Analysis of the Level-Release Polynomial from a Hydroelectric Plant

Ieda HIDALGO
FT, Unicamp
Campinas, Sao Paulo, Brazil
iedahidalgo@gmail.com

Secundino SOARES F.
FEEC, Unicamp
Campinas, Sao Paulo, Brazil
dino@cose.fee.unicamp.br

Darrell FONTANE
Civil Engineering, CSU
Fort Collins, Colorado, USA
fontane@engr.colostate.edu

João Eduardo LOPES
FEC, Unicamp
Campinas, Sao Paulo, Brazil
jelopes1@gmail.com

Marcelo CICOGNA
Anhanguera Educacional
Valinhos, Sao Paulo, Brazil
marcelo.cicogna@gmail.com

Donato SILVA F.
EDP Bandeirante Brazil
Sao Paulo, Sao Paulo, Brazil
donato.filho@edpbr.com.br

ABSTRACT

The mathematic representation of the tailrace elevation as function of the water release can be modified, for example, by the geomorphologic impact of large floods. The level-release polynomial from a hydroelectric plant is important information to computational models used for optimization and simulation of the power generation systems operation. They depend on data quality to provide reliable results. Therefore, this paper presents a method for adjusting of the tailrace polynomial based on operation data recorded by the plant's owner or company. The proposed method uses a non-linear regression tool, such as Trendline in Excel. A case study has been applied to the data from a large Brazilian hydroelectric plant whose operation is under the coordination of the *Electric System National Operator*. The benefits of the data correction are analyzed using a simulation model for the hydroelectric plants operation. This simulator is used to reproduce the past operation of the plant, first with official data and second with adjusted data. The results show significant improvements in terms of quality of the data, contributing to bring the real and simulated operation closer.

Keywords: Data Analysis, Hydroelectric Plants, Level-Release Polynomial, Tailrace Polynomial, Simulation Models.

1. INTRODUCTION

The objective of power generation systems operation planning is to ensure an economic and reliable operation policy for the system. In countries like Brazil this planning is characterized as a problem of dynamic optimization which is large-scale, interconnected, stochastic, and nonlinear. This presents a great challenge to electrical engineers, hydrologists and modelers.

In general, the energy planning is done with the aid of computational tools for optimization, simulation and streamflow forecasting. These tools manipulate data using mathematical models. For this reason, the data quality has great influence over the results of the planning. Sometimes, what explains the unexpected behavior of these models is the poor quality of data provided to them [1] [2] [3].

The need to monitor data is not restricted to large and complex systems for electrical generation. All measurements are prone to errors that can be either systematic or random. However, few articles have been published in the data consolidation area.

Lopes (2003) [1] mentioned that problems in the quality of the data used by the Brazilian energy sector may overestimate the energy available in the *National Interconnected System*. In this work, he concludes: "As far as discuss alternative models is important to correct the data used to represent the plants."

According to Lopes (2007) [4], "The lack of a single and reliable database for Brazilian hydroelectric plants is source of problems." In this work, Lopes makes a critical analysis of the data quality of Brazilian hydroelectric plants.

Diniz et al. [5] studied two mathematical models to represent the efficiency of turbine-generator units. To find the coefficients of the models, they used a linear regression technique on the points of the efficiency hill curve.

Hidalgo et al. (2009a) [6] described a data manager and a queries builder focusing on critical analysis of the data involved in the hydroelectric operation planning. This article also presents a correction in the level-release polynomial of a Brazilian plant using simultaneously the data manager, the queries builder and Excel.

Hidalgo et al. (2009b) [7] analyzed six functions that influence hydroelectric operation planning. For this, a data manager, a queries builder and a simulation model for the hydroelectric plants operation are used. This article shows that although each of these modules has a specific objective, they all can be used as tools for evaluating of data consistency.

Hidalgo et al. (2009c) [8] explored two applications of a simulator as a tool for data analysis of hydroelectric plants. The first application aims to reproduce the water discharge values sequence recorded by the plant. The second has a goal of reproduction of the sequence of generation values. The advantages and disadvantages of each application are discussed in this article.

Hidalgo et al. (2009d) [9] presented a method for calibration of the overall efficiency function from hydroelectric plants. Besides, this article shows a comparative analysis between the overall efficiency curve and the turbine efficiency curve.

Given the importance of data quality for power generation systems, this paper presents a method for analyzing and correcting of the level-release polynomial from hydroelectric plants. The procedures use the following variable data recorded by the plant: tailrace level and water discharge.

Initially, the production function is described. Then, the process for adjusting of the level-release polynomial is explained. After that, a case study is showed. Finally, an analysis of results and the conclusions are presented.

2. PRODUCTION FUNCTION

The most common formulations of the Brazilian system for hydroelectric operation planning focus on the production function. The goal of the production function, Eq. (1), is to quantify the power generation of a hydroelectric plant in terms of operational variables.

$$p = k \, . \, \eta_t \, . \, \eta_g \, . \, [h_{fb}(x) - h_{tr}(u) - h_{pl}] \, . \, q \tag{1}$$

where:

p	Is the instantaneous power obtained in the conversion process of the hydraulic potential energy to electrical energy (MW).
k	Is the gravity constant, multiplied by the water specific weight and divided by 10^6. Its value is 0.00981 (MW/(m³/s)/m).
$\eta_t \, . \, \eta_g$	Is the efficiency of the turbine-generator set in the conversion process of the mechanical energy to electrical energy.
x	Is the water storage in the reservoir of the plant (hm³).
$h_{fb}(x)$	Is the forebay elevation which is function of the water storage x (m).
u	Is the total water release of the plant, that is, the sum of the water discharge and the water spillage (m³/s).
$h_{tr}(u)$	Is the tailrace elevation which is function of the water release u (m).
h_{pl}	Is the penstock head loss which is function of the water discharge (m).
q	Is the water discharge by the turbines of the powerhouse (m³/s).

3. ADJUSTING THE LEVEL-RELEASE POLYNOMIAL

The adjustment of the level-release polynomial requires the data pairs "tailrace level and water release" recorded by the plant's owner or company for a selected period. The readings of tailrace level must have accuracy in centimeters without rounding. It is important that the selected period is recent to represent the current situation of the downstream river. It is also important that this period includes historical data on large floods in order to establish the function's maximum limits.

The data pairs "tailrace level and water release" are plotted on a graph resulting in a cloud of points. Using this set of points a polynomial function can be adjusted as can be seen in Fig. 1. In this case was used the Trendline tool in Excel. It is important that the polynomial is extrapolated up to the corresponding outflow for the maximum spillage capacity so that the valid range considers all the possible values of water release. It is also necessary to indicate the valid range of the function.

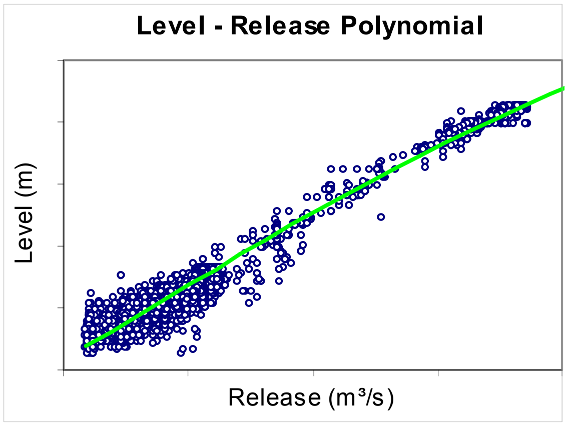

Fig. 1. Polynomial adjustment for the cloud of points from tailrace operation.

Since the level-release polynomial is adjusted to a cloud of points, it is interesting to take note of determination coefficient (R-squared) of the equation.

For some hydroelectric plants the elevation of the tailrace level also depends on downstream plant reservoir. In this case the plant can have more than one polynomial to represent the tailrace.

4. CASE STUDY

The proposed methodology has been applied to the data from a large Brazilian hydroelectric plant whose operation is under the coordination of the *Electric System National Operator*. The results are presented in Fig. 2.

This figure shows, for the analyzed plant, a comparison between the official and the adjusted level-release polynomial. The small circles are the data pairs "tailrace level and water release" for the period from September 1, 2006 to August 31, 2007. This period corresponds to a complete year, reflecting the hydrological seasonality and including one of the largest floods that occurred in January 2007.

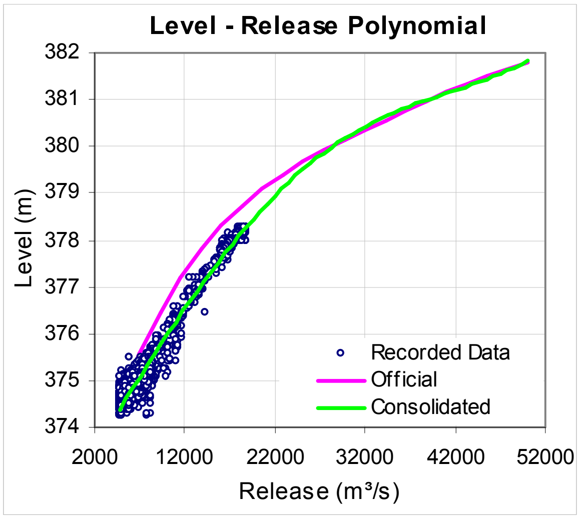

Fig. 2. Correction of the level-release polynomial.

For the adjustment process, the following technique was used. First, a polynomial was fitted to the cloud of points available in the database. According to the cloud of points, the valid range of this polynomial was from 374.76 to 378.64 m. This polynomial needed to be extrapolated to the spillage maximum capacity, 50,000 m³/s. However, there were no records in the database for the range from 378.65 to 381.77 m. Therefore, the points of the official polynomial for this interval without records were added to the graph and a second polynomial was adjusted to the complete range.

The benefit of this adjustment technique is the attainment of a single polynomial which is both coherent to the points “tailrace level and water release” of the database and coherent to the interval in which there are no records of operation.

According to Fig. 2 the official polynomial has almost its entire curve outside the cloud of points. This official polynomial was defined during the plant’s design. It takes into account the estimated downstream channel’s geometry and a maximum total release related to the spillway capacity. After some huge floods, this polynomial has not been checked with measured tailrace levels during the plant’s operation. It is important to mention that in Brazil the total release is not measured in each operational time interval. It is calculated using the verified generation, the measured gross head, and the calculated water spillage.

This difference between the official and adjusted polynomial could be a source of accumulative errors in the gross head calculated by the operation planning models and compromises the mathematical result of the production function, Eq. (1).

5. ANALYSIS OF RESULTS

In order to assess the benefits of the proposed methodology a simulation model for the hydroelectric plants operation was used. This simulator is in use by Brazilian companies and can be applied for planning the future operation or reproducing the past operation [10]. It can check different operational policies and has operational constraints such as: maximum storage, release and generation that are checked for each simulated plant in all time intervals (*t*).

The tool used is able to simulate the plant’s operation from the initial volume (x_0), and from the values sequence of generation (p), water spillage (s) and total inflow (inter basis or incremental y and total upstream releases u_j). These variables, which are input data to the simulator, are in bold in the schematic representation of the mass balance equation shown in Fig. 3.

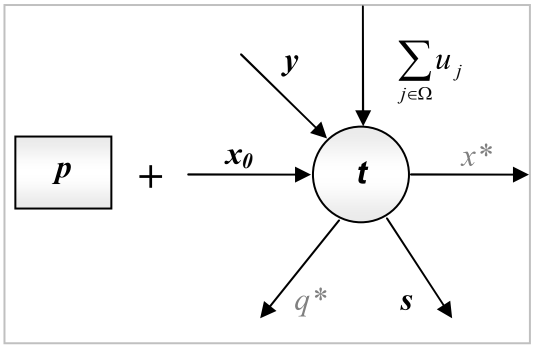

Fig. 3. In bold, input data for the simulator when its aim is to reproduce the water discharge values sequence.

where:

Ω Is the upstream plants index set from the analyzed plant.
x^* Is the reservoir volume calculated by the simulator (hm³).
q^* Is the turbines’ water discharge calculated by the simulator (m³/s).

The choice of this operating policy is due to the fact that the forebay and tailrace levels, the electric generation, and the water spillage are measured variables. Water inflow is calculated based on the mass balance equation.

The simulator was used to reproduce the past operation of the analyzed plant. The variable data recorded by the plant were compared to the resulting data of the simulation from September 10th to 24th in 2006.

Fig. 4 shows a comparison between the recorded data by the plant and the simulated data using official level-release polynomial. As can be seen in this figure, using official polynomial, the final simulated forebay level of the period is 0.20 m lower than the recorded. This occurs because of the errors in the gross head calculated by the simulation model, as mentioned in Section 4. Since the plant’s reservoir is big, this difference is significant.

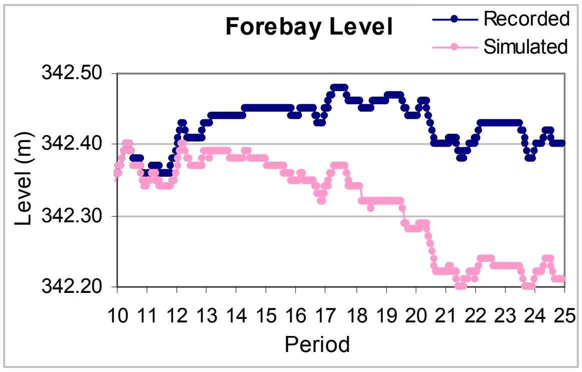

Fig. 4. Forebay level values recorded and simulated using official level-release polynomial.

Fig. 5 illustrates a comparison between the recorded data by the plant and the simulated data using adjusted level-release polynomial. In this figure, using the adjusted polynomial the biggest different between forebay level recorded and simulated is 0.05m, during all periods.

Other studies were applied in different operation periods. In all of them the use of the consolidated level-release polynomial brings the real and simulated operation closer.

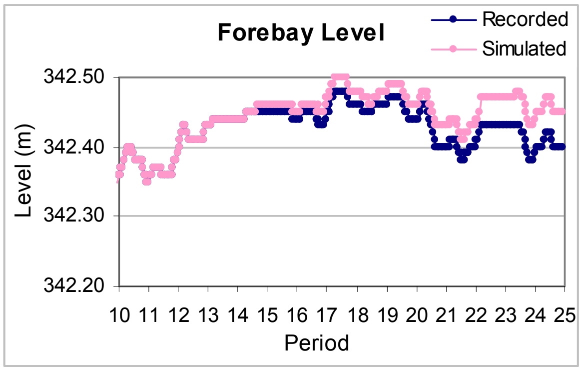

Fig. 5. Forebay level values recorded and simulated using adjusted level-release polynomial.

6. CONCLUSIONS

This paper presented a methodology for adjusting of the tailrace polynomial from hydroelectric plants. It is based on operation data recorded by the plant's owner or company and uses a non-linear regression tool, Trendline in Excel. The choice of the level-release polynomial for the adjust process is due to the influence that such function has in the hydroelectric operation planning.

The proposed methodology was applied to the data from a large Brazilian hydroelectric plant. A simulator of the hydroelectric operation was used with two objectives. The first was to analyze the behavior of this computational model, initially with official polynomial and later with adjusted polynomial. The second objective was to assess the effectiveness of the proposed methodology.

Two conclusions were obtained from the results. The first is that the quality of the data has great influence on the results of a model mainly about what is expected of the mathematical representation of the modeled system. That can be observed comparing the Fig. 4 and the Fig. 5. The second conclusion confirms that the methodology is effective because, as was shown in Fig. 5, the data correction contributes for bringing the plant's simulated and real operation closer.

The contribution of this work is not limited to the development of a methodology for consolidation of the level-release polynomial from hydroelectric plants. Since reliable input data make the result of computational models closer to reality, the proposed methodology aids in the choice of an economic and reliable operation for the hydroelectric system. In order to facilitate the application of this methodology, the process may be automated.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] Lopes, J. E. G. (2003). “The relevance of the optimization and simulation models of Brazilian hydroelectric system.” Ildo Luís Sauer. The reconstruction of Brazilian electric sector, Peace and Earth, São Paulo, Brazil, 289–300.

[2] Rodrigues, M. S. (2002). “On-line quality control of tele-transmitted hydrological data.” MS thesis, Federal Univ. of Itajuba, Minas Gerais, Brazil.

[3] Oliveira, L. C. K., and Canellas, A. V. B. (1999). “Importance of reliable water-meteorological data for water resources management.” Proc.,Symp. on Water Resources Management of Gramado, Rio Grande do Sul, Brazil.

[4] Lopes, J. E. G. (2007). “Model for operation planning of hydrothermal systems for electrical energy production.” Ph.D. thesis, State Univ. of Sao Paulo, Sao Paulo, Brazil.

[5] Diniz, A. L., Esteves, P. P. I. and Sagastizabal, C. A. (2007). “A mathematical model for the efficiency curves of hydroelectric units.” IEEE 1-4244-1298-6/2007, IEEE, New York, USA.

[6] Hidalgo, I. G., Soares, S., Fontane, D. G., and Cicogna, M. A. (2009a). “Management and analysis of data from hydroelectric plants.” Proc., IEEE-Power Systems Conf. & Exhibition (PSCE), IEEE, Seattle, Washington, USA.

[7] Hidalgo, I.G.; Fontane, D.G.; Soares, S.; Cicogna, M.A. (2009b). “Computer Aided System for Managing, Controlling and Analyzing Data from Hydroelectric Plants”. ASCE World Environmental & Water Resources Congress (EWRI), Kansas, Missouri, USA.

[8] Hidalgo, I. G., Fontane, D. G., Soares, S., and Cicogna, M. A. (2009c). “A simulator of the hydroelectric plants operation as tool for analyzing data.” Proc., World Congress on Computer Science and Information Engineering (CSIE), Los Angeles, California, USA.

[9] Hidalgo, I. G., Soares, S., Fontane, D. G., Lopes, J. E. G., and Cicogna, M. A. (2009d). “Method for Calibration of the Overall Efficiency Function from Hydroelectric Plants.” Power Systems Computation Conference (PSCC), Stockholm, Wisconsin, Sweden.

[10] Cicogna, M. A., Fontane, D. G., Hidalgo, I. G., Lopes, J. E. G. (2009). "Multireservoir Simulation Using Multipurpose Constraints and Object-Oriented Software Design." World Environmental & Water Resources Congress 2009, EWRI/ASCE, Kansas City, Missouri, EUA.