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REVIEW

The Development of Lightning Protection and Grounding Systems: A Survey

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ABSTRACT

The development in the industry and the increasing demand for electrical energy has made it necessary to provide electrical energy safely and continuously. A well-designed and implemented lightning protection and grounding system will protect users and equipment against malfunctions in electrical installations. Therefore, lightning protection and grounding systems have become an essential topic in recent years, and many studies have been conducted in the literature based on this. In this study, we reviewed more than 45 studies on this subject conducted in the past five years.

Keywords: Lightning protection, grounding systems, power systems, artificial intelligence-based methods

Introduction

Electric energy has become an indispensable part of our lives. Especially for the growing and developing industry, electrical energy is even more vital. Ensuring continuity of production, safety of people and animals, and reducing costs depend on the correct and reliable installation of electrical systems. Systems that are not designed correctly can harm humans or animals. In addition, repairs or equipment changes can lead to serious costs or interruption in production. Therefore, grounding and lightning protection systems have been a topic of many studies in recent years. Lightning discharge currents are dissipated safely in the grounding system by lightning protection systems. Lightning protection systems protect the electrical and mechanical components in the buildings against lightning discharge currents. Lightning can cause serious damage to transmission and distribution lines, wind turbines, or buildings. Lightning is one of the most frequent events causing transmission line outages. Estimating lightning outages before they occur is an effective method that can be used to prevent negative consequences. Nowadays, artificial intelligence-based applications using lightning and lightning outage data recorded in power systems are becoming widespread to estimate lightning outages.

Grounding is defined as the joining of inactive sections and zero conductors and the sections connected to them in a conductive way with the help of an electrode. In other words, earthing, which ensures the prevention of leakage that may occur in electronic devices without causing damage, is the process of transmitting electrical currents to the ground. This ensures the protection of life and property in the event of a possible electrical leak. Damages are prevented both in the structure of the buildings and in human health.

In this study, we reviewed recent studies on lightning protection and grounding systems and also artificial intelligence-based lightning protection and grounding systems. Thus, it is aimed to provide a broad perspective on these subjects to the researchers.

Literature Review

The articles examined are presented under the following titles: Lightning Protection, Grounding Systems, and Artificial Intelligence-Based Lightning Protection and/or Grounding Systems. Recently, artificial intelligence-based studies have become quite common and important. Therefore, artificial intelligence-based lightning protection and grounding systems were examined under a different title. The method, algorithms, and the software used in articles examined in this survey are summarized in Figure 1.

Lightning Protection

Today, the use of renewable energy sources has increased signifi-

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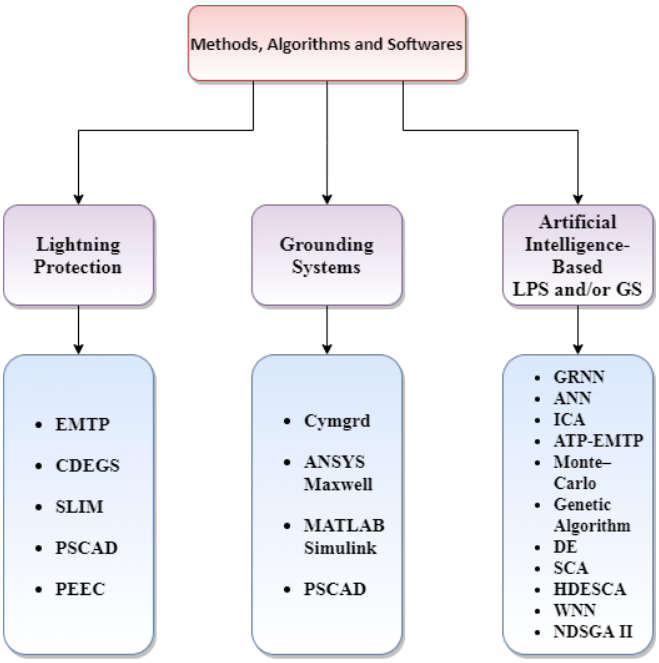

Figure 1. Methods, algorithms, and software used in the articles

cantly, and the number of solar and wind power plants installed worldwide has also increased. These power plants are generally built on large areas with high altitudes. In wind farms, both the areas where they are installed, and the special structure of the turbines make them more vulnerable to lightning strikes. Therefore, the location of the wind farm, influence of the local terrain, and seasonal variation of lightning play a critical role for conducting risk assessment [1].

The distance between the turbines is also important for lightning protection in wind farms. In the study conducted by Zhang et al. [2], the distance between two wind turbines required for protection against lightning is calculated on the basis of the new electrical geometric model of wind turbine blade. The results showed that for a typical 1.5 MW wind turbine, the layout distance in the vertical direction should be 4-6 times the length of the blade.

Lightning strikes can seriously damage wind turbines. This causes high cost and time loss to replace or repair components damaged by lightning strikes [3]. In addition, lightning strikes can be a serious danger for operators. Therefore, lightning protection systems are essential and vital to protect both the turbines components and human operators. Damages caused by lightning strikes on a wind turbine blade can be classified as delamination, deboning, tip detachment, and shell detachment. Garolera et al. [4] investigated 304 lightning damages on wind turbine blades in different wind farms in USA, and it was observed that the most frequent lightning damage was delamination.

Receptor behaviors under the lightning strikes were experimentally investigated through various experimental configurations. In the study conducted by Guo et al. [5] the experiments indicated that although negative lightning strikes are much more common than positive lightning strikes in nature, positive lightning strikes have higher peak currents than negative lightning strikes. Therefore their damage may be greater and more severe.

A lightning protection system is critical in the design and installation of a wind farm. Deshagoni et al. [6] used CDEGS software package to find the factors that determine the effectiveness of a wind turbine generator. The results showed that grounding system is crucial for wind turbine lightning protection systems. Moreover, it has been observed that low resistivity soil sites and proper design of soil stratification and earth electrodes can improve the effectiveness of the grounding system. An experimental study that was conducted using a small-scale wind turbine has also shown that a grounding system is essential for design of lightning protection system of the wind turbine [7].

Overvoltage can damage underground cables sometimes when direct lightning strikes the wind turbine. Sekioka et al. [8] used electromagnetic transients program (EMTP) for lightning surge analysis when the direct lightning struck the generation system. As a result, it has been revealed that the cable model plays a critical role for accurate surge analysis. In addition, simulation results show that the lightning overvoltage depends on the grounding condition of the cable sheath.

In the study conducted by Long et al. [9] self-consistent leader inception and propagation model is used for analyzing the effect of the rotation angle of the blade and the wind and the prospective return stroke peak current on the location of lightning strikes. The results show that only when the blade of a wind turbine rotates sufficiently from its initial position until the start of the dart leader approach, a new strike point is created.

Lightning strikes are also a serious problem for solar PV systems. When lightning strikes a solar PV system, transient voltage and current appears. Zaini et al. [10] simulated the effects of lightning strikes on a solar PV system by using PSCAD. The results indicated that a transient current will appear at the nearest point to the lightning strike. Zhang et al. [11] proposed a PEEC method for analyzing lightning transients in PV systems. Further, an experiment was conducted for the confirmation of the proposed method. Although the induced voltage was not significantly affected by soil resistivity, the results of the study revealed that the voltage between the DC cable and ground was significantly affected by the soil resistivity.

It is crucial to protect the transmission and distribution lines against lightning to provide consumers with quality and continuous electrical energy. To improve the lighting protection level, arrester and grounding line can be used for distribution lines [12]. A distribution feeder can be affected by lightning in two ways. First, the lightning can have a direct effect on overhead distribution lines. Second, lightning strikes the ground and as a result of this an overvoltage is induced in the insulator strings [13].

In the study conducted by Banjanin [14] special lightning protection methods were examined comparatively, and their efficiencies was calculated and compared for reduction to the overhead lines back-flashover rate. The EMTP/alternative transients program (EMTP-ATP) software was used for creating system equivalent circuits. It has been demonstrated that using underbuilt wires can provide a highly efficient lightning protection system.

Gu et al. [15] conducted the risk assessment of an ultrahigh voltage DC line as an example to improve the existing electrogeometric model. The back propagation neural network algorithm was applied to integrate three methods of warning using radar echoes, atmospheric electric fields, and lightning detection data to develop the warning model.

Ding et al. [16] established Sunan unified power flow controller (UPFC) using the EMTP-ATP to analyze the lightning invasion wave. In addition, a double exponential wave was used to simulate the waveform of lightning current. Simulation results suggested that the arrangement of the arrester has an essential role in limiting the lightning overvoltage level in UPFC.

Resende and Lopes used [17] , the EMTP-RV software to examine the transient behavior of the pole-mounted distribution transformers (DT). The results showed that installing a surge protection device not only on the medium voltage (MV) side of the transformer but also on the low voltage (LV) side is necessary for full protection of the pole-mounted DT.

In the study conducted by Zhang et al. [18] numerical simulation was used to analyze the relationship between the lightning protection effect of ground resistance and overhead ground wire, lightning strike position, insulator type, and tower type for the 10 kV distribution line. From the results, it was observed that the tower type, ground resistance, and insulator type had significant effects on lightning protection.

Grounding Systems

Implementing an efficient grounding system is not an easy task. Good planning and design require quality equipment and experienced practitioners. The grounding system is not expensive compared with the entire electrical facility, but it is an investment for the future of the facility. Grounding systems protect humans, buildings, and equipment from overvoltage, fire, and electrical leakage from metal surfaces.

To design an economical and reliable grounding system, the soil resistance of the site must be accurately measured. The Wenner method is frequently used in the literature to measure soil resistance. In the study conducted by Salam et al. [19] soil resistivity of two different sites (one with wet soil and one with dry soil) near the electrical substation were measured with the Wenner four-pole equal method, and the accuracy of the measurements was checked by taking the measurements and calculations into account with the Cymgrd simulation software. As a result, simulation results were found to be very close to the measurements.

There are many methods recently used in the literature to improve grounding performance. If the soil resistance value is unacceptable, methods such as salting treatment, chemical treatment, and vertical rods can be used to reduce the soil resistance [20]. Faudzi et al. [21] reduced the ground electrode resistance by using palm oil fuel ash as the backfill, and improvements in grounding performance exceeding 90% were achieved. Myint et al. [22] demonstrated that earthing resistance value could be changed with changing the electrode diameter and length and variation of the spacing of electrodes on earthing resistance.

Gonçalves et al. [23] presented two electrical models to simulate the responses of the grounding system to current impulses with capacitive or inductive characteristics. For the evaluation of the models, experimental tests were conducted in two different grounding systems. It was revealed that the proposed model had advantages such as ease of circuit implementation and parameter calculation.

The major role of wind turbines grounding system is reducing the overvoltage, thus preventing the damage caused by lightning. Grounding system of low impedance provides a suitable ground termination to limit dangerous overvoltage [24].

Wind turbine grounding systems generally show capacitive behavior when frequency-dependent soil parameters are considered [25]. In the study conducted by Sunjerga et al. [26] the impedance of the interconnected wind turbine grounding system was investigated using numerical simulation in which frequency-dependent soil parameters were considered. As a result, it was observed that when the conductivity of the soil was poor, additional horizontal wires and the interconnection of the wind turbine grounding systems can help keep the impedance within the recommended values. Similar results were obtained from analysis in the study conducted by Sunjerga et al. [27].

Alipio et al. [28] evaluated the relationship between the lightning response of the wind turbine grounding systems and the frequency dependence of the ground electrical parameters It was observed that the frequency dependence effect decreases the impulse impedance and the grounding potential rise. With the widespread use of offshore wind turbines worldwide, many studies on grounding systems for offshore turbines have been conducted [29-31]. Guo et al. [32] proposed topologies and strategies that could be used in grounding fault clearance in series connection based offshore wind farms were proposed. The experiments and simulations revealed that these strategies and topologies were practicable for this purpose.

Zhu et al. [33] examined a four-plate capacitive power transfer system experimentally and theoretically with different grounding connections. The system output performance and electric field distribution of the proposed system with different grounding connections were analyzed using MATLAB Simulink and ANSYS Maxwell. The result showed that when one pair of the coupled transmitter and receiver plates was grounded, some improvement was achieved. This type of grounding connection had a minimum ef-

fect on power transfer and also achieved the lowest leakage electric field and the highest voltage gain.

Djamel et al. [34] developed a model to calculate the transient behavior of the grounding systems when a lightning struck the power system. The results showed that the electrical properties of the soil, the lightning current intensity, and the geometry of the ground electrode significantly affected the impulse performance of the grounding systems.

In the study conducted by Rizk et al. performance of the thermal power plant grounding system was investigated when lightning strikes a nearby transmission tower. The thermal power plants are typically constructed close to the water for cooling process; therefore, in the study, impact of the nearby sea was considered. The results revealed that the sea had considerable impact on the propagation of electromagnetic fields through the grounding system and the distribution of the ground potential rise on the grounding system owing to its high conductivity.

Jayamaha et al. [36] evaluated the ground fault characteristics of DC micro grids using PSCAD/EMTDC under different grounding configurations. Analyses have shown that the safe operation of DC micro grids depends on the proper selection of ground fault detection scheme and the grounding configuration.

Trifunovic and Kostic [37] aimed to calculate grounding resistance of the grounding system used in typical 110 kV transmission line towers. They used a method based on the finite element method modeling and proposed that as this method was general, it could be applied to any grounding system.

Niquepa et al. [38] presented modeling and simulation of an underground mining power system with a high resistance ground. Distributed capacitance of conductors was taken into account. It has been noted that for a well-designed high resistance grounding method, the distributed capacitance of the entire system should be taken into account.

Artificial Intelligence-Based Lightning Protection and/or Grounding Systems

Studies are ongoing to develop lightning protection systems to prevent line outages and ensure safe and quality power transmission. However, to prevent lightning outages, besides a well-designed lightning protection system, the operation mode needs to be adjusted beforehand. This is possible by predicting lightning outages. Grounding systems provide protection against fault currents arising from situations such as lightning in electrical systems. In recent years, engineers have to estimate the behavior of grounding systems; and therefore, multiple studies on the same have been conducted in the literature.

In the study conducted by Aslani et al. [39] an automated approach to numerical analysis is presented to measure the number of direct lightning strikes at high towers. The lightning leader progression for all possible lightning current values and for all lightning leader tip positions in the space above the tower was performed using the conventional numeric method.

Sarajcev et al. [40] proposed a novel approach that used a combination of statistical lightning protection systems efficiency and genetic algorithm (GA) in designing techno–economically optimal external lightning protection systems of open-air substations. A large number of lightning strikes were simulated by means of the Monte–Carlo method. In addition, GA was employed to design the lightning protection systems for optimal design of air termination. According to the results, GA has been successfully used to optimize station protection designs.

Xie et al. [41] analyzed data from a power company's operation and management system for general regression neural networks (GRNN) input parameters, and then GRNN was built to perform lightning outage prediction. Comparison with back propagation and radial basis function neural networks was made to validate the effectiveness of the proposed method. According to the simulation results, the proposed method provided better prediction performance. Ullah et al. [42] proposed object detection using artificial neural network (ANN) to protect the buildings from the lightning strikes. The ANN was trained by different input, output, and hidden layer. As a result, different objects have been successfully identified for the lightning strike configuration using this method.

In the study conducted by Graditi et al. [43] the non-dominated sorting GA II was used to solve an optimization problem, which concerned the optimal reconfiguration of automated distribution networks that contain different grounded HV/MV transformers and also included safety issues among the objectives.

In grounding system behavior, two sections are important: soil ionization and inductive behavior. Gholami Farkoush et al. [44] investigated lightning effect on the grounding body by focusing on the inductive behavior of the grounding grid. A grounding simulation was designed in ATP-EMTP under lightning strike in normal computation. GA was proposed to a system for the optimization of the grounding grids. Gholami Farkoush et al. [45] analyzed and optimized the touch and step voltages in a power grid by using similar methods.

Gabr et al. [46] proposed GA to control the cost of grounding grid under the same security limitations. The proposed method was used to design the substation grounding grid of the "El Qasr" power plant. Moreover, CYMGRD software was used to simulate the design.

Sengar and Chandrasekaran [47], aimed to reduce the total cost and limit the value of the safety parameters to obtain the most suitable grounding system. For this purpose, sine-cosine algorithm, differential evolution, and hybrid sine-cosine algorithm with differential evolution algorithm (HDESCA) were used, and their effectiveness was evaluated in the design. The results indicated that the design based on HDESCA technique provided minimum safety parameters and less cost compared with the others.

Androvitsaneas et al. [48] developed a model to predict the behavior of grounding systems using wavelet neural network (WNN).

Classification of the articles by years			
	Lightning Protection	Grounding Systems	Artificial Intelligence-Based LPS and/or GS
2016	4,10	34,37	43,46,48
2017	2,9,17	19,28	
2018	1,3,5,8,13,14	20,24,26,29,30,31,36,38	40,44
2019	6,7,11,12,15,16,18	23,25,27,35	39,41,42,45,47
2020		21,22,32,33	

Figure 2. Classification of the articles by years

For the training of the developed WNN, measurements of rainfall height and soil resistivity obtained from a field were used. The results show that the developed WNN was successful in predicting ground resistance for all rods.

Discussion

In this article, the recent studies on lightning protection and grounding systems were examined and the importance of this issue, which has increased in recent years, was reiterated. In addition, it has been observed that there is a focus on artificial intelligence-based studies leading to an improvement in this field. All reviewed articles are summarized by years in Figure 2.

Conclusion

The importance of lightning protection and grounding systems is increasing in many different areas with increasing focus in research on this subject as evidenced by literature review. With the incessant increase in power systems capacity and voltage grade, the proper design of lightning protection and grounding systems becomes more and more essential. Many different methods are used for the design and optimization of grounding and lightning protection systems. For instance, programs such as ATP-EMTP, PSCAD, and MATLAB are frequently used for simulation and analysis in recent studies. In addition, successful development of artificial intelligence-based algorithms has enabled these algorithms to be used in studies on lightning protection and grounding systems. In addition to the methods currently used, future studies should focus on artificial intelligence-based algorithms, which are relatively less in the literature and are available for development.

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References

1. V. March, "Key issues to define a method of lightning risk assessment for wind farms," Electric Power Systems Research, vol. 159, pp. 50-57, 2018. [Crossref]
2. W. Zhang, L. Zhang, J. Cui, G. Wang, T. Zhao, L. Zou and X. Wang, "Optimal layout of wind farm for lightning protection based on lightning leader development model," The Journal of Engineering, vol. 13, pp. 2261-2265, 2017. [Crossref]
3. T. Funabashi, K. Yamamoto and S. Sekioka, "Lightning protection and EMC issues of renewable energy sources," In 2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility EEE EMC & APEMC 2018, Singapore, May 14-17, 2018, IEEE, 2018. pp. 805-810. [Crossref]
4. A. C. Garolera, S. F. Madsen, M. Nissim, J. D. Myers and J. Holboell, "Lightning damage to wind turbine blades from wind farms in the US," IEEE Transactions on Power Delivery, vol. 31, no. 3, pp. 1043-1049, 2016. [Crossref]
5. Z. Guo, Q. Li, Y. Ma, H. Ren, Z. Fang, C. Chen, and W. H. Siew, "Experimental study on lightning attachment manner to wind turbine blades with lightning protection system, " IEEE Transactions on Plasma Science, vol. 47, no.1, pp.635-646, 2018. [Crossref]
6. R. G. Deshagoni, T. Auditore, R. Rayudu and C. P. Moore, "Factors determining the effectiveness of a wind turbine generator lightning protection system," IEEE Transactions on Industry Applications, vol. 55, no. 6, pp. 6585-6592, 2019. [Crossref]
7. A. S. Zalhaf, M. Abdel-Salam, D. E. A. Mansour, M. Ahmed and S. Ookawara, "An Experimental Study of Lightning Overvoltages on a Small-scale Wind Turbine Model," Energy Procedia, vol. 156, pp. 442-446, 2019. [Crossref]
8. S. Sekioka, H. Otoguro and T. Funabashi, "A study on overvoltages in windfarm caused by direct lightning stroke," IEEE Transactions on Power Delivery, vol. 34, no. 2, pp. 671-679, 2018. [Crossref]
9. M. Long, M. Becerra and R. Thottappillil, "On the attachment of dart lightning leaders to wind turbines," Electric power systems research, vol. 151, pp. 432-439, 2017. [Crossref]
10. N. H. Zaini, M. Z. A. Ab-Kadir, M. Izadi, N. I. Ahmad, M. M. Radzi, N. Azis and W. W. Hasan, "On the effect of lightning on a solar photovoltaic system," In 2016 33rd International Conference on Lightning Protection, ICLP 2016, Estoril, Portugal, September 25-30, 2016 IEEE, 2016. pp. 1-4. [Crossref]
11. Y. Zhang, H. Chen and Y. Du, "Lightning protection design of solar photovoltaic systems: Methodology and guidelines," Electric Power Systems Research, vol. 174, pp. 105877, 2019. [Crossref]
12. X. Tang, F. Yang, Z. Zheng, Y. Hu, X. Wu, and H. Hou. "Research on the Improving Lighting Protection Level for Strong Lightning Activity Area and Easily Suffering Lighting Strike Distribution Line," Procedia Computer Science, vol. 155, pp. 809-814, 2019. [Crossref]
13. R. J. Cabral, R. C. Leborgne, A. S. Bretas, G. D. Ferreira, and J. A. Morales, "Lightning protection system design for distribution networks based on System Average Interruption Frequency minimization," Electric Power Systems Research, vol. 160, pp. 1-12, 2018. [Crossref]
14. M. S. Banjanin, "Application possibilities of special lightning protection systems of overhead distribution and transmission lines," International Journal of Electrical Power & Energy Systems, vol. 100, pp. 482-488, 2018. [Crossref]
15. S. Gu, J. Wang, M. Wu, J. Guo, C. Zhao, and J. Li, "Study on lightning risk assessment and early warning for UHV DC transmission channel," High Voltage, vol. 4, no. 2, pp. 144-150, 2019. [Crossref]
16. T. Ding, F. Tao, H. He, J. Zhong, J. He and H. He, "Study on the lightning overvoltage protection of a 500 kV unified power flow controller station," The Journal of Engineering, vol. 16, pp. 1100-1106, 2019. [Crossref]
17. F. O. Resende and J. A. P. Lopes, "Using low-voltage surge protection devices for lightning protection of 15/0.4 kV pole-mounted distribution transformer," CIRED-Open Access Proceedings Journal, vol. 1, pp. 888-892, 2017.

18. H. Zhang, X. Li, C. Wei, Z. Ma, K. Mao, and X. Wu, "Simulation of Lightning Protection Effect for Overhead Ground Wire of 10kV Distribution Lines," In 2019 4th International Conference on Intelligent Green Building and Smart Grid, IGBSG 2019, Yichang, China, September 6-9, 2019, IEEE, 2019. pp. 270-273. [Crossref]
19. Md. A. Salam, Q. M. Rahman, S. P. Ang, and F. Wen, "Soil resistivity and ground resistance for dry and wet soil," Journal of Modern Power Systems and Clean Energy, vol. 5, no. 2, pp. 290-297, 2017. [Crossref]
20. S. C. Malanda, I. E. Davidson, E. Singh, and E. Buraimoh, "Analysis of Soil Resistivity and its Impact on Grounding Systems Design," In 2018 IEEE PES/IAS PowerAfrica, Cape Town, South Africa, Jun 26-29, 2018, IEEE, 2018. pp. 324-329. [Crossref]
21. A. H. M. Faudzi, C. L. Wooi, N. A. Ahmad, S. N. M. Arshad, H. N. Afrouzi, and M. N. K. Rohani, "A study on copper and galvanized grounding performance using palm oil fuel ash as new additive material," In Journal of Physics: Conference Series, vol. 1432, no. 1, pp. 012037, 2020. [Crossref]
22. S M. Myint, K. T. Hla, and T. T. Tun, "Effective earthing system of electrical power engineering department using optimal electrodes," International Journal of Advanced Technology and Engineering Exploration, vol. 7, no. 63, pp. 28-35, 2020. [Crossref]
23. M. F. B. R. Gonçalves, E. G. da Costa, A. F. Andrade, V. S. Brito, G. R. S. Lira and G. V. R. Xavier, "Grounding system models for electric current impulse," Electric Power Systems Research, vol. 177, pp. 105981, 2019. [Crossref]
24. R. Alipio, M. T. C. de Barros, M. A. O. Schroeder and K. Yamamoto, "Lightning and Low-Frequency Performance of Interconnected Grounding Systems of Wind Turbines," In 2018 34th International Conference on Lightning Protection, ICLP 2018, Rzeszow, Poland, September 0-7, 2018, IEEE, 2018. pp. 1-6. [Crossref]
25. R. Alipio, D. Conceição, A. De Conti, K. Yamamoto, R. N. Dias, and S. Visacro, "A comprehensive analysis of the effect of frequency-dependent soil electrical parameters on the lightning response of wind-turbine grounding systems," Electric Power Systems Research, vol. 175, pp. 105927, 2019. [Crossref]
26. A. Sunjerga, Q. Li, D. Poljak, M. Rubinstein and F. Rachidi "Transient Impedance of Interconnected Wind Turbine Grounding Systems," In 2018 26th International Conference on Software, Telecommunications and Computer Networks, SoftCOM 2018, Croatia, Supetar September 13 - 15, 2018, IEEE, 2018. pp. 1-4. [Crossref]
27. A. Sunjerga, Q. Li, D. Poljak, M. Rubinstein and F. Rachidi, "Isolated vs. interconnected wind turbine grounding systems: Effect on the harmonic grounding impedance, ground potential rise and step voltage," Electric Power Systems Research, vol. 173, pp. 230-239, 2019. [Crossref]
28. R. Alipio, D. Conceicao, R. N. Dias, S. Visacro and K. Yamamoto, "The effect of frequency dependence of soil electrical parameters on the lightning performance of typical wind-turbine grounding systems," In 2017 International Symposium on Lightning Protection, XIV SIPDA 2017, Natal - RN, Brazil, October 2-6, 2017, IEEE, 2017. pp. 353-358. [Crossref]
29. S. Tao, X. Zhang and Y. Wang, "A modeling analysis of grounding resistance and sea surface potential on the jacket foundation offshore wind turbines," In E3S Web of Conferences, EDP Sciences, vol. 72, pp. 01004, 2018. [Crossref]
30. R. Araneo, G. Lovat, S. Celozzi and P. Burghignoli, "Numerical analysis of mutual transient voltages in grounding systems of offshore wind farms," In 2018 International Applied Computational Electromagnetics Society Symposium, ACES 2018, United States, March 24-29, 2018, IEEE, 2018. pp. 1-2. [Crossref]
31. E. Stracqualursi, R. Araneo, P. Burghignoli, S. Celozzi and G. Lovat, "Offshore Wind Towers Interaction Through Their Grounding Systems," in 2018 International Symposium on Electromagnetic Compatibility, EMC EUROPE 2018, Netherlands · University of Applied Science, August 27-31, 2018, IEEE, 2018. pp. 908-912. [Crossref]
32. G. Guo, K. Zha, J. Zhang, Z. Wang, F. Zhang and J. Cao, "Grounding Fault in Series-Connection-Based Offshore Wind Farms: Fault Clearance," IEEE Transactions on Power Electronics, vol. 35, no. 9, pp. 9357-9367, 2020. [Crossref]
33. Q. Zhu, L. J. Zou, M. Su, and A. P. Hu, "Four-plate capacitive power transfer system with different grounding connections," International Journal of Electrical Power & Energy Systems, vol. 115, pp.105494, 2020.
34. I. Djamel, F. H.Slaoui and S. Georges, "Transient response of grounding systems under impulse lightning current," in 2016 Electric Power Quality and Supply Reliability, PQ 2016, Tallinn, Estonia, August 29-31, 2016, IEEE, 2016. pp. 71-75. [Crossref]
35. M. E. M. Rizk, M. Lehtonen, Y. Baba and S. Abulanwar, "Performance of Large-Scale Grounding Systems in Thermal Power Plants Against Lightning Strikes to Nearby Transmission Towers," IEEE Transactions on Electromagnetic Compatibility, vol. 61, no. 2, pp. 400-408, 2019. [Crossref]
36. D. K. J. S. Jayamaha, N. W. A. Lidula, and A. D. Rajapakse, "Ground Fault Analysis and Grounding Design Considerations in DC Microgrids," in 2018 IEEE 4th Southern Power Electronics Conference, SPEC 2018, Singapore, Singapore, December 10-13, 2018, IEEE, 2018. pp. 1-8. [Crossref]
37. J. Trifunovic and M. Kostic, "Quick calculation of the grounding resistance of a typical 110kV transmission line tower grounding system," Electric Power Systems Research, vol. 131, pp. 178-186, 2016. [Crossref]
38. J. D. R. Niquepa, G. A. G. Patiño and J. C. C. Galeano, "Single Phase and Resonance Fault Analysis in Highly Resistive Grounding Power Systems in Underground Mining," International Journal of Applied Engineering Research, vol. 13, no. 18, pp. 13754-13761, 2018.
39. F. Aslani, M. Yahyaabadi and B. Vahidi, "An intelligent-reduced time method to analyze lightning performance of communication towers and validation using experimental tests," Electric Power Systems Research, vol. 173, pp. 143-152, 2019. [Crossref]
40. P. Sarajcev, D. Jakus, J. Vasilj and S. Vodopija, "Application of genetic algorithm in designing high-voltage open-air substation lightning protection system," Journal of Electrostatics, vol. 93, pp. 43-51, 2018. [Crossref]
41. Y. Xie, C. Li, Y. Lv and C. Yu, "Predicting lightning outages of transmission lines using generalized regression neural network," Applied Soft Computing, vol. 78, pp. 438-446, 2019. [Crossref]
42. I. Ullah, M. N. R. Baharom, H. Ahmad, F. Wahid, H. M. Luqman, Z. Zainal and B. Das, "Smart lightning detection system for smart-city infrastructure using artificial neural network," Wireless Personal Communications, vol. 106, no. 4, pp. 1743-1766, 2019. [Crossref]
43. G. Graditi, M. L. Di Silvestre, D. La Cascia, E. R. Sanseverino and G. Zizzo, "On multi-objective optimal reconfiguration of MV networks in presence of different grounding," Journal of Ambient Intelligence and Humanized Computing, vol. 7, no. 1, pp. 97-105, 2016. [Crossref]
44. S. Gholami Farkoush, T. Khurshaid, A. Wadood, C. H. Kim, K. H. Kharal, K. H. Kim and S. B. Rhee, "Investigation and optimization of grounding grid based on lightning response by using ATP-EMTP and genetic algorithm," Applied Sciences, vol. 8, no. 9, pp. 1664,2018 [Crossref]
45. S. G. Farkoush, A. Wadood, T. Khurshaid, C. H. Kim, M. Irfan and S. B. Rhee, "Reducing the Effect of Lightning on Step and Touch Voltages in a Grounding Grid Using a Nature-Inspired Genetic Algorithm with ATP-EMTP," IEEE Access, vol. 7, pp. 81903-81910, 2019. [Crossref]
46. A. Z. Gabr, A. E. Helal and H. E. Said, "Optimal design of substation grounding grid based on genetic algorithm technique," International Journal of Computer and Systems Engineering, vol. 10, no. 7, pp. 863-869, 2016.
47. K. P. Sengar, and K. Chandrasekaran, "Designing of cost minimum substation grounding grid system using DE, SCA, and HDESCA techniques," IET Science, Measurement & Technology, vol. 13, no. 9, pp. 1260-1267,2019. [Crossref]
48. V. P. Androvitsaneas, A. K. Alexandridis, I. F. Gonos, G. D. Dounias and I. A. Stathopulos, "Wavelet neural network methodology for ground resistance forecasting," Electric Power Systems Research, vol. 140, pp. 288-295, 2016. [Crossref]