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# Hydro energy potential of cooling water at the thermal power plant

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ABSTRACT

The hydro energy of the gravity water flow from the coal-fired thermal power plant units to the river in an open cooling system of turbine condensers is determined. On the basis of statistical data for a long time period, the water net head duration curve due to the river annual level change, as well as the reduction of the hydro energy potential due to the thermal power plant overhauls periods, are evaluated in the case study of the Thermal Power Plant "Nikola Tesla B" in Serbia. A small hydro power plant is designed for the utilization of this hydro energy, and the economic benefits of the project are calculated. The internal rate of returns and pay back periods are calculated in dependence of the electricity price and total investment costs. The increase of profitability is assessed, bearing in mind that the plant might be realized as the Clean Development Mechanism project according to the Kyoto protocol. The obtained results show that the project is economically attractive, and it can be carried out with standard matured solutions of hydro turbines available at the market. Even for the relatively low electricity price from small hydro power plants in Serbia of 0.08 €/kW h the internal rate of return and the pay back period are 17.5% and 5.5 years.



## 1. Introduction

Natural hydro energy sources of rivers are widely used for the electricity production [1]. However, the exploitation of large hydro energy sources is mainly saturated, especially in developed countries. Further construction of large hydro power plants (HPP) is often burdened with the unacceptable high investments, and/or undesirable environmental consequences. Hence, in recent years, a wide interest and activity is directed towards the utilization of energy potentials of small streams, and building of small HPP [2–4], as well as towards other natural hydro power sources, such as sea waves [5]. Besides these natural sources, there is also potential to utilize hydro energy in technical systems. Generally, such solutions must a priori satisfy several conditions: they should not violate the technical system safety, they must be environmentally acceptable, and they must be energetically and economically beneficial.

Recently, a few projects considered the utilization of the hydro energy of the turbine condenser cooling water at thermal and nuclear power plants. Wherever possible the water for the turbine condenser cooling is supplied from and returned to a natural source, such as a river, lake or sea. The cooling-water flows from the thermal or nuclear plant back to the natural water source due to gravity since the discharge of the cooling water at the plant is at a higher elevation. The hydro energy of this return cooling-water flow can be utilized for the electricity production in a small HPP. Since the cooling-water flow is the necessary prerequisite for the thermal or nuclear power plant operation, its residual energy (that is always available during plant operation) can be regarded as renewable. For example, a HPP with a generation capacity of 7.5 MW uses the available hydro energy of the sea water, which serves as a coolant for eight units of a thermal power plant (TPP) in South Korea [6]. Also, a HPP with two hydro turbines with capacity of 5 MW each, has been built at the Bulgarian Kozloduy nuclear power plant (with two units, the capacity of 1000 MW each) [7]. The HPP is operated by the cooling water from the Danube river.

The energy utilization of water stream that is returned from the technical system to the environment is also applied at the seawater reverse osmosis plants [8,9]. The energy of the brine stream at a high pressure is recovered by the hydraulic turbine at the plant outlet, where the turbine is directly coupled with the centrifugal pump that supplies the seawater to the desalination plant. Before the 1980s, Francis turbines were applied, but later on they were replaced by Pelton turbines, since they provide higher system efficiency. Recently, the so-called isobaric-chamber devices, or the

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pressure exchange devices have been introduced, in order to further improve the energy-recovery efficiency [9]. For the existing TPP, the main difficulty for the application of such devices is a large distance (tens of meters, or more) between the location of the cooling water intake, and the location of the cooling water discharge back to the river. The other major drawback for the application of the pressure exchange devices is a need for a large number of unites, since the water flow through one pressure exchange unite is below one cubic meters per second, while the cooling-water flow rate at the TPP is of the order of tens of $m^3/s$ (depending on the plant power). Obviously these issues should be the topics for further engineering investigation and development.

The purpose of this paper is to demonstrate and evaluate the hydro energy potential of the river water that is used for cooling of the turbine condensers at the TPP. The water is pumped from the river to the TPP condenser, and returned back to the river by gravity flow. The water-flow energy potential is determined by its net head and flow rate. While the flow rate of the cooling water is more or less constant, its net head significantly changes in time, depending on the river water level variations. The hydro energy of the cooling-water flow is available only during the TPP operation, while during overhauls and plant trips it is not available. The influence of the net head temporal variation and the annual TPP operational period on the energy potential of the cooling-water flow are evaluated in the case study of the thermal power plant "Nikola Tesla B" in Serbia. The calculation is based on statistical data for a period of two decades. A small HPP is designed in order to use the cooling water energy, and the economic benefit of the project is estimated.

## 2. Approach to the feasibility study of the cooling water energy utilization at a TPP

The utilization of energy of the cooling water gravity flow from TPP back to the river differs from the conventional utilization of the river stream energy in several issues. The cooling-water flow is practically constant during the TPP operation, since a large plant is designed for the base load production. It means that TPP operates at the design power and with constant operational parameters throughout the year, leading to a constant cooling-water flow rate. On the contrary, an available flow rate considerably varies for a conventional run-of-the-river HPP. Also, the cooling-water flow completely stops during overhauls or plant trips.

For a cooling water HPP, a net head is obtained due to the fact that the water level in the pool downstream of the TPP condensers has to be at a higher elevation than the maximum water-surface level of the recipient river. During the most time of the year, the river elevation is much lower than the above mentioned maximum, providing the head for HPP. On the other side, for a conventional HPP, the head must be provided by the dam.

Having in mind these differences the feasibility study of the cooling water energy utilization is performed through the following main steps:

- The duration curve for the gross head between the thermal power plant and the river water-level should be calculated, using the hydrological statistical data for the available time period.
- The head loss of cooling-water return-flow from the thermal power plant towards the recipient river should be calculated by taking into account the friction losses along the channel and local losses. Knowing the head loss, the available net head is determined.
- In general, the hydro turbine should be selected for the low net head and a high water flow rate. The minimal and maximal values of the net head, acceptable for the turbine operation, should be defined based on the turbine design characteristics.
- The electricity production should be calculated based on the annual net head duration curve, the maximal and minimal heads acceptable for the hydraulic turbine operation, the water flow rate, the total HPP efficiency (taking into account the efficiency of the hydraulic turbine, the mechanical transmission system and the electric generator), as well as reductions due to the estimated overhaul periods and plant trips.
- The civil work design should provide the site-location and dimensioning of the power house and appurtenant structures with the hydro-mechanical equipment, resulting with the capital costs, as well as the efficient construction management.
- The present value of the total costs should be determined based on the total cost of equipment, and civil work, and the present value of operational and maintenance costs. Also, the value of the annual electricity production should be calculated. The project profitability should be determined considering the pay back period and the internal rate of return.
- Since the project contributes to the reduction of the carbon dioxide emission and it will be performed in the non-Annex I country to the United Nations Framework Convention on Climate Change, the benefits of its execution within the framework of the Clean Development Mechanisms of the Kyoto protocol has to be considered.

The procedure described in this paper is applied and evaluated to the real case of the open cooling water system at the coal-fired thermal power plant, as an example of the project implementation.

## 3. Cooling water system at the thermal power plant

Utilization of hydro energy of the water flow for the cooling of a turbine condenser is studied for the case of the coal-fired TPP "Nikola Tesla B" in Serbia. The plant has two identical units with the power of 620 MW each. The plant thermal unit has two condensers, the main one for the condensation of steam that exits from the main turbine, and the auxiliary one for the small turbine which is a prime mover for the steam boiler feedwater pump. These condensers are cooled with the water from the Sava river (Fig. 1). The cooling-water flow is provided by two parallelly connected pumps. After passing through the main and auxiliary condensers, the cooling water is collected in a water pool from which it spills, and by gravity flows back to the river. The head, resulting from the difference between the pool elevation and the river level, and the considerable water flow rate of 20 $m^3/s$ (per each unit), provide an energy potential that can be utilized by a small HPP. The cooling-water flow rate is practically constant, while the water head depends on the river water level, ranging between 69 m and 78 m above the see level, as indicated in Fig. 1. The water levels of the Sava river at the TPP site-location are recorded during the 20 years period, from 1986 till 2006.

Concrete buried channels, conveying the cooling water from the TPP pools towards the existing outlet structure at the river bank, are shown in Fig. 2. There are four such channels, one per each of the two existing units, while the other two channels were built for another two planned units. At present, the construction of one additional (third unit) is in preparation, and the hydro energy potential of the cooling water for this unit is also taken into account in this study. All channels have the same quadratic $3\ m \times 3\ m$ cross-section, while their lengths vary, due to the different distances between the TPP units and the river bank. A planned location of the small HPP site at the river bank is also presented in Fig. 2.

## 4. Estimation of net head

The gross water head $H_g$ is represented by the difference of the upstream $H_{uwl}$ and downstream $H_{dwl}$ water levels. The upstream