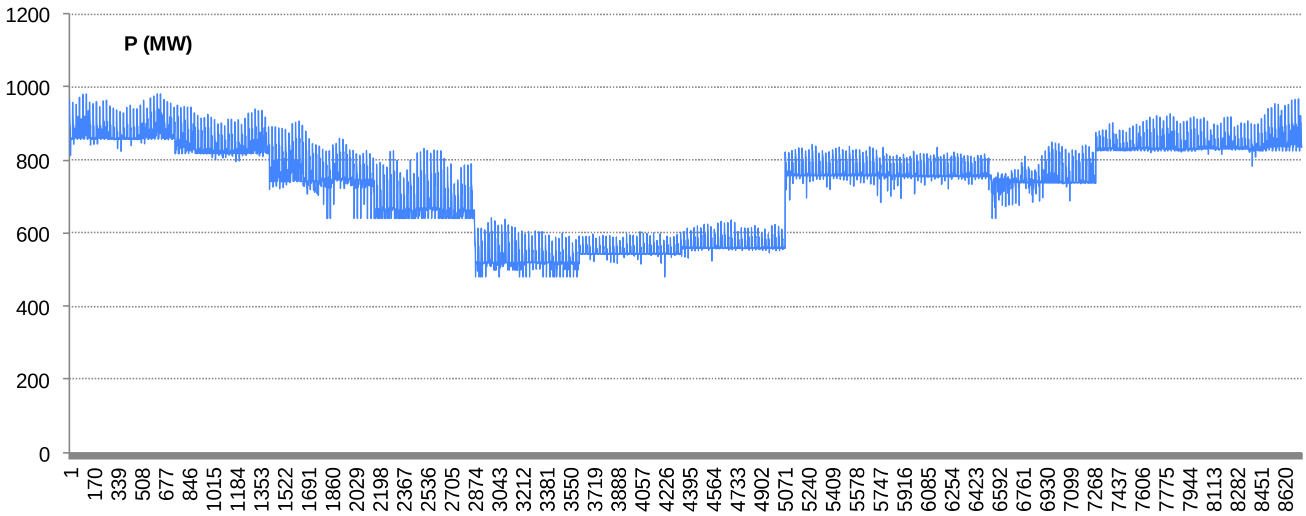


Figure 14. Base load covered of TPP Coal + Import with 6400 GWh.

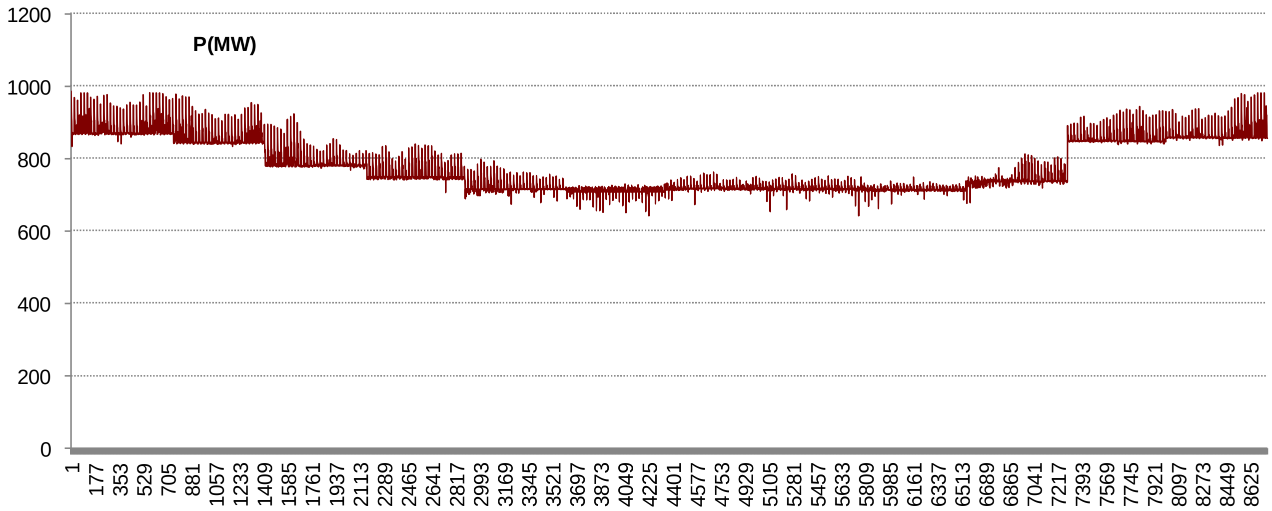


Figure 15. Base load covered of NPP with 6800 GWh.

8 Simulation of Scenario – with Nuclear Power Plant of 1000 MW

This case presents the operation of the power plants with nuclear power plant of 1000 MW (nuclear option) mainly for the base load instead of lignite TPP and import. Figure 11 gives the contribution of each type of resource for this scenario.

- Case – Both, Cebren and Galiste are reversible HPP
- Instead of TPP Bitola and Import – Nuclear Power Plant (NPP) of 1000 MW

Figures 12 and 13 show the operation of the plants for given winter and summer week respectively. Figure 14 and Figure 15 present the yearly base load covered with fossil fuels+import (6400 GWh), and covered with nuclear power plant (6800 GWh).

9 Conclusion

Reversible HPP can have significant role in the power system, especially for the hydro power complex with low natural water inflow. In order to have better economical income from the operating regime, it is very important the water managing between the upper and lower reservoir for the time period. This paper presents the hydro-nuclear operation of Cebren and Galiste with NPP. Reversible HPP is the appropriate solution for the complex power system. The advantage of this complex system is the additional peak energy with reversible HPP Cebren and Galiste (high tariff of selling), where the base loads capacity of NPP can be use for pumping regime (low tariff of buying). This managing can have financial benefit of the hydro – nuclear complex

HPP Cebren and HPP Galiste are one of the biggest investments in energy sector in Macedonia for the next 10 years. Therefore, it is very important to analyze the role of the whole hydro power complex of Crna River in the Macedonian Power System.

Besides the energy benefit, the additional point can be the financial benefit with the economical and reasonable price for electricity in pumping operating regime comparing with the same one in generating regime in peak loads.

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