Database with information on the electric grid of the national interconnected system for application in short term operation planning in Brazil

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Abstract. In Brazil, the operation planning of the hydro-thermal-wind power system and subsequent power dispatch is carried out by the National Electric System Operator (ONS) using a hierarchical chain of software tools, which includes medium, short, and very short-term time horizon models. Currently, only the latest software in the chain provides a more detailed representation of data regarding the transmission lines of the National Interconnected System (SIN). However, studies indicate that a more detailed consideration of the electrical grid in medium or short-term horizons can bring the operation closer to planning. Therefore, the Laboratory of Technologies and Bioinspired Solutions of the Federal University of ABC of the Federal University of ABC (LabBITS) seeks to implement the transmission system data of SIN, available through the Expansion and Reinforcement Plan (PAR). Consequently, the objective of this work is to identify and process the PAR information using JAVA programming, registering and managing the database with MySQL, so that this data can be intuitively utilized to support the development of modules for the studies of the Brazilian electrical system operation within a bioinspired computational platform called Energ.IA. [1]

Keywords: Database, Electric Planning, National Interconnected System, Power Flow.

1 Introduction

The production and transmission system of electric energy in Brazil is part of the National Interconnected System (SIN), an extensive connected network that enables energy generation at one point and its distribution throughout the Brazilian territory, aiming to optimize resources to meet demand.

The Energy Research Company, EPE [1], highlights in its annual balance that Brazil has a hydro-thermal-wind energy matrix, with intermittent renewable sources such as hydroelectric and wind generation being predominant. The use of thermal power generation helps maintain the system since it tends to supply the load when intermittent sources are affected by unfavorable weather conditions.

Regarding energy transportation, the SIN has an extensive network of high-voltage transmission lines that connect various generators to consumers across the country. This activity maximizes the utilization of the energy matrix by taking full advantage of intermittent resources at opportune moments and increasing system reliability. According to the National Electric System Operator, ONS [2], the national transmission network had an extension of about 180,000 km in 2022, with a projected increase to 216,000 km by 2027.

The planning of the national hydro-thermal-wind system operation is a complex and large-scale problem that considers numerous system variables, such as energy generation, transmission capacity of the basic network, and

[1]Energ.IA is an artificial intelligence and optimization tool platform developed by UFABC's LabBITS (Laboratory of Technology and Bioinspired Solutions) and applied to solve energy and system planning problems Electric Power

the predicted system load, CEPEL [3]. To address this, ONS performs operation planning through a hierarchical chain of software tools, including the models NEWAVE, DECOMP, and DESSEM, responsible for energy dispatching for medium, short, and very short-term horizons, respectively.

The representation of the electrical grid differs in the computational models used for operation planning. DESSEM is the only software in this chain that incorporates more detailed data of SIN transmission lines in the first 24 hours, making it a suitable optimizer for short-term hydro-thermal-wind dispatch. The other models have a simplified representation with energy trunks connected between fictitious subsystems in Brazil. However, detailed representations of the transmission network in medium and short-term horizons offer advantages in terms of energy dispatch efficiency, bringing operation closer to planning, according to Andriolo [4] and Moraes [5].

Electric network data is frequently used in Load Flow (or Power Flow) studies to assess parameters such as the system's state (complex voltages at the buses), the distribution of flows (active and reactive powers flowing through the lines), and other relevant quantities, Monticelli and Garcia [6]. The Linear Power Flow (or DC Power Flow) is employed by the DESSEM model for the analysis and optimization of the operation of the National Interconnected System (SIN), serving as a simplified approach based on the coupling between active power and voltage angles in the system. In this scenario, the effects of reactive power are disregarded. The DC Power Flow significantly reduces computational complexity, proving especially effective in high-voltage systems, where the coupling between active power and voltage angles is more pronounced, CEPEL [3].

Therefore, the Laboratory of Technologies and Bioinspired Solutions of the Federal University of ABC of the Federal University of ABC (LabBITS) aims to implement an open platform for general access to information used in the hydro-thermal-wind operation planning of Brazil. This platform aims to facilitate and simplify data retrieval for studies on the subject. To achieve detailed information on the power grid, it is necessary to obtain data from the SIN transmission system, which is made available by ONS through the Expansion and Reinforcement Plan (PAR). According to ONS [7], PAR reflects ONS's perspective on the necessary expansion of the Basic Network (RB) to preserve network security and performance.

The objective of this work is to identify and process the information from the Brazilian electrical transmission network, coming from PAR, using JAVA programming and registering and managing it in a MySQL database so that this data can be found in a single repository and utilized in power flow studies of the Brazilian electrical system in all horizons of the hydro-thermal-wind operation planning of SIN.

The paper will initially present an overview of the general scenario of the Brazilian electrical system's operation planning followed by the mathematical formulations that are responsible for the power flow. This is followed by the methodology section, containing the data used and a brief explanation, and then an example of how the created database can be used for a power flow study. Finally, the article concludes by presenting the next steps to be consolidated, as well as the benefits to be achieved.

1.1 Mathematical formulation

The DC model is derived by linearizing the equations of active power flow in the network. Neglecting losses, the equation of net power flow p_i in a circuit i between two buses k and m is given by Equation (1). Considering the approximations $v_k = v_m = 1\ pu$, $\sin\theta_{km} = \theta_{km}$, and $b_i = -x_i^{-1}$, Equation (2) is obtained.

$$p_i = -v_k \cdot v_m \cdot b_i \cdot \sin\theta_{km} \tag{1}$$

$$p_i = -b_i \cdot \left(\theta_{fr(i)} - \theta_{to(i)}\right) = \frac{\theta_{fr(i)} - \theta_{to(i)}}{x_i} \tag{2}$$

As the injection of net power at each bus is equal to the sum of the flows leaving the bus, we arrive at the matrix formulation exemplified in Equation (3).

$$p = \boldsymbol{B} \cdot \theta \tag{3}$$

where:

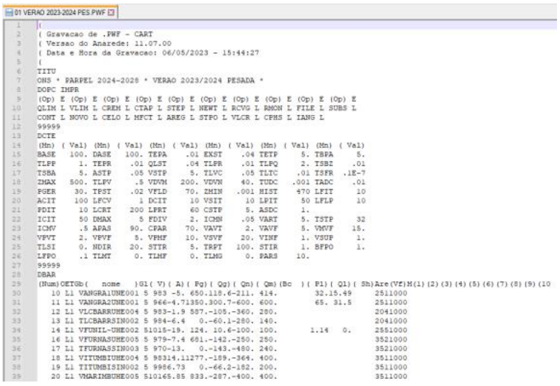
v_k and v_m represent the voltages of buses *k* and *m*;
b_i is the susceptance of circuit *i*;
θ_{km} is the angular difference $(\theta_k - \theta_m)$;

x_i is the reactance of circuit i;
p is the vector of net power injections;
θ is the vector of nodal voltage angles;
B is the network susceptance matrix;

2 Methodology

The PAR files are made available on the ONS's relationship portal with the agents, SINtegre [8]. They are prepared annually for a horizon of 5 years from the current year, considering light, medium, and heavy load levels.

Altogether, the PAR reference case consists of 33 PWF files, with 11 files for each of the light load, medium load, and heavy load levels. These 11 files for each load level represent the 5-year study horizon divided into summer (December to March) and winter (June to September), the two extreme seasons concerning the system load. Files downloaded from the SINtegre database are text files, such as the file shown in Figure *1*.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TSBA     5. ASTP    .05 VSTP     5. TLVC    .05 TLTC    .01 TSFR  .1E-7
ZMAX   500. TLPV     .5 VDVM   200. VDVN    40. TUDC   .001 TADC    .01
PGER    30. TPST    .02 VFLD    70. ZMIN   .001 HIST    470 LFIT     10
ACIT    100 LFCV      1 DCIT     10 VSIT     10 LPIT     50 LFLP     10
PDIT     10 LCRT    200 LPRT     60 CSTP     5. ASDC     1.
ICIT     50 DMAX      5 FDIV     2. ICMN    .05 VART     5. TSTP     32
ICMV     .5 APAS    90. CPAR    70. VAVT     2. VAVF     5. VMVF    15.
VPVT     2. VPVF     5. VPMF    10. VSVF    20. VINF     1. VSUP     1.
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   12 L1 VLCBARRUHE004 5 983-1.9 587.-105.-360. 280.                     2041000
   13 L1 TLCBARRSIN002 5 984-6.4   0.-60.1-280. 140.                     2041000
   14 L1 VFUNIL-UHE002 51015-19. 124. 10.6-100. 100.       1.14   0.     2551000
   16 L1 VFURNASUHE005 5 979-7.4 681.-142.-250. 250.                     3521000
   17 L1 TFURNASSIN003 5 970-13.   0.-143.-480. 240.                     3521000
   18 L1 VITUMBIUHE004 5 98314.11277.-189.-364. 400.                     3511000
   19 L1 TITUMBISIN002 5 9986.73   0.-66.2-182. 200.                     3511000
   20 L1 VMARIMBUHE005 510165.85 833.-287.-400. 400.                     3511000
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Figure 1. Data structure of the PAR file

The PWF files are standardized and divided into sections that start with a label and end with a predetermined number (99999). Within each section, data is arranged in rows, and in each row, variables are stored in fixed column intervals, without any character of separation between the values. If a variable value does not exist, empty characters are used in the designated columns for that variable. Table 2 displays only the information of the PAR file that are directly loaded into the database tables.

Table 1. Information on the origin of the variables in the database

Label	Columns	Variable name	Variable type	Stored in the Table
DBAR	1:5	Numero	int	barra
DBAR	7	Estado	char(1)	barra
DBAR	8	Tipo	tinyint	barra
DBAR	11:22	Nome	varchar(24)	barra
DBAR	25:28	Tensao	float	patamar
DBAR	29:32	Angulo	float	patamar
DBAR	33:37	GeracaoAtiva	float	patamar
DBAR	38:42	GeracaoReativa	float	patamar
DBAR	43:47	GeracaoReativaMin	float	patamar
DBAR	48:52	GeracaoReativaMax	float	patamar
DBAR	53:58	TensaoFixa	float	patamar
DBAR	59:63	CargaAtiva	float	patamar
DBAR	64:68	CargaReativa	float	patamar
DBAR	69:73	CapacitorReator	float	patamar
DBAR	74:76	Area	int	barra
DLIN	1:5	DaBarra	int	linha
DLIN	11:15	ParaBarra	int	linha
DLIN	16:17	Circuito	int	linha

DLIN	21:26	Resistencia	float	linha
DLIN	27:32	Reatancia	float	linha
DLIN	33:38	Susceptancia	float	linha
DLIN	39:43	Tap	float	linha
DLIN	44:48	TapMin	float	linha
DLIN	49:53	TapMax	float	linha
DLIN	59:64	BarraControlada	int	linha
DLIN	65:68	CapacidadeMax	float	linha
DCSC	1:5	DaBarra	int	linha
DCSC	10:14	ParaBarra	int	linha
DCSC	15:16	Circuito	int	linha
DCSC	46:51	Reatancia	float	linha
DELO	14:18	CapacidadeMax	float	linha

Table 2 highlights the parameters extracted from the PAR file that are not directly loaded into the database as they undergo preprocessing to relate the information of the direct current (DC) links to alternating current (AC) line data. Subsequently, the processed data is loaded into the line table of the database.

Table 2. Information used in the LCACC processing

Lable	Columns	ID	Variable type
DELO	1:5	Number of DC link ID	int
DELO	8:12	Tensão do elo CC	float
DELO	20:39	Nome do elo CC	String
DCBA	1:5	Número de ID da barra CC	int
DCBA	10:21	Nome da barra CC	String
DCBA	24:28	Tensão da barra CC	float
DCBA	72:75	Número do Elo CC	int
DCLI	1:4	Da barra CC	int
DCLI	10:12	Para barra CC	int
DCLI	18:23	Resistência	float
DCNV	1:4	Número de ID do conversor	int
DCNV	8:12	Número da barra CA	int
DCNV	14:17	Número da barra CC	int
DCNV	19:22	Número da barra neutra	int

A database was developed using MySQL [9], and based on the structure of the PAR information, considering the system's bus data, transmission lines, and load levels, the data was extracted in PWF format using JAVA [10] programming. The extracted data was then remodeled and loaded into four tables. The tables belonging to this database are described as follows.

Table PAR. Presents the file identification data. Study year, reference publication year, publication date, PWF files, and comments regarding the data. These pieces of information are related to the other three tables.

Table Barra. Contains the general data of the PAR buses. Identification number and name, state (connected or disconnected), type of bus, area number to which the bus belongs, subsystem (an aggregator that allows integration between energy data), and the PAR table identifier.

Table Patamar. The table stores the electrical parameters of the buses for each load level (light, medium, and heavy). Highlighting the voltage and phase angle of the bus, active and reactive power generation, active and reactive load, capacitor reactor, and identifiers of the Bus table.

Table Linha. The table provides data about the transmission lines connecting the system buses. It includes identifiers for the From/To buses, line resistance and reactance, transformer TAP, connection type (AC, DC, or CSC - Controllable Series Capacitor), and the identifier of the PAR table.

Figure 2 displays the tables that were created in MySQL Workbench [9].

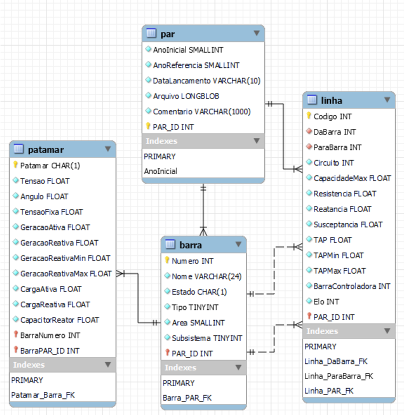

Figure 2. Visualization of the tables created in MySQL Workbench [9]

3 Example of use

To validate a Linear Power Flow study, a JAVA [10] programming routine was developed to extract specific information from the MySQL [9] database, such as: bus identification, active generation and load of buses, bus-to-bus connection details, and line reactance. The data from the 2021 Expansion and Reinforcement Plan (PAR 2021 - Summer 2021/2022) for the heavy load scenario was utilized. In this configuration, the National Interconnected System (SIN) comprises 7724 interconnected buses and around 11137 transmission lines.

In this context, the nodal voltage angles will be determined, requiring the inversion of the susceptance matrix. As previously discussed, this matrix represents the interconnections between network nodes, indicating the degree of connection and energy transmission capacity between them. In large-scale power systems like the SIN, the matrix B tends to become highly sparse (with most elements being zero), Monticelli [11]. To address this issue, sparsity techniques were employed to optimize the matrix, storing only non-zero elements and thus reducing memory consumption.

Furthermore, in power systems, the susceptance matrix is symmetric, necessitating alternative approaches to obtaining its inverse. One such method is the LU decomposition, which breaks down the matrix into two components: a lower triangular matrix (L) and an upper triangular matrix (U). This decomposition simplifies the solution of linear equations and systems, enabling the rapid computation of the inverse of the susceptance matrix. The process involves elementary operations that transform the original matrix into L and U, making the solution computationally efficient and applicable to large-scale power systems, Monticelli [11].

3.1 Validation of the matrix *B* construction

Due to the dimensions of matrix B (7724 x 7724), it is convenient to validate the algorithm that constructs the susceptance matrix. For this purpose, one random position was defined and later cross-referenced with the information in the MySQL database.

Position [1434, 6330]. This represents the connection between buses 1755 and 8704 of the system.

Figure *3* illustrates the connection report between buses 1755 and 8704 extracted from the *B* matrix construction algorithm.

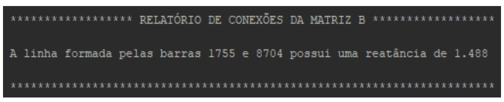

Figure 3. Connection report between buses 1755 and 8704 of the system

Meanwhile, Figure *4* depicts the query executed on the MySQL, whose values correspond to the connections report.

	DaBarra	ParaBarra	Reatancia
▶	1755	8704	1.488

Figure 4. Result of the query for the connection between buses 85 and 86 in the system

3.2 Determination of nodal voltage angles

Once the inverse matrix is determined using Equation (3), the vector of nodal voltage angles is obtained.

In order to illustrate the obtained results, a section of the SIN was chosen as an example. A section composed by Três Irmãos Hydropower Plant (UHE Três Irmãos) was selected, with its corresponding bus numbered 520. In this section, this generating bus is connected to other buses. With the reactance of these lines known, which can be retrieved from the MySQL database, and based on the calculated angles for each bus, the values of net power are obtained using Equation (2). Table *3* presents the data for this section of the system.

Table 3. Data from the sections composed by UHE Três Irmãos

To bus	From bus	Reactance	Angle (To bus)	Angle (From bus)	Net power
542	520	2,193	0,58 º	4,29 º	1,69
542	538	0,795	0,58 º	0,14 º	-0,55
542	539	0,712	0,58 º	0,05 º	-0,74
542	543	2,155	0,58 º	0,001 º	-0,26

Figure 5 presents the selected section, highlighting the values defined for the buses and lines.

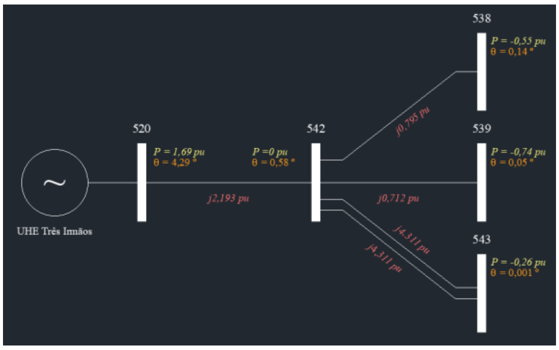

Figure 5. Section composed by UHE Três Irmãos

4 Contributions

The sample presented in Section 3 is just a small example of the potential offered by the newly established database. Future use of data stored in the database will make possible:

- Reproduction of the test;
- Elimination of typo errors while inputting parameters automatically;
- Easy updating of system parameters with data imported from ONS;
- Integration with energy planning data;

Thus, this database will gather important information for electric planning studies and contribute to the continuous development and future research activities at LabBITS.

5 Conclusion

The operational complexity of the Brazilian electricity system is noteworthy, owing to the extensive territorial coverage and the size and features of its hydro-thermal-wind network. This necessitates the implementation of effective strategies to minimize operational costs. Consequently, this article showcases the LabBITS team recent advancements in constructing a database for seamless integration into the Energ.IA platform, which is aimed to support energy planning and its decisions making process. The database was initially constructed based on parameters from the Brazilian transmission system. These parameters are utilized as data in electric planning and expansion studies of the National Interconnected System (SIN), and updated information is incorporated into the platform annually for a 5-year horizon, segmented into summer and winter periods and featuring 3 load levels. This updating process enables fresh research studies with current parameters and reflects the status of the actual system.

The database proves to be an engaging tool for electrical planning studies. With it, application and comparative tests can be conducted, and knowledge can be accumulated without wasting development time, rewriting previously tested codes, or rectifying typographical errors in input parameters. Thus, with a comprehensive database in place, more intricate and realistic scenarios can be assessed, and novel solutions can be proposed to enhance the operation of the Brazilian system.

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