Database structured model for energy planning applications

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Abstract. Actual updated data from the hydroelectric and thermoelectric energy system in Brazil is provided by the National System Operator (ONS). It is made available as a package of digital files (text and binaries). Researchers at the Laboratory of Bio-Inspired Technologies and Solutions from Federal University of ABC (LabBITS - UFABC) implemented a platform for accessing the information of this Brazilian electric power generation system from a SQL (Structured Query Language) database, regularly updated from the ONS's provided package of files. The database is accessed by the laboratory researchers via a REST (Representational State Transfer) API (Application Programming Interface) which is used to supply the parameters of the energy system models used in the energy planning calculations for the Energ.IA platform. This paper presents the recent achievements of the team of under-graduate students, guided by seniors' researchers of the LabBITS. Students have developed a Java library which connects with the remote database and pulls the updated power system parameters to instantiate Java object models and parametrized calculation methods of the Brazilian electricity generation system. Those models are then used to simulate system operation or in optimization routines within the Energ.IA platform. A simplified case study is presented to demonstrate its use.

Keywords: database, energy planning, hydrothermal systems.

1 Introduction

The Brazilian electricity production system was, in 2022, 61.9% hydroelectric [1]. This, added to the growing demand for electricity, makes the systems responsible for generation and transmission to take on commitments with society, making it essential to have a good management of resources used to obtain electricity, in order to ensure that all energy in contracting environments, whether free (ACL) or regulated (ACR) is supplied at lower costs and with reliability. Studies carried out by Brazil's Energy Research Company (EPE) have shown that the demand growth rate is up to 3.3% per year [2].

Ensuring that the supply of electricity complies with the actual generation capacity of the Brazilian electrical matrix requires that the planning and operation of the system be carried out using computational tools that are compatible with the physical reality of the installed infrastructure. This imposes the need for quite complex studies and actions so that a strategy for generation can be created over a planning period without compromising the future. In view of this, this article presents the development of a computational tool to a more adequate management of the availability of an energy resource that would consequently benefit the electricity market in Brazil, since it provides greater security for the supply of electricity in the country, as well as greater security for the supply of electricity.

This article is organized as follows: initially a brief introduction to the operation planning problem. Then the adopted mathematical formulation in Section 1. Section 2 presents the proposed implementation. In Section 3, a case study is shown for a subsystem belonging to Brazil. Finally, the article concludes by presenting the next steps to be consolidated as well as the benefits to be obtained.

2 Proposed Approach

The method used in this article to describe the water-based energy resources in the computational model is the representation of power plants in the same basin by equivalent energy reservoirs, using real data. This is done by obtaining the data through a proprietary Platform, proposing techniques for optimization and decision making in the planning and programming of the energy operation and commercialization. This Platform is named 'Energ.IA', being a computational tool based on intelligent techniques that is under continuous development at UFABC by the research group, coordinated by professor Patricia Teixeira Leite Asano, at the Laboratory of Bioinspired Technology and Solutions – LabBITS.

It is noteworthy that the entire implementation was developed by accessing the model parameters remotely, via API ("Application Programming Interface" or REST ("Representational State Transfer"). Those are the main parameters that are used to make up the equivalent systems that calculates hydroelectric energy conversion (average MWh).

As the Brazilian system is in constant growth and change, with an increasing demand over time, the entry of new ventures or the expansion of existing plants, most of the data provided varies over the period, due to the complexity of entering this condition, the scenarios built in this work will be static, but the Energ. IA platform also allows the calculation with dynamic system variables. In the following sections, the mathematical formulation for the formulation with the parameters of the hydraulic plants necessary for the calculation of the equivalent energy system is presented. The modeled system is the same presented in Souza et al.'s work [3], but parameters were updated with the information from September, 2022 which was previously (automatically) loaded in the Energ.IA databank (same input data from the official planning software [4, 5] which is made available monthly by CCEE - Electrical Energy Commercialization Chamber).

2.1 Mathematical formulation

Given that reservoir measurement is often made by volume, the altitude quota is defined by the difference in level between the water surface of the reservoir and the surface of the ocean, and, depending on the storage, the corresponding quota is obtained through the quota-volume polynomial, as shown in Equation 1

$$COTA_{J,t}^{Vol_{J,t}} = PCV_{J,1} + PCV_{J,2}.Vol_{J,t} + PCV_{J,3}.Vol_{J,t}^{2} + PCV_{J,4}.Vol_{J,t}^{3} + PCV_{J,5}.Vol_{J,t}^{4} \quad (1)$$

where: $PCV_{J,n}$: n^{th} coefficient of the quota-volume polynomial of the power plant J (*m x hm³*); $COTA_{J,t}^{Vol_{J,t}}$: Quota of the power plant J associated with the volume $Vol_{J,t}$ by the quota-volume polynomial in the respective instant *t* (*m*); $Vol_{J,t}$: Volume of the reservoir J in the instant *t* (*hm³*).

The average quota for a given volume is calculated according to the equation:

$$COTAMED_{J,t}^{Vol_{J,t}} = \int_{Vmin_J}^{Vol_{J,t}} COTA_{J,t}^{Vol_{J,t}} d_{VOL} \Big/ \left(Vol_{J,t} - Vmin_J\right) \quad (2)$$

where: $COTAMED_{J,t}^{Vol_{J,t}}$: Average quota of the power plant J associated with the average between the minimum volume and the volume ($Vol_{J,t}$) in the instant *t*, according to the polynomial quota-volume (*m*); $Vmin_J$: Minimum volume of the J power plant reservoir (*hm³*).

To calculate the water head relative to the quota of a power plant, the quota above sea level of the surface of the downstream river and the losses are discounted. In this case, the losses are given in meters (*m*):

$$H_{J,t}^{Vol_{J,t}} = COTA_{J,t}^{Vol_{J,t}} - CFUGA_{J,t} - CPHID_J \quad (3)$$

$$HEQ_{J,t}^{Vol_{J,t}} = COTAMED_{J,t}^{Vol_{J,t}} - CFUGA_{J,t} - CPHID_J \quad (4)$$

where: $CFUGA_{J,t}$: Quota of the tailrace after the powerplant J at stage *t* (*m*). The tailrace can also be calculated by a polynomial that depends on the outflow. In this case the producibility becomes even more non-linear; $CPHID_J$: Coefficient of hydraulic losses of the plant J (*m*); $H_{J,t}^{Vol_{J,t}}$: Water head associated with a given volume $Vol_{J,t}$ of plant J in stage *t* (*m*); $HEQ_{J,t}^{Vol_{J,t}}$: Equivalent water head, associated with the average quota, from the minimum volume to a given volume $Vol_{J,t}$ of plant J in stage *t* (*m*).

Another factor that affects the amount of energy generated is the producibility, being a unique coefficient for each power plant, which approaches the plant's performance, encompassing the hydraulic circuit, turbine, generator, transformer and auxiliary services. Thus, the greater the producibility of a plant, the greater the energy generated in relation to the energy that comes into contact with the turbine. So, the energy generated at a given height is called by Souza et al [3] as the equivalent productibility:

$$\rho_{J,t}^{Vol_{J,t}} = \eta_J . H_{J,t}^{Vol_{J,t}} \quad (5)$$

$$\rho_{J,t}^{eq,Vol_{J,t}} = \eta_J . HEQ_{J,t}^{Vol_{J,t}} \quad (6)$$

where: $\rho_{J,t}^{Vol_{J,t}}$: Equivalent productibility of plant J (*MW*/(*m³/s*)), corresponding to the quota corresponding to volume $Vol_{J,t}$ in stage *t*; $\rho_{J,t}^{eq,Vol_{J,t}}$: Equivalent producibility, considering the equivalent drop height (4), obtained from the minimum volume to the given volume $Vol_{J,t}$ of plant J considered at stage *t;* η_J: Specific productibility of power plant J (*MW*/(*m³/s*) */month*).

It is also necessary to convert ***m³/s*** to ***hm³/month*** and vice versa, where the factor ($FATOR_r$) is calculated according to the number of days in the month. In this work, an average number of days per month was adopted considering 365 days per year, resulting in a factor of about 2.63, as can be seen in the demonstration below:

$$\Delta T = \frac{365\ days.24h.60min.60s}{12months} = 2{,}628{,}000 \text{ and } FATOR_r = \frac{1\ month\ (s)}{1\ \ hm^3(m^3)} = \frac{2.628.000\ s}{100^3\ m^3} = 2.628 \ (7)$$

From the parameters provided so far, Souza et al [3] considers how to calculate the total amount of energy generated by all power plants in the same river basin.

Thus, the maximum storable energy of a system of power plants in the same basin is calculated by adding the products of the useful volume of each reservoir by its accumulated productivity. Accumulated productivity is understood as the sum of the productivity of the reservoir itself and the productivity of all reservoirs and run-of-river plants downstream until the end of the cascade. The equation below expresses this procedure to calculate the maximum storable energy of system *i* in instant *t*.

$$EA_{i,t} = \frac{1}{FATOR_r} \sum_{J=1}^{NUSI_i} VUTIL_J \;.\sum_{K \in \Psi_{J,t}} \rho_{k,t}^{Vmax_J} \qquad (8)$$

where: $EA_{i,t}$: Maximum storable energy of system i at stage t ($MWmonth$); $NUSI_i$: Number of power plants in the system *i*; $\Psi_{J,t}$: Set composed of hydroelectric plant J and all plants downstream of J in stage *t*.

For the calculation of the useful volume of the powerplant used in Equation 8, the following equation:

$$VUTIL_J = Vmax_J - Vmin_J \qquad (9)$$

The stored energy can also be calculated as a function of a given volume, according to the following expression:

$$EA_{i,t}^{Vol_{J,t}} = \frac{1}{FATOR_t} \sum_{J=1}^{NUSI_i} (Vol_{J,t} - Vmin_J)\,.\sum_{K \in \Psi_{J,t}} \rho_{K,t}^{eq,Vol_{J,t}} \qquad (10)$$

where: $EA_{i,t}^{Vol_{J,t}}$: Stored energy for a given volume ($Vol_{J,t}$) in system *i* at the beginning of stage *t* (*MWmonth*).

Controllable energy is the amount of energy that can be generated by the inflow to the reservoirs, provided that the inflow is fully converted into energy by the reservoirs themselves and the run-of-river plants downstream to the river. The controllable energy can also be obtained by adding the incremental flows to each reservoir multiplied by the equivalent average productivity in all the plants downstream of it. The incremental flow is given by the natural inflow discounted from the natural inflows to the reservoir plants immediately upstream [3]. This can be done by Equation 11:

$$EC_{i,t} = \sum_{J \in R_{i,t}} QIr_{J,t} \,.\left(\sum_{k \in \Psi_{j,t}} \rho_{k,t}^{med}\right) \qquad (11)$$

where: $EC_{i,t}$: Controllable energy inflow to system *i* at stage *t* (*MWmonth*); $QIr_{j,t}$: Incremental flow to plant J in stage *t*, considering only upstream reservoir plants (*m³/s*); $R_{i,t}$: Set composed of all powerplant with reservoirs of system *i* in stage *t*.

Run-of-river energy is the energy generated by incremental flows to run-of-river plants, once it cannot be stored. It is worth mentioning that part of the energy generated in run-of-river plants is controlled by the reservoirs upstream of the plant; this controllable portion generated by run-of-river plants has already been included in controllable energy. The determination of the incremental flow is made from the natural flow, from which the natural flows to the reservoir plants immediately upstream of the run-of-river plant are discounted. Thus, the gross run-of-river energy is given by the sum of the incremental flow between the plant and the upstream reservoirs multiplied by the plant's productibility:

$$EFIOB_{i,t} = \sum_{J \in F_{i,t}}^{NUSI_i} QIr_{J,t} . \rho_{J,t} \qquad (12)$$

where: $EFIOB_{i,t}$: Gross run of river energy inflow to system *i* in stage *t* (*MWmonth*); $QIr_{j,t}$: Incremental flow to plant J in stage *t*, considering only upstream reservoir plants (*m³/s*); $F_{i,t}$: Set composed of all run-of-river powerplants of system *i* in stage *t*.

Adding the results of Eq. (11) and (12), we get the total Natural Affluent Energy in a system:

$$ENA_{i,t} = EC_{i,t} + EFIOB_{i,t} \qquad (13)$$

where: $ENA_{i,t}$: Natural Affluent Energy inflow to system *i* in stage *t* (*MWmonth*).

The last equation considered in this article presents the energy generated by the maximum hydraulic capacity of a system, with can be calculated as a function of the maximum intake flow of each of the powerplants

$$GHMAX_{i,t} = \sum_{j=1}^{NUSI_i} QMAX_{J,t} . \rho_{J,t} \qquad (14)$$

where: $GHMAX_{i,t}$: Maximum hydraulic generation to system *i* in stage t (*MWmonth*); $QMAX_{J,t}$: Maximum intake flow of hydroelectric plant J at stage t (m^3/s).

2.2 Database Development

In order to build a single database, with information to study different operational scenarios, the electrical system data has been obtained directly from the CCEE repository in a file package called 'Price Decks', in which the files necessary for processing the NEWAVE program [4, 5] are collected. It is a reference for the sector. This file package is encapsulated in .ZIP format and contains text files with different data structures as well as binary data files.

To facilitate the use of this information and allow a better understanding and reuse by the researchers, a complete re-reading of this data was carried out by the research group and the system parameters were reorganized into tables and a single MySQL database. Using JAVA programming, parameters of monthly price deck packs can be extracted, sorted and automatically saved in the database. Once stored, it is possible to manage the database, analyze the lifecycle of the information packages in time and export data in JSON format (JavaScript Object Notation) with any SQL query (Structured Query Language), locally or remotely.

The foundation of the architecture is a JAVA application that feeds the microservice database which, in turn, has a REST (Representational State Transfer) interface that allows a secure externalization of the standardized information contained in the database, in JSON data format. Security is done through the authentication of a JWT (JSON Web Token) access token generated by the user microservice which is responsible for managing user entities and their permissions. Through this token, a user can be authenticated through an endpoint of the REST interface of the user identification application to later be authorized to access the resources of the main API (Application Programming Interface).

To close the cycle, a Web Client application that acts as a consumer of the data provided by the main API after authentication was built, thus being able to use the information stored in the database to feed models and simulations in different devices as illustrated in Figure 1.

Energ.IA SQL database, contain the same information found in the 'Price Deck'. A comprehensive description of the parameters can be found in [4,5]. The raw files imported from the CCEE repository are either text files or binary files, which require different and more complex manipulation to extract the information.

Thus, based on the equations shown on Section 2.1, methods were developed in Java programming language, in which the parameter's values were automatically retrieved from the database. In the next section, to demonstrate the practical use, a case study is presented for which data directly provided by the Energ.IA database is used. In this study, historical data of natural inflows are used to build artificial inflow scenarios, important information for the planning optimization.

2.3 Case study

To validate the implemented platform, tests were carried out using a section of the Paraná basin in the south of the country (Figure 2), the same set used in the example of Souza et al [3].

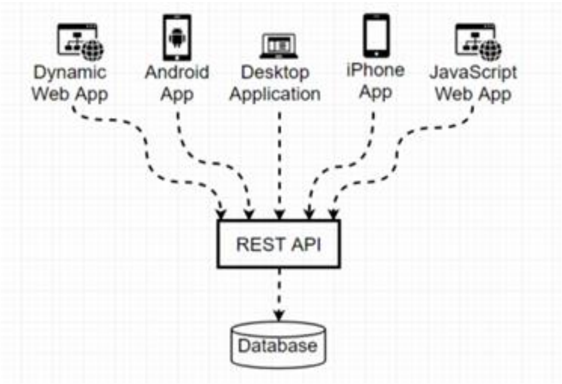

Figure. 1. Functional structure of access to the Energ.IA database. (Source: adapted from [6])

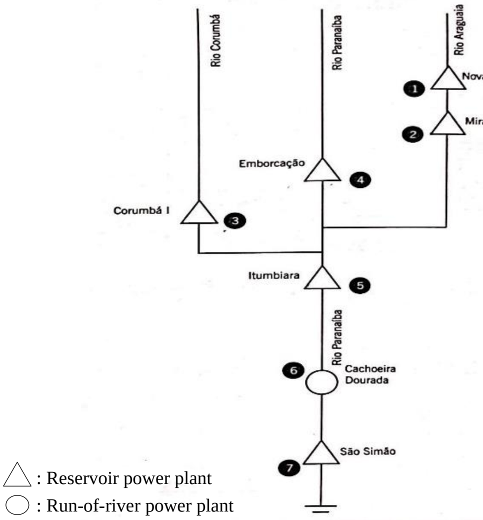

Figure 2. Power plant system at Paraná basin (Source: adapted from [3])

It is important to mention that the example from [3] has omitted two power plants recently added to the system and those plants were also removed from the test system used in this study, is spite of the fact the parameters were available in the Eneg.IA database.

For this study, the test system was implemented with three flow scenarios so that the sensitivity of the parameters could be perceived: A long term average (MLT) was calculated with the data between the years 1931 to 2020, and two other flow scenarios were selected. In these cases, past affluences were imported from the database from two different periods, the years of 1954 and 2014, being both considered critical years of low affluence. Figure 3 illustrates the natural inflow at São Simão.

In addition to the power plant parameters. Using the equivalent reservoir calculation methodology from [3], the various parameters of the equivalent energy system were calculated: equivalent productibilities (Equation 7), the average productivity associated with a height relative to 65% of the useful volume (Equation 8).

Therefore, the maximum storable energy available at the given system, calculated using Equation 10, presents the following value:

$$\boldsymbol{EA_{1,t}} = \mathbf{40493.45\ MWmonth}$$

Also, using Equation 14, the maximum hydraulic generation of the system is:

$$\boldsymbol{GHMAX_{i,t}} = \mathbf{7128.89\ MWmonth}$$

Most of the powerplants in the system have reservoirs, and so they can store and control its energy use, which depends on the amount of new energy provided by the natural flows of water at a given month, so using Equation 11, the amount of energy provided by these natural flows can be found. Alongside with the controllable energy, the 8th plant (Cachoeira Dourada) has no reservoir to store water, and therefore, cannot control its energy use. For this plant, considering the natural flows provided, and using Equation 12, we can calculate the amount of energy generated in this plant. So, adding both the results of these equations, we then get the total amount of energy provided at a given month. The results can be seen in Figure 4, below:

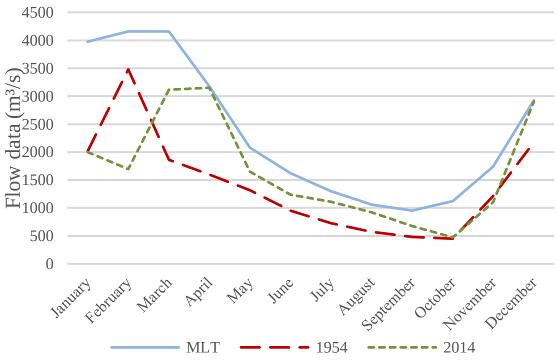

Figure 3. Flow scenarios for 'São Simão ' powerplant in each series.

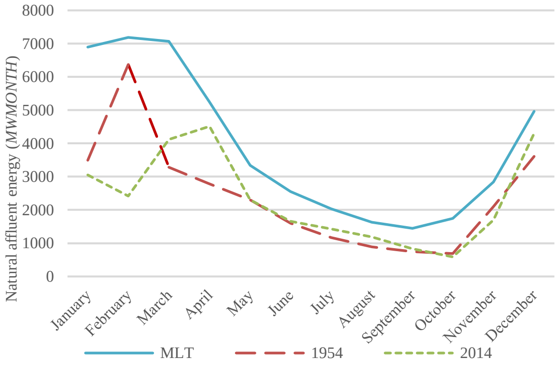

Figure 4: Total natural affluent energy in the system for each scenario.

According to this figure, one can observe that the difference between flow scenarios can be translated in the amount of energy available at a given month, as expected. The example of this case study illustrates one of the evaluations necessary for the planner decision-making process, and the actual use of the database to recover the update system information.

3 Conclusions

At the end of this work, it was possible to perceive the increasing importance of developing methodologies that present efficient answers to the problem of energy operation planning. In this sense, it is essential to provide computational tools that enable adequate planning for decision-making to avoid risk situations such as electricity scarcity or blackouts. The results presented, in the test cases, demonstrate the usability of the computational tool and the autonomy to carry out studies which are key to propose new methodologies for determining the optimal operation of the generation system. Finally, it is expected that this work and the potential of the tool can contribute to foster discussions in the environmental and energy planning areas.

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