Optimal intra-station regimes of hydropower plants with asymmetric energetic characteristics

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ABSTRACT

Improvement of exploitation of existing HPPs is important task. One of the most interesting aspects is improvement of overall efficiency of HPPs steady-state regimes. Achievement of higher efficiency results in reduction of water consumption. The saved and stored water allows for additional energy generation at the HPPs. The paper presents methodology for analysing optimal intra-station regimes of HPPs (a.k.a. optimal unit allocation/dispatching) availing with asymmetric energetic characteristics of gen-units and waterways, i.e. the HPPs developed and commissioned in two stages, run-of-river HPPs availing with several large and one small gen-unit for releasing guaranteed discharge, as well as multi-unit HPPs during the course of refurbishment/uprating. The optimization model is able to cope with various technical constraints, i.e. boundaries of turbines' exploitation ranges, as well as total spinning reserve and manoeuvrability of load variations of the active gen-units of HPP. A Case Study is presented. Findings show that for the analysed asymmetric HPPs energy generation over long-term periods can be increased for over 3%, as well as the revenues of the owner companies.

Key words: hydropower plants, optimal intra-station load dispatching, additional energy generation

1. Introduction

Improvement of exploitation of existing electric-power and water-utility systems, being infrastructure basis of utmost importance, surely comprises quite wide spectrum of organizational, socio-ecological, economic, technological and technical, as well as legislative questions. Necessity of permanent resolving of these questions is undoubtful nowdays, when these systems are dynamically evolving.

In regard of hydropower sector, such questions comprise, in example, improvement of technology and procedures for maintenance of equipment and upkeep of hydrotechnical structures of HPPs, modernization of their control systems, technological integration with other participants within belonging electric-power and water-utility systems etc. One of the crucial questions, for sure, is improvement of exploitation regimes of HPPs, with consideration of their ancillary services at deregulated electric power market environment.

Resolving the issues that relate to improvement of exploitation of existing HPPs allows for increase of their functionality within electric-power systems, as well as achievement of corresponding savings of hydropower resources, i.e. increase of energy generation and revenues for ancillary services. Outcoming benefits comprise appropriate increase of profit of HPP owner companies, as well as contribution of HPPs to the reduction of TPPs gas emissions.

Improvement of exploitation of existing HPPs have always been of great importance and required systematic approach and involvement of appropriate specialists. Nowdays, when electric-power and water-utility systems are dynamically evolving, exploitation regimes of HPPs are to be thoroughly re-considered. Professional attractivity of addressing such issues in unquestionable.

2. Problem statement

2.1. Technical formulation

Optimal Intra-Station Load Dispatching (OIntraSLD) problem is technically formulated in the following manner:

> *For the given value of headwater elevation and given status of gen-units availability for operation, determine the composition of active gen-units and load sharing among them, so to satisfy all applicable technical constraints and to provide that working process of the HPP performs in some sense in extremal way.*

2.2. Mathematical formulation

2.2.1. Generic form

Generic form of mathematical statement of the OIntraSLD problem is as follows:

$$extr.\, GF\left(\overline{s}, \overline{X}, \overline{P}\right)$$

subject to the constraints:

$$\overline{s} \in S_{available} \,,$$
$$g_i\left(\overline{X}, \overline{P}\right) = 0 \,,\; i = 1, \ldots, N_{EQ} \,,$$
$$h_i\left(\overline{X}, \overline{P}\right) \leq 0 \,,\; i = 1, \ldots, N_{NEQ} \,,$$

whereas:

$\overline{X}$	- vector of state variables,
$\overline{P}$	- vector of state parameters,
GF	- goal function (optimization criterion),
$g_i\left(\overline{X}, \overline{P}\right)$	- equality constraints,
N_{EQ}	- entire number of equality constraints,
$h_i\left(\overline{X}, \overline{P}\right)$	- inequality constraints,
N_{NEQ}	- entire number of inequality constraints,
$\overline{s}$	- vector of composition of active gen-units,
$S_{available}$	- set of all possible vectors of gen-units compositions, as per their availability for operation.

OIntraSLD problem belongs to the class of non-linear, combinatorial, binary programming subject to non-linear constraints. It deals with multi-dimensional, multi-funnel, multi-modal functions, whereas non-linear constraints apply to the state variables, state parameters and to the quantities which are explicit and implicit functions (of equality and inequality nature) of theirs.

Such kind of mathematical problems do not avail with general analytic solutions. Therefore, in solution-finding it is necessary to engage appropriate numerical apparatus.

2.2.2. Concrete form

Concrete form of mathematical statement of the OIntraSLD problem used in the research is as follows:

$$\min_{\bar{s} \in S_{available}} . Q_{HPP}(\overline{Q})$$

subject to the constraints:

1. plant-origin ones (to assure satisfying of all the necessary/envisaged constraints that are applicable to the entire HPP)

$$\bar{s} \in S_{available};$$
$$P_{HPP,switchyard}(\overline{Q}) = P_{HPP,switchyard}^{required} \quad [MW],$$
$$\Delta P_{HPP,RR}(\overline{Q}) \geq \Delta P_{HPP,RR}^{required} \quad [MW],$$
$$\dot{P}_{HPP,MLV}(\overline{Q}) \geq \dot{P}_{HPP,MLV}^{required} \quad [MW/s];$$

2. unit-origin ones (to assure satisfying of all the necessary/envisaged constraints that are applicable to each particular gen-unit – i.e. turbines workpoints to remain within real boundaries of their exploitation zones)

$$Q_i \geq Q_{i,\min}, \; i = 1, \ldots, N_{AGR},$$
$$Q_i \leq Q_{i,nom}, \; i = 1, \ldots, N_{AGR},$$
$$P_{T,i} \leq P_{T,i,\max}, \; i = 1, \ldots, N_{AGR},$$
$$a_{GV,i} \leq a_{GV,i,\max}, \; i = 1, \ldots, N_{AGR},$$

whereas:

$\overline{Q}$ - vector of turbine discharges, [m³/s],

$\min . Q_{HPP}(\overline{Q})$ - minimization of total discharge of HPP, [m³/s],

$P_{HPP,switchyard}(\overline{Q})$ - total active output of HPP (switchyard parity), [MW],

$\Delta P_{HPP,RR}(\overline{Q})$ - total spinning reserve of HPP (turbine parity), [MW],

$\dot{P}_{HPP,MLV}(\overline{Q})$ - total manoeuvrability of load variation of HPP (turbine parity), [MW/s];

$\bar{s}$ - vector of composition of active gen-units, [/],

$S_{available}$ - set of all possible vectors of gen-units compositions, as per their availability for operation, [/];

$Q_{i,\min}$ - minimal discharge of turbine operating range of i-th gen-unit, [m³/s],

$Q_{i,nom}$ - rated turbine discharge of i-th gen-unit, [m³/s],

$P_{T,i,\max}$ - declared limit of turbine output of i-th gen-unit (rated output – if no over-loading is envisaged, respectively maximal output – if over-loading at high net heads is envisaged), [MW/s],

$a_{GV,i,\max}$ - declared limit of guide vanes opening of i-th gen-unit (rated opening – if no over-opening is envisaged, respectively maximal opening – if over-opening at low net heads is envisaged), [/];

N_{AGR} - number of gen-units at the HPP, [/].

The following quantities are selected as characteristic ones for the optimization problem:

- goal function (optimization criterion)	minimization of total discharge of HPP,
- optimization variables	turbine discharges,
- optimization parameters	headwater elevations, as well as constellation of availability of gen-units,
- constraints	HPP total active output (switchyard parity) and two issues crucial for providing prerequisites for HPP ancillary service of participation in primary frequency regulation – minimal values of HPP total spinning reserve (turbine parity) and total manouvreability of load variation (turbine parity).

As per the applied form of mathematical statement of the problem, the goal function is decomponed in terms of gen-units availability. This means that the optimization problem ($\min.Q_{HPP}(\overline{Q})$) is being solved via sub-optimization (i.e. partial optimization problems), over the entire set of feasible compositions of active gen-units ($\overline{s} \in S_{available}$). For several reasons, this approach is mathematically more convenient compared to the non-decomponed approach (with gen-units activity indices s_i embedded directly in the goal function as additional optimization variables, leading to increased dimensionality and direct binarity of the problem, i.e. $GF = \min.Q_{HPP}(\overline{s},\overline{Q}) = \min.(\overline{s}^T \cdot \overline{Q}) = \min.\sum s_i \cdot Q_i$.

2.2.3. Other possible formulations of goal function (optimization criterion)

As per nature of HPP exploitation, other formulations of goal function are also possible.

In example, a HPP that is being exploited in the regime of demanded total discharge (Q_{HPP} defined) may be optimized for maximization of active output at switchyard parity (i.e. $GF = \max.P_{HPP,switchyard}(\overline{Q})$). In such case, the value of Q_{HPP} is to be considered as one of the technical constraints which are to be satisfied.

As another example, a HPP operating under deregulated market conditions (incomes gained both in regard of active output and participation in primary frequency regulation as an ancillary service) may be optimized for maximization of the $GF = \max.(c_P \cdot P_{HPP,switchyard} + c_{prf} \cdot \Delta P_{HPP,prf})$. Here c_P and c_{prf} are selling prices for active output and output variations (rms value) within primary frequency regulation.

3. Problem solution

3.1. Modelling of energetic characteristics of HPP elements (waterways and generating equipment)

All the elements of a HPP are modelled via regression polynomials of appropriate form.

Tailwater characteristics are modelled via 3D-regression polynomial $z_{TW} = f(Q_{HPP}, z_{HW}^{downstream\ HPP})$. Waterways headloss characteristics are modelled quadratic polynomial $\Delta H_i = k_i \cdot Q_i^2$. Turbine efficiency characteristics are modelled via 3D-regression polynomial $\eta_T = f(Q_T, H_T)$, i.e.

$$\eta_T = f(Q_T, H_T) = a_1 + \\ + a_2 \cdot H_T + a_3 \cdot Q_T + \\ + a_4 \cdot H_T^2 + a_5 \cdot Q_T^2 + a_6 \cdot Q_T \cdot H_T + \\ + a_7 \cdot Q_T^3 + a_8 \cdot H_T^3 + a_9 \cdot H_T \cdot Q_T^2 + a_{10} \cdot H_T^2 \cdot Q_T + \\ + a_{11} \cdot H_T^4 + a_{12} \cdot Q_T^4 + a_{13} \cdot H_T^3 \cdot Q_T + a_{14} \cdot H_T^2 \cdot Q_T^2 + a_{15} \cdot H_T \cdot Q_T^3$$

Generator efficiency characteristics are modelled via 2D-regression polynomial $\eta_G = f(P_G)$, ignoring influence of power factor $\cos\varphi$, i.e. $\eta_G = a_1 + a_2 \cdot P_G + a_3 \cdot P_G^2 + a_4 \cdot P_G^3 + a_5 \cdot P_G^4$. Step-up transformer efficiency characteristics are modelled as $\eta_{TR,P} = \frac{P_{TR} - \Delta P_{TR}}{P_{TR}} = 1 - \frac{1}{P_{TR}} \cdot \left[\Delta P_{no-load} + \Delta P_{short-circuit}^{nom} \cdot \left(\frac{S_{TR}}{S_{TR}^{nom}} \right)^2 \right]$. HPP auxiliary consumption is modelled as a fixed value.

3.2. Finding feasible constellations of active gen-units

Not all compositions from the set of all *possible* compositions (as per availability of gen-units) should be investigated. Prior to optimization runs, it is necessary to determine:
- the set of *equivalent* compositions (out of all possible compositions), and
- the set of *feasible* compositions (out of the equivalent ones).

This assures two important issues – just feasible solutions to be furtherly passed to optimization runs as well as significant decrease of problem dimensionality.

Finding *equivalent* compositions from the set of all possible compositions as per availability of gen-units is being done by transition from nameplate numbers of gen-units at the HPP onto the vector of type and number of gen-units as per each type. Here, type of gen-units means type of energetic characteristics of the gen-units and their appurtenant waterways. At HPPs availing with symmetric energetic characteristics there is only one type of gen-units. On the other side, at HPPs availing with asymmetric energetic characteristics either of turbines/generators or of the waterways, there are two (or more) types of gen-units.

As an example, let's consider a HPP availing with 6 gen-units, 3 of them being refurbished ones, while the remaining 3 are still to undergo refurbishment. There are 2 types of gen-units, 3 of the first type and 3 of the second type. Consider that all of them are available for operation. Total *possible* number of gen-units compositions is $C_{possible} = 2^{N_{AGR}} = 2^6 = 64$. On the other side, the number of *effective* compositions is just $C_{effective} = \prod_{type=1}^{N_{type}} (N_{AGR}(type) + 1) = (3+1) \cdot (3+1) = 16$.

Furthermore, not all of the equivalent compositions are always *feasible*. It depends on the values of technical constraints that are involved. For instance, when some relatively low value of active output of HPP is required, some of the compositions (with 5÷6 gen-units) are infeasible. Also, when some high value of active output of HPP is required, many of the compositions (with 1÷4 gen-units) are clearly infeasible. Furthermore, if relatively high value of active output of HPP, combined with relatively high values of spinning reserve and/or manoeuvrability of load variation to remain at the HPP is required, this might influence infeasibility of compositions with 5 active gen-units, leading just 6 gen-units as feasible.

The pre-selection of feasible compositions out of equivalent ones strongly depends on the scope and values of the technical constraints that are involved in the optimization problem. In any case, this significantly reduces dimensionality of the optimization problem – from as many as several tens of compositions of active gen-units onto just a few ones.

3.3. Methodology of solving Optimal Intra-Station Load Dispatching problem

Therefore multiple solving of partial optimization problems over the set of all feasible compositions of active gen-units is necessary. Overall-optimal solution is ultimately obtained by ranking the solutions of partial optimization problems (ref. Item 2.2.2.) as per their goal function values.

Solving partial optimization problems may be done either by employment of global optimizers or by multi-start local optimizers.

4. Case study

4.1. Description of the hydropower system

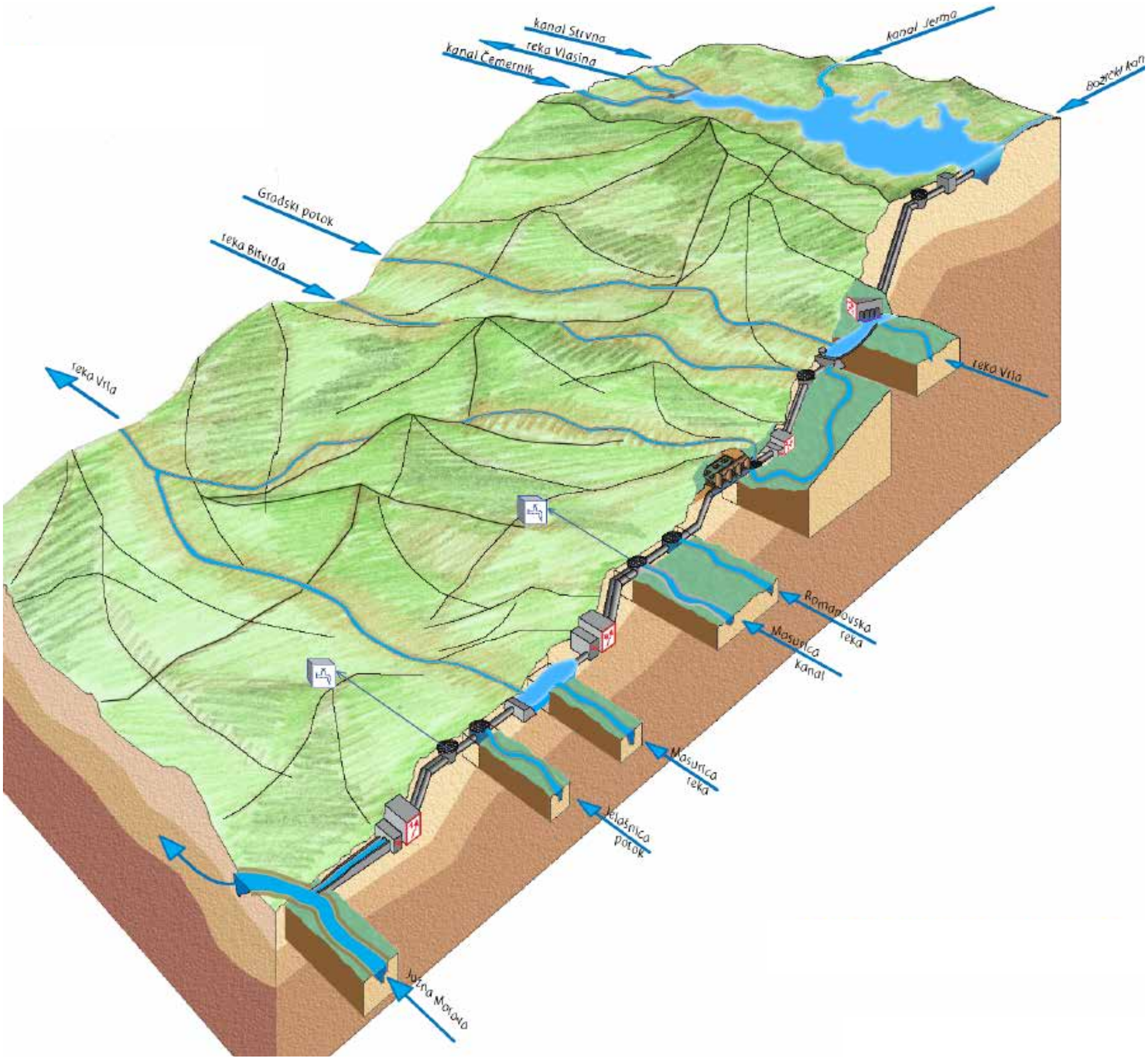
Developed methodology has been applied to an existing cascaded hydropower system (HPPs Vrla 1 to Vrla 4 in Serbia). The optimization has been done just via 4 separate intra-station optimal dispatchings, i.e. no inter-station optimization has been performed. Inter-station load dispatching (no-optimal one) is kept as per the existing procedures of the owner company.

Main characteristics of the system are stated herebelow.

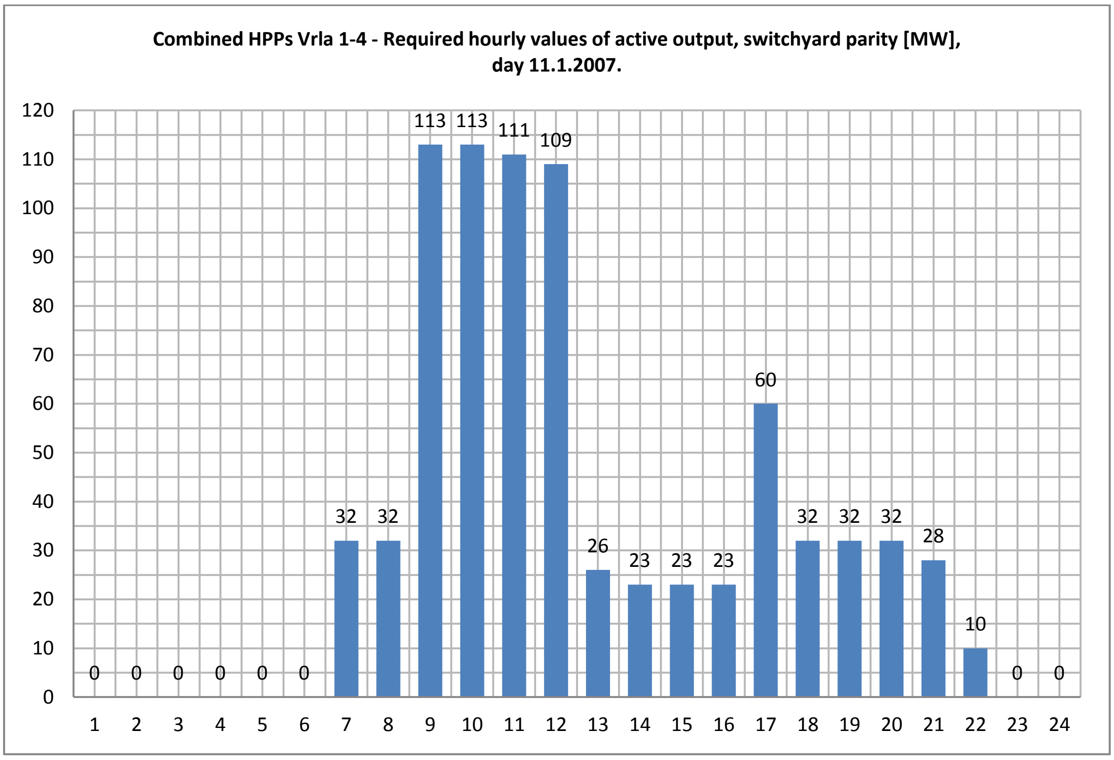
	entirely	HPP 1		HPP 2		HPP 3		HPP 4	
		phase 1 (1958)	phase 2 (1977)	phase 1 (1958)	phase 2 (1977)	phase 1 (1958)	phase 2 (1977)	phase 1 (1958)	phase 2 (1977)
- number of HPPs	4	/		/		/		/	
- number of gen-units	10	4		2		2		2	
		2	2	1	1	1	1	1	1
- type of turbines	/	Pelton		Francis		Francis		Francis	
- HPP installed turbine output [MW]; turbine rated output [MW]	130	50.6		24.2		29.2		25.5	
		2 x 11.7	2 x 13.6	11.3	12.9	13.5	15.7	11.4	14.1
- max. turbine operating output [MW]	≈ 123	≈ 48		≈ 22.6		≈ 27.3		≈ 23.6	
- average annual energy generation [GWh/y]	310	105		55		82		68	
- total installed discharge [m^3/s]	/	18.5		18.5		18.5		18.5	
- turbine rated discharge [m^3/s]	/	2 x 4	2 x 5.25	8.5	10	8.5	10	8.5	10
- gross head range, approx. [m]	865	340 (343÷334)		160 (162÷157)		205 (206÷203)		170 (172÷168)	
- average annual operating time, approx. [h/y; h/day]	/	2600 (7.5)	2800 (8)	3350 (9.5)	3500 (10)	3050 (8.5)	4050 (11.5)	3050 (8.5)	4150 (12)
- average annual number of gen-units starts, approx. [start/y]	/	210	230	220	330	260	360	235	340

Due to limited space, no detail characteristics of the waterways (head losses characteristics) and equipment (turbine hill charts and generator efficiency characteristics) can be fully presented.

As can be seen, each of the HPPs avail with asymmetric energetic characteristics. The system had been commissioned in 2 phases (1958. and 1976.). Waterways and gen-units within each of the HPPs are mutually quite different (penstock diameters, turbine hill charts, installed discharges etc.).


kanal Strvna
reka Vlasina
kanal Čemernik
kanal Jerma
Gradski potok
reka Bitvrđa
reka Vrla
reka Vrla
Romanovska reka
Masurica kanal
Masurica reka
Jelašnica potok
Južna Morava

4.2. Comparative results of actually performed regimes and intra-station optimal ones



Results as per separate HPPs

HPP: Vrla 1									**Day: 11.1.2007.**
time [h]	duration [h]	output $P_{HPP}^{switchyard}$ [MW] (requirement by regional Dispatching Center)	generated active energy $E_{HPP}^{switchyard}$ [MWh]	actually performed regimes at the HPP		optimal intra-station regimes		water savings due to optimal intra-station regimes	
				discharge Q_{HPP} [m³/s]	utilized water W_{HPP} [m³ * 10³]	discharge Q_{HE}^{opt} [m³/s]	utilized water W_{HPP}^{opt} [m³ * 10³]	discharge ΔQ_{HE}^{opt} [m³/s]	water ΔW_{HE}^{opt} [m³ * 10³]
01	1	0	-	-	-	-	-	-	-
02	1	0	-	-	-	-	-	-	-
03	1	0	-	-	-	-	-	-	-
04	1	0	-	-	-	-	-	-	-
05	1	0	-	-	-	-	-	-	-
06	1	0	-	-	-	-	-	-	-
07	1	12	12	4.316	15.53832	4.090	14.72544	0.2258	0.81288
08	1	12	12	4.316	15.53832	4.090	14.72544	0.2258	0.81288
09	1	44	44	16.167	58.20228	15.807	56.90340	0.3608	1.29888
10	1	44	44	16.167	58.20228	15.807	56.90340	0.3608	1.29888
11	1	44	44	16.167	58.20228	15.807	56.90340	0.3608	1.29888
12	1	42	42	15.408	55.46844	14.930	53.74944	0.4775	1.71900
13	1	8	8	2.824	10.16712	2.714	9.77076	0.1101	0.39636
14	1	8	8	2.824	10.16712	2.714	9.77076	0.1101	0.39636
15	1	8	8	2.824	10.16712	2.714	9.77076	0.1101	0.39636
16	1	8	8	2.824	10.16712	2.714	9.77076	0.1101	0.39636
17	1	23	23	7.979	28.72404	7.888	28.39644	0.0910	0.32760
18	1	12	12	4.316	15.53832	4.090	14.72544	0.2258	0.81288
19	1	12	12	4.316	15.53832	4.090	14.72544	0.2258	0.81288
20	1	12	12	4.316	15.53832	4.090	14.72544	0.2258	0.81288
21	1	6	6	2.181	7.85232	2.051	7.38180	0.1307	0.47052
22	1	0	-	-	-	-	-	-	-
23	1	0	-	-	-	-	-	-	-
24	1	0	-	-	-	-	-	-	-
		Σ=	295	Σ=	385.01172	Σ=	372.94812	Σ=	12.06360

- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 295\ {}^{MWh}/_{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 385012\ {}^{m^3}/_{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.766210\ {}^{kWh}/_{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 372948.1\ {}^{m^3}/_{day} = -3.1\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.790995\ {}^{kWh}/_{m^3} = +3.23\%)$
- saved water, as per optimal intra-station regimes	$\Sigma \Delta W_{HPP}^{opt} = 12064\ {}^{m^3}/_{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma \Delta W_{HPP}^{opt} = 9.542\ {}^{MWh}/_{day} = +3.23\%$

HPP: Vrla 2									**Day: 11.1.2007.**
time [h]	duration [h]	output $P_{HPP}^{switchyard}$ [MW] (requirement by regional Dispatching Center)	generated active energy $E_{HPP}^{switchyard}$ [MWh]	actually performed regimes at the HPP		optimal intra-station regimes		water savings due to optimal intra-station regimes	
				discharge Q_{HPP} [m³/s]	utilized water W_{HPP} [m³ * 10³]	discharge Q_{HE}^{opt} [m³/s]	utilized water W_{HPP}^{opt} [m³ * 10³]	discharge ΔQ_{HE}^{opt} [m³/s]	water ΔW_{HE}^{opt} [m³ * 10³]
01	1	0	-	-	-	-	-	-	-
02	1	0	-	-	-	-	-	-	-
03	1	0	-	-	-	-	-	-	-
04	1	0	-	-	-	-	-	-	-
05	1	0	-	-	-	-	-	-	-
06	1	0	-	-	-	-	-	-	-
07	1	6	6	5.399	19.43748	4.663	16.78608	0.7365	2.65140
08	1	6	6	5.399	19.43748	4.663	16.78608	0.7365	2.65140
09	1	21	21	16.532	59.51520	16.218	58.38588	0.3137	1.12932
10	1	21	21	16.532	59.51520	16.218	58.38588	0.3137	1.12932
11	1	21	21	16.532	59.51520	16.218	58.38588	0.3137	1.12932
12	1	20 (9+11)	20	15.413	55.48608	15.311	55.11924	0.1019	0.36684
13	1	7 (3+4)	7	6.089	21.91932	5.329	19.18476	0.7596	2.73456
14	1	4 (0+4)	4	3.338	12.01572	(3.338)	(12.01572)	(0)	(0)
15	1	4 (0+4)	4	3.338	12.01572	(3.338)	(12.01572)	(0)	(0)
16	1	4 (0+4)	4	3.338	12.01572	(3.338)	(12.01572)	(0)	(0)
17	1	12	12	9.476	34.11360	8.714	31.36968	0.7622	2.74392
18	1	6	6	5.399	19.43748	4.663	16.78608	0.7365	2.65140
19	1	6	6	5.399	19.43748	4.663	16.78608	0.7365	2.65140
20	1	7 (4+3)	7	6.108	21.98772	5.329	19.18476	0.7786	2.80296
21	1	7 (4+3)	7	6.108	21.98772	5.329	19.18476	0.7786	2.80296
22	1	3	3	2.636	9.48996	(2.636)	(9.48996)	(0)	(0)
23	1	0	-	-	-	-	-	-	-
24	1	0	-	-	-	-	-	-	-
		Σ=	155	Σ=	457.32708	Σ=	431.88012	Σ=	25.44470

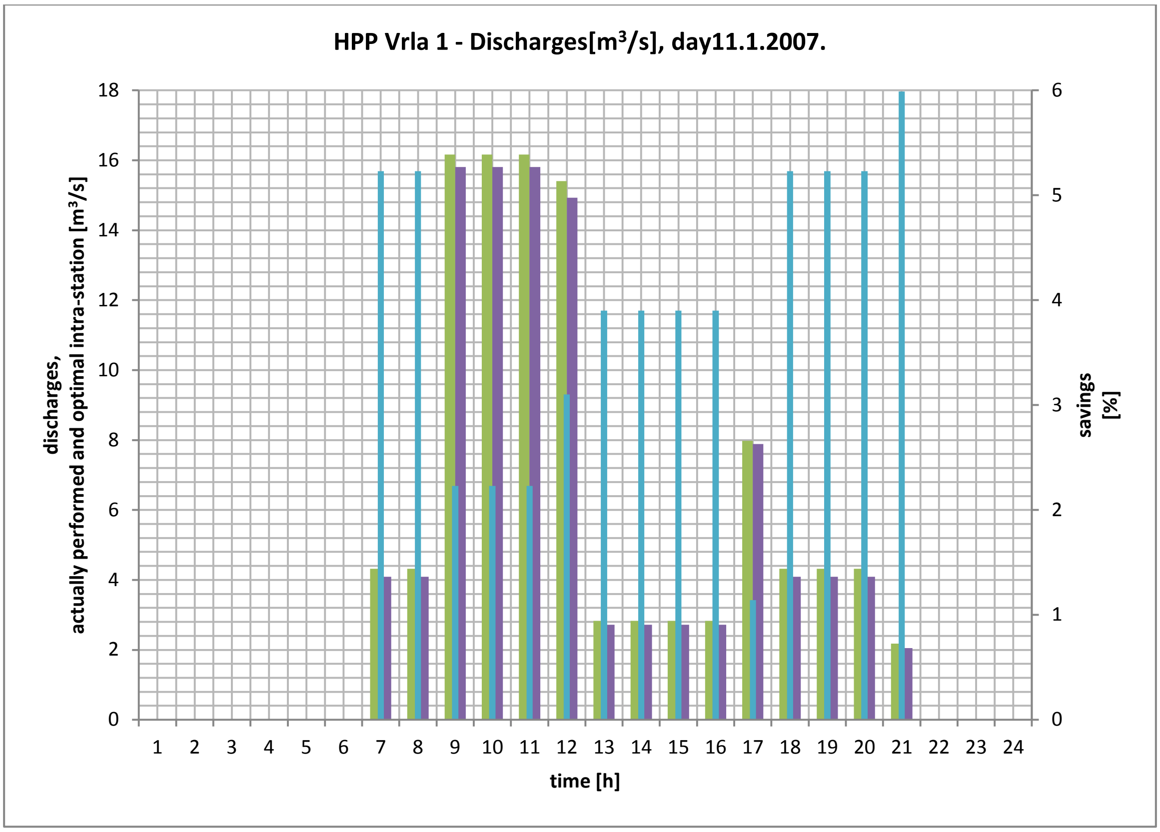
- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 155\ {}^{MWh}/_{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 457327\ {}^{m^3}/_{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.338926\ {}^{kWh}/_{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 431880.1\ {}^{m^3}/_{day} = -5.6\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.358896\ {}^{kWh}/_{m^3} = +5.89\%)$
- saved water, as per optimal intra-station regimes	$\Sigma \Delta W_{HPP}^{opt} = 25445\ {}^{m^3}/_{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma \Delta W_{HPP}^{opt} = 9.133\ {}^{MWh}/_{day} = +5.89\%$

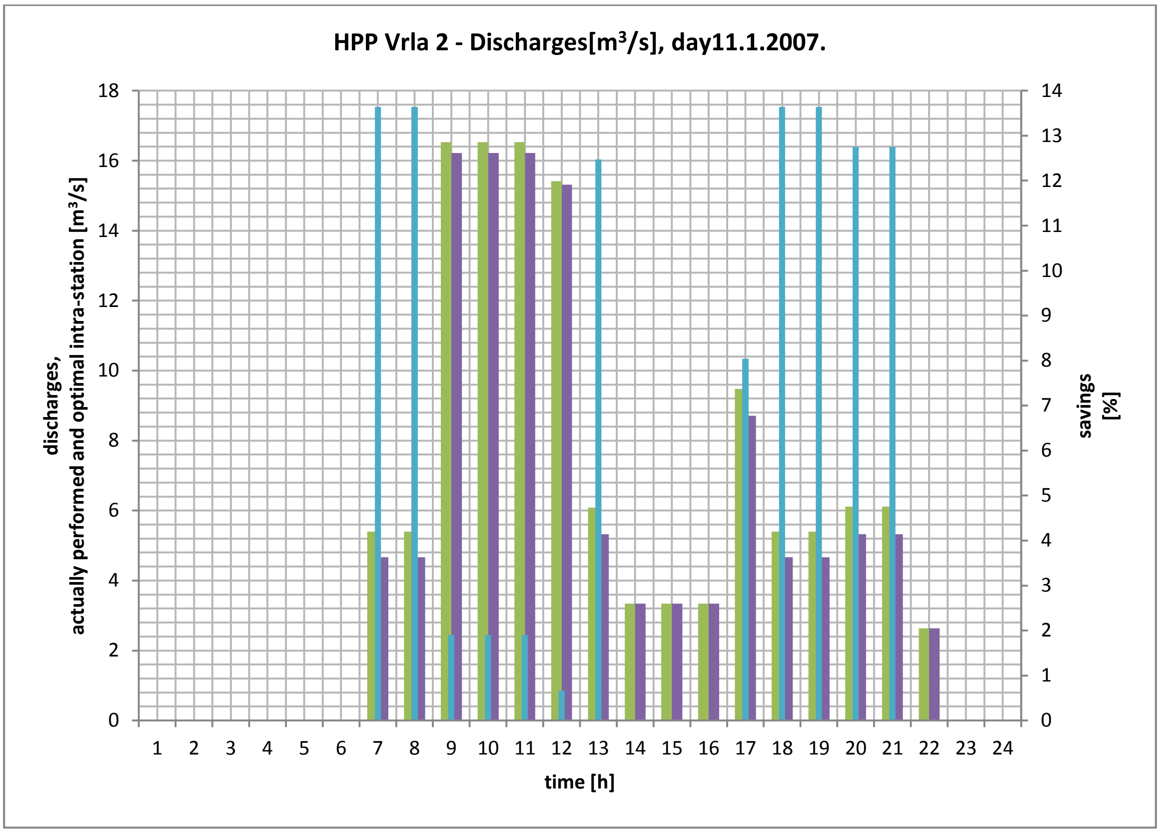
HPP: Vrla 3									**Day: 11.1.2007.**
time [h]	duration [h]	output $P_{HPP}^{switchyard}$ [MW] (requirement by regional Dispatching Center)	generated active energy $E_{HPP}^{switchyard}$ [MWh]	actually performed regimes at the HPP		optimal intra-station regimes		water savings due to optimal intra-station regimes	
				discharge Q_{HPP} [m³/s]	utilized water W_{HPP} [m³ * 10³]	discharge Q_{HE}^{opt} [m³/s]	utilized water W_{HPP}^{opt} [m³ * 10³]	discharge ΔQ_{HE}^{opt} [m³/s]	water ΔW_{HE}^{opt} [m³ * 10³]
01	1	0	-	-	-	-	-	-	-
02	1	0	-	-	-	-	-	-	-
03	1	0	-	-	-	-	-	-	-
04	1	0	-	-	-	-	-	-	-
05	1	0	-	-	-	-	-	-	-
06	1	0	-	-	-	-	-	-	-
07	1	8	8	5.503	19.8108	4.942	17.7912	0.5602	2.01672
08	1	8	8	5.503	19.8108	4.942	17.7912	0.5602	2.01672
09	1	25	25	15.585	56.106	15.573	56.0628	0.0119	0.04284
10	1	25	25	15.585	56.106	15.573	56.0628	0.0119	0.04284
11	1	25	25	15.585	56.106	15.573	56.0628	0.0119	0.04284
12	1	25	25	15.585	56.106	15.573	56.0628	0.0119	0.04284
13	1	6	6	3.915	14.094	(3.915)	(14.0940)	(0)	(0)
14	1	6	6	3.915	14.094	(3.915)	(14.0940)	(0)	(0)
15	1	6	6	3.915	14.094	(3.915)	(14.0940)	(0)	(0)
16	1	6	6	3.915	14.094	(3.915)	(14.0940)	(0)	(0)
17	1	13	13	8.141	29.3076	7.613	27.4068	0.5278	1.90008
18	1	8	8	5.503	19.8108	4.942	17.7912	0.5602	2.01672
19	1	8	8	5.503	19.8108	4.942	17.7912	0.5602	2.01672
20	1	7 (2+5)	7	4.981	17.9316	4.429	15.9444	0.5520	1.98720
21	1	8	8	5.503	19.8108	4.942	17.7912	0.5602	2.01672
22	1	7 (0+7)	7	4.429	15.9444	(4.429)	(15.9444)	(0)	(0)
23	1	0	-	-	-	-	-	-	-
24	1	0	-	-	-	-	-	-	-
		Σ=	191	Σ=	443.023	Σ=	428.891	Σ=	14.132

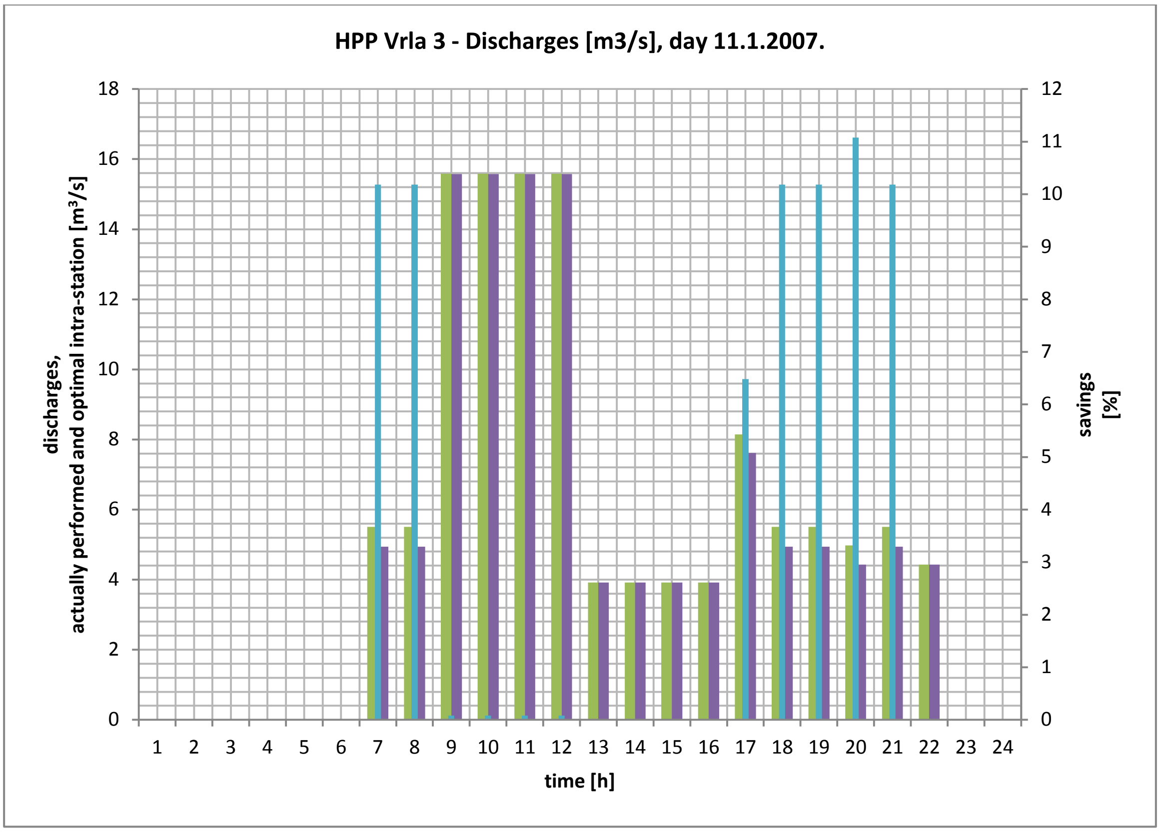
- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 191 \ {}^{MWh}/_{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 443023 \ {}^{m^3}/_{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.431129 \ {}^{kWh}/_{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 428891 \ {}^{m^3}/_{day} = -3.2\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.445335 \ {}^{kWh}/_{m^3} = +3.30\%)$
- saved water, as per optimal intra-station regimes	$\Sigma \Delta W_{HPP}^{opt} = 14132 \ {}^{m^3}/_{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma \Delta W_{HPP}^{opt} = 6.293 \ {}^{MWh}/_{day} = +3.30\%$

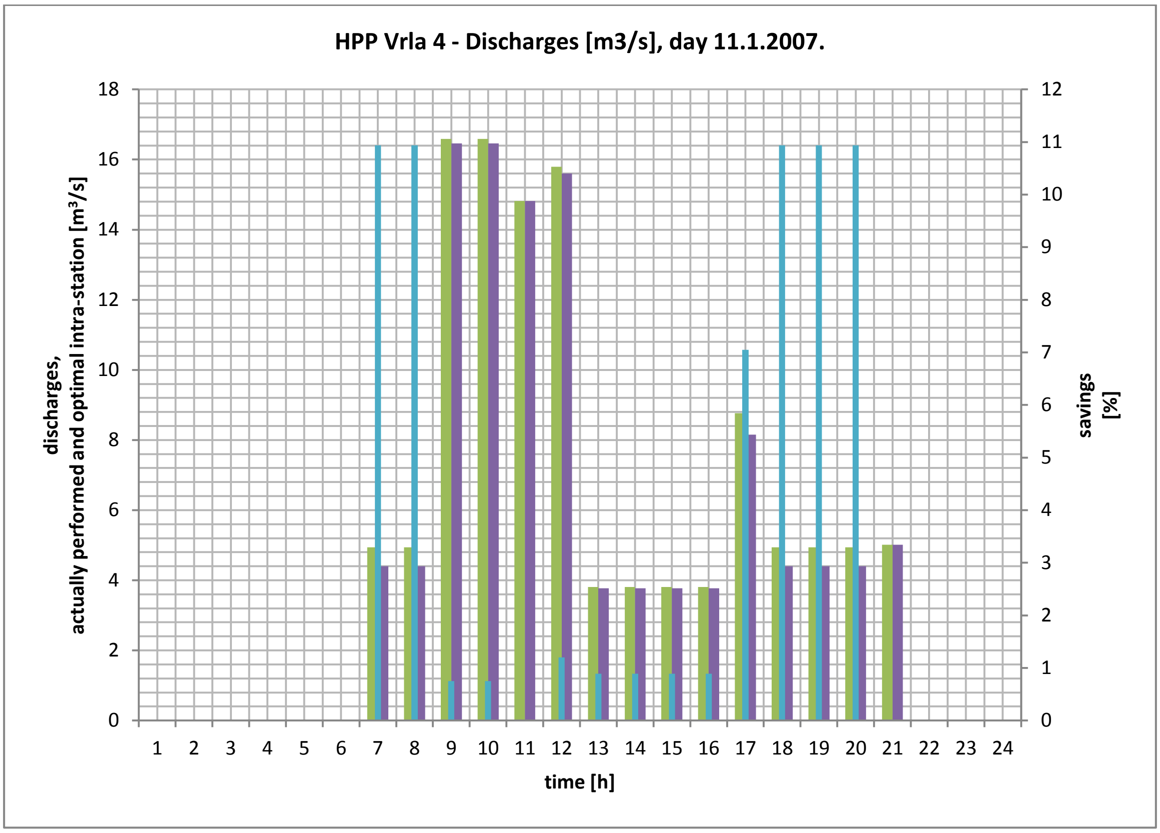
HPP: Vrla 4									**Day: 11.1.2007.**
time [h]	duration [h]	output $P_{HPP}^{switchyard}$ [MW] (requirement by regional Dispatching Center)	generated active energy $E_{HPP}^{switchyard}$ [MWh]	actually performed regimes at the HPP		optimal intra-station regimes		water savings due to optimal intra-station regimes	
				discharge Q_{HPP} [m³/s]	utilized water W_{HPP} [m³ * 10³]	discharge Q_{HE}^{opt} [m³/s]	utilized water W_{HPP}^{opt} [m³ * 10³]	discharge ΔQ_{HE}^{opt} [m³/s]	water ΔW_{HE}^{opt} [m³ * 10³]
01	1	0	-	-	-	-	-	-	-
02	1	0	-	-	-	-	-	-	-
03	1	0	-	-	-	-	-	-	-
04	1	0	-	-	-	-	-	-	-
05	1	0	-	-	-	-	-	-	-
06	1	0	-	-	-	-	-	-	-
07	1	6 (3+3)	6	4.944	17.7984	4.403	15.8508	0.541	1.9476
08	1	6 (3+3)	6	4.944	17.7984	4.403	15.8508	0.541	1.9476
09	1	23	23	16.584	59.7024	16.460	59.2560	0.124	0.4464
10	1	23	23	16.584	59.7024	16.460	59.2560	0.124	0.4464
11	1	21 (9+12)	21	14.818	53.3448	(14.817)	(53.3448)	(0)	(0)
12	1	22	22	15.796	56.8656	15.606	56.1816	0.190	0.6840
13	1	5	5	3.809	13.7124	3.775	13.5900	0.034	0.1224
14	1	5	5	3.809	13.7124	3.775	13.5900	0.034	0.1224
15	1	5	5	3.809	13.7124	3.775	13.5900	0.034	0.1224
16	1	5	5	3.809	13.7124	3.775	13.5900	0.034	0.1224
17	1	12	12	8.769	31.5684	8.151	29.3436	0.618	2.2248
18	1	6 (3+3)	6	4.944	17.7984	4.403	15.8508	0.541	1.9476
19	1	6 (3+3)	6	4.944	17.7984	4.403	15.8508	0.541	1.9476
20	1	6 (3+3)	6	4.944	17.7984	4.403	15.8508	0.541	1.9476
21	1	7	7	5.009	18.0324	(5.009)	(18.0324)	(0)	(0)
22	1	0	-	-	-	-	-	-	-
23	1	0	-	-	-	-	-	-	-
24	1	0	-	-	-	-	-	-	-
		Σ=	158	Σ=	423.0576	Σ=	409.0284	Σ=	14.0292

- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 158\ {MWh}/{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 423058\ {m^3}/{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.373472\ {kWh}/{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 409028\ {m^3}/{day} = -3.3\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.386281\ {kWh}/{m^3} = +3.40\%)$
- saved water, as per optimal intra-station regimes	$\Sigma \Delta W_{HPP}^{opt} = 14029\ {m^3}/{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma \Delta W_{HPP}^{opt} = 5.419\ {MWh}/{day} = +3.40\%$


HPP Vrla 1 - Discharges[m³/s], day11.1.2007.
discharges, actually performed and optimal intra-station [m³/s]
savings [%]
time [h]
0
2
4
6
8
10
12
14
16
18
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


HPP Vrla 2 - Discharges[m³/s], day11.1.2007.
discharges, actually performed and optimal intra-station [m³/s]
savings [%]
time [h]
0
2
4
6
8
10
12
14
16
18
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


HPP Vrla 3 - Discharges [m3/s], day 11.1.2007.
discharges, actually performed and optimal intra-station [m³/s]
savings [%]
time [h]
18
16
14
12
10
8
6
4
2
0
12
11
10
9
8
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


HPP Vrla 4 - Discharges [m3/s], day 11.1.2007.
discharges, actually performed and optimal intra-station [m³/s]
savings [%]
time [h]
18
16
14
12
10
8
6
4
2
0
12
11
10
9
8
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Overview of combined results for all 4 HPPs

day	$\Sigma E_{HPP\,Vrla1-4}\ [MWh]$	$\Sigma\Delta E_{HPP\,Vrla\,1-4}\ [MWh]$	$e_{HPP\,Vrla\,1-4}$ [%]
	totally generated active energy, for the entire 4 HPPs	**additional energy generation, from saved water (absolute value)**	**additional energy generation, from saved water (percentual value)**
11.1.2007.	**799 MWh**	**30.39 MWh**	**+3.80%**

HPP Vrla 1	
- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 295\ {MWh}/{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 385012\ {m^3}/{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.766210\ {kWh}/{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 372948.1\ {m^3}/{day} = -3.1\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.790995\ {kWh}/{m^3} = +3.23\%)$
- saved water, as per optimal intra-station regimes	$\Sigma\Delta W_{HPP}^{opt} = 12064\ {m^3}/{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma\Delta W_{HPP}^{opt} = 9.542\ {MWh}/{day} = +3.23\%$
HPP Vrla 2	
- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 155\ {MWh}/{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 457327\ {m^3}/{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.338926\ {kWh}/{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 431880.1\ {m^3}/{day} = -5.6\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.358896\ {kWh}/{m^3} = +5.89\%)$
- saved water, as per optimal intra-station regimes	$\Sigma\Delta W_{HPP}^{opt} = 25445\ {m^3}/{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma\Delta W_{HPP}^{opt} = 9.133\ {MWh}/{day} = +5.89\%$
HPP Vrla 3	
- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 191\ {MWh}/{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 443023\ {m^3}/{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.431129\ {kWh}/{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 428891\ {m^3}/{day} = -3.2\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.445335\ {kWh}/{m^3} = +3.30\%)$
- saved water, as per optimal intra-station regimes	$\Sigma\Delta W_{HPP}^{opt} = 14132\ {m^3}/{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma\Delta W_{HPP}^{opt} = 6.293\ {MWh}/{day} = +3.30\%$
HPP Vrla 4	
- totally generated active energy at the HPP	$\Sigma E_{HPP}^{switchyard} = 158\ {MWh}/{day}$
- totally utilized water, as per actually performed regimes	$\Sigma W_{HPP} = 423058\ {m^3}/{day}$ $(e_{HPP} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}} = 0.373472\ {kWh}/{m^3})$
- totally utilized water, as per optimal intra-station regimes	$\Sigma W_{HPP}^{opt} = 409028\ {m^3}/{day} = -3.3\%$ $(e_{HPP}^{opt} = \frac{\Sigma E_{HPP}^{switchyard}}{\Sigma W_{HPP}^{opt}} = 0.386281\ {kWh}/{m^3} = +3.40\%)$
- saved water, as per optimal intra-station regimes	$\Sigma\Delta W_{HPP}^{opt} = 14029\ {m^3}/{day}$
- additional energy generation, from saved water	$\Delta E_{HPP}^{opt} = e_{HPP}^{opt} * \Sigma\Delta W_{HPP}^{opt} = 5.419\ {MWh}/{day} = +3.40\%$

5. Conclusions

1. Optimization of exploitation regimes of HPPs allows for significant additional energy generation and benefits to the owner companies.

2. Intra-station optimization is applicable to any HPP, both the ones availing with asymmetric and the ones with symmetric energetic characteristics. Anyhow, the HPPs with asymmetric energetic characteristics are far more eligible to optimization gains.

3. Primary potential for intra-station optimization of HPPs lies in the asymmetry of the energetic characteristics (constructive-type specifics).

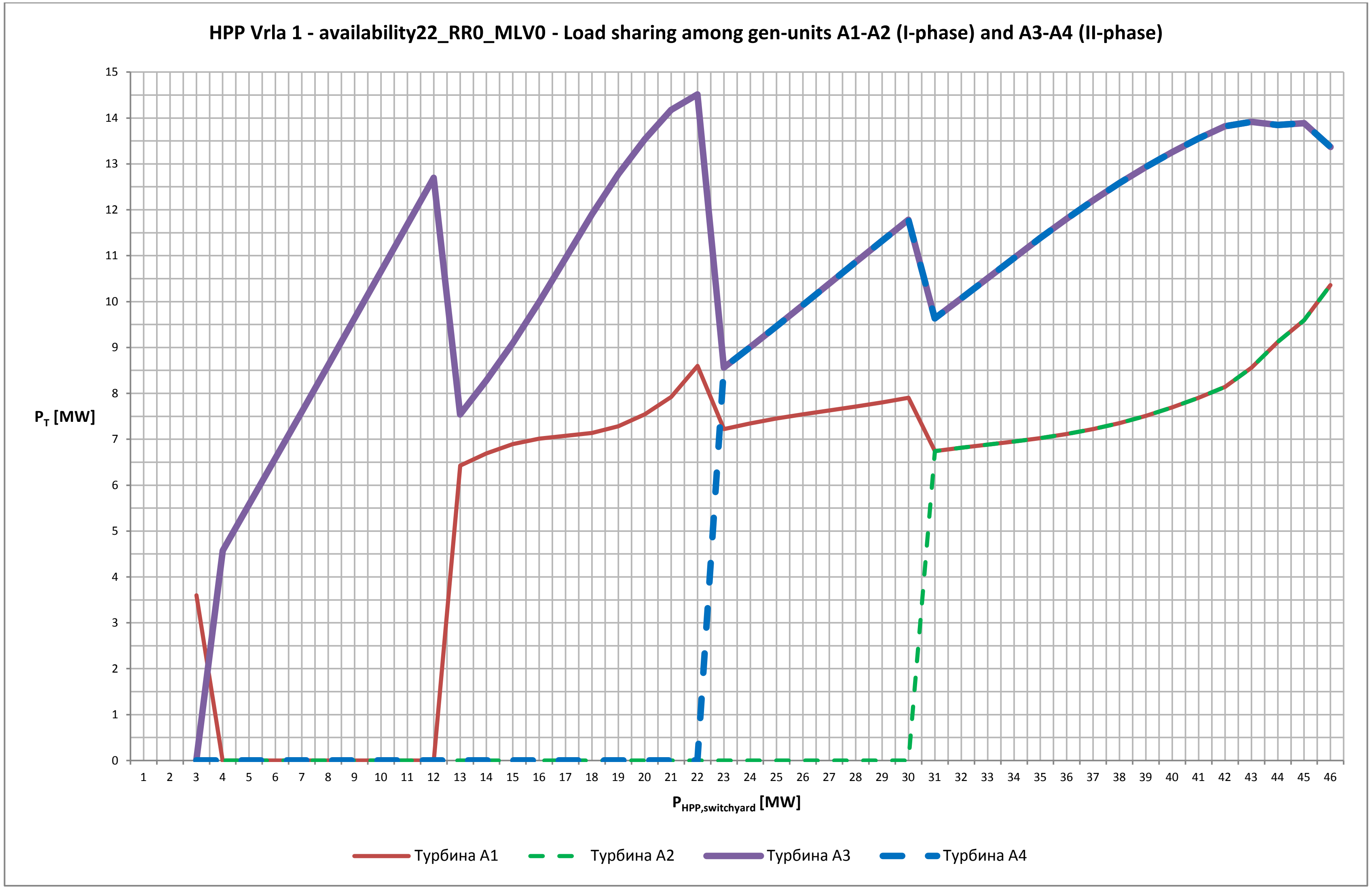
Secondary potential for intra-station optimization lies in the involvement of complex technical constraints onto their exploitation regimes and in the cases when HPPs are being predominantly exploited at medium outputs, far apart from installed/maximal output (regime-type specifics).

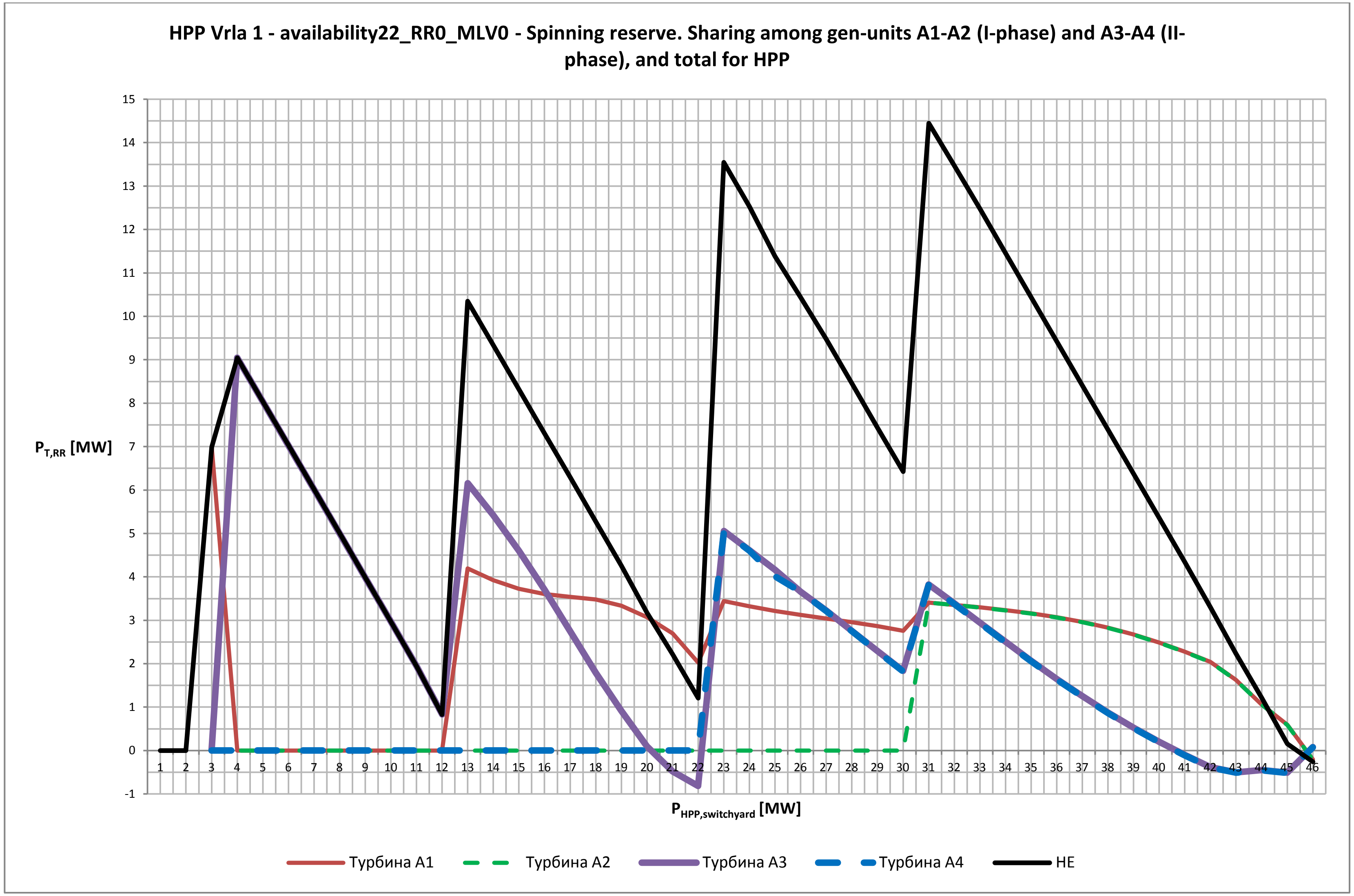
Eligibility for optimization gains drastically increases with increase of overall complexity of exploitation conditions. This is self-evident, because under complex conditions there are no simple, straightforward solutions of extremal regimes, and therefore advanced numerical models are to be employed.

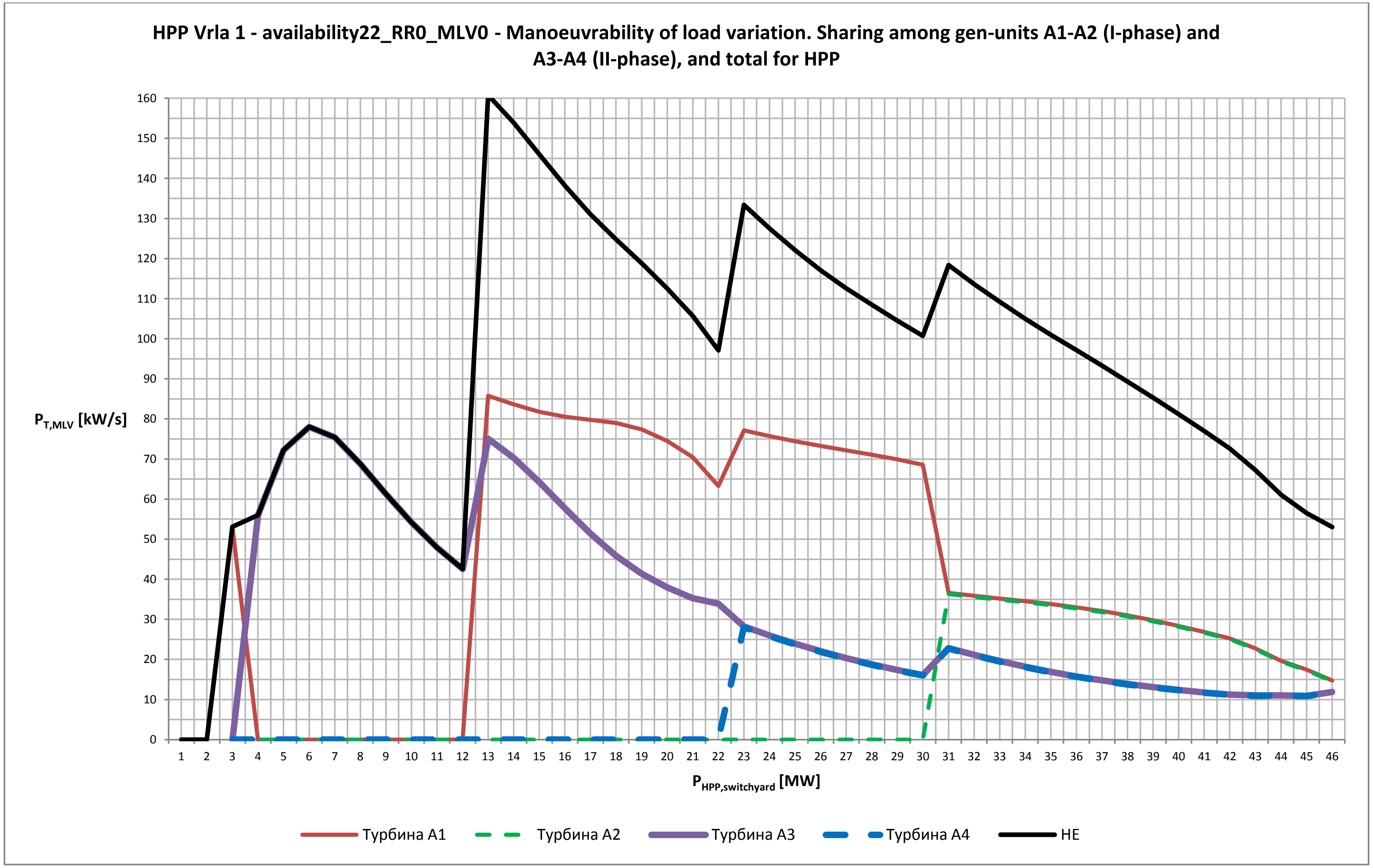
4. Implementation of developed intra-station optimization tools is readily applicable at HPPs. Neither efforts in regard of any public licences or consents, nor in regard of interventions or reconstructions at HPPs are necessary. All that is needed are just Tables of optimal intra-station regimes and their due application by HPP exploitation personnel.

5. The system of HPPs Vrla 1-4 that had been analysed within the Case Study avails with quite complex and asymmetric energetic characteristics. It is shown that additional energy generation, obtainable by implementation of intra-station optimization, is as high as 3% (10 GWh/year). This benefit is equivalent to 1230 t/year of equivalent coal, or to annual consumption of approx. 1400 households (at approx. 600 kWh/month), or to approx. 600.000 EUR/year (at 6 EURc/kWh).

6. For illustrative purposes, one of the elaborated Tables of optimal intra-station regimes (for HPP Vrla 1) and charts depicting the characteristic values are enclosed herebelow.


HPP Vrla 1 - availability22_RR0_MLV0 - Load sharing among gen-units A1-A2 (I-phase) and A3-A4 (II-phase)
P_T [MW]
$P_{HPP,switchyard}$ [MW]
Турбина А1
Турбина А2
Турбина А3
Турбина А4


HPP Vrla 1 - availability22_RR0_MLV0 - Spinning reserve. Sharing among gen-units A1-A2 (I-phase) and A3-A4 (II-phase), and total for HPP
P_T,RR [MW]
P_HPP,switchyard [MW]
Турбина А1
Турбина А2
Турбина А3
Турбина А4
HE


HPP Vrla 1 - availability22_RR0_MLV0 - Manoeuvrability of load variation. Sharing among gen-units A1-A2 (I-phase) and A3-A4 (II-phase), and total for HPP
P T,MLV [kW/s]
P HPP,switchyard [MW]
Турбина А1
Турбина А2
Турбина А3
Турбина А4
HE

HPP Vrla 1 availability22_RR0_MLV0

availability of gen-units	requirements for HPP exploitation $P_{HPP,switchyard}$	$P_{HPP,RR}$	$P_{HPP,MLV}$	composition of active gen-units	Q_{HPP}	$Q_T(1)$	$Q_T(2)$	$Q_T(3)$	$Q_T(4)$
[/]	[MW]	[MW]	[kW/s]	[/]	[m³/s]	[m³/s]	[m³/s]	[m³/s]	[m³/s]
N/A	1	0	0						
N/A	2	0	0						
"1111	3	6.987	53.1	"1000	1.265	1.265	0	0	0
"1111	4	9.046	56	"0010	1.591	0	0	1.591	0
"1111	5	8.036	72.2	"0010	1.915	0	0	1.915	0
"1111	6	7.028	78	"0010	2.244	0	0	2.244	0
"1111	7	6.017	75.4	"0010	2.58	0	0	2.58	0
"1111	8	5.003	68.8	"0010	2.924	0	0	2.924	0
"1111	9	3.985	61.3	"0010	3.272	0	0	3.272	0
"1111	10	2.966	54.2	"0010	3.624	0	0	3.624	0
"1111	11	1.945	47.9	"0010	3.977	0	0	3.977	0
"1111	12	0.83	42.6	"0010	4.333	0	0	4.333	0
"1111	13	10.349	160.8	"1010	4.758	2.196	0	2.562	0
"1111	14	9.339	153.9	"1010	5.101	2.288	0	2.812	0
"1111	15	8.326	146	"1010	5.448	2.357	0	3.091	0
"1111	16	7.31	138.2	"1010	5.799	2.4	0	3.399	0
"1111	17	6.291	131.1	"1010	6.152	2.422	0	3.73	0
"1111	18	5.272	124.8	"1010	6.507	2.445	0	4.063	0
"1111	19	4.253	118.8	"1010	6.865	2.496	0	4.369	0
"1111	20	3.171	112.5	"1010	7.229	2.592	0	4.637	0
"1111	21	2.215	105.7	"1010	7.604	2.732	0	4.871	0
"1111	22	1.206	97.1	"1010	7.996	2.996	0	5	0
"1111	23	13.545	133.4	"1011	8.364	2.477	0	2.944	2.944
"1111	24	12.53	127.5	"1011	8.726	2.522	0	3.102	3.102
"1111	25	11.384	122.1	"1011	9.092	2.561	0	3.265	3.265
"1111	26	10.438	117.1	"1011	9.461	2.596	0	3.433	3.433
"1111	27	9.479	112.6	"1011	9.834	2.628	0	3.603	3.603
"1111	28	8.46	108.5	"1011	10.21	2.659	0	3.775	3.775
"1111	29	7.441	104.5	"1011	10.589	2.694	0	3.948	3.948
"1111	30	6.422	100.7	"1011	10.973	2.735	0	4.119	4.119
"1111	31	14.45	118.4	"1111	11.356	2.346	2.346	3.333	3.333
"1111	32	13.469	113.6	"1111	11.73	2.374	2.374	3.491	3.491
"1111	33	12.474	109.2	"1111	12.107	2.4	2.4	3.654	3.654
"1111	34	11.457	105	"1111	12.488	2.427	2.427	3.817	3.817
"1111	35	10.439	101	"1111	12.873	2.457	2.457	3.98	3.98
"1111	36	9.421	97.2	"1111	13.261	2.492	2.492	4.138	4.138
"1111	37	8.405	93.3	"1111	13.656	2.536	2.536	4.292	4.292
"1111	38	7.389	89.3	"1111	14.057	2.59	2.59	4.439	4.439
"1111	39	6.373	85.3	"1111	14.468	2.655	2.655	4.579	4.579
"1111	40	5.358	81.2	"1111	14.889	2.733	2.733	4.712	4.712
"1111	41	4.344	77	"1111	15.323	2.824	2.824	4.837	4.837
"1111	42	3.307	72.6	"1111	15.775	2.932	2.932	4.956	4.956
"1111	43	2.234	67.2	"1111	16.248	3.124	3.124	5	5
"1111	44	1.213	61.1	"1111	16.76	3.402	3.402	4.978	4.978
"1111	45	0.154	56.5	"1111	17.277	3.639	3.639	5	5
"1111	45.503	-0.259	53	"1111	17.549	3.994	3.994	4.781	4.781

availability of gen-units	$P_{HPP,switchyard}$	$P_{HPP,turbine\ parity}$	$P_T(1)$	$P_T(2)$	$P_T(3)$	$P_T(4)$	$P_{HPP,generator\ parity}$	$P_G(1)$	$P_G(2)$	$P_G(3)$	$P_G(4)$
[/]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
N/A	1										
N/A	2										
"1111	3	3.602	3.602	0	0	0	3.277	3.277	0	0	0
"1111	4	4.574	0	0	4.574	0	4.279	0	0	4.279	0
"1111	5	5.584	0	0	5.584	0	5.283	0	0	5.283	0
"1111	6	6.593	0	0	6.593	0	6.287	0	0	6.287	0
"1111	7	7.603	0	0	7.603	0	7.293	0	0	7.293	0
"1111	8	8.617	0	0	8.617	0	8.3	0	0	8.3	0
"1111	9	9.635	0	0	9.635	0	9.307	0	0	9.307	0
"1111	10	10.654	0	0	10.654	0	10.315	0	0	10.315	0
"1111	11	11.675	0	0	11.675	0	11.324	0	0	11.324	0
"1111	12	12.696	0	0	12.696	0	12.334	0	0	12.334	0
"1111	13	13.968	6.425	0	7.543	0	13.333	6.1	0	7.233	0
"1111	14	14.978	6.694	0	8.284	0	14.34	6.371	0	7.969	0
"1111	15	15.991	6.892	0	9.099	0	15.347	6.57	0	8.777	0
"1111	16	17.007	7.014	0	9.993	0	16.354	6.693	0	9.662	0
"1111	17	18.026	7.076	0	10.95	0	17.363	6.756	0	10.607	0
"1111	18	19.046	7.139	0	11.907	0	18.372	6.818	0	11.554	0
"1111	19	20.064	7.282	0	12.782	0	19.381	6.962	0	12.419	0
"1111	20	21.08	7.546	0	13.535	0	20.391	7.227	0	13.164	0
"1111	21	22.096	7.922	0	14.175	0	21.401	7.604	0	13.797	0
"1111	22	23.109	8.596	0	14.513	0	22.411	8.279	0	14.131	0
"1111	23	24.349	7.222	0	8.564	8.564	23.394	6.902	0	8.246	8.246
"1111	24	25.364	7.346	0	9.009	9.009	24.402	7.026	0	8.688	8.688
"1111	25	26.38	7.452	0	9.464	9.464	25.409	7.133	0	9.138	9.138
"1111	26	27.397	7.544	0	9.927	9.927	26.417	7.225	0	9.596	9.596
"1111	27	28.416	7.628	0	10.394	10.394	27.425	7.31	0	10.058	10.058
"1111	28	29.434	7.71	0	10.862	10.862	28.433	7.392	0	10.521	10.521
"1111	29	30.454	7.8	0	11.327	11.327	29.442	7.482	0	10.98	10.98
"1111	30	31.473	7.907	0	11.783	11.783	30.452	7.59	0	11.431	11.431
"1111	31	32.75	6.743	6.743	9.632	9.632	31.449	6.42	6.42	9.304	9.304
"1111	32	33.767	6.816	6.816	10.068	10.068	32.457	6.493	6.493	9.735	9.735
"1111	33	34.784	6.882	6.882	10.51	10.51	33.465	6.56	6.56	10.172	10.172
"1111	34	35.802	6.95	6.95	10.951	10.951	34.473	6.628	6.628	10.608	10.608
"1111	35	36.819	7.024	7.024	11.386	11.386	35.482	6.703	6.703	11.038	11.038
"1111	36	37.837	7.113	7.113	11.805	11.805	36.491	6.792	6.792	11.453	11.453
"1111	37	38.854	7.221	7.221	12.205	12.205	37.5	6.901	6.901	11.849	11.849
"1111	38	39.87	7.353	7.353	12.582	12.582	38.51	7.033	7.033	12.222	12.222
"1111	39	40.885	7.51	7.51	12.933	12.933	39.519	7.191	7.191	12.569	12.569
"1111	40	41.9	7.693	7.693	13.257	13.257	40.529	7.375	7.375	12.89	12.89
"1111	41	42.915	7.903	7.903	13.554	13.554	41.539	7.586	7.586	13.184	13.184
"1111	42	43.929	8.142	8.142	13.822	13.822	42.548	7.825	7.825	13.449	13.449
"1111	43	44.939	8.556	8.556	13.914	13.914	43.557	8.24	8.24	13.539	13.539
"1111	44	45.947	9.122	9.122	13.851	13.851	44.566	8.806	8.806	13.477	13.477
"1111	45	46.96	9.59	9.59	13.89	13.89	45.576	9.272	9.272	13.515	13.515
"1111	45.503	47.462	10.36	10.36	13.371	13.371	46.083	10.039	10.039	13.002	13.002