Simple Algorithm for Maximum Water Saving at Hydroelectric Power Plants

R. Abritta, F. F. Panoeiro, I. C. S. Junior, A. L. M. Marcato, *Senior Member, IEEE,* and L. M. Honório

***Abstract*—Environmental concerns have led to increased research, development and usage of renewable energy sources. In some countries, e.g. Brazil, most of the energy is generated by Hydroelectric Power Plants. Regarding these, since power demands can be attended by different operation conditions, it is desired that the planning be optimized in order to minimize losses or resources usage, among others objective functions possibilities, depending on the established goal. Aiming at water saving, which prevents reservoir shortages and, therefore, helps to secure long-term generation potential, this paper presents an algorithm that guarantees load attendance while discharging the minimum possible amount of water at power plants with identical generating units. The algorithm was applied to the data from HPP Luiz Eduardo Magalhães, which is located at Lajeado town, Tocantins state, Brazil. Results have shown that the algorithm fulfills the given purpose of saving as much reservoir water as possible.**

***Index Terms*—Hydroelectric power generation, Renewable energy sources, Environmental engineering, Optimization, Resources saving.**

I. Introduction

The Energy Operation Planning has great importance in the system operation [1]-[4] and, in Brazil, is divided in very short, short, medium, and long-term schedules, which correspond to 1 to 7 days, 1 week to 1 year, 1 to 5 years, and 5 to 10 years, respectively. However, these time lengths may change from location to location. This paper addresses the very short-term planning, more specifically, the Day-Ahead Operation Planning (DAOP), i.e., the definition of which / how many generating units (GUs) must operate at each period of the following day based on forecasted power demands.

In Brazil, the System National Operator (ONS) provides the day-ahead generation goals to all power plants and each of these is responsible for managing its operation and generate the required power. Since reservoirs are susceptible to shortages due to lack of rain, it may be desired to save as much water as possible depending on the weather scenario. Within this context, this paper presents a DAOP algorithm, inspired in [5] and [6], for maximum water saving at Hydroelectric Power Plants (HPPs).

It is important to highlight that the proposed algorithm is applicable exclusively to HPPs with identical GUs, i.e. identical turbines and generators, which are very common in Brazil. Although it will not be proved in this paper, in HPPs with this characteristic, the optimal dispatch of the GUs occurs when each of them generates the same power, which can be easily verified through simulations, and is not true for HPPs with not identical GUs. This fact greatly simplifies the problem since the determination of which units are on or off at each period of the planning horizon becomes a determination of how many units are on at each period, where the demanded power is equally distributed among all online units.

The HPP Luiz Eduardo Magalhães, more commonly referred to as HPP Lajeado, which has an installed capacity of 902.5 MW, was subjected to the proposed algorithm. Simulations led to the following conclusions: (i) considering the original algorithm formulation, minimizing losses at HPPs is not equivalent to minimizing water flow, and (ii) the presented algorithm guarantees that power demands are attended while the maximum possible amount of water is saved.

Regarding this paper's organization, section II describes the problem, section III presents simulations and results, and section IV concludes the work.

II. Problem Formulation

The algorithm here presented is based on [5] and [6]. In [5], power losses functions are obtained and these losses are associated with power costs. Also considering start-ups and shutdowns costs, the objective function aims at minimizing the total day-ahead operation cost of the HPP Itaipu Binacional. In [6], the cost approach is left aside, i.e. start-ups and shutdowns costs of GUs at each plant are not considered, and the objective function minimizes total power losses. The formulation is expanded in order to optimize the operation of multiples HPPs.

No major modification was done to the original algorithm. However, for reasons yet to be explained, the present paper works around water flow functions instead of power losses functions.

Regarding the HPP data, the following information is required to obtain the mentioned functions:

- Total number of GUs in the HPP (n_{gu});
- Penstock losses coefficient (k_p) or the penstock head loss (h_p), depending on the HPP modeling;

The development presented in this paper came from the ANEEL R&D project (PD-00673-0052/2018) financed by EDP, to whom the authors are grateful.

R. Abritta, F. F. Panoeiro, I. C. S. Junior, A. L. M. Marcato, and L. M. Honório are with the Postgraduate Program in Electrical Engineering of the Federal University of Juiz de Fora, Juiz de Fora – Minas Gerais, 36036-000, Brazil (e-mails: ramon.abritta@engenharia.ufjf.br, frederico.panoeiro@engenharia.ufjf.br, ivo.junior@ufjf.edu.br, andre.marcato@ufjf.edu.br, leonardo.honorio@ufjf.edu.br).

- Generators' efficiency curve polynomial, which provides the generator's efficiency (η_g) as a function of the generated active power (p_g);
- Turbines' efficiency curve, also known as Hill-Curve, which provides the turbine's efficiency (η_t) as a function of the HPP's net head (h_n) and the water flow in one unit, i.e., the total water flow (q) divided by the number of operating GUs (n);
- GUs' minimum (q_l) and maximum (q_u) water flow values, which are extractable from the Hill-Curve;
- Reservoir elevation (h_r);
- Level-release polynomial, which provides the tailrace elevation (h_t) as a function of the water release, which is equal to the sum of q and spillage.

The calculation of h_p depends on the HPP model adopted. It is usual in the literature to obtain this parameter as in (1), where h_p is written as a function of q. However, in some cases, h_p is treated as a constant value, which is the case of HPP Lajeado, where ONS established a fixed value for h_p since, in this case, such consideration has minimal impact on results.

$$h_p = k_p . q^2 \quad (1)$$

The Hill-Curve is a data set granted by the turbine manufacturer that relates turbine efficiency levels to water flow and net head samples. The Cavitation Limits (CL) demarcate operation zones that are harmful to the turbine and, hence, may decrease its lifespan. Fig. 1 depicts HPP Lajeado's Hill-Curve. It is possible to observe the limits L1, L2, L3 and L4, L2 being for during guarantee period and L4 for after guarantee period. The parts of L2 and L4 non-parallel to the h_n axis, and the whole L1 and L3 curves are each adjusted by a second-order polynomial that provides q/n as a function of h_n. Furthermore, a black box needs to be adjusted to the Hill-Curve data in order to return η_t for any values of q/n and h_n in the relevant region. The importance of CL polynomials and Hill-Curve black box will soon be clarified.

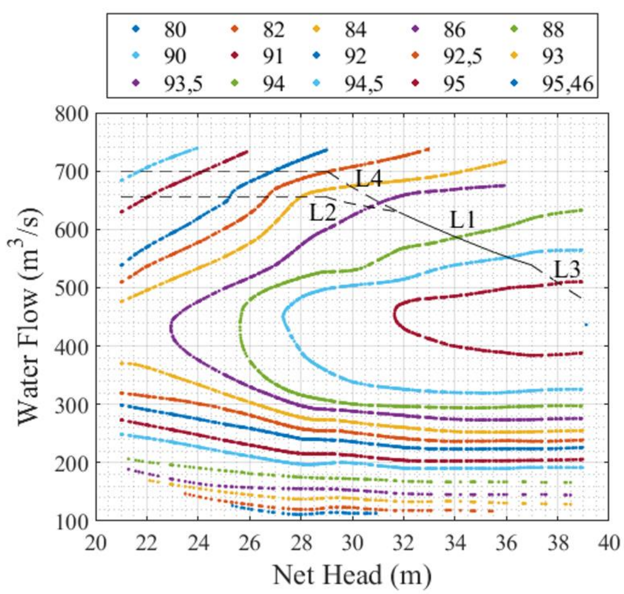

Fig. 1. HPP Lajeado's Hill-Curve.

When addressing short-term planning, variations on h_r are irrelevant [5]-[6], which is especially true for on-the-river HPPs since these plants' reservoirs' levels variations are negligible. This fact allows h_r to be treated as a constant value, i.e., variations due to incoming water flow and water release can be ignored with no significant impact on results.

Given the previously described considerations, the steps to obtain the power losses/water flow functions are:

(i) Vary n from 1 to n_{gu};

(ii) For the current value of n, vary q from $n \cdot q_{min}$ to $n \cdot q_{max}$, which means that each turbine discharges q/n;

(iii) For the current value of q, calculate h_t using the level-release polynomial;

(iv) Determine h_p either by using (1) or by obtaining its predefined value, depending on the model, and then calculate h_n using (2);

$$h_n(q) = h_r - h_t(q) - h_p(q) \quad (2)$$

(v) According to the CL and their describing polynomials, verify the feasibility of the current value of q with respect to h_n. If feasible, proceed to step (*vii*). Else, go back to step (*ii*) with the next value of q;

(vi) Calculate the mechanical power (p_m) in MW for one of the n units with (3), where g is the gravitational acceleration, ρ is the reservoir water density, and $k = 10^{-6}$ transforms W in MW;

$$p_m = k . g . \rho . \eta_t(h_n(q), q/n) . h_n(q) . q/n \quad (3)$$

(vii) Utilize the generator polynomial and an iterative method to solve (4) and obtain p_g for the current value of q and n;

$$p_g = p_m . \eta_g(p_g) \quad (4)$$

(viii) Calculate penstock losses (p_1), losses due to tailrace elevation (p_2) and turbine losses (p_3) using (5), (6) and (7) respectively, where η_{max} is the maximum efficiency of the turbine. The total losses (p_{ltot}) in MW is given by the sum of all three components;

$$p_1 = k . g . \rho . \eta_g(p_g) . \eta_t(h_n, q/n) . h_p . q \quad (5)$$

$$p_2 = k . g . \rho . \eta_g(p_g) . \eta_t(h_n, q/n) . (h_t(q) - h_t(q_l)) . q \quad (6)$$

$$p_3 = k . g . \rho . \eta_g(p_g) . (\eta_{max} - \eta_t(h_n, q/n)) . h_n(q) . q \quad (7)$$

(ix) To obtain power losses functions, store p_{ltot}. To obtain q functions, step (*viii*) is not required, and the current q value must be stored. Obviously, $n . p_g$ is always stored, which corresponds to the total generation ($p_{g_{tot}}$);

(x) Determine the minimum (p_{l_n}) and maximum (p_{u_n}) generated power for each n by initializing them with big and null values, respectively, and testing, for each q, if $p_{g_{tot}}$ is smaller than p_{l_n} or greater than p_{u_n}.

(xi) Proceed to step (*ii*) with the next q value, or to step (*i*) with the next n value if q is greater then $n \cdot q_{max}$, or finish the process if n is greater than n_{gu}.

Once the step-by-step is executed, a set of points relating generated power to power losses or/and water flow is created. The data is then adjusted by polynomials, which allow the observation of power intervals where losses or water flow is minimized for each number of online GUs. In order to preserve the data's information properly, it is recommended to fit the points using piecewise interpolation instead of a single polynomial for each function.

It is of great importance to emphasize that the power losses considered in [5] and [6] correspond to generation potential losses, and not to actual losses at the system, i.e., if at any q value in the step-by-step process, one calculates the power losses (p_{loss}) using (8), one will realize that the obtained value differs from the losses provided by the original step-by-step.

$$p_{loss} = p_g/(\eta_g.\eta_t) - p_g \tag{8}$$

Considering a planning horizon of T periods and day-ahead generation goals P_d, where $d = 1,2 \ldots, T$, the lower (n_{d_l}) and upper (n_{d_u}) bounds for the number of GUs capable of attending the demand of each period can be calculated by the pseudo-code presented in Fig. 2.

- "Do 1": do k vary from 1 to T
  - "Do 2": do m vary from 1 to n_{gu} with step equal to 1
    - If $p_{u_m} > P_k$
      - $n_{k_l} = m$
      - Interrupt "Do 2"
  - "Do 3": do m vary from n_{gu} to 1 with step equal to -1
    - If $p_{l_m} < P_k$
      - $n_{k_u} = m$
      - Interrupt "Do 3"

Fig. 2. Pseudo-code to determine the bounds of n at each period of the planning horizon.

With the bounds determined, the final step consists of verifying, for each period, which of the possible operation conditions provides fewer power losses or less water flow, depending on the approach. The next section presents the results of the algorithm applied to HPP Lajeado.

III. Simulations and Results

The algorithm described in the previous section was utilized to obtain both power losses functions, as in the original works that inspired this paper, and water flow functions of the HPP Lajeado. The HPP data and other parameters can be consulted in the Appendix. A step of 0.01 was used to vary water flow values. Figs. 3 and 4 show, respectively, power losses and water flow functions for each n. Some regions of interest were highlighted in Fig. 4 since the functions' proximity compromises visual analysis. These regions show the intersections between the functions of 3 and 4 GUs and also between the functions of 4 and 5 GUs.

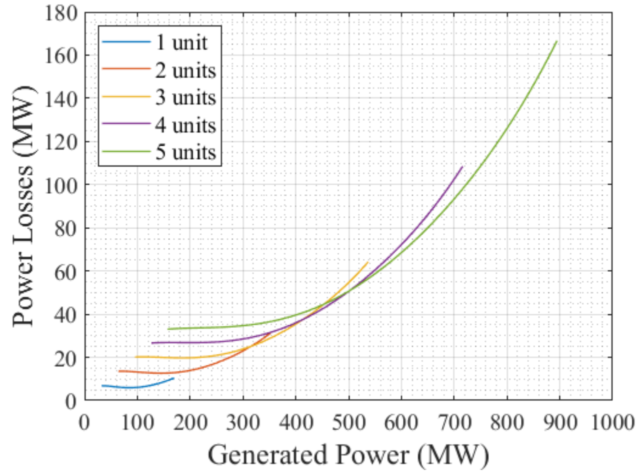

Fig. 3. Power losses functions of HPP Lajeado.

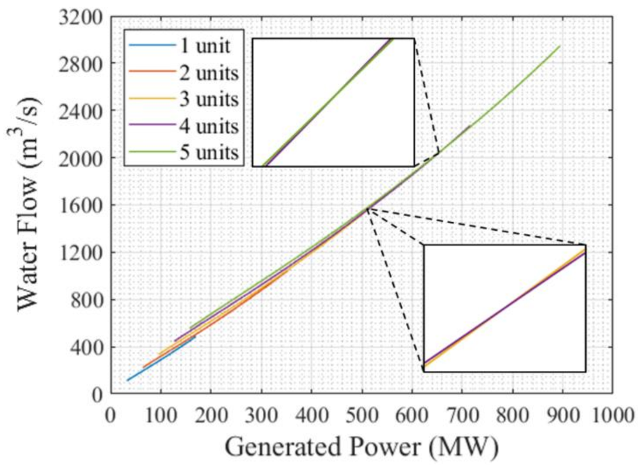

Fig. 4. Water flow functions of HPP Lajeado.

If, as in this work, start-up and shutdown costs are not considered, the presented algorithm simplifies the problem to the point where no optimization technique is necessary since the functions provide enough information for the decision of how many GUs must operate to attend the power demand and optimally minimize power losses or water flow. Determining the mentioned costs was not part of this project. Nevertheless, if the reader wishes to study and consider them, we encourage the studying of [5] and [6] for an optimization approach to the problem and of [7] and [8], in which instructions on how to estimate such costs are provided.

With the focus of minimizing resources usage, the total losses and total water flow curves for 4 and 5 GUs were normalized from 0 to 1 and plotted together in Fig. 5, where the intersections of the curves were tagged so that comparisons and analysis could be done. Within the generation ranges, it is possible to observe that:

- If $p_{g_{tot}} < 502.34$, operating with 4 units results in fewer power losses and less water flow;
- If $p_{g_{tot}} > 663.35$, operating with 5 units results in fewer power losses and less water flow;
- If $502.34 < p_{g_{tot}} < 663.35$, operating with 5 units results in fewer power losses, but in higher water flow.

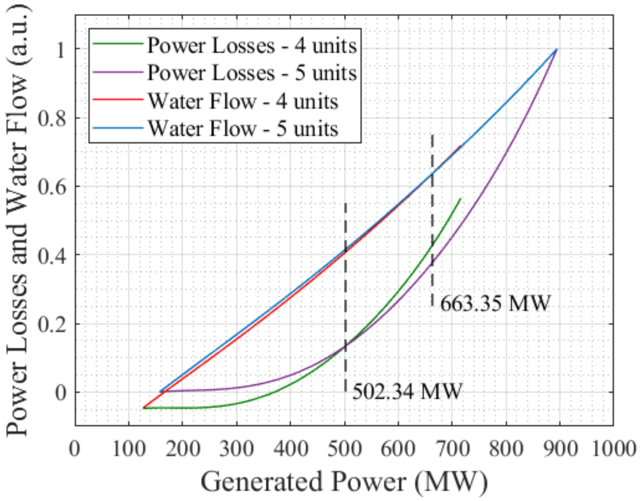

Fig. 5. Power losses and water flow functions for 4 and 5 units.

These observations prove that minimizing the power losses obtained as presented in [5] and [6] is not equivalent to minimizing water flow since there are regions where a certain operation guarantees minimum losses, however, consumes more resources. For instance, in order to generate 600 MW while minimizing losses, 5 GUs would be set online, though minimum water usage in granted by operating 4 GUs.

In step (*viii*) of the algorithm presented in Section II, it is possible to replace the power losses calculations by (8), thus obtaining actual losses. Fig. 6 depicts these functions for HPP Lajeado and shows that the intersection between the functions of 4 and 5 GUs occur at the same generation value of the water flow functions intersection, i.e., minimizing such losses is equivalent to minimizing water flow.

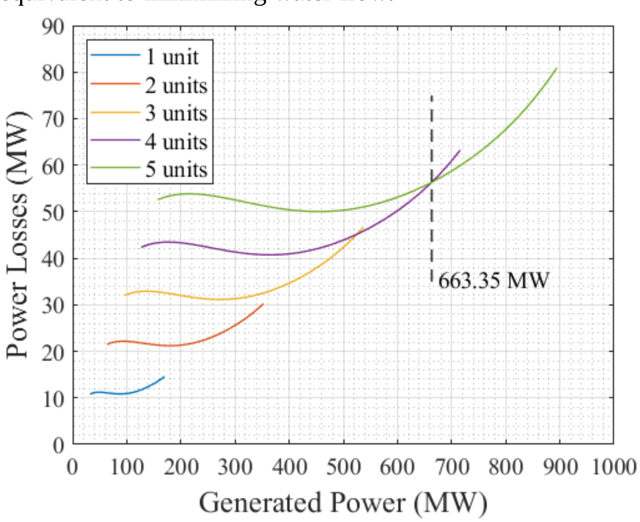

Fig. 6. Actual power losses functions of HPP Lajeado.

A case study was performed with power demands (see Appendix) retrieved from the operation historical of HPP Lajeado. No spinning reserve was considered, though one can easily incorporate them in the pseudo-code shown in Fig. 2 by summing the reserve to the demand when calculating the lower bound. Table I exhibits the total water volume discharged during one day of operation considering both functions initially presented. Although both approaches attend the required demand, the usage of water flow functions provided a saving of approximately 0.7 hm^3 of water compared to the original power losses functions. Such saving can scale to very significant values if longer periods of time are considered, for instance, weeks, months or years, i.e., the presented approach to the problem is efficient in maximizing water saving at HPPs.

TABLE I
TOTAL DISCHARGED VOLUME FOR ONE DAY OF OPERATION CONSIDERING POWER LOSSES FUNCTIONS AND WATER FLOW FUNCTIONS

Function	**Volume (hm^3)**
Power losses	158.5854
Water flow	157.8829

We highlight that the presented algorithm should be applied in periods where saving reservoir water is of great importance, for example, in situations where incoming water flow is reduced due to lack of rain, and avoiding the utilization of expensive thermal units is desired. On the other hand, if the incoming flow is expressive to the point where there is spillage (a phenomenon where water is sent directly from the reservoir to the downstream since the reservoir is unable to store the incoming flow), minimizing water flow in the turbines not only is unnecessary, it is also unwise. In case of such abundance, the best practice is to operate the GUs in a way that start-ups and shutdowns are avoided as much as possible since these are the main contributors to machines' lifespan reduction [7]. However, obviously, always respecting operation bounds.

IV. CONCLUSIONS AND FURTHER WORKS

This paper presented a DAOP algorithm for maximum reservoir water saving at HPPs with identical GUs. The algorithm was applied to a Brazilian HPP, HPP Luiz Eduardo Magalhães, and has shown to satisfactorily fulfill the task of minimizing water flow during the planning horizon. Furthermore, the results proved that minimizing power losses at HPPs taking the steps presented in [5] and [6] does not guarantee maximum water saving.

As possible further works, we intend to carry out a detailed study of HPP Lejeado in order to estimate machines start-up and shutdown costs, and, consequently, vastly review the optimization literature so that a suitable technique is chosen to solve the cost-based problem.

V. APPENDIX

Table II shows the generation goals. Table III reveals part of the simulation data. The generators and turbines efficiency polynomials are given by (9) and (10), respectively, and their coefficients values are shown in Tables IV and V, respectively. The level-release polynomial is given by (11), with its coefficients presented in Table VI. The parts of L2 and L4 non-parallel to the net head axis, L1, and L3 polynomials are given by (12), (13), (14), and (15), respectively. The parts of L2 and L4 parallel to the net head axis have water flow values equal to 656 and 700 m^3/s, respectively. Table VII exhibits the net head intervals of the cavitation limits.

TABLE II
GENERATION GOALS FOR EACH PERIOD OF THE NEXT DAY

Period	Demand (MW)	Period	Demand (MW)
1	550	25	850
2	550	26	850
3	550	27	850
4	550	28	850
5	400	29	850
6	350	30	850
7	350	31	850
8	350	32	850
9	350	33	850
10	350	34	850
11	350	35	850
12	350	36	550
13	350	37	550
14	350	38	550
15	350	39	550
16	350	40	550
17	350	41	550
18	550	42	550
19	550	43	550
20	550	44	550
21	550	45	550
22	850	46	550
23	850	47	550
24	850	48	550

TABLE III
PARTIAL SIMULATION DATA

Parameter	Value
g	9.8 m/s^2
p	997 kg/m^3
n_{gu}	5
h_p	0.7 m
q_{min}	111.21 m^3/s
q_{max}	700 m^3/s
h_r	212 m

$$\eta_g(p_g) = g_3.p_g^3 + g_2.p_g^2 + g_1.p_g + g_0 \tag{9}$$

TABLE IV
COEFFICIENTS OF THE GENERATORS' EFFICIENCY POLYNOMIAL

Coefficient	Value
g_3	$1.1641.10^{-8}$
g_2	$-6.5472.10^{-6}$
g_1	$1.2615.10^{-3}$
g_0	0.9024

$$\begin{aligned}\eta_t(h_n, q) &= t_{20}.h_n^5 + t_{19}.h_n^4 + t_{18}.h_n^4.q + t_{17}.h_n^3 \\ &+ t_{16}.h_n^3.q + t_{15}.h_n^3.q^2 + t_{14}.h_n^2 \\ &+ t_{13}.h_n^2.q + t_{12}.h_n^2.q^2 + t_{11}.h_n^2.q^3 \\ &+ t_{10}.h_n + t_9.h_n.q + t_8.h_n.q^2 + t_7.h_n.q^3 \\ &+ t_6.h_n.q^4 + t_5.q^5 + t_4.q^4 + t_3.q^3 \\ &+ t_2.q^2 + t_1.q + t_0\end{aligned} \tag{10}$$

TABLE V
COEFFICIENTS OF THE TURBINES' EFFICIENCY POLYNOMIAL

Coefficient	Value
t_{20}	$-8.765.10^{-6}$
t_{19}	$1.283.10^{-3}$
t_{18}	$2.411.10^{-7}$
t_{17}	$-7.163.10^{-2}$
t_{16}	$-4.324.10^{-5}$
t_{15}	$1.688.10^{-8}$
t_{14}	1.845
t_{13}	$2.73.10^{-3}$
t_{12}	$-1.751.10^{-6}$
t_{11}	$8.853.10^{-11}$
t_{10}	-20
t_9	$-7.554.10^{-2}$
t_8	$6.671.10^{-5}$
t_7	$-1.432.10^{-8}$
t_6	$4.123.10^{-12}$
t_5	$1.315.10^{-12}$
t_4	$-3.459.10^{-9}$
t_3	$3.71.10^{-6}$
t_2	$-2.591.10^{-3}$
t_1	1.223
t_0	94.94

$$h_t(q) = a_4q^4 + a_3q^3 + a_2q^2 + a_1q + a_0 \tag{11}$$

TABLE VI
LEVEL-RELEASE POLYNOMIAL COEFFICIENTS

Coefficient	Value
a_4	$-5.7384.10^{-17}$
a_3	$4.4759.10^{-12}$
a_2	$-1.3583.10^{-7}$
a_1	$2.4155.10^{-3}$
a_0	171.3660

$$L2(h_n) = 1.1451h_n^2 - 78.5229h_n + 1969.1079 \tag{12}$$

$$L4(h_n) = 1.5116h_n^2 - 116.8417h_n + 2816.9843 \tag{13}$$

$$L1(h_n) = 0.5858h_n^2 - 57.9756h_n + 1881.2691 \tag{14}$$

$$L3(h_n) = 0.4240h_n^2 - 61.2295h_n + 2223.1058 \tag{15}$$

TABLE VII
INTERVALS OF THE CAVITATION LIMITS IN THE HILL-CURVE

Limit	Range in h_n axis
L2 (parallel to h_n)	21.01 to 28.95
L4 (parallel to h_n)	21.01 to 29
L2 (non-parallel to h_n)	28.95 to 31.82
L4 (non-parallel to h_n)	29 to 31.82
L1	31.82 to 36.97
L3	36.97 to 39.11

VI. ACKNOWLEDGMENT

The authors thank the support of the Electrical Engineering Postgraduate Program (PPEE) of the Federal University of Juiz de Fora (UFJF), INERGE, ANEEL, and the technicians of all companies involved.

VII. REFERENCES

[1] L. A. Terry, M. V. F. Pereira, T. A. A. Neto, L. F. C. A. Silva, and P. R. H. Sales, “Coordinating the Energy Generation of the Brazilian National Hydrothermal Electrical Generating System”, *Interfaces*, vol. 16, no. 1, pp. 16-38, Feb. 1986.

[2] I. C. Silva, S. Carneiro, E. J. de Oliveira, J. L. R. Pereira, P. A. N. Garcia, and A. L. M. Marcato, “A Lagrangean multiplier based sensitive index to determine the unit commitment of thermal units,” *International Journal of Electrical Power & Energy Systems*, vol. 30, no. 9, pp. 504-510, Nov. 2008.

[3] B. H. Dias, M. A. Tomim, A. L. M. Marcato, T. P. Ramos, R. B. S. Brandi, I. C. S. Junior, and J. A. P. Filho, “Parallel computing applied to the stochastic dynamic programming for long term operation planning of hydrothermal power systems,” *European Journal of Operational Research*, vol. 229, no. 1, pp. 212-222, Aug. 2013.

[4] E. C. Finardi, and M. R. Scuzziato, “Hydro unit commitment and loading problem for day-ahead operation planning problem,” *International Journal of Electrical Power & Energy Systems*, vol. 44, no. 1, pp. 7-16, Jan. 2013.

[5] A. Arce, T. Ohishi, and S. Soares, "Optimal dispatch of generating units of the Itaipu hydroelectric plant," *IEEE Transactions on Power Systems*, vol. 17, no. 1, pp. 154-158, Feb. 2002.

[6] A. S. A. Encina, S. S. Filho, T. Ohishi, and M. A. Cicogna, “Unit Commitment of Hydro Dominated Systems,” *International Journal of Emerging Electric Power Systems*, vol. 9, no. 4, 2008.

[7] O. Nilsson and D. Sjelvgren, "Hydro unit start-up costs and their impact on the short term scheduling strategies of Swedish power producers," *IEEE Transactions on Power Systems*, vol. 12, no. 1, pp. 38-44, Feb. 1997.

[8] O. Nilsson and D. Sjelvgren, "Variable splitting applied to modelling of start-up costs in short term hydro generation scheduling," *IEEE Transactions on Power Systems*, vol. 12, no. 2, pp. 770-775, May 1997.

VIII. BIOGRAPHIES

Ramon Abritta obtained the B.Sc. degree in Electrical Engineering, with emphasis in Power Systems, from the Federal University of Juiz de Fora (UFJF), and is currently studying at the same institution to become an M.Sc. His fresh started research career involves optimization and computational intelligence. His special fields of interest include the very short-term operation of hydroelectric and thermal power plants.

Frederico Ferreira Panoeiro obtained the B.Sc. degree in Control and Automation Engineering from the Federal Center of Technological Education of Minas Gerais (CEFET-MG), Leopoldina Campus, and the M.Sc. degree in Electrical Engineering from the Federal University of Juiz de Fora (UFJF), where he is currently studying to obtain his D.Sc. degree. He is a member of the Heuristic and Bio-inspired Optimization Group (GOHB - UFJF). His fields of interest include bio-inspired optimization, artificial intelligence, electrical power systems optimization, control, and automation.

Ivo Chaves da Silva Junior received the B.Sc. and M.Sc. degrees from the Federal University of Juiz de Fora (UFJF), Juiz de Fora, MG, Brazil, in 2001 and 2003, respectively, and the D.Sc. degree from COPPE/Federal University of Rio de Janeiro, Rio de Janeiro, Brazil, in 2008. Since 2009, he has been a Professor with the Electrical Engineering Department, UFJF. His research interests include power economics, optimization, and power systems analysis.

André Luís Marques Marcato received the B.Sc. degree in Electrical Engineering from the Federal University of Juiz de Fora, Juiz de Fora, Brazil, in 1995, and the M.Sc. and D.Sc. degrees in Electrical Engineering from the Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, Brazil, in 1998 and 2002, respectively. In 2012, he carried out his postdoctoral year at London Imperial College and at the Engineering Faculty of the University do Porto. He is currently an Associate Professor with the Federal University of Juiz de Fora. He is a senior member of the IEEE (Institute of Electrical and Electronics Engineers) Power and Energy Society and the IEEE Robotics and Automation Society. He was the Chair of IEEE Minas Gerais Section and IEEE RAS Chapter. He has been teaching and researching in the areas of energy planning, control theory, optimization, and robotics. His main activities are related to optimization techniques applied to hydrothermal coordination, operation, and expansion planning of electrical systems. He coordinates or coordinated research projects with many energy companies in the Brazilian Electrical Sector, for example, CEPEL, Petrobras, Light, CESP, Cemig, Duke Energy, and China Three Gorges Corporation.

Leonardo de Mello Honório received the B.Sc. degree in Electrical Engineering from the Federal University of Juiz de Fora in 1993, and the M.Sc. and D.Sc. degrees in Electrical Engineering from the Federal University of Itajubá in 1999 and 2002, respectively. He was a visiting researcher at the University of California, Irvine in 2006, and in the Electrical Faculty of the University of Porto in 2012. He was a Professor in the Federal University of Itajubá from 2002 to 2010, and the coordinator of the post-graduation program in Electrical Engineering of UNIFEI from 2005 to 2010. He is currently an Associate Professor with the Federal University of Juiz de Fora. He is experienced in Electrical Engineering with emphases in areas such as energy transmission, energy distribution, information technology, and robotics. His main research themes are evolutionary algorithms, stochastic methods, optimal power flow, autonomous vehicles, fuzzy logic, pattern recognition, and optimization. He was the coordinator of the first Brazilian autonomous car project. He was the coordinator of an international underwater vehicle project to survey dams at hydroelectric power plants. He is a member of the managing committee of the National Institute of Electrical Energy (INERGE). He was a member of the CBA programs committee in 2008 and 2010. He has participated in more than 15 Research and Development projects.