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On the Principles of Turbine Type Selection and Their Control in the HPP Design

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Abstract

The article reviews the issues related to the increase of annual energy production of the run-of-the-river hydropower plant (HPP) without increasing the HPP annual design flow. The turbine type selection approach, that is different from a traditional one and that ensures maximum efficient use of the hydropower plant's available water resources, is provided. The results of simulation of the HPP average daily energy production and the software, specially developed for this purpose, are also given.

Keywords: Run-of-the-River HPP, Francis-Type Turbine, Ossberger-Type Turbine, Technical Minimum Flow of the Turbine

Introduction

Climate change is the greatest challenge of the 21st century. The incidence of natural disasters, such as: floods, droughts, abnormal-ly high environmental temperature, earthquakes etc., has consid-erably increased in the recent years. All the aforesaid is related to the global warming phenomenon. Global warming is mainly caused by increased concentration of the so-called "greenhouse gases" in the atmosphere as a result of human activity. Implementation of preventive measures against global warming and its consequences has become the modern world's primary concern.

The humanity needs energy for implementation of it practical activities and the demand for it is annually increasing. Fossil-fuel power stations are the main polluters of the earth's atmosphere. The most effective way to reduce "greenhouse gases" is to use so-called "green energy", which is inexhaustible and is based on the use of natural processes in the environment. Renewable energy sources have great potential to reduce "greenhouse gas" emissions from fos-sil fuel combustion and thereby mitigate the climate change impact. At the given stage of engineering and technology development, the hydropower engineering represents a competitive source of renew-able energy. It is characterized by fairly high efficiency and greater service period (over 60 years), as well as low operation and mainte-nance costs. Therefore, compared to other renewable energy sourc-es, the hydropower engineering is given preference to and its devel-opment is still topical despite its certain impact on the environment.

It is very important to minimize the environmental impact. In this regard, the preference is given to the run-of-the-river HPPs, one of the priority tasks of which is maximum efficient use of the available water resources.

1. Methodology

1.1 Basic methods of research

Software has been developed with the aim to study the efficient use of water resources, which allows simulation of the average dai-ly energy production through average daily river flows in case of using different turbines and for their different design flows. Head losses due to friction in penstock and change of turbine efficien-cy according to the flow, as well as hydropower unit's losses due to downtime, are taken into account in computation. Simulation of different models has proved that the stereotype approaches, fre-quently used in the run-of-the river HPP design, cannot ensure op-timal development of the river water resources.

1.2 Typical approaches during the design of HPPs

There are frequent attempts to maximize the installed capacity of the HPP and, for this purpose, to maximize its capacity design flow rate, which is sometimes counterproductive. The design cost con-siderably increases, the hydropower unit's losses due to downtime also increase, the unit capacity factor drops and the project be-comes less cost-effective. On the other hand, a typical approach for small HPPs lies in selection of the types and the number of hydropower units. Two hydropower units on Francis-type turbines are traditionally selected in the majority of designs. However, for the reasons considered below, they cannot ensure efficient devel-opment of the water resources.

Sometimes, the HPP design flow is selected inaccurately, using

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only the river multiyear average monthly flow rate chart (Figure 1). This is a major mistake, since the chart does not allow determining the time period, within which the hydropower units will be provided with selected flow.

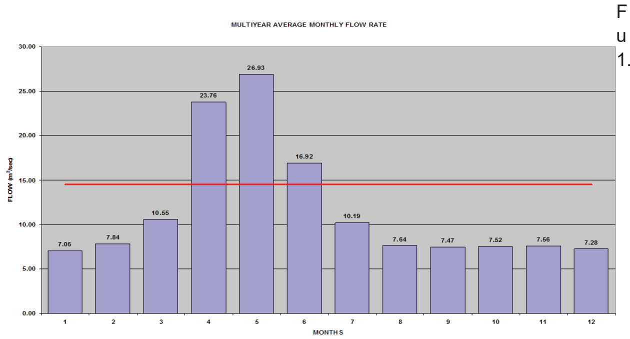


Fig-ure 1.

Another major blunder is that all characteristics of the selected turbines are, in most cases, not taken into account when selecting the HPP design flow. Namely, the technical minimum flow of the turbines, that is different for different-type turbines, is not taken into consideration. Minimum technical flow of the turbines is given in the table below.

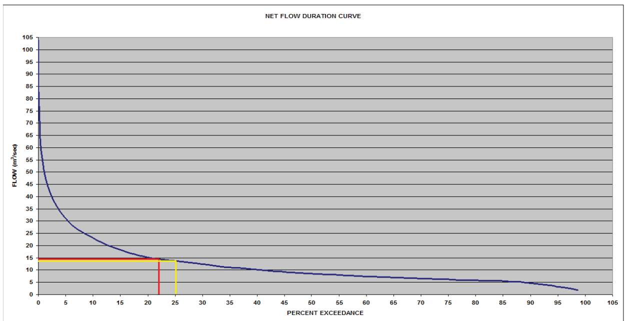
Turbine type	Qmin (% of Qdesign)
Francis	40
Ossberger	6
Pelton - 1 nozzle	12
Pelton - 2 nozzle	10

of the turbine minimum technical flow, at which, for less flow, a turbine shall stop; the turbine downtime probability increases due to the low flow in turbine. The simulation results have proved that when selecting the design flow that is more than certain marginal value, the average annual energy production will slightly increas-ing or not increase at all, whereas the hydropower unit's value will con-siderably increase. In other words, further increase of the tur-bine's design flow loses its significance.

2. Basic principles of determining the HPP design flow

According to the generally recognized principles, the HPP design flow shall be determined using the HPP net flow (river actual flow minus environmental flow) duration curve (Figure 2).

Figure 2.



For building a flow duration curve, it is essential to gather infor-ma tion on at least 30-year daily flow of the river or, if not available, to identify the selected river flow based on the similar river data, which is related to additional funds. This method is sometimes re-jected for costs purposes and, therefore, the design flow is selected in-accurately.

The design flow is considered economically justified, provided that the design flow for all hydropower units of the HPP is ensured for at least 60 days, which on the HPP net flow duration curve cor-responds to 16.5-17% exceedance. The simulation results have proved that this is not always applicable. Namely, in case of selec-tion of two equal-capacity Francis-type turbines, the de-sign flow of the cost-efficient HPP shall be placed on the HPP net flow duration curve within the 22-25 percent exceedance interval, as shown in figure 2. This is quite logical, since the spring water abundance period mainly lasts for almost 90 days.

3. Alternatives for increasing the HPP average annual energy production

Increase in the HPP design flow aims at increasing the average an-nual energy production. However, as mentioned above, this some-times does not yield the desirable result. There are two alter-natives for increasing the HPP average annual energy production. The first one implies increase of the number of turbines or applica-tion of low design flow turbines, which will reduce the hydropower unit's down-time losses. However, it is less justified from the eco-nomic point of view. The second alterative, that is more economi-cally justified, requires rejection of the traditional method of turbine selection.

Two equal-capacity Francis-type turbines are traditionally se-lected for the medium-head HPPs. This is justified for two reasons: 1. turbine service in the operation process becomes more easier; 2. Francis-type turbine has relatively high efficiency on the design flow. However, it is not taken into consideration that the minimum technical flow of this type of turbine makes 40% of the design flow and, for the flow lower than that, the turbine is stopped. In other words, the hydropower unit downtime and, in case of run-of-the-river HPPs, idle discharge of the water resources, are the case. Dependence of the turbine efficiency on the flow passing through the turbine, which is sharply decreasing for the low flows (Figure 3). and, consequently, resulting in reduction of the HPP energy pro-duction, has not been taken into account either.

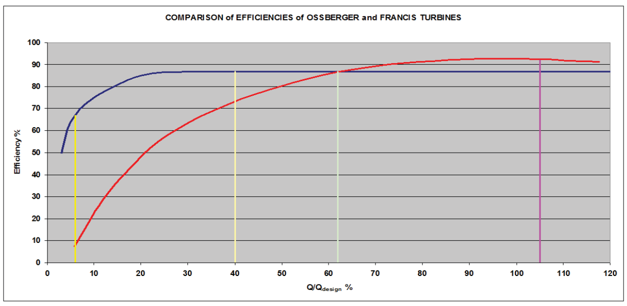


Figure 3.

The results of the HPP daily energy production simulation has proved that it will be possible to more efficiently use the water re-sources, provided that we break the common practice and reject the use of two identical turbines. Two variants have been con-sid-ered for one and the same design flow during simulation: 1. two units with Francis-type turbines and 2. one unit with Francis-type turbine and one unit with Ossberger-type turbine.

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The minimal technical flow of the Ossberger-type turbine makes 6-7% of the design flow; its efficiency vs. flow curve is uniform in the flow broad diapason and up to 62% of the design flow exceeds the Francis-type turbine efficiency (figure 3). This means that within 6 - 62% design flow range, the Ossberger-type turbine can produce more electric power than the Francis-type turbine within 40-62% design flow diapason.

In line with the aforesaid, turbine control has been envisaged during simulation. According to it, in case of simulation of the second variant, when the HPP total flow is lower than 62% of the design flow, then only the Ossberger-type turbine unit is operating. When the HPP total flow exceeds 62% of the design flow, then the Francis-type turbine starts operating, whereas the Ossberger-type turbine wicket gate control is executed so that the Francis-type turbine be provided with the flow equal to up to 105% of the design flow, since, in this case, the Francis-type turbine has more efficien-cy and more energy can be produced.

Conclusion

The simulation results have proved that the HPP average annual energy production for the second variant has increased by 10-12%; the installed capacity factor has increased and, in other words, the HPP project has become more cost-efficient. It is possible to further increase the average annual energy production through optimal selection of correlation of capacities of the Ossberger and Francis-type turbines, which depends on the specific project location, its river flow duration curve. Selection of optimal correlation of capaci-ties using developed software is not associated with any problems..

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