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RESEARCH ARTICLE OPEN ACCESS

PROPOSAL OF COMPUTATIONAL TOOL DO SUPPORT MAINTENANCE DECISION FOR ELECTRIC POWER GRIDS

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ABSTRACT

The Equivalent duration of electric power service interruptions per customer unit (DEC) and the Equivalent frequency of electric power service interruptions per customer unit (FEC) are determinant indexes for the application of penalties by the National Agency for Electrical Power (ANEEL) of Brazil over concessionary companies. Established by ANEEL's 'Procedures for Electrical Power Distribution on the National Electrical System' (PRODIST Module 8), these indexes indicate the continuity of services, consequently the quality of services, must be kept low, therefore methodologies capable to support company´s decisions for cost reduction of operations and penalties by underperformance are always wanted. This analysis of power grids' failures and repair operations uses information about the electrical distribution of the State of Rio de Janeiro converted into data that includes costs and other details surrounding maintenance operations. The objective is to compute and to find the optimum allocation of resources to attenuate most of the impact of power outages. The discrepancies found along the development of this work had to be controlled by averages, standard deviations and the estimation of uncertainties. The steps were established targeting cost reductions opportunities, based on the several documents such as reports provided to ANEEL by the concessionary company responsible for the power distribution for the City of Rio de Janeiro; the PRODIST Module 8; weather data for the areas where the power grids are located; and the month of the year and number of typical occurrences. The conclusions are limited by the choices of computational methods applied, the quality of the information acquired, and by the efforts spent to adjust and reorganize all the information into data.

I. INTRODUCTION

Between the standard parameters [1] used to measure the power quality in Brazil special attention is given to the continuity of the services for the distribution of electric power which, by means of collective continuity indexes for the period of time and frequency of the electrical distribution interruptions, allows the National Agency of Electrical Power (ANEEL) to monitor, evaluate and control the performance of the concessionary companies responsible for the power distribution.

These interruptions are classified and calculated [2]; and the two initial classes are titled Short Duration Voltage Variation (VTCD), for variations with the duration from one (1) second to less than three (3) minutes; and up to the time needed for emergency occurrences that take more than three minutes. In both cases, there are financial compensations to be paid by the concessionaries of power distribution services.

Between the faults that generate financial compensations were highlighted the interruptions and individual occurrence frequency by consumer unit respectively: DIC, established by the interval time of de occurrence; FIC, the repetition frequency; DMIC, the maximum duration time of the continuous interruption by consumer unit (or connection point); and DICRI, the violation of the limit of individual continuity with reference to a Critical Day per consumer unit or connection point.

The financial compensations are paid by the monetary reference value EUSD, which corresponds to the value of charges for the use of the system of power distribution by the reference month of the latest measurement, whenever a violation of the individual index limit for the DIC, FIC and DMIC happens, in relation to the monthly, trimestral or annual period calculation.

For the violations of the individual continuity limit of the index DICRI, the concessionary must compensate consumers and power generation central plants with access to the system distribution, including the ones connected to the transmission grid owners of Other Transmission Installations (DIT), providing credit in bills to be paid up to two months after the accrued period.

The concern with power quality indexes is worldwide, and is demonstrated in many correlated researches; between them is plausible to quote the following works: “Condition monitoring techniques and diagnostic test for lifetime estimation of power transformers avoiding failure/faults that can cause blackout and not energy supplied to consumers” [3], “Maintenance management systems focused in availability” [4], “Impact of new generation sources (in special mini/micro distributed generation) within the distribution network” [5, 6].

The financial impact of fail events without de correct planning are solved during emergencies; these cases are converted into data analyzed for the creation of computational prevision and estimate price for the network repairs and maintenance actions - targeting future cost reductions. Based on the history and registry of previous “repairs on demand”, considering the condition of the distribution network, extrapolations are made in order to anticipate future actions for the financial cost reductions for problems caused by interruptions and variations at the consumers units integrated into the collective (DEC); and to reduce the frequency of the interruptions integrated into (FEC) that have equivalent names (SAIDI) - System Average Interruption Duration Index, and (SAIFI) - System Average Interruption Frequency Index, as established by the U.S. Department of Energy regulation [7]. There are other researches focused in the duration of the financial impact, e.g. the correct localization of the knowledge basis, such as related on [8]; or in mathematical tools to construct the problem model [9]. The paper structure will be as follows: section II describes the database; section III depicts the Auxiliary Tables; section IV describes the Automatic Classification used for the project, section V introduces the WEKA explorer, and section VI presents the conclusion. By the end is presented the work acknowledgements and references.

II. DATABASE

To use of the information obtained from a concessionary’s reports to build the CSV-Excel tabled plan “PREVDEC_INTERRUPTIONS” for the years 2014, 2015, 2016, 2017 and 2018, it was necessary to correct, from the original table, attributes unfit to the analysis, which means, it was necessary to classify and treat the initial information into a database.

After the classification, the archive received eleven new attributes that included data of the weather conditions at the State of Rio the Janeiro during the days and hours of the maintenance occurrences; and economic data about the population surrounding the network who lives “below normal conditions” according to the classification and database provided by the Brazilian Institute of Geographical Statistic (IBGE), 2010, the latest available.

The information was combined in a CSV file with 52173979 bytes. The final file included the field PROD_QS_MD, the product of the attributes QTY_CONS and MIN_DURATION; and the attribute MONTH, extracted from the date of the occurrences of the fail/interruption of the distribution network because the final planning for the intervention must be monthly; the weather conditions; and seasonality of social/economical problem, such as unemployment after relevant commercial-calendar dates and the end of employment contracts, which may influence the consumer characteristics affecting the distribution network problems indexes, which would make more complex the classification and analysis method of cluster and final grouping. After this change to the database were removed multi-valued fields resulting on a final plan-table with 36 attributes in a 36292Kbytes file. The Table 1 presents the list of attributes used for classification.

Table 1: PREVDEC_INTERRUPTIONS_2017.CSV DATA.

Nº	Data structure, CSV format	
	Attribute	***Description***
01	DATE_REF	Year and month of the occurrence
02	NUM_DOCUMENTO	Document number
03	NUM_ID_INTERRUPCAO	Interruption number
04	NUM_ID_ITEM	Sequential number of the affected area
05	COD_CONJUNTO	Set number
06	COD_CONJUNTO_ANEEL	Set code number
07	DES_CONJUNTO	Set description
08	NUM_ID_HIERARQUIA	Hierarchic position number
09	COD_HIERARQ	Hierarchic code
10	COD_SIGLA	Acronym code of parts of the system
11	DES_HIERARQ	Neighborhood description
12	NUM_ID_MUNICIPIO	City Code
13	NOM_MUNICIPIO	City Name
14	COD_TIPO_DISP_OPER	Controlled device type code
15	COD_EQUIP_OPER	Controlled equipment code
16	DES_EQUIP	Controlled equipment description
17	DES_LABEL_DISP_OPER	Controlled device draw label
18	DES_LABEL_SUBEST	Substation draw label
19	DES_LABEL_ALIMENT	Feeder draw label
20	DES_COMPL_LABEL_ALIMENT	Feeder complementary draw label
21	QTD_CONS	Consumers quantity
22	MIN_DURACAO	Interruption interval in minutes
23	DAT_INICIO	Beginning of occurrence date in format: ‘YYYY/MM/DD HH:MM:SS’
24	DAT_TERMINO	End of occurrence date in format: ‘DD/MM/YYYY HH:MM:SS’
25	DAT_TERMINO_CORR	Fixed ‘End of occurrence date’ in format: ‘DD/MM/YYYY HH:MM:SS’
26	TAG_PROG_ACID	????
27	NUM_IDT_GRUPO_CAUSAS	Group of causes identification number
28	NUM_IDT_CAUSA_INTERRUPCAO	Interruption cause identification number
29	DESC_CAUSA	Cause description
30	COD_TIP_EXPURGO	Exception type code
31	DES_TIP_EXPURGO	Exception type description

Source: Authors, (2020).

By treating the attributes was obtained a CSV file and an automatic class sequencer program. The automatic class sequencer program was developed for this work to generate the auxiliary tables and its foreign keys codified (COD_) for the alphanumeric attributes in CSV format; simultaneously generated corresponding ARFF files, ready to be used with the WEKA program [10]. WEKA has in numerous applications and is known by academics, having many publications such as described in [11-13]. The development is the result of research to the literature included in the software packages MSVB, VB3, VB4, VB5, VB6 and MSDN between others.

III. AUXILIARY TABLES

The following auxiliary tables were created (Tables 2 to 16) for this work and the identified classes substituted at the main table by its equivalent code, reducing the total size of the file and the computational weight for processing the different analysis methods for data correlation. Unidentified objects were substituted by the symbol (?), the ARFF notation for unidentified elements; and the attribute. DES_CONJUNTO was dismembered in two fields, DES_CONJUNTO and TIP_DES_CONJUNTO; due to the size of the tables, some are presented only with few lines.

III.1 DES_CONJUNTO

It was divided into 107 classes in two separated attributes, COD_CONJUNTO and DES_CONJUNTO - Table 2.

Table 2: COD_CONJUNTO.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_CONJUNTO	DES_CONJUNTO
02	D001	AREIA_BRANCA_AEREO
03	D002	COELHO_DA_ROCHA
04	D003	MENA_BARRETO_AEREO
05	D004	CAMARI
- - -	- - -	- - -
105	D104	BOTAFOGO_AEREO_URBANO
106	D105	BARRA_2
107	D106	SANTO_ANTONIO_AEREO_URBANO
108	D107	CAMERINO_SUBTERRANEO

Source: Authors, (2020).

III.2 TIPO_DES_CONJUNTO

It was divided into 6 classes in two separated attributes, COD_TIP_DES_CONJUNTO and TIPO_DES_CONJUNTO - Table 3.

Table 3: COD_TIPO_DES_CONJUNTO.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_ TIPO_DES_CONJUNTO	TIPO_DES_CONJUNTO
02	T1	AEREO
03	T2	?
04	T3	AEREO_URBANO
05	T4	AEREO_MT/MT
06	T5	AEREO_AT/MT
07	T6	SUBTERRANEO

Source: Authors, (2020).

III.3 DESC_SIGLA

It was divided into 10 classes in two separated attributes, COD_SIGLA and DESC_SIGLA - Table 4.

Table 4: COD_DESC_SIGLA.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_SIGLA	DESC_SIGLA
02	S01	BX/NI
03	S02	CS/CE
04	S03	VP/TR
05	S04	OE/JP
06	S05	LE/PE
07	S06	CS/BA
08	S07	VP/VR
09	S08	BX/CX
10	S09	LE/ME
11	S10	OE/CG

Source: Authors, (2020).

III.4 DESC_ HIERARQ

It was divided into 91 classes in two separated attributes, COD_DES_HIERARQ and DES_HIERARQ – Table 5.

Table 5: COD_DES_HIERARQ.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_DES_HIERARQ	DES_HIERARQ
02	H01	BELFORD_ROXO
03	H02	MESQUITA
04	H03	VILA_DE_CAVA
05	H04	CENTRO
- - -	- - -	- - -
89	H88	MATOSO
90	H89	PAES_LEME
91	H90	SIMAO_PEREIRA
92	H91	SANTANA_DESERTO

Source: Authors, (2020).

III.5 COD_MUNICIPIO

It was divided into 36 classes in two separated attributes, COD_MUNICIPIO and NOME_MUNICIPIO - Table 6.

Table 6: COD_ MUNICIPIO.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_MUNICIPIO	NOM_MUNICIPIO
02	M01	BELFORD_ROXO
03	M02	MESQUITA
04	M03	NOVA_IGUACU
05	M04	RIO_DE_JANEIRO
- - -	- - -	- - -
36	M35	SIMAO_PEREIRA(MG)
37	M36	SANTANA_DO_DESERTO(MG)

Source: Authors, (2020).

III.6 COD_EQUIP

It was divided into 37 classes in two separated attributes, COD_EQUIP and DES_EQUIP - Table 7.

Table 7: COD_EQUIP.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_MUNICIPIO	NOM_MUNICIPIO
02	E01	DISJUNTOR
03	E02	RAMAL
04	E03	CHAVE_FUSÍVEL_MT_DERIVAÇÃO
- - -	- - -	- - -
37	E36	AUTO_TRANSFORMADOR_MT
38	E37	CHAVE_SECCIONADORA_MT_SF6_C.R.

Source: Authors, (2020).

III.7 DES_LABEL_DISP_OPER

The classification of the attribute resulted in 153.510 values for the 262.763 instances; this result served the purpose of eliminating the attribute due to its large dispersion and lack of convergence. It is presented in a resumed form at Table 8.

Table 8: COD_DLD_OPER.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_DLD_OPER	DES_LABEL_DISP_OPER
02	DO000001	ABRDJ3781
03	DO000002	412973612
04	DO000003	CF-857811
05	DO000004	412041659
- - -	- - -	- - -
153508	DO153507	420984907
153509	DO153508	411151989
153510	DO153509	413462798

Nº	Data structure, CSV format	
	Attribute	*Description*
153511	DO153510	410709003

Source: Authors, (2020).

III.8 DES_LABEL_SUBEST

It was divided into 391 classes in two separated attributes, COD_SUBEST and DES_LABEL_SUBEST - Table 9.

Table 9: COD_SUBEST.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_SUBEST	DES_LABEL_SUBEST
02	S001	ABR
03	S002	MNB
04	S003	CRM
05	S004	CMR
- - -	- - -	- - -
389	S388	JDB_Null
390	S389	SAT_SAT
391	S390	ETV_ETV
392	S391	SRD_ESP

Source: Authors, (2020).

III.9 DES_LABEL_ALIMENT

It was divided into 3862 classes in two separated attributes, COD_DES_ALIMENT and DES_LABEL_ALIMENT - Table 10.

Table 10: COD_DES_ALIMENT.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_DES_ALIMENT	DES_LABEL_ALIMENT
02	A0001	[ABR_010]
03	A0002	[MNB_001]
04	A0003	[CRM_0007]
05	A0004	[CMR_33090]
- - -	- - -	- - -
3860	A3859	LDA_PENNA
3861	A3860	LDS_30560
3862	A3861	LDS_24163
3863	A3862	LDS_1960

Source: Authors, (2020).

III.10 COD_CL_ALIMEN

It was divided into 3911classes in two separated attributes, COD_CL_ALIMENT and DES_COMPL_LABEL_ALIMEN - Table 11.

Table 11: DES_COMPL_LABEL_ALIMEN.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_CL_ALIMENT	DES_COMPL_LABEL_ALIMEN
02	DA0001	LDA AUREA
03	DA0002	LDA SALUSSE
04	DA0003	LDA PARIS
05	DA0004	LDS 33090/LDA SILVINO
- - -	- - -	- - -
3909	DA3908	[ETV] LDA PENNA
3910	DA3909	[BRR] LDS 30560
3911	DA3910	[SAT] LDS 24163
3912	DA3911	[SAT] LDS 1960

Source: Authors, (2020).

III.11 ATRIBUTO DESC_CAUSA

It was divided into 99 classes in two separated attributes, COD_CAUSA and DESC_CAUSA - Table 12.

Table 12: ATRIBUTO DESC_CAUSA.

Nº	Data structure, CSV format	
	Atribute	*Description*
01	COD_CAUSA	DESC_CAUSA
02	C01	FALHAS_EM_EQUIPAMENTOS-REDE_DE_MT_PARTIDA_0U_MAU_ESTADO
03	C02	FALHAS_EM_EQUIPAMENTOS-RAMAL_AEREO
04	C03	FALHAS_EM_EQUIPAMENTOS-CHAVE_FUSIVEL
05	C04	FALHAS_EM_EQUIPAMENTOS-ESTAI
- - -	- - -	- - -
97	C96	PROGRAMADA-ENTREGA_DE_OBRAS
98	C97	PROGRAMADA-OBRA_CIVIL
99	C98	PROGRAMADA-OUTRAS_DISTRIBUIDORAS
100	C99	GERACAO-NAO_PROGRAMADO

Source: Authors, (2020).

III.12 COD_CL_ALIMENT

It was divided into 3911 classes in two separated attributes, COD_CL_ALIMENT and DES_COMPL_LABEL_ALIMEN - Table 13.

Table 13: COD_CL_ALIMENT.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_CL_ALIMENT	DES_COMPL_LABEL_ALIMEN
02	DA0001	LDA AUREA
03	DA0002	LDA SALUSSE
04	DA0003	LDA PARIS
05	DA0004	LDS 33090/LDA SILVINO
- - -	- - -	- - -
3909	DA3908	[ETV] LDA PENNA
3910	DA3909	[BRR] LDS 30560
3911	DA3910	[SAT] LDS 24163
3912	DA3911	[SAT] LDS 1960

Source: Authors, (2020).

III.13 COD_EXPURGO

It was divided into 4 classes with two separated attributes, COD_EXPURGO and DES_TIP_EXPURGO - Table 14.

Table 14: COD_ EXPURGO.

Nº	Data structure, CSV format	
	Attribute	*Description*
01	COD_EXPURGO	DES_TIP_EXPURGO
02	X1	SEM_EXPURGO
03	X2	DIA_CRITICO-ACIDENTAL
04	X3	SITUACAO_DE_EMERGENCIA
05	X4	DIA_CRITICO-PROGRAMADA

Source: Authors, (2020).

The weather information of the City of Rio de Janeiro between the days of January 1st, 2017 to October 31, 2019 were obtained from the Internet site timeanddate.com, converted and organized in the format CSV and ARFF. The final file with 4137 instances and thirteen (13) attributes refers to the daily weather registers collected in interval of six (6) hours. Table 15 (CLIMA E TEMPO-RJ) presents the following attributes for the analysis.

Table 15: CLIMA E TEMPO – RJ.

Nº	Data structure, CSV format	
	Attribute	***Description***
01	HORA_S	Hour of registration of the weather data
02	DIA_S	Week day of registration of the weather data
03	DIA_N	Day of registration of the weather data
04	ANO_MES	Year and Month composition of the registration of the weather data to the format YYYYMM
05	HORA_I	Initial time of the weather data registration
06	HORA_F	End time of the weather data registration
Registry for a specific year, month and day between the time interval HORA_I and HORA_F		
07	TEMP_MAX	Maximum Temperature, ºC
08	TEMP_MIN	Minimum Temperature, ºC
09	PRESS	Atmospheric Pressure, mbar
10	VENTO	Wind velocity in km/h
11	HUMID	Relative Humidity (%)
12	ANO_MES_DIA	Converted Data to the format ISO 8601 YYYYMMAA
13	DESC_TEMP	Qualified description of the weather conditions

Source: Authors, (2020).

For the association of the table with the classified attribute DESC_TEMP with 34 values for the descriptions of the weather condition was used the resumed organization show on Table 16.

Table 16: DESC_CLIMA.

Nº	Data structure, CSV format	
	Attribute	***Description***
01	COD_CLIMA	DESC_CLIMA
02	CL01	SUNNY
03	CL02	SCATTERED_CLOUDS
04	CL03	THUNDERSTORMS_OVERCAST
...	...	...
32	CL31	SCATTERED_SHOWERS_MOSTLY_CLOUDY
33	CL32	THUNDERSTORMS_FOG
34	CL33	DRIZZLE_MOSTLY_CLOUDY

Source: Authors, (2020).

IV. AUTOMATIC CLASSIFICATION

The following steps were necessary for the creation of an automatic classification system:

- To initialize the VBA-Excel program [10]
- To make subroutines in VBA-Excel
- Function Open CSV to get the CSV data
- Function classification to start the process
- Function Classification filter for the automation
- To evaluate the input data.

Analyzing the Figure 1 is possible to observe that most fails occurred at weather conditions between 25ºC to 29ºC.

Interruption frequency by month Graphic (2017).

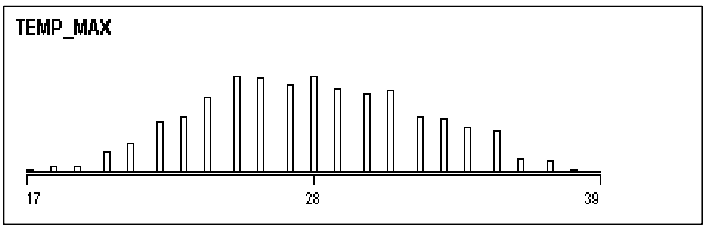

Figure 1: Maximum Temperature (ºC) and fails per month (2017).
Source: Authors, (2020).

V. WEKA EXPLORER

VBA EXCEL resources combined to Weka [11-14] were used for the generation of the following graphics and tables. The software provides a learning environment combined with knowledge, such as the name behind acronym suggests, allowing studies and the development of algorithm for future projections, in this case, the ideal planned actions to reduce DEC and FEC by means of the innumerous machine learning resources available at the virtual workbench where it is allowed to visualize data during analysis for the construction of the primitive model. At this section are presented correlations and analyzed the problem's data nature that was classified by means of VBA Excel.

Figure 2 shows one of the desired configuration screens for the software output.

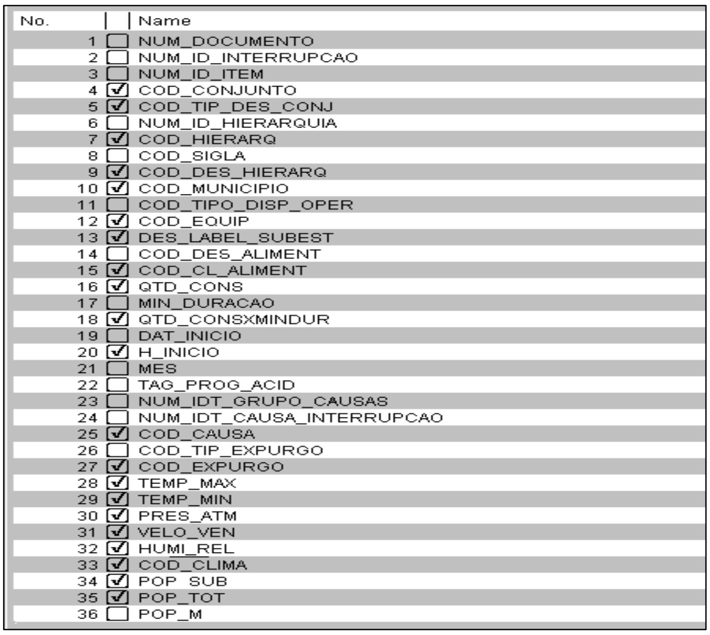

Figure 2: WEKA EXPLORER – Configuration.
Source: Authors, (2020).

The following examples show the output for the developed software from the use of data classification (Figures 3 to 6).

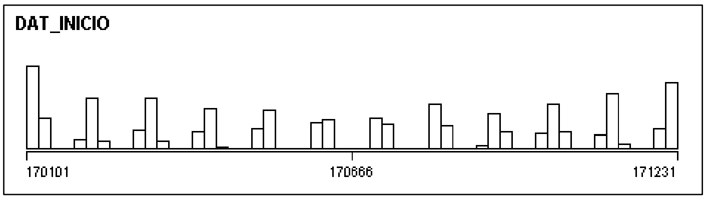

Figure 3: Graphic of the Interruption frequency during one year by month.
Source: Authors, (2020).

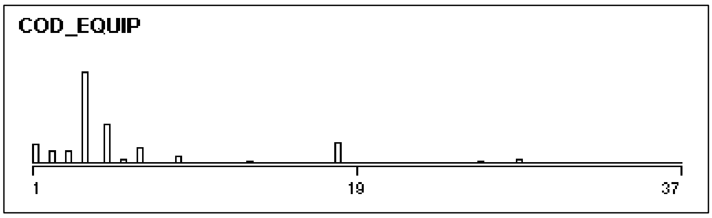

Figure 4: Graphic of the Interruption frequency during by equipment based on Table 7.
Source: Authors, (2020).

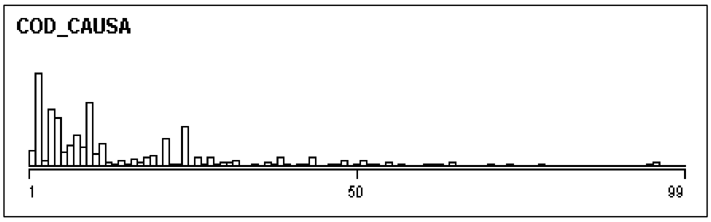

Figure 5: Graphic of the Fault frequency.
Source: Authors, (2020).

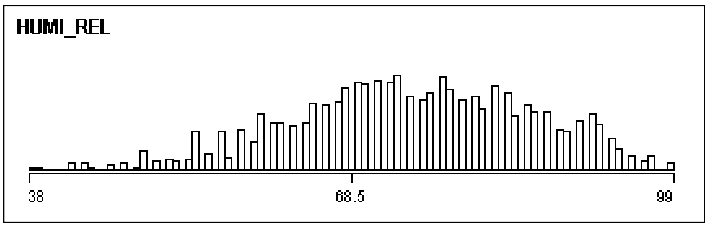

Figure 6: Graphic of the Relative humidity % during the period of analysis.
Source: Authors, (2020).

Another possible application for the software it´s to cross analysis between the weather conditions (e.g. atmospheric pressure) versus the causes of problems from the maintenance data table, which showed that for pressures near 1032 mbar there was a larger frequency of fails registered for the year 2017.

With the classification of the occurrence dataset per month, there is the confirmation of a bigger index of failures during the summer vacation (January) and by the end of the semester (from October to December), as showed by Figure 7 - Interruption frequency by month Graphic (2017) (axel x, H_INICIO, axel y, MES).

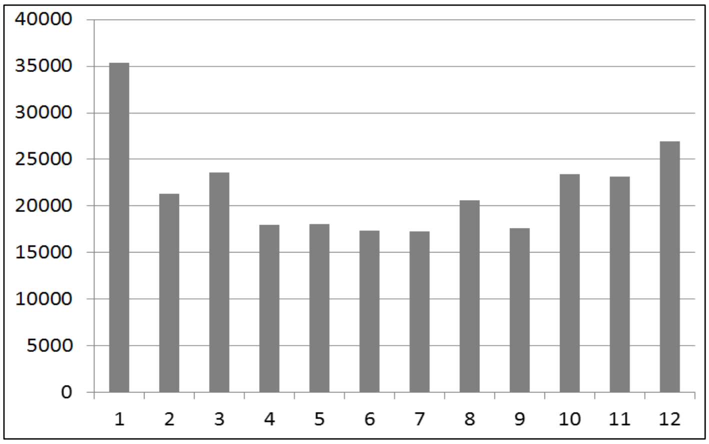

Figure 7: Graphic of the Relative humidity % during the period of analysis.
Source: Authors, (2020).

VI. CONCLUSIONS

Although many resources were used, after the analysis of the occurrence patterns it was not possible to find correlations to indicate a unique path to the machine learning for projections of strategic plans to apply for the power network maintenance. However, for the present study was available only the data of 2017; considering the seasonal aspects of maintenance, it is proposed to extend the evaluation to include the years 2018 and 2019, nevertheless the tool proved useful for the analysis of the databank and may indicate paths for the maintenance teams to act targeting planning the reduction of indicators that have direct impact over power quality. The individual analysis pointed to areas that should receive more attention considering that they concentrated the problems correlated to major fails cases, and basing on the study of the databank were found, respectively from the most severe to the lower frequency the following items:

- Equipment faults – Aerial power lines
- Equipment faults – Connections and equipment anchorage
- Environment – Tree branches and falling trees
- Third part action – Public service companies or its contractors and undetermined reasons – After power network inspection
- Equipment faults – Broken power network’s BT or in bad conservation conditions, transformers, and Broken power network’s MT or in bad conservation conditions
- Third part action – Objects over the power network
- Natural phenomena - Storms

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