Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

Historical Data Analysis of Lightning and its Relation with the Portuguese Transmission System Outages

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Abstract—**Lightning caused around 26% of the total number of faults in the Portuguese Transmission system in the analysed period. Based on historical data, this study uses incident data from 2001 until 2008 (2157 faults in overhead lines) and lightning data from 2003 until 2008 (around 1.65 million cloud-to-ground flashes). The performance of the lightning monitoring system is analysed and the statistical analysis of the incidents caused by lightning is made. Therefore, several indicators are presented, such as average failure rate per 100km and the percentage of these faults from the total. In addition, month and hour fault distributions are shown and the overhead lines with the worst performance in terms of lightning are identified. The aim of this analysis is to characterize this type of faults in order to evaluate the impact caused by lightning on an operational level. It will be one of the many inputs of a risk assessment methodology.**

Index Terms—**Failure Rate, Lightning, Outages, Portuguese Transmission System, Reliability.**

I. INTRODUCTION

Nowadays, society is dependent on electrical energy, thus electric power systems play an essential role in our daily life. Power system's complex structure composed of thousands of elements has to be exhaustively analyzed, because their failure may interfere with its normal operation and power system's security must be kept.

In order to get a real-time insight in the likelihood and consequences of grid incidents caused by lightning, this paper presents the analysis of faults caused by lightning in the Portuguese Transmission System, combining the information of the monitored lightning strikes in Portugal and the Portuguese TSO historical incidents database.

Lightning monitoring systems are widely used by other countries, such as US [7], Sweden [8], UK and Ireland [9], the Netherlands [10], Austria [11], South Africa [12], Israel [13], China [14] and Japan [15], among many others.

Through the historical data, it is possible to affirm that most incidents originate from overhead lines (on average 91% of the incidents with origin in the Portuguese transmission system, from 2001 until 2008). Overhead lines (OHL), by its own dispersion over a wide geographic area and because of the many different ground characteristics where they are deployed, are more exposed to the action of external factors which cause most of the grid incidents.

Incidents have many possible causes from which the most frequent and usual in the Portuguese transmission system are lightning, fog in combination with pollution (classified as weather – atmospheric causes), storks and forest fires (classified as environmental causes).

Lightning caused around 26% of the total number of faults between 2001 and the end of 2008. It was possible to conclude that only around 0.02% of the cloud-to-ground lightning occurring in Portuguese territory caused OHL faults. There is no absolute protection against lightning and it is considered an uncontrollable incident's cause, although OHL reliability performance can be improved with better insulation coordination.

This paper characterizes the faults caused by lightning in order to evaluate their impact on an operational level. Section II defines lightning and describes its impact in the transmission system. Section III presents the input data used in this study, as well as the functioning of the lightning monitoring system and general organization of the incident's data base. Section IV explains the algorithm used to assess the performance of the lightning monitoring system. Section V presents the incident's statistical analysis. In addition, some international results are also mentioned.

II. LIGHTNING

Lightning is the transfer of significant charge between two charged objects. A lightning occurs because of a charge separation between cloud and earth or within a cloud, caused by meteorological processes (it typically occurs during thunderstorms).

Lightning electrical discharge is visible by the human eye as a lighting flash and can occur from cloud-to-cloud and cloud-to-ground. The electrical discharge consists of an

This work was supported by Rede Eléctrica Nacional, SA and by Electrical Engineering Faculty Porto University, Portugal.

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electrical current with amplitude ranging from 1kA up to 400kA (registered by the detection network), approximately, with a rise time in the order of a few up to tens of microseconds. The duration of one lightning discharge can be from several tens up to several thousand microseconds. Multiple strokes can occur shortly after each other.

Whenever a lightning charge propagates to earth, it must have an "attachment point," which is the origin of the upward stream of charge [5]. Overhead lines are very good attachment points, because they are usually in exposed locations spread across the country, being considerably taller than adjacent objects.

A lighting current induces a high voltage between the object that it strikes and remote objects. Because phase conductors of an overhead line connect remote objects, when a lightning hits for example a ground wire, it induces a voltage between the ground wire and the phase conductors and when that voltage exceeds the insulation level, a back flash occurs, electrically connecting the phase with the ground wire. This connection causes a short-circuit in the power system and the short-circuit current maintains the ionized conducting air channel after the lightning has already disappeared.

The protection systems of the overhead line will trigger due to the fault and, consequently, open the applicable circuit breakers, clearing the fault by disconnecting the faulty line. Subsequently, in the absence of an electrical current, the air looses its conductivity, and therefore the overhead line can safely be reclosed, without causing a new short-circuit.

The appearance of short-circuit immediately after reclosing the breaker indicates the permanence of the fault and damage on the equipment, causing protection systems to operate again.

From 2001 until 2008, only 5% of the faults caused by lightning had an automatic disconnection after reclosing the breaker.

III. INPUT DATA

A. Lightning Monitoring System (LMS)

In 2007, the Portuguese TSO has acquired a real-time monitoring system that provides the control room operators with real-time information on the lightning that are detected in the national territory, giving geographical and amplitude information.

In the control room the lightning detection data is presented to the operator in an ordinary PC, with a user-friendly interface, which allows in real-time:

- to identify and keep track of thunderstorms;
- to correlate the lightning with the fault (i.e., with protection system's operation);
- to activate additional security measures, such as the cancelation of planned outages; a closer look is taken at N-2 contingencies, especially when two lines share the same towers over a long distance and the implementation of remedial actions identified as necessary (for instance the implementation of a special topological scheme).

The software used to visualize and import the data is "Jobs v5.3 – Visualization and Analysis of Lightning Data" from *Météorage*, France. This system has already been working since June 2002 in the Portuguese Meteorological Institute, which is the owner of the detection network.

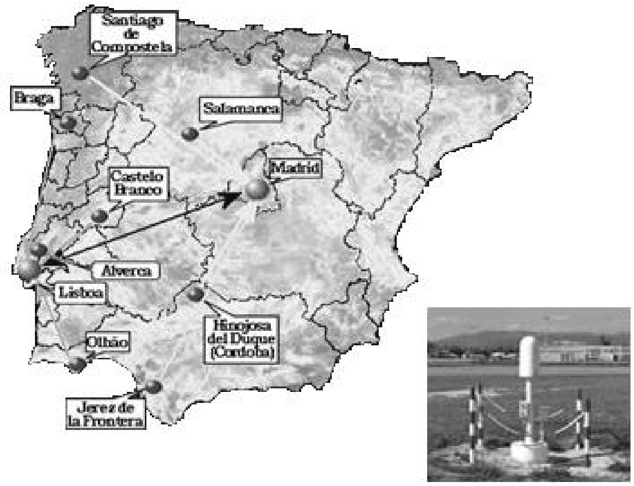


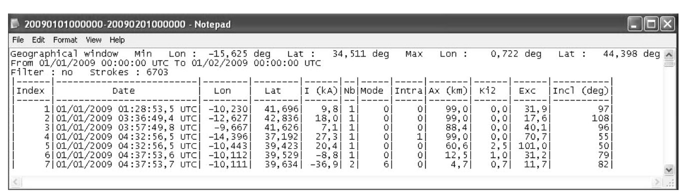
Fig. 1. Sensors of the Lightning Detection Network [1]

The network is composed of detection and communication equipment, allowing the population of an historical data base. Nowadays, the whole system has 18 detectors, 4 in Portugal in addition with 14 in Spain and since December 2002 that lightning detection data is shared between both countries, improving the accuracy of the measurements.

In the Portuguese case, the information is shared with the 5 nearest detectors in Spain. Multiple sensors are used to detect lightning.

Reference [5] refers that three methods are used to locate the lightning discharge, regarding latitude and longitude (in WGS84): magnetic direction finding, time of arrival and the combination of both (which improves accuracy).

The system also provides the measurement of the intensity, polarity and orientation of the discharge. After being detected, the lightning information is immediately transmitted to the data centre via VPN. The information is automatically stored in an ASCII file.


20090101000000-20090201000000 - Notepad
File Edit Format View Help
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From 01/01/2009 00:00:00 UTC To 01/02/2009 00:00:00 UTC
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Index	Date	Lon	Lat	I (kA)	Nb	Mode	Intra	Ax (km)	Ki2	Exc	Incl (deg)
1	01/01/2009 01:28:53,5 UTC	-10,230	41,696	9,8	1	0	0	99,0	0,0	31,9	97
2	01/01/2009 03:36:49,4 UTC	-12,627	42,836	18,0	1	0	0	99,0	0,0	17,6	108
3	01/01/2009 03:57:49,8 UTC	-9,667	41,626	7,1	1	0	0	88,4	0,0	40,1	96
4	01/01/2009 04:32:56,5 UTC	-14,396	37,192	27,3	1	0	1	99,0	0,0	70,7	55
5	01/01/2009 04:32:56,5 UTC	-10,443	39,423	20,4	1	0	0	60,6	2,5	101,0	50
6	01/01/2009 04:37:53,6 UTC	-10,112	39,529	-8,8	1	0	0	12,5	1,0	31,2	79
7	01/01/2009 04:37:53,7 UTC	-10,111	39,634	-36,9	2	6	0	4,7	0,7	11,7	82

Fig. 2. Lightning detection data file

The software provider estimates a location error in the Portuguese territory smaller than 500m for the ellipse major axis with 50% of probability and an efficiency of more than 90% for lightning with a current peak bigger than 5 kA [5]. The ellipse circumscribes a region centred in the recorded stroke location, within which there is a 50% probability of occurrence. Not all lightning strokes are detected. The detection efficiency will be dependent on the number of sensors, their configuration and geometry. Reference [12] gives a very good insight about detection efficiency and location accuracy of a LMS.

More than 1.65 million cloud-to-ground lightning records were taken into the analysis (lightning strokes beyond Portuguese borders were detected); both positive and negative flashes were included. With this tool, ground flash density maps were drawn, as in figure 3.

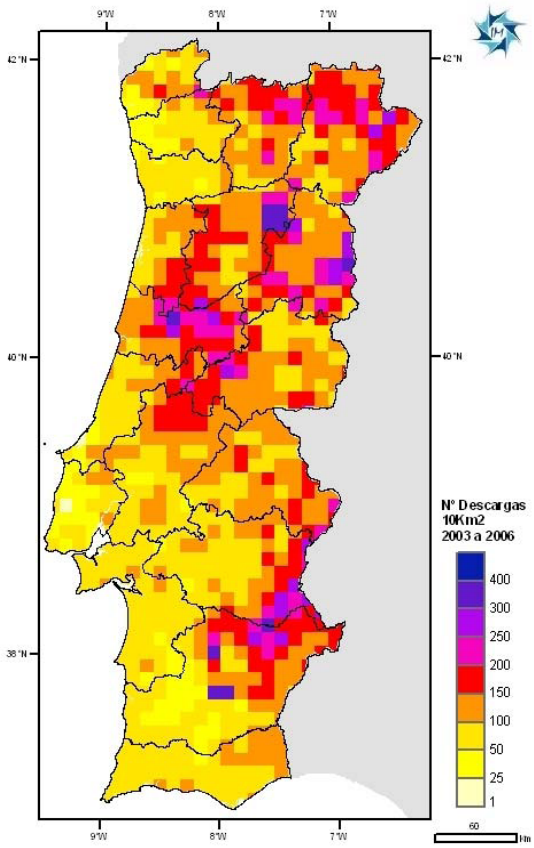

Fig. 3. Overall ground flash density per $10km^2$ between 2003 and 2006 [5]

Table I presents the amount of positive and negative cloud-to-ground lightning flashes and maximum, minimum and average amplitudes per year. The positive flashes represent approximately 20% and the negative flashes 80% of the total amount.

TABLE I
POSITIVE AND NEGATIVE CLOUD-TO-GROUND LIGHTNING FLASHES

Year	Total nº of strokes	Nº of Positive	Nº of Negative	I_{MAX} (kA)	I_{MIN} (kA)	I_{AVG} Positive (kA)	I_{AVG} Negative (kA)
2003	56983	13542	43441	423,9	-354,5	19,5	-20,8
2004	69141	11022	58119	363,6	-469,1	17,2	-20,9
2005	39847	8946	30901	466,5	-295,6	14,8	-16,9
2006	77131	17855	59276	344,6	-415,2	16,0	-18,0
2007	129197	22927	106270	319,7	-294,3	13,0	-16,2
2008	49837	9239	40598	361,1	-376,0	16,3	-17,8

As already mentioned, the complete historical database of lightning records was used in the development of this work. They have an important role when evaluating the risk of faults caused by lightning, allowing characterization of this threat to the transmission system.

B. *Incidents Database*

The Portuguese TSO incident database was developed internally by the TSO staff and is being used since the beginning of 2001, containing all incident records until now. This application allows the management of the entire incident's information, increasing the effectiveness of data entering and treatment with strict criteria and therefore obtaining an accurate event analysis and highly reliable records.

Reference [2] presents a detailed description of the database. For each incident record the information which characterizes it is stored, such as: fault date and time, affected grid elements (directly involved in the initiating fault or a affected as consequence), incidents' cause (the initiating fault cause, however each grid element can have a distinct and own cause), energy not supplied and interruption time (in case it exists); and for both circuit-ends of each grid element: operated protection system functions, fault clearing time, short-circuit current and restoration agent.

An incident can be defined as an event that leads to disconnection (not planned) of one or more grid elements – incident elements, which may lead to demand not supplied [2].

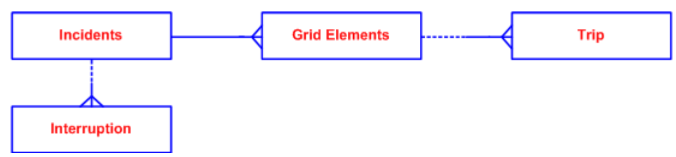

Fig. 4. Incident structure [2]

Hence, an incident can have one or more faults associated, e.g. a lightning that causes short-circuit in two OHL that share the same tower. This common cause incident has registered in the same record two grid elements (2 faults).

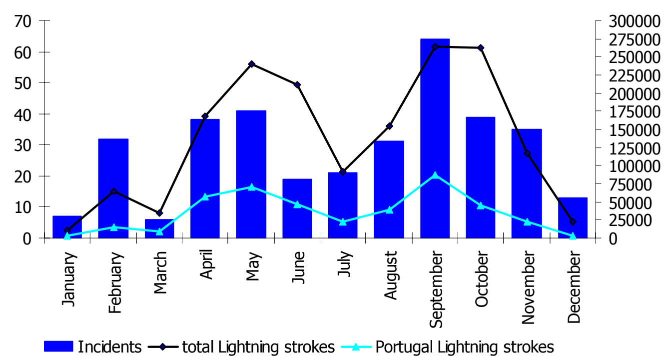

Fig. 5. OHL faults caused by lightning and cloud-to-ground lightning per month between 2003 and 2008

From 2003 until 2008, the correlation between the number of cloud-to-ground flashes in Portuguese territory and the number of faults per month is 85%. In 2005, the number of lightning strokes was considerably smaller than in the other years under analysis, decreasing the number of faults caused by lightning in the transmission system.

IV. DETECTION PERFORMANCE ANALYSIS

In order to analyze the performance of the lightning monitoring system, several steps were performed towards the identification of which lightning has caused each incident. For the first three steps, an application was developed in SQL using Microsoft Access. The fourth step used a geographical tool called RENMap that displays the geographical representation of the Portuguese Transmission System, and because it is just a visualization tool this step was made manually. The given steps towards this result were the following:

1. To select only the lightning data that is located inside a defined area, which is a rectangle that includes the Portuguese territory plus 100 km around it. The increase of 100 km in the country's area is justified by the maximum error found on the detection network records.
2. To compare the date and time of the selected lightning with the SCADA date and time for each incident, both having time synchronization by GPS. The comparison aims to find faults that occurred almost simultaneous with the lightning, i.e., the time of the incident can be up to 3 seconds later as the lightning time. This assumption was made considering the worst clearing time for the fault, which means the distance relay operating in the zone 3. The output of this step is a matrix identifying all possible lightning per incident.
3. To check for each incident if the selected lightning strikes are located exactly or in the vicinity of the affected OHL (considering the detection error associated to each lightning – it is defined as an ellipse and its semi-major axis and angle is given in the detection information). For each incident, if a lightning fulfils also this requirement of being exactly or in the vicinity of the OHL path, it is considered to be the cause of the incident. If more than one lightning fulfils the requirement, the biggest amplitude and the lowest detection error will determine the choice.

This analysis was performed per month, because of the huge amount of lightning strikes.

Regarding just the detection of lightning that causes faults in the transmission system, the performance of the network detection was measured as in (1):

$$\eta_{LMS} = \frac{n^{o}\ of\ \ faults\ with\ a\ detected\ \ lightning\ associated}{total\ number\ of\ \ faults\ caused\ by\ lightning} \quad (1)$$

From 2003 until 2008, the performance of the lightning monitoring system was on average 75%.

The last half of 2002, was not considered in the calculations, because it was the beginning of the detection network where the system was still under testing (time to correct infancy problems) and actually the performance was much lower than in the remainder of the analysed years.

Regarding the lightning strikes which were associated with OHL faults, 11% are positive and 89% are negative, being the maximum amplitude +239.3 kA, the minimum -190.1 kA and the average -34.3 kA.

Before 2007, when the Portuguese TSO did not have available the real-time lightning monitoring system, the uncertainty in order to confirm the cause "Lightning" was higher. The presence of lightning that could be the cause of faults was confirmed by a technician in the vicinity (normally in one of the circuit-ends of the affected OHL). This local information was combined with the lightning data displayed in Meteorological Institute of Portugal website [4], just providing the geographical representation, with a cross, of the detected lightning per period of time.

Through this analysis, we have detected some faults (exactly 7) which were classified with the cause Unknown had a plausible lightning to be associated. After 2007, this situation did not happen anymore and the degree of uncertainty is reduced when classifying faults caused by lightning.

In the case that no plausible lightning to be associated with a fault is detected by the monitoring system, but the fault and the lightning flashes are witnessed by a technician, obviously the cause will be classified as lightning. This exact situation happened on 28th of November 2008, where the fault happened close to a substation and it was witnessed by one technician that reported the fact to the control room.

It is reasonable to classify the described and equivalent situations as caused by lightning, because the monitoring system does not detect every lightning stroke. According to the software provider, lightning strokes are not reported by sensors if their wave shapes are abnormal or if the signal is bellow the sensor threshold.

V. STATISTICAL ANALYSIS OF INCIDENTS

The second part of this work was the statistical analysis of the incidents caused by lightning since 2001 until the end of 2008.

A. Characterization of faults caused by lightning

About 98.5% of the faults caused by lightning affect OHL, while the other 1.5% affects mainly transformers (TR).

Concerning OHL, the tower geometry, the soil resistivity, the insulation level and the number and position of ground wires are aspects that influence the reliability of grid elements in case of lightning.

The incident's set of data under analysis is composed by 2157 OHL faults and 541 were classified as being caused by lightning (from 2003 to 2008, 347 faults).

TABLE II
YEARLY PERCENTAGE OF OHL FAULTS CAUSED BY LIGHTNING

Year	2001	2002	2003	2004	2005	2006	2007	2008
%	29.8	31.2	20.9	30.2	3.2	24.3	41.7	38.7

Fig. 6 presents the occurrence of faults caused by lightning on each voltage level. Through the graph, it is possible to observe that the lower the voltage level, the more affected is the network by this natural phenomenon.

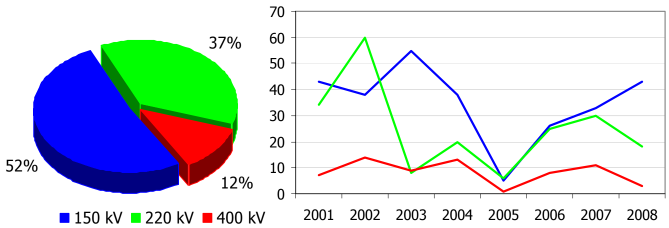

Fig. 6. Average Percentage and number of faults (OHL+TR) caused by lightning per voltage level from 2001 until 2008

In figure 7, it is possible to observe that faults caused by lightning occur during the whole year, mainly in May, August, September and October.

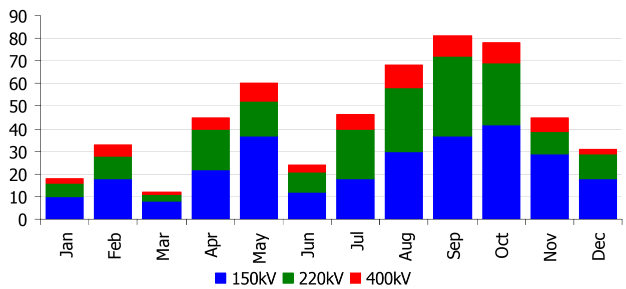

Fig. 7. Month Distribution of faults caused by lightning strikes in OHL from 2001 until 2008

Faults caused by lightning occur mainly in the afternoon and beginning of the evening period (66% of the faults occurs from 12h until 24h), although the night to dawn also has a significant amount of faults. Analysing the cloud-to-ground lightning that have struck inside the Portuguese geographical boundary, around 80% occur from 12h to 24h.

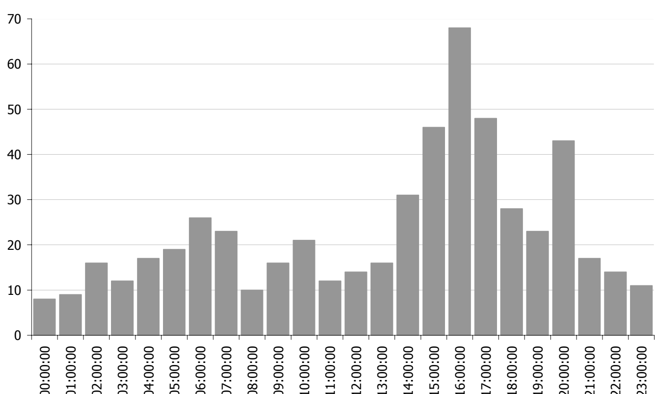

Fig. 8. Hour distribution of faults caused by lightning strikes (OHL + TR) from 2001 until 2008

B. *Independent and common-cause faults*

In terms of faults caused by lightning, two types of faults are identifiable:

– Independent faults - caused by different things and which are not related to each other; they can be single (the most common case), double or multiple.

– Dependent faults - triggered by the same fault (short-circuit), such as common cause faults (normally OHL sharing the same tower and path). The different cause faults (such as hidden failures in adjacent grid elements) will not be under analysis.

In the Portuguese Transmission system common cause faults caused by lightning represent about 31% from the total and the length of OHL sharing the same tower represents on average about 15% of the OHL total length.

TABLE III
NUMBER AND TYPES OF FAULTS CAUSED BY LIGHTNING

Year	Total	Independent	Common Cause
2001	84	50	34
2002	110	78	32
2003	72	46	26
2004	71	49	22
2005	12	10	2
2006	56	34	22
2007	73	56	17[a)]
2008	63	29	34

a) One common cause fault affecting three OHL – two sharing the same tower and one in a very near parallel path.

C. *Number of faults caused by lightning per 100 km*

To compensate the changes in the length of the Portuguese transmission network, the number of faults caused by lightning per 100km is yearly calculated as in (2).

$$Iq_{ij} = \frac{n^{o}\ of\ faults_{ij}}{C_{ij}} \cdot 100 \qquad (2)$$

where:

i is the year:

j is the voltage level;

C_{ij} is the OHL total length in the ith year and jth voltage level.

Fig. 9 shows that with the network development, the number of kilometres per line varies and in the last years the exposed length has increased.

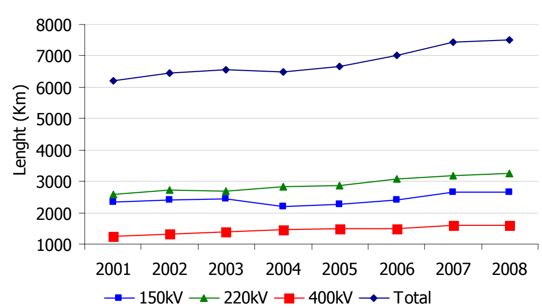

Fig. 9. OHL length development from 2001 until 2008

Lightning is one of the incident's causes which affect the whole territory, thus the total OHL length is considered. From 2001 until 2008, the average number of faults caused by lightning per 100km is shown in Table IV.

TABLE IV

AVERAGE NUMBER OF FAULTS PER 100 KM CAUSED BY LIGHTNING

Year	150 kV	220 kV	400 kV
Average	1.445	0.850	0.582

Fig. 10 presents a comparison between the average number of faults regarding the main causes and the total number of OHL faults. And zoomed above is shown the percentage of these faults from the total per voltage level. The four main causes represent on average 76% of the faults in the Portuguese transmission system (82% if only OHL are considered).

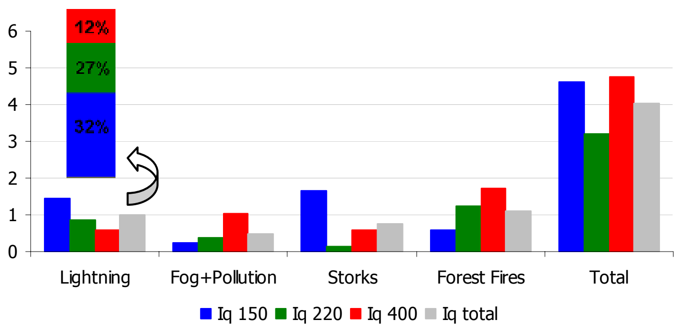

Fig. 10. Average number of faults per 100km of the faults main causes and their number from 2001 to 2008.

D. Absolute and relative frequency

The absolute frequency is the number of times a specific event occurred, such as the trip of a particular OHL, in the study period. This indicator was calculated for every OHL in the Portuguese Transmission system. Afterwards, the relative frequency was also calculated per voltage level as in (3) and (4).

$$RF_i = \frac{AF_i}{\sum_{i=1}^{n} AF_i} \quad (3)$$

$$RF_i^{km} = \frac{RF_i}{d_i} \quad (4)$$

where:

RF_i is the relative frequency of the i[th] OHL;

AF_i is the absolute frequency of the i[th] OHL;

n is the total number of OHL;

d_i is the length of the i[th] OHL;

RF_i^{km} is the relative frequency per km of the i[th] OHL.

The relative frequency per km is the best indicator to judge an OHL performance, because it gives a normalized measure by the total number of events and by the length.

Just to illustrate the relative frequency calculation, Table V shows the relative frequency of the 400kV OHL. This voltage level was chosen because of table dimension.

TABLE V

RELATIVE FREQUENCY OF 400 KV OHL

OHL_i	AF_i	RF_i	d_i (km)	RF_i^{km}
L4007	5	0,0847	68,1	0,00124524
L4010	4	0,0678	96,0	0,00070596
L4012	2	0,0339	59,1	0,00057399
L4014	3	0,0508	29,4	0,00172780
L4018	1	0,0169	96,2	0,00017612
L4019	10	0,1695	59,6	0,00284568
L4020	1	0,0169	34,1	0,00049709
L4021	3	0,0508	1,1	0,04548073
L4024	1	0,0169	213,7	0,00007930
L4025	7	0,1186	223,4	0,00053101
L4032/4602	2	0,0339	65,5	0,00051724
L4035	3	0,0508	133,2	0,00038187
L4036	3	0,0508	86,5	0,00058793
L4039/4040	2	0,0339	123,5	0,00027447
L4039	1	0,0169	59,4	0,00028533
L4040	2	0,0339	64,1	0,00052880
L4041	1	0,0169	57,6	0,00029446
L4050	7	0,1186	1,1	0,10737020
L4055	1	0,0169	40,7	0,00041638

E. OHL corridors with the worst performance

Fig. 11 shows the OHL corridors with a worst performance in terms of the higher relative frequency of faults per km.

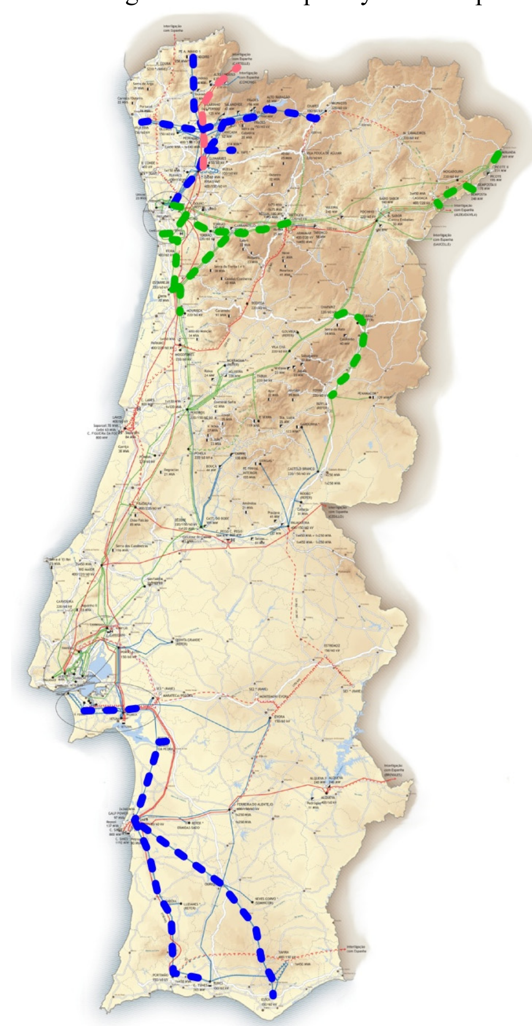

Fig. 11. OHL corridors geographical representation with the higher relative frequency per km, regarding faults caused by lightning.

During the study period, several topology changes happened, modifying past OHL and creating new ones. The most common change was the splitting of a very long OHL in two new ones connecting them into a new substation somewhere in the middle. Therefore, the past and current OHL were considered to determine the current OHL with the worst performance.

F. Some international statistics results

The preponderant role assumed by lightning as one of the main causes of forced outages, i.e. incidents, is not exclusive to the Portuguese transmission system.

Reference [6] presents the major cause contribution to forced outage statistics for Mid-Continent Area Power Pool transmission system, where weather is the predominant cause for line-related incidents and after dividing weather into several sub-causes. Lightning is the one that contributes most to the decrease of OHL reliability. In this paper is also noted that outages caused by lightning are more frequent in summer.

Reference [16] has available online the grid disturbance and fault statistics from Nordel (including Danish, Finnish, Icelandic, Norwegian and Swedish information). Regarding faults in OHL caused by lightning, from 1998 until 2007, they represent about half of the Nordel faults (42% in 400 kV OHL; 59.9% in 220 kV OHL and 52.1% in 132 kV OHL). In these results lightning is also pointed as a disturbance cause in summer.

In the Portuguese transmission system, summer is also the most severe season for grid disturbances. Regarding to faults caused by lightning, during the study period, 139 faults occurred from November to March and 402 faults occurred from April to October.

Similar to Nordel, also the Portuguese TSO (REN) publishes every year the Quality of Service report [17], containing detailed information about grid disturbances and fault statistics.

VI. CONCLUSIONS

This paper briefly describes the Portuguese lightning monitoring system and analyses the impact of lightning in the transmission system, presenting a statistical analysis from 2001 to 2008.

Lightning is one of the main causes of disturbances in the power transmission system. In the Portuguese transmission system, it causes on average about 26% of all faults, including OHL and transformers. Faults caused by lightning occur all over Portugal (depending on the lightning location) and during the whole year, although May, August, September and October are the worst months. They are more concentrated in the afternoon and in the early evening period.

In case of lightning, the likelihood of common cause faults increases and as shown in Table I, their amount is significant, considering the total amount of faults caused by lightning in the Portuguese Transmission System. This result strengthens the additional security measures taken by the control room operators, which are influenced by weather conditions and forecast, where a closer look is taken at N-2 contingencies, especially when two lines share the same towers over a long distance (so called double line by UCTE) and the permission to start or continue planned outages are re-evaluated.

As mentioned in international statistics, summer is more severe than winter, regarding faults caused by lightning. However, not only lightning makes summer season the worst for reliability, also forest fires and fog in combination with pollution (which are much more seasonal) may increase significantly the number of faults in summer.

Lightning monitoring systems are widely used. In the Portuguese case, it was possible to conclude that the performance of the network detection was on average 75%, during the study period, regarding only the detection of lightning that cause faults in the transmission system. The percentage of cloud-to-ground strikes detected in Portugal that causes OHL faults in the Portuguese Transmission system was around 0.02%.

The lightning detection information reduces the uncertainty when classifying incidents and improves significantly the effectiveness of operation decisions, thus reducing the risk in terms of disturbances caused by lightning.

The lightning monitoring system data was analysed from 2003 until 2008; in the future, with more data, both in the lightning and incidents data base, the statistical meaning will increase and further conclusions may be drawn. Hence, the outage statistics analysis must continue, because it allows:

- the identification of weak points needing improvements;
- to evaluate the effect of improvements and maintenance activities (the average failure rates per 100km is a key performance indicator to evaluate performance);
- the calculation of expected failure rates based on historical data combined with the actual condition (if lightning is predicted or occurring for operations environment), which can be an input to assess risk;

Finally, in a competitive market environment where reliability (long-term) and operational risk (short-term) are more relevant issues, statistical analyses have gained a new meaning for several areas within a utility and they must include the system's own characteristics.

VII. FUTURE DEVELOPMENTS

This work is part of the development of a risk assessment methodology and further work is already being developed, specifically about risk of lightning. In the detection performance analysis, the fourth step will be done in a more automatic way, as soon as the geographical information system is implemented in the Portuguese TSO. It will contain the geographical data of all towers, allowing the comparison of lightning coordinates with the affected OHL ones.

As future developments, these results, correlated with other design influencing factors and with the lightning strikes density in the area of each tower, per OHL, will be included in a severity matrix of all grid elements.

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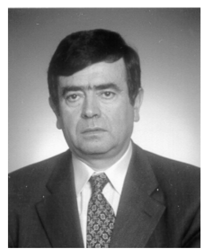
IX. Biographies

Susana A. B. de Almeida was born in Porto in 1977. She received her “Licenciatura” (five-year course) and “Mestrado” (M.Sc) degrees in Electrical Engineering and Computers from Faculdade de Engenharia da Universidade do Porto, Portugal, in 2000 and 2006, respectively. After a short working period in Efacec, she is with Rede Eléctrica Nacional, S.A. since the beginning of 2001. Currently she is working in System Operator Division (for both Grid Operation and Studies and Development Departments) and towards her PhD degree in a part time collaboration with Faculdade de Engenharia da Universidade do Porto, Portugal, also in electrical engineering. She won the REN prize 2005 edition, in 2006, attributed to M.Sc. students’ thesis in the Power Engineering domain. She is a CIGRÉ member and participated in CIGRÉ WG C2.3.

Cristina Loureiro was born in Barcelos in 1984. She received her "Mestrado" (M.Sc) degree in Electrical Engineering and Computers from Faculdade de Engenharia da Universidade do Porto, Portugal, in 2008. She is with Galp Energia since December of 2008 and she is working in Porto Refinery Conversion Project.



Fernando P. Maciel Barbosa received the “Licenciatura” degree (five-year course) in Electrical Engineering from FEUP (Porto University) in 1971 and the M.Sc. and the Ph.D. degrees in Power Systems from UMIST in 1977 and 1979, respectively. His main research interest areas include Power System Reliability and Power System Analysis. He is a full Professor of Electrical and Computer Engineering with FEUP, where he has been since 1971. He has published several research papers in national and international conferences. He is a CIGRÉ member and participates on CIGRÉ WG6, Distribution Systems and Dispersed Generation. He is member “Conselheiro” of the Portuguese professional association of Engineers “Ordem dos Engenheiros” and an IEEE Senior Member.

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