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# A Method to Obtain Lightning Peak Current in Indonesia

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**Abstract:** Lightning is a modern societal problem that continues to increase in line with technological growth. Today's infrastructure is very vulnerable to disturbances caused by weather conditions. The most influential weather phenomenon in this regard is the weather produced by cumulonimbus (CB) clouds. Almost every year, tanks and refineries in Indonesia explode due to lightning strikes. Furthermore, there have been several instances of outages in transmission and distribution lines, as well as lightning-related fatalities in mining areas. Lightning characteristics are widely used as important data for designing lightning protection systems. However, in Indonesia, there is still a need to obtain proper lightning characteristic data. Indonesia is a maritime country located in the tropics, making its geographical conditions highly conducive to the formation of cumulonimbus (CB) clouds. Therefore, this paper presents direct lightning peak-current measurements using magnetic tape, which has been installed in several provinces in Indonesia. The paper reports the local lightning characteristics for these provinces and presents a method for obtaining lightning data. To efficiently collect lightning data on a large scale, we propose a measurement system consisting of a lightning-event counter and magnetic tape. While magnetic tape has been widely used in laboratory testing, this research discusses its application and measurement results in natural lightning conditions in the field. The novel lightning characteristics obtained for several provinces in Indonesia are expected to assist professionals in designing lightning protection systems that match the local lightning characteristics, ultimately minimizing the impact of lightning damage.

**Keywords:** lightning peak current; direct measurement; magnetic tape; tropical area

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## 1. Introduction

Indonesia is a tropical country located at the equator, surrounded by oceans, which means it experiences hot weather throughout the year. Being a maritime nation with numerous islands, Indonesia generates a significant amount of aerosols from sea salt. Additionally, Indonesia's humid climate, abundant forests, rivers, and lakes are the primary factors contributing to the formation of lightning clouds, specifically cumulonimbus clouds (CB clouds). It is widely believed that CB clouds in Indonesia are responsible for a high number of lightning strikes.

Indonesia is naturally influenced by monsoons, with prevailing winds carrying moisture from the Pacific Ocean towards Australia, leading to the rainy season from October to April. Conversely, when the winds reverse their course from Australia to Asia, they bring less moisture from the Indian Ocean, resulting in the dry season, which typically spans from April to October.

Lightning strikes can result in the destruction of building structures, damage to electrical systems [1], tree damage [2], explosions in tank farms [3,4], equipment damage [5], loss of life [6,7], and various other negative impacts [8–13]. Statistics on oil tank failures reveal that from 1995 to 2021, lightning in Indonesia triggered an oil tank fire every single year [14]. In regions like Indonesia that experience frequent and intense lightning activity, traditional tank structures are no longer inherently resilient against the destructive effects of lightning strikes. This means that the standard protective measures built into these tanks are often insufficient to prevent damage when they are subjected to lightning strikes of significant magnitude. In such areas, lightning poses a heightened risk to tank structures due to the elevated likelihood of lightning strikes. The sheer power and energy associated with these strikes can overwhelm the built-in safeguards, potentially leading to structural damage, fires, or other hazardous consequences. Therefore, additional lightning protection measures and strategies beyond the standard safeguards become imperative in these high-risk zones to ensure the safety and integrity of tank structures.

Observing lightning parameters is crucial to reduce the risk of lightning strikes [15–20]. The four main lightning-related parameters include peak current, lightning current steepness, charge of current, and impulse force. It is important to note that the characteristics of lightning in the tropics and subtropics are distinct [21–23]. To design an effective lightning protection system, calculations must take into account local lightning parameters and appropriate lightning characteristics [24–28]. These lightning parameters serve as the foundation for designing lightning protection for equipment and for assessing the potential effects on nearby structures. Among these parameters, lightning current is one of the most critical for analyzing lightning damage and developing lightning protection strategies [29,30].

Several investigations have been conducted in Indonesia using the Lightning Detection System to acquire lightning characteristics. Since 1994, Java Island has been the site for lightning monitoring, utilizing the magnetic direction finder (MDF) method. The median value of lightning current in this area is around 26 kA. [31].

On the other hand, some previous research has presented various measurement results using the time of arrival (TOA) and IMPACT (a combination of TOA and MDF) techniques. TOA and MDF are the most commonly used techniques for geolocating lightning in ground-based lightning stations. Since 1992, a tall tower has been used for investigations conducted on Tangkuban Perahu Mountain in West Java. Since 1995, the Indonesia Lightning Detection System has been in use to monitor lightning activity and collect data on tropical lightning characteristics in Indonesia using the TOA approach. Based on measurement data, it was found that a 50% probability of a lightning incident corresponds to a current of 40 kA [21]. The current study in [32] revealed that the median lightning peak current in West Java province was between 15–19.9 kA when using the IMPACT technique. Similarly, the study in [33] presented median peak current data for Central Java province for the 2018 period, ranging between 15–19.9 kA, using the IMPACT technique. Meanwhile, the study in [34] showed that the median peak current in South Sumatra province ranged from 20–24.9 kA, utilizing the IMPACT technique. Additionally, the study [35] indicated that a peak current of 25–30 kA in Jakarta had a 50% probability of a lightning event when employing the IMPACT technique. All of these previous lightning measurements were conducted using the Lightning Detection System.

The most popular methods for conducting accurate direct measurements of lightning characteristics are instrumented towers and triggered lightning [36–39]. This paper presents a novel direct lightning measurement method that has been applied in Indonesia. The Peak-Current Measurement System (PCM) comprises a lightning-event counter (LEC) and magnetic tape. During the measurement period, more than 80 strokes were recorded, with more than 20 strokes recorded and examined. When comparing the measurement data from the magnetic tape with the lightning peak current data from Indonesia's lightning detection network, JADPEN, no statistically significant differences were found. The study in [36] presented a comparison of the measurement data, which can help in improving both systems. Furthermore, the study in [34] explained that statistical results from the monitoring system can provide better solutions for existing problems. The study in [40] highlighted that the nature of lightning currents can be determined through measurements taken on tall towers.

In Indonesia, a similar system has been employed for the purpose of gauging lightning peak current. This system relies on the Lightning-event counter (LEC), which registers a rising count each time a lightning strike occurs. To analyze this data, magnetic tape records are processed using software called Audacity. The information derived from these measurements serves a valuable role in decision-making regarding maintenance actions for the lightning protection system. Essentially, by monitoring the frequency and intensity of lightning strikes through the LEC and processing this data with Audacity 3.3 software, authorities or facility managers can gain insights into the performance and potential vulnerabilities of their lightning protection infrastructure. This, in turn, enables them to take proactive steps to ensure the safety and reliability of their systems in the face of lightning-related hazards.

This paper aims to propose a method for obtaining lightning peak current through direct measurement and presents lightning characteristics in Indonesia. Additionally, local data from several provinces in Indonesia are also presented.

The rest of the paper is organized as follows. Part II describes the tower scheme and measurement system. Part III explains the calibration of magnetic tape. Part IV describes a method of lightning peak-current measurement. Part V describes the results and discussions, while Part VI explains the conclusion of the research.

## 2. Tower Scheme and Measurement System

This section explains the tower scheme and measurement system employed in this study. The tower comprises an air terminal, double-shielded down conductor (DSDC), measurement system, and an integrated grounding system. DSDC is a specialized shielded cable designed to divert lightning currents away from the structure.

In the upper part of the DSDC, the shield and core of the cable are not connected to each other, as depicted in Figure 1. This configuration ensures that the entire current flows inside the cable. In the lower part of the DSDC, the shield and core of the cable are connected, enabling the measurement of the lightning current by the measurement system. The measurement system consists of a lightning-event counter (LEC) and magnetic tape. This system provides a simple and cost-effective means of collecting lightning data in Indonesia.

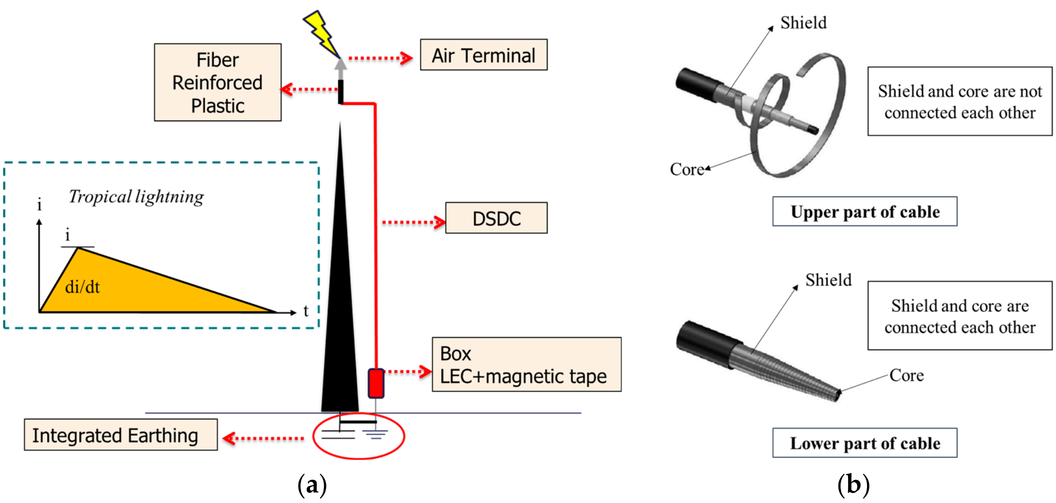



**Figure 1.** The tower scheme: (**a**) component installed in tower, (**b**) illustration of upper part and lower part of cable.

### *2.1. Lightning-Event Counter (LEC)*

The lightning-event counter is utilized to measure the number of lightning strikes within a measurement range of 0.5–200 kA. A study in [41] has demonstrated a positive correlation between LEC data and the Lightning Detection System data.

### 2.2. Magnetic Type

The magnetic tape measures the lightning peak current by detecting the eliminated pre-recorded signal caused by the magnetic field of lightning. It can detect lightning peak currents within the range of 0.5–200 kA. The study in [42] elaborated that lightning current measuring systems should be capable of safely recording lightning currents with amplitudes of up to 200 kA.

This measuring instrument has an accuracy of ±5%. The magnetic tape was installed at the base of the tower using shielded cable, which allows the current to flow from the top of the tower to the ground and triggers the LEC.

## 3. Calibration of Magnetic Tape

An accurate measurement equipment called "magnetic tape" was tested and calibrated in the High Voltage Engineering Laboratory at the Technical University in Munich, Germany, as shown in Figure 2 [21]. This magnetic tape was chosen because it is inexpensive, simple, and can be easily installed in various locations. Another reason for selecting magnetic tape is the nature of the magnetic material, which retains its magnetism effectively and requires a large magnetic field intensity H to demagnetize it.

**Figure 2.** Calibration of magnetic tape.

The basic principle of using magnetic tape as a tool to measure the magnitude of the peak lightning current passing through a conductor is as follows: when there is a flow of lightning current through the conductor, it generates a magnetic field around the conductor. This magnetic field erases the reference signal that was previously recorded on the magnetic tape. The length of this signal erasure is proportional to the amount of current flowing through the conductor. A correlation was established between the length of the eliminated signal and the lightning peak current flowing through the conductor located near the magnetic tape.

An impulse current with a waveform of 8/20 µs, in accordance with the IEC 62305/2010 standard [24], was injected into the conductor where the magnetic tape was installed. The purpose of this step was to calibrate the magnetic tape measurement. The range of injected impulse current ranged from 2 kA to 100 kA. The lightning peak current was measured using a pulse-current transformer, as shown in Figure 3. Each current level resulted in erasures of the pre-recorded signal on the magnetic tape with different lengths.

IEC type I (Normal), IEC type II (Chrome) and IEC type IV (Metal/Ferro) were used and compared.

Several impulse currents were injected to calibrate three types of magnetic tape, as detailed in Table 1. These various types of magnetic tape exhibited unique responses to the lightning impulse current. Typically, a standard reference signal used is a sinusoidal signal with a frequency range of 300–1000 Hz, as this frequency range offers an optimal signal removal reading on an oscilloscope or recording device. Consequently, the selected tapes demonstrated the best signal response at frequencies of 315 Hz and 1000 Hz. Therefore, the pre-recorded signals on the magnetic tape were set to 315 Hz and 1000 Hz. As depicted in Figures 4 and 5, the lightning impulse current induced the erasure of this pre-recorded signal. Importantly, the duration of signal erasure on the magnetic tape was directly proportional to the magnitude of the lightning current flowing through the conductor. Figure 6 displays the calibration results for the standard magnetic tape, which had initially been loaded with a 315 Hz signal.


**Figure 3.** Pulse current transformer.

**Table 1.** Calibration of the magnetic tape involved injecting impulse current in the High Voltage Engineering Laboratory at the Technical University in Munich.

| Peak Current (kA) | Frequency (Hz) | Length of Eliminated Signal (cm) | | |
|---|---|---|---|---|
| | | Chrome | Normal | Ferro |
| 2.12 | 315 | - | 1.02 | 1.23 |
| | 1000 | - | 1.16 | 1.25 |
| 3.18 | 315 | 0.83 | 1.54 | 1.70 |
| | 1000 | 0.92 | 1.80 | 2.13 |
| 5.14 | 315 | 1.80 | 2.58 | 2.79 |
| | 1000 | 1.66 | 2.68 | 2.84 |
| 7.2 | 315 | 2.32 | 3.13 | 3.27 |
| | 1000 | 2.42 | 3.29 | 3.65 |
| 9.5 | 315 | 2.84 | 3.65 | 3.98 |
| | 1000 | 3.32 | 4.12 | 4.36 |
| 14.7 | 315 | 3.7 | 4.65 | 4.95 |
| | 1000 | 3.8 | 5.62 | 5.85 |
| 20 | 315 | 5.02 | 5.95 | 6.25 |
| | 1000 | 4.81 | 6.78 | 7.12 |
| 21.1 | 315 | 5.76 | 6.59 | 7.25 |
| | 1000 | 5.31 | 7.63 | 7.96 |
| 30 | 315 | 6.85 | 7.92 | 8.34 |
| | 1000 | 6.61 | 8.82 | 9.48 |
| 45.5 | 315 | 9.50 | 10.90 | 12.06 |
| | 1000 | 9.65 | 12.60 | 13.50 |
| 61 | 315 | 12.3 | 14 | 15.30 |
| | 1000 | 12.34 | 15.50 | 16.80 |
| 70 | 315 | 14.04 | 15.10 | 16.20 |
| | 1000 | 13 | 16.40 | 18.53 |
| 80 | 315 | 15.20 | 15.90 | 17.73 |
| | 1000 | 15.23 | 18.62 | 19.95 |
| 88.6 | 315 | 17.50 | 18.50 | 20 |
| | 1000 | 16.5 | 22 | 24.50 |
| 90.3 | 315 | 19 | 19.58 | 21.52 |
| | 1000 | 20.34 | 25.17 | 29.06 |
| 100.3 | 315 | 21.80 | 23.65 | 25.97 |
| | 1000 | 22.28 | 27.11 | 32.51 |

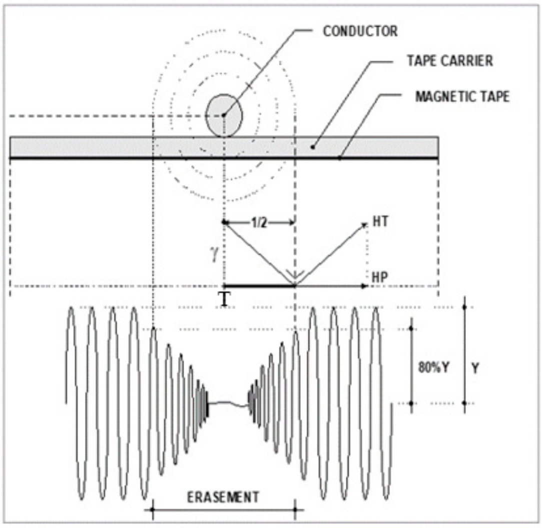



**Figure 4.** The eliminated pre-recorded signal. HP is magnetic field removal reference signal, HT is magnetic field at point T, $\gamma$ is tape carrier thickness or acrylic, and Y is peak of signal magnitude.

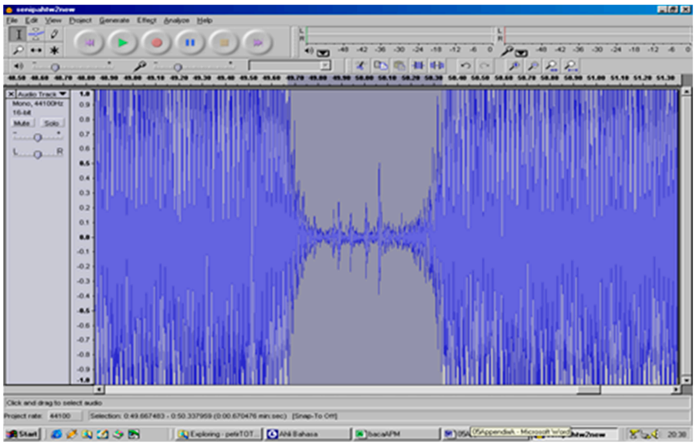


**Figure 5.** The eliminated pre–recorded signal view in Audacity software.

The correlation of peak impulse current with the length of eliminated 315 Hz sinusoidal signal were expressed with the following equation:

IEC type IV (Ferro):

$$I = 0.55 + 1.05l + 0.35l^2 - 0.01l^3, \quad (1)$$

IEC type II (Chrome):

$$I = 1.28 + 1.98l + 0.39l^2 - 0.01l^3, \quad (2)$$

IEC type I (Normal):

$$I = 0.86 + 0.88l + 0.44l^2 - 0.01l^3 \quad (3)$$

Ferromagnetic tape is capable of detecting lightning currents as low as 2 kA. Chrome magnetic tape, on the other hand, can measure higher lightning currents than the other two types. Normal magnetic tape provides a moderate measurement capability for assessing natural lightning currents in field applications.

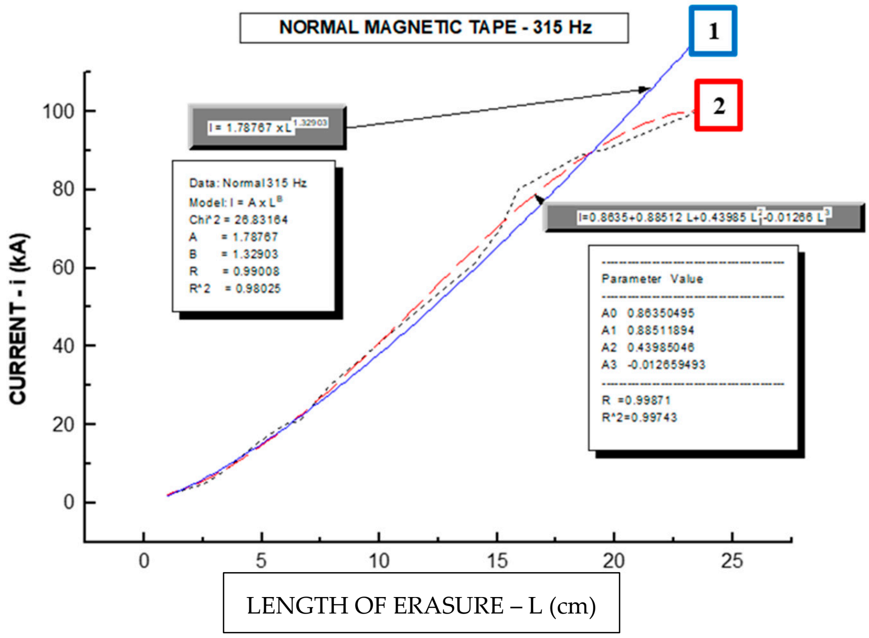
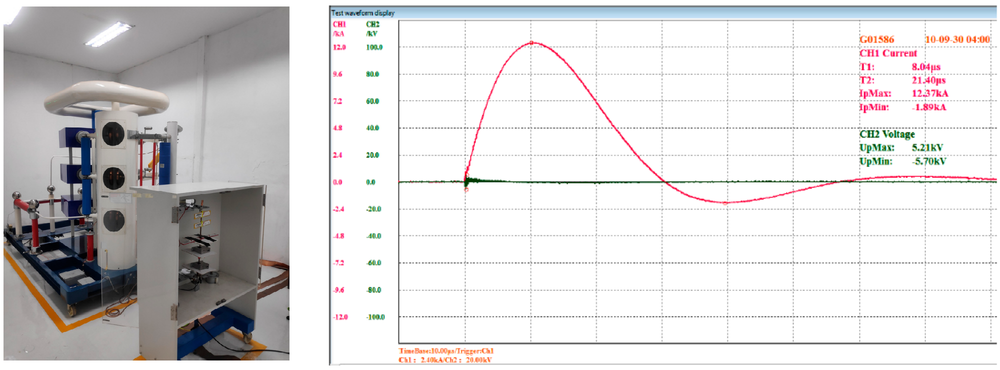



**Figure 6.** The calibration of normal magnetic tape–315 Hz. Graph line 1 in red shows the linear regression, while graph line 2 in blue line shows the polynomial regression [21].

To evaluate the effectiveness, accuracy, and precision of the applied method, performance tests were conducted in a high-voltage laboratory in Indonesia, as illustrated in Figure 7. The magnetic tape and lightning-event counter were installed inside a grounded panel. Pearson current transformers were employed to detect 8/20 µs impulse currents generated by the surge generators.




(**a**) (**b**)

**Figure 7.** Performance test in a high voltage laboratory in Indonesia: (**a**) equipment setup (**b**) injected surge current in monitoring system.

Direct measurements using magnetic tape were conducted on Tangkuban Perahu Mountain. The lightning data obtained from the magnetic tape was also verified and compared with data from the lightning detection system (LDS). The study [21] revealed that the lightning peak current derived from this measurement closely matched the values recorded by the lightning detection system (LDS) data. The coefficient of correlation between the magnetic tape data and LDS data is 0.97, indicating a strong positive correlation.

## 4. Method of Lightning Peak-Current Measurement

A simplified method for conducting this measurement is presented in Figure 8. Magnetic tapes were previously installed in the lightning protection system's conductor. The magnetic tape is securely clamped using acrylic to protect it from damage caused by heat and weather. The lower limit of measurable peak lightning current in magnetic tapes is influenced by the type of magnetic material used and the thickness of the acrylic insulation. Both the magnetic tape and LEC are firmly placed within a grounded panel box. This setup is designed to prevent induction caused by indirect lightning strikes, which could potentially affect the reading and the erasing of signals on the magnetic tape.

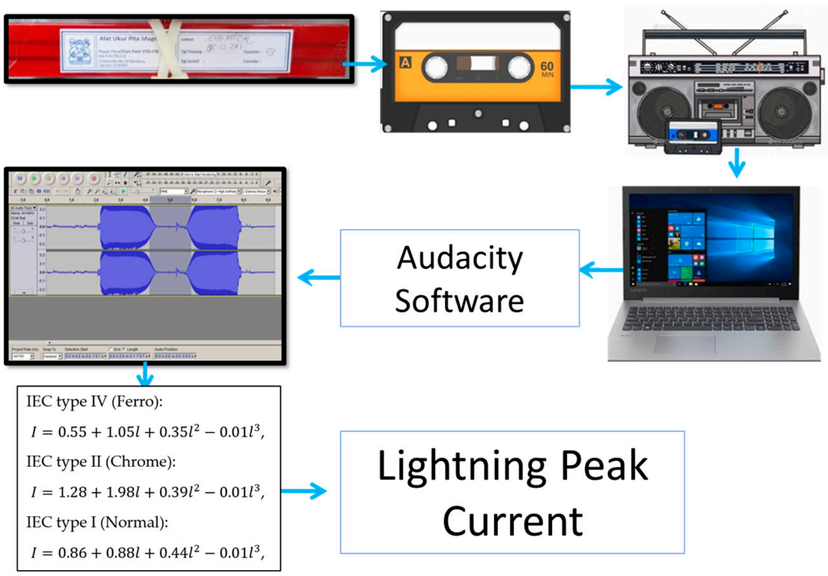



**Figure 8.** Flowchart of the proposed methodology.

To monitor the occurrence of lightning strikes, a lightning-event counter (LEC) is installed to record the number of lightning strikes. The presence of a single incremental reading on the LEC indicates the need to replace the previously installed magnetic tape with a new one. The magnetic tape is then inserted into a cassette so that it can be read using a tape player. The tape player operates at a speed of 4.76 cm/s. Utilizing Audacity software, the length of the eliminated signal can be detected and measured. Subsequently, the value of the lightning peak current is calculated using Equations (1)–(3).

The measurement system under discussion has been implemented across a diverse range of tall and elevated structures. These installations encompass various types of constructions, such as freestanding masts, refinery facilities, transmission towers, tank storage areas, telecommunication towers, and tall buildings. These deployments have not been limited to specific types of structures but have extended to a wide variety of high-elevation installations. Furthermore, these measurement systems have been strategically positioned in areas characterized by a high frequency of lightning strikes. This study provides visual representations to illustrate the geographical distribution of these systems, emphasizing their locations in regions known for high lightning activity. As part of future research endeavors, the system can be utilized to gather data on the frequency of lightning strikes. Researchers can investigate how variables such as the height of structures, the type of construction, and the geographic location (whether on land or near bodies of water such as oceans) impact the likelihood and intensity of lightning strikes. This data could provide valuable insights into lightning risk assessment and help inform the design and implementation of lightning protection measures for structures of varying types and in different geographical contexts.

The 150 kV transmission tower depicted in Figure 9 is located in Sumbawa, an area known for a high incidence of outages caused by lightning. The measurement system has been installed at the base of the lightning protection system to assess the frequency of lightning strikes on this transmission tower. Data collected from the magnetic tape can serve as a valuable reference for conducting maintenance on lightning protection systems.

**Figure 9.** Installation of measurement system in transmission tower.

As shown in Figures 10 and 11, these measurement systems have been installed on stack and refinery structures. For three months since its installation in January 2017, 17 lightning strikes have been recorded on the lightning-event counter (LEC). These stack and refinery structures are located in Central Java, an area known for its very high lightning-strike activity. To date, more than 40 lightning strikes have been recorded on these structures.

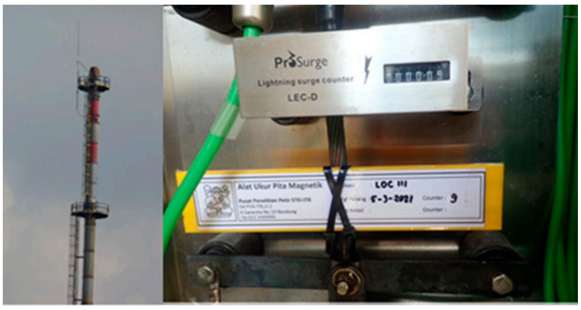



**Figure 10.** Installation of measurement system in stack structure.

**Figure 11.** Installation of measurement system in refinery structure.

Figure 12 depicts the measurement systems installed on telecommunications towers in Depok and Bogor, which commenced in 2013. Over the course of a year within the measurement period, these systems recorded more than 20 instances of lightning strikes, as documented by both the lightning-event counter (LEC) and the magnetic tape. Bogor is renowned for its exceptionally frequent thunderstorm occurrences, earning it the distinction of being not only the city with the highest number of thunder days in Indonesia but also one of the top-ranking cities globally in this regard. In contrast, Depok, while not experiencing thunderstorms as frequently as Bogor, is noteworthy for recording lightning activity with the highest peak current in Indonesia. This information underscores the significance of these measurement systems in monitoring and comprehending lightning patterns and incidents in these specific regions.

**Figure 12.** Installation of measurement system in a telecommunication tower.

Figure 13 depicts measurement systems on air traffic controllers in Sorowako, which marks a significant development initiated in 2019. This specific location has garnered attention due to its notable and recurring issue: a high incidence of equipment damage resulting from lightning strikes. In this context, the installation of measurement systems serves a crucial role. These systems are instrumental in tracking and assessing lightning activity in the area, offering valuable data that can aid in understanding the extent and frequency of lightning-related equipment damage. By monitoring lightning strikes and their impact, it becomes possible to develop more effective lightning protection measures and enhance the resilience of critical equipment in this vital facility, ultimately ensuring safer and more reliable air traffic control operations in Sorowako.

**Figure 13.** Installation of measurement system in tower near Air Traffic Controller.

Figure 14 depicts a cathedral located in Jakarta that has been grappling with a recurring issue: a significant number of lightning disturbances that affect the electronic equipment and sound system within the church premises. This situation necessitated the installation of a specialized measurement system as part of the lightning protection system implemented in the church.

Since the installation of the measurement system, it has actively recorded the peak values of lightning currents in this area. Remarkably, these recorded peak values have reached as high as 22 kA (kiloamperes). These exceptionally high peak currents vividly illustrate the magnitude and intensity of lightning strikes that the church frequently experiences. Equipped with this valuable data, the church can make more informed decisions to protect its equipment and systems, ensuring their continued operation and preventing damage during thunderstorms and lightning events.

Figure 15 depicts a measurement system that has been strategically installed at an offshore facility, serving a pivotal role in comprehending the characteristics of lightning peak currents occurring in oceanic regions. This initiative aims to gather essential data regarding lightning strikes in the maritime environment, which can differ significantly from those experienced on the mainland.

**Figure 14.** Installation of measurement system in a church.

**Figure 15.** Installation of measurement system at an offshore facility.

This long-term endeavor serves a dual purpose. Firstly, it enables the detailed mapping of lightning peak currents in oceanic areas, offering insights into the specific nature of lightning occurrences at sea. By collecting such data, researchers and experts can gain a deeper understanding of the unique challenges posed by lightning in maritime regions.

Secondly, over time, the data acquired from offshore measurement systems can be systematically compared with the characteristics of lightning peak currents observed on the mainland. This comparative analysis has the potential to yield valuable insights into the variations in lightning behavior between coastal and inland areas. It can also assist in enhancing safety measures and lightning protection strategies for both offshore facilities and those on the mainland, contributing to improved safety standards and overall preparedness in the face of lightning-related challenges.

Figure 16 depicts a free-standing mast protection system installed to protect geothermal power plant facilities. To obtain data related to the characteristics of the local lightning peak current in this area, a measurement system was installed at the bottom of the lightning protection system.

In areas with tank facilities, the risk of lightning strikes causing fires and explosions is notably high. A specialized measurement system has been strategically deployed, as depicted in Figure 17. This installation serves a critical purpose in understanding and mitigating the risks associated with lightning-related disturbances. By acquiring data on the peak current characteristics of lightning in these specific areas, it becomes possible to tailor and design a lightning protection system that is precisely suited to the local lightning conditions. This approach ensures that the protective measures implemented are optimized to address the unique challenges posed by lightning strikes in this environment.

The data gathered from this measurement system plays a pivotal role in the design and implementation of an effective lightning protection system. It helps engineers and safety experts make informed decisions regarding the selection of lightning protection measures, grounding systems, and surge protection devices. Ultimately, this proactive approach minimizes the risk of lightning-induced fires and explosions, safeguarding both personnel and valuable assets within the tank facility.

**Figure 16.** Installation of free-standing mast with measurement system in a geothermal power plant facility.


**Figure 17.** Installation of measurement system in tank area.

The measurement system installation is also conducted on critical structures, including the Palembang Light Rail Transit (LRT) station, as depicted in Figure 18. Situated in a wind reversal area, Palembang experiences relatively high lightning activity. The characteristics of lightning current in Palembang holds great significance for enhancing the lightning protection system within the LRT system.

**Figure 18.** Installation of measurement system in light rail transit station.

In open mining areas where mobility is essential, a mobile lightning protection system is a necessity, allowing personnel and equipment to move around safely while working. To fully implement the mobile LPS system, it is possible to install a magnetic tape and LEC measurement system, as illustrated in Figure 19.

When there is lightning strike, the LEC number increases. The magnetic tape is replaced with a new one, and the old magnetic tape must be read using Audacity software.

The lightning peak current reading result for the Bogor Telecommunication Tower utilizing Audacity program is displayed in Figure 20. The length of the eliminated signal above indicates that the highest lightning current is 12.59 kA.

**Figure 19.** Installation of measurement system in a mobile lightning protection system for a mining area.

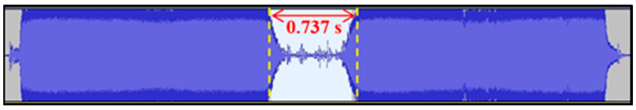



**Figure 20.** Lightning peak-current measurement result in Telecommunication Tower, Bogor.

The lightning peak current reading for the Palembang Tower utilizing Audacity software is displayed in Figure 21. The lightning peak current is 21.6 kA based on the length of the eliminated signal.

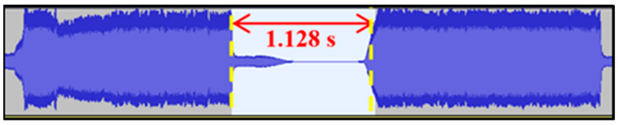



**Figure 21.** Lightning peak-current measurement result in Tower, Palembang.

The results of the Audacity software's lightning peak current reading for Jakarta's Cathedral Church are shown in Figure 22. The lightning peak current is 11.35 kA based on the length of the eliminated signal.

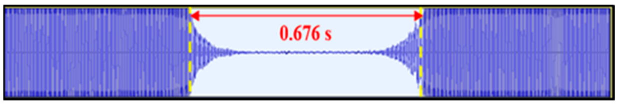



**Figure 22.** Lightning peak-current measurement result in Cathedral Church, Jakarta.

The lightning peak current reading for the Pontianak Tower using Audacity software is displayed in Figure 23. The lightning peak current is 84.8 kA based on the length of the eliminated signal.

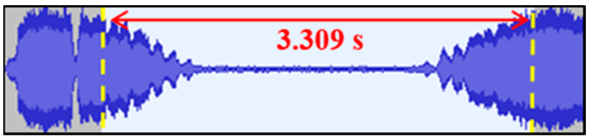



**Figure 23.** Lightning peak-current measurement result in Tower, Pontianak.

The lightning peak current reading obtained with Audacity software for Stack in Cilacap is shown in Figure 24. The lightning peak current is 31.3 kA based on the length of the eliminated signal.

The lightning peak current reading for the Depok Telecommunication Tower using Audacity software is shown in Figure 25. According to the length of erased signal, the peak lightning current is 8.4 kA.

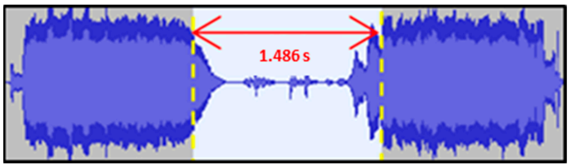



**Figure 24.** Lightning peak-current measurement result in Stack, Cilacap.

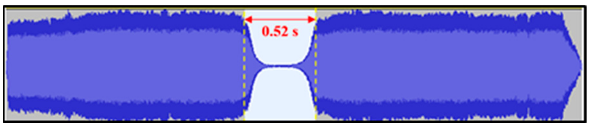



**Figure 25.** Lightning peak-current measurement result in Telecommunication Tower, Depok.

## 5. Results and Discussion

Figure 26 provides a comprehensive visual representation of the results obtained from measuring lightning peak currents across several provinces in Indonesia. These provinces encompass South Sumatra, Riau Islands, DKI Jakarta (the metropolitan area), West Java, Central Java, West Kalimantan, Central Kalimantan, East Kalimantan, and South Sulawesi. Contained within this figure is a dataset comprising 120 measurements of lightning peak currents. Each measurement corresponds to a specific occurrence of a lightning event within one of these provinces. These measurements yield valuable insights into the varied lightning characteristics and levels of activity found across these regions. This information is of paramount importance when it comes to crafting effective lightning protection systems and safety measures tailored to the unique conditions prevailing in each locality.

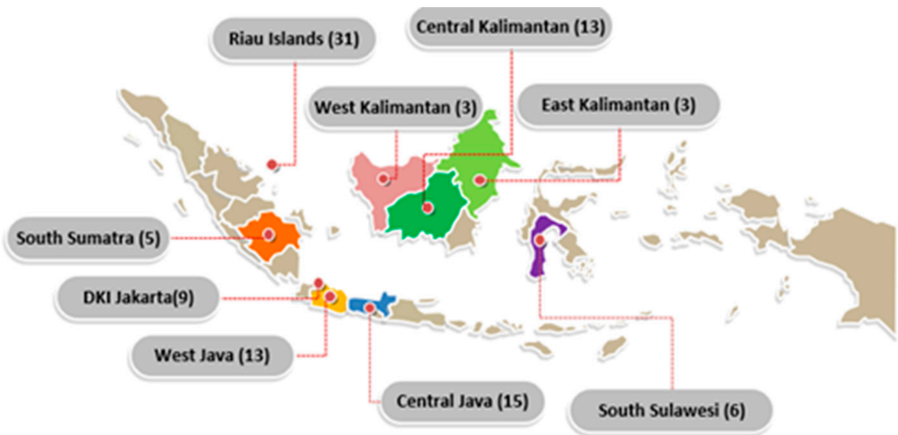



**Figure 26.** Lightning peak-current measurement results for several provinces in Indonesia.

Based on these measurements, the local lightning characteristics of some provinces can be obtained.

### *5.1. South Sumatra*

Some measurements are conducted in South Sumatra as shown in Table 2.

**Table 2.** Lightning peak-current measurement in South Sumatra.

| No. | Location | Date | Peak Current (kA) |
|---|---|---|---|
| 1 | WTP, Palembang | 12 October 2018 | 55.3 |
| 2 | WTP, Palembang | 10 December 2018 | 34 |
| 3 | Gunung Megang Station, Muara Enim | 5 August 2020 | 69 |
| 4 | TO2ME, Palembang | 20 March 2020 | 74.5 |
| 5 | Tower, Palembang | 29 August 2020 | 19.9 |

**Table 2.** *Cont.*

| No. | Location | Date | Peak Current (kA) |
|---|---|---|---|
| 6 | LRT Station, Palembang | 18 March 2021 | 13.4 |
| 7 | LRT Station, Palembang | 18 March 2021 | 11.9 |
| 8 | LRT Station, Palembang | 18 March 2021 | 14.8 |
| 9 | LRT Station, Palembang | 18 March 2021 | 28.83 |
| 10 | LRT Station, Palembang | 19 March 2021 | 12 |
| 11 | LRT Station, Palembang | 3 June 2022 | 11.9 |
| 12 | LRT Station, Palembang | 3 June 2022 | 8.2 |

Figure 27 shows the probability versus lightning peak-current statistics for South Sumatra. The statistics indicate a 50% probability level of a lightning peak current of 21 kA. The mean and median of the measurement data are 29.4 kA and 17.4 kA, respectively.

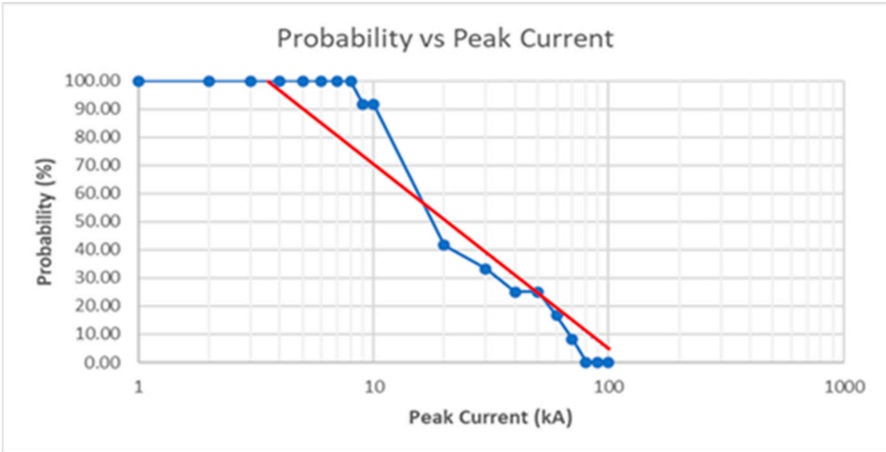



**Figure 27.** Probability vs. Lightning Peak-Current Statistics in South Sumatra. The graph line in red shows the probability vs. lightning peak current plot, while graph line in blue line shows the lightning data plot.

*5.2. DKI Jakarta*

Some measurements are conducted in DKI Jakarta as shown in Table 3.

**Table 3.** Lightning peak-current measurement in DKI Jakarta.

| No. | Location | Date | Peak Current (kA) |
|---|---|---|---|
| 1 | CNOOC South Wanda, Kepulauan Seribu | 24 March 2017 | 25.03 |
| 2 | Waskita Tower, Jakarta | 25 April 2017 | 3.4 |
| 3 | Katedral Church, Jakarta | 5 August 2020 | 12.5 |
| 4 | Job Camp Area, Jakarta | 15 April 2018 | 10.04 |
| 5 | Katedral Church, Jakarta | 23 November 2018 | 22.10 |
| 6 | Katedra Church, Jakarta | 23 November 2018 | 13.7 |
| 7 | Katedra Church, Jakarta | 14 March 2020 | 15.4 |
| 8 | Rama Delta Tower, Kepulauan Seribu | 2 May 2020 | 33.23 |
| 9 | House, Jakarta | 1 January 2021 | 23.97 |
| 10 | Jakarta (Tower Manggarai) | 30 May 2022 | 62.5 |

Figure 28 presents the probability versus lightning peak-current statistics for DKI Jakarta. The statistics reveal a lightning peak current of 18 kA at a 50% probability level. The mean and median of the measurement data stand at 22.2 kA and 18.8 kA, respectively.

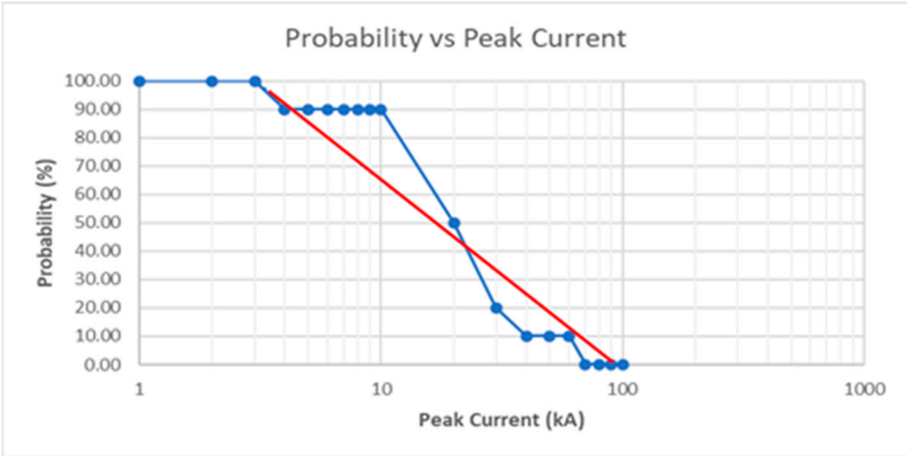



**Figure 28.** Probability vs. Lightning Peak-Current Statistics in DKI Jakarta. The graph line in red shows the probability vs. lightning peak current plot, while graph line in blue line shows the lightning data plot.

### *5.3. West Java*

Some measurements are conducted in West Java as shown in Table 4.

**Table 4.** Lightning peak-current measurement in West Java.

| No. | Location | Date | Peak Current (kA) |
|---|---|---|---|
| 1 | Tangkuban Perahu, Bandung | 19 March 1933 | 25.2 |
| 2 | Tangkuban Perahu, Bandung | 27 March 1993 | 3.5 |
| 3 | Tangkuban Perahu, Bandung | 6 April 1993 | 52 |
| 4 | Tangkuban Perahu, Bandung | 12 April 1993 | 30 |
| 5 | Tangkuban Perahu, Bandung | 16 August 1993 | 19.8 |
| 6 | Tangkuban Perahu, Bandung | 17 November 1993 | 61.2 |
| 7 | Tangkuban Perahu, Bandung | 23 November 1993 | 18 |
| 8 | Tangkuban Perahu, Bandung | 14 January 1994 | 7.28 |
| 9 | Tangkuban Perahu, Bandung | 6 February 1994 | 10.9 |
| 10 | Tangkuban Perahu, Bandung | 8 February 1994 | 4 |
| 11 | Tangkuban Perahu, Bandung | 13 March 1994 | 7.5 |
| 12 | Tangkuban Perahu, Bandung | 18 March 1994 | 8.8 |
| 13 | Tangkuban Perahu, Bandung | 3 December 1994 | 2.7 |
| 14 | Tangkuban Perahu, Bandung | 8 December 1994 | 30 |
| 15 | Tangkuban Perahu, Bandung | 10 October 1995 | 80 |
| 16 | Tangkuban Perahu, Bandung | 24 October 1995 | 28 |
| 17 | Tangkuban Perahu, Bandung | 7 January 1996 | 20 |
| 18 | Tangkuban Perahu, Bandung | 14 January 1996 | 30 |
| 19 | Tangkuban Perahu, Bandung | 21 January 1996 | 28 |
| 20 | Tangkuban Perahu, Bandung | 21 February 1996 | 20 |
| 21 | Tangkuban Perahu, Bandung | 13 March 1996 | 24 |
| 22 | Tangkuban Perahu, Bandung | 5 April 1996 | 27 |
| 23 | AHM Plant, Bandung | 3 March 2011 | 18.3 |
| 24 | ITB Building, Bandung | 7 March 2011 | 13.37 |
| 25 | Tangkuban Perahu, Bandung | 23 February 2017 | 62.72 |
| 26 | Tangkuban Perahu, Bandung | 23 February 2017 | 33.03 |
| 27 | Tower, Bogor | 27 February 2017 | 9 |
| 28 | Industry, Bekasi | 21 June 2017 | 21.26 |
| 29 | Tower, Bekasi | 14 February 2019 | 14.15 |
| 30 | Power Plant, Cirebon | 1 November 2019 | 36.3 |
| 31 | Telecommunication Tower, Bogor | 20 January 2020 | 11.9 |
| 32 | Telecommunication Tower, Depok | 20 January 2020 | 4.6 |
| 33 | Geothermal Power Plant, Bandung | 2 March 2020 | 3.51 |
| 34 | Telecommunication Tower, Bogor | 25 November 2021 | 7.8 |
| 35 | Telecommunication Tower, Depok | 25 November 2021 | 8.4 |

Figure 29 shows the probability versus lightning peak-current statistics for West Java. At a 50% probability level, the statistics indicate a lightning peak current of 35 kA. The mean and median of the measurement data are 22.3 kA and 18.9 kA, respectively.

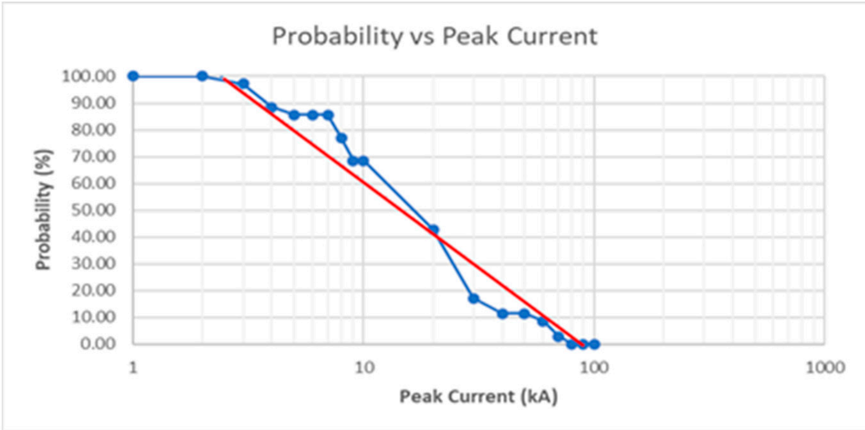



**Figure 29.** Probability vs. Lightning Peak-Current Statistics in West Java. The graph line in red shows the probability vs. lightning peak current plot, while graph line in blue line shows the lightning data plot.

## *5.4. Central Java*

Some measurements are conducted in Central Java as shown in Table 5.

**Table 5.** Lightning peak-current measurement in Central Java.

| No. | Location | Date | Peak Current (kA) |
|---|---|---|---|
| 1 | Refinery structure, Cilacap | 30 December 2015 | 19.88 |
| 2 | Stack, Cilacap | 30 December 2015 | 64.64 |
| 3 | Stack, Cilacap | 8 September 2018 | 14.2 |
| 4 | Refinery Structure, Cilacap | 8 September 2018 | 37.5 |
| 5 | Refinery Structure, Cilacap | 16 January 2019 | 6.3 |
| 6 | Stack Structure, Cilacap | 2 July 2019 | 122.8 |
| 7 | Stack Structure, Cilacap | 2 July 2019 | 54.3 |
| 8 | Refinery Structure, Cilacap | 2 July 2019 | 2 |
| 9 | Stack, Cilacap | 2 July 2019 | 16.1 |
| 10 | Geothermal Power Plant, Wonosobo | 12 August 2020 | 10.7 |
| 11 | Refinery Structure, Cilacap | 21 January 2020 | 7.3 |
| 12 | Stack, Cilacap | 17 December 2020 | 10.3 |
| 13 | Stack, Cilacap | 18 December 2020 | 10 |
| 14 | Stack, Cilacap | 5 March 2021 | 35.2 |
| 15 | Stack, Cilacap | 5 March 2021 | 27.3 |

Figure 30 presents the probability versus lightning peak-current statistics for Central Java. The statistics reveal a lightning peak current of 22 kA at a 50% probability level. The mean and median of the measurement data are 29.2 kA and 16.1 kA, respectively.

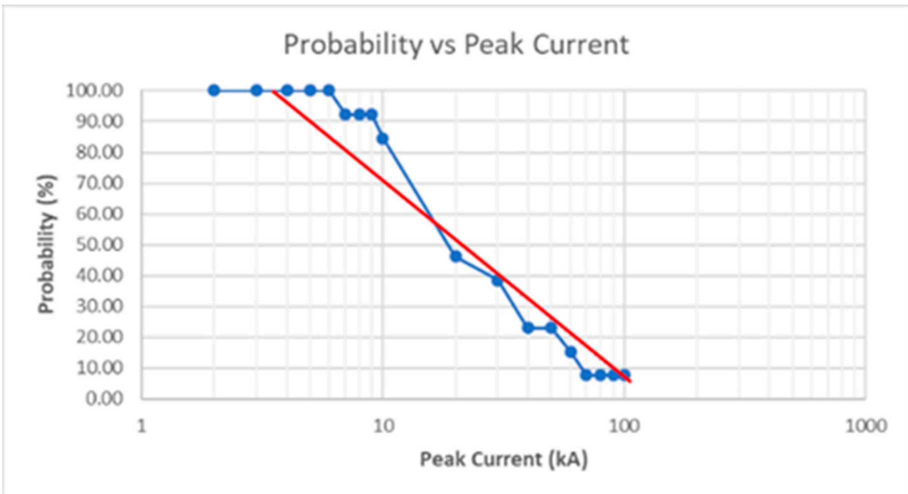



**Figure 30.** Probability vs. Lightning Peak-Current Statistics in Central Java. The graph line in red shows the probability vs. lightning peak current plot, while graph line in blue line shows the lightning data plot.

### 5.5. Central Kalimantan

Some measurements are conducted in Central Kalimantan as shown in Table 6.

**Table 6.** Lightning peak-current measurement in Central Kalimantan.

| No. | Location | Date | Peak Current (kA) |
|---|---|---|---|
| 1 | Tower, Lamandau | 1 February 2018 | 7.66 |
| 2 | Tower, West Kotawaringin | 16 October 2018 | 60.2 |
| 3 | Tower, Lamandau | 28 January 2019 | 15.22 |
| 4 | Tower, Lamandau | 29 January 2019 | 18.85 |
| 5 | Tower, Lamandau | 10 October 2019 | 16.54 |
| 6 | Tower, West Kotawaringin | 10 October 2019 | 41.42 |
| 7 | Tower, West Kotawaringin | 10 October 2019 | 29.8 |
| 8 | Tower, Lamandau | 10 October 2019 | 30.92 |
| 9 | Tower, West Kotawaringin | 10 October 2019 | 22.03 |
| 10 | Tower, West Kotawaringin | 10 October 2019 | 22.03 |
| 11 | Tower, West Kotawaringin | 10 October 2019 | 35.3 |
| 12 | Natai Baru Estate, West Kotawaringin | 10 October 2019 | 2.8 |
| 13 | Tower, West Kotawaringin | 1 February 2020 | 91.4 |

Figure 31 depicts the probability versus lightning peak current statistics for Central Kalimantan. At a 50% probability level, the statistics indicate a lightning peak current of 19 kA. The mean and median of the measurement data stand at 30.3 kA and 22 kA, respectively.

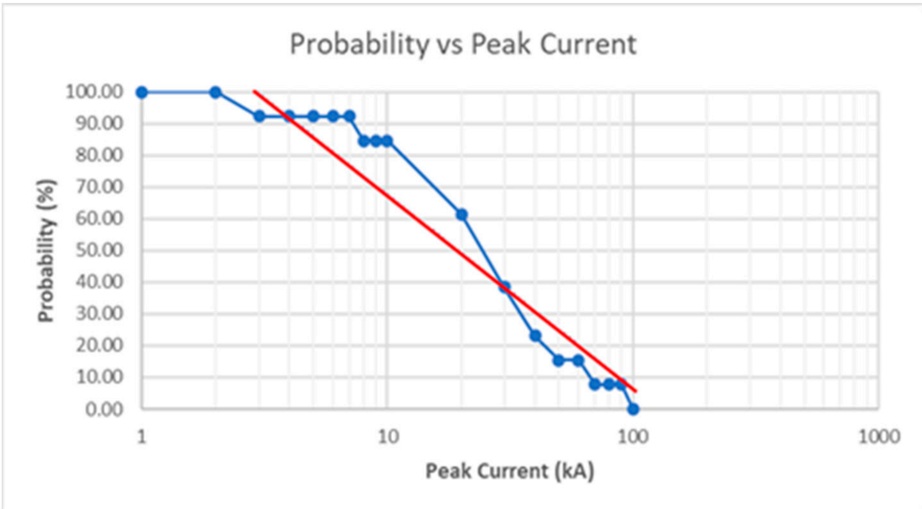



**Figure 31.** Probability vs. Lightning Peak Current Statistics in Central Kalimantan. The graph line in red shows the probability vs. lightning peak current plot, while graph line in blue line shows the lightning data plot.

### 5.6. Riau Island

Some measurements are conducted in Riau Islands as shown in Table 7.

Figure 32 illustrates the probability versus lightning peak-current statistics specific to West Java. At a 50% probability level, the statistics reveal a lightning peak current of 12 kA. The mean and median of the measurement data stand at 17.2 kA and 9.6 kA, respectively.

The summary of lightning characteristic for several provinces in Indonesia are shown in Table 8.

Varying lightning peak-current statistics among different provinces can necessitate distinct lightning protection systems. When using a smaller lightning peak current as the basis for rolling sphere method calculations, it may result in the need for a greater number of lightning protection systems to be installed in specific locations.

**Table 7.** Lightning peak-current measurement in Riau Islands.

| No. | Location | Date | Peak Current (kA) |
|---|---|---|---|
| 1 | Tower, Batam | 27 September 2012 | 9.58 |
| 2 | Tower, Batam | 27 September 2012 | 42.12 |
| 3 | Transmission Tower, Riau Islands | 27 December 2017 | 25.26 |
| 4 | Transmission Tower, Batam | 18 April 2018 | 38.5 |
| 5 | Transmission Tower, Bintan | 9 June 2018 | 2.42 |
| 6 | Transmission Tower, Bintan | 9 June 2018 | 8.31 |
| 7 | Transmission Tower, Bintan | 9 June 2018 | 9.33 |
| 8 | Transmission Tower, Bintan | 9 June 2018 | 110.02 |
| 9 | Transmission Tower, Bintan | 10 June 2018 | 11.53 |
| 10 | Transmission Tower, Bintan | 10 June 2018 | 8.64 |
| 11 | Transmission Tower, Bintan | 10 June 2018 | 2.42 |
| 12 | Transmission Tower, Bintan | 10 June 2018 | 3.4 |
| 13 | Transmission Tower, Bintan | 11 June 2018 | 1.78 |
| 14 | Transmission Tower, Bintan | 19 June 2018 | 3.01 |
| 15 | Transmission Tower, Bintan | 19 June 2018 | 5.77 |
| 16 | Transmission Tower, Bintan | 20 June 2018 | 4.87 |
| 17 | Transmission Tower, Bintan | 21 June 2018 | 40.5 |
| 18 | Transmission Tower, Bintan | 21 June 2018 | 13.52 |
| 19 | Transmission Tower, Bintan | 13 December 2018 | 25.4 |
| 20 | Transmission Tower, Bintan | 13 December 2018 | 26.47 |
| 21 | Tower, Batam | 14 January 2019 | 6.3 |
| 22 | Transmission Tower, Bintan | 20 May 2019 | 2.25 |
| 23 | Transmission Tower, Bintan | 20 May 2019 | 24.4 |
| 24 | Transmission Tower, Bintan | 21 May 2019 | 2.8 |
| 25 | Transmission Tower, Bintan | 21 May 2019 | 14.8 |
| 26 | Transmission Tower, Bintan | 22 May 2019 | 13.94 |
| 27 | Transmission Tower, Bintan | 22 May 2019 | 9 |
| 28 | Transmission Tower, Bintan | 23 May 2019 | 3.2 |
| 29 | Transmission Tower, Bintan | 24 May 2019 | 26.47 |
| 30 | Transmission Tower, Bintan | 24 May 2019 | 12.31 |
| 31 | Transmission Tower, Bintan | 24 May 2019 | 25.93 |

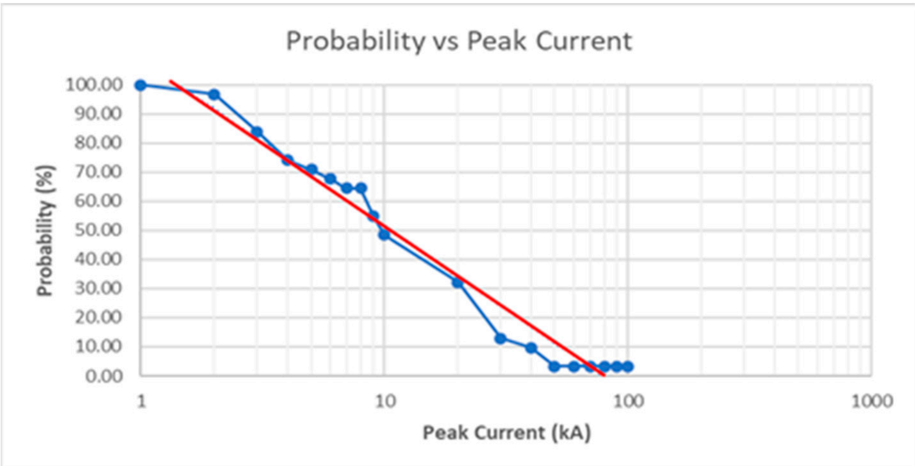



**Figure 32.** Probability vs. Lightning Peak Current Statistics in Riau Islands. The graph line in red shows the probability vs. lightning peak current plot, while graph line in blue line shows the lightning data plot.

In the entirety of the data collected in Indonesia, the lightning peak current falls within the range of 2–123 kA. The mean and median of the measurement data are 24 kA and 18 kA, respectively. According to the statistics a lightning peak current of 17 kA has a 50% probability level, as illustrated in Figure 33.

**Table 8.** Lightning peak-current measurement in several provinces, Indonesia.

| No. | Province | Sample Number | 50%-Value kA |
|---|---|---|---|
| 1 | South Sumatra | 12 | 21 |
| 2 | DKI Jakarta | 10 | 18 |
| 3 | West Java | 35 | 15 |
| 4 | Central Java | 15 | 22 |
| 5 | Central Kalimantan | 13 | 19 |
| 6 | Riau Island | 31 | 12 |

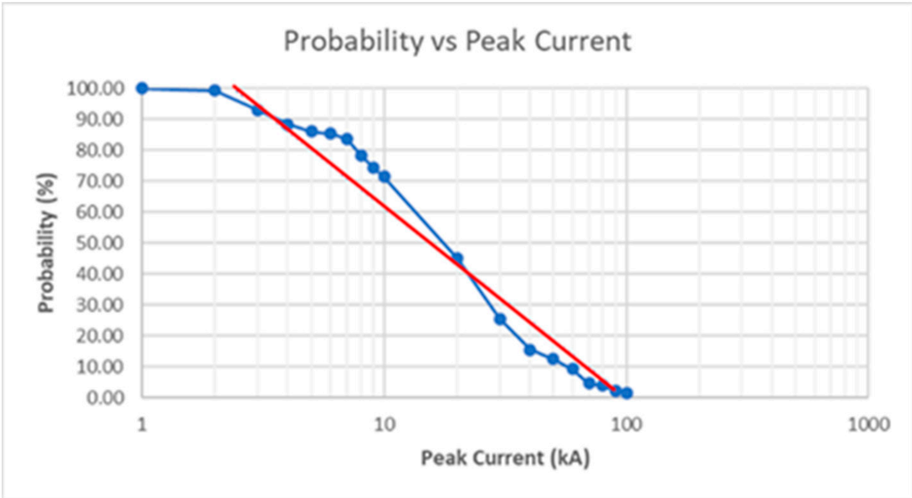



**Figure 33.** Probability vs. Lightning Peak-Current Statistics in Indonesia. The graph line in red shows the probability vs. lightning peak current plot, while graph line in blue line shows the lightning data plot.

Figure 34 presents a comparison of lightning current distributions from various studies. Hojo obtained lightning current distribution data in Japan during his summer research, employing the same method as Syarif Hidayat. The curve from IEEE serves as a reference for calculating the behavior of lightning strikes on transmission lines, while Soetjipto collected lightning data through measurements using magnetic links on transmission towers.

Based on Figure 33, the statistics in this study appear lower than those in other studies. Specifically, at a 50% probability, this study reports a lightning peak current of 17 kA. It is important to note that these variations can be influenced by the different measurement methods employed in previous studies conducted in Indonesia. For instance, Zoro used the time of arrival (TOA) technique, while Syarif Hidayat utilized a magnetic direction finder (MDF) indirect measurement system. To achieve a more nuanced and accurate understanding of lightning data statistics, it may be advisable to carry out further measurements and consider the incorporation of diverse measuring instruments. This expanded approach could provide a more comprehensive view of lightning behavior and its variations across different scenarios and regions. However, it is essential to note that conducting such an exhaustive and detailed analysis extends beyond the specific focus and objectives of this paper.

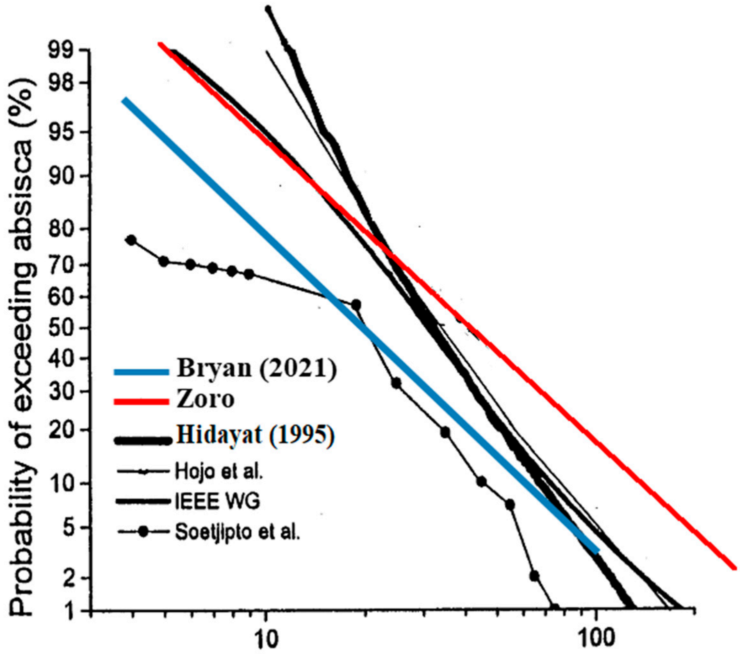



**Figure 34.** Comparison of Lightning Peak-Current Statistics in Indonesia.

## 6. Conclusions

This paper focuses on direct lightning measurement in several provinces of Indonesia. The measurement system comprises a magnetic tape and a lightning-event counter, offering a straightforward approach to measuring both the frequency of lightning strikes and their peak current.

This paper proposes a method for easily and massively obtaining lightning peak current data. The calibration of magnetic tape in a high-voltage laboratory using the impulse current 8/20 μs standard waveform is elaborated upon. Various impulse currents with differing magnitudes and frequencies are injected to calibrate three types of magnetic tape.

Furthermore, this study presents the installation of the measurement system across various locations, considering differences in object height, type, and location. This monitoring system serves the dual purpose of collecting lightning data in diverse settings and aiding in the selection of maintenance actions for lightning protection systems.

Innovatively, this paper introduces a statistical approach to lightning peak currents for several provinces in Indonesia. This local lightning statistics can serve as the foundation for designing lightning protection systems tailored to the unique lightning conditions in each region. By leveraging these lightning characteristics, we anticipate a reduction in the impact of lightning damage in Indonesia.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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