Coordinating Operational Security Analysis Among Electric Power Systems

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***Abstract*—The National Transmission Network emerged in Portugal as a consequence of a significant increase on consumption as well as production of electricity. Over the years its size has been increasing and it becomes even more complex, when the Portuguese and Spanish sides decided to create the first connection between them, in the second half of the XX century. This is quite important because this connection linked Portugal to the rest of the European countries. Thereafter, the operation of the National Transmission Network has to follow European rules. On the other hand, if any other European country has an incident on its grid, it can affect all countries, specially the nearest ones. The number of incidents grows a lot, as many countries are connected. Thus, it is evident that coordination among countries is a necessity. A new methodology for that was defined in 2019 at the European level, by the Agency for the Cooperation of Energy Regulators. This methodology is studied in this dissertation. Each Transmission System Operator should apply it for the Coordination Security Analysis, communicating with every interested part/country. A software application is developed in this dissertation, based on this methodology. The aim of this dissertation is to identify the Portuguese Observability Area and external contingencies. Adjusting some values on the developed application, it is possible to define this area as well as analyse how different power and current limits can affect it, studying what is the Spanish grid part for what the Portuguese side should have attention.**

***Index Terms*—Contingency, Electrical Transmission Systems, Observability Area, Operational Security, Power Flow Influence Factor.**

I. INTRODUCTION

The Portuguese Transmission Grid emerged for connect 2 substations in the north of Portugal. In 1994 appeared the Portuguese Transmission System Operator (TSO) entitled Redes Energéticas Nacionais (REN) [1], [2]. Ensuring the correct function of its infrastructures is one of the main aims of REN, as well as to ensure the service continuity and a secure supply of electrical energy. The grid that is concessionaire to REN is composed of elements with nominal voltage values that correspond to Very High Voltage (VHV). The nominal values of the voltage are 150 kV, 220 kV and 400 kV. The European Transmission Grid has evolved over the years, with this evolution the global system has become more complex. The increase in complexity was caused by the interconnections of operational areas, with the growing investment in renewable energy, as well as the appearance of the energy market. One of the negative consequences of this evolution was the increase in the number of incidents that occur on the grid, which led to the definition of a Methodology for Coordinating Operational Security Analysis (CSA). Thus, the TSOs needed to apply the methodology that consisted of identifying an Observability Area and a List of External Contingencies [3], [4]. In the Portuguese case, REN only needs to check which part of the Spanish grid it needs to observe and the Spanish contingency list, as the Portuguese grid is only connected to the Spanish grid. The Portugal have 9 interconnections with Spain, in which 6 are in 400 kV and the remaining 3 are in 220 kV. These interconnections increase the influence of the Spanish grid in the Portuguese elements. So the aims are to develop an application using Python according to the Agency for the Cooperation of Energy Regulators methodology for CSA and using the tool to identify the Observability Area and a List of External Contingencies. The inputs of the application are Comma-Separated Values (csv) files with information about the Portuguese and Spanish grid from Power System Simulation (PSS). The outputs are csv files withe the elements that satisfy the user-imposed requirements.

II. BACKGROUND

A. REN's role in Europe

At European level, the Portuguese TSO belongs to COoRdination of Electricity System Operators (Coreso) and European Network of Transmission System Operators for Electricity (ENTSO-E).

1) Coreso: Coreso one of the first regional technical coordination centers that aggregates more than one TSO, starting on December 19, 2018. This center emerged after several incidents that occurred in Europe due to lack of coordination among TSOs. This coordination center is one of the six Regional Security Coordinators (RSC) present in Europe, as can be seen in figure 1. RSCs provide services to TSOs, in order to assist them in the operational security of their system. Over the years, several TSOs joined Coreso, a center of which Portugal started to be a part in 2015, with the entry of REN for shareholders. Currently, Coreso is composed of nine shareholders, as can be seen in figure 2 [5], [7], [6]. It provides five distinct services to TSOs [6], [8]:

- Individual Grid Models (IGM) and Common Grid Models (CGM);
- Coordinated Security Analysis (CSA);
- Coordinated Capacity Calculation (CCC);

- Short and Medium-Term Adequacy (SMTA);
- Outage Planning Coordination (OPC) .

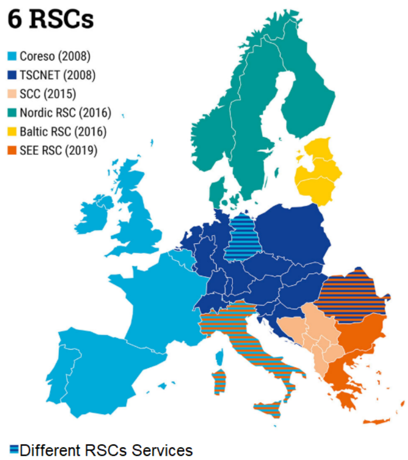

Fig. 1. European's RSC (Source from [6]).

Fig. 2. Shareholders of CORESO (Source from [7]).

The service provided by Coreso to TSOs within the scope of the CSA consists of: applying the methodology for the security analysis (including contingency regimes), identifying the risks of violating the operational safety limits in the TSO's operational area, check the robustness of the results against uncertainties, analyzing several possible scenarios of renewable energy generation, finding remedial actions (with cross-border relevance), as well as coordinating the findings and proposals for remedial actions with the other RSC. This service is performed at least for the day-head and for the infradays, according to a set of timestamps defined regionally [8].

2) ENTESO-E: ENTSO-E consists of forty-two TSOs from thirty-five of the fifty European countries. One of the objectives of this European grid is to regulate the internal energy market and to ensure its optimal functioning. Another relevant point is the high integration of energy from renewable sources in the European energy system, preserving the energy supply [9].

B. Definitions

It is essential to have knowledge of some concepts inherent to the development of the tool, in order to understand what is defined in the methodology.

1) Contingency / Unplanned Outage: A contingency is an unexpected failure or an unplanned outage that occurs in an element belonging to the transmission system, that is, the disconnection of an element from the grid without prior knowledge [10], [11].

2) Control Area: The control area is an area of the ENTSO-E transmission system that is operated by a single TSO. This area can coincide with a country, as is the case in Portugal, or even just be a demarcation of the points for measuring the power exchanged, as for example in Germany where there is more than one TSO. Each area has generation units and loads connected to it [11].

3) Monitored Resource: In accordance with the calculation of the Net Transfer Capacities (NTC), it is necessary to define which Critical Network Element (CNE) elements affect the maximum capacity that can be exchanged between the two countries. So each TSO has to use a methodology based on power exchange variation, to define which are the most critical elements of its own grid, that is, the elements that it is necessary to monitor (Monitored Resource, MR) [12].

C. European Incidents

1) Incidents in 2018: The total number of incidents recorded in 2018 on the European transmission grids was 3030. A characterization of the incidents is carried out according to geography, in this case Portugal belongs to Continental Europe. Due to the size of Continental Europe, this is the region with the highest number of incidents. If you take into account the number of incidents per TeraWatt Hour of energy consumed, the most affected region remains Continental Europe, where there is about one incident for each TeraWatt Hour of energy consumed, but there is less disparity in the observed values. Regarding the number of incidents per hundred kilometers, the region where Portugal is no longer the one with the highest number, but the number of incidents per hundred kilometers is 2.31, which makes it the second region with the highest value [13].

III. Developed Software Tool

A. Methodology

The methodology to be applied is based on the influence that a contingency on the grid of an adjacent TSO has on the grid under study, as a contingency is unpredictable and can have negative consequences for operational security. Initially, it is essential to define three elements:

- the *t* element that belongs to the grid in the TSO A control area and in which the variation of active power between the contingency $N-1$ and the contingency $N-2$;

- the i element is located in the same control area where the t and is an interruption (contingency $N-1$);
- the r is the second contingency (contingency $N-2$) and is outside the TSO control area.

In the figure 3 are represented the three elements. This methodology intends to evaluate the influence that the contingency in the control area of the neighboring TSO has on the element t.

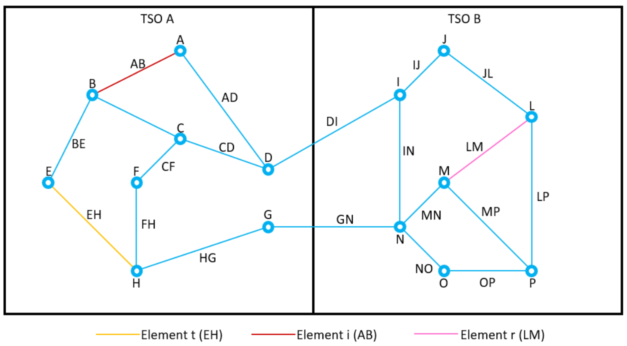

Fig. 3. Methodology to be implemented.

The way to calculate the influence of the external contingency to the TSO have in its grid are mathematically presented on expressions 1 and 2, where $IF_r^{pf,f}$ is the Power Flow Filtering Influence Factor and $IF_r^{pf,id}$ is the Power Flow Identification Influence Factor [14].

$$IF_r^{pf,f} = MAX\left(\frac{P_{s,n-i-r}^t - P_{s,n-i}^t}{P_{s,n-i}^r} \cdot 100\right) \quad (1)$$

$$IF_r^{pf,id} = IF_r^{pf,f} \cdot \frac{PATL^{s,r}}{PATL^{s,t}} \quad (2)$$

In expression 1 the letter s represented the scenario that is being analyzed and t, i, r are the elements previously described. The remaining elements are powers, the letter P is the active power and PATL is Permanently Admissible Transmission Loading. Expression 2 is used to calculate the Power Flow Identification Influence Factor corresponding to the percentage variation of the active power of element t, in scenario s, when elements i and r are disconnected. In expression 1 is used to calculate the Power Flow Filtering Influence Factor. According to this methodology, element r can only be considered contingency when the two influencing factors are above the defined minimum limits.

B. Scenarios

The power that flows in each element of the grid varies every second, but the grid can be characterized according to its general behavior, that is, the combination of the generation and consumption profile can be classified according to the season, the production of renewable energies, the power flows in cross-border connections, among other factors. Energy consumption is dependent on ambient temperature. In the case of Portugal, which is inserted in a region where there is a high temperature variation throughout the year, there are two consumption peaks, one in winter (low temperatures) and another in summer (high temperatures). So one must study a winter peak and a summer peak. One of the meteorological conditions that affects energy production is precipitation, as the amount of water available for the production of hydro power is strongly dependent on precipitation. Another condition of the generation profile is the energy market, where it is possible to buy or sell it. Thus, the power flows in the cross-border connections is affected by market prices, which in the case of Portugal is Mercado Ibérico de Electricidade (MIBEL). Within the scope of this work, four representative scenarios of the grid are studied:

- February 17, 2020 at 8:00 pm (scenario A);
- May 13, 2020 at 4:00 am (scenario B);
- May 13, 2020 at 1:00 pm (scenario C);
- July 30, 2020 at 1:00 pm (scenario D);

In scenario A, which is a typical winter day, the peak consumption hour (20:00 h) was selected for the study, which results from the coexistence of industrial and domestic consumption. On this day there is a high hydro and wind production and Portugal had a surplus of energy, which it exported, as can be seen in the figure 4. This scenario presents the highest consumption value of the scenarios to be studied. Among the various scenarios, this is the one with the highest consumption value [15].

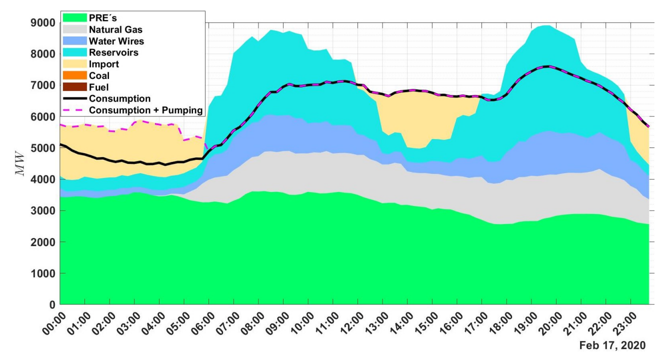

Fig. 4. Production and consumption diagram for February 17, 2020 (Source from [15]).

Scenario B and scenario C refer to the same spring day but at different times. Scenario B represents an empty hour, on a day when the average temperature is considered mild and energy is imported. Scenario C shows an hour of higher consumption, with an export value of around 1000 MW. This scenario presents a lower consumption than those identified at the winter and summer peak. These characteristics of the generation and consumption profile of May 13, 2020 are evident in the figure 5 [16], [15].

Scenario D, representative of the summer season, presents little water production, since several regions of Portugal are normally affected by water scarcity phenomena, and presents a significant decrease in the production of energy from wind power when compared with the others scenarios. On this day it is important to note that the main source of electricity

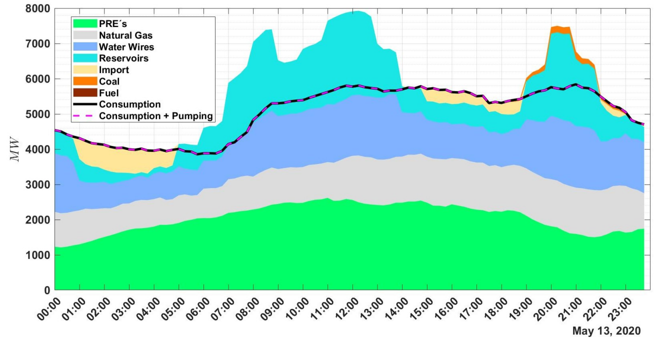

Fig. 5. Production and consumption diagram for May 13, 2020 (Source from [15]).

generation is thermal generation, which is also a point of distinction in this scenario compared to the previous ones. For this scenario,it is chosen the profile on 13:00,because there is a high value of consumption (including pumping). The characterization of this scenario is visible in the figure 6 [16], [15].

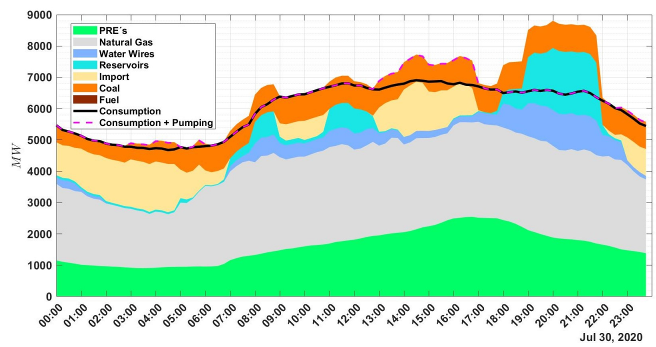

Fig. 6. Production and consumption diagram for July 30, 2020 (Source from [15]).

C. Input Files

So there are four different types of input files with all the necessary information.

1) Monitor Resource: One of the input files contains the elements to be monitored, which can be lines or auto transformers. This file is provided by REN and is used in all scenarios. In order to prepare this file, all elements of the Portuguese Transmission Network are analyzed, including interconnections, and all elements that presented a variation of 10 % in the power carried over in the studied scenarios are selected. For the development of the tool, the information that is extracted from the file is the element that will be monitored. This element is characterized by the source and destination bus, respectively designated by *i* and *j*, as well as by the circuit number.

2) Mapping File: There are two mapping files for each scenario, one with elements from the Portuguese grid and another with elements belonging to the Spanish grid. The content of these files constitutes a possible identification of all the elements observed in the scenario. The need for this type of file is due to the fact that the tool developed identifies each element using a numeric code, facilitating the algorithm. However, it is necessary that in the end the tool presents the user the respective name of the element, in order to clarify and facilitate its recognition by the user. These files are found in the scenario folder, where the files with the power values that flows in each element are also in different circumstances.

3) Power Flow of the Elements: To apply the methodology, it is necessary to know the power that flows in each element in different circumstances, these being the $N-1$ and $N-2$ regimes. The $N-1$ regime consists of the correct functioning of the grid when one of the elements goes out of operation, without prior knowledge, that is, a contingency occurs. The network must be prepared to maintain a correct functioning in this regime. By analogy, the $N-2$ regime is when two contingencies exist simultaneously. Files with the power flow values were generated through the *PSS* simulator, where the grid of the intended scenario was initially placed and changes were made to simulate its behavior. These changes consist of disconnecting one or two elements at the same time. Each file generated is constituted by the information of the power flow in each element of the grid when elements are disconnected.

4) 4)Permanently Admissible Transmission Loading of the Elements: The previously described files do not have the power limit that can be admissible on the Spanish elements, so another file with this information is needed. Thus, a new file is used which consists of the line identification (name, numeric code and circuit number), as well as the line power limits depending on the seasons. During the development of the tool, it is observed that some elements are not present in this list. The elements that are not on the list are new elements that have been built, they may be elements that are generally disconnected or they may not yet appear on the list due to lack of information from REE (*Red Eléctrica de España*). As the grid is dynamic and can change at any moment, it is necessary to define a criterion for the elements that are not present in the file. For this reason, typical limit values are added at the end of the file for the 400 kV-220 kV auto transformers or vice versa, as well as for the 400 kV and 220 kV.

D. Data Processing

To apply the aforementioned methodology, a tool is developed in *Python*. The tool receives as input the files described above, as well as some variables that the user can define, executes the algorithm that was implemented and sends some files with the results abroad. Initially the tool opens the graphical user interface window, illustrated in the figure 7. The user indicates where the files with the power flows results are located, which file describes the elements to be monitored and the file where the limits of the Spanish grid elements are present. The user is asked for the minimum value he wants for each of the influencing factors, as well as the minimum value that can be carried over the elements according to the voltage level. Thus, the user is asked for the power values to use in the power filters in the $N-2$ regime and the power difference in the MR between the two operating regimes. Finally, the

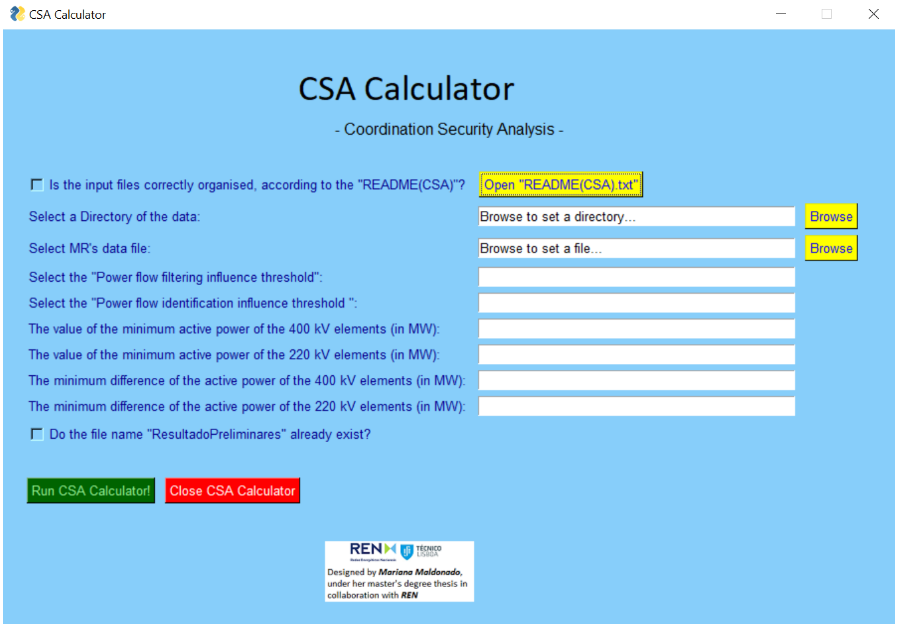

Fig. 7. Graphical tool interface.

user must also indicate whether the files are organized as the tool requires for their correct operation. When the user presses the *"Run CSA Calculator!"* Button, the algorithm that is implemented according to the expressions 1 and 2 in the methodology starts.

The first thing the tool does is to define the directories from which it will work. Then, if the user informs that the folders are not organized, the tool organizes them, as the tool is structured to execute the algorithm with this specific organization mode. Subsequently, information is obtained from the input files that are used in all scenarios. In each analyzed scenario, it is necessary to import the information present in the mapping files of both grids. To later select the maximum limit for Spanish elements, there is a need to define the season based on the date of the scenario. Thus, according to the table I, the season is defined.

TABLE I
SEASONS DEFINED BY *Red Eléctrica de España*.

	First Day	**Last Day**
Winter	November 1st	March 31th
Spring	April 1st	May 31th
Summer	June 1st	August 31th
Autumn	September 1 st	October 31th

The tool recognizes each element through the numeric codes associated with it. Thus, all files that only have the name of the element, that is, do not contain the numeric code, oblige the crossing of the data through the mapping file. Thus, for the tool, each element is treated as a number to facilitate the algorithm. Under these conditions there are two types of files, the file with the MRs and the one with the maximum power values of the Spanish elements. For each element to be monitored in each scenario, it is necessary to proceed to the following set of processes. Firstly, the tool imports all the files from this scenario present in the folder with the element's numeric code. This function imports a file referring to the $N-1$ operation of the grid and all files corresponding to $N-2$ where one of the elements disconnected is the same as in $N-1$. Then, the two influencing factors are calculated for each set of elements, that is, for each contingency-MR set. Thus, for each MR there is $\#contingencies \times \#MRs$ sets to evaluate. The function that performs the calculation is the most complex function of the tool, as it requires a high number of searches in the different files.When performing the calculation, it is observed whether the elements respect the input parameters that the user intends to use. That is, if they are respected:

- minimum power of 10 MW to the value of power that flows on the the Spanish contingency under the $N-1$ operating regime;
- minimum power value that flows in the MR under $N-2$ operating regime, this minimum value can be adjusted by the user and the user can choose to set different minimum values according to the element's voltage level;
- minimum variation power of the MR between the two operating regimes of the grid and which, analogously to the previous criterion, the user can adjust this parameter as well as the different minimum values according to the voltage level of the element ;
- in case the MR belongs to a tripod line, the previous criterion must be fulfilled by the MR and by another section of the line.

If one of the criteria is not met, the value of the two influencing factors is assigned a value of 0. If, on the other hand, all criteria are met, the calculation of the Filter Influence Factor is performed first using the expression 1 and then the calculation of the Identification Influence Factor using the expression 2. This order of performance of the calculations is due to the factor that the expressions differ only from a multiplicative factor constituted by the ratio between the maximum power limit that can flow in the MR and in the contingency. Finally, it is necessary to inform the use of the calculations performed, so functions are used by the tool to write the output files. As soon as all the calculations for a scenario are performed, an output file is generated where the values of the two influencing factors associated with each combination are stored. When all the scenarios have already been analyzed, the function that writes the results that fulfill all the filters and that also fulfill the influencing factors defined by the methodology is executed. Thus, for each combination, the highest Power Flow Identification Influence Factor value that meets the desired criteria is selected.

E. Output Files

In the same way that there are several input files, there are also several types of output files. The output files are divided into scenario results and overall results. The structure of all output files is the same, what varies is the filtering done to the results in order to make it easier for the user to read.

1) Scenario Results: For each analyzed scenario, the tool generates three different files. After performing the algorithm to analyze a scenario, a file is written where all the calculations made and associated with each contingency-MR combination are presented. Thus, if you only want to change the limits of the influencing factors, it is not necessary to run the calculation algorithm again. If the user wants to change the list of MRs or the power limits, then it is necessary to run the algorithm again. In each file the name contains the moment when the network was extracted, that is, the day and time, as well as the prefix ResultsPreliminary. Another type of output file is to filter the information found in the first output file in the scenario. In this way, all contingency-MR combinations that are above the threshold for the influencing factors desired by the user are selected. In this file it is possible to know, for the various combinations of Spanish contingency and Portuguese element, if the Power Flow Identification Influence Factor and the Power Flow Filter Influence Factor are above the defined limits. In this file you can acquire information on the Spanish contingency affecting the Portuguese grid and the variation of active power normalized to the maximum limits of the grid elements and non-standardized, in percentage, that it causes in a grid element under the responsibility of REN. To facilitate counting the number of contingencies in each scenario, an output file is also generated where only the name of each contingency is displayed once. For this contingency, the highest value of the identification influence factor is presented, as well as the filtering influence factor that gave rise to it. This file is generated from the file previously described. With the results obtained for each scenario, it is possible to conclude which association of generation and consumption profile brings the most problems to the national grid.

2) Global results: After obtaining the result of all scenarios, two files are generated with the set of all analyzed scenarios, so the user receives a concatenation of all calculations performed by the application. The first type of global results file, as its name implies, is the concatenation of the files with elements that buy the criteria imposed by the user of each scenario. In order to generate this type of file, all the information of the results obtained by scenario is imported and, subsequently, ordered according to the value of the identification influence factor. This is the last file to be generated and analogously to what happens in each scenario, a file is produced in which each contingency is only referred to once for its highest calculated value for the Power Flow Identification Influence Factor.

IV. Results and Discussion

The additional filters to the methodology that help in the automation of the process, are filters based on the active power because the whole methodology is based on the active power that flows in the elements.

A. Adding filters

The first filter added to the methodology is to limit the minimum power value that passes through each Spanish element, that is, to define the Spanish element with contingency it must present a power value higher than that defined. This filter is necessary because in the methodology both influencing factors have the power of the Spanish element as a divisor, which for low power values can cause high influencing factors. Thus, a filter was established for the contingency active power that should not be less than 10 MW. This value cannot be changed by the user, it is a fixed value of the tool. The remaining active power filters are applied only to Portuguese elements. So one filter verifies that the Portuguese element in operation regime $N-2$ has an Minimum Active Power (MAP) value higher than the minimum desired by the user and the other verifies the Active Power Variation (APV) in the element. The first filter is only applied to the $N-2$ case because it can be verified that the active power in $N-1$ is very low but in $N-2$ it is not and these are the cases that we want to analyze and if the active power in the element decreases it will no longer be analyzed because it does not overload the element, it can even be beneficial. There are three types of elements in the contingencies, at two voltage levels, for this reason the power filters must be different and according to the voltage level. Thus, five power minimums are defined, two for the minimum power in the MR when the double contingency occurs, one for each different voltage level and two for the APV. As can be seen in the figure 7 this data is requested from the user. At this stage in the development of the tool, it was also decided to add a filter for Portuguese tripod line (line with 3 branches). So this filter is applied to the Portuguese lines being analyzed and consist of at least two of the three sections of the line simultaneously meeting the minimum power variation criteria required by the user.

B. Set the thresholds

In order to understand the impact of the variation of each filter, it was decided to vary one filter at a time, except in the case of MAP that the value of the two voltage levels varies simultaneously. Thus, the first filter analyzed was the MRs MAP filter, but in this case it was decided to vary the filter applied to 400 kV and 220 kV simultaneously, since it was realized that this had little impact. The remaining filters remain constant in all analyzes of the MAP filter. Figure 8 shows the evolution of the number of contingencies according to the value applied to each filter. The name of each element (x-axis) is assigned as follows: MAP (400 kV) _ APV (400 kV) _ MAP (220 kV) _ APV (220 kV) _ $IF_r^{pf,id}$ _ $IF_r^{pf,f}$. With this figure you can see that it is necessary to reach high MAP values for the global list of contingencies to change. Thus, the lowest MAP value that reached a constant contingency value is selected. This value corresponds to MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, and the results are shown in the table II.

TABLE II
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 3 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW AND APV = 5 MW FOR ALL ELEMENTS.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	466	47
13/05/2020 - H04	482	47
13/05/2020 - H13	3966	450
30/07/2020 - H13	399	39
Global	-	460

The next step to define the list of contingencies is to study the impact of the APV applied to the variation of the active power of the Portuguese elements. In this way, this filter was varied and the results obtained are presented in the tables III, IV, V, VI, VII and VIII.

TABLE III
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 3 % , $IF_r^{pf,id}$= 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 7.5 MW AND APV(220 kV) = 5 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	429	43
13/05/2020 - H04	442	41
13/05/2020 - H13	2225	378
30/07/2020 - H13	335	35
Global	-	387

When comparing the results that were obtained with the MAP (400 kV) equal to 5 MW and 7.5 MW it is noticed that there is a decrease of 73 contingencies, which represents 16% of the contingencies. It is possible to verify that the contingencies of scenario C went from 450 contingencies to 387 contingencies with the increase in the value applied to this filter, which represents a decrease of 72 contingencies in this scenario, a value that is very close to the reduction

TABLE V
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 3 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 12.5 MW AND APV(220 kV) = 5 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	369	39
13/05/2020 - H04	379	37
13/05/2020 - H13	666	85
30/07/2020 - H13	270	27
Global	-	97

of contingencies in the total results. What is noticeable in the difference in the results is that 66% of the elements are Spanish lines of 220 kV, 30% are lines of 400 kV and the remaining 4% they are transformers in substations. Another evidence is that the elements that are excluded from the list are distributed throughout the Spanish territory, but most close to the consumption centers. The elements near the border are very few and have a short length so that the value applied to this filter can be increased.

TABLE IV
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 3 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV)=35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 10 MW AND APV(220 kV) = 5 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	393	40
13/05/2020 - H04	410	40
13/05/2020 - H13	1417	308
30/07/2020 - H13	303	34
Global	-	317

When the filter for elements of 400 kV takes the value of 10 MW the contingency list has 317 contingencies as can be seen in the table IV, this decrease corresponds to an 18% decrease in contingencies. Again, most of the contingencies that are not presented in these results, when compared to those in the table IV, are contingencies that were identified in scenario C. The elements excluded from the list of contingencies are 2 transformers, 14 lines of 400 kV and the remaining 55 lines of 220 kV. It is notable that the increase in the value of this filter mainly affects 220 kV lines. In this case, most of the elements that left the list are distributed in specific areas of Spain, that is, they are not very dispersed throughout the territory. These zones have a very significant distance from the border between Portugal and Spain.

When running the application with the value of 12.5 MW for the elements 400 kV, the greatest decrease is observed when the minimum value of this filter is increased, since the number of contingency decreases from 317, a value registered with the filter equal to 10 MW, to 97. In terms of differences in the final list of contingencies, it is noticed that there is a decrease of 220 contingencies which means less 70%. In this comparison, the elements that decrease the most are the 220 kV lines, the decrease in these lines is equivalent to 58% of the elements that leave the list, the 400 kV correspond to 31% and the rest are transformers. In addition to the high percentage of contingency reductions, it is clear that the proximity to

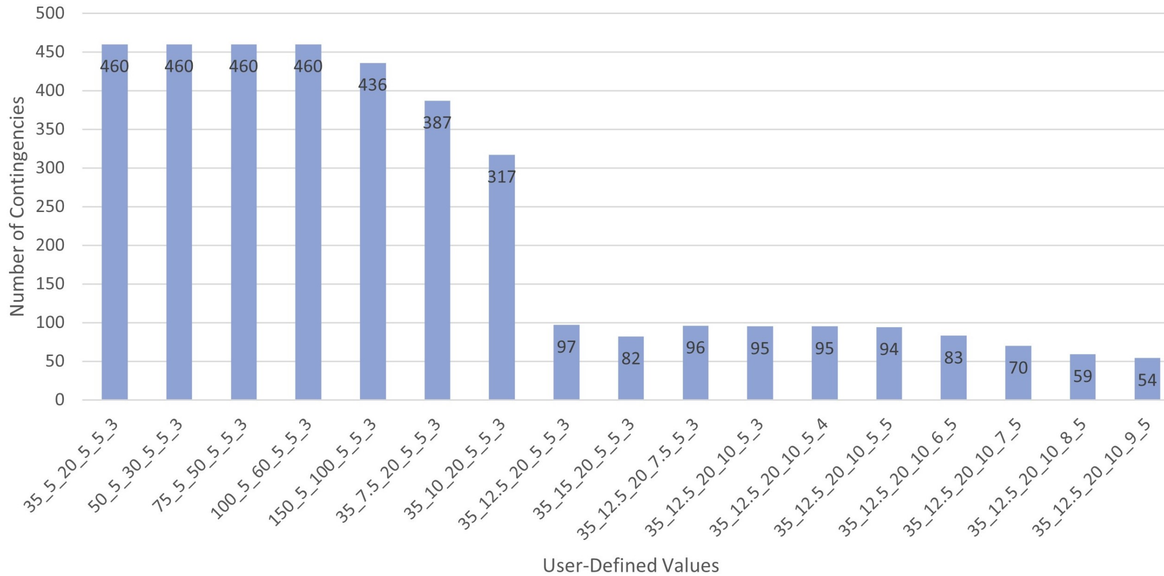

Fig. 8. Number of contingencies for the filters.

TABLE VI
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 3 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 15 MW AND APV(220 kV) = 5 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	345	39
13/05/2020 - H04	349	35
13/05/2020 - H13	522	68
30/07/2020 - H13	258	26
Global	-	82

TABLE VII
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 3 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 12.5 MW AND APV(220 kV) = 7.5 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	357	37
13/05/2020 - H04	367	37
13/05/2020 - H13	662	85
30/07/2020 - H13	266	26
Global	-	96

TABLE VIII
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 3 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 12.5 MW AND APV(220 kV) = 10 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	346	37
13/05/2020 - H04	364	37
13/05/2020 - H13	653	83
30/07/2020 - H13	264	26
Global	-	95

Portugal of the elements excluded from the list is greater and this increase is caused by the high number of 220 kV lines that no longer belong to the same list. With a more detailed observation of the results obtained for 10 MW it was found that there are contingencies that belong to the list of elements with maximum capacities in the order of thousands of MW extremely far from the border, where only a few tens of MW flows and cause high values in the influencing factors. In this way, the same filter was tested for a higher value, the selected value was 15 MW and the results shown in the table VI were obtained.

Comparing the results obtained with the last two values attributed to the APV (400 kV), it appears that there is a difference of 15 contingencies. Contrary to what happened in the other comparisons, most of the contingencies that do not appear in the list of 15 MW, but are present in the results of 12.5 MW, are Spanish lines of 400 kV and represent 80% of the excluded elements, the remaining 20% correspond to 220kV lines. So we choose to use this filter with the value of 12.5 MW.

To define the value that the last additional filter, APV (220 si kilo volt), must be varied with the following values: 5 MW, 7.5 MW and 10 MW. The results are in the tables V),VII) and VIII), respectively. The filter with higher values was not tested because it is a filter that applies to elements with a lower voltage level and therefore less power compared to the filter to be applied to elements of 400 kV. When the results are compared with the 5 MW filter with 7.5 MW, it is observed that there is a decrease in only one contingency. This contingency was a transformer. By raising the filter to 10 MW, another contingency that corresponds to another transformer is eliminated. Thus it is concluded that the filter should take the value of 10 MW.

Finally, it is necessary to define the thresholds of the two influencing factors in order to define the area of observability and the list of external contingencies. To do this, the $IF_r^{pf,f}$ was started from 3% to 4% and in this case there was no change in the list of contingencies in the observability area. By increasing the filter to 5%, the results are shown in the table IX where the list can be completed, it decreases in a contingency. The contingency that disappears from the list corresponds to a 400 kV line that is quite far from the border between Portugal and Spain. Therefore, this filter can take the maximum value suggested in the methodology defined by ACER.

TABLE IX
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 5 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 12.5 MW AND APV(220 kV) = 10 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	328	37
13/05/2020 - H04	353	37
13/05/2020 - H13	606	82
30/07/2020 - H13	236	25
Global	-	94

In the figure 8 there is a summary of the results obtained when the $IF_r^{pf,id}$ is varied. When comparing the results obtained with the $IF_r^{pf,id}$ equal 6% with those obtained for 5%, a difference of 11 contingencies is observed, 8 correspond to the lines of 400 kV and 3 are 220 kV lines. These are distributed in Spanish territory, especially in areas far from the border. Therefore, it was decided to increase the value of this filter to 7. Using the same figure, the results obtained for 7% and 6% are compared, it can be seen that there is a decrease of 13 contingencies in the area of observability. This decrease is caused by the exclusion of 7 lines of 400 kV and 6 lines of 220 kV. The proximity of these lines to the Portuguese border is greater than in the lines that increase the factor to 6%, which is justified by the proximity of some lines of the lowest level of tension in the contingencies. This way, the value attributed to this factor is increased again to 8%. With this value of $IF_r^{pf,id}$ there are 59 contingencies which reflects a decrease of 11 contingencies compared to the last analyzed value, where 91% are lines with the highest voltage level present in Spain and the remaining 220 kV . These lines are further away from mainland Portugal compared to the elements present in the list that will define the area of observability. In this way, the value attributed to the $IF_r^{pf,id}$ continues to increase.When the value of 9 % is attributed to $IF_r^{pf,id}$ there is a reduction of 5 contingencies. In defining this factor, it is the first time that the number of contingencies that are excluded from the list is less than 10. In this case, the observability area is not changed, for this reason the value that should be given to this factor is 8%. The table ref presents the results obtained with $IF_r^{pf,id}$ of 8 %. With these contingencies, the area of observability is defined.

To obtain the list of external contingencies, it is only necessary to vary the $IF_r^{pf,id}$ to values higher than those previously studied, as the methodology foresees this factor between 15% and 25%. Thus, all external contingencies are within the area of observability. By varying this factor, it appears that the higher its value, the smaller the number of contingencies as was already known and as can be seen in the table XI. It is possible to verify that the distance to the border between Portugal and Spain from the elements that prevail is small, as well as the list is composed mostly of elements of the highest tension level. To define the list of external contingencies, it was observed the location of the contingencies present in the list defined by the factor with the value of 15% (minimum value defined by the methodology). Thus, it appears that a line is very far from the other elements and this line has an $IF_r^{pf,id}$ of 23%. In this way it is defined that the list should not contain this line so it must use the $IF_r^{pf,id}$ with the value of 24 %. For this value, the resulting list has 75% of the 400 kV elements, as this grid is used in Portugal to make interconnections to the neighboring grid.

TABLE X
NUMBER OF CONTINGENCIES FOR $IF_r^{pf,f}$ = 8 % , $IF_r^{pf,id}$ = 5 % , MAP (400 kV) = 35 MW, MAP (220 kV) = 20 MW, APV(400 kV) = 12.5 MW AND APV(220 kV) = 10 MW.

	# Contingencies-MR	# Contingencies
17/02/2020 - H20	243	28
13/05/2020 - H04	247	26
13/05/2020 - H13	411	52
30/07/2020 - H13	153	19
Global	-	59

TABLE XI
NUMBER OF EXTERNAL CONTINGENCIES ACCORDING TO THE $IF_r^{pf,id}$.

$IF_r^{pf,id}$ **(%)**	**#Conting.**	**400 kV**	**220 kV**	**Transformers**
15	37	32	4	1
16	34	30	3	1
17	33	29	3	1
18	31	27	3	1
19	27	23	3	1
20	25	21	3	1
21	19	15	3	1
22	19	15	3	1
23	17	13	3	1
24	16	12	3	1
25	15	11	3	1

V. CONCLUSION

The National Transmission Network began in the 20th century and over the years the size of the grid has increased as well as its complexity. It was not only the Portuguese energy transport grid that evolved, but the entire European grid. Thus, the grids of each country are interconnected, leading to the necessity to develop methodologies and requirements for the Coordination Security Analysis. Thus, one of the objectives of this dissertation was to develop an application/tool that would allow obtaining a list of external contingencies and a list of contingencies to limit the area of observability. Another focus was to analyze the results obtained through the application and define the best suitable values for each parameter to define the final lists.

In order to understand the necessity to define the area of observability and external contingencies, it was verified what originated several incidents that occurred in Europe and that had consequences for more than one TSO. To later understand the methodology to be applied, it was inevitable to understand first several concepts related to the methodology such as what is a contingency, what is the control area, among others.

Then, the methodology developed by ACER for the Coordination of Security Analysis and the best way to apply it were studied. The expressions used to calculate the $IF_r^{pf,id}$ and the $IF_r^{pf,f}$ were analyzed and it was found that it was necessary to collect data about the powers that flows in the various Portuguese and Spanish elements. The essential data to apply the methodology corresponds to the values of active power that flows in each element at the moment to be evaluated, as well as the PATL of the element. Regarding the active power data, it was found that it was necessary to have data relating to two operating regimes of the grid. These two regimes consist of having an $N-1$ operation, that is, when only one element of the grid is disconnected and an $N-2$ regime that by analogy consists of disconnecting two elements from the grid. Another segment of this work was to select the moments/scenarios that were intended to be studied, since the set of scenarios under study must characterize the annual functioning of the grid. It is known that there are several factors that influence the demand for electricity by consumers, such as climate, precipitation and time of day, or better, if it is a time of coexistence between industrial and household load. All of these factors lead to the peak and off-peak value taking different values throughout the year in the same way that it affects the time at which they occur. Thus, after having all this knowledge, the implementation process of the application that was carried out in the *Python* began in accordance with the requirements requested by REN.

The application was developed in order to have a graphical interface that facilitates the user's handling. Thus, all the information that the user has to enter is questioned only in a moment and the user is able to view all the values that he enters together. Then the application starts to execute the algorithm that was implemented. The algorithm is structured as: one scenario is executed at a time and for each scenario it starts by executing the actions that only need to be performed once per scenario and then enters a cycle where it performs the calculation of the influencing factors. After performing all the calculations that the user wants for each scenario, the tool returns a file with that information. After the application performs all the algorithms and calculations, it will inform the user about the determined contingencies. This list depends on the user's requirements imposed on the graphical interface.

Several filters were implemented on the tool, in order to obtain a better and more realistic final list. One of the filters added to the methodology is to filter the active power of the Spanish elements, so that elements with very low power flows do not cause very high influencing factors. It was decided to implement power filters for the Portuguese elements and to introduce a filter for tripod lines. Thus, the power filters are applied to the values of the active power of the elements only in the $N-2$ operating regime. This filter does not eliminate cases in which the active power in $N-1$ is low and in $N-2$ is high, which is what we want to evaluate. The other filter applied to the active power, compares the active power between the two operating regimes,in order to select a contingency relevant when the variation of the active power is greater than the value defined by the user. The last extra filter on the application verifies if the MR is a tripod line. This filter checks if at least two sections respecting all restrictions imposed by the user. Thus, using the last version of the developed application, the observability area and the list of external contingencies were defined based on the obtained results. Therefore, it is possible to conclude that the objectives defined for this dissertation were successfully achieved.

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