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LOAD FLOW, THREE-PHASE SHORT-CIRCUIT AND DYNAMIC ANALYSIS STUDIES IN ELECTRICAL POWER SYSTEMS

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INTRODUCTION

The study of load or power flow in electrical systems is essential for designing infrastructure and predicting the required voltages, currents, and powers. The 2018 IEEE Std 3002.2 standard (IEEE, 2018) allows you to simulate situations that could hardly be safely tested in the real world. In addition, this type of analysis makes it possible to identify problems related to system loss, loading of new equipment, and other occurrences. One of them is the occurrence of faults in electrical systems that result in large variations in the currents and voltage of the three-phase network. Thus, dynamic analyses allow the study of short circuits in these systems while statistical analyses focus on the charge flow. This discussion is based on standardized technical norms to obtain a reliable theoretical basis for the procedures used in academic studies on this important topic of electrical engineering.

Andrade (2014) highlights the importance of studying protection in electrical systems to ensure that the substation devices act correctly. Souza (2018), in turn, argues that it is necessary to carry out computer simulations to assess whether the system is stable and to determine reactive power limits in the transmission lines. For this, several software can be used, as each one provides different information about the same circuit. Thus, only with the combination of the results obtained by several programs is it possible to have a complete analysis of the electrical network.

Munhoz, Castillo and Montero (1998) highlight the motivation for the use of software for analysis in electrical systems. The user is able to perform diagnoses and solutions more accurately if the characteristics are faithful. Arend, Ney and Bernardon (2017) show how to change a critical region to a less unstable one through the use of these software. Guarini et

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al. (2007) reinforce the need for studies in Electric Power Systems due to the expansion of this sector in Brazil, which requires simulations to prevent blackouts. Software helps to obtain the best results in these processes.

Load flow is an important tool for determining grid status and power distribution. Studies can be carried out to assess how the system would behave in specific cases, improving voltage and current profiles. Passos Filho (2000) states that more practical modeling is possible through the results obtained with the analysis of the power flow. This allows unique solutions to be developed for each situation, aiding in the planning and operation of these complex electrical systems.

Before the 70s, power flow studies generated oversizing of electrical systems due to the lack of accurate mathematical tools. With the increase in these requests, the limits of the system were reached and there was a large increase in losses. Jastale (2020) uses flow to analyze these possible limits in advance, while Gomes (2018) observes voltages and currents in cases of short circuit. Oliveira (2010), in turn, points out that despite the lower incidence of this specific type of short circuit in the electrical network, its impact is significant and requires an adequate dimensioning of this network and its protections with three-phase analysis.

Rosentino (2010) and Mariano (2017) point out the need to evaluate fault currents, as well as thermal and dynamic stresses for the adequate sizing of networks. Bourges et al. (2012) highlight the importance of locating the most critical points in a SEP due to faults, as regions far from the generating units can be affected by voltage and current instability. Thus, it is important to analyze system behaviors to maintain its stability and make changes/improvements when necessary.

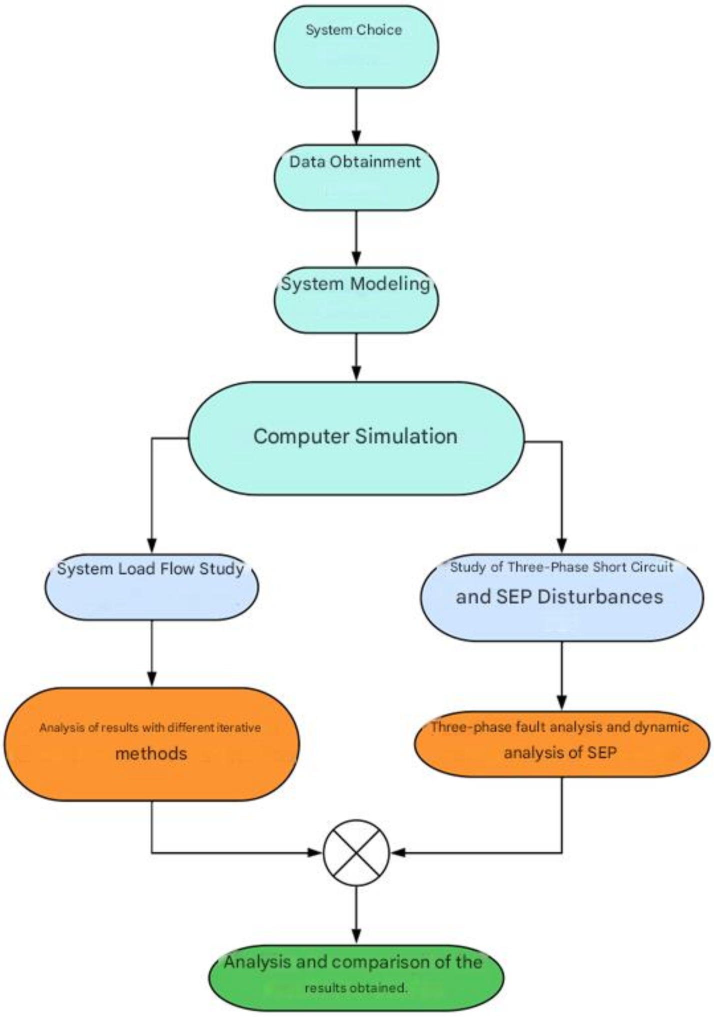
OBJECTIVE

The present study aims to analyze the use of software to perform load flow, three-phase short circuit and dynamic analysis studies in electrical power systems. The Brazilian National Interconnected System (SIN) is responsible for conducting the energy generated mainly by hydroelectric plants to corporate consumers and homes, but it can suffer several types of variations in current, resulting in a lack in the network. Thus, the simulation of these failures with preventive measures would be beneficial for the whole society. The general objectives of the research are: i) to carry out studies of the flow of the cargo; ii) evaluate the consequences of the three-phase short circuit; iii) perform dynamic analysis in the electrical power systems and iv) comparative of the results obtained by the different software used. Among the specific ones, the following stand out: i) presentation of the modeling of the main equipment necessary for the management of this problem; ii) theoretical foundation of these studies and iii) comparison of the data obtained through a three-phase fault in the electrical system. In this way, it is possible to avoid the collapse of industrial networks as well as irregular supply to the population.

METHODOLOGY

Using software, the steps for carrying out the studies of: i) cargo flow; ii) three-phase short circuit; and iii) dynamic analysis of the SEP. The following sections will present in detail everything from choosing the system to analyzing the results. The Figure 1 presents the set of steps and/or processes employed during the performance of the work.

Figure 1: Methodology Flowchart.

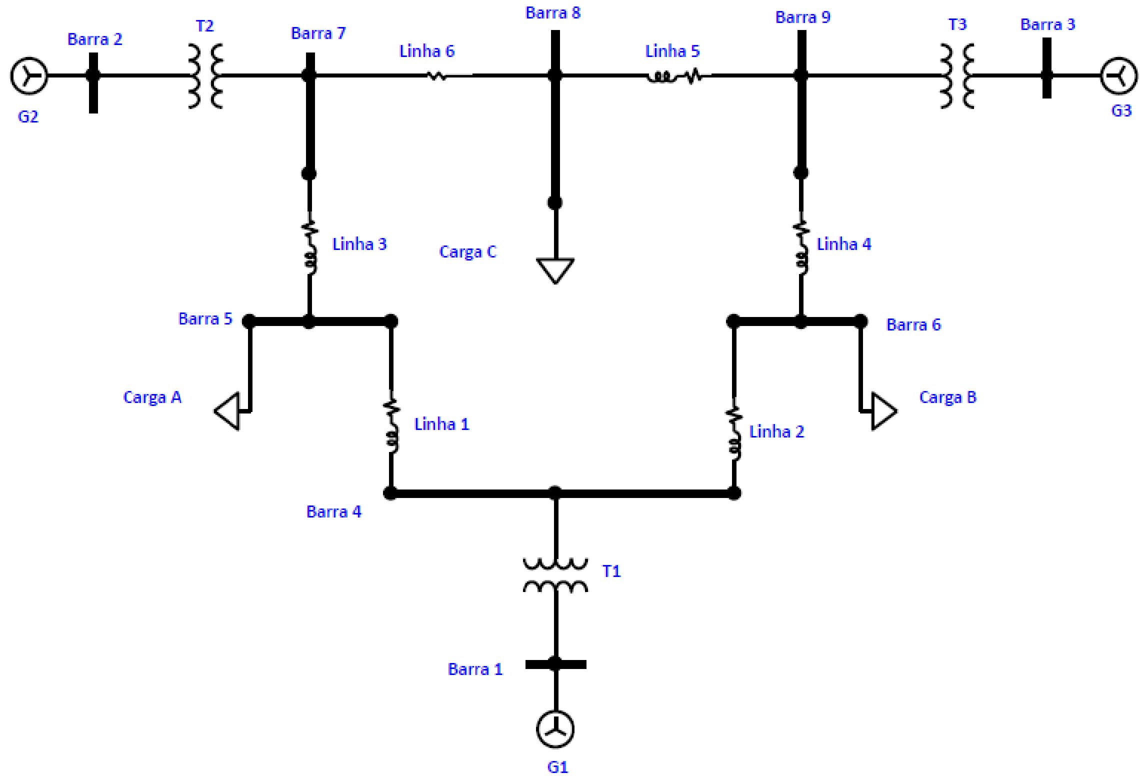


The model consists of a set of: i) nine bars; ii) six transmission lines; iii) three power transformers; iv) three power generation centers; and v) three load centers.

The criterion for choosing the system was based on the applicability of the concepts of SEP analysis, such as the studies already mentioned. The complexity of the system ensures the evaluation of all the components that make up a type of network that has the three fundamental aspects of a system, namely: i) generation; ii) transmission; iii) distribution; and iv) consumption of a SEP.

The 9-bar model of the IEEE and Vittal et al. (1977) was chosen to obtain the data. The parameters were defined by ANAREDE. Due to three simulation softwares, attention is required in the insertion of data so that all parameters are equal between the programs. System modeling requires adaptation to fit each specific software. For this, it is necessary to perform mathematical modeling so that all parameters are identical between software. The Figure 2 presents the model adapted for carrying out the studies (VITTAL et al., 2019).

Figure 2: IEEE 9-Bar Example Circuit.



In the Cepel package and in the PSP-UFU, the voltage level can be set in p.u.. In ANAREDE, it is necessary to insert and/or design each element of the system for parameterization of the bars with the definition of a voltage base group.

For generators, it is necessary to insert the transformers and for the loads there is no need to configure, since in the parameterization of the bars the active and reactive consumption was inserted. With this, all components would be ready for the automated power flow by the software. However, these data would not yet be considered as results of the evaluation of the system.

The model of the 9-bar system was parameterized in ANAREDE and the base file exported to ANAFAS. The "ANA" and "lst" file must be loaded with the settings, performing the conversion that results in an already modeled file. Thus, it is possible to carry out three-phase short-circuit studies in the ANAREDE and ANAFAS software.

The modeling process in the PSP-UFU follows the same steps as in ANAREDE, with the system already parameterized in it, it is possible to obtain the model in the UFU software.

The use of software is an efficient way to model and evaluate results in studies of the analysis of interconnected systems. For this, iterative methods such as Gauss-Seidel and Newton Raphson can be used to verify the optimal load flow, as well as the short circuit in single-phase, two-phase, two-phase-ground and three-phase buses. In this sense, the ANAFAS, ANAREDE AND PSP-UFU software are recommended for simulations, as they have distinct characteristics. ANAFAS performs fault analysis in the system and its consequences on the network, while ANAREDE analyzes load flow and its sizing. Finally, the PSP-UFU is used for detailed analysis of the topology of electrical networks. Thus, the aforementioned software allows the optimization of the results obtained in studies on the analysis of interconnected systems through mathematical modeling and convergence of results.

To perform the load flow studies, it is necessary to choose some parameters for the system to convert the results, such as: i) iteration method for convergence; ii) maximum number of iterations; and iii) accuracy of the results.

To perform the short-circuit study, it is necessary to parameterize some study options such as: i) fault bar; ii) duration time; iii) instant of occurrence of the fault; and iv) orientation of the reference voltage. Using the chosen software, the parameters are described, as follows: i) fault occurrence bar; and ii) orientation of the reference voltage. With these parameters established, it is possible to perform the configuration in each software.

An analysis of data and information generated by each report between the PSP-UFU, ANAREDE and ANAFAS software will be carried out to compare the results obtained. The 9-Bar system will be used as a reference to validate the percentage of equality of the values. The comparison will also serve to evaluate the performance of these programs by identifying the differences between their results and helping to improve the data analysis process.

DEVELOPMENT

Brazil has large territorial extensions, among which there are transmission lines that take the generating sources to the places where the energy is destined: industries and homes. Charge flow is a process that studies electrical systems and allows you to verify their behavioral characteristics. This flow shows the power flowing through the system, and it can be represented by bars or transmission lines. Through the simulation of the data obtained with the load flow, real occurrences can be predicted more easily, allowing the establishment of contingency measures to prevent failures in the electrical system. In addition, other important aspects of the network are also visible in relation to the requests between the load/generator bars, as well as the impacts generated in the disturbances present in it.

Stability is one of the main factors for the proper functioning of an electrical network. It is necessary that the voltages remain within the defined maximum limits, in addition, there are limiting parameters that serve as a control of the severity of disturbances in the Electric Power System (SEP). These random variations affect the quality and/or stability of the network and are perceived by users through the intermittent brightness of the lights at low voltage.

In Brazil, the nominal frequency of oscillation is between 59.9 Hz and 60.1 Hz. When disturbances occur in the distribution network, the generating units need to maintain this range to ensure a balance between generation and consumption.

Another important concern regarding the operation of SEPs is the short circuit, which consists of a low-impedance circuit between different potentials and can take the voltages of the bars to zero while raising the currents of the circuit above the initial values. In our country, due to the great technological diversity of distributed generation, these failures tend to be more frequent. To minimize their impacts on the energy system, it is necessary to adopt appropriate technical measures, in addition, there are several other common potential causes: inadequate insulation; mechanical problems; lightning strikes directly indirectly; switching surges; overcurrent due to excessive load and human errors in maintenance and inspection. Thus, it is essential to predict future failures to avoid significant technological losses in the SEL

Short circuits are classified as permanent and temporary. Permanent CC's happen when the failure damages the system, requiring a team to correct the problem. Temporary ones, on the other hand, have a protection system that involves a circuit breaker and a supervisory relay, turning off the system as soon as the safety level is detected.

In a three-phase system, there is a junction of the three phases being called symmetrical short. The pre-fault voltage drops abruptly to 0 while the sources supply currents of short I_{cc} according to the "force" of the busbars. When each bar reaches the limit established by the protector, he acts by interrupting the fault. Thus, it is possible to analyze the capacity of the member in relation to the fault by the contribution to the current and drop in voltage during this process - defined with S_{cc} (power/pre-fault voltage x current).

Studies on short circuits allow simulations that help in the operation of the system as well as equipment interruption parameters; thermal capacity of the components; adjustment of relays; mechanical forces and calculation of the terrestrial grid (SATO & FREITAS 2015). Knowledge of this information makes prevention and control simpler if it is carried out using computer software for interpretation in the most complex circuits (GALLI et al., 2017).

Simulation is a technique used to replace or amplify experiments, allowing the analysis of models through abstraction. The use of this technique facilitates the learning process and the achievement of more accurate results in complex systems. The simulation is based on the creation of a virtual environment that allows verifying and testing results before implementation in reality, making it possible to observe how the chosen parameters affect the behavior of the system. The software developed for studies through this tool offers interactive screens that help in processing data.

The market offers a variety of software for simulations, such as those from CEPEL: Simultaneous Fault Analysis (ANAFAS), Electrical Network Analysis (ANAREDE), Optimal Power Flow (FLUPOT) and Harmonic Behavior and Modal Analysis (HARMZS). Other software can also be found such as xSpider (EATON, 2019), OpenDSS (EPRI, 1997) and ETAP (ETAP, 2019). In addition, there is open source software with the PSP-UFU created by the Federal University of Uberlândia.

ANAREDE is a software aimed at studying the operation and planning of large electrical systems developed by CEPEL. Among the program's tools, iterative methods to solve calculated equations with power flow, network equivalent and definition of complementary networks stand out. Thus, PV curves are obtained that show the relationship between power/voltage of the system, verifying stability/restrictions necessary for the analysis.

ANAVAS, on the other hand, was created aiming at missing analyses of any size, making it possible to carry out individual or macro studies automatically generated by the software itself, presenting solutions based on the specified failure, in addition to informative reports on missing voltages/current, as well as the contribution of the elements under observation and monitoring on a case-by-case basis by the user, without extraordinary hardware or software requirements.

Finally, the PSP-UFU demonstrates the veracity and accuracy of results when used as an application tool in a research environment, offering its distribution free of charge and being an easy-to-use software and presenting data on the output of the load flow and the stipulated faults (OLIVEIRA, 2019).

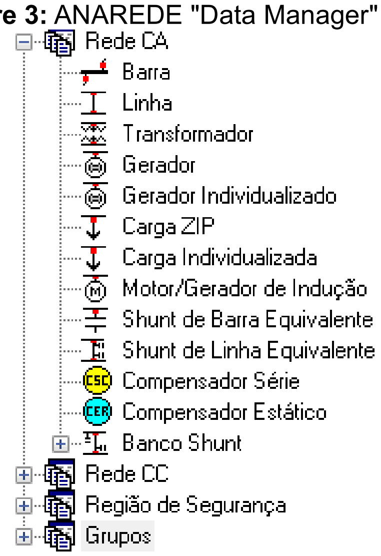
To implement a real system, it is necessary to start with a survey of the characteristics of the system to be studied. At this stage, you must know the size and equipment that make up your infrastructure. After that, software is used to calculate the variables under different conditions, allowing to verify if the project meets the expectations established at the beginning. If there is any discrepancy between the results and the initial project, it is possible to make adjustments to the infrastructure to improve its performance.

Next, it is necessary to install all equipment according to the project specifications and configure them accordingly. Finally, final tests are carried out before the system is put into operation. Thus, this section describes the results obtained through the computer simulation of a system according to the methodology detailed above.

The base file of the 9-bar system that is inserted in the ANAREDE examples was used, it is necessary to configure the PSP-UFU according to the data in the selected file. To perform the data extraction, it is necessary to access the "Data Manager" screen of ANAREDE.

With the selection screen as shown in Figure 7, the data is presented as the choice is made by clicking on each type of equipment.

Figure 3: ANAREDE "Data Manager" screen.



With the selection screen as shown in the Figure 3, the data is presented as the choice is made by clicking on each type of equipment.

Table 1: Data extracted from the Generators.

Generator Name	Bar Name	Bar Type	Voltage (p.u.)	Angle (degrees)	Ger. Active (MW)	Ger. Reactive (MW)
Generator 1	Bar 1	2	1,07	0	142,5	10,88
Generator 2	Bar 2	1	1,07	-1,8	90	-2,6
Generator 3	Bar 3	1	1,07	-1,4	85	-13,7

A Table 1 It has basic data on the region, voltage and angle of the generators. The active/reactive powers are also shown. For studies at the PSP-UFU, the sequence impedance values are required, without the parameterization of the impedances, the values referring to the fault simulations present an error, thus preventing the configurations from being carried out.

The screen displays the acronym that denotes Not a Number (NAN), showing that there is a lack of data for the continuity of the settings. However, the software presents a base file with the 9-bar circuit for performing simulations. The impedance values are extracted and tabulated as shown in the Table 2.

Table 2: Data on the reactance of the PSP-UFU Generators.

Name of Generators	Sequence Impedances (p.u.)		
	Posi reactance. ()X_1	Reactance Denied. ()X_2	Zero Reactance ()X_0
Generator 1	0,051680	0,074290	0,020672
Generator 2	0,101830	0,149365	0,040732
Generator 3	0,154105	0,202053	0,061642

The resistances were considered as 0, and the reactances presented in p.u., with this, it is possible to perform the simulation of the system faults. With the tabulated data, the next data to be obtained will be from the system bars. By performing the same data extraction process, the Table 3 Displays the data of the system bars.

Table 3: Data extracted from the set of 9 Bars of the system.

Bar Name	Guy	Tension Base (kV)	Voltage (p.u.)	Angle (degrees)	Generation Active (MW)	Reactive Generation (MW)	Load Active (MW)	Load Reactive (MW)
Bar 1	2 - Ref.	1	1,075	0	142,5	10,88		
Bar 2	1- PV	1	1,075	-1,8	90	-2,6		
Bar 3	1- PV	1	1,075	-1,4	85	-13,7		
Bar 4	0 - PQ	1	1,072	-4,1				
5 Bar	0 - PQ	1	1,05	-7,7			125	50
6 Bar	0 - PQ	1	1,064	-6,7			90	30
7 Bar	0 - PQ	1	1,078	-4,6				
8 Bar	0 - PQ	1	1,069	-6,4			100	35

Bar 9	0 - PQ	1	1,083	-3,9				

As shown in Table 3, the extracted data show the stresses of each bus, according to the base stress of the busbars, the angles of each one, as well as the generation inserted in the bus, as well as the installed load. The next data to be obtained are presented in the Table 4which shows the data from the system generators.

Table 4: Generator data extracted from the system's 9-bar set.

Bar DE	Bar TO	Resistance *(%)	Reactance(%)	Tap	CapacityNormal (MVA)
Bar 1	Bar 4	0	5,76	1	250
Bar 2	7 Bar	0	6,25	1	200
Bar 3	Bar 9	0	5,86	1	300

The Table 4 informs the bars of the screws: "DE" and "STOP", as well as resistance, reactance, tap and normal capacity. The Table 5 Shows the data of the system lines with their settings.

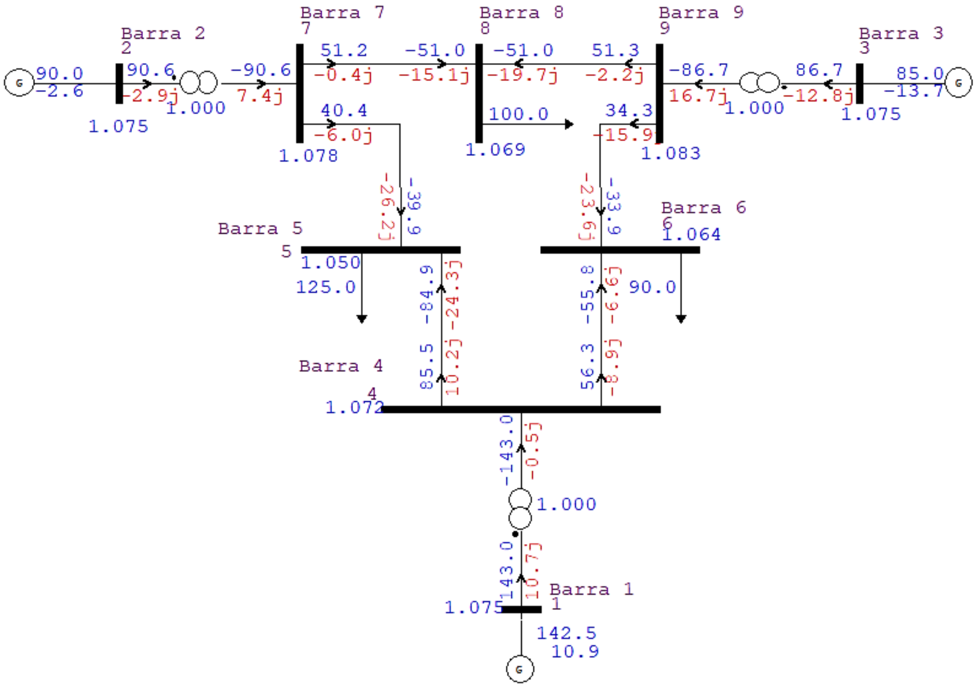
Table 5: Data extracted from the system rows.

Name	Bar DE	Bar TO	Resistance (%)	Reactance(%)	Susceptance(Mvar)	CapacityNormal (MVA)
Line 1	Bar 4	5 Bar	1	8,5	17,6	300
Line 2	Bar 4	6 Bar	1,7	9,2	15,8	200
Line 3	6 Bar	Bar 9	3,9	17	35,8	200
Line 4	7 Bar	5 Bar	3,2	16,1	30,6	300
Line 5	7 Bar	8 Bar	0,85	7,2	14,9	300
Line 6	8 Bar	Bar 9	1,19	10,08	20,9	300

A Table 5 It contains data such as resistance, reactance, susceptance, and capacity of each line. Thus, it is possible to set up a circuit in the PSP-UFU to study load flow and short circuit.

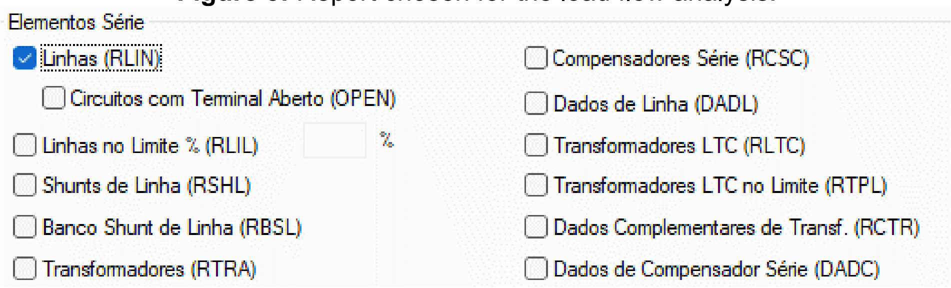
The analysis of the system with the flow in each software will be carried out through simulation with the software established in the Methodology, using the iteration method for the convergence of the results. The data were obtained directly from the base file, present in the examples provided by the ANAREDE software, dispensing with the parameterization of the equipment in other instances. The Figure 4 shows the circuit with flows in the branches of the system after being mounted on the ANAREDE.

Figure 4: Circuit with ANAREDE load flow.



To be able to extract the results, it is necessary to activate the software's reports menu. To access the selection of the expected results, it is necessary to follow the following steps: Access the menu of the software's HMI screen → Select the "Analysis" tab → "Choose the "Reports" tab. After following the specified path, a page opens, and in this Section, the user requests the required set of results. The Figure 5 Displays the report chosen in the software for the extraction of the result set.

Figure 5: Report chosen for the load flow analysis.



As presented below, the Table 6 displays the load flow generated by the software with the RLIN report.

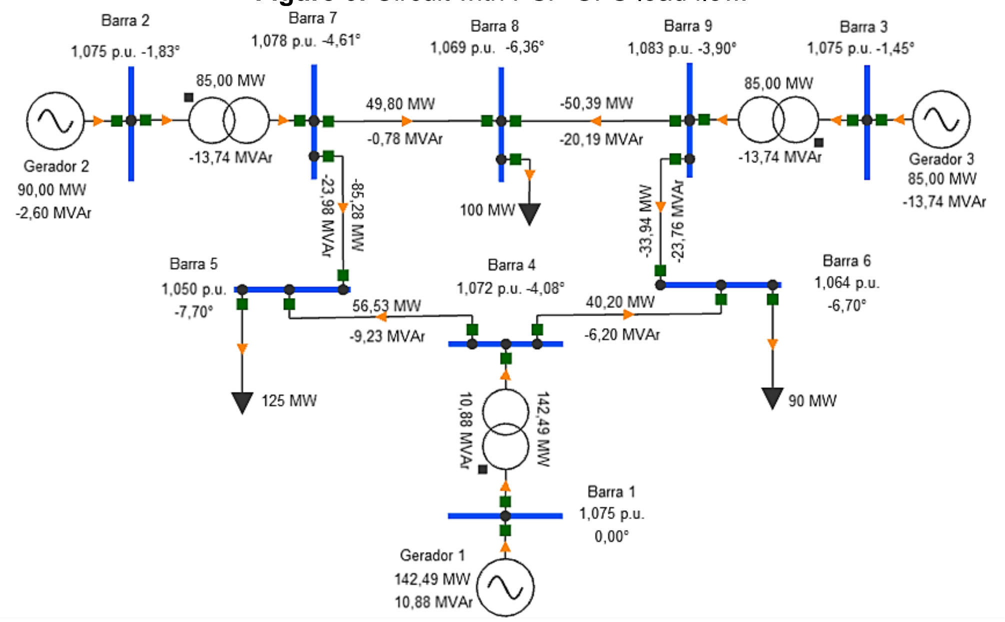
Table 6: Results of the conversion of the load flow in ANAREDE.

Bar DE	Guy	Bar TO	Fluxo At. (MW)	Fluxo Reat. (MW)	Fluxo(MVA)	Capac.Normal (MVA)	Loss Active(MW)	Loss Reat. (MW)
Bar 1	2 - Ref.	Bar 4	142,49	10,88	142,91	250	0,00	10,18
Bar 2	1- PV	7 Bar	90,00	-2,60	90,04	200	0,00	4,38
Bar 3	1- PV	Bar 9	85,00	-13,74	86,10	300	0,00	3,76
Bar 4	0 - PQ	Bar 1	-142,49	-0,70	142,49	250	0,00	10,18
Bar 4	0 - PQ	5 Bar	85,96	9,93	86,53	300	0,68	-14,05
Bar 4	0 - PQ	6 Bar	56,53	-9,23	57,28	200	0,47	-15,46
5 Bar	0 - PQ	Bar 4	-85,28	-23,98	88,59	300	0,68	-14,05
5 Bar	0 - PQ	7 Bar	-39,72	-26,02	47,48	300	0,48	-32,22
6 Bar	0 - PQ	Bar 9	-33,94	-23,76	41,43	200	0,4	-39,54
6 Bar	0 - PQ	Bar 4	-56,06	-6,24	56,41	200	0,5	-15,46
7 Bar	0 - PQ	Bar 2	-90,00	6,98	90,27	200	0,0	4,38
7 Bar	0 - PQ	5 Bar	40,20	-6,20	40,68	300	0,5	-32,22
7 Bar	0 - PQ	8 Bar	49,80	-0,78	49,80	300	0,19	-15,59
8 Bar	0 - PQ	7 Bar	-49,61	-14,81	51,78	300	0,19	-15,59
8 Bar	0 - PQ	Bar 9	-50,39	-20,19	54,28	300	0,27	-21,91
Bar 9	0 - PQ	Bar 3	-85,00	17,49	86,78	300	0,00	3,76
Bar 9	0 - PQ	6 Bar	34,34	-15,77	37,79	200	0,40	-39,54
Bar 9	0 - PQ	8 Bar	50,66	-1,72	50,69	300	0,27	-21,91

A Table 6 presents the flow in the branches, and the flows are presented: i) active power; ii) reactive power; iii) apparent power; as well as iv) normal capacity of the branch; v) active losses; and vi) reactive losses. It is notorious to see that the ANAREDE report brings several important information, such as reactive losses in the branches.

Using a precision number with a scale of 10-4 and performing a maximum number of up to 20 iterations, it is possible to obtain the PSP-UFU screen with the flows already presented as presented by the Figure 6.

Figure 6: Circuit with PSP-UFU load flow.



A Figure 6 It presents the load flows in the branches as well as the basic parameterized data regarding the bars and generators of the system. The software performed the load flow calculations performing a total of 5 iterations in a time of 1ms (one millisecond) using the Newton Raphson method. The Table 7 Displays the load flow data on the branches.

Table 7: Results of the conversion of the load flow in the PSP-UFU.

Name	From	Towards	Active Power (MW)	Rear Power . (MVAr)
Line 1	7 Bar	8 Bar	49,798	-0,783
Line 1	8 Bar	7 Bar	-49,612	-14,810
Line 2	8 Bar	Bar 9	-50,388	-20,190
Line 2	Bar 9	8 Bar	50,660	-1,722
Line 4	5 Bar	Bar 4	-85,280	-23,980
Line 4	Bar 4	5 Bar	85,958	9,929
Line 5	Bar 4	6 Bar	56,534	-9,228
Line 5	6 Bar	Bar 4	-56,061	-6,236
Line 3	7 Bar	5 Bar	40,202	-6,197
Line 3	5 Bar	7 Bar	-39,720	-26,020
Line 6	6 Bar	Bar 9	-33,939	-23,764
Line 6	Bar 9	6 Bar	34,340	-15,773
Trafo 2	Bar 2	7 Bar	90,000	-2,596
Trafo 2	7 Bar	Bar 2	-90,000	6,980
Trafo 3	Bar 3	Bar 9	85,000	-13,736
Trafo 3	Bar 9	Bar 3	-85,000	17,495
Trafo 1	Bar 1	Bar 4	142,491	10,880
Trafo 1	Bar 4	Bar 1	- 142,491	-0,701

The software presents the converted data with a total of up to 12 decimal places in its report, however, Table 7 presents only a total of 4 places for easy verification. This then displays the type of branch equipment in which the flow is concentrated, the bars to which the equipment is connected, as well as the active and reactive flow of the sections.

As presented in the methodology, the results will be compared between the software, ANAREDE and the PSP-UFU. To make the comparisons, Equation 1 presents the calculation used.

$$Dif._{\%} = \frac{D_{ref.} - D_{obt.}}{D_{ref.}} \quad (1)$$

Where:

$Dif._{\%}$ = shows the percentage difference

$D_{ref.}$ = Displays software reference data

$D_{obt.}$ = presents the data obtained by the other software

Equation 1 presents the percentage difference using , as a reference data, and subtracting from , data obtained by the other software, and divided by the reference data. In this comparison, the values of the Cepel package will be used as a reference. $D_{ref.} D_{obt.}$

Table 8 presents the deviations of the results of the load flow between ANAREDE, in the Table 6 and the PSP-UFU, in the Table 7.

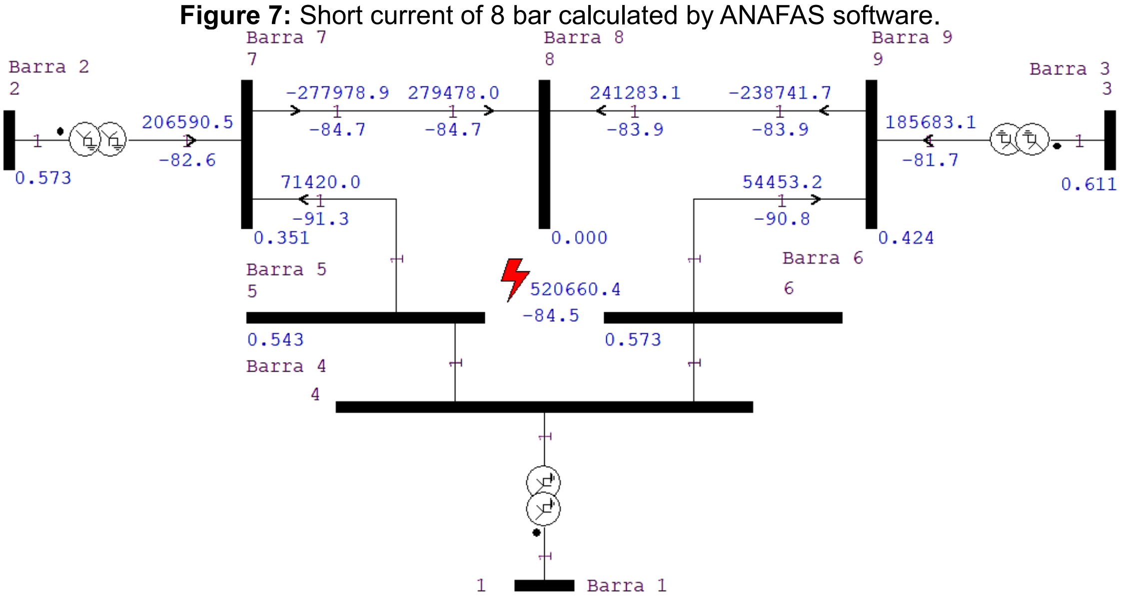
Table 8: Difference Percentage of the system's power flows.

DE Bar	Bar TO	ANAREDE Active Flow (MW)	ANAREDE Reactive Flow (MW)	PSP-UFU (MW) Active Stream	Fluxo Reativo PSP-UFU (MW)	Diff.% Active Flow	Diff.% Reative Flux
Bar 1	Bar 4	142,49	10,88	142,49	10,88	0,00%	0,00%
Bar 2	7 Bar	90,00	-2,60	90,00	-2,60	0,00%	0,17%
Bar 3	Bar 9	85,00	-13,74	85,00	-13,74	0,00%	0,03%
Bar 4	Bar 1	-142,49	-0,70	-142,49	-0,70	0,00%	0,20%
Bar 4	5 Bar	85,96	9,93	85,96	9,93	0,00%	0,01%
Bar 4	6 Bar	56,53	-9,23	56,53	-9,23	0,01%	0,03%
5 Bar	Bar 4	-85,28	-23,98	-85,28	-23,98	0,00%	0,00%
5 Bar	7 Bar	-39,72	-26,02	-39,72	-26,02	0,00%	0,00%
6 Bar	Bar 4	-56,06	-6,24	-56,06	-6,24	0,00%	0,06%
6 Bar	Bar 9	-33,94	-23,76	-33,94	-23,76	0,00%	0,02%
7 Bar	Bar 2	-90,00	6,98	-90,00	6,98	0,00%	0,00%
7 Bar	5 Bar	40,20	-6,20	40,20	-6,20	0,01%	0,05%
7 Bar	8 Bar	49,80	-0,78	49,80	-0,78	0,00%	0,39%
8 Bar	7 Bar	-49,61	-14,81	-49,61	-14,81	0,00%	0,00%
8 Bar	Bar 9	-50,39	-20,19	-50,39	-20,19	0,00%	0,00%
Bar 9	Bar 3	-85,00	17,49	-85,00	17,50	0,00%	0,03%
Bar 9	6 Bar	34,34	-15,77	34,34	-15,77	0,00%	0,02%
Bar 9	8 Bar	50,66	-1,72	50,66	-1,72	0,00%	0,14%

The results found in the Table 8 have the highest deviation of 0.3941% (reactive power from Bar 7 to Bar 2). It is notorious then to verify that the load flow in the software presents a greater difference in the reactive powers than in the active powers, however, the largest difference in the active powers presents a value of 0.0064% (referring to the flow from Bar 4 to Bar 1).

According to the methodology presented, the ANAFAS and PSP-UFU software present in their work areas, the representation of the lack in a different way. In the performance of the short-circuit studies, the three-phase fault considered is performed at bar 8. The parameterization of the instant of occurrence of the fault is not carried out, as well as the duration time, then presenting the results of the maximum values obtained. The software of the Cepel package adopted is ANAFAS and will be compared to the PSP-UFU. According to the methodology adopted, the system is shown showing the current in A (ampere) as shown in Figure 13.

Figure 7: Short current of 8 bar calculated by ANAFAS software.



The software displays the short current indicated by the lightning symbol in red, as well as the angle of the current in positive sequence. ANAFAS does not present the contribution chains in the entire section, which implies the need to generate a report of the contributions. The Table 9 Displays the fault current data at 8 bar generated by the software.

Table 9: ANAFAS data regarding the fault current in the bar.

Bar Namemissing	Phase A		Phase B		Phase C	
	Corrente (p.u.)	Angle	Corrente (p.u.)	Angle	Corrente (p.u.)	Angle
8 Bar	9,018	-84,5	9,018	-24,5	9,018	-144,5

Checking the impact of the branches of the system, it is necessary to carry out an analysis of the system stresses in the event of a fault. To do this, you can extract the information on the stresses of the members with the same report as the short on the member. The Table 10 Displays the post-fault member stress data.

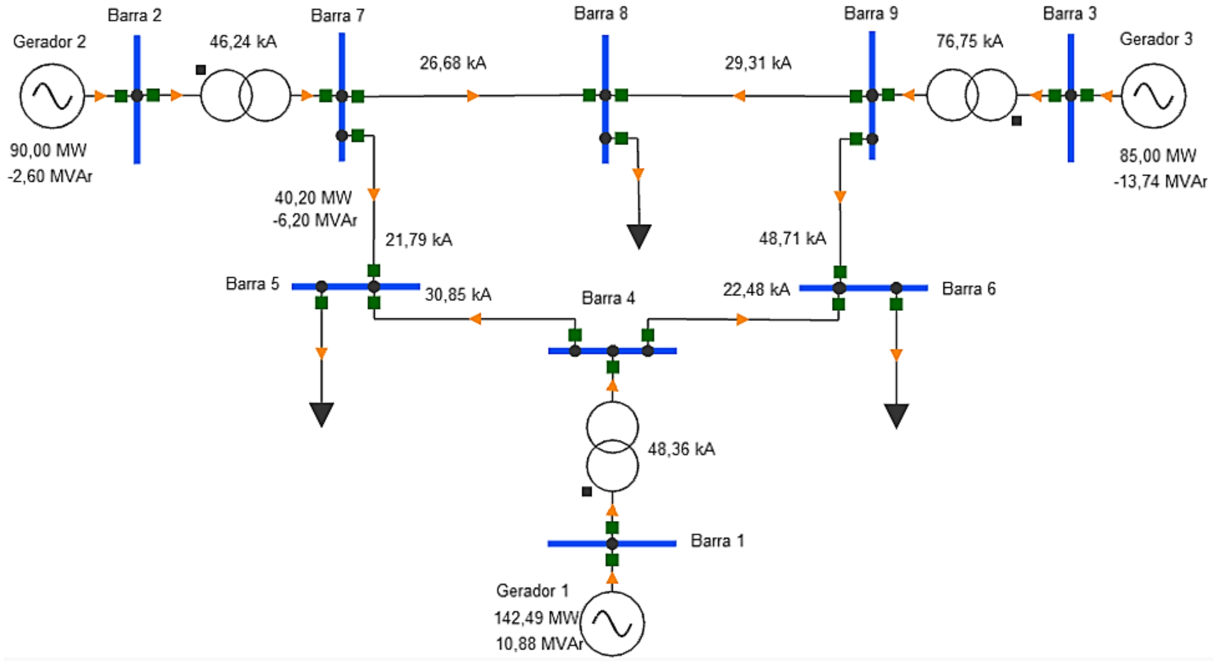
Table 10: Data on post-foul tensions at ANAFAS.

Bar Name	Phase A		Phase B		Step C	
	Voltage (p.u.)	Angle	Voltage (p.u.)	Angle	Voltage (p.u.)	Angle
Bar 2	0,573	2,0	0,573	-118,0	0,573	122,0
Bar 3	0,611	2,1	0,611	-117,9	0,611	122,1
5 Bar	0,543	-5,4	0,543	-125,4	0,543	114,6
6 Bar	0,573	-4,1	0,573	-124,1	0,573	115,9
7 Bar	0,351	-1,5	0,351	-121,5	0,351	118,5
8 Bar	0,000	-84,5	0,000	-24,5	0,000	-144,5
Bar 9	0,424	-0,7	0,424	120,7	0,424	119,3

With the post-fault stresses presented, it is notorious that the bars closest to the fault bar suffer the greatest impact from the voltage drop, while the stress at bar 8 decays to zero. Bars 1 and 4 are not presented by the report, however, due to the theoretical foundation, it can be said that they do not decay drastically due to the branch being connected to a reference bar.

Performing the study with the software, it is possible to carry out the study of faults using the load flow of the system. Therefore, it is possible to analyze the results through the absence regime and by analyzing an approximation of a case with the system in operation. The following sections present the results and considerations pointed out, then showing the results found between the analyses. Considering the original system currents, the Figure 8 presents the flow of the pre-fault current in the system.

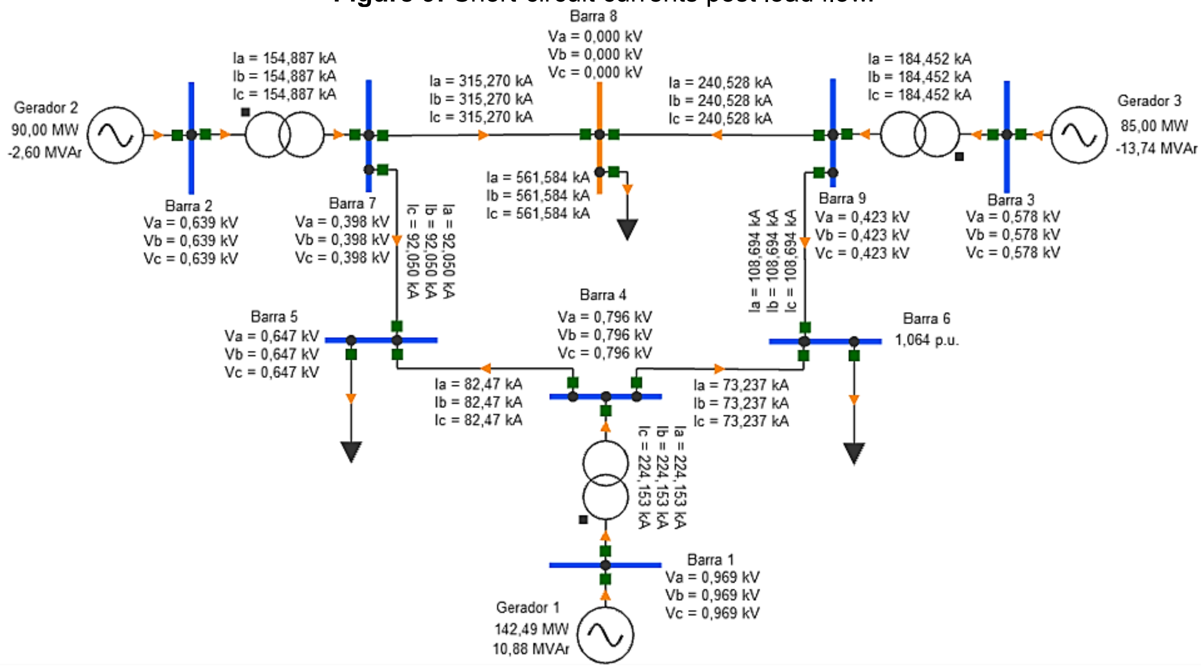
Figure 8: Currents flowing through the 9-bar system at PSP-UFU.



By verifying the functionality of the software, it is possible to perform a short-circuit analysis considering the presence of load flow. With the analysis, it is possible to obtain values that are closer to a real scenario of events. With the system already assembled due to previous analyses, the lack of PSP-UFU software will be analyzed.

Analyzing the figure presented, it is possible to verify that the highest current circulating through the lines is 48.71kA, and verifying the highest current in the system, it is possible to notice the current that passes through transformer 3, with a value of 76.75kA. Such contributions will be used to perform the analysis of the system's behavior in the event of a shortage. It is noted that it is possible to extract the reports of the short-current values after the load flow has been carried out, causing the results to undergo some changes as shown in the Figure 9, which presents the fault data and the contributions of the equipment to the short-current at the fault location bus.

Figure 9: Short-circuit currents post load flow.



The fault is represented with the orange color of the bar that was selected for the occurrence of the fault. To facilitate the understanding of the results, the software prints the reports in table format as well as in the load flow studies. The Table 11 displays the short current data in bar 8.

Table 11: Data from the PSP-UFU regarding the short current in bar 8.

Bar Namemissing	Phase A		Phase B		Phase C	
	Corrente (p.u.)	Angle	Corrente (p.u.)	Angle	Corrente (p.u.)	Angle
8 Bar	9,7269	-84,3598	9,7269	155,6402	9,7269	35,6402

The Table 11 Displays the data of the three-phase short-current in the system, as well as the angle of each phase. However, to perform a macro analysis of the impact of the fault on the bar, it is necessary to verify the consequences of the fault on the other bars, generators and lines. The Table 12 presents the impact of the fault on the other bars.

Table 12: Post-fault stress data at bar 8.

Bar Name	Phase A		Phase B		Step C	
	Voltage (p.u.)	Angle	Voltage (p.u.)	Angle	Voltage (p.u.)	Angle
Bar 1	0,96908	0,6279	0,9691	-119,3721	0,9691	120,6279
Bar 2	0,63857	0,7896	0,6386	-119,2104	0,6386	120,7896
Bar 3	0,57787	2,5758	0,5779	-117,4242	0,5779	122,5758
Bar 4	0,79638	-3,5176	0,7964	-123,5176	0,7964	116,4824
5 Bar	0,64672	-7,2343	0,6467	-127,2343	0,6467	112,7657
6 Bar	0,65988	-5,6459	0,6599	-125,6459	0,6599	114,3541
7 Bar	0,39803	-2,8394	0,3980	-122,8394	0,3980	117,1606
8 Bar	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Bar 9	0,42286	-0,4562	0,4229	-120,4562	0,4229	119,5438

A Table 12 presents the impact of the foul, then showing the post-foul tensions and their angles. It is notorious that the voltage drop in the bars is significant, especially in the region close to the fault, as in bars 7 and 9. However, when checking bar 1, it does not suffer as much impact, since it is the reference bar of the system, and which guarantees the operation of the system in case of contingencies. Bars 4, 5 and 6 are the ones that decrease the least due to being close to Bar 1. It is noticeable that the generators inject current into the grid upon the occurrence of the fault. The Table 13 presents the currents that generators inject into the grid.

Table 13: Data on the currents injected by the generators in the PSP-UFU.

Generators	Phase A		Phase B		Step C	
	Corrente (p.u.)	Angle	Corrente (p.u.)	Angle	Corrente (p.u.)	Angle
Generator 1	3,2052	-62,9895	3,2052	177,0105	3,2052	57,0105
Generator 2	3,7174	-75,2736	3,7174	164,7264	3,7174	44,7264
Generator 3	2,5909	-70,5672	2,5909	169,4328	2,5909	49,4328

As a way to make up for the lack of impedance in the bar, the generators perform the injection of current requested by the system, then increasing in the case of Generator 2 by up to almost 5 times the value of the nominal current injected before the fault.

As Generator 2 has the highest contribution if the current components are observed, such values are due to the respective generator having the highest value of active power in the system and because it is close to the bar that caused the fault. The largest contribution after Generator 2 is given by Generators 3 and 1 respectively, following the same consideration of the active power value of each equipment.

To perform the comparison analyses between the softwares, the results obtained will be used to present the deviation between the ANAFAS software and the PSP-UFU. The three-phase fault current was obtained by the two software with similar results, the lack of the PSP-UFU will be considered considering the load flow. The Table 14 presents the deviation of the results obtained between the Table 9 of ANAFAS and the Table 11 of the PSP-UFU.

Table 14: Difference between the results of the currents and angles of the circuit.

Bar Name	Phase A		Phase B		Phase C	
with lack	Corrente (p.u.)	Angle	Corrente (p.u.)	Corrente (p.u.)	Angle	Corrente (p.u.)
8 Bar	7,86%	0,17%	7,86%	735,27%	7,86%	124,66%

The deviation of the Table 14 presents a percentage lower than 1% considering the value of the short current, thus showing that the software performs a convergence of the results in a similar way. However, the software does not agree between the angles presented, reaching close to 562% in the case of Phase B. The analysis performed presents the objective of the study with little divergence. Making a consideration (not presented in the manual) based on the theoretical knowledge of the work, it is correct to say that ANAFAS considers the 0° angle as an initial parameter, while the PSP-UFU uses the angles of the bars, so the values would certainly present divergences.

Performing an analysis of the system stresses, the PSP-UFU shows the stresses of all the bars in the system, while ANAFAS shows only the bars that are not connected to the reference bar. The Table 15 presents the deviation between the Table 10 of ANAFAS, and the Table 12 of the PSP-UFU, in relation to the values of the tensions between the software.

Table 15: Difference between post-fault tensions between software.

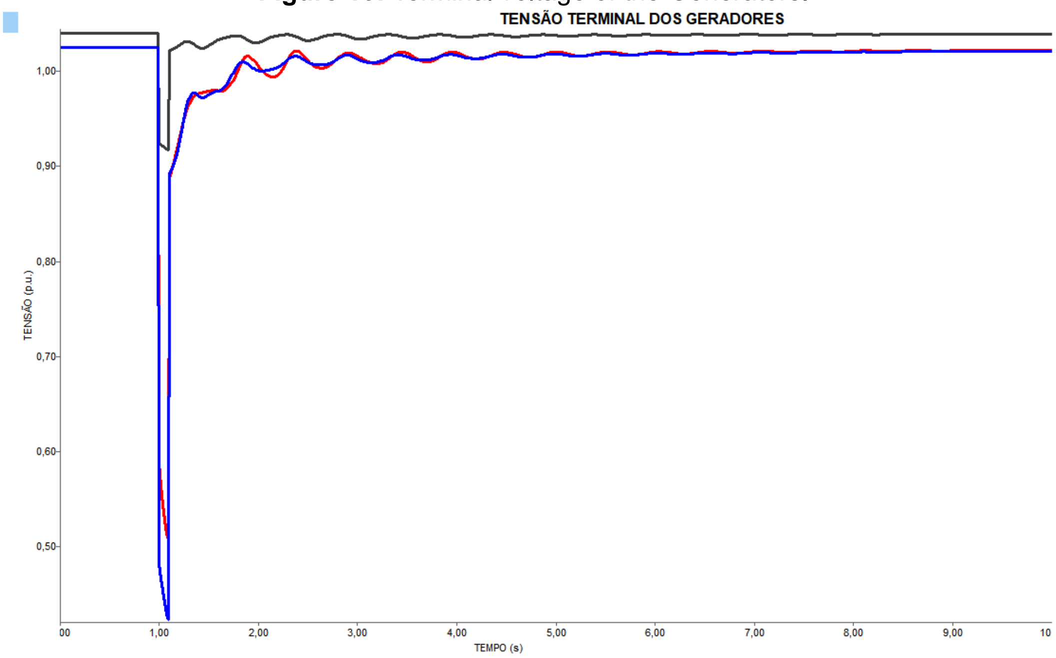
Bar Name	Phase A		Phase B		Step C	
	Voltage (p.u.)	Angle	Voltage (p.u.)	Angle	Voltage (p.u.)	Angle
Bar 2	11,44%	60,52%	11,45%	1,03%	11,45%	0,99%
Bar 3	5,42%	22,66%	5,42%	0,40%	5,42%	0,39%
5 Bar	19,10%	33,97%	19,10%	1,46%	19,10%	1,60%
6 Bar	15,16%	37,70%	15,17%	1,25%	15,17%	1,33%
7 Bar	13,40%	89,29%	13,39%	1,10%	13,39%	1,13%
8 Bar	0,00%	100,00%	0,00%	100,00%	0,00%	100,00%
Bar 9	0,27%	34,83%	0,26%	199,80%	0,26%	0,20%

As can be seen, the software shows a divergence of almost 89% (angle of the fault current of Bar 3 in phase A). The currents of all bars have a divergence of less than 15%, as in the case of Bar 2, which has a divergence of less than 4%. The two software programs present in the fault report, the currents that circulate through the system, but only the PSP-UFU presents in its reports, the contributions of the generators through the injection of current in the system.

With the analysis presented of the three-phase fault after the load flow in the PSP-UFU, the same type of analysis was performed in the ANAFAS software. It is then considered that the software does not export the flow data from ANAREDE, the faults are considered without the presence of a load flow, thus denoting a 0° angle value as the basis of the process of convergence of the results.

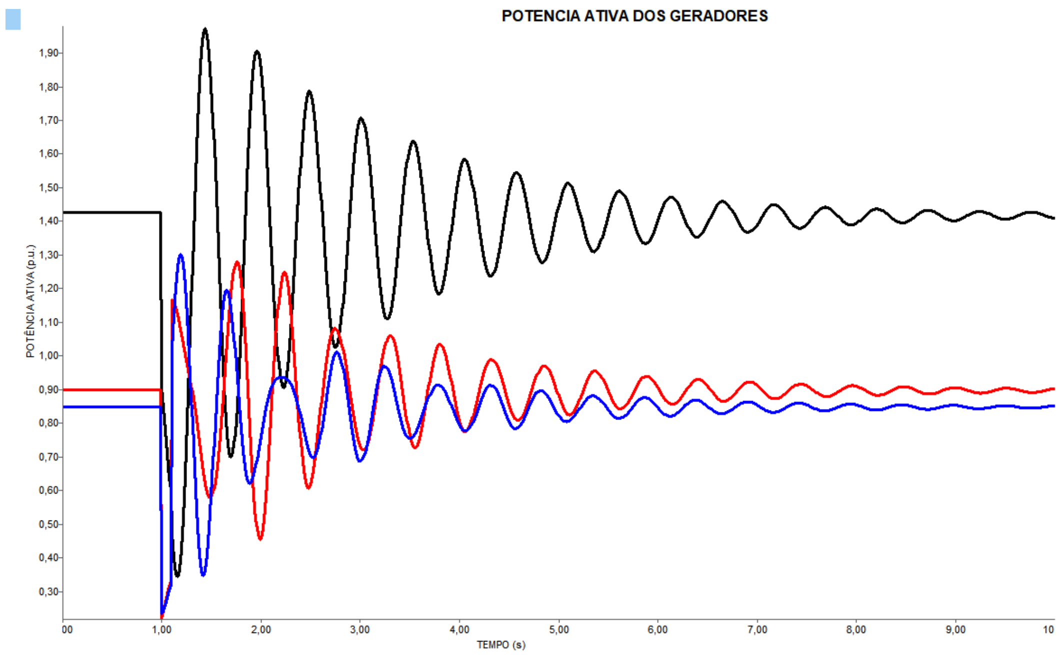
To perform an analysis of the system behavior, a check in the form of graphs would help in understanding the results. The PSP-UFU performs the stability execution process and thus presents a screen where it is possible to choose the data that will be represented through graphs. The terminals of the generators undergo changes as a result of the fault, thus generating a voltage decay as shown in the Figure 10. Generators 1, 2 and 3 are represented in the colors, black, red and blue respectively.

Figure 10: Terminal voltage of the Generators.



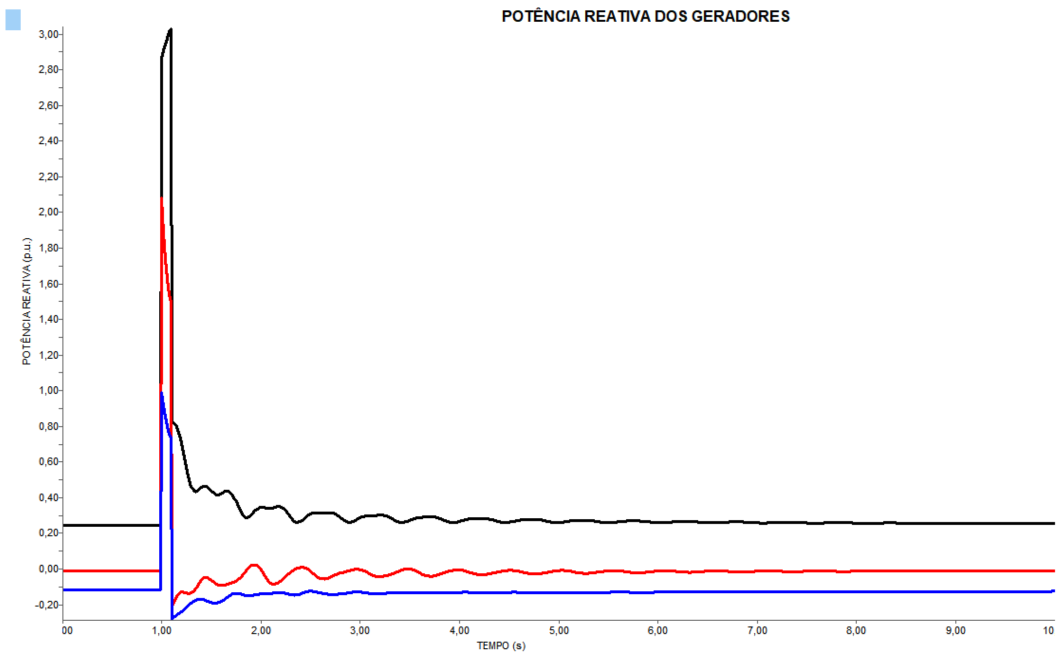
Generator 3 with its representation in blue color suffers the greatest impact of the lack due to the power supply being lower than that of the other generators. As Generator 1 is connected to a reference bar of the system, the voltage sag is less than 10%, that is, the generator was able to maintain the quality of the voltage satisfactorily. While Generator 1 maintained the voltage quality, the other generators did not work with the same efficiency, resulting in voltage sags, greater than 30% in Generator 2, and greater than 40% in Generator 3. The active power supply of the generators also undergoes a sudden change with the influence of the fault, as shown by the Figure 11.

Figure 11: Active Power after the Generators fail.



Following the same color pattern as Figure 11, Generator 1 represented in black has a greater peak variation, reaching close to 245%, due to this generator being connected to a reference bar, or it can be considered as a system safety bar that ensures that the system maintains the necessary demand power. The reactive power of the system also undergoes an extreme variation, as shown in Figure 18.

Figure 12: Post-fault Reactive Power of the Generators.



With the color representation pattern already mentioned, the Generator that suffers the greatest disturbance is Generator 1, because it is responsible for controlling the voltage of the system's reference bar, therefore, most of the reactive power requests are demanded from Generator 1.

FINAL CONSIDERATIONS

This work uses computer simulations to analyze electrical systems, compare different software and determine the importance of theoretical foundations and data quality to obtain reliable results. The work also analyzes different software used to simulate electrical systems, with a focus on short circuits. Despite the challenges, the PSP-UFU proved to be more complete in terms of transitory analysis.

The study encountered difficulties in data collection, but successfully overcame obstacles using example models and identified the need for data validation for practical applications. The difficulties encountered in the simulation were: lack of clarity in the manual, lack of examples, complex calculations and problems with file conversion.

Despite the initial limitations due to the learning curve of the software, the results of the simulations using ANAREDE and PSP-UFU proved to be satisfactory and consistent, allowing detailed analyses of the electrical system, as well as the effects of changes in the generator. The similarity of the results obtained in both procedures increases the reliability of the analysis performed. The short-circuit calculations show good agreement, but the phases show greater differences. The methods used are valid, but additional analyses could enrich the study.

The present study analyzes electrical power systems, evaluating the load flow and the influences of three-phase faults on the behavior of the system. To carry out the study, it was necessary to have a large theoretical framework on electrical power systems and their components, which include generators, transformers, busbars, lines and loads.

The work details the analysis process used for the load flow and the three-phase short circuit, in addition to exposing the conceptualization and analysis methodologies. The study also presents the behavior, consequences and disturbances that can occur in a system due to the flow of load and the occurrence of faults. The ANAREDE, ANAFAS and PSP-UFU software were used to perform the simulations and analyses. With the formulated methodology, the system data were obtained through the base file of the IEEE 9 bus system, located in the examples folder of the ANAREDE software.

After checking and entering the data into the software, the simulation process generated a series of results. The load flow analyses between ANAREDE and PSP-UFU were performed using the Newton Raphson method. The power flow presented showed great efficiency in the results, allowing the analysis of the behavior of the system components and the comparison of the results obtained by the software.

ANAFAS, used as a reference for the three-phase short-circuit study, does not consider the existence of a load flow in the system, presenting only the fault currents. With the use of the PSP-UFU to compare the results, a difference was noted in the calculations of current angles in certain phases. Even with the divergences of the angles, the values of voltage and current were satisfactory.

The PSP-UFU is able to carry out fault studies with the load flow, allowing the obtaining and comparison of results to show the influence of the fault on a functioning system. The study analyzes electrical power systems, evaluating the load flow and the influences of three-phase faults on the behavior of the system.

The ANAFAS and PSP-UFU software were used for simulation and analysis, and divergences in the calculations of the angles of voltages and currents were observed. The consideration of initial angles of the bars in ANAFAS is zero, while in the PSP-UFU, the angles of the bars are considered in their initial parameterization.

The objectives of the work were achieved, with the study of the load flow and the modeling of the system according to the requirement of each software. The load flow simulations and comparisons between ANAREDE and PSP-UFU allowed to evaluate the behavior of the network and its components. The three-phase short-circuit study at ANAFAS and PSP-UFU highlighted the importance of sizing a network in the event of a three-phase fault.

The process of comparison of results showed the importance of validating different results, for a detailed analysis and questioning of the process of calculations of the software in the market. In order to carry out a new study, it is essential to complete the search for data from the equipment to deepen the proposed research. However, conducting new research without a basis for comparison will lead to new findings that cannot be verified; Therefore, conducting new research will require a solid foundation of theoretical research, as well as a lot of mathematical investigation.

As a suggestion for new complementary works, topics that were not addressed in this project include: study of harmonic components of the system, elaboration of a model of voltage and speed regulators, study of multiple faults at the same instant, study of faults at distant points and with sequenced interval, and methods of resizing the system in order to reduce costs.

The object of study of the proposed work is extremely important for the maintenance of the system, as well as the correct sizing of the SEP to be able to withstand the consequences of disturbances caused by various factors. As an evolution of the topic addressed, an interesting proposal would be the implementation of a solution based on coordination and selectivity of a protection model for the occurrence of a fault in any bar of the system.

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