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ON THE FEASIBILITY OF THE CONSTRUCTION OF NEW HYDROPOWER PLANTS IN UKRAINE

Abstract. There are presented results of feasibility analysis of the building of new hydropower plants in Ukraine according to the Hydropower development program for the period till 2026, which was approved by our Government in 2016.
Keywords: alternative, feasibility, hydropower plants, pairwise comparison, renewable energy, risk

Introduction

As renewable energy, especially solar and wind, steadily has been increasing in our country, so has been the need for additional high-maneuver hydropower capacities to provide the stable and reliable operation of the national combined energy system (CES).

Table 1 – Renewable energy in Ukraine (MW)[1]

Renewable Energy	Years										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019[3]
Wind[2]	84	87	151	194	334	426	426	438	465	533	706
Solar[2]	-	3	191	326	616	411	432	531	742	1388	2072
Household solar	-	-	-	-	-	0.1	2	17	51	157	157
Small hydropower	66	68	71	73	75	80	87	90	95	99	99
Biomass	-	-	-	6	17	35	35	39	39	52	52
Biogas	-	-	-	-	7	14	17	20	34	46	51
New	-	8	255	186	450	-83	33	136	291	849	862
Total	150	158	413	599	1049	966	999	1135	1426	2275	3137

[1] Without large hydropower generation
[2] Without power generation in the Autonomous Republic of Crimea and in the occupied territory of Donbas (in total, Russia has arrogated 633.7 MW of renewable energy of Ukraine)
[3] According to data for the first quarter of 2019

Admittedly, the role of maneuver power sources in the CES is best fulfilled by hydropower plants (HPPs) and pumped-storage hydropower plants (PSHPPs).

Table 2 – Comparative characteristics of manoeuvrable qualities of main types of power plants

Types of power plants	Technical minimum load, % (the ratio of minimum permissible power to the installed power)	Regulation range, %	Time to set the full power, min	
			After stopping	From the “hot” state
Nuclear	85-90	10-15	390-660	60
Thermal (coal, oil)	70-80	20-30	90-180	20-50
Gas turbines	0	100	15-30	0.5
Hydraulic	0	100	1-2	0.25-0.5
Pumped-storage	0	200	1-2	0.25-0.5

It is believed that for the stable and reliable operation of the CES, the share of maneuver capacities in its overall electricity balance should be about 15-20%. However, at present, the domestic hydropower is capable of reliably providing only about 8-9% of the overall electricity balance in the country. Therefore, the decision on a further increase of hydropower capacity in the country laid out in the famous Hydropower Development Program for the period till 2026 seems to be rational.

Some general remarks concerning current state of hydropower in Ukraine

The main functions of domestic hydropower are the regulation of frequency and load schedules in the CES and the formation of an emergency power reserve.

Table 3 – Hydropower (HP) in Ukraine from 2010 till 2018 (MW)

Power plants	Years								
	2010	2011	2012	2013	2014	2015	2016	2017	2018
Large HP	5400.2	5400.2	5400.2	5724.2	5724.2	6048.2	6048.2	6048.2	6048.2
Small HP	68	71	73	75	80	87	90	95	99
Total hydropower	5468.2	5471.2	5473.2	5799.2	5804.2	6135.2	6138.2	6143.2	6147.2
Share, %, of small HP in total HP	1.24	1.30	1.33	1.29	1.38	1.42	1.47	1.55	1.61
Share, %, of HP in total renewable energy[1]	97.19	92.98	90.14	84.68	85.73	86.00	84.39	81.16	72.99
Share, %, of small HP in renewable energy[2]	43.04	17.19	12.19	7.15	8.28	8.71	7.93	6.66	4.35

[1] With large hydropower

[2] Without large hydropower

The Hydropower development program for the period till 2026

Table 4 – The expected outcomes of the Program

Power plants		Installed capacity *N*, MW	Power generation *E*, MW·h	Cost *C*, 10^9, hryvnias
Dniester PSHPP	the second stage	324 (421[I])	388.5 (515.5[II])	2.8
	the third stage	972 (1263[I])	1165.5 (1546.5[II])	8.4
Tashlyk PSHPP		604 (861[I])	582 (785[II])	14.9
Kaniv PSHPP		1000 (1120[I])	1017 (1153[II])	40.5[III]
Reconstruction of existing HPPs		307	330	22.33
Kakhovka HPP#2		250	44	13.47[IV]
Upper Dnistrovskyi cascade of HPPs		390	710	31.9[V]
Small hydropower[VI]		88	120	-
Total		3935 (3665[I])	4387 (4000[II])	134.3

[I] Pumped-storage mode
[II] Energy consumption in pumping mode
[III] USD 1.5 billion at prices for January 1, 2013
[IV] 0.42 billion Euros at prices for January 1, 2013
[V] 1.1 billion Euros at prices for January 1, 2014
[VI] Private investments

Topicality, general objective and particularities of the research

In practice, not only cost indicators and ratio of expected results determine feasibility of projects. Projects may be effective but not feasible. The effectiveness of any project can be stimulated by various kinds of preferences, for example, in the form of a “green tariff” for produced electricity, etc. However, a feasible project does not necessarily have to be absolutely effective too. For example, the Program’s project for the reconstruction of existing hydropower plants of the Dnipro and Dniester cascades may be considered quite feasible. Provided it is needed, various alternatives to its implementation may be analyzed to find among them a more efficient one.

This report presents the results of feasibility analysis of perspective plans for the second stage of modernization and reconstruction of the existing HPPs of the Dniprovsky and Dnistrovsky cascades, building the Kakhovka HPP #2 and six new HPPs on the river Dniester, as well as boosting small hydropower in the country. The analysis is based on a pairwise comparison of several alternatives by the criterion of minimum aggregate risk taking into account the risk of lost (unused) opportunities. Components of aggregate risks of compared alternatives are estimated in dimensionless units for main water-energy and operability characteristics, and costs of commissioning of new hydrogenerating capacities.

The peculiarity of the solution of the problem is that the project of the second stage of the reconstruction of existing hydroelectric plants of the Dnipro and Dniester cascades in the Program is accepted as a “zero” alternative.

Formalization of the research: Risks of alternatives and decision making

The task of multicriteria optimization on a countable set of admissible alternatives $\mathbf{A} = \{a_i\}$, $i = \overline{1, n}$, while their pairwise comparison, is reduced to the next optimization problem:

$$d_{opt} = \{a_{i,opt} \mid a_{i,opt} \in \mathbf{A} \wedge r_{i,opt} = \min(r_{i,j}, r_{j,i}) \; \forall (a_i, a_j)\}, i, j = \overline{0, n}, \; i \neq j, \qquad (1)$$

where $r_{i,j} = l_i + g_j$, $r_{j,i} = l_j + g_i$ are aggregate risks, respectively, for an alternative a_i when comparing it with the a_j, and the a_j comparing with the a_i; l_i, l_j and g_i, g_j are the values of the normalized convolutions of criteria, which are subject to minimization or maximization, of the a_i and a_j presented as own (or systemic) risks and risks of unused possibilities of the a_i, a_j; $l_i = \sum_{k=1} l_{k,i}$, $g_j = \sum_{k=1} g_{k,j}$

The score of some value y_k of the corresponding characteristic will be like that:

$$r(y_k) = \mu_k \cdot \lg y_k + y_{k,0}, \; \mu_k = \frac{L}{\lg y_{k,\max} - \lg y_{k,\min}}, \; y_{k,0} = -\mu_k \lg y_{k,\min}, \qquad (2)$$

where μ_k is module, $y_{k,0}$ is zero point on the integral log scale length L (let L = 10) for characteristic y_k, $y_{k,\max}$, $y_{k,\min}$ are maximum and minimum values of y_k. If $y_{k,\min}$ = 0 it will be counted that $y_{k,0}$ = 0, $\mu_k = \frac{L}{\lg y_{k,\max}}$, $r(0)$ = 0.

Solving the problem and results obtained

Totally, there were considered and pairwisely compared next eight alternatives ordered and numbered according to increasing installed capacity:

1) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades;

2) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades, and also the further development of small hydropower in the country;

3) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades, and also the construction of the Kakhovka HPP#2;

4) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades, the construction of the Kakhovka HPP#2 and the further development of small hydropower in the country;

5) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades and the building of the Upper Dnistrovskyi cascade of HPPs;

6) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades, the construction of the Upper Dnistrovskyi cascade of HPPs and the further development of small hydropower in the country;

7) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades, the construction of the Kakhovka HPP#2 and the construction of the Upper Dnistrovskyi cascade;

8) the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades, the construction of the Kakhovka HPP#2 and the Upper Dnistrovskyi cascade of HPPs, and the further development of small hydropower.

Table 5 – The characteristics of alternatives $a_0 \div a_7$

Alternatives	Characteristics				
	N, MW	E, MW·h	C, 10^9, hrs	C_E	N_{reg}, MW
a_0	307	330	22.33	330	276.3
a_1	395	450	22.33	930	293.9
a_2	557	374	35.8	374	513.8
a_3	645	494	35.8	974	531.4
a_4	697	1040	54.23	1040	529.8
a_5	785	1160	54.23	1640	547.4
a_6	947	1084	67.7	1084	767.3
a_7	1035	1204	67.7	1684	784.9

$$C_E = \sum_{k=1} E_k \cdot v_k, \qquad N_{reg} = \sum_{k=1} N_k \cdot c_k \tag{3}$$

where E_k is the total quantity and v_k is score value of tariff of the unit of electricity produced by the source with the index k; N_k is the installed capacity and c_k is the reliability coefficient concerning regulation possibilities of the source with the index k. If electricity is produced at large HPPs score value of tariff $v_k = 1$; at small HPPs, $v_k = 5$; the HPPs of the Dniprovsky and Dnistrovsky cascades, $c_k = 0.9$; the Kakhovka HPP#2, $c_k = 0.95$; the Upper Dnistrovskyi cascade, $c_k = 0.65$; the small hydropower, $c_k = 0.2$.

Table 6 – Results of numerical assessment of risk components of the alternatives $a_0 \div a_7$

Alternatives	Systemic risk			Risk of unused possibilities		
	C	C_E	l	N_{reg}	E	g
a_0	0.00	0.00	0.00	0.00	0.00	0.00
a_1	0.00	6.36	6.36	0.59	2.40	2.99
a_2	4.26	0.77	5.02	5.94	0.97	6.91
a_3	4.26	6.64	10.90	6.26	3.12	9.38
a_4	8.00	7.04	15.04	6.24	8.87	15.10
a_5	8.00	9.84	17.84	6.55	9.71	16.26
a_6	10.00	7.30	17.30	9.78	9.19	18.97
a_7	10.00	10.00	20.00	10.00	10.00	20.00

Table 7 – Decision table for pairwise comparison of the considered alternatives

a_i/a_j	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
a_0	-	**2.99**	**6.91**	9.38	15.10	16.26	18.97	20.00
a_1	**6.36**	-	**13.27**	9.97	21.46	22.62	25.33	26.36
a_2	**5.02**	**8.01**	-	**14.40**	**20.13**	**21.28**	**24.00**	**25.02**
a_3	10.90	13.88	**17.80**	-	26.00	27.16	29.87	30.90
a_4	15.04	18.03	**21.95**	24.42	-	31.30	34.01	35.04
a_5	17.84	20.83	**24.75**	27.22	32.94	-	36.81	37.84
a_6	17.30	20.28	**24.21**	26.68	32.40	33.56	-	37.30
a_7	20.00	22.99	**26.91**	29.38	35.10	36.26	38.97	-

The best alternative is a_2. This alternative is burdened with the lowest risk when pairwise comparison with any other alternative among the considered alternatives a_i, $i=\overline{0,7}$.

Conclusions

The results of our research show that the best alternative to build new hydropower plants in the country among the considered alternatives the alternative a_2 is. This is the second stage of reconstruction of the HPPs of the Dniprovsky and Dnistrovsky cascades and also the construction of the Kakhovka HPP#2. This alternative should be considered the most feasible to improve situation in the domestic hydropower without significant risks.

As well as, it should be noted that alternatives, which provide for the further development of small hydropower in the country, are worse than alternatives which neglect its development. It may indicate that decision to develop small hydropower in the country under the current conditions and thanks to the "green tariff" is questionable and ungrounded.

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