Colombian Total Lightning Detection Network and early detection of failure risks for power systems

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Abstract— This paper presents the deployment of a new total lightning detection network in Colombia. Historic data from 2011 to 2012 are used to reevaluate the lightning parameters such as ground flash density, multiplicity, polarity and others. Lightning detections from LINET are used to develop real time warnings and the opportune detection of failure risks for power lines.

Index Terms—Thunderstorm nowcasting, severe weather recognition, total lightning detection, failure risk.

I. INTRODUCTION

S has been reported by several studies [1-7], the lightning Aphenomenon has its maximum recurrence in tropical regions and its physical parameters present variations compared with those typically observed in other regions of the word. One of the most lightning active zones worldwide is the region that connects the Magdalena River Valley in Colombia with the Catatumbo in Venezuela [8], besides the geographical location, the big mountains in this region originates very lightning dense locations, which are within the highest Ground Flash Densities reported. Some figures show that between 60 and 70% of the failures in the Colombian Power Transmission System are caused by lightning and more than 10000 power distribution transformers are destroyed every year; in addition, it is believed that lightning is one of the most important causes of power quality disturbances, in particular Sags [9]. This paper presents the implementation of the first Total Lightning Detection Network in Colombia based on LINET systems [10] and its application on the power quality improvement, mainly for power distribution lines.

From the viewpoint of power systems design and protection, the variation in time and space of lightning parameters that measure the incidence (e.g. ground flash density, multiplicity) and intensity (e.g. return stroke peak current, polarity) makes that international standards cannot be directly applied in tropical countries such as Colombia. Some standards as IEEE1410 [13] have added some modifications for giving special considerations for tropical zone, however more historic data are required.

On the basis of the Smart Grids concept, the real time information about one of the most recurrent causes of power quality disturbances, the lightning, allows developing smart strategies for significantly reducing the unavailability of power distribution systems. Some examples about the opportune prediction of the failure risk caused by lightning for real power distribution systems in Colombia are shown.

II. VLF/LF LIGHTNING DETECTION SYSTEM LINET

Betz et al [11] presented in 2004 a new VLF/LF (very low frequency/low frequency) lightning detection technique named LINET. The location procedure is based on the known Time Of Arrival (TOA) method, however the improved algorithm is able to provide not only information of the horizontal (latitude, longitude) position of the observed lightning events but also of its vertical position. As described by [12], LINET is sensible to VLF/LF signals from several processes involved on intracloud - IC and cloud to ground - CG events, which present strong currents flowing in relative long channels. For CG strokes (or VLF/LF events) the emissions are supposed to be arisen from the ground strike point. For IC strokes, the VLF/LF channel source points are not precisely defined, however it is expected those are due to vertical channel components. IC and CG strokes can be discriminated when the used baselines between sensors are shorter than about 250 km. Depending on the number of sensors, the baselines and the internal detection thresholds; it is possible to detect very weak strokes down to about 2 kA; due to the limited number of sensors available up to date this goal is reached only in parts of the network.

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III. LINET LIGHTNING DETECTION NETWORK IN COLOMBIA

Ten VLF/LF magnetic field antennas where installed between late 2011 and early 2012, covering more than 80% of the Colombian territory with high detection efficiency and location accuracy. Fig. 1 shows the magnetic loops antenna, GPS and processing units that compose each station. Fig. 2 shows the current total lightning detection network operative in Colombia composed by sensors located at the cities: Bogotá, Tunja, Ibagué, Barrancabermeja, Medellín, Cúcuta, Campo Rubiales, Montería, Barranquilla and Pasto.

Both cloud-to-ground CG and intra-cloud IC flashes are detected, with a reliable discrimination based on the Time of Arrival – TOA technique with a modification for obtaining 3D solutions [10]. In addition, weak strokes with peak currents bellow 10 kA are also identified which represents a high improvement in the detection efficiency. Inside the blue region in Fig. 2 the cloud-to- ground strokes with currents of about 4 kA or higher are reliably detected and in the orange region a detection is reached for cloud-to-ground strokes of 8 kA or higher. Fig. 3 shows the minimum detectable return stroke peak current in all the country.



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Figure 2. Colombian total lightning detection network composed by 10 LINET stations.



Magnetic field and GPS antennas



Local processing unit

Figure 1. Magnetic field antenna, GPS and local processing unit.

The historic lightning detections from September 2011 to December 2012 were used to study and reevaluate the lightning incidence parameters in Colombia. In that period of time the network detected around 12 million flashes.

Next sections present a general characterization of the most important lightning parameters used for engineering applications such as the Ground Flash Density – GFD, Return Stroke Peak Current – I, Multiplicity - M and Polarity - P. In addition, the monthly and hourly lightning incidence and the topographical dependence of the GFD are also given.



Figure 3. Minimum detectable return stroke peak current given in kA.

IV. ANALYSIS OF HISTORIC DATA

A. Ground Flash Density - GFD

Figure 4 presents an updated Ground Flash Density - GFD map for 2012. GFD was computed using areas of 3x3 km. The most lightning active areas are located across the Magdalena River valley, in between the Central and Eastern Andean Mountains, and in the Catatumbo (Venezuela); the most lightning active zones in the country are almost the same found in previous studies [6-9], however, the GFD values for 2012 present a substantial increase with places such as Guaranda and Ayapel that report more than 92 cloud-to-

ground flashes/km²year. According to our knowledge, last values are the highest ever reported by a lightning location system in the tropics.

Map on Fig. 4 also shows a clear dependence of the lightning incidence on the orography of the country. The highest altitude zones of the Central and Eastern Andean Mountains are coincident with very low values of GFD, less than 1 flash/km²year or 0 in many parts. On the other hand, the highest GFD values are found in foothills. Sections bellow presents this dependence in more detail.



Figure 4. Colombian Ground Falsh Density - GFD (Cloud-to-ground flashes/km2/year) measured in Colombia and West Venezuela during 2012

B. Return Stroke Peak Current

The amplitude of the return stroke current is analyzed by considering two cases: the complete lightning data set with currents from 2 kA onwards due to the demonstrated good data quality for weak strokes, and a selection of CG flashes with 15 kA or higher in order to carry out comparisons with previous studies (e.g. [9, 10]).

Fig 5 gives the average flash peak currents measured during 2012 per month. November, December and January exposed the highest average return stroke peak currents varying from 37 to 41 kA when only CG strokes with currents higher than 15 kA where evaluated. The most lightning active months tend to present lower average return stroke currents of about 30 kA. In the case when the complete database is considered, the maximum average currents vary from 30 to 35 kA and the lowest ones about 17 kA.



Figure 5. Average return stroke peak currents given by months.

C. Multiplicity

Approximately 66% of total CG flashes have multiplicity equal to 1 and 91% has less than 4. Only 38 flashes had more than 20 subsequent strokes; one flash had a maximum of 35 for 2012. Figure 6 gives the number of flashes as a function of the multiplicity.



Figure 6. Multiplicity of negative and positive CG flashes in the highest lightning detection efficiency area of the network during 2012.

D. Monthly and hourly variation

Previous studies [1-7] reported that the central region of Colombia presents a bimodal behavior with maximum lightning incidence in April, May, October and November, whereas the north coast has a monomodal tend with maximum lightning incidence in June, July and August. Historic data from 2012 exposes the behavior shown in Figure 7. for all regions in Colombia. During the stormiest months, such as April, May and September, up to 900.000 flashes are detected.

In general more than 70% of all CG flashes detected presented negative currents. Some months such as May and July exposed a little increased incidence of positive flashes with percentages of 38 and 35%, respectively. Some specific locations presented predominant incidence of positive flashes during some months, however these aspects will be addressed in further work.



Figure 7. Monthly variation of the number of flashes

Figure 8. gives the number of flashes detected as a function of the hour, in local time. Most of the flashes are detected from 17:00 to 02:00 h. The minimum lightning incidence is observed from 08:00 to 13:00 h. Data also showed that mountainous zones commonly present short-lived storms during the afternoon, whereas the lowlands and large valleys exposes long-lived and widespread storms lasting until dawn.



Figure 8. Hourly variation of the number of flashes

E. Dependence on the terrain altitude

In addition, the effects of the topography on lightning incidence were initially studied in the central Colombian mountainous regions with altitudes from 300 to 4300 msl. Very few examinations are available in the world for the effects of the altitude on the lightning incidence [10, 11] and any investigation has been carried out in a place with such wide range of altitudes. Figure 9 shows the dependence of the GFD on the altitude; the most lightning active zones are located from 500 to 1500 msl and the minimum GFD values are found at altitudes higher than 2500 msl.



Figure 9. Ground Flash Density – GFD (Cloud-to-ground flashes/km²/year) as a function of the altitude in Colombia.

Historic data also shows a general increase of the GFD values when comparing the 2012 results with those for previous studies from approximately a decade ago. The improvement in the lightning detection technology, with high detection efficiency, is in part the cause; however, based on the analysis of all previous studies with different measurement techniques in Colombia, it is also noted that the lightning activity in the country has really increased during last years.

V. ON THE EARLY IDENTIFICATION OF POWER LINES FAILURE RISKS

As has been discussed by several authors [10-12], the good quality lightning detection represents very valuable information for storm cells identification, recognition of severe weather and thunderstorms nowcasting. Commonly these kinds of data are used for implementing lightning warning systems for people safety; in this case, it was studied how to develop lightning warning method focused on the direct forecast of a failure in a power system.

A real power distribution network, with 90 km approximately and located in the Llanos Orientales of Colombia, was used as experimental system. From June 2011 and July 2012, nine outage episodes caused by lightning were reported. Figure 10. shows the storm episode on 17 October 2011 when a power outage was reported. The studied failure episodes are summarized in Table I.



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Figure 10. Lightning incidence on the distribution power system during 17 october 2011. Colored dots denote CG and IC lightning locations. The solid black line gives the path of the power distribution network.

Warnings were triggered by using alarm criteria based on the total lightning rates (CG and IC strokes/min). As it was expected, when warnings were triggered with 1 stroke/min, all outages were correctly warned, however 68% of the total alarms were false. The higher stroke rate used the smaller false alarm number; nonetheless, failures to warn (outage without a previous alarm) could also happen with high stroke rates. When 5 strokes/min were used for triggering warnings, 100% of outages were correctly warned and only in 39% of alarms close strokes were detected but there were not outage. Table I gives the warning trigger time, outage time and the dwell time for the nine episodes. Lead times vary from 12 to 49 min with an average value of 32 min.

TABLE I			
OUTAGE EVENTS AND WARNING TIMES			
Outage Date	Warning trigger time	Outage time	Lead time
	(local time)	(local time)	(min)
03/10/2011	15:28:07	15:54:51	27
12/10/2011	15:39:08	16:18:29	39
12/10/2011	15:39:08	16:28:16	49
17/10/2011	14:14:14	14:51:24	37
08/11/2011	20:36:52	20:56:11	19
30/11/2011	22:38:58	23:20:23	41
09/04/2012	13:09:33	13:21:19	12
09/04/2012	13:09:33	13:27:20	18
21/05/2012	01:19:06	02:01:38	43

As an example, Figure 11. gives the stroke rate measured during the storm episode on 3 October 2011, when a power outage was reported. The storm reached up to 90 strokes per minute in an area 2800 km² (area covered by the power network); at 15:28 the storm reached 5 strokes/min inside the monitored area and the alarm was triggered; at 15:54 the power interruption was detected. From the alarm time to the outage time 27 min passed, enough time to take preventive actions.



Figure 11. Storm episode on 3 october 2011 and, warning triggering and power line failure times.

VI. CONCLUSIONS

Historic data of the Colombian total lightning detection system, during its first operation year, are presented. Good quality data with high detection efficiency and location accuracy allowed evaluating lightning parameters in the central and north regions of the country. Weak strokes with currents as low as about 2 kA can be detected in the highest detection efficiency zone.

The most lightning active zones were found almost at the same regions reported in previous studies, such as [5-7], however, very high ground flash density values were found in many places, with magnitudes up to 92 flashes/km²year; according to our knowledge, those values are the highest measured by a lightning detection network in the tropics.

General results about return stroke peak current, multiplicity, monthly and hourly variations and the dependence on altitude of the lightning activity were given. The highest average return stroke peak current of 41.3 kA was observed during December. Around 66% of CG flashes had only one stroke (multiplicity = 1), last result agrees studies carried out in other countries [14].

Thanks to the orography of Colombia, it was possible to study how the mountains affect the lightning activity. The highest ground flash densities were found in regions at altitudes from 500 to 1500 msl; the observation carried out at altitudes up to 4500 msl showed lower ground flash densities for higher altitudes. High quality lightning detection is worth to develop methodologies focused on the early thunderstorm detection. In this paper the early detection of lightning risks for power lines, was explored. Historic data about outages of a real power line and lightning were used for evaluate outages warning criteria. By using the lightning rates as the alarm criterion, 100% of the outages caused by lightning, presented during one year, were correctly warned. On the other hand, only 39% of the thunderstorm cases when lightning flashes stroke the power line neighborhood, the alarm was trigger without a subsequent outage.

Opportune detection of lightning risks for power systems is a powerful application on the smart grids framework; if adequate preventive actions are developed, such as to increase the strength of power systems during the lightning incidence (e.g. changes of configuration) and to reestablish faster the power service, the power quality levels in Colombia can be greatly improved.

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