Quality analysis of the defect location information in transmission line outages caused by fires

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ABSTRACT

This paper analyzed the quality of the information regarding power outages caused by fires in the Brazilian transmission system in the years 2018 and 2019. Six transmission line trunks with asymmetrical performance regarding fire-related outages in the period were selected. The selected trunks correspond to twelve 500 kV transmission lines with a total length of 3,998 km. Outage, geospatial transmission line data and fire outbreak information was compared for twelve transmission lines of interest, all located in regions with a high incidence of fires. The results suggest that the data provided by the transmission line fault locating equipment is not accurate when compared to the fire outbreak data provided by satellites.

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1. INTRODUCTION

The main function of transmission lines (TL) is to transport large blocks of energy between the generation and load centers [1], [2]. To this end, these lines travel distances that can range from a few kilometers to thousands of kilometers. The operation of these facilities is often a major engineering challenge [3]. Until the end of 2016, the Brazilian transmission system was composed of 252 contracts distributed to 159 utilities, responsible for maintaining and operating 130 thousand km of transmission lines at voltages ranging from 138 to 800 kV as well as about 500 substations with an installed transformation capacity exceeding 320 GVA [4]–[6]. In 2019, the system had 51 thousand km of 500 kV transmission lines, with an estimated 75 thousand km to be reached in 2024 [7].

The transmission systems are designed to absorb simple contingencies, that is, the loss of an installation or piece of equipment, without interrupting power supply to the final consumer [8]. To meet this requirement, it is common to find situations where two electrical points (substations) are connected by two different transmission lines [9]. In this situation, the set of lines that connect these electrical points are called trunks. These trunks can be understood more comprehensively as a set of transmission lines arranged in series or in parallel [10].

The performance of the Brazilian transmission system is monitored through a specific system, owned by the national grid operator. This system collects, classifies and consolidates the data on forced outages and disturbances for statistical purposes and the calculation of performance indicators [11]. The transmission utilities are responsible for providing the information on forced outages to the grid operator. The information must contain a brief description of the disturbance, informing the disconnected equipment, the type of defect, the involved phase, the location of the defect and the cause of the outage [12].

The passage through rough terrain and the operation under adverse weather conditions facilitate the occurrence of failures in transmission lines. These failures can cause instability of the power system and lead to great economic loss. Locating and quickly removing faults in transmission lines can prevent the disruption of power grid stability [13]. With this in mind, several methods have been proposed for locating faults in power grids [14]–[17].

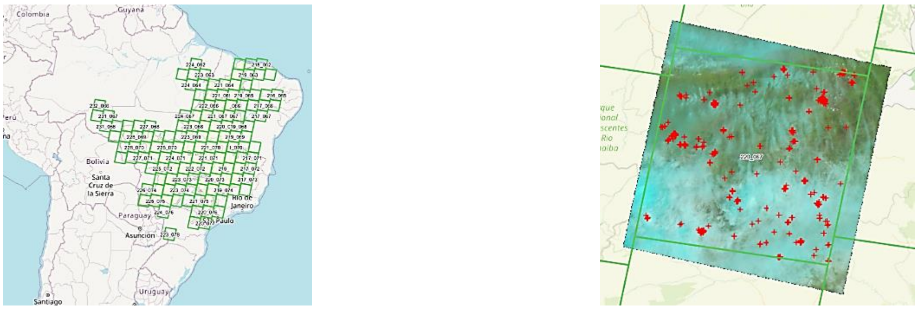
Silva *et al*. [18] developed a fault location system for transmission lines using complex-domain neural networks. The test case analyzed a 100 km-long, 400 kV transmission line. Several simulations were made with variations of factors that could affect the fault location. The results indicated location errors representing between 0.55% and 6.82% of the line length, depending on the scenario. A transient signal spectrum was also used to study the location of defects on a 240 km line, operating at 400 kV. The fault location accuracy varied between 0.03% and 4.21% of the line length [19]. In both studies, the precision of the fault location decreased with the increase of the fault impedance. Defects caused by fires typically have an impedance between 10 and 70 Ω [20]. Occurrences caused by fires usually have a higher fault impedance value [21] than those caused by atmospheric discharges, and they are usually followed by an unsatisfactory automatic reclosing, leading to the need for manual reclosing and -sometimes- for inspection of the line by the maintenance team [22].

Since 1989, Brazil has the National Center for the Prevention and Combat of Forest Fires (*Centro Nacional de Prevenção e Combate aos Incêndios Florestais, Prevfogo*). This is a specialized center within the Ibama framework and it answers for the forest fire prevention and fighting policies throughout the national territory, including activities related to educational campaigns, training and qualification of rural producers and fire fighters, monitoring and research. The system is composed of several units spread out across the country [23].

For the monitoring work, Prevfogo coordinates with the National Space Research Institute (*Instituto Nacional de Pesquisas Espaciais*, INPE), which runs the *Queimadas* program [24]. This program receives resources from the Amazon Fund [25] and it is the main fire detection system available at the national level. The *Queimadas* program generates and distributes several products on a daily basis, such as geographical coordinates of fire outbreaks, e-mail alerts of occurrences in areas of special interest, fire risks, smoke concentration estimates and the mapping of burned areas. All data and products are published on the internet at no cost to the user, about three hours after their generation.

To carry out its work, the INPE uses all the satellites that have optical sensors operating at the 4 µm mean thermal band. Currently, the AVHRR/3 images of the polar NOAA-15, NOAA-18, NOAA-19, and METOP-B satellites, the MODIS images of the NASA TERRA and AQUA satellites, the VIIRS images of the NPP-Suomi satellite, and the images of the geostationary GOES-13 and MSG-3 satellites, are used. Each polar orbiting satellite produces at least two sets of images per day, and the geostationary satellites generate several images per hour, with INPE processing more than 200 images per day specifically to detect fire outbreaks in vegetation. The fire outbreak detection system for the polar orbit satellites can capture a fire front of about 30 m long by 1 m wide, or larger. For the geostationary satellites, the front needs to be twice this size to be located. The spatial resolution of the image, the "pixel", for the AVHRR (NOAA-18 and 19 satellites) and MODIS (AQUA and TERRA satellites) sensors is 1 km x 1 km. In other words, a fire of a few dozen m^2 will be identified as having at least 1 km^2 [24].

The *Queimadas* program makes information available, free of charge, on fire outbreaks in all critical areas of the national territory. Figure 1 shows the coverage and detection area of fire outbreaks. In Figure 1(a) the quadrants highlighted on the map of Brazil represent a mosaic of images corresponding to the monitored areas. Figure 1(b) shows the detail of one of the mosaic scenes, with emphasis on the fire outbreaks.



(a) (b)

Figure 1. Fire outbreak detection coverage of the *Queimadas* program (a) overview of Brazil and (b) detail of area 220_067 located at the border of the states of Bahia and Tocantins [26]

Each cross in this image represents one or more detected fire outbreaks. The power transmission utilities have different tools at their disposal to locate defects caused by fires: the fault locating equipment, installed on the transmission line itself; and the spatial optical sensors, used by INPE. This work will evaluate the quality of the data reported to the grid operator regarding the outages caused by fires.

2. METHOD

Data was analyzed from forced outages that occurred in the Brazilian transmission system in the years 2018 and 2019 and which were declared by the transmission utilities to the national grid operator [11]. The obtained data contained information on the date, time, installation, outage cause and declared location of the defect. The outages caused by fires were selected based on this data. Six transmission line trunks with asymmetrical performance regarding fire-related outages in the period were selected. The selected circuits are highlighted in Table 1.

Table 1. Transmission trunks and lines selected for the study [27]

Trunks	Installation	Length (km)
1	TL 500 kV COLINAS/RIB.GONCALVES C 1 TO/PI	379
	TL 500 kV COLINAS/RIB.GONCALVES C 2 TO/PI	367
2	TL 500 kV IMPERATRIZ/COLINAS C 1 MA/TO	343
	TL 500 kV IMPERATRIZ/COLINAS C 2 MA/TO	343
3	TL 500 kV IMPERATRIZ/P.DUTRA C 1 MA	388
	TL 500 kV IMPERATRIZ/P.DUTRA C 2 MA	388
4	TL 500 kV RIB.GONCALVES/S.J. PIAUI C L3 PI	353
	TL 500 kV RIB.GONCALVES/S.J. PIAUI C L4 PI	353
5	TL 500 kV TERESINA II/P.DUTRA C C9 PI/MA	210
	TL 500 kV TERESINA II/P.DUTRA C C8 PI/MA	208
6	TL 500 kV TERESINA II/SOBRAL III C V8 PI/CE	334
	TL 500 kV TERESINA II/SOBRAL III C V9 PI/CE	332

The six selected trunks cover the states of Piauí, Tocantins, Maranhão, and Ceará, as can be seen in Figure 2, and they correspond to twelve 500 kV transmission lines with a total length of 3,998 km. The forced outages due to fires that occurred in the period were highlighted for the six selected trunks. Using the Geospatial Transmission Management System (*Sistema de Gestão Geoespacializada de Transmissão*, GGT) [28], the geographic coordinates of each span between the transmission line towers of interest were obtained. Using the *Queimadas* program [24], data was obtained on the fire outbreaks that hit the spans of the transmission lines in the period of interest. The fire outbreak data were obtained with a resolution of 1 km^2 (INPE, 2020).

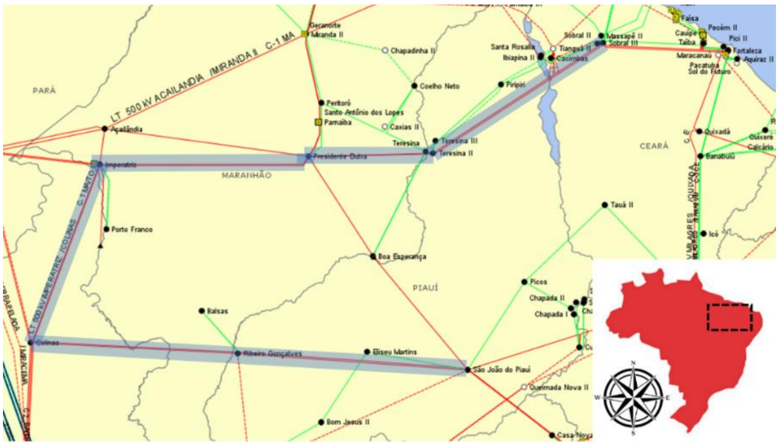


Figure 2. Schematic of the analyzed transmission lines [27]

The fire outbreak data were compared with the transmission line outage data in order to validate the cause of the reported outage. The location of the defect and the spans where fire outbreaks were identified on the same date were also compared. Based on this information, the following could be assessed: i) whether the reported fire-related outages had associated fire outbreaks; ii) whether the location of the reported defect for the fire-related outage corresponded to the location of the fire outbreaks; and iii) whether or not a particular fire outbreak was capable of causing a transmission line outage at a specific date.

To determine whether a fire-related outages was correctly reported, we looked for fires that affected at least one span of the transmission line on the same date as the event. Cases in which validations were not possible were classified as false positives. For validation, the following logical test was adopted:

$$\begin{aligned}&if\ FO_{date} = F_{date}\\&then\ FO_{report} = True\\&else\ FO_{report} = False\\&end\ if\end{aligned}$$

where FO_{date} represents the date of occurrence of the outages due to burning of the transmission line, F_{date} represents the date of occurrence of the fire under the transmission line, and FO_{report} indicates whether the fire-related outages was correct (true) or not (false).

To validate the location of the defect, the georeferenced position of the fire point pointed by the satellite was used as a reference and, from there, it was compared with the location reported by the fault locators of the transmission line protection. The location was validated with the following condition met:

$$F_{dist} - \varepsilon \leq L_{dist} \leq F_{dist} + \varepsilon \tag{1}$$

where F_{dist} represents the focus distance indicated by the satellite, L_{dist} represents the tripping distance indicated by the fault locator, and ε represents the margin of error considered.

The analysis of the consequence of a fire under the transmission line was also carried out. The date of occurrence of the fire under the line was compared with the occurrence or not of its outage on the same date. In this case, disconnections with coincident dates were validated. For this purpose, the following logical test was adopted:

$$\begin{aligned}&if\ F_{date} = O_{date}\\&then\ F_{con} = True\\&else\ F_{con} = False\\&end\ if\end{aligned}$$

where: F_{date} represents the date of occurrence of the fire under the transmission line, O_{date} represents the date of occurrence of the outage of the transmission line, and F_{con} indicates whether there was (true) or not (false) the outage of the transmission line caused by the focus. Based on the number of analyzed outages and the known environmental conditions during the study period, the number of outages incorrectly classified as caused by fires and the number of outages caused by fires whose defect location was inaccurate could be estimated for the entire Brazilian transmission system.

3. RESULTS AND DISCUSSION

Based on the ONS data, 7,439 forced outages occurred in the Brazilian transmission system between the years 2018 and 2019. Considering the 12 transmission lines (TL) under study, the number of disconnections was 165. The summarized classification of the causes of these outages can be seen in Table 2. Table 2 highlights the outages caused by fires and those without an identified cause. Considering the entire transmission system, 12.0% of the outages were caused by fires in the period. When we restrict the lines selected for this study, the percentage of outages caused by fires reaches 40.6%, being the main cause of outages in this set.

Table 2. Forced outages in the Brazilian transmission system in the years 2018 and 2019

Classification	Entire transmission system		System studied	
	Number of outages	Percentage of outages	Number of outages	Percentage of outages
Other causes	5611	75.4%	81	49.1%
Indeterminate	933	12.5%	17	10.3%
Fires	895	12.0%	67	40.6%
Grand total	7439	100.0%	165	100.00%

3.1. Outages reported as caused by fires

The 67 outages caused by fires in the lines of interest were compared with the historical data on fire outbreaks obtained from the INPE. For each outage, fire outbreaks were sought affecting at least one transmission line span at the same date of the event. The results of this analysis can be seen in Table 3, including details per transmission line under study.

Table 3. Outages caused by fires in 2018 and 2019 broken down by lines of interest

Installation	Outages classified as caused by fires		
	Total	Validated	Percent
TL 500 kV Colinas/Rib. Gonçalves C1	3	2	66.7%
TL 500 kV Colinas/Rib. Gonçalves C2	4	4	100.0%
TL 500 kV Imperatriz/Colinas C2	1	1	100.0%
TL 500 kV Imperatriz/P. Dutra C1	7	7	100.0%
TL 500 kV Imperatriz/P. Dutra C2	3	3	100.0%
TL 500 kV Rib. Gonçalves/S. J. Piauí C1	14	12	85.7%
TL 500 kV Rib. Gonçalves/S. J. Piauí C2	19	16	84.2%
TL 500 kV Teresina II/P. Dutra C1	2	1	50.0%
TL 500 kV Teresina II/P. Dutra C2	5	5	100.0%
TL 500 kV Teresina II/Sobral III C1	1	1	100.0%
TL 500 kV Teresina II/Sobral III C2	8	7	87.5%
Grand total	67	59	88.1%

Table 3 reveals that in 8 out of 67 shutdowns (11.94%) classified as fires, it was not possible to identify fire outbreaks in any span of the line under analysis on the reported day. These outages could be considered false positives for fires. The existence of false positives was found in 5 out of 11 lines with reported outages caused by fires. It is important to note that in the TL 500 kV Imperatriz/Colinas C1, no fire-related outages were reported in the years 2018 and 2019. Considering the 895 fire-related outages of the entire transmission system (see Table 2), one can state with a 95% confidence level and an error margin of ±7.47%, that there are between 40 and 174 outages whose causes were wrongly classified as fires.

3.2. Accuracy of the reported defect location

Considering the indicated position of the fire occurrence, the location reported by the fault locators was compared with the geospatial data of the fire outbreaks captured by the satellites. The comparison was made by span for each transmission line. Typically, power utilities use the fault locator data to report the location of defects in a transmission line. As described in several studies on the subject, however, fires are high-impedance disturbances, and in such cases the error of locator equipment can reach 6.82% of the line length [18]–[20], [29]. The average length of the twelve transmission lines under study is 330 km. That is, for these lines the fault locator error can reach 22 km.

In the case of the location reported, therefore, an error of 10 km was considered in relation to the reported central point, which corresponds to a 20 km stretch of the line. The central point was obtained from the geospatial tracing of the transmission line and the indicated distance of the defect reported by the fault locator of the utility to the grid operator. For the fire outbreaks, a resolution of 1 km^2 was considered as provided by the sensors of the constellation of satellites, even for fire fronts of only 30 m; that is, all the affected spans were considered within a 1 km radius from the central point of the occurrence of a fire outbreak. In the case of several adjacent fire outbreaks, the entire affected area was considered.

All those outages where at least one of the spans reported by the fault locators of the line coincided with the span affected by the fire outbreak on the same date were considered as coinciding. A radius of 10 km was established considering the reported location of the outage. Within this radius, 19 fire outbreaks were identified that affected the installation. This was one of the outages classified as coinciding in Table 4.

According to the data in Table 4, there are 22 fire-related outages where it was possible to identify fire outbreaks coinciding with the fault location reported by the transmitting agent. These 22 cases are those considered as accurately located and the remaining 37, considering only the validated set of outages in Table 3, are considered as inaccurately located. For the 895 fire-related outages of the entire transmission system (see Table 2), one can estimate with a 95% confidence level and an error margin of ±10.82%, that there are between 504 and 698 outages classified as fire whose locations were reported inaccurately to the grid operator.

It is important to highlight that both the grid operator and the transmission system utilities have tools to refine the location data of defects caused by fires in transmission lines, such as the data provided by the *Queimadas* program [24]. The use of fault location information proved to be inadequate for an analysis by transmission line span. Considering the wildfire phenomenon, fire outbreaks are one available type of information with adequate precision for the analysis by span.

Table 4. Classification of outages regarding the fire outbreak location

Installation	Classification of outages		
	Validated	Coincident	Percent
TL 500 kV Colinas/Rib. Gonçalves C1	2	2	100.0%
TL 500 kV Colinas/Rib. Gonçalves C2	4	2	50.0%
TL 500 kV Imperatriz/Colinas C2	1	1	100.0%
TL 500 kV Imperatriz/P. Dutra C1	7	0	0.0%
TL 500 kV Imperatriz/P. Dutra C2	3	0	0.0%
TL 500 kV Rib. Gonçalves/S. J. Piauí C1	12	6	50.0%
TL 500 kV Rib. Gonçalves/S. J. Piauí C2	16	7	43.8%
TL 500 kV Teresina II/P. Dutra C1	1	1	100.0%
TL 500 kV Teresina II/P. Dutra C2	5	2	40.0%
TL 500 kV Teresina II/Sobral III C1	1	0	0.0%
TL 500 kV Teresina II/Sobral III C2	7	1	14.3%
Grand total	59	22	37.3%

3.3. Consequence of fire outbreaks on transmission line performance

In the 2018-2019 period, INPE registered 47,762 fire outbreaks that affected the twelve transmission lines under study. Based on the day of each outbreak, a comparison was made with the outages of the transmission lines. Table 5 shows the results found per transmission line.

Table 5. Fire outbreaks in the spans of the twelve analyzed transmission lines

Installation	Quantities of fire outbreaks		
	Total outbreaks	Outbreaks that caused the outage	Percent
TL 500 kV Colinas/Rib. Gonçalves C1	4200	133	3.2%
TL 500 kV Colinas/Rib. Gonçalves C2	4432	287	6.5%
TL 500 kV Imperatriz/Colinas C1	1255	53	4.2%
TL 500 kV Imperatriz/Colinas C2	1070	8	0.7%
TL 500 kV Imperatriz/P. Dutra C1	4622	99	2.1%
TL 500 kV Imperatriz/P. Dutra C2	4735	88	1.9%
TL 500 kV Rib. Gonçalves/S. J. Piauí C1	9839	2032	19.8%
TL 500 kV Rib. Gonçalves/S. J. Piauí C2	9839	3145	32.0%
TL 500 kV Teresina II/P. Dutra C1	2122	544	25.6%
TL 500 kV Teresina II/P. Dutra C2	2144	516	24.1%
TL 500 kV Teresina II/Sobral III C1	1558	78	5.0%
TL 500 kV Teresina II/Sobral III C2	1513	276	18.2%
Grand total	47762	7259	15.2%

Through this analysis, it was concluded that there were 7,259 fire outbreaks that caused the outage of one of the twelve transmission lines for any reported reason. The reasons that lead a fire outbreak to cause an outage or not, are not the object of this study. It should be noted, however, that there is a higher prevalence of cause (outbreak) and effect (outage) in some specific lines.

In TL 500 kV Rib. Gonçalves/S. João do Piauí C2, 32.0% of the fire outbreaks caused outages of the installation. In TL 500 kV Imperatriz/Colinas C2, only 0.7% of the outbreaks led to the outage of that circuit. Considering transmission lines trunks, the stretch between the Teresina II and Sobral III substations was observed to have a prevalence of 5% of outbreaks that caused outages for circuit 1 (C1) and 18.2% for circuit 2 (C2), that is, 3.6 times higher. Considering that both transmission lines have equal origin and destination points and very similar paths, a more in-depth analysis is needed to explain this difference in performance.

4. CONCLUSION

For 11.94% of the outages classified as caused by fires in the period under analysis, no corresponding fire outbreak was detected. Considering the entire Brazilian transmission system, there may be up to 174 outages whose causes were mistakenly classified as fires. It was also found that in 67.16% of the outages declared as provoked by fires, there were no fire outbreaks within a 10 km radius of the point indicated by the fault locator. That is, in the years 2018 and 2019 there were at least 504 outages classified as fires whose locations were imprecisely reported to the grid operator. Finally, it was found that 15.2% of the fires that hit spans of the twelve transmission lines under study caused the outage of these equipment. When the transmission lines were analyzed individually, a significant difference was observed in the prevalence of the fires that caused outages. For an analysis by span, it is concluded that the fire outbreak data are more reliable than the data provided by the fault locating equipment of the transmission lines.

REFERENCES

[1] V. P. de Menezes, "Linhas de Transmissão de Energia Elétrica: Aspectos Técnicos, Orçamentários e Construtivos," *UFRJ/ Escola Politécnica*, 2015.

[2] N. A. H. Al-Zubaydi, "Smart Technology Based Empirical Mode Decomposition (EMD) Approach for Autonomous Transmission Line Fault Detection Protection," *EAI Endorsed Transactions on Energy Web*, vol. 9, no. 38, p. e7, May 2022, doi: 10.4108/ew.v9i38.733.

[3] L. Weng, Y. Zhang, Y. Yang, M. Fang, and Z. Yu, "A mobility compensation method for drones in SG-eIoT," *Digital Communications and Networks*, vol. 7, no. 2, pp. 196–200, May 2021, doi: 10.1016/j.dcan.2020.07.011.

[4] T. R. V. da Costa, T. M. M. Pinheiro, J. M. M. da Silva, I. S. Vieira, A. B. Barnabé, and S. D. de Castro, "Aplicação da regulação responsiva na fiscalização dos serviços de eletricidade no Brasil," in *XVII Encuentro Regional Iberoamericano Del Cigre*, 2017, p. 11, [Online]. Available: https://eriac.itaipu.gov.py/?page_id=3096.

[5] ONS, "Avaliação da Operação Eletroenergética do SIN," *Operador Nacional do Sistema Elétrico - ONS*, 2016. .

[6] ANEEL, "Relatório de Análise: desligamentos forçados do sistema de transmissão," Brasília," *Agência Nacional de Energia Elétrica - ANEEL*, 2016. http://www.aneel.gov.br/informacoes-tecnicas/-/asset_publisher/CegkWaVJWF5E/content/analise-do-desempenho-de-instalacoes-de-transmissao/656808?inheritRedirect=false&redirect=http%3A%2F%2Fwww.aneel.gov.br%2Finformacoes-tecnicas%3Fp_p_id%3D101_INSTANCE_Cegk.

[7] ONS, "O Sistema em Números," *Operador Nacional do Sistema Elétrico - ONS*, 2023. http://www.ons.org.br/paginas/sobre-o-sin/o-sistema-em-numeros (accessed Jun. 06, 2020).

[8] ONS, "Qualidade do Suprimento," *Operador Nacional do Sistema Elétrico - ONS*, 2023. http://ons.org.br/paginas/resultados-da-operacao/qualidade-do-suprimento (accessed Nov. 04, 2018).

[9] A. S. Gazafroudi, F. Neumann, and T. Brown, "Topology-based approximations for N-1 contingency constraints in power transmissio," *International Journal of Electrical Power & Energy Systems*, vol. 137, p. 107702, May 2022, doi: 10.1016/j.ijepes.2021.107702.

[10] J. Santiago and M. C. Tavares, "Analysis of half-wavelength transmission line under critical balanced faults: Voltage response and overvoltage mitigation procedure," *Electric Power Systems Research*, vol. 166, pp. 99–111, Jan. 2019, doi: 10.1016/j.epsr.2018.10.002.

[11] ONS, "Submódulo 18.2 - Relação dos sistemas e modelos computacionais," *Operador Nacional do Sistema Elétrico - ONS*, 2016. http://ons.org.br/paginas/sobre-o-ons/procedimentos-de-rede/vigentes.

[12] ONS, "Submódulo 22.7 Síntese Gerencial das Principais Perturbações do SIN," *Operador Nacional do Sistema Elétrico - ONS*, 2023. http://www.ons.org.br (accessed Jun. 05, 2020).

[13] Z. He, K. Liao, X. Li, S. Lin, J. Yang, and R. Mai, "Natural Frequency-Based Line Fault Location in HVDC Lines," *IEEE Transactions on Power Delivery*, vol. 29, no. 2, pp. 851–859, Apr. 2014, doi: 10.1109/TPWRD.2013.2269769.

[14] H. Ha, B. Zhang, and Z. -l. Lv, "A novel principle of single-ended fault location technique for ehv transmission lines," *IEEE Transactions on Power Delivery*, vol. 18, no. 4, pp. 1147–1151, Oct. 2003, doi: 10.1109/TPWRD.2003.817505.

[15] C. E. M. Pereira and L. C. Zanetta, "Fault Location in Transmission Lines Using One-Terminal Postfault Voltage Data," *IEEE Transactions on Power Delivery*, vol. 19, no. 2, pp. 570–575, Apr. 2004, doi: 10.1109/TPWRD.2004.824391.

[16] K. Ramar and A. A. A. Eisa, "New fault location algorithms for transmission lines in interconnected power systems," *International Journal of Power and Energy Systems*, vol. 28, no. 3, pp. 241–251, 2008, doi: 10.2316/journal.203.2008.3.203-3531.

[17] J. Izykowski, E. Rosolowski, and M. Mohan Saha, "Locating faults in parallel transmission lines under availability of complete measurements at one end," *IEE Proceedings - Generation, Transmission and Distribution*, vol. 151, no. 2, p. 268, 2004, doi: 10.1049/ip-gtd:20040163.

[18] A. P. A. da Silva, A. C. S. Lima, and S. M. Souza, "Fault location on transmission lines using complex-domain neural networks," *International Journal of Electrical Power & Energy Systems*, vol. 43, no. 1, pp. 720–727, Dec. 2012, doi: 10.1016/j.ijepes.2012.05.046.

[19] M. S. Mamiş, M. Arkan, and C. Keleş, "Transmission lines fault location using transient signal spectrum," *International Journal of Electrical Power & Energy Systems*, vol. 53, pp. 714–718, Dec. 2013, doi: 10.1016/j.ijepes.2013.05.045.

[20] W. M. de Sousa, C. A. Costa, I. H. P. Junior, and C. S. P. Filho, "Sistema de localização automática de faltas em linhas de transmissão utilizando dados de dois terminais-experiência da CEMIG," in *Anais do XVIII SNPTEE Seminário Nacional de Produção e Transmissão de Energia Elétrica*, 2005, pp. 1–8, [Online]. Available: https://www.cgti.org.br/publicacoes/sistema-de-localizacao-automatica-de-faltas-em-linhas-de-transmissao-utilizando-dados-de-dois-terminais-experiencia-da-cemig/.

[21] M. Mishra and R. R. Panigrahi, "Taxonomy of high impedance fault detection algorithm," *Measurement*, vol. 148, p. 106955, Dec. 2019, doi: 10.1016/j.measurement.2019.106955.

[22] L. V. Cunha, "Desempenho de linhas de transmissão frente a descargas atmosféricas: influência do efeito corona na ruptura a meio de vão," Ph.D. dissertation, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, 2010.

[23] IBAMA, "Centro Nacional de Prevenção e Combate aos Incêndios Florestais (Prevfogo)," *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis - IBAMA*, 2018. https://www.ibama.gov.br/prevfogo (accessed Nov. 25, 2018).

[24] INPE, "Programa de Monitoramento de Queimadas," *Instituto Nacional de Pesquisas Espaciais – INPE*, 2017. http://www.inpe.br/queimadas (accessed Sep. 21, 2017).

[25] Fundo Amazônia, "Banco Nacional do Desenvolvimento Econômico e Social - BNDES, Ministério da Economia - ME, and Ministério do Meio Ambiente - MMA," *Fundo Amazônia*, 2020. http://www.fundoamazonia.gov.br/pt/home/ (accessed Oct. 26, 2020).

[26] INPE, "Área Queimada 30m," *Instituto Nacional de Pesquisas Espaciais - INPE*, 2020. http://queimadas.dgi.inpe.br/queimadas/aq30m/ (accessed Jun. 06, 2020).

[27] ONS, "SINDAT Home Controle Sistema," *Operador Nacional do Sistema Elétrico - ONS*, 2023. http://betasindat.ons.org.br/SINDAT/Home/ControleSistema (accessed Sep. 01, 2017).

[28] P. G. Júnior *et al.*, "Sistema de Gestão Geoespacializada da Transmissão – GGT," *Eletro Evolução*, vol. 6, no. 91, pp. 45–52, 2018, [Online]. Available: https://drive.google.com/file/d/1l0A6ugM_bKdzQ-1VXRYOT3TBpAaYTolx/view?usp=sharing.

[29] R. Arranz, Á. Paredes, A. Rodríguez, and F. Muñoz, "Fault location in Transmission System based on Transient Recovery Voltage using Stockwell transform and Artificial Neural Networks," *Electric Power Systems Research*, vol. 201, p. 107569, Dec. 2021, doi: 10.1016/j.epsr.2021.107569.

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