APPLICATION OF THE ELECTROMAGNETIC FIELD METHOD TO STUDY A COMMUNICATION SATELLITE SITE DAMAGED BY LIGHTNING

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Abstract –

This paper presents a case study of a satellite communications site at which equipment was damaged during a lightning storm. The transient ground potential rise (GPR) and stress voltages on the damaged equipment (HPA) during a lightning storm are obtained using the electromagnetic field theory method. The stress voltage on the HPA is reduced by 75% (from 25 kV to 6 kV) when the isolated signal ground wire is electrically bonded to a nearby equipment ground. An extended grounding system has little influence on the stress voltages at the beginning of the transient period; however, it reduces the stress voltages significantly (by about 50%) after the first 3 µs.

I. Introduction

In recent years, rapid growth of wireless communications has put higher demands on the reliability and quality of the services provided by telecommunications companies. In countries such as Malaysia, that have high keraunic levels, equipment damage at communications sites due to lightning strikes is one of the main causes of interruption of service, particularly, when digital electronic devices are used.

This paper presents a case study of a satellite communications site at which equipment was damaged during a lightning storm. Electromagnetic field theory method is used to carry out the study: a computer model is set up which contains conductor networks, including both aboveground metallic structures and grounding systems. A realistic lighting strike is then simulated. The ground potential rise (GPR) values of the building structure and equipment are computed for the existing grounding system and with alternative grounding arrangements. In this paper, we focus on improvements that can be obtained from enhancement of the grounding system and modification of the equipment's signal grounding locations.

II. Description of the Problem Being Studied

Fig. 1 shows the configuration of the conductor network used in the computer model. There is an antenna on the roof of each of the two equipment rooms, Lab-1A and Lab-2A. The two equipment rooms are hexagonal in shape and are interconnected. There are also several antennas outside this building, as indicated in Fig. 2. The supporting frame of the antenna on Lab-2A was struck by lightning and damage was observed in the Lab-2A equipment room below and in the control room: (a) In the control room, the CPU boards at the Antenna Control Unit (ACU-1 and ACU-2) were damaged; (b) In Lab-2A, the High-Power Amplifier (HPA) was damaged.

Aboveground conductors include the antenna support, the steel rebars of the building and steel casings of the equipment in the equipment room Lab-2A. The antenna support is modeled as a steel pipe with 3 cm outer radius and 1 cm wall thickness. The rebars of the building and equipment frame are represented by solid steel conductor with a radius of 1 cm. The grounding loop conductors consist of copper strips (approximately 25 mm by 3 mm) that are buried 0.5 m below the earth surface. The equipment frames are placed 0.1 m above the earth surface (see Fig. 1(c)). In the present analysis, a skeleton of the building rebar is modeled which includes only the rebars of the ground floor at Lab-2A and in the Control Room (see Fig. 1(a)). Fig. 1 represents the existing grounding system. Fig. 2 presents the first proposed enhancement of the existing grounding system, consisting of the installation of ground loops at other buildings and antennas, as well as interconnections between them.

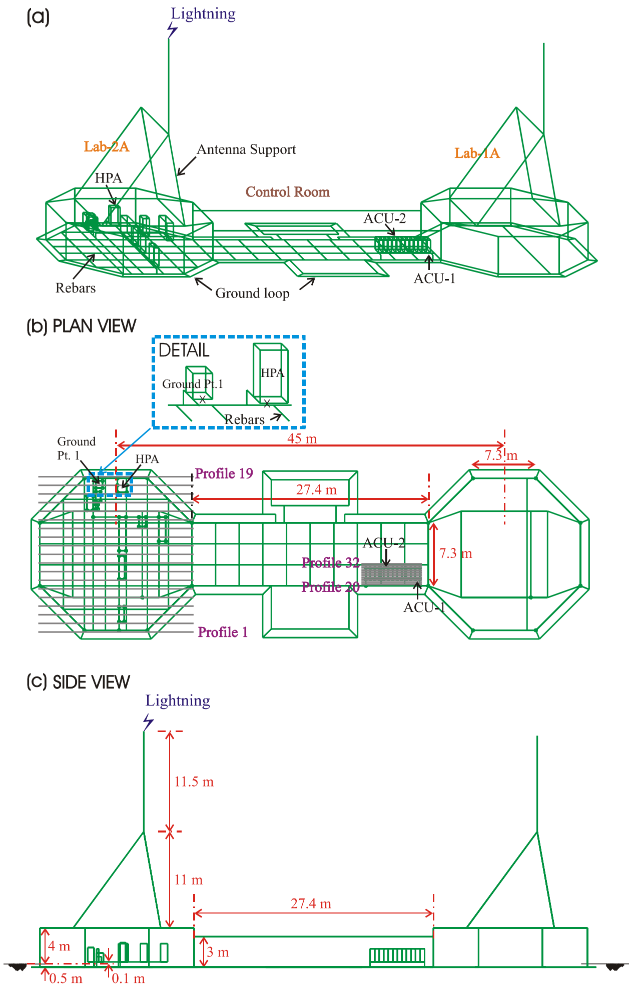

Fig. 1. *Existing grounding system modeled.*

The following three different grounding systems were studied and compared while the above ground structures remain the same: (a) extended grounding system shown in Fig. 2; (b) existing grounding system shown in Fig. 1(b) without rebars in Lab-2A and Control Room; (c) existing grounding system with rebars shown in Fig. 1(b). The ground potential rise of the conductors as well as the scalar potentials and electromagnetic fields on the ground floor of Lab-2A (Profiles 1-19 in Fig. 1(b)) and at ACU (Profiles 20-32 in Fig. 1(b)) were computed. The scalar potentials and electromagnetic fields have been computed at a number of observation points located on a horizontal plane, at the earth surface (which is also the floor level).

As shown in Fig. 1, a direct lightning strike has been simulated by injecting a current at the top of the supporting frame of the Lab-2A antenna. A uniform soil with a 12 Ω-m resistivity was measured and modeled. A relative permittivity (with respect to free space) of 1 and relative permeability (with respect to free space) of 1 are assumed for the soil model.

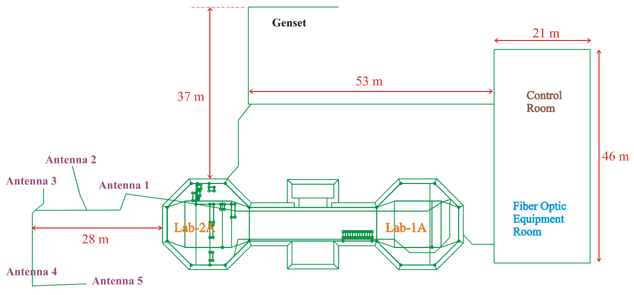

Fig. 2. *Extended grounding system modeled.*

The lightning surge is modeled as an ideal *current* source whose wave shape is a double exponential given by

$$I(t)=I_m\left[e^{-\alpha t}-e^{-\beta t}\right] \quad , \quad (1)$$

where I_m = 35,706 A, α = 14203.84 sec^{-1} and β = 4880435 sec^{-1}. Fig. 3 displays the waveform of the lightning surge current. The waveform of the lightning surge is characterized by a 1.2/50 μs wave, with a peak magnitude of 35 kA (an average value observed in the area). The surge signal decays towards zero at about 500 μs.

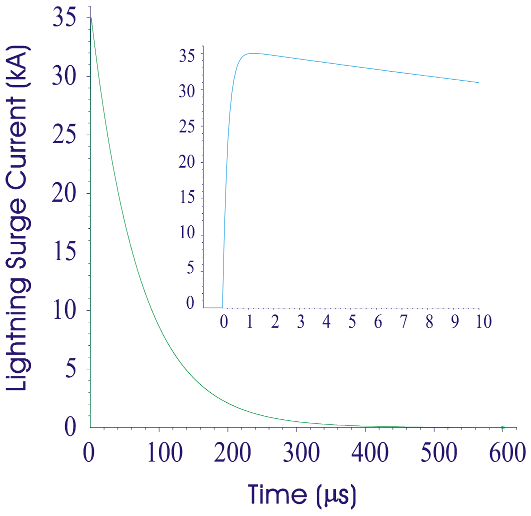

Fig. 3*. A 1.2/50 μs lightning surge current.*

III. Computation Methods

The field theory approach used in this paper is an extension to low frequencies of the moment method used in antenna theory. By solving Maxwell's electromagnetic field equations, the method allows the computation of the current distribution (as well as the charge or leakage current distribution) in a network consisting of both aboveground and buried conductors with arbitrary orientations. The scalar potentials and electromagnetic fields are thus obtained. The effect of a uniform earth of arbitrary resistivity, permittivity and permeability is completely taken into account by the use of the full Sommerfeld integrals for the computation of the electromagnetic fields. The details of the methods are described in [1] and its references.

To obtain the transient GPR and electromagnetic fields, a number of representative frequencies are selected from the frequency spectrum of the surge signal and then used to compute the frequency domain responses of the GPR and electromagnetic fields. The inverse Fourier transform is applied to the frequency domain responses to obtain the transient GPR and electromagnetic fields. The computation of the frequency domain responses is carried out using the HIFREQ engineering module of the CDEGS software package [2] based on the field theory approach. The Fourier transforms are carried out using the FFTSES engineering module of the CDEGS software package.

IV. Computation Results

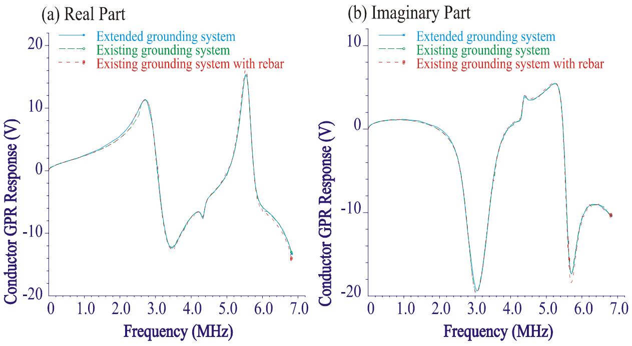

Fig. 4. *Unmodulated frequency spectrum of conductor GPR at HPA.*

Figs. 4 to 6 show the unmodulated conductor GPR, the modulated conductor GPR and the time domain transient ground potential rises on the frame of the HPA, respectively, for the three cases studies. The unmodulated system response is generated by applying a unit energization (1A in this case) to the conductor network at each frequency studied. This response defines the characteristics of the conductor network in the frequency domain. It is independent of the input surge signal and therefore provides valuable information about the frequency response of the system being studied. The unmodulated system response is modulated by the frequency spectrum of the surge signal to obtain the so-called modulated system response, which is used to obtain the time domain response via the inverse Fourier transform.

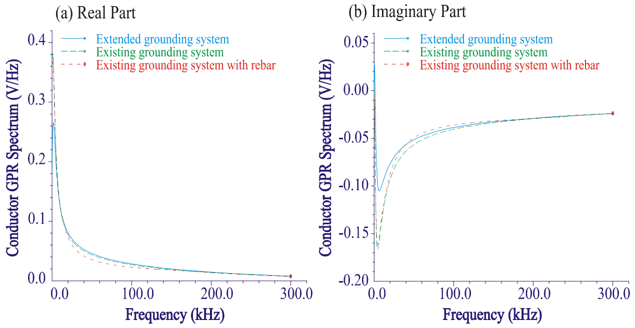

Fig. 5. *Modulated frequency spectrum of conductor GPR at HPA.*

The spectra in Figs. 4 and 5 indicate that the enhancement of the grounding system only affects the conductor GPRs at low frequencies. The conductor GPR at high frequencies remain virtually the same with the extended grounding system or with the rebar of the concrete floor modeled. The influence of the grounding system on low frequency responses is evident in the transient GPR response, as shown in Fig. 6. The modulated spectra of the three systems are almost identical above 300 kHz. The transient GPR in the extended grounding system decays towards zero more quickly than that in the existing grounding grid. The system exhibits resonance at about 2.7 MHz and 5.4 MHz, which approximate the overall dimension of the network.

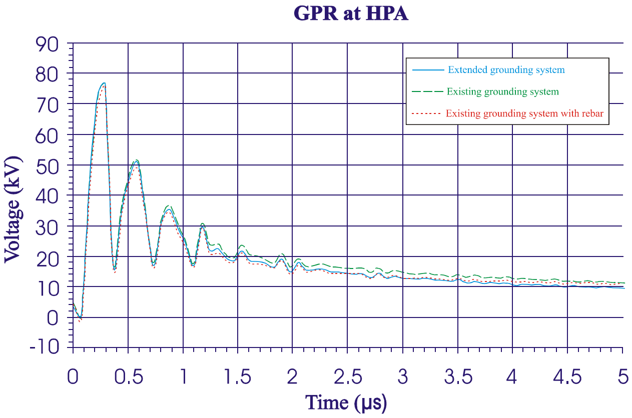

Fig. 6. *Transient ground potential rise at HPA.*

The stress voltages at the HPA are presented in Figs. 7 and 8. The stress voltage in Fig. 7 is computed as the ground potential difference (GPD) between the GPR of the frame of the HPA and the potential of a point on the earth surface under the HPA, which represents the isolated ground of the signal wires. In all three cases, the maximum stress voltages are about 25 kV, a value which is large enough to damage the HPA. The extended grounding system has little influence on the stress voltages at the beginning of the transient, however, it reduces the stress voltages significantly (by about 50%) beyond 3 μs. If the isolated ground of the signal wires of the HPA is tied to Ground Pt. 1 (the detail in Fig. 1(b) marks the two locations by “x” between which the stress voltage is computed), the stress voltage (shown in Fig. 8) is now reduced to about 6 kV (almost 75%). This underlines the need for short ground connection leads for protection of equipment during transients. The stress voltages computed at ACU-1 and ACU-2 are similar to those computed at the HPA with a maximum value of about 20 kV.

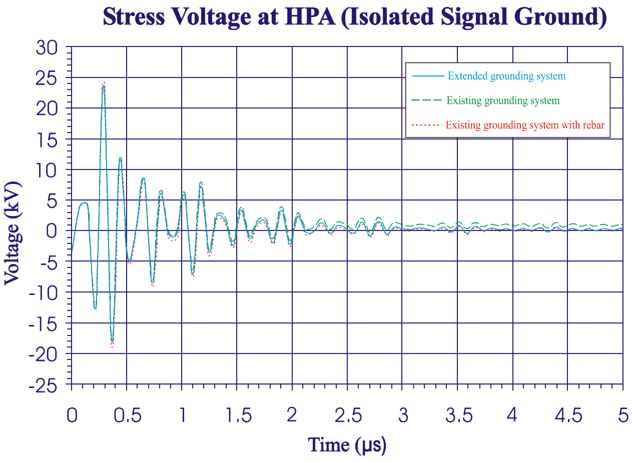

Fig. 7. *Stress voltage at HPA between equipment frame and isolated signal ground.*

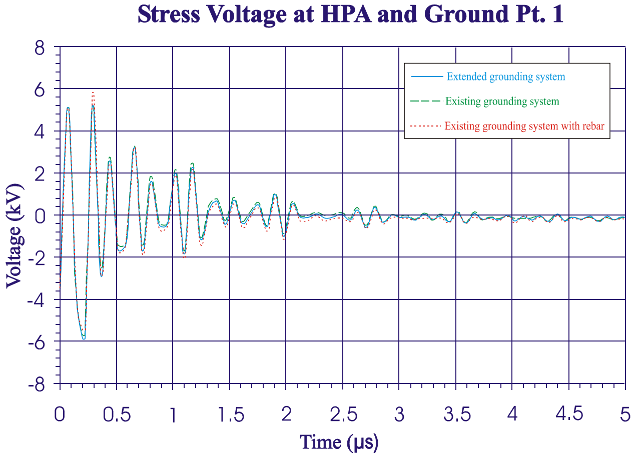

Fig. 8. *Stress voltage at HPA between equipment frame and Ground Pt.1.*

V. Discussion and Conclusions

The transient GPR and stress voltages on the damaged equipment (HPA) during a lightning storm have been obtained by the electromagnetic field theory method. The stress voltage on the HPA is reduced by 75% (from 25 kV to 6 kV) when the isolated signal ground wire is electrically bonded to a nearby equipment ground. Further stress voltage reductions could be achieved by short local connections of the signal ground to the equipment frame ground. The extended grounding system has little influence on the stress voltages at the beginning of the transient; however, it reduces the stress voltages significantly (by about 50%) after the first 3 μs.

Although a simplified aboveground conductor network is studied in this paper, the stress voltages analyzed at other locations of the network indicate that these voltages are strongly influenced by the aboveground conductor network (especially along the lightning current conduction path). It appears that an accurate model of the aboveground conductors along the lightning current conduction path (include modeling of rebars) is critical in determining the stress voltages on the equipment. A future study will be conducted to investigate these aspects.

References

[1] S. Fortin, F. P. Dawalibi, J. Ma, and W. Ruan, "Effects of AC Power Line Configuration and Current Unbalance on Electromagnetic Fields", *Proceedings of The 57th American Power Conference*, Chicago, pp. 170-175, April 1995.

[2] F. P. Dawalibi and F. Donoso, Integrated Analysis Software for Grounding, EMF, and EMI, *IEEE Computer Applications in Power*, Vol. 6, No. 2, 1993, 19-24.

Biographies

Dr. Winston Ruan received the B.Sc. degree in physics from Lanzhou University, P. R. China in 1985. He received the Ph.D. degree in experimental physics in 1993, from the University of Manitoba, Winnipeg, Canada, where he worked from 1987 to 1992 on constructing a SQUID AC susceptometer/ magnetometer and studied magnetic phase transitions in reentrant magnetic alloys with quenched structural disorder. In 1993, he worked on Electrical Impedance Tomography using induced current methods, as a postdoctoral fellow in the Institute of Biomedical Engineering at Ecole Polytechnique, University of Montreal.

Since April 1994, he has been with the R&D Department of Safe Engineering Services & technologies ltd. His research interests include the computation of electromagnetic fields, transient phenomena due to lightning or switching, as well as AC interference between transmission lines and pipelines.

Robert D. Southey, Eng., graduated from McGill University, Montreal, in December 1985 with a B. Eng. (Honours) degree in Electrical Engineering. From that time to the present, he has worked for Safe Engineering Services & technologies ltd., where he is now manager of the Applied R&D Department. He has been extensively involved in several major AC interference mitigation design studies and grounding studies.

Mr. Southey is a member of IEEE and a registered Engineer in the Province of Quebec.

Nurul Aishah Idris received B.Eng. in Electrical Engineering from Universiti Teknologi Malaysia in 1998. The title of her final year project was ‘Measurements and Analysis of Induced Effect of Lightning to Overhead and Underground Telecommunication Cables’. Her six months Industrial Training was at Institute of High Voltage and High Current (IVAT), Universiti Teknologi Malaysia. She joined Telekom Malaysia in Research and Development Division in 1998. Currently she is attached to Network Protection Unit. She also actively involved in Telekom Malaysia QIT on power related issues jointly organized by several divisions of Telekom Malaysia.

For biographies of Dr. Farid P. Dawalibi, see " HVDC Advanced Analysis Methods for Grounding Design and DC Interference Mitigation Techniques " by J. Liu, F. P. Dawalibi, J. Ma and R. Southey in this proceedings.