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ANALYSIS OF POWER DISPATCH IN THE SHORT TERM, IN TUCURUÍ HYDROELECTRIC PLANT, THROUGH LOSSES IN THE GENERATION PROCESS

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Abstract. *This paper aims to carry out a general analysis of the dispatch in the short-term schedule of the Tucuruí hydroelectric plant. The problem has been approached from the standpoint of the losses existing in the energy conversion process. The losses were considered due to friction in the internal flow system adduction, raising the level of downstream due to the water flow and the turbine operation outside its maximum efficiency. Such losses were written in the form of loss of power. From these definitions the real losses were calculated based on historical data generation plant, for a defined period, according to a specific procedure for the calculation. From the curve fitting, adjusted to set points, it is possible to observe the variation of total losses due to the power plant dispatch. This allows the evaluation of the ideal number of units for operation in order to minimize losses, and the relationship between the number of generating units in operation and the power losses generated and dispatched. The results of this case of study show the importance of the method to defining the number of generating units and the respective operating points, since, according to the studied plant, show the great potential of economy and efficiency of the power generation process with savings equivalent to an installed capacity of several hydroelectric plants. The study also aims to draw attention to the need for guideline from regulatory agencies focused on energy optimization and rational use of water resources that could be contemplated as a financial compensation, like the improvements incorporated into the assets of the hydroelectric power plants, consolidated practice by the National Electricity Agency (ANEEL), in Brazil.*

Keywords: *Optimization, Power Dispatch, Losses.*

1. INTRODUCTION

Electricity is included in modern society as a major source of energy. In addition, the demands for electricity continues to grow and to supply it is necessary massive investments in generation, transmission and power distribution. Thus, the decision-making process in the energy sector is an important aspect because it can result in high financial, social and environmental costs (Oscullo, 2002). We note, therefore, the need for proper planning of the operation allowing the electric power generation is made based on the principle the efficient use of all resources that compose the system. There is still no agreement or broad treatise on the preservation and rational use of water. The most significant initiatives in this area focus on the World Water Forum that meets every three years, representatives of governments, international organizations, non-governmental organizations, financial institutions and industries, as well as scientists, experts in water issues, business people and academics. However, despite the participation of official delegations of several countries, it is not official event of the United Nations - UN (Silva, 2012).

Brazil can be considered as a privileged country in terms of availability of renewable resources for energy use. Among them, we highlight water resources, accounting for over 90% of electricity generation in the country (Brasil, 2007). The hydropower resources in Brazil, both in terms of its capacity already installed as your untapped potential, represent an asset of great strategic and economic importance. In North America, for example, about 70% of the potential is performed. Brazil, in his turn, has limited the exploitation of 25% of this potential (Faria Filho *apud* Kelman, 2007).

Since 2004, the generation, distribution, transmission and commercialization were separated product (energy) and services (transmission and distribution), aimed at introducing competition in the generation and commercialization. In general, the main objective of these reforms is to introduce market standards in the generation and supply of electricity, as well as improve the efficiency of generation, transmission and distribution (Sollero, 2004).

Society is currently seeking sustainable development, which is related to the exploitation of natural resources and environmental protection, aiming at the same time improve the human condition and preserve biological systems. There is a global trend to combat wasting through efficient equipment and new consumer habits. Moreover, economic constraints lead us to the rational use of available capacities, instead of building new generating units and transmission systems. To adapt the electrical system to the new need for modernization, energy conservation programs have been created through the National Electricity Conservation Program (PROCEL) and others research and development programs (Pinto, 2001).

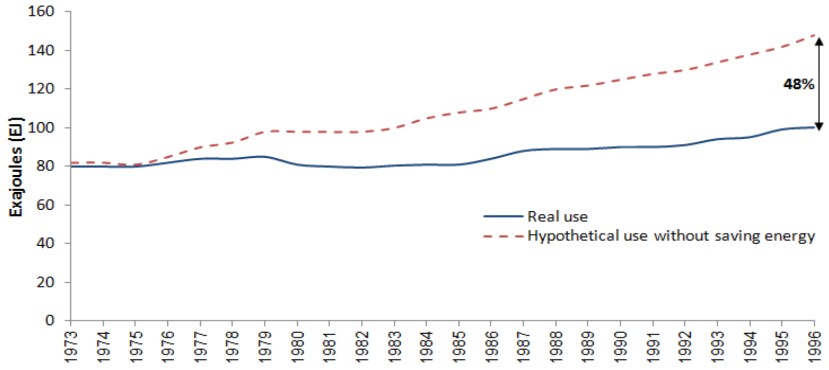

Figure 1. Gain of efficiency in OECD countries, 73 to 98. Source: Adapted from Goldemberg, 2007

As an example, Fig. 1 shows the energy consumption of countries belonging to the Organization for Economic Cooperation and Development (OECD), by the year 1996. We can see that, in about 20 years, through rational consumption and combat the waste, it was possible to achieve savings of almost 48% if no measures had been adopted. Thus, we note the importance of rational use of energy, which in the case of hydroelectric plants is related to the efficient use of water resources.

In this context is the importance of knowing, in the dispatch process of hydroelectric plants, existing losses in power generation. Considering that, from this knowledge may be possible the establishment of improvement plans to minimize these losses. The objective is to evaluate the current power dispatch method in the short term, of the Tucuruí hydroelectric plant, with respect existing losses in the power generation process, to base the implementation of programs that seek to optimize this process and the use of hydric resources. Then, from this need, it is proposed a stimulus of the National Electricity Agency (ANEEL), as done about the improvements incorporated in the assets of the facility.

2. CHARACTERIZATION OF LOSSES IN POWER DISPATCH

In the context of sustainable development, the exploitation of natural resources has a central importance. On this, hydroelectric plants are inserted, whose principle is the conversion of the energy contained in the dammed water into electricity used by industries and residency. This conversion is to be carried out rationally and optimally taking into consideration the operational aspects and contributing to the efficient use of energy in its different forms. In the case of hydroelectric plants, there is a factor so-called efficiency which is responsible for determining the amount of energy that was really transformed. Thus, the increased efficiency of transformation implies a greater economy by minimizing losses. Hydroelectric plants generate electricity from hydraulic potential energy transformation using the turbine-generator set, and the efficiency of the transformation of energy is heavily influenced by the operating point of these generators (Bastos, 2004).

The efficiency of a generator can be expressed in terms of the effective portion of the transformation of hydraulic energy, accumulated in the plant's reservoir, into electrical energy or active power delivered to the consumer. They may also be associated with the various losses which occur due to factors such as changes in upstream and downstream levels, pressure losses in penstock and the turbine-generator efficiency, whose losses are caused from the variations of flow (Bastos, *et al.*, 2004). In this sense, any percentage that can improve the efficiency of conversion of hydraulic energy into electrical energy is seen very favorably, especially when considering the huge hydraulic generating capacity installed in the country. In an estimation exercise (Bortoni, *et al.*, 2002) in a country like Brazil, where, in the beginning of year 2000, annual energy generation was around 360 TWh, an improvement of only 1% in the efficiency of the generating units would result in a gain of 3.6 TWh, which equals approximately the power demanded in a city with more than one million people.

The generators have a large variation in their efficiency over the operating range, generally around 10%, so that the choice of the operating point of each generator set becomes a key issue in optimizing the plant efficiency (Ohishi, 2001). Several studies have been developed to solve the pre-dispatch problem. The papers about generation optimization in hydroelectric plants are developed mainly under the aspect of minimizing the losses associated with the generation process, minimizing turbined flow and maximizing total efficiency of the generating unit. From the determination of the function of losses, called the objective function, then it proceeded to apply various methods in order to function optimization through mathematical programming.

Ohishi (2001) describes that most pre-dispatch models presented in the literature consider a hydrothermal system in which the hydroelectric generation is valued by replacing thermal generation. However for purely hydroelectric systems is necessary another view that this case is the consideration as optimization criteria, the minimization of losses in operation, since this approach seeks to maximize the efficiency of hydroelectric plants. In this paper, the pre-dispatch model consists of a two-subproblems solution that refers to determining the number of machines in operation and each power generating unit. The model solution is made by Lagrangian Relaxation and a heuristic approach.

In the paper of Santos (2001) the optimization of the function of losses is described in a pre-dispatch problem, considering as criteria losses associated with generating efficiency, elevation of downstream level and hydraulic losses due to flow. The model is based on two solutions of issues, the number of units in operation is formulated based on integer variables and the power dispatch, which determines the economic dispatch for each time interval, formulated by real variables. The first one is solved by genetic algorithms, because it is a combinatorial problem, and the second is solved by Lagrangian Relaxation.

Provençano (2003) makes an approach in two stages of pre-dispatch problem. Initially, establishes the relationship between the turbine-generator set of variables so that, thereafter, the optimization models can be studied. Losses in the turbine-generator set were considered as power losses per unit operating outside its maximum efficiency, elevation of downstream level and hydraulic losses in the penstock.

Arce Encina (2006) addresses the optimal dispatch problem of generating units adopting as criteria the evaluation of losses associated with the generation system, caused by rising tailrace level, by varying the hydraulic efficiency and the friction of water flow in pipes of the hydraulic system. It also considers other losses, which refer to the costs associated with starts and stops of the generating units. These two approaches are used for assessing the loss in generation process. From this function, a mathematical treatment is applied of the solution in order to function minimization.

Acosta (2008) developed a dispatch model of generation units at power plants that adopts the performance criterion the turbined flow every hour, the number of starts and stops and the combination of these. This approach makes determining function of losses a programming problem, combinatorial and non-linear, the solution can be complicated as the number of available generating units increases. In this paper, to solve the optimization problem is proposed the solution of the objective function by the Genetic Algorithm method.

Arce Encina (2008) uses a model solution to the objective function written in terms of losses associated with the elevation of downstream level, internal flow in the penstock and loss of efficiency due to operation outside the maximum efficiency point of the turbine. This approach leads to an optimization problem where the objective function to be minimized, comprising of entire and continuous decision variables, featuring a mixed-integer programming problem. This complication is bypassed by means of a heuristic approach that decomposes the original problem into two dispatch subproblems: units and loads. The first one sets the number of generating units that must operate every hour and the second one, the power units should generate every hour.

Kadowaki (2009) in his paper about generation programming in the short term, uses an objective function based on the sum of all losses in the form of power at each plant, in the adopted planning horizon. This approach aims to have a minimization problem for, applying Lagrangean, get the number of units committed to operate and their respective powers in each plant that composes a particular system.

2.1 Losses due to variations in the downstream level

The upstream level, over a hydrological cycle can vary greatly, in some cases the difference can reach up to 15 m. In this paper will not be considered variations in the upstream level, since in the short-term horizon, it remains practically constant. On the other hand, the downstream level, even in one day, can undergo considerable variation, due mainly to the turbined flow, according Ohishi (2001). We can express the power produced by a generator unit by means of the Eq. (1).

$$P = 10^{-6} \cdot g \cdot \rho \cdot \eta_T \cdot h \cdot Q \qquad (1)$$

where P is the power (MW), g is the acceleration of gravity (m/s²), ρ is the density (kg/m³), η_T is the total efficiency of turbine-generator conversion (%), h is the net head (m) and Q is the turbined flow (m³/s).

The net head h is given by the difference between the upstream and downstream levels, discounted hydraulic losses due to internal flow in the penstocks:

$$h = h_m - h_j - h_{AD} \qquad (2)$$

where h_m is the upstream level (m), h_j is the downstream level (m), h_{AD} is the losses due to internal flow in the penstocks.

The loss due to variations in the downstream level can be expressed, so as power loss:

$$p_{jN} = 10^{-6} \cdot g \cdot \rho \cdot \eta \cdot (\Delta h) \cdot Q_N \quad (3)$$

where p_{jN} is loss, in MW, due to variation of the downstream level with N machines.

$$\Delta h = h_j(Q_N) - h_j(Q_{min}) \quad (4)$$

where Q_{min} is the minimum turbined flow with N units in operation and Q_N is the flow of water turbined with N units in operation.

2.2 Losses due to Internal flow in the penstock

The hydraulic loss results in decreased of the net head due to pressure loss caused by friction of the water on the inner walls of the penstock and spiral casing. Several authors (Acosta, 2008; Arce Encina, 2008; Provençano, 2003; Santos, 2001) represent such loss as a function of roughness and dimensions of the hydraulic circuit as follows.

$$p_{aN} = 10^{-6} \cdot g \cdot \rho \cdot \eta \cdot (k \cdot Q^2) \cdot Q_N \quad (5)$$

where p_{aN} is hydraulic loss, in MW, due to N operation units; k is a constant that expresses the characteristics of the adduction system (penstocks and spiral casing), expressed in s^2/m^5.

2.3 Losses due to variations in turbine efficiency

The reduction in the conversion efficiency of the turbine-generator set may be expressed in terms of power, as was done by Ohishi (2001), as follows:

$$p_{rN} = 10^{-6} \cdot g \cdot \rho \cdot (\eta_{max} - \eta) \cdot h \cdot Q_N \quad (6)$$

where p_{rN} is the loss in MW, associated with variation in the turbine efficiency; η_{max} is maximum efficiency of the turbine and η is the efficiency of the current operating point.

2.4 Total losses

In order to evaluate the generation process it is possible determine losses, considering different operational settings raised by the data available in the plant, according the following procedure. The total power loss is calculated as the sum of the losses previously described.

$$p_N = p_{jN} + p_{aN} + p_{rN} \quad (7)$$

The procedure adopted to determine these losses consists in the variation of turbined flow from a minimum value until it reaches a maximum for a given setting units in operation. And for each turbined flow value the following calculations were made: a) annotation of the upstream level, b) annotation of the downstream level [$h_j(Q_N)$], c) calculation of hydraulic losses [p_{aN}], d) calculation of net head using Eq. (2), e) determination of the efficiency value (η) of the turbine through the hill curve, f) calculation of the total loss using Eq. (7). Starting from these points is performed a polynomial fit of the total loss (p_N) calculated according to the power generated at the plant, as shown in Fig. 2.

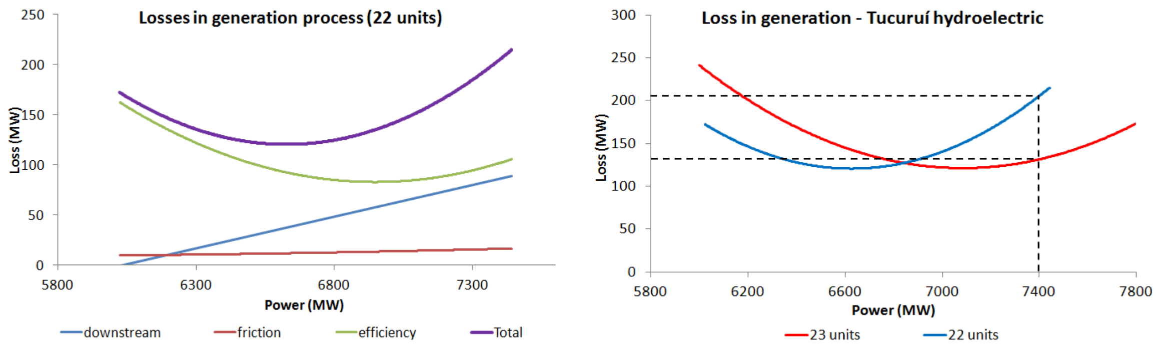

Figure 2. Curve of losses in the generation process and losses with different units committed.

In Fig. 2, first one graph, it is possible observe the three kinds of losses considered in this paper. The loss due to elevation of downstream level has a linear behavior in order that depends solely on the linear variation of the quantity level downstream. The loss curve for friction, as shown in Eq. (5), varies with the square of the flow. In the Fig. 2 chart, this curve looks like a straight, by virtue of their small change to the x-axis. This small inclination is due to the pressure loss constant k. The loss curve for efficiency turbine has greater influence on the total loss by being much higher than the other losses. Its quadratic form shows that there is an operating point that this efficiency loss can be minimized. This curve shape influences the total loss curve in order to give it the same way, showing that there is also a point of operation, in the dispatch mode, where the losses are minimal.

To plot the curves were used data loss calculated for a typical day in which a number of generating units of the plant was in operation. In the Fig. 2 we can see that the minimum loss that can be achieved is approximately 120 MW, while the demand is 6,600 MW.

In addition to the power generated, the loss function is also dependent on the number of machines in operation. We can see from Fig. 2, second one graph, that the power that must be generated by the plant, at a given moment, can be satisfied by 22 or 23 units, for example. In this case, to attend the demand of 7,400 MW, the choice of 23 generating units for operation ensures better energy use, with losses of 125 MW, compared to 205 MW of losses, with 22 units in operation.

As losses curves were shown for different numbers of units in operation, it is possible plot all the loss curves from 13 to 23 units in operation to assessment of the overall behavior of the plant units, as shown in Fig. 3.

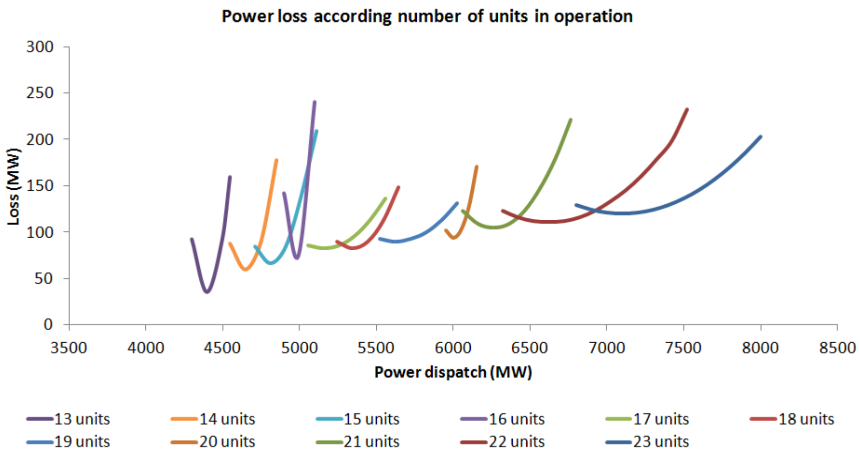

Figure 3. Losses in the generation, according to the number of machines and dispatched power

3. ANALYSIS OF LOSS IN PLANT GENERATION SCHEDULE

Two cases are analyzed to highlight existing losses in the process and optimization opportunity. In case 1, Tab. 1, with the real values of scheduled generation and that was attended in each specified hour is displayed.

Table 1. Generating predictive sample for a specific day.

Hour (h)	Power (MW)	Number of units in operation
06:30 – 07:00	6,550	22
07:00 – 07:30	7,250	22
17:00 – 17:30	7,000	22

Table 1 shows that there is considerable variation in power to be attended by the plant, by request of the National System Operator (ONS), each hour shown. Note, in Fig. 5, that from the demand of 7,000 MW is preferred to operate with 23 generating units. Whereas to attend the demand of 6,550 MW, operate with 22 units provides smaller losses.

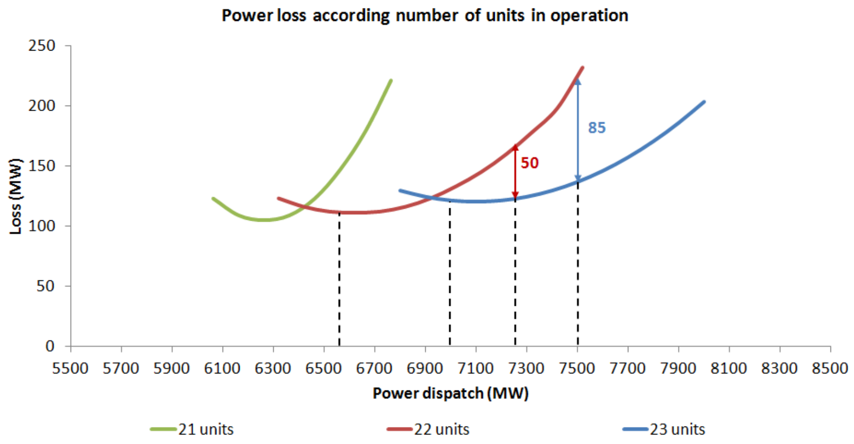

Figure 4. Losses in the generation for 21, 22 and 23 units in operation

However, the energy dispatched, in this particular day, was attended with 22 generating units at all times. Thus, as noted in the Fig. 4, by selecting an appropriate operating point of units, power would meet the required demand with a lower number of machines, avoiding losses in the range of 50 to 85 MW, in case of greater demands.

In another situation, the following schedule generation was attended by the plant according to the data shown in Tab. 2.

Table 2. Generating predictive sample for a typical day.

Hour (h)	Power (MW)	Number of units in operation
14:30 – 15:00	5,550	18
15:00 – 15:30	5,600	18
16:30 – 17:00	5,500	19

This schedule, as well as the previous, represents real demand emitted by ONS. In Tab. 2, unlike the other situation where the load variation is 700 MW, the difference in considered intervals is 100 MW.

In this case, three demands must be satisfied in the described time. Consider only the case of the demand generation 5,600 MW, which can be attended with 18 or 19 units. In this situation, 18 units have been committed, leading to a loss of 130 MW. As we can see in Fig. 5, if they were used 19 units, losses in generation would be 90 MW and can, then, avoided the waste of up to 40 MW.

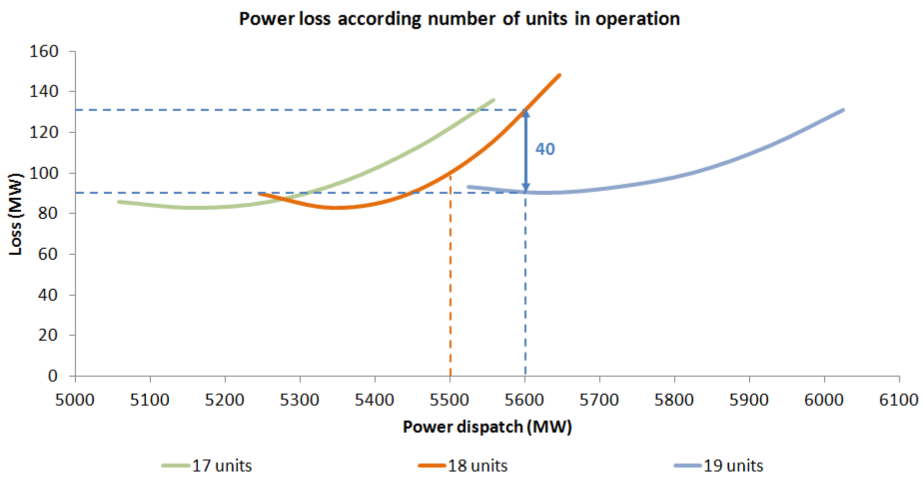

Figure 5. Losses in the generation for 17, 18 and 19 units in operation

Still observing Fig. 5, in order to attempt demand of 5,500 MW, from the standpoint of minimal losses, 18 or 19 units can be committed, since the losses at this point are equal.

4. CONCLUSIONS

In this paper it was possible to show the importance of knowing the power dispatch method in the short term, for a hydroelectric plant. We note that the losses in the generation process, here addressed as caused by the rise in the downstream level, friction on the inner walls in the intake system, and operating outside the maximum efficiency can be considerable and go undetected when the only goal is to meet the National System Operator, regardless of the operating point of the generating units. The choice of operating point, in practice, could mean an increase of energy to meet the needs of industries, residences, hospitals, etc., especially important in times of scarcity.

We can, moreover, highlight the importance of this analysis regarding to the use of the natural resource. The hydroelectric plants are generally designed to take advantage of source of potential energy available in nature. Thus, it is a question of social responsibility and respect for nature the use of this resource wisely, avoiding waste, especially considering the changes caused by the implementation of large projects like this.

Given the current shift in the paradigm of business management and the development of organizational thinking as the exploitation of natural resources and the importance given to environmental issues, we can consider this work as a starting point in Tucuruí power plant, for discussions over the use of water, as a raw material for the production process of the company. Since knowledge, in quantitative terms, the losses that can be avoided may cause positive changes to the enterprise, both as operational, financial and maintenance standpoint.

Financially, the return for the energy sold varies according to time of year and the market value of the unitary megawatt in that day. Thus, the estimate of this financial return opportunity can become somewhat representative of the reality. However, the energy sold outside contracts with electricity-intensive customers, follows the rules of free trade where the price is set by demand. For example, with the selling price of the unitary megawatt, in this environment, of R$ 10.10 the company could get a revenue of R$ 242.40/MW per day. Other way to understanding the return would be keep this potential energy for later use.

It is also possible to analyze the operation with minimal losses from the operational and maintenance point of view. The energy that is not transformed into shaft power, while passing through the turbine, can be divided into two parts: the kinetic energy, which is responsible for conducting turbined water for the tailrace, by the suction tube; and the energy transformed into other forms such as heat, noise and vibration. The latter two forms of energy can be observed by operators and maintainers nearby machines, featuring a worker's exposure situation risks of occupational diseases. Thus, reduction of noise and vibration coming from the inefficient transformation process in turbine, can lead to improvements in the operators and maintainers workplace.

We also note that even in the current context of respect for the environment, hydroelectric plants generally do not have electricity dispatch methods focused on the optimal use of water resources. And in particular, could result in competitive advantage and increased market value of companies, for example, on the stock exchanges.

In this study, is shown the importance of choosing the optimal point of the generating units for operation. Existing losses in the generation process, in this case, can become significantly high, compared in terms of power. This fact is because of the size of the plant, which amplifies the results, due to the 8,535 MW of installed capacity. In percentage terms, such losses may represent low values. However, if we compare their absolute values, become comparable to other hydroelectric plants. Thus, the elimination of losses in the generation process of Tucuruí Hydroelectric could represent, depending on the case, the brazilian generation plants as Coaracy Nunes in Amapá, Samuel, in Porto Velho and Curuá-Una, in Pará.

Therefore, we note the importance of this issue and especially the potential for improvements in existing power generation plants, especially considering a national panorama of scarcity energy to attend the growing demand in the country, a topic appellant in the Brazilian political scene. However, power generation companies have no guidelines focused at optimizing the generation. From this need, there could be stimulation of the National Electricity Agency (ANEEL), for example in the form of financial compensation, like the improvements incorporated in the assets of the facility, recognized by her. This measure could result in high productivity and consequently the possibility of redirection of large investments to other areas such as health, education.

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