UNIVERSITI PUTRA MALAYSIA

INFLUENCE OF BENT DOWN CONDUCTOR FOR LIGHTNING PROTECTION SYSTEM

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FK 2017 74

INFLUENCE OF BENT DOWN CONDUCTOR FOR LIGHTNING PROTECTION SYSTEM

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Philosophy

August 2017

DEDICATION

It is He who shows you the **lightning**, as a fear (for travellers) and as hope (for those who wait for rainfall). And it is He Who brings up or originates the clouds (heavy with water). And **thunder** glorifies and praises Him, and so do the angels because of His Awe, He sends the **thunderbolts**, and therewith He strikes whom He wills, yet they (disbelievers) dispute about Allah. And He is Mighty in strength and severe in punishment.

(Ar-Ra'd (The Thunder): verse 12-13, Holy Quran)

Momentous for hubby; Ashrul, thanks for being narcissistic, Hannah, Harraz, Mak and Abah, for the unconditionally and continuously support throughout this melancholic journey

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

INFLUENCE OF BENT DOWN CONDUCTOR FOR LIGHTNING PROTECTION SYSTEM

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AMIZAH MD. ARIFFEN

August 2017

Chairman : Ir. Mohd Zainal Abidin bin Ab. Kadir, PhD
Faculty : Engineering

Down conductor is one of the pivotal parts of the Lightning Protection System. It plays a key role in rerouting lightning captured by the air termination system to the earth termination system. In Malaysia, the standard practice for lightning protection is adapted from the International Electrotechnical Commission, which consists of the IEC 62305 series. For the enhancement and safe protection from lightning, external and internal lightning protection is compulsory for each protected structure (building). A straight down conductor, is ideally suited for the best-case scenario regarding reliability and safety protection. One to aesthetical aspects, down conductor is undesirably bent in most current buildings. However, only the primary bare type of a down conductor is undergone such process, and bent at a certain degree which depending on the structure itself.

Neither the Malaysian Standard, IEC, nor Institute of Electrical and Electronics Engineers has ever specified the permitted bending degree of the down conductor. Therefore, the purpose of this research is to evaluate the bending degree effect on down conductors, by looking at electric field distribution around the bent area with the presence of concrete wall and reinforcement bar.

The numerical analysis performed in this study referenced the implied (not formalised) manufacturing down conductor specifications which use entirely copper materials for the down conductor. The use of aluminum and galvanised iron types are also evaluated in this study. Three conditions of angles of the down conductor; smaller than 90º angles, 90º and wider than 90º angles are modelled with a minimum cross-sectional area according to the standard for the worst-case scenario with the implementation of the lightning protection system. Experimental work is further conducted to validate the results from conducting the numerical analysis. This is to ensure accuracy and completeness of the results. A thorough evaluation of the electric field is analysed in correlation with the critical breakdown value.
In this study, it was determined that the bending down conductors had a significant effect on electric field distribution at the bent (vertex) area with the interaction of

concrete wall and reinforcement bar. The smaller the angles of the bending down conductor, the more this contributed to intensifying the electric field in the bent area, especially at the inner part of the angle that was less than 90º. For the 90 º angle, the electric field distribution is considered lower compared with the smaller angle and for the wider than 90º angles, it is less than the previous angles conditions. Therefore, that critical bent would be the ones with smaller than 90º, i.e. 30º and 60º. Hence, it could be concluded that, the optimum angle which is more than 90º is proposed for down conductor installation of a protective structure. This is because the lower electric field reduce the chances of arcing occurrences to the nearby human and structure. Thus, this rule should be adapted as an important guideline for the contractors, and architects in the building construction industry. This proved beneficial for designing the lightning protection system to achieve best safety and protection.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN BENGKOKAN KONDUKTOR PENGALIR TURUN UNTUK SISTEM PERLINDUNGAN KILAT

Oleh

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Pengalir turun adalah merupakan bahagian penting dalam Sistem Perlindungan Kilat. Ianya berperanan mengubah laluan arus kilat dari kawasan penamatan udara ke kawasan penamatan bumi. Di Malaysia, amalan piawaian perlindungan kilat digubah daripada International Electrotechnical Commission yang terdiri dari siri IEC 62305. Bagi penambahbaikan dan kebolehpercayaan perlindungan daripada kilat, ia mewajibkan perlindungan dalaman dan luaran untuk setiap struktur (bangunan) yang dilindungi. Secara idealnya, pengalir turun yang lurus atau tanpa sudut lebih baik digunakan untuk perlindungan. Berpunca dari aspek estetika, pengalir turun dipasang secara tidak sengaja mengikut senibina sesebuah struktur, pada kebanyakan bangunan ketika ini. Pengalir turun jenis yang terdedah terutamanya, seringkali melalui proses ini dan di bengkokkan pada darjah tertentu untuk disesuaikan dengan bentuk struktur tersebut.

Walau bagaimanapun amalan ini tidak terdapat dalam Standard Malaysia, IEC, mahupun Institute of Electrical and Electronics Engineers tentang had sudut lenturan untuk pengalir turun. Maka dengan itu, tujuan kajian ini adalah mengkaji kesan sudut lentur pada pengalir turun dari segi medan elektrik pada kawasan bengkok dengan kehadiran dinding konkrit dan bar tetulang.

Analisis berangka yang intensif dilaksanakan menyerupai contoh model sebenar yang spesifikasinya diperoleh dari pengeluar-pengeluar yang menggunakan bahan tembaga untuk pengalir turun. Penggunaan dari jenis aluminium dan besi bergalvani turut dianalisis didalam kajian ini. Tiga keadaan sudut bengkokan pengalir turun; sudut kecil kurang dari 90º, sudut 90º dan sudut besar daripada 90º telah dimodelkan dengan luas keratan rentas yang minimum mengikut piawaian untuk keadaan paling kritikal dengan mengaplikasikan system perlindungan kilat. Ujikaji telah dijalankan untuk menentusahkan bahagian analisis berangka. Ini diperlukan untuk memastikan ketepatan

dan kesahihan keputusan yang diperolehi, terhadap medan elektrik yang telah dianalisis berdasarkan perbandingan nilai kritikal.

Didalam kajian ini, telah didapati sudut melengkung di pengalir turun mempunyai kesan yang penting terhadap taburan medan elektrik pada kawasan bengkok (mercu) dengan interaksi terhadap dinding konkrit dan bar tetulang. Semakin kecil sesuatu sudut pengalir turun, semakin menyumbang terhadap peningkatan medan elektrik pada bahagian yang dilentur, terutamanya bahagian dalam lenturan. Untuk sudut 90º, taburan medan elektrik dianggap rendah berbanding dengan sudut kecil dan untuk sudut yang besar daripada 90º, ianya semakin kurang daripada kondisi sudut - sudut sebelum ini. Dengan itu, sudut yang kritikal ialah sudut yang kecil daripada 90º; seperti 30º dan 60º. Oleh itu, ianya boleh disimpulkan, sudut yang optimum iaitu lebih daripada 90º di cadangkan pada pemasangan pengalir turun terhadap struktur yang dilindungi. Ini kerana, medan elektrik yang rendah mengurangkan potensi terjadinya percikan kepada manusia dan struktur yang berdekatan. Justeru, peraturan ini, seharusnya diadaptasi sebagai panduan penting bagi kontraktor dan arkitek di dalam bidang pembinaan bangunaan. Ini adalah terbukti bermanfaat dalam merekabentuk sistem perlindungan kilat untuk mencapai keselamatan dan perlindungan yang terbaik.

ACNOWLEDGEMENTS

In the Name of Allah, the Most Beneficent, the Most Merciful, first of all, the deepest honour to Allah the Almighty, with His blessings and generosity, enabled the author to achieve this research triumphantly.

The author would like to convey the inmost appreciation to Professor Ir. Dr. Mohd Zainal Ab Kadir for his guidance, support, idea and inspiration throughout the process until completing the PhD, and not forgetting to Professor Dr. Chandima Gomes and Assoc. Prof. Dr. Jasronita Jasni.

Also, thanks to Dr. Mahdi Izadi for his valuable remarks, comments and assistance in accomplishing the research. Next, the author would give a special acknowledgement to Mr. Muzammil and the staffs of the High Voltage Lab, of Centre for Electromagnetic and Lightning Protection Research (CELP) for assisting the experimental work. Lastly, thanks to all colleagues, Syahmi, Syahrun, Ayu, Anas and Norpisah.

I certify that a Thesis Examination Committee has met on 24 August 2017 to conduct the final examination of Amizah Md. Ariffen on her thesis entitled "Influence of Bent Down Conductor For Lightning Protection System" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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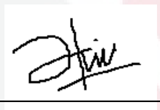

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- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATION, SYMBOLS AND UNITS

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
LPS	Lightning Protection System
LPL	Lightning Protection Level
s	separation distance
LPZ	Lightning Protection Zone
LEMP	Lightning Electro-Magnetic Pulses
mm	millimetre
H	Height
r	radius
kV	kilo volt
mH	milli Henry
m	metre
MA	mega ampere
µA	micro ampere
mm^2	millimetre square
AL	aluminium
GI	galvanised iron
Cu	copper
RH	Relative Humidity

CHAPTER 1

INTRODUCTION

1.1 Background

Lightning protection is vital in Malaysia because the mean annual per day with lightning are 309 days based data from Malaysian Meteorological Department [1]. This is the reason why Malaysia has second highest lightning density in the world, where Kuala Lumpur is reported to be the top five areas [2, 3].

In April 2014 there was a case that involved a lightning strike at the top floor of Sekolah Kabangsaan Kangkar Tebrau, Johor Bharu that caused a fire and severely damaged the school's computer facilities, and buildings, resulting in a repair bill of RM1 million, and affected 180 special needs students [4]. An inspection to the damaged school, which was established in 1938, resulted a report that show it was not equipped with a proper lightning protection system. Most of its building blocks were equipped with rubber insulations on the roofs and that was the obvious cause of the fire when struck by lightning [4]. This is one of examples of many more similar incidents happened in Malaysia due to improper Lightning Protection System installed on buildings.

The rise in the number of lightning incidents is associated with the increase in lightning density as Malaysia located near the equator it is prone to extremely frequent lightning occurrence throughout the year [5]. Ab Kadir et al. [6] stated that Malaysia's location was a contributory factor to the high level of vertical updrafts which may produce more moist air and cold fronts due to the abundance of the sun's rays every day. The global warnings along with climate change are the major factors that influence the extremity of the lightning phenomenon [7]. This is because when the temperature rises, the mercury level also rises and there is higher presence of moisture which contributes to the formation of thunderstorm clouds [8].

1.2 Problem Statement

Practically, the installation of down conductor is undesirably bent due to aesthetic value of the structure in the Lightning Protection System. According to the rules, there were no guidelines stated neither MS IEC 62305 series, nor other established standards for bending degree of down conductor and the permitted bending degree. Nevertheless, MS IEC 62305-3 suggested, that the common structure, it must be more than two down conductors with a safety distance in between to be cautioned and if practicable it is placed at the unprotected corner [9]. Moreover, it only states that a straight and vertical down conductor is advisable in order to provide the shortest distance to earth for lightning current to be dispersed into earth [9]. Furthermore, there is limited scientific evidence in journals pertaining to this particular matter. Therefore, there is no bent degree limitation when installing the down conductor. Figure 1.1 shows some of the practical installation of down conductor which has been bent due to the structure of the building.

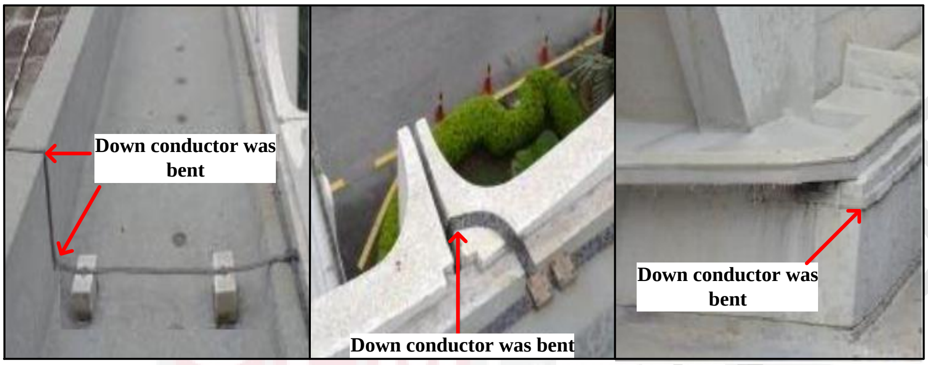

Figure 1.1: The practical installation of down conductor is bent due to the structure of the building [10]

Another significant reason is for the bent down conductor, in terms of safety to the protected structure and users. As based on the electric field, there are differences due to the mutual inductance effect on the bending part of down conductor. Thus, the higher electric field on the bent down conductor, there is a possibility of arcing into the reinforcement bars along the concrete. Furthermore, there is the possibility of arcing to the nearby external objects and humans from the bent down conductor besides the magnetic force and skin effect that will detach the down conductor from the wall. An example is recently, according to the Department of Public Works, Malaysia, report; there was a case related to this bent conductor in which at Building of the Malaysian Parliament, it was found to have a distinct burn mark on a nearby wall [11]. This indicated a serious problem as this Malaysian Parliament building is an old building, which used an external down conductor system that might not be able to function properly by limiting the rise of potential at the point of strike, causing a burn mark and damaging some part of the wall being protected.

Next, there is some scientific evidence of a study undertaken by Yusof [10] which only investigated the bending part of down conductor itself. Thus, the research gaps are addressed, namely, the need to consider and determine the bending effect in the case of lightning protection of structures. Hence, the research does not considering on the behaviour of widely used down conductors material under different down conductor angles and as well as the critical values of breakdown and electric fields in the case of down conductor installed on concrete buildings with the ground parameters. Therefore, in this study, all these issues will be investigated including those effects; such as variation of angles, type of materials and different ground parameters due to the electric field propagation.

Therefore, based on these, since down conductors play a major role to divert the lightning current safely to the earthing system during a lightning strike from air termination rod, a thorough study is needed involving the optimum safety angle need to be applied. Since most of the building contractors and architects prioritise the exquisiteness, practical and design elements of the building instead of lightning safety, so the LPS might not have been given adequate attention.

1.3 Objective

The objectives of this research are:

i. To evaluate the effect of various bent angles of down conductor on electric field distributions.

ii. To evaluate the conditions of concrete and air humidity effects on the critical angle of down conductors.

iii. To consider the effects of ground parameters and grounding system on the critical angles of down conductors.

iv. To assess the separation distance between the concrete and angle of down conductors and the conductor material effects.

v. To recommend critical angles for optimum safety in the installation of down conductors.

Since the IEC62305 has not provided, any specific guidelines regarding the bending degree of down conductor, so the first objective here is to investigate the consequence of varying angles when tested with high voltage and high current. This is important, as a down conductor is a part of the Lightning Protection System (LPS), so only high current and high voltage could resemble the real lightning phenomenon. The next objective is to analyse the reactions for different concrete conditions (dry and wet) with embedded rebar in different rates of air humidity (dry air and humid air), in conjunction with a variety of angles. It is known that, the electromagnetic effect is due to the charge density with respect to the angle variances and when there is the density of charge, a temperature which is associated with the humid or dry air condition and dry or wet concrete also will be affected as heat is a by product of charge density. Generally, resistivity is higher with increasing temperature in conductors and is lowered with increasing temperature in insulators [12]. The third and fourth objective are to evaluated the effect of parameters; grounding parameters and grounding system, separation distance and material type on the angles of down conductor. The last objective is to evaluate the most appropriate bending degree of reliability in down conductor installation, which is very important regarding optimal angle for the best LPS protection.

1.4 Scope of work

The scope of work for this research are:

i. The copper, aluminium and galvanised steel materials were focused with a dimension of 25 mm x 2.5 mm which is the minimum dimension recommended by MS IEC standard.
ii. The variations of angles were set on 30º, 60º, 90º, 120º, 150º and 180º.
iii. The evaluations were based on the standard wave shapes of 8/20 µs, 0.25/100 µs and 10/350 µs of lightning impulse current and 1.2/50 µs of lightning impulse voltage.
iv. The implemented LPS in the numerical analysis was according to the Malaysian standard MS-IEC 62305 parameter as proposed.
v. The grounding parameter effects, separation distance, conditions of concrete (dry and wet) and different air humidity rates (dry and wet) were focused in relation to the angle variations.

1.5 Thesis Organisation

This thesis contains five chapters. Chapter 1 provides the background of the current lightning issues, mainly focusing on the Malaysian scenario. Moreover, the main objective, problem statement and scope of work are also explained in this chapter.

Chapter 2 focuses on the literature review involving the LPS, installation according to recognised standards, and on current issues related to this research. This chapter provides a detailed discussion of the LPS based on a standard for prudent protection from lightning in structure as well as the relevant protected structure.

The methodology used in this research is given in Chapter 3, which includes numerical analysis and observational study. The numerical analysis, likewise, known as the simulation is the main method used, and this is validated by the experimental study.

Chapter 4 provides an overview of the detailed analysis of the results, evaluations and validation of both methods. This is a critical part of the research which will support and validate the entire research.

Finally, Chapter 5 concludes with the findings and makes recommendations for future related research.

REFERENCES

[1] www.met.gov.my/index.php

[2] H.Z. Abidin, R. Ibrahim, *Thunderstorm Day and Flash Density in Malaysia*. National Power and Energy Conference (PeCon), Bangi, Malaysia, 2003.

[3] M. A. Cooper, R. L. Holle, *How to Use Public Education to Change Lightning Safety Standards (And Save Lives and Injuries)*, 14th Symposium on Education, January 2005.

[4] http://news.asiaone.com/news/edvantage/malaysian-headmistress-worries-about-special-needs-students-after-school-struck

[5] N.R. Misbah, M.Z.A Ab Kadir, C. Gomes, *Modelling and Analysis of Different Aspect of Mechanism in Lightning Injury*, Proc. 4th International Conference on Modelling, Simulation and Applied Optimization (ICMSAO), 2011.

[6] M.Z.A. Ab Kadir, M.A. Cooper, C. Gomes, *An Overview of the Global Statistics on Lightning Fatalities*, Proceeding of the 30th International Lightning Conference on Lightning Protection, 2010.

[7] http://www.thunder.nsstc.nasa.gov/Lightning and Atmospheric electricity Research/

[8] A. Sia, E. Tai, Land of Lightning. *The Star Online,* 2009

[9] Protection Against Lightning Part 3: Physical damage to structures and life hazard, MS IEC 62305-3:2007.

[10] Norpisah Mohd Yusoff (2015), *Effect of Bending Degree of Down Conductor on Lightning Current Diversion in Lightning Protection System Installation*, Msc. dissertation, Universiti Putra Malaysia.

[11] Closed Report of Malaysia's Department of Public Works, 2014.

[12] http://physics.info/electric-resistance/

[13] M. Uman (2001), *The Lightning Discharge*, Dover Pubns.

[14] V. A. Rakov, M. A. Uman (2003), *Lightning Physics and Effects*, Cambridge University Press.

[15] K. Berger, R. B Anderson, H. Kroninger, *Parameters of lightning flashes*, Electra, vol. 41, pp 23-47, 1975

[16] J.D. Schoene (2007), *Direct and nearby lightning strike interaction with test power distribution lines*, Ph.D. dissertation, University of Florida.

[17] K. Berger, Blitzstromparameter von Aufwaertsblitzen, Bull. Schweiz. Elektrotech, vol. 69, pp 353-360, 1978.

[18] M. A. Uman (2008), *The Art and Science of Lightning Protection*, Cambridge University Press.

[19] M. A. Uman (1987), *The Lightning Discharge*, International Geophysics Series, Vol 39, Academic Press Inc.

[20] Cohen I.B. (1990), *Benjamin Franklin's Science.* Cambridge, MA: Harvard University Press.

[21] Protection of Structures Against Lightning Part 1: General Principles Section 1: Guide A – Selection of Lightning Protection Systems, IEC 61024-1-1, 1993.

[22] Protection Against Lightning-Part 1: General Principles, MS IEC 62305-1: 2007.
[23] C. Bouquegneau, (2010), Chapter 6-*External lightning protection system*, Lightning Protection, Vol. 58, pg 307-353.
[24] C. Mazzetti, (2003), Chapter 10-*Principles of protection of structures against lightning*, The Lightning Flash, Vol.34, pg 503-545.
[25] Standard for the Installation of Lightning Protection Systems, National Fire Protection Association, NFPA 780: 2008.
[26] A. M. Ariffen, M. Z. A. Ab-Kadir, C. Gomes, J. Jasni, M Izadi, *On the bending effects of a copper-type down conductor*, 32nd International Conference on Lightning Protection, ICLP, Shanghai, China, 2014.
[27] N. Morii, H. Sato, *A Method For Selecting Lightning Protection Level*, 30th International Conference on Lightning Protection-ICLP 2010.
[28] Guido Ala, Maria Luisa Di Silvestre, *A Simulation Model for Electromagnetic Transients in Lightning Protection Systems*, IEEE Transactions On Electromagnetic Compatibility, 2002.
[29] P. Hasse, P. Zahlmann (2010). Internal Lightning Protection. In V. Cooray, *Lightning Protection*, (pp 355-442). IET Power and Energy Series 58: The Institution of Engineering and Technology (IET).
[30] Protection against Lightning-Part 4: Electrical and Electronic Systems within Structures, MS IEC 62305-4: 2007.
[31] Low-voltage Surge Protective Devices-Part 1: Surge Protective Devices Connected to Low-Voltage Power Distribution Systems-Requirements and Tests, IEC 61643-1, 2005.
[32] F. Fiamingo, M. Marzinotto, C. Mazetti, Z. Flisowski, G.B. Lo Piparo, G.L. Aminucci, *Evaluation of SPD Protection Distance in Low Voltage Systems*, Journal of Electrostatics 65, Elsevier: 363-370, 2006.
[33] G. Vijayaraghavan, M. Brown, M. Barnes, S. Mackay. (2004). *Practical Grounding, Bonding, Shielding and Surge Protection*, Newnes Press- Elsevier.
[34] Standard for the Installation of Lightning Protection Systems, MS: National Fire Protection Association, NFPA 780: 2011.
[35] Christopher Miles, *Continuity Testing Of Lightning Protection Systems*, 30th International Conference on Lightning Protection-ICLP 2010.
[36] Code of Practice for Protection of Structures Against Lightning, BS 6651: 1999.
[37] D. Kokkinos, N. Kokkinos, J. Koutsoubis, M. Klabana, Ath. Triantafillides, *Effect of Direct Lightning Strike in the Down Conductors Embedded into the Reinforcement*, 28th International Conference on Lightning Protection, 2006.
[38] Kazuo Hiruma, Takeo Sonehara, *Performance of Reinforcing-steel with Joints for Down-conductors and Resistance of a building where rebar and Joints were connected by Connectors*, 32nd International Conference on Lightning Protection (ICLP), Shanghai, China, 2014.

[39] Kazuo Hiruma, Takayuki Nihei, Takeo Sonehara, Shigeru Yokoyama, Hideo Shimokawa, *Performance of Reinforcing-steel with threaded rebar joints and mortar-grouted joints used as down-conductors for lightning protection*, Asia-Pacific International Conference on Lightning, pp. 291-295, June 2013.

[40] Kazuo Hiruma, Yoshikane Kojima, Performance of reinforcing-steel with mortar-grouted joints connected by lightning connectors, General Meeting of the Institute of Electrical Installation Engineers of Japan, pp. 395-396, August 2013.

[41] Takeo Sonehara, Shunichi Yanagawa, Kazuo Hiruma, Shigeru Yokoyama, *Test results of lightning impulse current applied to threaded-rebar joints and mortar-grouted joints, Asia-Pacific International Conference on Lightning*, pp. 291-295, June 2013.

[42] S. Cristina, A. Orlandi, *Calculation on the induced effects due to a lightning stroke*, Proc. Inst. Elect. Eng. Vol. 139, no. 4, pp. 374-380, 1992.

[43] A. Orlandi, F. Schietroma, *Attenuation by a lightning protection system of induced voltages due to direct strikes to a building,* IEEE Trans. Electromagn. Compat., vol. 38, pp.43-50, 1996.

[44] C. Bucella, S. Cristina, A. Orlandi, *Frequency analysis of the induced effects due to the lightning stroke radiated electromagnetic field*, IEEE Trans. Electromagn. Compat., vol. 34, pp. 338-344, 1992.

[45] A. Sowa, *Surge current distribution in building during a direct lightning stroke*, IEEE Int. Symp. Electromagnetic Compatibility, pp. 248-252, 1991.

[46] A. Sowa, *Induced voltages in electronic systems within the buildings which are struck by lightning*, Proc. 18th Int. Conf. Lightning Prot. Munich, Germany, pp. 239-243, 1985.

[47] J. P. Bruhin, *Shielding efficiency of reinforced steel in concrete against lightning,* Proc. 6th Int. Wroclaw Symp. Electromagnetic Compatibility, Poland, pp. 475-484, 1982.

[48] S. Cristina, M. D' Amore, A. Orlandi, *Lightning stroke to a structure protection system- Part I: Current distribution analysis,* Proc. 6th Int. Symp. High Voltage Eng. 1989.

[49] G. Casinovi, A. Geri, G. M.Veca, *A Magnetic field near a concrete wall during a lightning stroke,* IEEE Trans. Magn. Vol. 25, no. 5, pp. 4006-4008, 1989.

[50] S. Cristina, A. Orlandi, *EMC effects of the lightning protection system: Shielding properties of the roof-grid,* Proc. Int. Symp. Electomagn. Compat., pp. 78-83, 1991.

[51] A. Orlandi, *Lightning induced transient voltages in presence of complex structures and nonlinear loads,* IEEE Trans. Electromagn. Compat., vol.38, no.2, pp 150-155, 1996.

[52] A. Orlandi, C. Mazzetti, Z. Flisowski, M. Yamarkin, *A Systematic approach for the analysis of the electromagnetic environment inside a building during lightning strike,* IEEE Trans. Electromagn. Compat., vol. 40, pp. 521-535, 1998.

[53] G. Maslowski, R. Ziemba, *Shielding of structures in the case of direct lightning strike*, Proc. 26th Int. Conf. Lightning Protection, pp. 562-567, 2002.
[54] I. A. Metwally, F. H. Heidler, *Computation of transient overvoltages in low-voltages installations during direct strikes to different lightning protection systems*, IEEE Trans. Electromagn. Compat., vol.49, no.3, pp. 602-613, 2007.
[55] K. Aniserowicz, *Computer analysis of electromagnetic field inside LPS in the case of lightning strike to a nearby tall object*, Proc. 29th Int. Conf. Lightning Protection, 2008.
[56] K. Aniserowicz, *Computer analysis of electromagnetic field inside LPS directly stroke by lightning*, Proc. 7th Int. Symp. Electromagn. Compat., Electromagn. Ecol., pp. 257-260, 2007.
[57] G. Maslowski, M. Gamracki, *Protection of structures against LEMP*, Proc. IEEE Bologna Power Tech. Conf. vol. 1, 2003.
[58] I. A. Metwally, F. H. Heidler, *Lightning transients in low-voltage installations inside different types of Class II Lightning Protection Systems,* IEEE Trans. Electromagn. Compat.,vol.24, pp.930-938, 2009.
[59] A. Geri, G. M. Veca, *A complete lightning protection system simulation in the EMI analysis*, Proc. IEEE Int. Symp. Electromagn. Compat.,pp.90-95, 1991.
[60] Y. Du, Q. B. Zhou, *Analysis of lightning induced impulse magnetic fields in the building with an insulated down conductor,* IEEJ. Trans. Fundam Mater, vol.126, no.2, pp.71-77, 2006.
[61] J. Chen, B. Zhou, F. Zhao, S. Qiu, *Finite difference time-domain analysis of the electromagnetic environment in reinforced concrete structure when struck by lightning,* IEEE Trans. Electromagn. Compat., vol.52, no.4, pp.914-920, 2010.
[62] M. Konig, *Transient overvoltages in large buildings with natural components during a direct strike,* Proc. Int. Conf. Lightning Protection, pp.545-550, 1996.
[63] S. Miyazaki, M. Ishii, *Role of steel frames of buildings for mitigation of lightning induced magnetic fields,* IEEE Trans. Electromagn. Compat., vol.50,no.2, pp.333-339, 2008.
[64] C. Bucella, S. Cristina, A. Orlandi, *Shielding performances of reinforced walls to the field radiated by lightning,* Proc. 8th Int. Conf. Electromagn. Compat., pp.60-66, 1992.
[65] M. Konig, *Lightning current distribution in typical buildings with natural components,* Proc. Int. Conf. Lightning Protection, 1994.
[66] M. Konig, H. Steinbigler, *Magnetic field distribution inside a gridlike spatial shield case of a direct lightning strike,* Proc. Int. Conf. Lightning Protection, pp.264-269, 1998.
[67] W. J. Zischank, I. A. Metwally, F. Hiedler, J. Wiesinger, A. Kern, M. Seevers, *Laboratory simulation of direct lightning strokes to a modelled building-Measurement of magnetic fields and induced voltages,* Proc. 26th Int. Conf. Lightning Protection, pp. 591-596, 2002.

[68] I. A. Metwally, W. J. Zischank, F. Heidler, *Measurement of magnetic fields inside single and double layer reinforced concrete buildings during simulated lightning currents,* IEEE Trans. Electromagn. Compat., vol. 46, no.2, pp.208-221, 2004.

[69] W. Zischank, F. Hiedler, J. Wiesinger, K. Stimper, A. Kern, M. Seevers, *Magnetic fields and induced voltages inside LPZ 1 measured at a 1:6 scale model building*, Proc. 27th Int. Conf. Lightning Protection, 2004.

[70] I. A. Metwally, F. Hiedler, *Reduction of lightning induced magnetic fields and voltages inside struck double layer grid like shields,* IEEE Trans. Electromagn. Compat. vol.50, no.4, pp.905-912, 2008.

[71] T. Maksimowicz, K. Aniserowicz, *Investigation of models of grid like shields subjected to lightning electromagnetic field: Experiments in the frequency domain,* IEEE Trans. Electromagn. Compat., vol. 54, no.4, pp. 826-836, 2012.

[72] S. Cristina, A. Orlandi, *Lightning channel's influence on currents and electromagnetic fields in a building struck by lightning,* Proc. IEEE Int. Symp. Electromagn. Compat., 1990.

[73] I. A. Metwally, F. Hiedler, W. J. Zischank, *Magnetic fields and loop voltages inside reduced and full scale structures produced by direct lightning strikes,* IEEE Trans. Electromagn. Commport., vol. 48, no. 2, pp. 414-426, 2006.

[74] M. Ishii, K. Miyabe, A. Tatematsu, *Induced voltages and currents on electrical wirings in building directly hit by lightning,* Electrical Power System Res. Vol.85, pp.2-6, 2012.

[75] A. Tatematsu, F. Rachid, M. Rubenstein, *Calculation of electromagnetic fields inside a building with layered reinforcing bar struck by lightning using FDTD method,* Proc. Int. Symp. Electromagn. Compat., pp. 386-389, 2014.

[76] A. Tatematsu, F. Rachidi, M. Rubenstein, *Analysis of Electromagnetic Fields Inside a Reinforced Concrete Building with Layered Reinforcing Bar due to direct and indirect lightning strikes using FDTD Method,* IEEE Trans. on Electromagn. Compat., vol. 57, no.3, 2015.

[77] F. D'Alessandro, *On the optimum rod geometry for practical lightning protection systems,* Journal of Electrostatics, vol. 65, pp 113-121, 2007.

[78] N. L. Aleksandrov, E. M. Bazelyan, F. D' Alessandro, Yu. P. Raizer, *Numerical simulations of thunderstorm-induced corona processes near lightning rods installed on grounded structures*, Journal of Electrostatics, vol. 64, pp 802-816, 2006.

[79] I. Izraeli, A. Braunstein, *Analysis and Design of protection systems for structures against direct lightning strokes Part 1: Theory,* IEE Proc. A 130, pp 140-144, 1983.

[80] M. Rezikina, *Software for Determination of 3D electrical field distribution in the vicinity of special installations and systems with lighting rods during thunderstorm,* Proceedings of 24th ICLP, Birmingham, UK, 1998.

[81] A.S. Farag, M. Shwehdi, C. A. Belhadj, T. C. Cheng, D. Penn, *Air Terminations for lightning protection of structures,* Proceedings of IEEE Conference on Electric Insulation and Dieletric Phenomena, 1998.
[82] V. Mazur, L.H. Ruhnke, A. Bondiu-Clergerie, P. Lalande, *Computer simulation of downward negative stepped leader and its interaction with a ground structure*, J. Geophys. Res. 10, 2000.
[83] U. Kumar, G. Ghosh, *On the efficacy of the lightning masts on structures*, Proceedings of the 12th International Symposium on High Voltage Engineering, India, pp. 2-25, 2001.
[84] T.R. Almeida, C.F. Antunes, *Influence of the distance between buildings and their shape on the electric field distribution,* Inf. Tecnol. 13, pp 143-148, 2002
[85] F. D'Alessandro, *The use of 'Field Intensification Factors' in calculations for lightning protection of structures*, Journal of Electrostatics 58, pp. 17-43, 2003.
[86] F. D'Alessandro, *Striking distance factors and practical lightning rod installations; a quantitative study,* Journal Electrostatic 59, pp 25-41, 2003.
[87] F. D'Alessandro, *Improved placement of Protective lightning rods on structures*, Proceedings of the Ground'2004 & 1st LPE, Brazil, pp. 138-143, 2004.
[88] C. Bucella, M. Feliziani, *A hybrid model to compute the effects of a direct lightning stroke on three-dimensional structures*, IEEE Trans. Magn 39, pp 1586-1589, 2003.
[89] User's Guide Maxwell 2D v15 - Electronic Design Automation software, Ansys Inc, 2012.
[90] User's Guide Maxwell 3D v15 – Electronic Design Automation software, Ansys Inc, 2012.
[91] http://www.ansys.com/Products/Simulation
[92] Marina Santo Zarnik, Darko Belavic, *An Experimental and Numerical Study of the Humidity Effect on the Stability of a Capacitive Ceramic Pressure Sensor*, Radio Engineering, Vol. 21, No. 1, pp. 201-206, April 2012.
[93] Eric R. Abram, Nicola Bowler, *Effect of Relative Humidity on the Curing and Dielectric Properties of Polyurethane Based Composites,* Annual Report Conference on Electrical Insulation and Dielectric Phenomena, 2005.
[94] C. G. Deshpande, A. K. Kamra, *The Atmospheric Electric Conductivity and Aerosol Measurement during Fog over The Indian Ocean*, Journal of Atmospheric Research 70, 2004.
[95] Recommended Grounding Practices, IEEE Standard 142-1991.
[96] British Standard Code of Practice, CP-1013: Earthing, 1965.
[97] British Standards on Structural Use of Concrete, BS 8110-1997
[98] Ade Ogundola, Ugo Reggiani, Leornardo Sandrolini, *Modelling Shielding Properties of Concrete,* Journal of Electromagnetic Compatibility, 2006.
[99] C. Thajudeen, A. Hoofar, F. Ahmad, T. Dogaru, *Measured Complex Permittivity of Walls With Different Hydration Levels and The Effect*

on Power Estimation of Twri Target Returns, Progress In Electromagnetics Research B, Vol. 30, pg. 177-199, 2011.

[100] Roman Kubacki, *New Attempt to Building Materials Permittivity Measurements*, PIERS Proceedings, Guangzhou, China, 2014.

[101] David, McGraw Jr., *The Measurement of The Dielectric Constant of Three Different Shapes of Concrete Blocks*, IJRRAS, Vol. 25, Issue 3, 2015.

[102] Kwok L.Chung, Lei Yuan, Songtoa Ji, Li Sun, Chengping Qu, Chunwei Zhang, *Dielectric Characterization of Chinese Standard Concrete for Compressive Strength Evaluation*, Applied Sciences, MDPI, Vol.7-177, 2017.

[103] Zuzana Hlavacova, *Electrical Properties of Some Building Materials*, Research and Teaching of Physics in the Context of University Education, Nitra, June, 2007.

[104] High Voltage Test Techniques, Part 1: General Definitions and Test Requirements, MS IEC 60060-1, 2008.

[105] W. Hauschild, E. Lemke (2014), *High-Voltage Test and Measuring Techniques*, Springer-Verlag Berlin Heidelberg.

[106] High-Voltage Testing Techniques, IEEE Std. 4-2013.

[107] Nick R. Buenfield, Gareth K. Glass, Alaa M. Hassanein, Jian-Zhong Zhang, *Chloride Transfort in Concrete Subjected to Electric Field*, Journal of Materials in Civil Engineering, Vol.10, Issue 4, 1998.