UNIVERSITI PUTRA MALAYSIA

MINIMUM SEPARATION BETWEEN LIGHTNING PROTECTION SYSTEM AND NON-INTEGRATED METALLIC STRUCTURES

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By

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In an event of direct lightning strike to a protected building which is integrated with an electrical or electronic system installed on the roof such as roof-top PV system, dangerous sparking may occur between external lightning protection system (LPS) and conductive components of the electrical system. To prevent such side flashes, a minimum separation distance between the metallic components and air termination system is required. Even though, IEC62305-3 Standard provides a formula to specify the necessary separation distance, so far there is no extensive study that has been done to evaluate the suitability of the application of equation to calculate the separation distance, specifically to the safety of electrical systems integrated into the roof top of building. In this study, a new computational method has been developed for calculation of the separation distance between an LPS and metallic components on the roof. In the proposed method which is based on the theoretical background of the IEC62305-3 Standard formula, the break down behavior of the gap geometry between the LPS and metallic components for the applied voltage across the gap is analyzed. PSCAD software was used to model the LPS and the lightning strokes. Separation distance has been computed considering the voltage-time area of the induced voltage across the gap as rectangle, triangle and trapezium and the results have been compared with the one considering the voltage-time area of the real voltage wave shape. It has been observed that calculated result for separation distance considering the real voltage wave shape is lower than the results for assumed voltage wave shapes. Finally, the value of separation distance which is obtained by the proposed method has been compared to the value obtained by IEC62305-3 Standard formula. The comparison indicates almost 20% difference between the values of separation distances calculated by the proposed method and IEC62305-3 standard formula, whereas the proposed method suggests lower values for separation distance. Therefore, it has been concluded that the IEC62305-3 Standard suggested formula overestimate the values of separation distance.

Furthermore, effects of two parameters of resistance and inductance of earthing system that influence the value of separation distance have been investigated. It has been

observed that the inductance of the earthing system plays an important role in increasing the potential across the gap and the separation distance in case of fast front lightning current, i.e. subsequent negative stroke and first negative stroke. While, influence of the earth resistance on the value of the separation distance is not remarkable for fast front lightning currents. However, for slow front lightning current such as positive stroke, the earth resistance plays an important role in determining the separation distance.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PEMISAHAN MINIMUM ANTARA SISTEM PERLINDUNGAN KILAT DENGAN STRUKTUR LOGAM BUKAN BERSEPADU

Oleh

SEYEDEH NARJES FALLAH

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Dalam kejadian sambaran kilat secara langsung ke bangunan yang dilindungi yang disepadukan dengan sistem elektrik dan elektronik yang dipasang pada bumbung seperti sistem PV atas-bumbung, percikan yang merbahaya boleh berlaku antara sistem perlindungan kilat luaran (LPS) dengan komponen konduktif sistem elektrik. Demi mencegah kejadian sambaran tidak langsung, satu jarak pemisahan minimum antara komponen logam dengan sistem penamatan udara amat diperlukan. Walaupun standard IEC62305-3 menyediakan satu formula untuk menentukan jarak pemisahan yang diperlukan, sehingga kini tiada penyelidikan yang telah dijalankan untuk menilai kesesuaian aplikasi rumusan untuk menentukan jarak pemisahan khususnya untuk keselamatan sistem elektrik yang bersepadu dengan bumbung atas bangunanan. Dalam kajian ini, satu sistem perkomputeran yang baru telah dibangunkan untuk mengira jarak pemisahan antara LPS dengan komponen logam atas bumbung. Dalam kaedah yang dicadangkan ini yang berasaskan teori di sebalik rumusan standard IEC 62305-3, ciri-ciri pecahan elektrik geometri celah antara LPS dengan komponen logam untuk voltan yang disalurkan pada celah itu telah dianalisa. Perisian PSCAD telah digunakan untuk pemodelan LPS dan sambaran kilat. Jarak pemisahan telah dikira dengan mengambil kira luas kawasan voltan-masa voltan aruhan seberang celah sebagai segiempat tepat, segitiga dan trapezium dan hasil dapatan telah dibandingkan dengan apabila mengambil kira luas kawasan bentuk gelombang voltan yang sebenar. Didapati bahawa hasil kiraan jarak pemisahan dengan mengambil kira bentuk gelombang voltan sebenar adalah lebih rendah daripada kes di mana bentuk gelombang voltan telah ditetapkan terlebih dahulu. Akhir sekali, jarak pemisahan yang dikira berdasarkan kaedah yang dicadangkan telah dibandingkan dengan nilai yang diperoleh menurut rumusan standard IEC62305-3. Perbandingan tersebut memperlihatkan perbezaan 20% antara nilai kiraan berdasarkan kaedah yang dicadangkan dengan yang berdasarkan rumusan standard IEC62305-3 manakala kaedah yang dicadangkan menyarankan nilai jarak pemisahan yang lebih rendah. Oleh itu, dapat disimpulkan bahawa rumusan standard IEC62305-3 telah terlebih anggar jarak pemisahan.

Tambahan pula, kesan dua parameter iaitu rintangan dan kearuhan sistem pembumian yang mempengaruhi nilai jarak pemisahan telah dikaji. Didapati bahawa kearuhan sistem pembumian memainkan peranan yang penting dalam meningkatkan voltan seberang celah dan jarak pemisahan bagi kes arus kilat hadapan cepat seperti sambaran negatif ekoran dan sambaran negatif pertama. Kesan rintangan bumi terhadap nilai jarak pemisahan adalah tidak ketara bagi arus kilat berhadapan cepat. Walaubagaimanapun, untuk arus kilat berhadapan lambat seperti sambaran positif, rintangan bumi memainkan peranan yang penting dalam pengiraan jarak pemisahan.

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I certify that a Thesis Examination Committee has met on 11th of July to conduct the final examination of Seyedeh Narjes Fallah on his thesis entitled "Minimum Separation Between Lightning Protection System and Non-Integrated Metallic Structures" in accordance with the Universities and University Colleges 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 relevant degree of Master of Science.

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List of Abbreviation

EFIE	Electric Field Integral Equation
EM	Electro Magnetic
EMTDC	Electromagnetic Transient Direct Current
IEC	International Electrotechnical Commission
LPL	Lightning Protection Level
LPS	Lightning Protection System
LPZ	Lightning Protection Zone
MM	Mesh Method
NEC	National Electric Code
PAM	Protective Angle Method
PEEC	Partial Element Equivalent Circuit
PSCAD	Power System Computer Aided Diagram
PV	Photo Voltaic
RSM	Rolling Sphere Method
SPD	Surge Protective Device

LIST OF SYMBOLS

$(\frac{di}{dt})_p$	Peak Current Derivative
Δt	Zero Time of the Voltage
μ_0	Permeability of the Earth
A	Voltage-Time Area
a	Radius of the Conductor
C	Capacitance
C'	Capacitance per Meter
C_i	Capacitance between the Conductor and the Ground
C_{ij}	Mutual Capacitance between Two Conductors of LPS
G	Conductance
G'	Conductance per meter
h	Space between Ring Conductors
i	Current
I	Peak current
l	Length of the Conductor
i_p	Peak current
k	Correction Factor for the Peak Current
k_c	Coefficient of Current Division
k_i	Coefficient of The Class of The LPS
k_m	Coefficient of Insulation Material
L	Inductance
L'	Inductance per Meter
L_i	Inductance of the Conductor
M_{ij}	Mutual Inductance between Two Conductors of LPS
n	Number of Down Conductors
R	Resistance

R'	Resistance per Meter
R_i	Resistance of the Conductor
S	Separation Distance
U_0	Static Breakdown Voltage
U_m	Peak Value of the Voltage
θ	Constant Equal to 534
ρ	Resistivity of the Conductor
ρ_e	Permittivity of the Earth
τ_1	Front Time
τ_2	Tail Time
ε	Permittivity of the Earth
υ	Voltage

CHAPER 1

INTRODUCTION

1.1 Research overview

In a lightning protected structure, the external Lightning Protection System (LPS) is intended to intercept direct flashes to the structure and conduct this lightning current to the ground without causing dangerous sparking. The external LPS consist of air termination system, down conductor and earth termination system. Air termination system prevents the direct lightning strike to the building by intercepting the lightning strikes and conducts this current through horizontal conductors to the vertical down conductors and disperses the current through earthing system to the soil [1]. Conduction of lightning current through the LPS increases the possibility of side flashes to the metal parts of the building and internal systems. Prevention of such side flashes is recommended in IEC 62305-3 Standard by either keeping a minimum separation distance between the LPS and metallic parts or integrating the LPS to the metallic components.

In building-integrated electrical system where parts of the system are installed on the roof, i.e. roof-top PV system, communication installation on the roof or broadcasting cables and components, integrating the LPS to the metallic parts in order to prevent the side flashes will expose electronic and electrical items of the system in to the danger. Therefore, in such cases the only option is to keep a minimum separation distance between LPS and metallic components. Studies on the separation distance between the LPS and the metallic structure on the roof are very important to evaluate the possibility of flashover in the gap distance between LPS and metallic components, and in order to provide an efficient lightning protection system [2].

PSCAD-EMTDC was used in this research for the purpose of node-potential analysis. This software is chosen because of its facilities to model compared to other end user software. It also provides the flexibility of building custom models, either by assembling those graphically using existing models, or by utilizing an intuitively designed Design Editor.

1.2 Problem Statement

In an event of direct lightning strike to a building with an electrical system installed on the roof, dangerous sparking may occur between external LPS and conductive part of the electrical system. Figure 1.1 shows a roof-top PV system as an example of electrical system installed on the roof of a protected building which is isolated by a distance from the air termination rod.

In order to prevent such side flashes a minimum separation distance is required to be maintained between the LPS and other conducting parts integrated with the building. IEC62305-3 Standard [1] provides a formula to calculate the separation distance to prevent arcing. This formula originally was developed in early 1980s for simple structures [56]. However, several important factors related to the potential differences have not been considered in this formula. Also this standard does not specify the possibility of having electrical system at roof-top such as photovoltaic (PV) panels, wind power generating systems, antenna structures for radio/communication base stations, television and satellite antenna systems, CCTV systems, roof-top sign boards and other lighting systems, which are integrated parts of many modern commercial or even some domestic buildings.

The formula proposed by the IEC62305-3 Standard [1], assumes an unrealistic square wave shape for the lightning current, thus the voltage drop due to that. Such assumption deviates the computational model considerably from the real situation. In a cloud-to-ground lightning flash, there are basically three types of possible lightning current wave shapes; in negative ground flashes the first stroke and subsequent strokes and positive ground flashes the usually single current impulse referred as positive stroke [8]. Each of these three types has their own temporal characteristics and amplitude distribution [52]. This shows that the real situation of injected current and the consequent voltage waveform is much more complex than the assumed square wave shape in IEC62305-3 Standard [1].

The IEC62305-3 Standard also neglects the effects of the earth resistance of the grounding system of the LPS. It is of interest to the engineering community to investigate whether there is a significant difference in the required minimum separation based on the grounding system performance. So far, no quantitative investigation has been done in this regard.

This study has been done to address the above technical problems in the field of lightning protection. The significance of such information is highly beneficial in the future due to the growing demand for micro-scale alternative energy sources such as roof-top mounted PV panels and wind energy generation systems. Nowadays, developed computer codes make it possible to revisit the specification of separation distance.

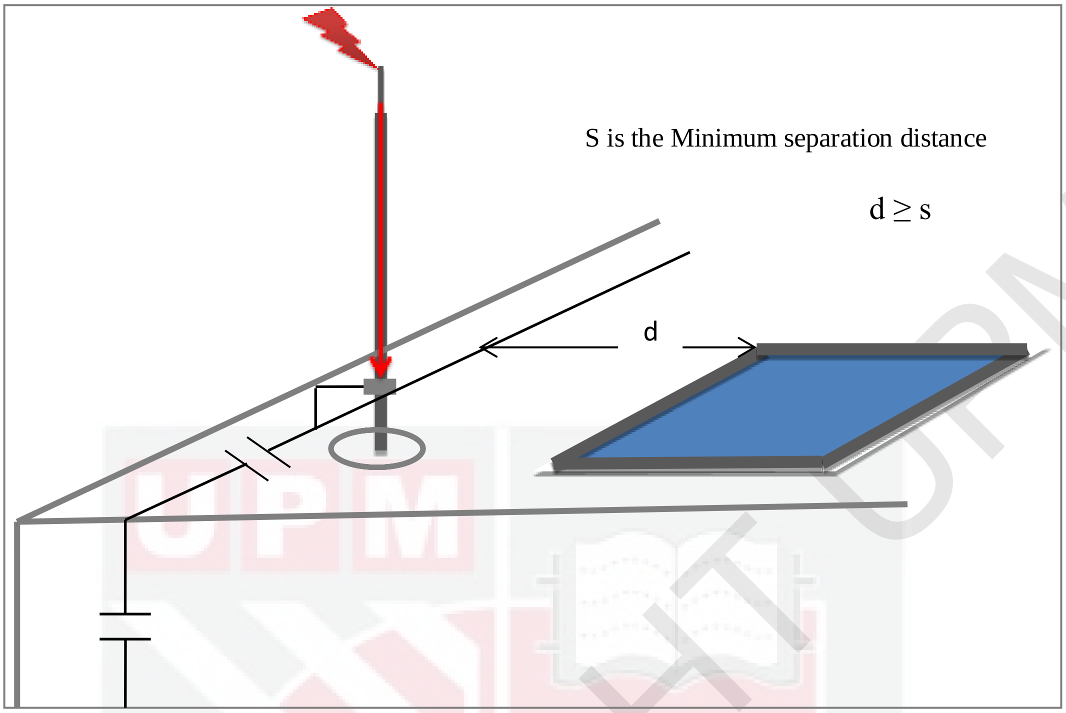

Figure 1.1: **Separation distance between the frame of PV panel and the LPS**

1.3 Objectives

Objectives of this research are:

1- To develop a new computational method for estimating the separation distance between metallic components on the roof such as roof-top PV systems and the LPS under any given circumstances.

2- To compare the separation distance computed by proposed method with the values computed by using IEC62305-3 Standard suggested formula.

3- To find the effect of electrical parameters of the LPS on the values of Separation distance.

1.4 Scope of Work

Scopes and limitations of this work are:

1- This research is based on circuit theory approach and does not include the electromagnetic coupling between the lightning channel and the conductors. Indeed the radiated field inside the building is also neglected.

2- The effect of lightning channel impedance is not included in the modeling of lightning current.

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