Preliminary Findings on Lightning Peak Currents in Cilacap City at Central Java, Indonesia

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Abstract: Indonesia is frequently plagued by intense lightning activity, leading to a multitude of incidents causing harm and devastation. As a proactive measure to mitigate future damages, an extensive research endeavor focusing on lightning peak currents was under taken in the maritime tropical continent region, particularly in Cilacap. This research aimed to curtail potential risks and enhance safety measures in the region.

The impetus for this investigation stemmed from a series of incidents involving tank explosions in Cilacap, located in Central Java, Indonesia. These occurrences served as pivotal triggers, prompting a comprehensive analysis of lightning peak current statistics. According to the data collected, there exists a 85% probability of a lightning event in Cilacap producing a peak current of 18 kA.

The implications of this research extend beyond the local scope, as the statistical insights gleaned from this study can serve as a foundational basis for the development of both national and international lightning protection standards. By integrating local statistics into the broader framework, a more comprehensive and effective approach to lightning protection can be devised, fostering greater resilience and safety measures not only in Cilacap but also in regions facing similar challenges globally.

Keywords: Component; formatting; style; styling; insert (key words)

1. Introduction

Indonesia, renowned for its maritime expanse, tropical climate, numerous islands, and dense forests, presents an environment conducive to the formation of Cumulonimbus (CB) clouds. This particular meteorological phenomenon, prevalent in the region, plays a significant role in fostering a high frequency of lightning occurrences, as shown in Figure 1. Additionally, the complex interplay between the monsoon and local wind patterns further contributes to the notable prevalence of lightning activity in Indonesia [1].

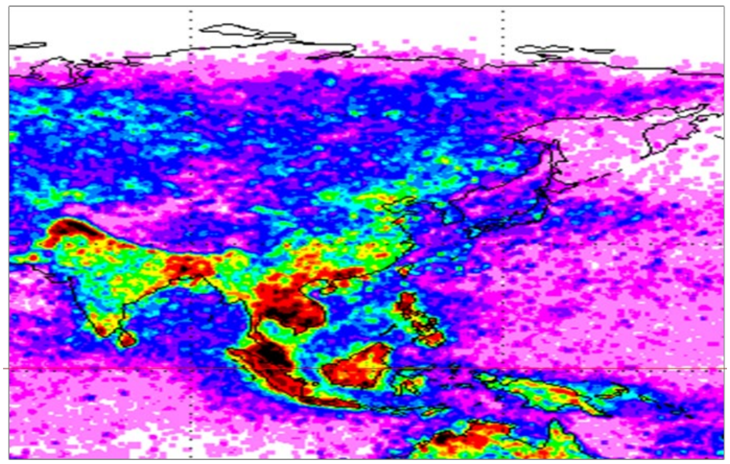

Figure 1. Lightning activity in Indonesia

Received: January 16th, 2024. Accepted: March 13rd, 2024
DOI: 10.15676/ijeei.2024.16.1.5

The consequences of such frequent lightning strikes are far-reaching, causing extensive damage and posing significant risks to various aspects of infrastructure and human life. Notably, incidents involving tank explosions, structural damage, equipment impairment, and even fatalities have been reported as direct results of lightning strikes in the region. In fact, tank fires due to lightning strikes have become a recurrent issue, particularly evident in annual reports from Indonesia.

The impact of lightning strikes has also been observed in the damaging effects on equipment associated with extra-high-voltage transmission lines, emphasizing the widespread nature of this issue [2–9]. Against this backdrop, Cilacap city has faced a concerning trend since 2021, with three incidents of tank fires directly attributed to lightning strikes [10]. This highlights the insufficiency of the current NFPA 780 standard in providing comprehensive protection for tanks and refineries against both direct and indirect lightning strikes, warranting a more robust and tailored approach to lightning protection design [11].

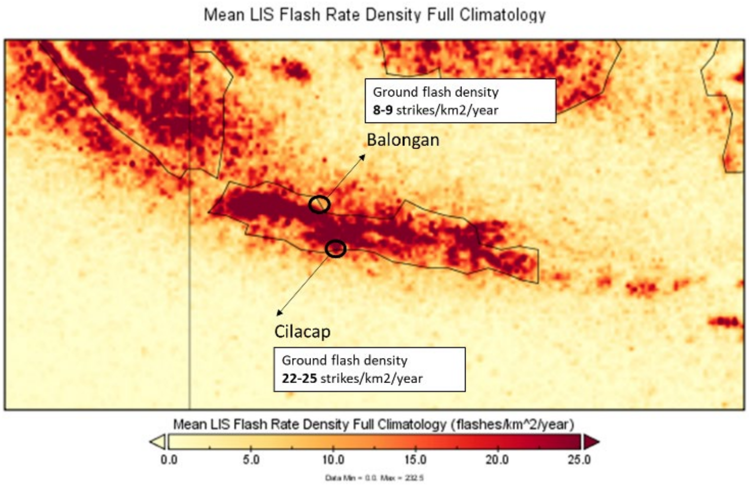

Figure 2. Ground flash density based on Lightning Imaging Sensor (LIS)

Moreover, the ground flash density in Cilacap has been noted to be relatively high, as depicted in Figure 2, underscoring the urgency to enhance the understanding of the local lightning parameters in Cilacap. Strengthening the analysis of existing conditions in Cilacap becomes imperative, serving as a critical step towards obtaining localized lightning parameters that can better inform and support the development of more effective lightning protection designs for the region's infrastructure and populace.

Among the crucial parameters contributing to the consequential damage caused by lightning, the lightning peak current stands out as a significant influencer [12]. This pivotal factor plays a critical role in shaping the design of lightning protection strategies [13], highlighting the paramount importance of understanding its characteristics.

Diverse techniques exist for measuring and analyzing the properties of lightning, each offering unique insights into its behavior [14–17]. These methods include both direct and indirect current measurements, each serving a distinct purpose in comprehending the dynamics of lightning phenomena.

Indirect measurement techniques involve the use of sophisticated lightning detection systems, which operate by capturing the electromagnetic field generated by lightning strikes [18–20]. Employing these systems enables researchers and experts to glean essential data without direct contact, ensuring a safer approach to understanding lightning activity.

On the other hand, direct measurements are conducted using specialized equipment installed on towers or high structures, enabling the direct assessment of lightning currents [21,22]. This approach, often implemented through instrumented towers, offers a high level of accuracy as it directly captures the precise flow of the lightning current through the measuring apparatus [23,24]. Notably, this method provides more reliable data crucial for developing effective lightning protection measures.

Prior studies have utilized a combination of towers and structures equipped with magnetic tape and lightning event counters, demonstrating the practical application of these techniques in real-world scenarios [25]. These innovative approaches serve as essential components in comprehensively analyzing lightning activity and formulating robust protection strategies to mitigate potential damages caused by lightning-related incidents [26].

2. Related Work

The statement provided implies that a previous study or studies on magnetic tape have been compiled and summarized in Table 1. This table presents various key findings, experiments, or advancements related to magnetic tape technology. These findings would include information on the evolution of magnetic tape technology, its properties, and its applications.

Furthermore, the statement suggests that this previous research has demonstrated how magnetic tape technology has progressed from its initial stages in laboratory settings to its practical implementation in real-world applications. This transition from laboratory-scale experiments to practical, real-world applications signifies the advancement and maturation of magnetic tape technology.

Overall, the purpose of discussing this previous research in the context of the development of magnetic tape technology is to highlight the trajectory of its progress, indicating how it has advanced beyond the confines of experimental settings and is now being utilized in various practical applications in the field.

Table 1. Previous related work

No.	Ref.	Description	Location
1	[27]	Calibration Method for magnetic tape lightning current detectors	Lightning Technology, Inc. laboratory in Massachusetts, United States of America
2	[28]	Installation of peak current measurement system for monitoring of arrester lifetime based on working times.	Sangasanga, East Kalimantan
3	[25]	Explanation of measurement principles using magnetic tape and lightning event counter. The measurement result in certain locations is also presented.	Bogor (West Java), Depok (West Java), Palembang (South Sumatera)
4	[29]	Analysis of 35 lightning peak current measurement.	West Java, Indonesia
5	[30]	Lightning protection design in Cilacap at Central Java, Indonesia	Cilacap, Central Java, Indonesia
6	[31]	A method to obtain lightning peak current in Indonesia	Indonesia

Based on figure 3, Although Cilacap is not situated in an area characterized by high lightning density, the refineries and tank farms in this region have encountered the detrimental impact of lightning fires on three separate occasions since 2020. This observation underscores the critical importance of implementing robust and comprehensive lightning protection systems tailored to the specific lightning characteristics prevalent in the region.

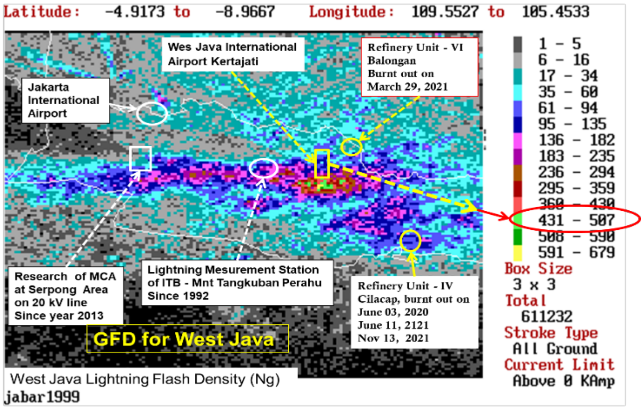

Figure 3. Lightning density in Java Island based on lightning detection system

The occurrence of lightning fires in an area with relatively low lightning density indicates that the severity of the impact of each lightning strike may be amplified, possibly due to various localized factors such as terrain, meteorological conditions, or specific features of the industrial installations themselves. This highlights the need for a nuanced understanding of the local environmental and infrastructural context to effectively address the risks posed by lightning strikes.

To mitigate the potential risks associated with lightning incidents, the installation of a proper lightning protection system becomes imperative. This system must be designed in accordance with the specific lightning characteristics prevalent in the region, rather than solely relying on general assumptions based on the broader regional lightning density. By aligning the lightning protection measures with the particular lightning behavior observed in Cilacap, the refineries and tank farm can significantly reduce the probability of lightning-induced fires and minimize the potential damage to the facilities and surrounding environment.

In essence, the repeated occurrence of lightning fires in an area with lower-than-average lightning density highlights the importance of tailoring lightning protection systems to the local lightning characteristics. By doing so, the refineries and tank farm in Cilacap can enhance their resilience against the adverse effects of lightning strikes and ensure the safety and sustainability of their operations.

3. Methodology

This article appears to discuss the measurement of lightning peak current using a specific measurement system. The system includes two main components: a lightning event counter and magnetic tape. The process involves laying the magnetic tape parallel to a 50 mm² Bare Copper conductor, likely for the purpose of capturing and recording the electrical activity associated with lightning strikes [32]. Figure 4 depicts an illustration of signal elimination resulting from lightning current. The length of the eliminated signal correlates positively with the peak current of the lightning.

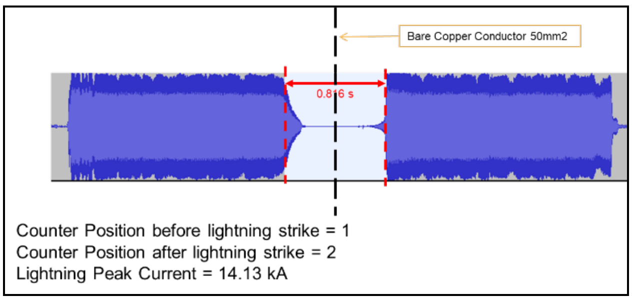

Figure 4. Illustration of eliminated signal due to lightning current

The magnetic tape serves as a crucial element in this system, presumably acting as a means of recording and storing data related to the lightning event. By placing the magnetic tape in close proximity to the Bare Copper conductor, it can capture and record the magnetic field changes induced by the lightning current passing through the conductor. This data is likely critical in understanding the characteristics and intensity of lightning strikes.

Furthermore, the lightning event counter is used to detect and record instances of lightning strikes that the magnetic tape has captured. It likely provides valuable information about the frequency and intensity of the lightning events that have occurred, thus aiding in the analysis, and understanding of lightning behavior in the specific environment under study.

The provided passage describes a methodology for measuring lightning peak current using a specific system that involves the use of magnetic tapes and the signal or audio reading software. The process seems to be implemented in the region of Cilacap, Indonesia, known for its high lightning activity.

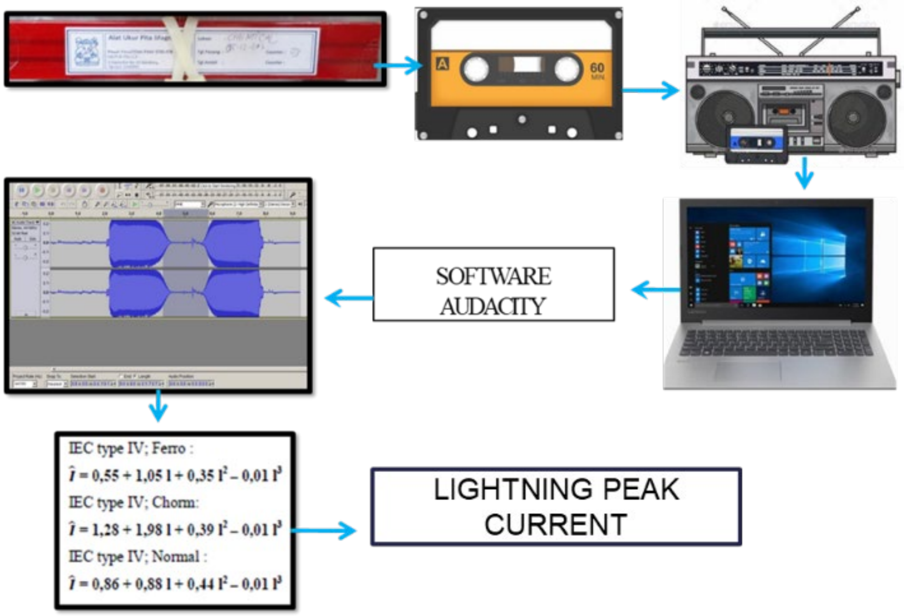

Figure 5. The process of obtaining the lightning peak current value from magnetic tape

The first part of the description highlights the importance of regularly replacing the magnetic tape when the lightning event counter records an increasing number of events. The old magnetic tape is then analyzed. It is inferred that the analysis involves examining the recorded signals on the magnetic tape, likely to understand the characteristics and patterns of the lightning strikes over time. The length of the signal erasure, possibly referring to the portion of the tape that indicates lightning activity, is found to have a correlation with the lightning peak current, suggesting that longer erasure might signify higher peak currents.

The methodology for measuring the lightning peak current, depicted in Figure 5, involves inserting the magnetic tape into a cassette and running it through a tape player. The tape player is connected to a computer that has the signal reading software installed. As the tape is run, the software visualizes the erasure of the prefilled signal, which is likely indicative of the lightning activity recorded by the magnetic tape. The length of the erasure is then converted into the lightning peak current using a magnetic tape formula, which likely involves a calibration process to establish the relationship between the erasure length and the corresponding current.

Moreover, the implementation of this methodology is specified to be in Cilacap, Indonesia, where multiple high structures and towers with high exposure to lightning activity have been equipped with both magnetic tapes and lightning event counters. This setup allows for the systematic monitoring and recording of lightning events in the area, providing valuable data for further analysis and research in understanding and mitigating the impact of lightning strikes on these structures and the surrounding environment.

In summary, the article outlines a method for measuring lightning peak current using a specialized measurement system that involves a magnetic tape and a lightning event counter. This system enables researchers to collect valuable data related to the magnetic field changes induced by lightning strikes and to monitor and record instances of lightning events, ultimately contributing to a better understanding of lightning phenomena.

4. Result and Discussion

The passage provides insights into the implementation of a measurement system in the Cilacap refineries and stack structures, both of which are situated in an area with frequent lightning disturbances. These disturbances pose a significant risk to the electronic equipment and may lead to potential tank fires, making the implementation of the measurement system crucial for monitoring and mitigating these risks.

Figures 6 and 7 illustrate the deployment of the measurement systems on the stack and refinery structures, highlighting the strategic placement of the systems to effectively capture and record lightning strikes in the vicinity. These systems likely comprise lightning event counters (LEC) integrated into the structures to precisely detect and count the occurrences of lightning strikes.

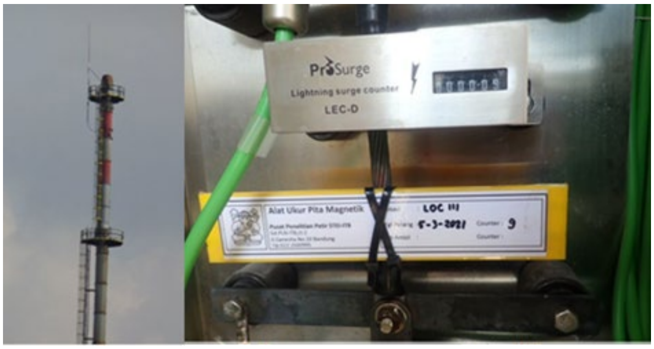

Figure 6. Installation of measurement system in Cilacap stack structure

In the initial three months since the installation of these measurement systems, a total of 17 lightning strikes have been recorded by the lightning event counter (LEC). This data underscores the significant frequency of lightning strikes in the area, emphasizing the necessity of monitoring and safeguarding the structures against potential damage caused by lightning.

Figure 7. Installation of measurement system in Cilacap refinery structure

The location of the stack and refinery in Central Java, known for its exceptionally high lightning strike activity, further accentuates the critical need for a robust monitoring system. With over 40 lightning strikes already recorded on the structures, it becomes increasingly evident that the region is highly susceptible to lightning-related incidents. This data emphasizes the importance of continuous monitoring and the implementation of precautionary measures to minimize the potential risks posed by lightning strikes to the safety and functionality of the stack and refinery structures in the area.

The passage indicates the extension of the measurement system's implementation to other tank areas that are similarly prone to frequent lightning strikes, leading to potential incidents such as fires and explosions. This expansion of the measurement system is crucial in ensuring the safety and security of the various tank areas affected by these risks.

Figure 8 illustrates the deployment of the measurement system in a free-standing mast structure located in Gresik, East Java. The installation of the system in this structure is indicative of the recognition of the heightened risk of lightning strikes in the area, thereby emphasizing the need for effective monitoring and preventive measures. The inclusion of a lightning event counter and magnetic tape in this system allows for the accurate detection, recording, and analysis of lightning strike occurrences in the vicinity.

Figure 8. Free standing mast (in Gresik) is equipped by magnetic tape and lightning event counter

The data recorded by the lightning event counter and magnetic tape in this location provide valuable insights into the frequency and intensity of lightning strikes in the area. This information is crucial for understanding the specific risk factors associated with lightning and for implementing appropriate safety protocols and measures to prevent potential fires, explosions, or other related incidents in the tank areas.

By deploying this measurement system in the free-standing mast structure in Gresik, East Java, the authorities, and stakeholders demonstrate a proactive approach to mitigating the risks associated with lightning strikes, thereby safeguarding the tank areas and minimizing the potential for hazardous incidents. This emphasis on preventive measures underscores a commitment to maintaining a safe and secure environment in the face of the challenges posed by frequent lightning disturbances in the region.

During a lightning strike, the LEC number experiences an increase. The old magnetic tape is substituted with a new one, and the former magnetic tape needs to be analyzed using Audacity software. The duration of the eliminated signal, measured in milliseconds, will be converted to centimeters by multiplying it with the tape player speed of 4.76 cm/s. Subsequently, it will be converted into lightning peak current values in kiloAmperes using the formula provided in Figure 5. Figures 9 through 12 present the outcomes of the conversion process for samples collected from various measurement locations.

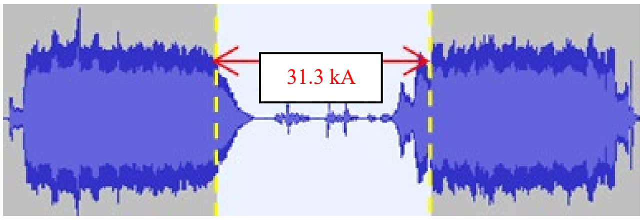

Figure 9. The peak current reading result using signal or audio reading software for refineries structure 1

Figure 9 shows the example of peak current reading result using signal or audio reading software for refineries structure 1. Based on the length of erased signal above, the peak current is 31.3 kA.

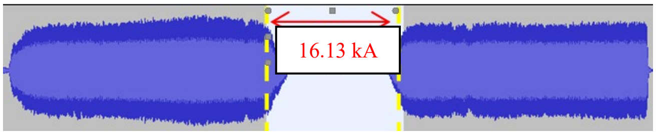

Figure 10. The peak current reading result using signal or audio reading software for refineries structure 2

Figure 10 shows the example of peak current reading result using signal or audio reading software for refineries structure 2. Based on the length of erased signal above, the peak current is 16.13 kA.

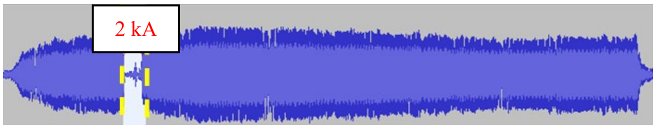

Figure 11. The peak current reading result using signal or audio reading software for elevator structure

Figure 11 shows the example of peak current reading result using signal or audio reading software for elevator structure. Based on the length of erased signal above, the peak current is 2 kA.

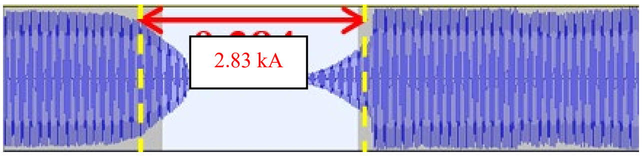

Figure 12. The peak current reading result using signal or audio reading software for regent structure

Figure 12 shows the example of peak current reading result using signal or audio reading software for regent structure. Based on the length of erased signal above, the peak current is 2.83 kA.

The provided information presents an analysis of 14 lightning peak current measurements. Figure 13, which displays the probability versus lightning peak current statistic in Cilacap, provides valuable insights into the distribution of lightning peak currents in the area.

The statistical information provided in the passage is significant for understanding the nature and characteristics of lightning activity in Cilacap. According to the data presented, for a 50% probability, the statistic indicates an 18-kA lightning peak current. This value signifies the likelihood of encountering a lightning peak current of 18 kA or lower in Cilacap, suggesting a substantial frequency of lightning strikes with this intensity in the region.

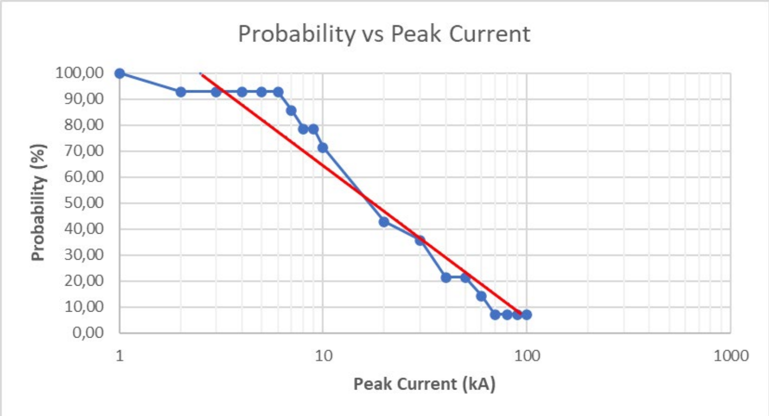

Figure 13. Probability vs lightning peak current statistic in Cilacap (red line shows the probability vs peak current graphic, while blue line shows the lightning event)

Furthermore, the mean and median of the measurement data are reported to be 30.56 kA and 20 kA, respectively. These values indicate the central tendency of the distribution of lightning peak currents, suggesting that the majority of the recorded lightning events exhibit peak currents around 20-30.56 kA.

Additionally, the range of the lightning peak current, spanning from 2 kA to 123 kA, provides critical information about the variability and extremes of the lightning peak currents observed in Cilacap. This wide range underscores the diverse nature of lightning events in the area, highlighting the possibility of encountering both moderate and significantly intense lightning strikes.

Overall, the comprehensive analysis of the lightning peak current measurement results, as illustrated by Figure 13 and the statistical data provided, offers valuable insights into the distribution, frequency, and intensity of lightning activities in Cilacap. This information is essential for developing effective safety protocols, risk assessment strategies, and lightning protection measures to ensure the safety of structures, equipment, and personnel in the region.

Referring to the Lightning Protection Level (LPL) in IEC 62305/ 2010 standard, lightning peak current statistic in this study are mapped to the probability and rolling sphere radius as shown in Table 2.

The article discusses the application of the Lightning Protection Level (LPL) in a vital installation located in Cilacap. According to the information provided in Table 2, the LPL is being applied based on the guidelines specified in the IEC 62305/2010 standard. This standard serves as a benchmark for evaluating the level of protection required against lightning strikes.

From the lightning protection level (LPL) in Table 2, it can be applied to the vital installation in Cilacap. The LPL in Table 2 is compared by LPL based on IEC 62305/2010. Lightning peak current and radius of the rolling sphere in Indonesia are quite smaller than the IEC 62305/2010 Standard, as shown in Table 3.

However, it is noted that the lightning peak current and the radius of the rolling sphere in Indonesia are relatively smaller when compared to the parameters outlined in the IEC 62305/2010 Standard, as shown in Table 3. This implies that the specific geographical location in Cilacap may experience less intense lightning phenomena compared to the parameters set by the international standard.

Despite the use of LPL from Table 2, it is emphasized that a more comprehensive evaluation of lightning data is necessary to ensure the accuracy and effectiveness of the lightning protection system. This suggests the importance of gathering and analyzing local lightning data to better tailor the lightning protection system to the specific environmental conditions of the region.

Table 2. Lightning Protection Level in Cilacap, Indonesia

LPL	I	II	III	IV
Peak current i_{max}	2.8 kA	3.5 kA	4.2 kA	4.5 kA
Rolling sphere radius r	15.3 m	18.3 m	21.1 m	22.3 m
Probability p	99%	91%	87%	84%

Table 3. Lightning protection level based on IEC 62305/ 2010 Standard

LPL	I	II	III	IV
Peak current i_{max}	3 kA	5 kA	10 kA	16 kA
Rolling sphere radius r	20 m	30 m	45 m	60 m
Probability p	99%	91%	87%	84%

The article further highlights the utilization of the rolling sphere method in designing the lightning protection system (LPS). This method, as demonstrated in Figure 14, aids in determining the coverage area of the LPS to safeguard the entire tank farm from potential direct strikes of lightning. By employing the rolling sphere method, engineers and designers can effectively calculate and implement the necessary protective measures to minimize the risk posed by lightning strikes to the vital installation in Cilacap.

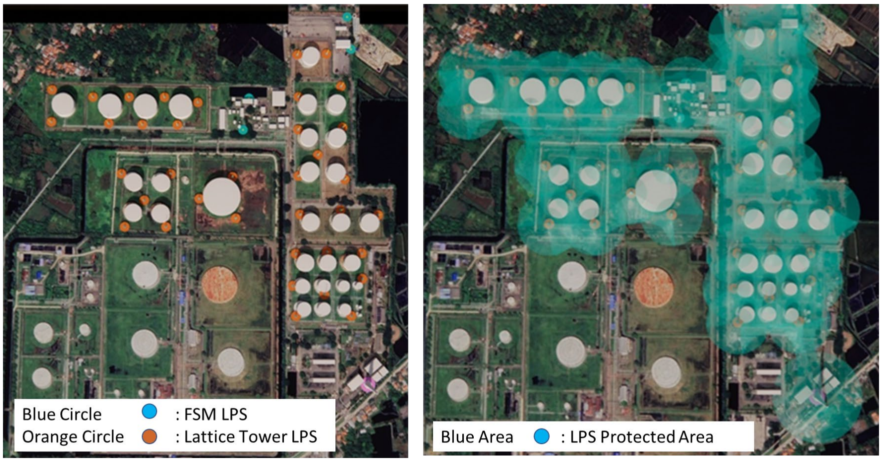

Figure 14. Application of rolling sphere method for oil and gas area in Cilacap

In summary, the article underscores the significance of accurately assessing the local lightning conditions and customizing the lightning protection system accordingly. By acknowledging the variations in lightning parameters between the regional context and international standards, it emphasizes the need for a comprehensive evaluation process that incorporates specific data to ensure the effective and appropriate application of the lightning protection measures.

5. Conclusions

This article presents the findings of a study that aimed to measure tropical lightning peak currents in Cilacap, located in Central Java, Indonesia, using the Peak Current Measurement System (PCM). The PCM consists of two components: the Lightning Event Counter (LEC) for counting lightning strikes and the Magnetic Tape for measuring the lightning peak current.

The study revealed that the median and mean values of the lightning peak current were 30.56 kA and 20 kA, respectively, with a range spanning from 2 kA to 123 kA. Additionally, the lightning peak current for a 50% probability of lightning events was found to be 18 kA, indicating relatively lower values compared to the standard.

Furthermore, the study also demonstrates the application of the rolling sphere method utilizing local lightning parameters. The results suggest that the tank farm should be adequately protected from direct lightning strikes. To enhance the understanding of lightning patterns in Cilacap, Central Java, Indonesia, it is recommended that further research be conducted, necessitating the collection of additional local lightning data for more precise statistical analysis.

6. Acknowledgment

This research is supported by Institut Teknologi Bandung.

7. References

[1]. Zoro, R. Influence of Tropical Monsoon and Local Wind Circulation to Lightning Discharge over Indonesia. In Proceedings of the 11th International Symposium on High-Voltage Engineering (ISH 99); IEE: London, UK, 1999; Vol. 1999, pp. v2-188-v2-188.

[2]. Candela Garolera, A.; Madsen, S.F.; Nissim, M.; Myers, J.D.; Holboell, J. Lightning Damage to Wind Turbine <?Pub _newline ?> Blades From Wind Farms in the U.S. *IEEE Trans. Power Delivery* **2016**, *31*, 1043–1049, doi:10.1109/TPWRD.2014.2370682.

[3]. Ito, H.; Yokoyama, S.; Matsui, M.; Sato, T. Explosive Damages of Structures Due to Winter Lightning. In Proceedings of the 2022 36th International Conference on Lightning Protection (ICLP); IEEE: Cape Town, South Africa, October 2 2022; pp. 307–310.

[4]. Cao, J.; Du, Y.; Ding, Y.; Li, Z.; Zhang, Y. Novel Evaluation of the Damage Rate of Surge Arresters Due to Lightning Stroke in a Distribution Network. In Proceedings of the 2022 36th *International Conference on Lightning Protection (ICLP); IEEE*: Cape Town, South Africa, October 2 2022; pp. 76–81.

[5]. Ab Kadir, M.Z.A.; Misbah, N.R.; Gomes, C.; Jasni, J.; Wan Ahmad, W.F.; Hassan, M.K. Recent Statistics on Lightning Fatalities in Malaysia. In Proceedings of the 2012 *International Conference on Lightning Protection (ICLP); IEEE*: Vienna, Austria, September 2012; pp. 1–5.

[6]. Navarrete-Aldana, N.; Cooper, M.A.; Holle, R.L. Lightning Fatalities in Colombia from 2000 to 2009. In Proceedings of the 2014 *International Conference on Lightning Protection (ICLP); IEEE*: Shanghai, China, October 2014; pp. 40–46.

[7]. Denov, B.; Hendratama, I.; Zoro, R. Lightning Protection System of Oil Storage Tank In Tropical Country. In Proceedings of the 2019 2nd *International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*; IEEE: Denpasar, Bali, Indonesia, October 2019; pp. 1–6.

[8]. Zoro, R.; Mefiardhi, R. Insulator Damages Due to Lightning Strikes in Power System : Some Experiences in Indonesia. In *Proceedings of the 2006 IEEE 8th International Conference on Properties & applications of Dielectric Materials*; IEEE: Bali, Indonesia, June 2006; pp. 677–682.

[9]. Harijanto, P.S.; Zoro, R. Analysis of Lightning Strike to Overhead EHV 500 KV Transmission System Jawa-Bali Crossing. In *Proceedings of the 2016 3rd Conference on Power Engineering and Renewable Energy (ICPERE)*; IEEE: Yogyakarta, Indonesia, 2016; pp. 275–280.

[10]. Budisatrio, F.H.; Denov, B. Tropical Lightning Strike Potential as a Cause of Oil Tank Fire in Indonesia. 6.
[11]. Denov, B.; Zoro, R. Evaluation of NFPA 780 Standard for Lightning Protection of Oil and Gas Installation in Indonesia.
[12]. Yang, B.; Fu, Y.-P.; Li, Y.-X.; Yao, M.-L.; Shi, L.-H. Optically Powered Lightning Current Measurement System for High-Tower Observation. *IEEE Access* **2018**, *6*, 17022–17028, doi:10.1109/ACCESS.2018.2799299.
[13]. Zoro, R. Tropical Lightning Current Parameters and Protection of Transmission Lines. *ijeei* **2019**, *11*, 506–514, doi:10.15676/ijeei.2019.11.3.4.
[14]. Cai, L.; Li, J.; Wang, J.; Zhou, M.; Xu, F.; Li, Q.; Fan, Y. Measurement of Return Stroke Current With Magnetic Sensor in Triggered Lightning. *IEEE Trans. Electromagn. Compat.* **2021**, *63*, 145–151, doi:10.1109/TEMC.2020.2986100.
[15]. Cai, L.; Li, J.; Su, R.; Zhou, M.; Xu, Z.; Li, Q.; Wang, J. Rocket-Triggered-Lightning Strikes to 10 KV Power Distribution Lines and Associated Measured Parameters of Lightning Current. *IEEE Trans. Electromagn. Compat.* **2022**, *64*, 456–463, doi:10.1109/TEMC.2021.3112713.
[16]. Diendorfer, G.; Zhou, H.; Pichler, H. Review of 10 Years of Lightning Measurement at the Gaisberg Tower in Austria.
[17]. Smit, J.R.; Hunt, H.G.; Schumann, C. First Lightning Current Measurements to the Sentech Tower, South Africa. In Proceedings of the 2021 35th *International Conference on Lightning Protection (ICLP) and XVI International Symposium on Lightning Protection (SIPDA); IEEE*: Colombo, Sri Lanka, September 20 2021; pp. 1–6.
[18]. Hidayat, S. Lightning Characteristics on Java Island, Observed by Lightning Location Network. In Proceedings of the 11th *International Symposium on High-Voltage Engineering (ISH 99); IEE*: London, UK, 1999; Vol. 1999, pp. v2-192-v2-192.
[19]. Hidayat, S.; Zoro, R. Observation of Lightning Discharges in Indonesia by Lightning Detection Network. In *Proceedings of the 2006 IEEE 8th International Conference on Properties and applications of Dielectric Materials*; IEEE: Bali, Indonesia, June 2006; pp. 844–847.
[20]. Hidayat, S.; Ishii, M. Lightning Discharges on Land and on Sea in Indonesia. In Proceedings of the 2006 *IEEE 8th International Conference on Properties and applications of Dielectric Materials*; IEEE: Bali, Indonesia, June 2006; pp. 315–318.
[21]. Birkl, J.; Bohm, T.; Diendorfer, G.; Heidler, F.; Paul, C.; Pichler, H. Measurement of Lightning Currents on High Structures and Wind Turbines. In *Proceedings of the 2018 34th International Conference on Lightning Protection (ICLP)*; IEEE: Rzeszow, September 2018; pp. 1–8.
[22]. Qiu, Z.; Wang, S.; Yang, Y.; Qin, Z.; Chen, M.; Lyu, F.; Guo, H.; Du, Y.-P.; Gao, Y.; Zhang, G. Optical and Current Measurements of Lightning Attachment to the 356-m-High Shenzhen Meteorological Gradient Tower in Southern Coastal Area of China. *IEEE Access* **2019**, *7*, 155372–155380, doi:10.1109/ACCESS.2019.2949127.
[23]. Alammari, A.; Alkahtani, A.A.; Ahmad, M.R.; Noman, F.M.; Esa, M.R.M.; Kawasaki, Z.; Tiong, S.K. Lightning Mapping: Techniques, Challenges, and Opportunities. *IEEE Access* **2020**, *8*, 190064–190082, doi:10.1109/ACCESS.2020.3031810.
[24]. Cai, L.; Hu, Q.; Zhou, M.; Ke, Y.; Li, Q.; Wang, J.; Fan, Y. Difference in Lightning Current Estimated by Lightning Location System Between Triggered Lightning to Ground and Distribution Line. *IEEE Trans. Electromagn. Compat.* **2021**, *63*, 2041–2049, doi:10.1109/TEMC.2021.3098690.
[25]. Denov, B.; Hidayat, S.; Suwarno; Zoro, R. The Application of Magnetic Tape to Measure Lightning Peak Current in Indonesia. In Proceedings of the 2021 IEEE *International Conference on the Properties and Applications of Dielectric Materials (ICPADM)*; IEEE: Johor Bahru, Malaysia, July 12 2021; pp. 194–197.

[26]. Hendratama, I.; Denov, B.; Zoro, R. Lightning Protection System Standardization on Indonesian Railway Operation Facilities. In Proceedings of the 2019 2nd *International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*; IEEE: Denpasar, Bali, Indonesia, October 2019; pp. 1–6.
[27]. Crouch, E. Calibration Tests on Magnetic Lightning Current Detectors.
[28]. Refiasto, S.; Denov, B. Installation of Multi Chamber Arrester to Improve Lightning Reliability Performance of Distribution Lines System in Oil and Gas Area.
[29]. Denov, B.; Hidayat, S.; Suwarno; Zoro, R. Tropical Lightning Peak Current Measurement at West Java, Indonesia. In *Proceedings of the 2022 36th International Conference on Lightning Protection (ICLP)*; IEEE: Cape Town, South Africa, October 2 2022; pp. 364–368.
[30]. Denov, B.; Zoro, R. Lightning Protection System for Oil and Gas Installation Case on Cilacap Area at Central Java, Indonesia. In *Proceedings of the 2017 6th International Conference on Electrical Engineering and Informatics (ICEEI)*; IEEE: Langkawi, November 2017; pp. 1–7.
[31]. Denov, B.; Hidayat, S.; Suwarno; Zoro, R. A Method to Obtain Lightning Peak Current in Indonesia. *Energies* **2023**, *16*, 6342, doi:10.3390/en16176342.
[32]. Zoro, R. Lightning Characteristic and Weather Condition in Tropical Region, Case on Tangkuban Perahu Mountain 1999.

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