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ANALYSIS OF THE EFFICIENCY OF OPERATION OF SMALL HYDRO POWER PLANTS EQUIPPED WITH CROSSFLOW TURBINES

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Abstract

When selecting sites for a SHPP, it is critical to select the appropriate type of turbines to be installed and estimate the plant's expected yearly output. We have analyzed the efficiency of the Crosflo flow type turbine, which has gained popularity in recent years. In this paper dependencies have been identified that determine the efficiency of each element of the unit, depending on the water flow, the plant's pressure, and the unit's power The carried out study enables the automation of computations for determining the output of the plant equipped with flow type turbines

Key words: water, small hydropower plant, turbine, capacity of the plant.

Intriduction

In the construction of a small hydropower plant, investors frequently by mistake accept the potential installed capacity of the plant. This approach is acceptable only if, for a variety of reasons, the plant maintains a consistent water flow throughout the year. However, in reality, the vast majority of plants do not match with such conditions. This is especially true for SHPPs erected in hilly areas prone to flash floods and subsequent dry spells. The output indicator, which is the ratio of the station's predicted yearly output to the output when the plant operates at maximum power throughout the year, is the key criterion for the economic efficiency of such plants. Under such conditions, the plant's output index may decrease to 0.4 or less [1-4].

Conflict Setting

With an unequal distribution of the river flow in the annual context, one should have a good understanding of the probable generation of the plant even at the stage of assessing the financial attractiveness of the site for the SHPP. To undertake such a study, the type of turbines installed at the plants and their primary characteristics, particularly the efficiency of each of the unit's elements not only in the nominal mode, but also across the entire range of flow fluctuations, must be determined.

Research Results

The first stage is to select the type of turbines to be installed. For small HPPs with heads of more than 200 m, the turbine type is usually obvious - Pelton turbines in horizontal or vertical design. Kaplan turbines and Crossflow flow type turbines operate successfully at heads ranging from 4 to 20 m. The following principle can be utilized for pre-selection in this range. In practice, Kaplan turbines are cost-effective in the following conditions: small HPPs with heads of more than 200 m, the choice of turbine type is typically straightforward - these are Pelton turbines in horizontal or vertical design. Practice shows that Kaplan turbines are cost-effective provided

$$Q_\mathrm{p} > H_\mathrm{p} \tag{1}$$

where: Q_p is the design flow, H_p is the design head of the turbine.

Otherwise, based on (1), installing a Crossflo turbine is more economically attracive. The matter becomes more challenging when deciding on a turbine size ranging from 20 to 200 m. A number of turbines, including the Francis and Crossflo, can run successfully in this range. To select the type of a turbine in this pressure range, quite professional calculations [3, 5-7] with the determination of the number of installed units, the annual output of the plant, the anticipated cost of the project when choosing one or another nu,mber of units in the plant, are required.

It is highly useful to discover the functional connections between the plant's parameters and the elements of the units installed at the plant in order to automate such calculations. It should be mentioned that the main properties of turbines such as Kaplan, Francis, and Pelton have been well studied. Crossflow flow type turbines, the design of which has evolved dynamically over the last 30-40 years, exacerbate the situation. Its primary manufacturers are Ossberger (Germany) and Cink Hydroenergy (Czech Republic). It is known that the flow type turbines produced by these companies operate in the range of heads from 3 to 20m and at water flow rates per turbine from 30 l/s to 12 m^3/s. Following that, an attempt is made to study the technical 200 characteristics of units equipped with Crossflo turbines using technical data from more than 60 units with a variety of operating heads and flow rates. At the same time, an attempt was made to determine the functional relationships between the parameters of the designed HPP and efficiency. elements of the unit, which will automate the calculations to determine the output of the station at the stage of its economic evaluation.

Units equipped with Crossflo flow type turbines, in contrast to other varieties, are typically equipped with a gearbox that guarantees synchronization of the turbine and generator speeds. The gearbox is an extra component whose efficiency should be considered when evaluating the plant's output. The following is an element-by-element analysis of the parameters of units equipped with flow turbines.

The turbine. This turbine is distinguished by the fact that it operates as an active turbine at high pressures (40 m and above) and as a reactive turbine at low pressures (3-40 m), with a discharge pipe fitted beneath the turbine. The features of flow type turbines that operate in the core or reactive zone vary slightly.

The zone of operation of the active turbine. For comparability of the results of the analysis of data from different turbines, the flow rates of water passing through the turbine are given as a percentage of the calculated flow rate of the units. A study of the characteristics of active flow turbines (Hnet> 40m) showed that its nominal efficiency (at the rated power of the turbine), in the overwhelming majority of cases it is constant and equals 0.87 (Fig. 1).
According to the passport data, the current efficiency of the turbine depends on the flow rate of water passing through the turbine at a given time Q_i. The results of the analyzes show that the efficiency of active turbines does not change until the water flow drops to 27 percent and remains equal to 87 percent [8]. After the flow rate drops below 27 percent, the turbine's efficiency curve is described by a polynomial of the second degree:

$$\eta_{\text{T}i} = -0.0381Q_i^2 + 2.1238Q_i + 57.33 \tag{2}$$

where $\eta_{\text{T}i}$ is efficiency turbines at a water flow rate equal to Q_i.

Dependence (2) is valid in the zone of the turbine operation 5-27 percent of the nominal flow rate.

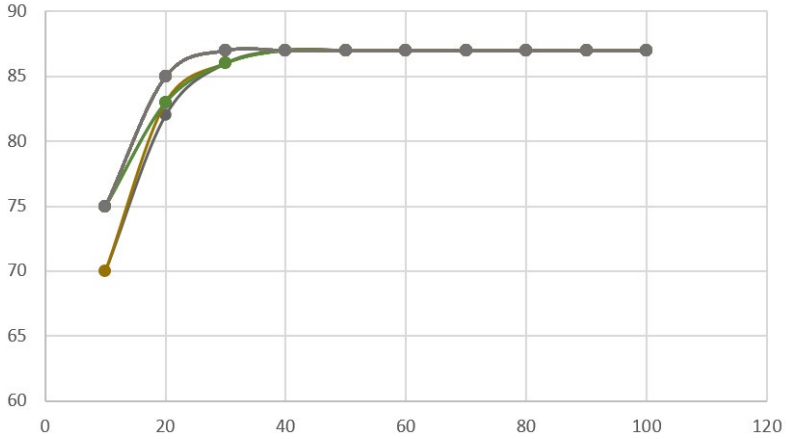

Fig. 1 Dependence of an active flow type turbine efficiency on the relative design water flow rate. Axis of abscissa - Q$_i$ (%), axis of ordinates - efficiency (%)

The jet turbine operating zone. In the zone of operation of a flow type turbine as a jet one its nominal efficiency is variable and mainly depends on the design pressure and is described by the equation [9,10].

$$\eta_{\text{T}} = 0.777{H_{\text{p}}}^{0.0243} \tag{3}$$

where η_{T} is the turbine's efficiency when the current flow Q_i passes through it.

In the case of jet turbines, as with active ones, the efficiency is constant and is determined by the flow rate fluctuations ranging from 27 percent to 100 percent (3). In the zone of flow rate from 5 to 27 percent the efficiency of the turbine is dependent on the water flow, and is determined by the dependence:

$$\eta_{\text{T}i} = \eta_{\text{T}} - 0.0323Q_i^2 + 1.83Q_i - 26.933 \tag{4}$$

where: $\eta_{\text{T}i}$ is the turbine efficiency when the current flow rate Q_i passes through it.

The gearbox. The presence of a gearbox as part of the unit with a flow type turbine has both negative and positive sides. The main drawback of this solution is the drop in the unit's efficiency drop on the gearbox by about 2-3 percent. As a positive one, it should be noted that such turbines have significantly low revolutions, which significantly increases their service life. With proper operation, flow turbines manufactured by the above companies equipped operate for approximately 40-45 years before the first overhaul.

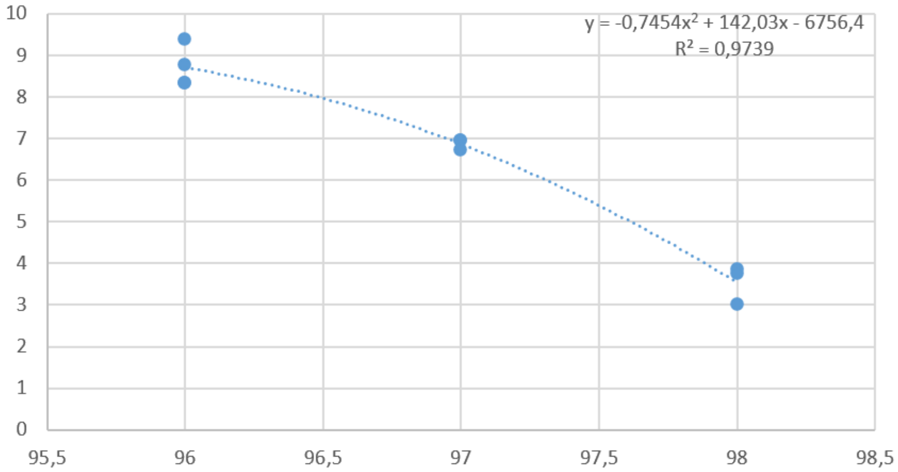

Fig. 2 Dependence of the nominal efficiency of the gearbox on the gear ratio.
The abscissa axis is efficiency (%), the y-axis is the gear ratio of the gearbox (without size)

The units manufactured by Cink-hydro-energy are overwhelmingly equipped with gearboxes manufactured by Siemens (Germany) or Vikof (Czech Republic). Rated efficiency such gearboxes mainly depends on the number of stages and gear ratio (Fig. 2) and varies between 96-98 percent.

Single-stage gearboxes have a nominal efficiency 98 percent. Such gearboxes operate in the range of design pressures of 20-200 m.

With a gear ratio in the range i=5-8, the units are equipped with two-stage gearboxes, the nominal efficiency is which is usually 97 percent.

According to the analyzes carried out, the calculated head of such turbines is in the range of 10-20m. and finally, with heads less than 10 m and a gear ratio of more than i = 8, the nominal efficiency reducer is 96 percent. The results of the analyzes are summarized in Table 1.

Table 1

Operating ranges of various gearboxes

Design head of the unit, m	Gearbox type	Gearbox gear ratio
<10	Two-stage	>8
10 to 20	Two-stage	5 to 8
>20	One-stage	< 5

According to technical data, efficiency of the gearbox depends on the flow rate of water passing through the turbine at a given time. To assess the nature of the change in efficiency of the gearbox, the technical data of 60 units with different initial parameters were analyzed. Fig.3

shows the results of data processing. As can be seen from Fig. 3, the efficiency of gearboxes with different gear ratios have the same intensity of efficiency drop with a drop in water flow rate, and only differ in the value of the nominal efficiency.

To automate the calculations, the functions of approximation of the change in efficiency of the gearbox were found depending on water flow rate.

The given curves are most accurately described by a polynomial dependence of the 6th degree. Moreover, the curves of all three ratings of gearboxes have the same coefficients and differ only in the absolute term value (Table 2).

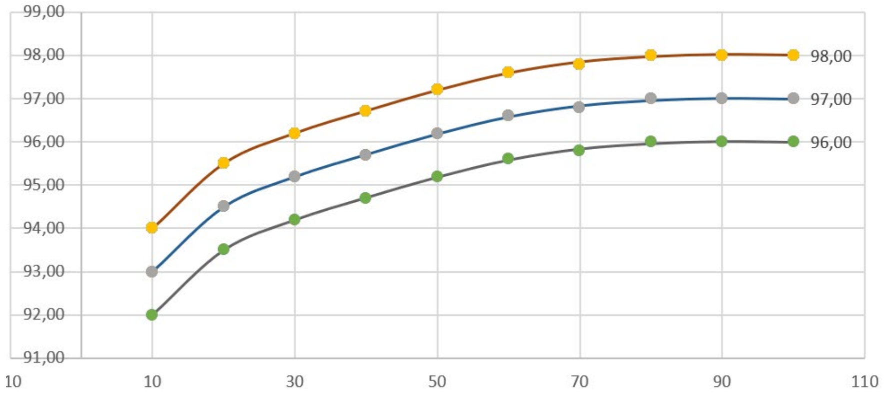

Fig. 3 Dependence of gearbox efficiency on percentage relative to the estimated water flow. Abscissa - Q_i (%), ordinate - efficiency (%)

Table 2

Dependency of approximation functions $\eta_p(Q_i)$

Design head, m	Coefficients of approximation polynomials of the 6th degree						
	6th	5th	4th	3d	2nd	1th	Absolute term
>20 m	-1.31944 E-10	5.03365 E-08	-7.63435 E-06	5.84409 E-04	-02.4101 E-2	0.56343	90.263
20 to10 m							89.263
<10 m							88.263

The generator. The units manufactured by Cink-hydo-enetgy and Ossberger are mainly equipped with generators manufactured by the German companies AEM and Siemens. These are synchronous hydro generators of horizontal design, brushless, self-excited. The rated speed of the generator is 1000 rpm, unless there are other special conditions. The nominal efficiency of the generator mainly depends on its power and ranges from 95 to 97%. Based on the research, a correlation was found between the installed power and the nominal efficiency of generators, which is described by the below linear dependence

$$\eta_{\text{gen}} = 0.0002N_{\text{y}} + 94.892 \tag{5}$$

where η_{gen} is the nominal efficiency of the generator, N_{y} is the installed power of the generator.

According to technical data, efficiency of the generator depends on the flow rate of water passing through the turbine at a given time. Fig. 4 shows the results of processing the technical data of generators.

As can be seen from Fig. 4, the efficiency of generators with different rated power have the same nominal efficiency drop when the water flow rate drops. Studies have shown that the coefficients of the 6th degree polynomial, approximating the drop in efficiency. generators of different rated power have the same coefficients and differ only in the value of the free term (Table 3).

Table 3

Dependency approximation functions $\eta_{\text{г}}(Q_i)$

Nominal efficiency (%)	A₁	A₂	A₃	A₄	A₅	A₆	C
97	-5.0E-10	1.892E-07	-2.938E-05	0.00237	-0.10647	2.625587	67.203
96.5							66.703
96							66.203
95.7							65.903
94.7							64.903

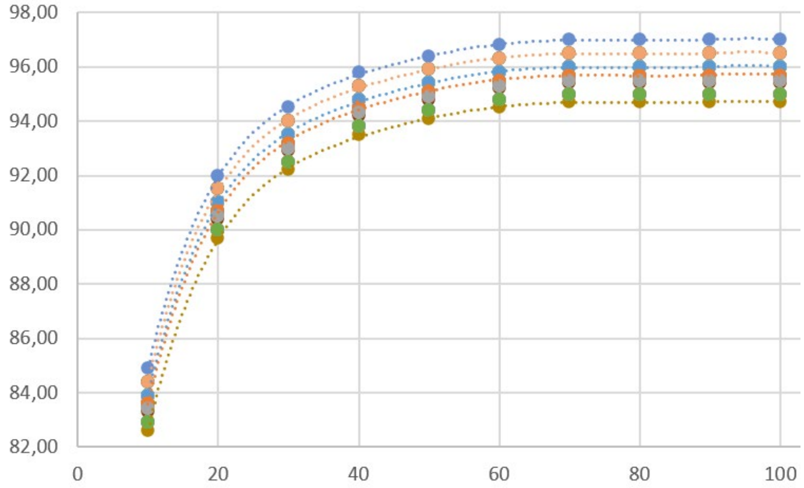

Fig. 4 Efficiency dependence generator from percentage relative to the estimated water flow
abscissa - Q_i (%), ordinate - efficiency (%)

Studies have shown that the values of the absolute term of polynomials of the 6th degree from the nominal efficiency of the generator, is a linear function (Fig.5), described by the below equation

$$C = \eta_{\text{gen}} - 29{,}797, \tag{6}$$

where η_{gen} is the nominal efficiency of the generator, C is the absolute term of the 6th degree $\eta_{\text{gen}i}$= f(Q_i) function.

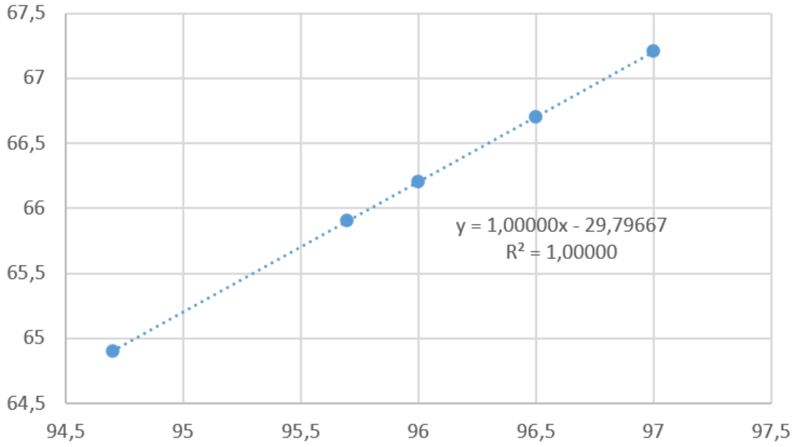

Fig. 5 Dependence of the free term of the polynomial of the 6th degree from the nominal efficiency
The abscissa axis is the nominal efficiency of the generator (%), the ordinate axis is the absolute term of the 6th degree polynomial (dimensionless)

From the above dependencies, we obtain an expression that allows us to determine the current efficiency of the generator based on the water flow at the moment and the rated power of the generator:

$$\eta_i = A_1 Q_i^6 + A_2 Q_i^5 + A_3 Q_i^4 + A_4 Q_i^3 + A_5 Q_i^2 + A_6 Q_i + 0{,}0002 N_{\mathrm{R}} + 65{,}094 \qquad (7)$$

where N_{R} is the rated power of the generator, A_1-A_6 are polynomial coefficients of 6th degree, given in the Table 3.

Conclusions

A study of the characteristics of active flowtype turbines revealed that its nominal efficiency is constant in the great majority of cases and equals 0.87. The nominal efficiency variable of the flow type turbine in its reactive mode of operation is mostly determined by the design head.

In the case of jet turbines, as with active ones, the efficiency remains constant over a cost range of 27 percent to 100 percent.

Efficiencyof gearboxes with different gear ratios have the same intensity of efficiency drop. with a drop in water flow rate , and only differ in the value of the negligible efficiency.

The nominal efficiency of a generator is determined mostly by its power and ranges from 95 to 97 percent. Relationship between installed power and nominal efficiency of generators, is described by a linear relationship. The dependencies obtained describes allow you to automate calculations to estimate efficiency. generator with a known rated power of the unit during a preliminary assessment of the station's output.

The obtained dependencies allow you to automate calculations to determine the efficiency. generator during a preliminary assessment of the station's output, with a known rated power of the unit.

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ՀՈՍՔԱՅԻՆ ՏՈՒՐԲԻՆՈՎ ԿԱՀԱՎՈՐՎԱԾ ՓՈՔՐ ՀԻԴՐՈԷԼԵԿՏՐԱԿԱՅԱՆՆԵՐԻ ՏԱՐՐԵՐԻ ԱՇԽԱՏԱՆՔԻ ԱՐԴՅՈՒՆԱՎԵՏՈՒԹՅԱՆ ՎԵՐԼՈՒԾՈՒԹՅՈՒՆ

Գաբայան Գ.Ս.[1], Թոքմաջյան Վ.Հ.[2, 3], Գաբայան Ս.Գ.[3], Բաբայան Ա.Ռ.[3], Պողոսյան Գ.Ա.[2]
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Փոքր հիդրոէլեկտրակայանների համար տեղամասեր ընտրելիս կարևոր է ճիշտ ընտրել տուրբինների տեսակը և գնահատել կայանի ակնկալվող տարեկան արտադրանքը: Սույն աշատանքում իրականացվել է հոսքային տուրբինի աշխատանքի արդյունավետության վերլուծություն, բացահայտվել են մի շարք կախվածություններ: Կատարված հետազոտությունների արդյունքները հնարավորություն են տալիս ավտոմատացնել հոսքային տուրբիններով կահավորված կայանի ելքի որոշման հաշվարկները:

Բանալի բառեր. ջուր, փոքր հիդրոէլեկտրակայան, տուրբին, կայանի հզորություն

АНАЛИЗ ЭФФЕКТИВНОСТИ РАБОТЫ ЭЛЕМЕНТОВ МАЛЫХ ГЭС, ОБОРУДОВАННЫХ ТУРБИНАМИ ПРОТОЧНОГО ТИПА

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При выборе площадок под МГЭС весьма важным является правильный выбор типа устанавливаемых турбин и оценка ожидаемой годовой выработки станции. Нами произведен анализ кпд распространенной в последние годы проточной турбины Кросфло. В данной работе выявлены зависимости, определяющие кпд. каждого из элементов агрегата в зависимости от расхода воды, напора станции и мощности агрегата. Произведенный анализ позволяет автоматизировать расчеты по определению выработки станции, оснащенной проточными турбинами.

Ключевые слова: вода, малая гидроэлектростанция, турбина, мощность станции.

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