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Lightning Characteristics Based on Date Observed with Shanghai Lightning Location System, China

***Abstract**. In this paper, an investigation into cloud-to-ground lightning activity data from the year of 2001 to 2010 collected by Shanghai lightning location system is shown, including the ground flash density maps of Shanghai City and comparison of annual lightning days with thunderstorm days collected by the Shanghai Meteorological Agency. At last, the peak current cumulative distribution of cloud-to-ground flashes is also discussed, which is suggested to be used in the design of transmission line lightning-proof for the Shanghai Municipal Electric Power Company.*

***Streszczenie.** W artykule przedstawiono analizę danych dotyczących liczby wyładowań atmosferycznych doziemnych z lat 2001-2010 w obszarze Szanghaju wraz z mapami i analizą rozkładu czasowego. (**Charakterystyka wyładowań atmosferycznych na podstawie danych systemu lokalizacji wyładowań atmosferycznych Szanghaju w Chinach**)*

Keywords: lightning location system, annual lightning days, ground flash density, peak current cumulative distribution.
Słowa kluczowe: System lokalizacji wyładowań atmosferycznych, gęstość wyładowań atmosferycznych doziemnych, całkowity rozkład prądu szczytowego.

Introduction

Effective risk analysis of faults in power system is the utmost importance in the design of adequate protection measurers. One of the main causes of damage for power system is certainly constituted by lightning. Lots of lightning location systems (LLS) have been installed worldwide to monitor lightning activities, especially the cloud-to ground (CG) flashes, which is a major cause of power interruptions and equipments damage in power systems. Till now, LLS are being operated in many countries and places, including the U.S. [1], U.K. [2], Japan [3], Canada [4], Austria [5], Sweden [6], Israel [7], Saudi Arabia [8], Portugal [9] and China [10, 11]. These systems collect information of lightning location, peak current, number of lightning strokes, and some other useful parameters related.

In China, research institutions began their work on LLS development in the late 1980s [12]. The first commercialized system started to operate in the An-Hui Electric Power Grid on March 30, 1993 [13]. And the Guang-Dong LLS collected more than one million CG lightning flash data during the first three years (1997-1999) [11]. Several studies have been carried out to investigate correlation among thunderstorm days, ground flash density, and transmission-line faults, etc.

In this paper, based on those published literatures [1-13] concentrated on investigation and discussion of CG lightning flash data collected by LLS, an investigation into CG lightning activity data from the year of 2001 to 2010 collected by a lightning detection and data analysis system in the Shanghai City, the business and economy center of China, is presented, corresponding work related may be summarized as follows:

1) Introduction of Shanghai lightning location system (SHLLS).
2) Comparison of lightning days (LDs) acquired from SHLLS with thunderstorm days (TDs) collected by the Shanghai Meteorological Agency (SHMLA).
3) Construction of the ground flash density (GFD) maps of Shanghai City from the database, which contains the information of more than one million flashes.
4) Discussion of the peak current cumulative distribution (PCCD) of CG flashes in Shanghai City and its districts.

This paper is arranged as follows: SHLLS is described in section II. Presentation of LDs map and Comparison of annual LDs with TDs is presented in section III. Section IV shows the GFD maps of Shanghai City. Then, the PCCD of CG flashes are discussed in section V. Section VI concludes the paper.

Shanghai lightning location system

Shanghai is the city located on the southeast fringe of China, borders Jiangsu and Zhejiang Province. It lies between north latitudes 30.67° and 31.88°, and east longitudes 120.85° and 120.20°. The city has an area of 6340.5 km^2 with three main islands named Chongming (CM), Changxing (CX), and Hengsha (HS), which is about 0.06% of the total mainland area. Lightning activities in the city are very violent. Each year, the statistic shows that there are more than 54 thunderstorm days and rainfall lies between 900 mm ~ 12000 mm. Lightning is considered as the single largest cause of faults in electric power transmission and distribution systems in the city [14].

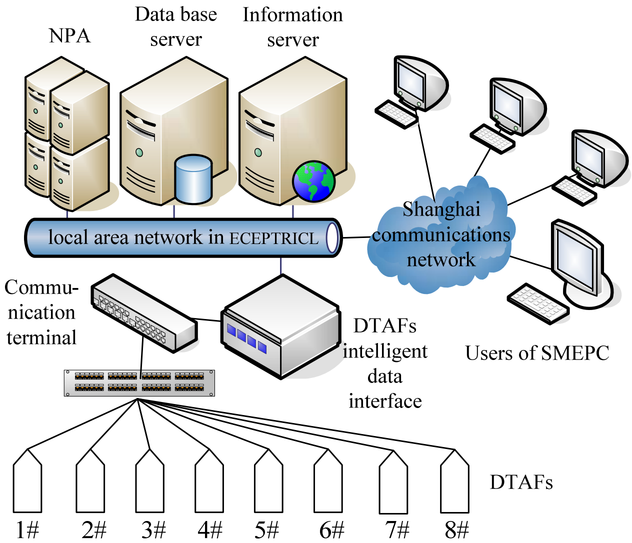

Fig.1. Diagram of the LLS used in SMEPC.

A LLS was put into operation in 1995 in the grid of SMEPC to improve system reliability and minimize system downtime. This system consisted of 4 combined magnetic direction and time-of-arrival finders (DTAFs), one network position analyzer (NPA), and one lightning location information analyzer and display system (see Fig. 1) [15]. In figure 1, the ECEPTRICL is a research unit of Stat Grid Cooperation of China (SGCC) named East China Electric

Power Test & Research Institute Company Limited. To improve its location accuracy and detection efficiency, 4 additional DTAFs were added in March 1999. DTAFs were designed to respond to magnetic fields emitted from return strokes in lightning flashes. Fig. 2 shows the distribution of these 8 DTAFs on the district map of Shanghai City (on the map, CM is Chong-ming district, JD is Jiading district, BS is Bao-shan district, DT is the downtown of Shanghai, PD is Pu-dong district, QP is Qing-pu district, SJ is Song-jiang district, MH is Min-hang district, NH is Nan-hui district, JS is Jin-shan district and FX is Fen-gxian district). The mean separation distance between two adjacent DTAFs is approximately 45 km.

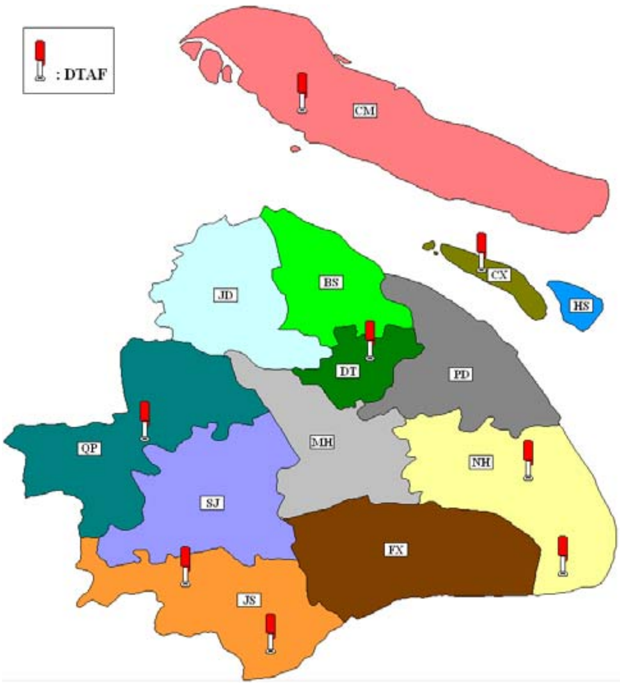

Fig.2. Distribution of DTAFs on the district map of Shanghai.

For using the same commercialized system operating in Guang-Dong and Fu-Jiang Provinces [11, 16], SHLLS also employs a location algorithm derived from magnetic detection and time-of-arrival (TOA) location methods. When a pulse magnetic field is detected by a DFAF, the DFAF will determine both direction to the flash location and TOA of the field. Usually an algorithm of waveform discrimination will be applied first to distinguish the signal of CG return strokes from others (e.g., signals of intercloud lightning strokes, local noises, etc.). This is accomplished by comparing the waveform to a set of preset criteria regarding rise time, pulse width, etc. As long as the signal of CG strokes is recognized, information of the direction, TOA, and signal strength will be sent to NPA. Date from reporting DTAFs will then be processed by NPA to determine the flash location with the location algorithm. There might have been multiple flashes detected during a short period. The flashes, however, are treated as a signal lightning even if they fall in the time window of 1 s [16].

The SHLLS estimates the peak current of a signal lightning using the peak signal amplitudes that are measured at each DTAF. Propagation effects are taken into account by introducing a range-normalized value of the signal strength for each reporting DTAF, using a signal propagation model. The resulting calibrated signal strength is taken to be the maximum over all DTAFs that reported the event and converted to a current using an empirical fit. More information can be found in literature [12, 17].

Presentation of LDs map and comparison of annual LDs with TDs

A. LDs map of Shanghai City from 2001-2010

The number of TDs in a year is an important figure in the design of lightning-proof for transmission lines. Traditionally, this figure is acquired from the SHMLA, which accumulates meteorological data collected at its local observation stations all over the Shanghai city. Alternatively, CG LDs is more popular used in the design and evaluation of lightning-proof for transmission lines. CG LDs can be estimated directly from the lightning data collected by a LLS. In SHLLS, the lightning data (e.g., time, location, polarity and peak current) is stored in its database. The total number of CG LDs in a year, then can be automatically counted.

Fig. 3 shows the LDs map of the Shanghai City using SHLLS data collected from 2001 to 2010 (a 10-year average map). Grades of A, B, C, D and E are used to indicate a district level of lightning activity. The LDs map gives the information that only four districts have LDs more than 40 days (CM is 43.4, QP is 41.1, NH is 40.6 and SJ is 40.7) and almost half of Shanghai City has LDs more than 35 days (JD is 36, PD is 36.1, MH is 35.2, FX is 36.6 and JS is 39.2.). And two islands, CX and HS are in grade A with less than 25 LDs for their small area (CX is 18.7 and HS is 13).

To show the detail information about the distribution of LDs, the LDs map of the Shanghai City in each 0.02°×0.02° mesh from 2001 to 2010 (a 10-year average map) and the number of meshes vs. their corresponding values in the LDs map are shown in Fig. 4 and Fig. 5. The Grades of A, B, C, D and E are also used to indicate a mesh level of lightning activity with more precise values. Fig.5 gives the information corresponding to Fig.4 that the min, max and median values of LDs is 2.478, 7.998 and 5.238 days per 4.24 km^2 in the area of Shanghai City, respectively. For the area with 50 km^2, the median values of LDs can be approximately to be 60 days.

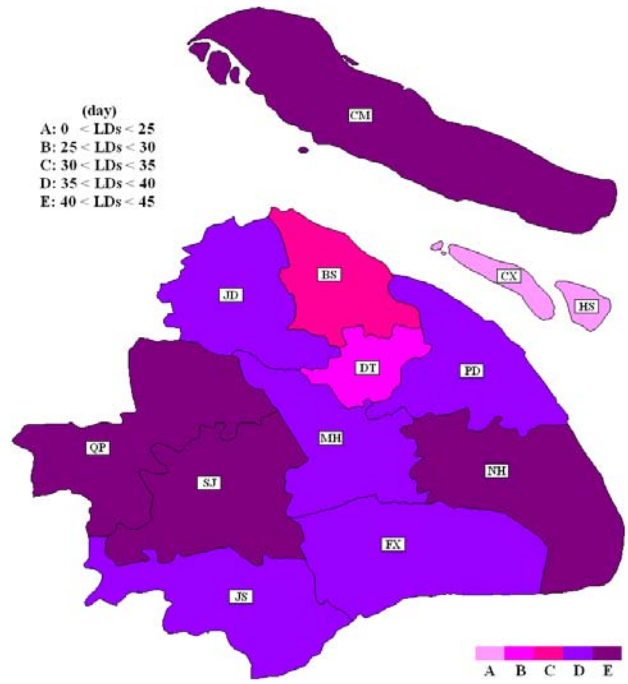

Fig.3.LDs map of Shanghai City using SHLLS data collected from 2001 to 2010 (a 10-year average map).

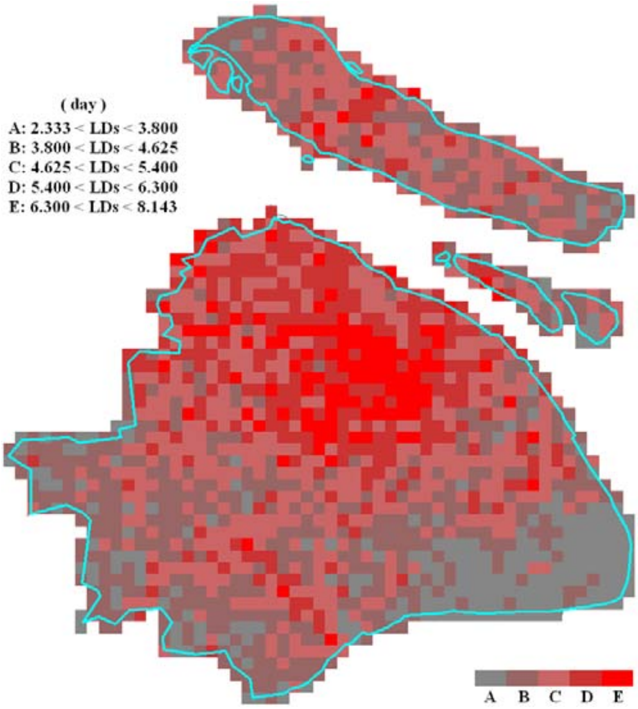

Fig.4. LDs map of Shanghai City in each 0.02°×0.02° mesh (4.24 km^2) from 2001 to 2010 (a 10-year average map).

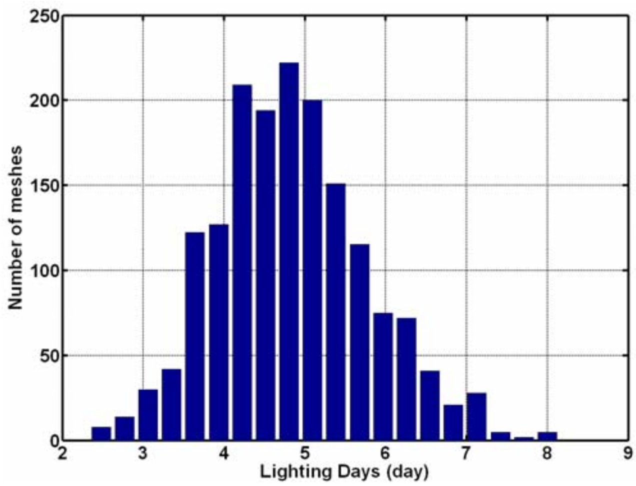

Fig.5. Number of meshes vs. their corresponding values in the LDs map show in Fig. 4.

B. Comparison of annual LDs with TDs

Table I shows the values of TDs obtained from 11 observation stations over 13 districts of the Shanghai City [18]. The district map of Shanghai City is given in Fig. 1 and Fig. 3. For comparison, the values of LDs obtained from SHLLS are presented in the table too. Fig. 6 shows the correlation of these two parameters graphically. It is noted that there is a strong correlation between these two sets of data. The correlation coefficient is found to be 0.81, which is more than the figures given in [11]. It is also noted that the LDs obtained from SHLLS is generally less than the TDs collected by SHMLA. This might be caused by the discrepancy in data collection methods. As stated above, the number of TDs reported by SHMLA is obtained from human observation. An observer may resister a thunderstorm even if the thunderclap comes from an intracloud or intercloud lighting event, which is not counted in SHLLS. Furthermore, the SHLLS may miss small lightning events owing to the imprecise detection efficiency.

Table 1. LDs from SHLLS and TDs from SHMLA

District	Grade in Fig. 3	LDs	TDs
CM	E	43.4	58
BS	C	33.1	48
JD	D	36	54
CX	A	18.7	40
HS	A	13	38
PD	D	36.1	46
DT	B	28	48
QP	E	41.1	58
MH	D	35.2	52
NH	E	40.6	53
SJ	E	40.7	51
FX	D	36.6	51
JS	D	39.2	67

For an electric power system, only the CG lightning can endanger the power device, so if more data are collected in the future, the CG LDs from LLS is more valuable for the insulation design of power systems [11].

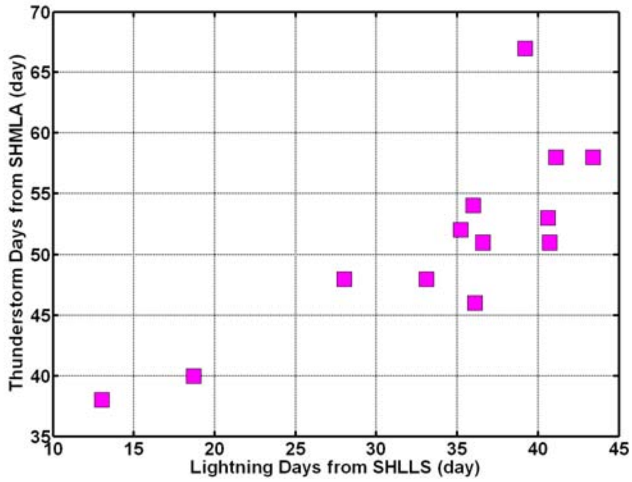

Fig.6. TDs collected in 11 weather stations and LDs collected by SHLLS in the corresponding district form the year of 2001 to 2010.

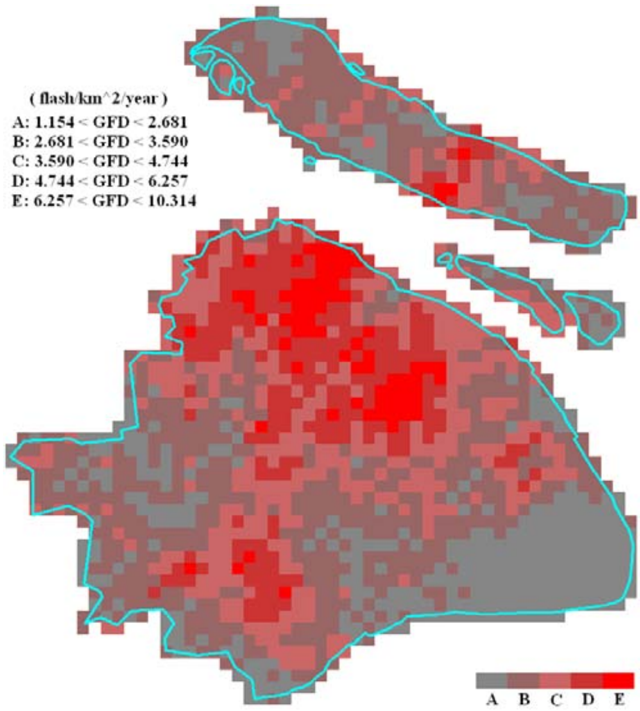

Fig.7. GFD map of the Shanghai City in 0.02°×0.02° mesh (approximately 4.24 km^2) from 2001 to 2010.

Ground flash density map of Shanghai City

Using a LLS, the direct measurement of CG strike locations is feasible and the GFD can be estimated in a more accurate way. Shown in Fig. 7, is a map of the GFD of the first stroke in CG flashes over the Shanghai City during 2001-2010. It was obtained from the SHLLS data in the period of 2001-2010 by counting all CG flashes that occurred in each 0.02° mesh. The measured GFD is not corrected for imperfect detection efficiency 92%.

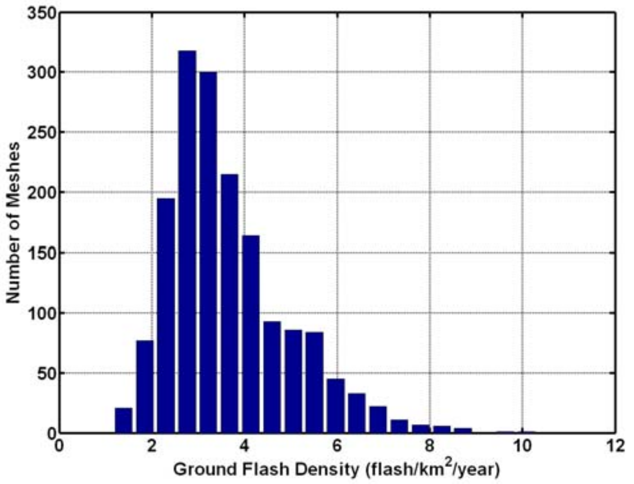

Fig.8. Number of meshes vs. their corresponding values in the GFD map shown in Fig. 7.

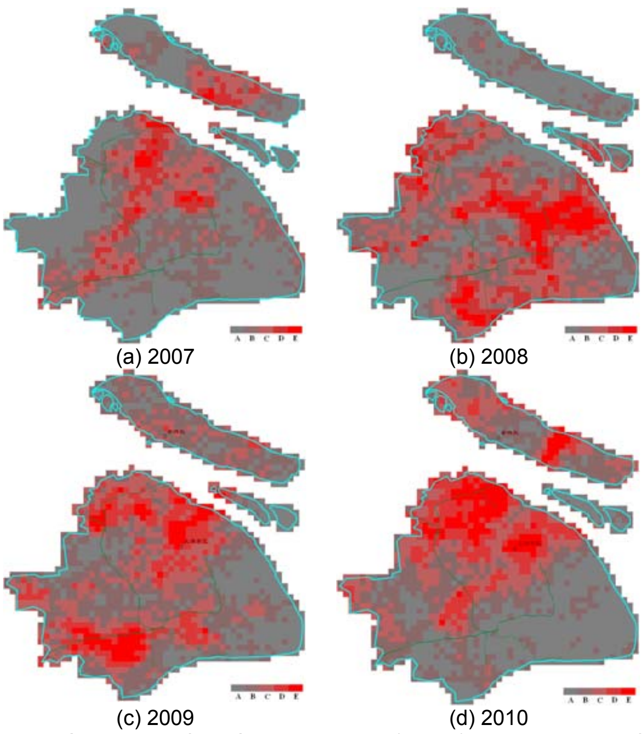

Fig.9. GFD maps of the Shanghai in 0.02°×0.02° mesh with data of 2007, 2008, 2009 and 2010, respectively.

In Fig. 7, grades of A, B, C, D and E are used to indicate a mesh level of lightning activity. The GFD map gives the information that less than 2/5 area of Shanghai City has the GFD of grade E with strong lightning activity, which lies between 6.257 *flash/km*^{2}*/year* and 10.314 *flash/km*^{2}*/year*. Fig. 8 shows the number of meshes vs. their corresponding values in the GFD map shown in Fig. 7. To show more information related to the time-variation of the GFD, Fig. 9 gives the GFD maps of Shanghai City with data collected of the year 2007 to 2010, respectively. The grades of A, B, C, D and E in Fig. 9 have the same values as shown in Fig. 7. These figures give the information that the lightning activity of Shanghai City has a strong randomicity, and all characteristic related to CG flashes should be updated periodically with new data by statistics.

Peak current cumulative distribution

Actually, all LLS including the SHLLS provide current amplitude values of CG strokes that may be affected by several uncertainties, such as ground propagation effects, the empirical formula used and calibration errors. But here, we still show the results inferred form the database constructed by the SHLLS.

The PCCD of all districts of Shanghai City is computed and compared with the curves given by the Chinese standard DL/T 620 [19], IEEE standard [20] and CIGRE [21] shown in Fig. 10 and 11. All present values of the peak current are related to the first stroke. The curve Shanghai shown in Figure 11 is a PCCD computed resorting to the data of all districts of Shanghai City.

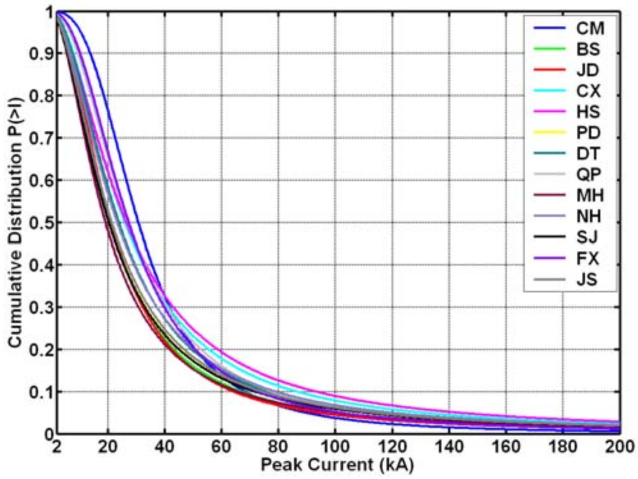

Fig.10. PCCD of all districts of Shanghai City from 2001 to 2010 (a 10-year fitting curve).

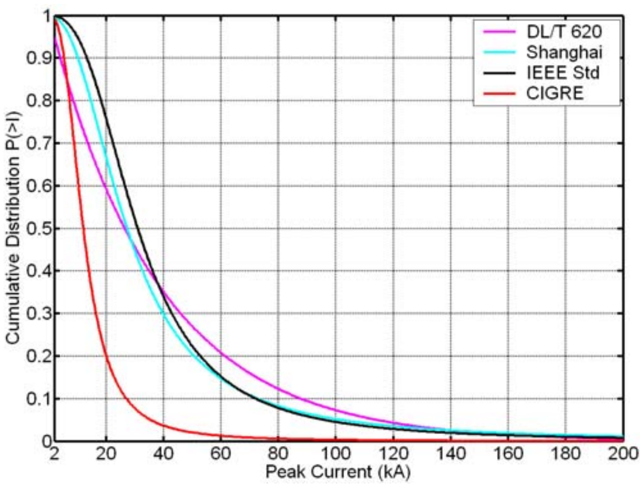

Fig.11. Comparison of PCCD of the whole Shanghai City and other formulas given in literature [19-21].

Along the ten years under study, the curves of all districts of Shanghai City almost have the same characteristic, and the Shanghai curve does match the IEEE Std. curve, but does not match the IEC curve and DL/T 620 so well. According to the IEC curve, only 20% and 5% of first CG strokes have a peak current of lower than 20 kA and 40 kA, respectively. However, for the Shanghai situation, almost 65% and 30% of first CG strokes have a peak current of lower than 20 kA and 40 kA, respectively, and 20% of first CG strokes have a peak current of lower than 50kA.

Conclusions

This paper investigates the CG lightning activities by using the data obtained form a LLS installed in Shanghai City, China. The TDs from SHMLA and LDs from SHLLS in the rim of Shanghai City are presented, and the GFD map and PCCD are shown. The following points have been concluded in this study.

1) TDs maps can be inferred resorting to the database of a LLS. And the correlation is found to be strong between the TDs acquired from SHMLA and LDs inferred from SHLLS.
2) A GFD map of Shanghai City using the database of 10 years is constructed. Therefore, it is possible to evaluate frequency of the lightning activity of subsections allover the Shanghai City.
3) The PCCD of CG strokes of Shanghai City has its own characteristic similar to IEEE Std. curve, but does no match the IEC curve and DL/T 620.
4) With the knowledge of the lightning activity in Shanghai City given in this paper, it is possible to estimate how often the transmission lines are exposed to direct and indirect strikes, and to optimize expenditures when routing, protecting, and/or upgrading new or existing lines.

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