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Analysis of Electric Field Intensity in Residential Areas Due to Lightning Strikes on Base Transceiver Station Towers

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Abstract: Base Transceiver Station (BTS) towers are highly vulnerable to lightning strikes. A lightning strike is a moving electric charge that generates an electric field and a magnetic field, both of which are vector quantities, and induces voltage around the tower. The closer to the tower, the greater the values of the electric field, magnetic field, and induced voltage generated. A 49-meter highs tower in Mataram City is located 25 and 300 meters from residential areas and public facilities. The metabolism of living organisms, such as blood circulation, nerve function, heart rate, lung function, cell growth, and cell division, are also vector quantities. Exposure of living organisms to external electric fields exceeding the threshold of ≥10 kV/m can disrupt their metabolism. It is crucial to determine the magnitude and direction of the electric field vector caused by lightning strikes on BTS towers and how it affects living organisms around the tower. Observations are based on Coulomb's Law and its derivative theories on electric fields. The peak lightning current in tropical areas ranges from 10 to 100 kA, with a frequency of 200 kHz. The electric field intensity at distances of 25 and 300 meters is 58.30, 584.50, 4.86, and 48.71 kV/m, respectively. These results indicate that a distance of 25 meters from the tower is not safe from exposure to high electric field intensity values.

Keywords: BTS tower; Electric field; Intensity; Lightning strikes; Transceiver station.

Introduction

The number of wireless telecommunication service users has increased rapidly from year to year. One of the supporting telecommunication facilities and infrastructure is the Base Transceiver Station (BTS) tower, the number of which is also increasing, to meet consumer needs. BTS towers must be equipped with an external Lightning Protection System (SPP). The external SPP aims to protect the tower and equipment in the BTS tower from lightning strikes (Negara et al., 2021; Mahadi et al., 2022). Air termination or finial is made of pointed copper, in the form of an anchor or branching in all directions at the end (Lucas, 2023). Air termination is connected to the down conductor using a jumper also made of copper (Damianaki et al., 2020; Lucas, 2023). The down conductor is then connected to the grounding electrode, namely a single rod electrode, or several electrode rods (grounding), in the form of a plate, in the form of a grid or a combination there of (Li & Jin, 2022; Martinez et al., 2021). Air termination or finial, one to two meters higher than the tip of the tower, so that lightning strikes the finial of the lightning protection system, and does not strike the BTS tower structure.

The lightning strike current is channeled by the lightning protection system to the ground, so that every

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lightning strike on the external SPP of the tower does not cause an explosion and thunderous sound (Deng et al., 2024; Ganongo et al., 2024). A lightning strike is the movement and meeting of electric charges on the ground and electric charges in the clouds of different polarities (Bian et al., 2023; Song et al., 2024). Referring to the Coulomb Force law, that electric charges of different polarities will attract each other and those of the same polarity or similar charges will repel each other. This theorem formulates that the magnitude of the Coulomb force is directly proportional to the magnitude of the two charges, and inversely proportional to the distance separating the two charges, and inversely proportional to the permittivity value of the media where the two charges are located (Poole, 2019). External SPP consists of air termination or finial, copper conductor or down conductor and grounding electrode or grounding, shown in Figure 1 (Bai et al., 2024).

Figure 1. BTS tower located near residential areas and equipped with external SPP

The electric field is a vector quantity. Metabolism of living things is also a vector quantity activity. Even the origin of living things since the fertilization of the egg cell by the sperm cell, is also a vector quantity activity. Furthermore, growth, division and cell regeneration, heartbeat, blood circulation, nervous system, and so on are also vector-shaped activities (Altyar et al., 2023; Di et al., 2023; Giannino et al., 2024). If living things are exposed to an electric field from the outside, it will affect the work of the living thing's metabolic vector. The World Health Organization (WHO) Standard, the International Commission on Non-ionizing Radiation Protection (ICNIRP), the International Radiation Protection Association (IRPA) and the International Electrotechnical Commission (IEC) issued a decision: that living things may be exposed to a maximum electric field intensity of 10 kV/m for a period of time that is not continuous. Referring to WHO, ICNIRP, IRPA and IEC standards, it is necessary to analyze the intensity of electric field exposure on living things, especially a housing complex 25 m away and a public facility building 300 m away from the BTS tower position in Mataram city (Chiaramello et al., 2019; Khadijah et al., 2024)).

Previous similar studies that underlie and relate to the study of electric field intensity are as follows. (Hopsort et al., 2024), examined the magnitude of the electric field intensity around a building 19 m high. The building is equipped with an external SPP with a 2 m long finial, two down conductors and two rod electrodes (grounding). A lightning current of 10 kA, 200 kHz flows divided into 2 down conductors, so that a current of 5 kA flows in each down conductor. The safe distance from the lightning strike point in terms of the Electric Field is 75 meters. The objects observed were two houses 70 and 300 m from the location of the building struck by lightning, the electric field intensity of the two houses was 11.461 and 0.658 kV/m respectively. Seniari, et al, 2021, conducted a study on the safe distance of residential areas in terms of the electric field intensity of a 42 m high BTS tower injected with a 10 kA, 200 kHz lightning current. The tower only consists of a down conductor.

The electric field intensity is below 10 kV/m or the safe distance between residential areas and the BTS tower, is at a distance of 280 m from the tower position. (Burtsev & Selivanov, 2021; Florkowski et al., 2021), studied two BTS towers separated by a distance of 25 m which were struck by lightning simultaneously. The radius of the Colonimbus cloud that has the potential for lightning is within a kilometer radius. So, it is assumed that lightning strikes occur simultaneously on both towers. The peak lightning current of 18 kA is evenly distributed across the two towers' external lightning protection systems. The electric field intensity at the middle of the distance between the two towers is zero V/m because the electric field intensity vectors from tower 1 and tower 2 are the same in size and opposite in direction. Other objects studied were two houses with a distance of 5 m from tower 1 and a distance of 12 m from tower 2. When lightning struck the two towers, the houses were exposed to electric fields of 358.119 kV/m and 144.488 kV/m respectively, and were categorized as unsafe based on various standards.

Jalilian et al. (2018) and Park et al. (2020), studied the electric and magnetic fields generated by medical equipment with Extremely Low Frequency (ELF) around the hospital. The results of measuring the intensity of the ELF electric and magnetic fields at the operator's position more than 40 cm, the ELF electric field is in the intensity range of 2.75 - 166 V/m and the ELF magnetic field is in the intensity range of 0.021-3.26 T. A distance of more than 100 cm from medical equipment, the intensity of the electric field and the intensity of the magnetic field are not significantly different from the intensity of the natural electric and magnetic fields. The position of the medical equipment operator is generally more than 40 cm from the position of the medical equipment. Abdulsalam et al. (2020), conducted a study to obtain exposure to electric and magnetic fields at distances of 0, 20, 40, 60 and 80 m from a mobile base station in Katsina, Nigeria. The average values of electric and magnetic field intensity were 21.03 mV/m and 55.78 µA/m, which are still within acceptable limits, or do not exceed 61 V/m and 0.16 A/m, which are safe limits.

Bjelland et al. (2024), took additional protection steps and strategies that exceeded the minimum requirements of the NFPA standard. The aim is to protect oil structures and refineries in Indonesia from lightning strike disasters. Additional lightning protection is specifically designed to avoid the unique risk of lightning strikes in tropical climate areas in Indonesia. The novelty in this study is specifically analyzing the magnitude of the intensity of the Electric Field around the tower with a total height of 49 meters, using the Coulomb Force Law and its derivative formula, namely residential areas that are 25 m away and public facility buildings that are 300 m away from the BTS tower position.

Method

This research was conducted in December 2022 to July 2023, using a descriptive method, namely a case study researchs on a tower in the city of Mataram. This study is to determine whether residential areas 25 m away and public facility buildings 300 m away from the BTS tower are safe in terms of exposure to electric field intensity. The electric field intensity is calculated and analyzed using the Coulomb Force Law and its derivative theory, namely electric field intensity. Indonesia is a tropical area at coordinates 6 ° N - 11 ° S and 95 ° 'BB–141 ° E. The characteristics of tropical lightning currents use the measurement results of the ITB research group in collaboration with JADPEN, and data from international journals, namely peak lightning currents (Io) 10 and 100 kA, and a lightning current frequency of 200 kHz. The time required for lightning to reach peak current (t) is 10-6 seconds. The constant values of materials such as air permittivity, vacuum permittivity are taken from several reference books. Lightning current in the form of impulses, namely:

$$i(t) = I_0 e^{j\omega t} = I_0 e^{j.2.\pi.f.t} \quad (1)$$

I_0 is the peak lightning current, f is the frequency of the lightning current and t is the time of the lightning current wavefront or the time required for lightning to reach the peak value, which is 1 µs or 1x10-6 seconds. The intensity of the electric field is analyzed using Coulomb's Law of Force. Coulomb's Law of Force states that unlike electric charges will attract each other and like electric charges will repel each other. The unit of Coulomb's force is Newton with the attractive force or repulsive force being directly proportional to the magnitude of the charge and inversely proportional to the distance between the two charges and also inversely proportional to the permittivity of the material separating the two charges.

$$\vec{F} \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r2} \overrightarrow{a_r} \quad (2)$$

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This Coulomb force is the attractive force between two point charges (Zhang & Feng, 2020). The derivative of Coulomb's law is the Electric Field Intensity. The electric field intensity is the Coulomb force experienced by a test charge with a value of one positive charge unit. The electric field caused by a point charge is formulated as:

$$\overrightarrow{\vec{E} = \frac{\vec{F}}{Q}} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \overrightarrow{a_r} \quad (3)$$

If there are N point charges spread over a conductor with a length of L (m), then the electric field generated around the tower struck by lightning is caused by the density of the long charges, namely:

$$\rho_L = \frac{Q}{L} \; C/m \quad (4)$$

BTS towers when struck by lightning, what is struck by lightning is not the structure of the BTS tower, but rather the lightning strikes the external Lightning Protection System (SPP) of the tower. The electric charge of lightning will be evenly distributed along the finial and down conductor, so that a line charge density appears, which will generate an electric field. Because: $\rho_L = \frac{Q}{L} C/m$ so, $Q = \int_0^L \rho_L \, dL$, with dL being the length or height of the down conductor and its finial. The electric field intensity around the BTS tower is analyzed using a cylindrical coordinate system with coordinates $A(r, \theta^0, z)$. With r is the radius of the tube, θ^0 is the angle forming the base or lid of the tube valued at 00-3600. Z is the height of the tube and is positioned as the core or axis of the tube. The tube coordinate system is used in the analysis of the electric field around the tower, because the phenomenon of generating an electric field around the lightning strike point resembles a tube object. The density of the length of the lightning charge as the center of the tube, the radius of the tube as a function of the distance between the density of the line charge and the points or locations whose electric fields are analyzed. The symbol Z is the height of the finial and down conductor installed on the tower.

This phenomenon shows that at the same height Z, the angle of 00-3600 will have the same impact as long as the radius of the tube is the same [Hayt, 2006]. Different effects will occur as a function of the radius of the tube, illustrated in Figure 2. The intensity of the electric field generated by the lightning strike current with constant parameters, and the same external SPP components, then the intensity of the electric field around the tower struck by lightning is a function of the distance between the tower and the points of location around the tower, or as a function of the radius of the tube. So that the intensity of the electric field generated by the density of line charges $Q = \int_0^L \rho_L \, dL$ where dL is the length component of the length of the finial and down conductor.

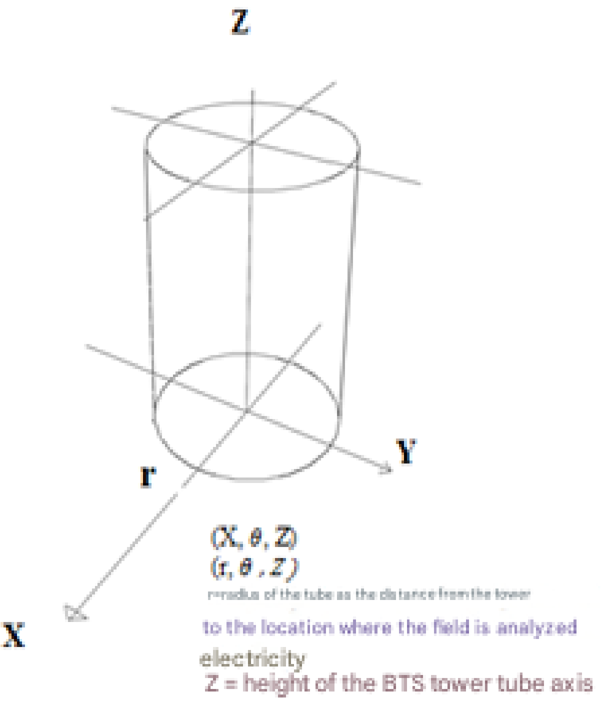

Figure 2. Illustration of a tube coordinate system on a BTS tower

The electric field in a vacuum by a point charge is formulated $\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r2}\overrightarrow{a_r}$ with $\overrightarrow{a_r}$ is a unit vector. If the electric field is generated by the density of line charges and is in the air, and not in a vacuum, then the electric field intensity becomes $E_r = \int_0^L \frac{\rho_L . dL}{2\pi\varepsilon_u . r}\overrightarrow{a_r}$. Air permittivity ($\varepsilon_u$) is the product of the permittivity of a vacuum (ε_0) with the relative permittivity of air (ε_{ru}) or written $\varepsilon_u = \varepsilon_0 . \varepsilon_{ru} N/m = \left(10^{-9} x \frac{1}{36\pi}\right)(1{,}0006) N/m$, The electric field intensity is analyzed using a cylindrical coordinate system with the position A (r, θ^0, Z), with r being the radius of the cylinder, θ^0 is the angle forming the base or lid of the tube with a value of 00-3600 and Z is the height of the tube and is positioned as the core or axis of the tube.

The tube coordinate system is used in the analysis of the electric field around the tower, because the phenomenon of generating an electric field around the lightning strike point resembles a tube shape. The density of the length of the lightning charge as the center of the tube, the radius of the tube as a function of the distance between the density of the line charge and the points or locations whose electric field is to be analyzed. The symbol Z is the height of the finial and down conductor installed on the tower. This phenomenon shows that at the same z height, the angle of 00-3600 will have the same impact as long as the radius of the tube is the same. Different impacts will occur as a function of the radius of the tube. The intensity of the electric field generated by the lightning strike current with constant parameters, and the same external SPP components, then the intensity of the electric field around the tower struck by lightning is a function of the distance between the tower and the points of location around the tower, or as a function of the radius of the tube. So that the Electric Field Intensity generated by the density of the line charge $Q = \int_0^L \rho_L \, dL$ with dL is the length component of the length of the finial and down conductor. The electric field intensity around the BTS tower when the external SPP installed on the tower is struck by lightning, $\vec{E} = \frac{1}{4\pi\epsilon_u}\frac{Q}{r2}\overrightarrow{a_r}$. The research tools used are: land meter, Lasser distance to measure the distance of residential areas with towers, lasser level. The data are processed with Matlab R2009a Software with license 12345678901112131415 and Microsoft Excel.

Result and Discussion

At a lightning current frequency of 200 kHz, then ωt =2.π.f.t =2x3.14x200.103x1.10-6 = 1.256 rad. Omega (ω), the unit is radians/second so the unit of ωt is radians. When the peak lightning current 10 kA, 200 kHz, then :

$= I_0 e^{j2\pi \cdot f \cdot t_P}$. $= 10.10^3 e^{j2.(3,14).(200 \cdot .10^3).(10^{-6})}$

$= 10.10^3 e^{j1,256}$. Euler's theorem states that $e^{j2\pi ft} = e^{j\omega t} = \cos \omega t + j \sin \omega t$.

So, with $\omega t = 1{,}256$ radians and values $\pi = 3{,}14 = 180^0$ so that $\frac{\omega t}{180^0} = \frac{1{,}256}{\pi}$ so that $\omega t = \frac{1{,}256}{\pi} x 180^0 = 71{,}96^0$. *so that* $e^{j2\pi ft} = e^{j\omega t} = \cos 71{,}96^0 + j \sin 71{,}96^0$

Lightning impulse current becomes:

$$i(t) = 10.000\ (\cos 71{,}96^0 + j \sin 71{,}96^0)$$

$$i(t) = \sqrt{3.096{,}8^2 + 9.508{,}4^2}\, tgn^{-1}\left(\frac{9.508{,}4}{3.096{,}8}\right)$$

$$i(t) = 10.000 \angle 71{,}96^\circ A$$

Thus, the magnitude of the lightning electric charge

$$Q = \int_0^{t_p} i dt$$

$$Q = \int_0^{10^{-6}} 10x10^3 e^{j1,256} dt(C)$$

$$e^{j2\pi ft} = e^{j\omega t} = Cos\,\omega t + jSin\omega t = Cos 71{,}96^0 + jSin 71{,}96^0$$

$$Q = \frac{10x10^3}{400x10^3 x\pi} \int_0^{10^{-6}} e^{j.400.10^3,\pi.t} dt$$

$$Q = \frac{1}{jx40\pi} \times \left[Cos 400.000\pi \cdot t + jSin 400.000\pi \cdot t\right]_0^{10^{-6}}$$

$$= -\frac{1}{40\pi} \times j(\cos 71{,}96 + j \sin 71{,}96)$$

$$Q = -\frac{1}{40\pi} xj[0{,}309 + j0{,}9508]$$

$$= -\frac{1}{40\pi} j(-0{,}6903 + j0{,}9508)$$

$$Q = 7{,}57x10^{-3} + j5{,}496x10^{-3} C$$

$$Q = \sqrt{(0{,}00757^2 x 0{,}005496^2} \angle \tan^{-1}(0{,}005496 / 0{,}00757)$$

$$Q = 0{,}0093547269 \angle 35{,}98^\circ C$$

$$MQ = 9{,}3547269 x10^{-3} C$$

The magnitude of the lightning electric charge is MQ = 9.35x10-3 Coulomb. Next, calculate the density of the electric charge in the finial and down conductor with the lightning electric charge evenly distributed on the finial and down conductor installed on a 47 m high tower. While the height of the finial is 2 m, so that the lightning current charge is evenly distributed on the length of the conductor 49 m. Because the radius of the down conductor is very small (in millimeters) compared to the distance of the influence of the lightning strike observed in meters, so from a distance the down conductor is like a line. Furthermore, the density of the lightning charge in the down conductor is assumed to be the density of the line charge, namely :

$$\rho_L = \frac{MQ}{L} = \frac{9{,}3547269 x10^{-3}}{49} = 0{,}1909127939 mC / meter$$

The results of the calculation and analysis of the intensity of the Electric Field of 10 and 100 kA, the frequency of lightning current 200 kHz with a total height of the BTS tower is 49 m. The intensity of the electric field in residential areas is 25 m away, public facility buildings are 300 m away and the safe distance according to various standards from the BTS tower struck by lightning is shown in table 1. The intensity of the Electric Field as a function of distance from the BTS tower is 49 meters high with lightning characteristics of 10 and 100 kA, 200 kHz, shown in Figure 3. The intensity of the electric field around the BTS tower decreases exponentially. It can be seen that the intensity of the electric field is greatly influenced by the value of the peak lightning current, at a constant lightning current frequency of 200 kHz. Lightning current of 10 kA, 200 kHz generates an electric field intensity of 10 kV/m according to the safe standards of INIRC, WHO, IEC and ICNIRP is a distance of 145 m and 1,460 m if the magnitude of the lightning strike current is 100 kA, 200 kHz.

Previous research (Deng et al., 2022; Shindo, 2018; Ströhle et al., 2018), found a safe distance between buildings as a lightning strike point at a distance of 75 meters, the building is 19 m high and its external SPP consists of 2 down conductor channels. The same peak lightning current is 10 kA, the lightning current frequency is 200 kHz and the time required for the lightning current to reach its peak is 10-6 s. Two down conductor channels divide the lightning current into two channels on each down conductor so that the intensity of the electric field generated is also smaller. The height of the building 19 m indicates that the density of the lightning charge is greater because the total amount of lightning charge is divided by 19 m. So the number of down conductors and the height of the tower or the height of the building struck by lightning also affect the intensity of the electric field generated (Ullah et al., 2017). The higher the tower or building struck by lightning, the smaller the density of the lightning charge, and the intensity of the electric field generated is also smaller (Jiang et al., 2020; Ullah et al., 2022; Wang et al., 2021).

Parekh et al. (2018); Thomas et al. (2016), research indicates that the safe distance between 42 m high towers is 280 m, because the tower only consists of one down conductor, so the current that generates a pure electric field is 10 kA, but the electric charge density decreases slightly because the tower is 42 m high.

Table 1. Electric Field Intensity (E) at a distance of 25 and 300 m, and the safe distance from the BTS tower Lightning Parameters: 10 kA, 200 kHz, lightning reaches peak current in 10-6 seconds

Distance from BTS tower (m)	Electric Charge (milli Coulombs)	Line Charge Density (mC/m)	Electric Field Intensity (E) kV/m
25	7.96	0.16	58.45
300	7.96	0.16	4.87
145	7.96	0.16	10.07
Lightning Parameters: 100 kA, 200 kHz, lightning reaches peak current in 10-6 seconds			
Distance from BTS tower (m)	Electric Charge (milli Coulombs)	Line Charge Density (mC/m)	Electric Field Intensity (E) kV/m
25	79.61	1.62	584.59
300	79.61	1.62	48.71
1.46	79.61	1.62	10.01

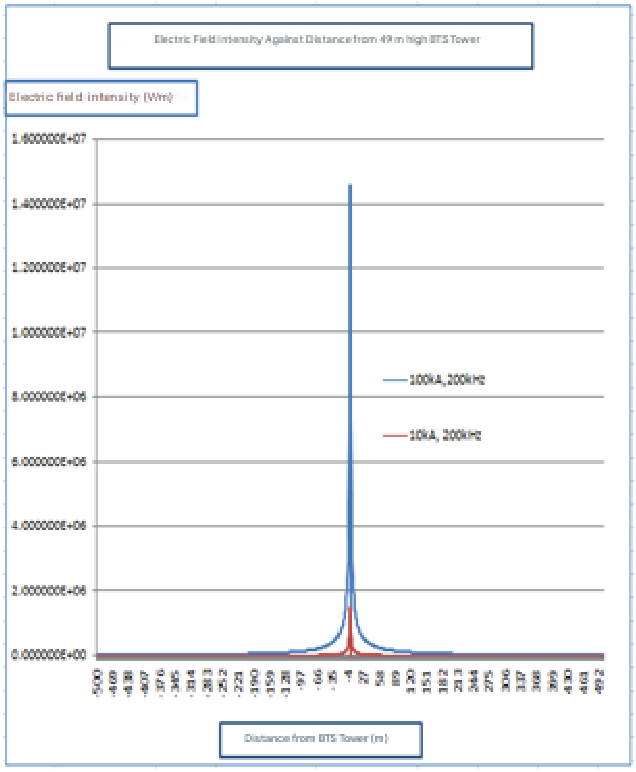

Figure 3. Electric Field Intensity around the 49 m high BTS Tower

Li et al., 2024; Napolitano et al. (2016), made an effort to optimize the lightning protection system, by obtaining the current and voltage induced on the telecommunications line due to lightning strikes. Analysis with numerical codes and measurements at the St. Privat d'Allier trigger station, to measure the disturbance spike on the telecommunications line near the station. The telecommunications network and telecommunications cables behave like very long and interconnected antennas where electromagnetic fields induce currents in a wide frequency range. Baliah et al. (2022) and Boukabou & Kaabouch (2024), conducted a comparative study with the aim of measuring and comparing the electric field strength, magnetic field strength and power density, as a function of distance from several telecommunications towers. Furthermore, the impact of exposure to electric fields and magnetic fields on human health was analyzed.

Denov et al. (2023), measured the peak lightning current in Central Cilacap with statistical results that 50% of the peak lightning current was 18 kA. The magnitude of the peak lightning current is useful for determining the National lightning protection standard, to reduce the potential for damage to equipment and electrical systems in the future. Denov et al. (2023), studied the impact of direct lightning strikes on tower structures based on surface current distribution and electric field intensity. Using Hybrid FEM/MoM software, the simulation of a 75 m high tower structure modeling and lightning parameters refer to the IEC 62305 standard, which is the tropical lightning standard. The maximum current occurs when the lightning current wave front reaches 1.2 µs, the lightning current amplitude is 40 kA and the lightning current frequency is 833.33 kHz. This study is useful for showing the distribution of lightning currents flowing in the tower foot structure when the tower is struck by lightning.

Conclusion

Residential settlements 25 m from the tower are not safe in terms of electric field intensity at lightning strikes of 10 and 100 kA, 200 kHz. Public facility buildings 300 meters from the tower are safe in terms of electric field intensity at lightning strike currents of 10 kA, 200 kHz, but not safe at 100 kA, 200 kHz. The safe distance from the tower is 145 m from the tower at lightning strike currents of 10 kA, 200 kHz. Determining the intensity of the electric field around the tower should be accompanied by direct measurements using certain measurement techniques so that they have more accurate comparison results. The parameters that contribute to the generation of electric field intensity are also used in detail.

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Author Contributions
Conceptualization, N. M. S.; methodology, S.; validation, A. N.; formal analysis, I. A. S. A.; investigation, I. M. G.; resources, M. S. M.; data curation, H. H.: writing—original draft preparation, B. W. D. S.; writing—review and editing, N. M. S.: visualization, S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

References

Abdulsalam, M., Bello, S., Sumaila, Y. A., Abubakar, H., Muhammad, I. B., Muhammad, B. G., & Sabiru, A. Y. (2020). Health Hazards Associated with Electric and Magnetic Field Intensities around Mobile Base Stations in Katsina State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *24*(2), 253–256. https://doi.org/10.4314/jasem.v24i2.10

Altyar, A. E., El-Sayed, A., Abdeen, A., Piscopo, M., Mousa, S. A., Najda, A., & Abdel-Daim, M. M. (2023). Future regenerative medicine developments and their therapeutic applications. *Biomedicine & Pharmacotherapy*, *158*, 114131. https://doi.org/10.1016/j.biopha.2022.114131

Bai, R., Chen, R., Lei, X., & Wu, K. (2024). A Test Report Optimization Method Fusing Reinforcement Learning and Genetic Algorithms. *Electronics*, *13*(21), 4281. https://doi.org/10.3390/electronics13214281

Baliah, J., Subramanian, B., Livingstone, D., Kanwal, B., Zaman, M. U., Srivastava, K. C., Abutayyem, H., Al-Johani, K., David, A. P., Shrivastava, D., & Alam, M. K. (2022). Comparative Analysis of Electric Field Strength, Magnetic Field Strength and Power Density around the Cell Phone Towers of Varying Characteristics with a Proposed Classification Facilitating Research on Human Population. *International Journal of Environmental Research and Public Health*, *19*(21), 14157. https://doi.org/10.3390/ijerph192114157

Bian, X., Wu, Y., Zhou, Q., Jiang, R., Zhang, Y., Chen, L., Qi, Q., & Lyu, W. (2023). Simulation of Cloud-to-Ground Lightning Strikes to Wind Turbines Considering Polarity Effect Based on an Improved Stochastic Lightning Model. *Atmosphere*, *14*(1), 108. https://doi.org/10.3390/atmos14010108

Bjelland, H., Gehandler, J., Meacham, B., Carvel, R., Torero, J. L., Ingason, H., & Njå, O. (2024). Tunnel fire safety management and systems thinking: Adapting engineering practice through regulations and education. *Fire Safety Journal*, *146*, 104140. https://doi.org/10.1016/j.firesaf.2024.104140

Boukabou, I., & Kaabouch, N. (2024). Electric and Magnetic Fields Analysis of the Safety Distance for UAV Inspection around Extra-High Voltage Transmission Lines. *Drones*, *8*(2), 47. https://doi.org/10.3390/drones8020047

Burtsev, A. V., & Selivanov, V. N. (2021). Method for Calculating of Lightning Impact Level on Overhead Transmission Line. *Applied Sciences*, *11*(14), 6609. https://doi.org/10.3390/app11146609

Chiaramello, E., Bonato, M., Fiocchi, S., Tognola, G., Parazzini, M., Ravazzani, P., & Wiart, J. (2019). Radio Frequency Electromagnetic Fields Exposure Assessment in Indoor Environments: A Review. *International Journal of Environmental Research and Public Health*, *16*(6), 955. https://doi.org/10.3390/ijerph16060955

Damianaki, K., Christodoulou, C., Kokalis, C.-C., Kyritsis, A., Ellinas, E., Vita, V., & Gonos, I. (2020). Lightning Protection of Photovoltaic Systems: Computation of the Developed Potentials. *Applied Sciences*, *11*(1), 337. https://doi.org/10.3390/app11010337

Deng, H., Su, F., Yuan, P., Chen, B., An, T., Chen, L., An, Y., & Liu, G. (2024). Exploring the relationship between lightning discharge current and plasma spectrum. *Journal of Atmospheric and Solar-Terrestrial Physics*, *261*, 106307. https://doi.org/10.1016/j.jastp.2024.106307

Deng, Y., Wang, Y., Chen, X., Wen, X., Lan, L., Xiang, M., Hao, P., & Ma, Y. (2022). Effectiveness of array of lightning triggering towers as regional lightning protection for transmission lines in areas with strong lightning activity. *Energy Reports*, *8*, 5246–5255. https://doi.org/10.1016/j.egyr.2022.03.192

Denov, B., Hidayat, S., Suwarno, & Zoro, R. (2023). A Method to Obtain Lightning Peak Current in

Indonesia. *Energies*, *16*(17), 6342. https://doi.org/10.3390/en16176342

Denov, B., Zoro, R., Suwarno, & Hidayat, S. (2023). Evaluation of NFPA 780 Standard for Lightning Protection of Oil and Gas Installation in Indonesia. *2023 International Symposium on Lightning Protection (XVII SIPDA)*, 1–5. https://doi.org/10.1109/SIPDA59763.2023.10349135

Di, X., Gao, X., Peng, L., Ai, J., Jin, X., Qi, S., Li, H., Wang, K., & Luo, D. (2023). Cellular mechanotransduction in health and diseases: From molecular mechanism to therapeutic targets. *Signal Transduction and Targeted Therapy*, *8*(1), 282. https://doi.org/10.1038/s41392-023-01501-9

Florkowski, M., Furgał, J., & Kuniewski, M. (2021). Lightning Impulse Overvoltage Propagation in HVDC Meshed Grid. *Energies*, *14*(11), 3047. https://doi.org/10.3390/en14113047

Ganongo, A. O., Gogom, M., Nianga-Apila, Obita, L. L. A., & Ganga, G. (2024). Optimisation of lightning current discharge to the ground in electrical networks: Introduction of the proportionality coefficient (K). *Electric Power Systems Research*, *231*, 110348. https://doi.org/10.1016/j.epsr.2024.110348

Giannino, G., Braia, V., Griffith Brookles, C., Giacobbe, F., D'Ascenzo, F., Angelini, F., Saglietto, A., De Ferrari, G. M., & Dusi, V. (2024). The Intrinsic Cardiac Nervous System: From Pathophysiology to Therapeutic Implications. *Biology*, *13*(2), 105. https://doi.org/10.3390/biology13020105

Hopsort, G., Cacciuttolo, Q., & Pasquier, D. (2024). Electrodialysis as a key operating unit in chemical processes: From lab to pilot scale of latest breakthroughs. *Chemical Engineering Journal*, *494*, 153111. https://doi.org/10.1016/j.cej.2024.153111

Jalilian, H., Teshnizi, S. H., Röösli, M., & Neghab, M. (2018). Occupational exposure to extremely low frequency magnetic fields and risk of Alzheimer disease: A systematic review and meta-analysis. *NeuroToxicology*, *69*, 242–252. https://doi.org/10.1016/j.neuro.2017.12.005

Jiang, R., Lyu, W., Wu, B., Qi, Q., Ma, Y., Su, Z., Wu, S., Xie, Z., & Tan, Y. (2020). Simulation of cloud-to-ground lightning strikes to structures based on an improved stochastic lightning model. *Journal of Atmospheric and Solar-Terrestrial Physics*, *203*, 105274. https://doi.org/10.1016/j.jastp.2020.105274

Khadijah, S., Adrianus Inu Natalisanto, & Pratiwi Sri Wardani. (2024). Mapping of Electromagnetic Field Radiation Intensity in the JL Base Transceiver Station (BTS) Area. Kenangan 05 and the Impact of Health in Society. *Jurnal Inotera*, *9*(1), 76–80. https://doi.org/10.31572/inotera.Vol9.Iss1.2024.ID295

Li, D., Sun, W., Song, K., Zhu, R., Zhong, Z., Ding, T., & Gao, J. (2024). Research on Differentiated Lightning Protection of Overhead Distribution Lines under Continuous Lightning Strikes. *Energies*, *17*(18), 4568. https://doi.org/10.3390/en17184568

Li, J., & Jin, L. (2022). The test method of the thunder and lightning direct effect protection equipment. *Journal of Physics: Conference Series*, *2378*(1), 012050. https://doi.org/10.1088/1742-6596/2378/1/012050

Lucas, J. R. (2023). Lightning Protection of Stupas in Sri Lanka. *Engineer: Journal of the Institution of Engineers, Sri Lanka*, *56*(3), 121–130. https://doi.org/10.4038/engineer.v56i3.7609

Mahadi, P., Vonica, E., Rezkika, S. I., & Novalianda, S. (2022). Evaluasi sistem penggroundingan tower base transceiver station pada PT. X. *Jurnal VORTEKS*, *3*(1), 209–215. https://doi.org/10.54123/vorteks.v3i1.160

Martinez, O., Ronda, S., Oliver, C., Marquez, P., & Miranda, J. M. (2021). Verification Protocols for the Lightning Protection of a Large Scale Scientific Instrument in Harsh Environments: A Case Study. *Journal of Power and Energy Engineering*, *09*(06), 12–28. https://doi.org/10.4236/jpee.2021.96002

Napolitano, F., Tossani, F., Borghetti, A., Nucci, C. A., Martinez, M. L. B., Lopes, G. P., Santos, G. J. G. D., & Fagundes, D. R. (2016). Lightning performance of a real distribution network with focus on transformer protection. *Electric Power Systems Research*, *139*, 60–67. https://doi.org/10.1016/j.epsr.2015.11.019

Negara, I. M. Y., Fahmi, D., Asfani, D. A., Hernanda, I. S., Pratama, R. B., & Ksatria, A. B. (2021). Investigation and Improvement of Standard External Lightning Protection System: Industrial Case Study. *Energies*, *14*(14), 4118. https://doi.org/10.3390/en14144118

Parekh, B. S., Ou, C.-Y., Fonjungo, P. N., Kalou, M. B., Rottinghaus, E., Puren, A., Alexander, H., Hurlston Cox, M., & Nkengasong, J. N. (2018). Diagnosis of Human Immunodeficiency Virus Infection. *Clinical Microbiology Reviews*, *32*(1), e00064-18. https://doi.org/10.1128/CMR.00064-18

Park, J., Jeong, E., & Seomun, G. (2020). Extremely Low-Frequency Magnetic Fields Exposure Measurement during Lessons in Elementary Schools. *International Journal of Environmental Research and Public Health*, *17*(15), 5284. https://doi.org/10.3390/ijerph17155284

Poole, G. (2019). Calculating Newton's Gravity (Big G) from Coulomb, Lorentz and Centripetal Force. *Journal of High Energy Physics, Gravitation and Cosmology*, *05*(03), 623–628. https://doi.org/10.4236/jhepgc.2019.53034

Shindo, T. (2018). Lightning striking characteristics to tall structures. *IEEJ Transactions on Electrical and Electronic Engineering*, *13*(7), 938–947. https://doi.org/10.1002/tee.22649

Song, Y., Xu, C., Li, X., & Oppong, F. (2024). Lightning-Induced Wildfires: An Overview. *Fire*, *7*(3), 79. https://doi.org/10.3390/fire7030079

Ströhle, M., Wallner, B., Lanthaler, M., Rauch, S., Brugger, H., & Paal, P. (2018). Lightning accidents in the Austrian alps – a 10-year retrospective nationwide analysis. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, *26*(1), 74. https://doi.org/10.1186/s13049-018-0543-9

Thomas, H., Marian, A., Chervyakov, A., Stückrad, S., Salmieri, D., & Rubbia, C. (2016). Superconducting transmission lines – Sustainable electric energy transfer with higher public acceptance? *Renewable and Sustainable Energy Reviews*, *55*, 59–72. https://doi.org/10.1016/j.rser.2015.10.041

Ullah, I., Baharom, M., Luqman, H. M., Ahmad, H., & Zainal, Z. (2017). Electric Filed Intensity of the Lightning Strikes on Lightning Air Terminals Installed on Building Structures. *International Journal of Electrical and Computer Engineering (IJECE)*, *7*(6), 3105. https://doi.org/10.11591/ijece.v7i6.pp3105-3113

Ullah, I., Bahrom, M. N. R. B., Khan, M. A., & Qazi, A. (2022). An Experimental Study of Electromagnetic Field Propagation Due to Lightning Upward Leaders and Its Probability on Different Small-Scale Structures. *Energies*, *15*(18), 6597. https://doi.org/10.3390/en15186597

Wang, L., Wan, H., & Chen, Y. (2021). Approximate Calculation and Feature Analysis of Electric Field in Space by Thunderclouds. *International Journal of Antennas and Propagation*, *2021*, 1–9. https://doi.org/10.1155/2021/1827619

Zhang, H., & Feng, S. (2020). One Method to Derivate Coulomb's Law between Two Charges. *Journal of Applied Mathematics and Physics*, *08*(12), 2880–2885. https://doi.org/10.4236/jamp.2020.812213