STUDY OF POWER CAPACITY THROUGH THE AUXILIARY WATER FLOW OF THE IGARAPAVA DAM FISHWAY

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Abstract. *The legislation of some brazilian states predicts the study and, in case its necessity is determined, obliges the construction of fishways in hydroelectric power plants, as a way of reducing the impacts caused by barriers on fish migration. Thus, different types of fishways, such as fish ladders and fish lifts have been implemented in the country, just as it has been done in other parts of the world. Besides having the knowledge on the biological characteristics of the fish species which will use the mechanism, fishways, in order to be efficient, must attract fish to its entrance and allow them to swim against the flow until they reach upstream levels of the barrier, where the fish can continue on their route. Therefore, it is of an extreme importance that the entrance of the fishway structure is facilitated, what can be accomplished with the liberation of a water flow close to this entrance. However, the deflection of this auxiliary flow, known as attraction flow, causes a decrease in the flow available for energy generation, which can represent a significant power loss in some dams. This paper presents a technical and economical study of the insertion of a small-size turbine on the attraction system of the fish ladder installed in the Igarapava Hydrolectric Power Plant (IHPP), on the Rio Grande, as a way of recuperating the energetic potential of the flow deflected for fish attraction.*

Keywords: water power plant, fish passage, attraction flow, energy regeneration, power generation through auxiliary water flow

1. Introduction

Although the water flow descending through a ladder type fishway's chute promotes an attraction, it is not always sufficient for fish orientation towards the entrance, creating a necessity of a complementary water discharge next to this entrance. This additional flow has the objective of establishing sufficient attraction so that the fish can find the mechanism's entrance. The insufficient amount of attraction is presented as one of the main factors which cause the malfunctioning of fishways (Clay, 1995, Lewis & O'Brien,1999 e Larinier, 2001).

The attraction flow, also known as auxiliary water flow is equivalent to a part of the inflow, which, in some cases, can represent a significant value relative to the overall available flow (Pavlov, 1989). This "water loss" and consequent reduction on energy generation can mean significant economical values, which can impede the undertaking, mainly considering small plants (Ferreira, 2004).

With the objective of identifying the impact of fishway implementation for fish passage in a dam, the necessity of a study which quantifies the power losses relative to the mechanism's installation, is created. This loss is strongly related to the water volume available downstream for fish attraction relative to the overall inflow available for the dam.

This paper proposes the study of an alternative of power generation through auxiliary water flow in the Igarapava Hydroelectric Power Plant (IHPP), where the possibility of using this flow for power generation through turbines will be analyzed, as an alternative for power recuperation. The total generation loss in the IHPP and the capacity of recuperating this lost power considering the hydraulic efficiency of the attraction system, and the efficiency of the generation unit used in the energy recuperation system, will be evaluated.

2. Characterization of the IHPP

The Igarapava Dam is located on the Rio Grande, between Minas Gerais and São Paulo States, ranging the Conquista and Sacramento counties (MG), and Igarapava and Rifaina (SP). It belongs to the partnership formed by five major companies: Companhia Vale do Rio Doce (38,145%), Companhia Mineira de Metais (23,9346%), Companhia Siderúrgica Nacional (17,924%), Companhia Energética de Minas Gerais-CEMIG (14,50%) and Mineração Anglogold (5,50%), as informed by the official report "Boletim de Engenharia n° 134" from ANEEL (ANEEL, 2004).

The IHPP is a run-of-river plant with a reservoir of 36,51 km² of flooded area, with an average accumulated water volume of 234,5 x 10^5 m^3 . The uncontrolled storage operates with a normal maximum water level in an elevation of 512,00m and normal minimum water level in an elevation of 511,50m.

The earth dam, Fig.1, is 740m long in the right bank, and 125 meters long in the left bank, with a 10 meters wide crest with a maximum of 32 meters in height on the right bank, and of 10 meters on the left bank. The surface spillway, located on the river course is equipped with 6 sector gates with 13,5m in width and 18,30m in height. The enclosed type powerhouse contains 5 generation units with Bulb Kaplan turbines, rotational velocity of 112,5 rpm that impounds 275 m^3/s at nominal flow condition under a total maximum head of 18,30 meters, according to the “IHPP Special” on the Estado de Minas newspaper (Jornal Estado de Minas, 1998).

Figure 1. Aerial View of the IHPP, on the Rio Grande.
Source: COPPE-Bira Soares- Estilos e Projetos Magazine- n° 11 - 1998/99

According to the IHPP’s partnership nation wide website, Igarapava was the first plant ever to use the Bulb type generation units in Brazil, developed with the objective of making technically and financially possible the power generation by low head dams. Each turbine has a nominal power of 42 MW, putting in action synchronous generators with a nominal power of 44,2 MVA (power factor of 0,95), therefore executing a total power of 210MW. The average firm power is of 129,7 MW. The plant’s nominal tension is 6,9 kV.

Three out of five units became operational in the first semester of 1999, one in July-1999 and the last one in September-1999, when the plant reached its full capacity (CEMIG /Infoinvest, 2004).

For the energy flow produced in IHPP, the substation which connects the plant to the distribution system is of conventional type.

2.1. The fishway

In 1999, a fish ladder was installed on the left bank of the Igarapava Dam. The vertical-slot fish ladder is 282 meters long and has a slope of 6% and 87 dissipation pools, distributed in three sections, whose connection is made by two curves (Fig.2).

The fish ladder was constructed in four main parts; the main structure, formed by the slots and pools, the entrance channel with 16,6 meters in length starting in an elevation of 493,00m, connecting the structure with the dam’s tailrace, the exit channel, with 27 meters in length starting from an elevation of 509,70 meters, connecting the structure with the reservoir, and the auxiliary flow system, subject of the study; alternative of power generation through auxiliary water flow (Hidricon, 1998)

Figure 2. Aerial view of the fish ladder in the IHPP
Source: Companhia Energética de Minas Gerais - CEMIG

2.2. The auxiliary water system of the Igarapava's fishway

The auxiliary water system for fish attraction is basically consisted in a conduct positioned parallel along the ladder, which conducts the volume taken from the floor of the fish ladder outtake channel, releasing it through a diffuser under the intake channel's bed.

The water intake, located on the floor of the outtake channel, is divided in two parts. The upstream screen is 2,40 meters wide and 9,0 meters long with a conduct of 1,0 meter in diameter and 31 meters in extension and the downstream screen is 2,0 meters wide and 4,80 meters long with a conduct of 0,7 meters in diameter and 10,5 meters in extension. Along the latter, a butterfly valve with 0,6 meters in diameter can also be found, with the objective of regulating the flow velocity next to the monitoring dial. These conducts, which were described above, are joined in a valve's well, where the system's main conduct starts, with a diameter of 1,10m and a length of 283m. The valve's well, where the conducts are connected, is shown on Figure 3.

Figure 3. Valve's well for the connection of the auxiliary water intake conducts

Under the screens, deflectors with a "U" profile are positioned, with the objective of uniform the velocity distribution along the screens. The both supply conducts also have screens in their intakes.

In the entrance area of the mechanism, the attraction water supply conduct is reduced to 1,0m of diameter which finds a butterfly valve with equal diameter after 7,0m.This valve regulates the system's flow. It is located inside an inspection well, with approximately 3,0m in width, 5,0m in length and 10,0m in height. Immediately past the valve, the conduct is enlarged to 1,40m in diameter and 3,0m in length, with 22 orifices with 25 cm in diameter, symmetrically displayed in the inferior part of the conduct, which has the function of flow liberation.

The orifices, the attraction flow and the water intake go through a deflector and a screen (3,0m in width relative to the intake channel's width and 8,0m in length) for energy dissipation and necessary alterations of the flow characteristics for fish attraction.

3. Evaluation of the power costs relative to a fishway

Although the water flow descending a ladder type fishway's chute can attract fish, it is not always sufficient to orient fish towards its entrance. Therefore, a necessity of complementary water discharge next to its entrance is created. This additional flow has the objective of establishing sufficient attraction so that the fish can find the fishway's entrance. According to Clay (1995) e Larinier (2001), the insufficient amount of attraction is one of the main factors which cause the malfunctioning of fishways,

The attraction flow, also known as auxiliary water system (AWS), corresponds to a share of the dam's inflow, which in some cases can represent a significant value of the available flow. This "water loss" and consequent power generation reduction can mean considerable economical values, even able to impede the implementation of the undertaking, mainly if small plants are considered.

With the objective of identifying the impact of a fishway implementation for fish passage in a dam, a necessity of a study which quantifies the power losses relative to the mechanism's installation is created, strongly related to the water volume available downstream for fish attraction relative to the overall flow available for the dam (Magalhães,2004).

This paper proposes the study of an alternative of power generation through auxiliary water flow in the IHPP, where the possibility of energy generation through this flow will be analyzed, as an alternative for power recuperation. The total generation loss in the IHPP and the capacity of recuperating this lost power considering the hydraulic efficiency of the attraction system, and the efficiency of the generation unit used in the energy recuperation system, will be evaluated.

In order to study a possible alternative of power generation through auxiliary water flow in a fishway, a series of initial consideration must be taken into account. The alternative of power generation through auxiliary water flow must be considered as a small generating unit, where the restrictions of energy generation are related to the environment components, and therefore, all the generation plans must be directed in order to respect these limitations. The operation time of this unit must be, at least, equal to the operation time of the fishway. Besides, the power generated through the recuperating system must be connected to the dam site generation.

The method used consists in promoting the simulation of an alternative of power generation through auxiliary water flow in the fishway until a maximum power value; proportional to the maximum flow used by the fish attraction system, is reached. This way, a matrix which will provide the data indicating the power benefits corresponding to each rate of regeneration can be identified.

Considerations for this simulation:

. The inflow is 6m^3/s, corresponding to the maximum attraction flow of the Igarapava Dam's fishway;

. The head is 18,30m, corresponding to maximum differential head during normal operation;

. The flow data used initially to calculate the average power generated by the Igarapava Dam is the daily average flow series of 2001 year;

. For the determination of the power recuperation rate through the fish attraction water system, the simulation chosen was carried for a twelve months system operation.

The data to be used is shown on Fig. 4 as follows. The assessment of the hydroelectric power generated at the Igarapava Dam was done for three different hypothetical situations. First, the average power generated by the Igarapava Dam was assessed without the fishway's operation. As a second hypothetical situation, the power capacity of the Igarapava Dam was assessed considering the fishway's operation. And finally, the hypothetical situation of power generation by the dam, with the operation of the fish ladder and the addiction of a special recuperating turbine unit, supposedly installed next to the fishway's attraction system.

The power generated (P) was calculated by Eq.1:

$$P = g.Q.H.\eta \qquad (1)$$

Where:

P - Power (kW)
g - Acceleration of gravity (m/s^2)
Q - Discharge (m^3/s)
H - Head (m)
η - Overall efficiency of the generating group (turbine/generator)

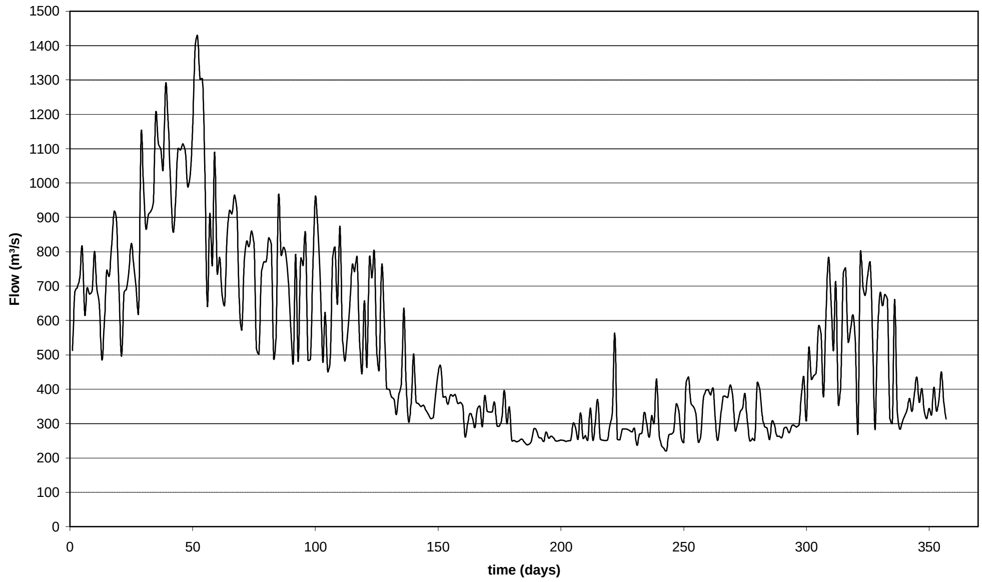

Figure 4. Daily Average Flow Series from Jan. 2001 to Dec. 2001

For the second hypothetical situation, when the operation of the fishway is considered, the flow of $6{,}0m^3/s$ was subtracted from the overall available flow, so as to obtain the power loss percentage of the total intake flow.

The values for the third hypothetical situation, considering the proposed power recuperation, were obtained repeating the procedures used for the second situation, adding the generation by the special turbine. In this case, using the Eq. (1), a turbine/generator efficiency of 87,5%, liquid head of 16,10m subtracting the head loss of the auxiliary system components and a constant flow of $6m^3/s$ were considered. This way, the average power generation was calculated for each one of the hypothesis.

The results obtained in the simulation are presented in Fig. 5, as follows.

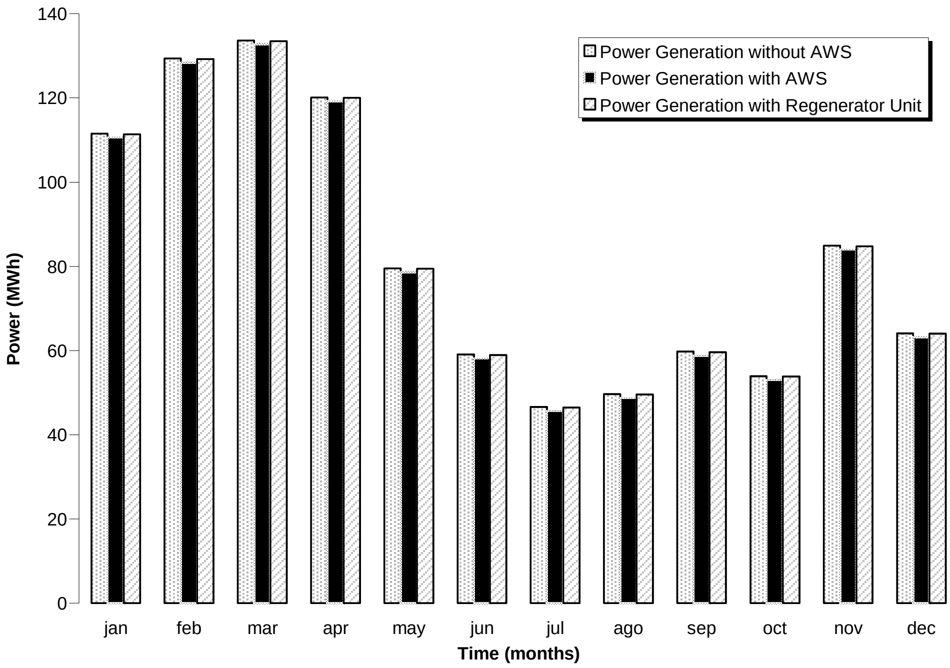

Figure 5. Results of the simulation of power generation throughout the year of 2001, under the 3 hypothesis of operations: without the AWS (auxiliary water flow), with the AWS and the operation considering the power recuperating system.

Calculating the power generated for each simulation hypothesis, it is observed that, for the simulation of the power generation throughout the year of 2001, under the 3 hypothesis (operation without the fishway, with the fishway and the operation considering the power recuperating system), we have:

. The average power obtained in the dam without the operation of the fishway is 82,65MW;
. The average power obtained in the dam with the operation of the fishway is 81,71MW, 1,14% less than the generation without the operation of the fishway;
. The average power obtained in the dam with the operation of the fishway and the power recuperating unit is of 82,54MW, 0,13% less than the maximum generation without the fishway operation.

The recuperating potential is of 88, 6% of the power supposedly lost in the fishway.

4. Discussion and Final comments

The developed studies, in a primary level, provided an overview which allows the power evaluation of the impact of the fishway operation in the Igarapava Dam generation. It is important to emphasize that the study has considered a continuous operation of the fishway throughout the year, foreseeing the possibility of interruptions out of the migration period.

The results presented show that it is possible to obtain a recuperation of potential energy flow spent in the fishway. Concerning the analyses, the power recuperation was of approximately 88,6%.

It can be concluded that, from the results presented, the insertion of a small power generation unit next to the fishway, would present a series of advantages, mainly concerning the possibility of power generation in situations of reduced flows in a high performance point. This suggests the high interest of studying the possibility of installation of an attraction flow system of larger capacity in future undertakings. This strategy could be advantageous for the improvement of attraction of the fishway.

Based on the presented results, the operation of the auxiliary water system can represent a power gain instead of a power loss, considering the power recuperation of the attraction flow. If the energy generated by the proposed special turbine could be negotiated as a small hydropower plant energy, therefore with a higher value, the capacity of the economical recuperation concerning the fishway ‘s loss could be doubled.

It is also important to emphasize that the analyses performed on this paper did not contemplate a power operation of the reservoir. Even though the Igarapava Dam is a run-of-river plant, it is possible to utilize a small reservoir volume in order to increase the power generation capacity of the Dam.

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6. Responsibility notice