UNIVERSITI PUTRA MALAYSIA

EVALUATION OF LIGHTNING RETURN STROKE CURRENT USING MEASURED ELECTROMAGNETIC FIELDS

MAHDI IZADI

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By

MAHDI IZADI

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

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DEDICATION

This thesis is dedicated to my wife, Madam Maryam Hajikhani, for her inestimable contributions in my life.

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

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Chairman : Associate Professor. Mohd. Zainal Abidin Ab Kadir, PhD

Faculty : Engineering

Lightning is an essence of natural phenomenon that can affect on the stability of power lines. It can directly strike the conductor lines, towers, or shielding wires (direct effect). Likewise, the induced over voltages can be generated on the lines, when the lightning strikes the ground surface or any tall object around power lines; so that the electromagnetic fields associated with the lightning channel are coupled with the line conductors (indirect effect). Several studies have been completed to evaluate the return stroke current which can be categorized into two groups; i.e. direct measurement of the current and inverse procedure algorithms based on measured electromagnetic fields for the determination of the return stroke current. In the direct measurement method, the current can be measured by setting current coils at the top of towers or by using the artificial triggered lightning technique to measure channel base currents. On the other hand, indirect methods can evaluate the return stroke current using measured fields and

they can cover a greater number of lightning occurrences compared to direct measurement. This study seeks to determine the channel base current and current wave shapes at different heights along lightning channel using measured electromagnetic fields (inverse procedure). It also intends to compute the electromagnetic fields associated with the same lightning channel at the other observation points (direct procedure) to validate the predicted current wave shapes using measured electromagnetic fields, while the ground conductivity is assumed to be perfect.

The first section of this study reviews and discusses the most important channel base current functions and current models and electromagnetic calculation methods. In the next sections, this study proposes the field expressions by 2^{nd} FDTD method in order to compute the electromagnetic fields due to realistic current functions in the time domain. For the generalization and linearization of field expressions, the general field equations are proposed directly in the time domain while supporting the most important channel base current functions directly needless of an extra conversion to the other domain. Consequently, the proposed electromagnetic calculation methods can be corroborated with the measured fields and the results from previous studies. Moreover, the field expressions due to inclined lightning channel are proposed and substantiated with the measured fields directly in the time domain, while a realistic channel base current function and the general form of engineering current model are applied.

This research proposed an inverse procedure algorithm using the proposed general fields' expressions and the particle swarm optimization algorithm (PSO) in the time domain where the full channel base current wave shape in time domain can be

determined. By considering the three electromagnetic fields components, this method can be applied to all distances from the lightning channel without any limitation. Moreover, in the proposed method, the attenuation height dependent factor can be determined using measured field while assuming it to be an unknown function based on the engineering model. The proposed method can predict the current wave shapes at different heights along the lightning channel and also support the most important general forms of channel base current functions. However, the improvement of Deindorfer and Uman on the Heidler function with an unknown variable is selected as the general channel base current function. Moreover, the current wave shapes are validated with measured field at other observation point when the determined current parameters and the proposed direct procedure algorithms are applied. It should be noted that the measured fields' data are obtained from the rocket-triggered lightning at two different radial distances from the lightning channel. The proposed algorithm is applied to the measured electric fields' data from the natural lightning channel while the radial distance is determined using the lightning location system and the simulated electric field using predicted current parameters which are then compared with the measured electric field.

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

PENILAIAN ARUS PANAHAN BALIK KILAT MENGGUNAKAN MEDAN-MEDAN ELEKTROMAGNET YANG DIUKUR

Oleh

MAHDI IZADI

April 2012

Pengerusi : Profesor Madya Mohd. Zainal Abidin Ab Kadir, PhD

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Kilat ialah satu sumber fenomena semulajadi yang boleh membawa kesan ke atas talian kuasa. Ia boleh menyambar secara langsung talian konduktor, menara, atau wayar perlindungan (kesan langsung). Begitu juga dengan voltan lebihan teraruh yang dijanakan di atas talian apabila kilat menyambar permukaan tanah atau mana-mana objek tinggi sekitar talian kuasa; di mana medan elektromagnet dikaitkan dengan saluran kilat dipasangkan dengan konduktor talian (kesan tidak langsung). Beberapa kajian telah dijalankan untuk menilai arus panahan balik yang boleh dikategorikan kepada dua kumpulan; iaitu algoritma pengukuran langsung arus dan algoritma prosedur songsang yang berdasarkan medan elektromagnet yang diukur untuk menentukan arus panahan balik. Dalam kaedah pengukuran langsung, arus boleh diukur dengan menetapkan gegelung arus di atas puncak menara atau dengan menggunakan teknik kilat-cetusan tiruan untuk mengukur arus asas saluran. Sebaliknya, kaedah tidak langsung dapat

menilai arus panahan balik menggunakan medan yang diukur dan ianya boleh meliputi lebih banyak kejadian kilat berbanding dengan pengukuran langsung. Kajian ini bertujuan untuk menentukan arus asas saluran dan bentuk gelombang arus pada ketinggian berbeza sepanjang saluran kilat dengan menggunakan medan elektromagnet yang diukur (prosedur songsang). Ia juga bertujuan untuk mengira medan elektromagnet yang dikaitkan dengan saluran kilat yang sama pada titik-titik pemerhatian yang lain (prosedur langsung) bagi mengesahkan bentuk-bentuk gelombang arus yang diramalkan dengan menggunakan medan elektromagnet yang telah diukur, sementara kekonduksian tanah adalah diandaikan sempurna.

Bahagian pertama kajian ini meninjau dan membincangkan arus asas saluran paling penting dan model arus beserta kaedah pengiraan elektromagnet. Dalam bahagian-bahagian berikutnya, kajian ini mengemukakan ungkapan-ungkapan medan menggunakan kaedah FDTD kedua bagi mengira medan elektromagnet disebabkan fungsi-fungsi arus benar dalam domain masa. Bagi pengumuman dan pelurusan ungkapan-ungkapan medan, persamaan-persamaan medan umum telah dicadangkan secara langsung dalam domain masa sementara menyokong fungsi-fungsi arus asas saluran paling penting secara langsung tanpa memerlukan penukaran tambahan kepada domain yang lain. Akibatnya, kaedah pengiraan electromagnet yang dicadangkan boleh disokong dengan medan yang diukur dan keputusan daripada kajian yang lalu. Tambahan pula, ungkapan-ungkapan medan umum disebabkan saluran kilat condong telah dicadangkan dan dibuktikan dengan medan yang diukur secara langsung dalam domain masa, sementara fungsi arus asas saluran benar dan bentuk umum model arus kejuruteraan digunakan.

Penyelidikan ini mencadangkan algoritma prosedur songsang menggunakan ungkapan-ungkapan umum dan algoritma pengoptimuman zarah kerumunan (PSO) dalam domain masa di mana bentuk gelombang arus asas saluran penuh di dalam domain masa boleh ditentukan. Dengan mempertimbangkan tiga komponen medan elektromagnet, kaedah ini boleh digunakan ke atas semua jarak dari saluran kilat tanpa apa-apa batasan. Tambahan pula, dalam cara yang disarankan, faktor bersandar ketinggian pengecilan boleh ditentukan dengan menggunakan medan terukur sementara menganggapnya sebagai satu fungsi yang tidak diketahui berdasarkan model kejuruteraan. Cara yang disarankan dapat meramalkan bentuk gelombang arus pada ketinggian berbeza di sepanjang saluran kilat dan juga menyokong bentuk-bentuk umum paling penting bagi fungsi arus asas saluran. Bagaimanapun, penambahbaikan oleh Deindorfer dan Uman padai fungsi Heidler dengan satu pembolehubah tidak dikenali dipilih kerana fungsi arus asas saluran umum itu. Tambahan pula, bentuk gelombang arus disahkan dengan medan yang diukur pada titik-titik pemerhatian lain apabila parameter arus yang dikira dan algoritma prosedur terus yang dicadangkan itu digunakan. Ia harus dicatat yang data medan yang diukur diperolehi daripada kilat cetusan-roket pada dua jarak jejari berbeza dari saluran kilat. Algoritma yang dicadangkan digunakan ke atas data medan-medan elektrik yang diukur dari saluran kilat semula jadi manakala jarak jejari ditentukan dengan menggunakan sistem lokasi kilat dan medan elektrik tersimulasi yang menggunakan parameter arus yang diramalkan yang kemudiannya dibandingkan dengan medan elektrik yang diukur.

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APPROVAL

I certify that an examination committee met on month/date/year to conduct the final examination of Mahdi Izadi on his Doctor of Philosophy thesis entitled "Evaluation of lightning return stroke current using measured electromagnetic fields" in accordance with University Putra Malaysia (higher degree) act 1980 and University Pertanian Malaysia (higher degree) regulations 1981. The committee recommends that the candidate be awarded the relevant degree.

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

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently submitted for any other degree at University Putra Malaysia or at any other institutions.

MAHDI IZADI

Date: 30 April 2012

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