Performance of Earthing Systems of Operational/Live Stations under Impulse Conditions

N. A. Idris, A. Ramli, N. Mohamad Nor, H. Ahmad

Abstract--A number of impulse investigations on earthing systems have been performed in the field [1-6]. The studies were conducted on a few types of earth electrode: vertical rods, horizontal electrodes and the mesh and other geometries of electrodes. The type selected may depend on the type of soil encountered and the available depth or area available. Impulse voltages of up to 3MV with impulse currents of up to 30kA were applied on earth electrodes with different configurations. The experimental results from previous studies in the field [1-6] revealed that under high currents, a 'non-linear' soil behaviour would occur. However, so far the field measurements were conducted on the imitative earth electrodes, and not on the live operating systems.

In this study, the performance and the electrical characteristics of earthing systems under impulse conditions were investigated. For the first time, the impulse tests were conducted on the earthing systems of operational stations, in which connected to the external paths and other equipments. Impulse voltages with increasing magnitudes up to 6kV were injected into the earth electrode. The results reveal that there is no flashover or damages on the equipments at the stations/sites under tests. It was also observed that the earthing systems are mainly inductive under impulse conditions of up to 6kV. It also includes the investigations on earthing systems using computer models [7]. The earth resistance values at power frequency and low-magnitude voltage and current of these selected sites were also obtained using Current Distribution Electromagnetic Interference Grounding and Soil Structure Analysis (CDEGS) [7]. The impedance values of the earthing systems were found to be ranging between 2.7Ω and 9.2Ω.

Keywords: Earthing System, Non-linear, Remote Earth, Impulse Impedance.

I. INTRODUCTION

Based on voltage and current measurements obtained from impulse tests on earth electrodes, two main observations were made by previous authors [1-6] to explain the non-linear soil behaviour;

(i) v-i curves form 'loops' due to differences in front and decay times between voltage and current traces,

(ii) reduction in earth resistance from it's steady-state values and it's decrease with current magnitude.

The main contributions of this paper are

i) So far, the impulse measurements conducted at field site are on the imitative earth electrodes, and not on the live operating systems. The research work in this paper is to observe the characteristics of earthing system of live/operating telecommunication station and a building under impulse conditions up to 6kV.

ii) Some literature work [3-6] indicated that the characteristics of earthing systems are dependent upon the AC earth resistance, where a lower degree of non-linear behaviour of soil was observed for a lower AC earth resistance value. It is proposed in this paper to clarify this point through calculations on AC earth resistance (using CDEGS) [7] and impulse tests application up to 6kV on practical earthing systems.

iii) In the ANSI/IEEE Std 81-1983 [8], it is mentioned that during impulse tests, the remote or auxiliary earth, which is preferably of the distributed type, such as a substation or an earth mesh, and carries the return current from the impulse generator should be significantly lower than that of the earth electrode under test. However, there is no mention in the standard [8] on the effect of the distance of the remote earth from the electrode under test, and this paper is to address this effect.

It is also important to obtain the earth resistance values at power frequency voltages and low-level conduction currents, as the reference/guide values, and particularly to observe the correlation between the AC earth resistance and the characteristics of earthing systems under impulse conditions, as described above. The conventional methods proposed in the standards [8-10] are Two-Point Method, Three-Point Method, Ratio Method, Staged Fault Tests and Fall of Potential Method. However, these methods may not be practical or even possible to conduct for large earthing systems. Buried structures near the measurement, such as transmission line tower and pole grounds and water pipes can also influence the measurements significantly. Ma et al [11] found that the earth impedance values obtained using the CDEGS [7] are close to that measured using a conventional method (Fall-of-Potential Method). This study [11] shows that the CDEGS can be used to obtain the earth impedance values at power-frequency or low voltage level. Due to that, computer application software, CDEGS is used in this study in order to determine the earth impedance magnitudes under low magnitude voltage and currents at power frequency.

This work was supported by Telekom Malaysia Ltd. under Project No. R&DC 0559.

N. A. Idris and A. Ramli are with Telekom R&D Pte. Ltd., Lightning Protection & EMC Unit, Idea Tower 2, UPM-MTDC, 43400 Serdang, Selangor, MALAYSIA (e-mail: nurul@rndtm.net.my).

N. Mohamad Nor is with the Faculty of Engineering, Multimedia University, Cyberjaya Campus, 63100 Cyberjaya, Selangor, MALAYSIA (e-mail: normiza.nor@mmu.edu.my).

H. Ahmad is with the Universiti Teknologi Malaysia, FOE, 81310 Skudai, Johor, MALAYSIA (email: hussein@fke.utm.my)

Presented at the International Conference on Power Systems Transients (IPST'05) in Montreal, Canada on June 19-23, 2005

Paper No. IPST05 - 007

II. COMPUTER MODELING OF EARTH RESISTANCES

In this computational analysis, CDEGS MALT software [7] was used. Ma et al [11] have validated the CDEGS software against the Fall-of-Potential (FOP) method, which shows that the method used in the present study is acceptable. First, the soil resistivity profile is determined with the most common method, which is a Wenner Four-Electrode Configuration, as outlined in the ANSI/IEEE Std 81-1983 [8], ANSI/IEEE Std 142-1991[9], and ANSI/IEEE Std 80-2000 [10]. Based on these measurements, CDEGS MALT software [7] was then employed to obtain the soil resistivity profiles, which are shown in Table 1. However, for each site, the diagrammatic and information of earthing systems configurations/dimensions are not available. Due to that, a new illustration of earthing configurations/dimensions is developed for each site (see Table 1). This is based on the number and location of earth chambers at the sites. In each earth chamber, it is assumed to have an 8ft rod buried in the ground, which is a typical size of the rod used in this country. It is also assumed that the station/earthing grid is commonly connected. It has been known and mentioned in the standards [8-10] that the nearby metallic structures can also influence and reduce the earth resistance value significantly. Thus, the presence of nearby buried metallic structures is also reasonably considered/included in the study.

After obtaining the complete diagrammatic/configuration of each site and the resistivity profiles, CDEGS MALT [7] is then used to compute for the earth resistance value. Table 1 summarises the calculated earth resistance value that is obtained for each site. These resistance values only provide guidelines/reference, and not the comparison study against the FOP method or for the validation purposes.

III. IMPULSE TEST CIRCUIT ARRANGEMENT

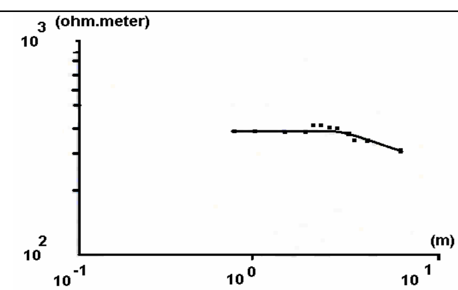
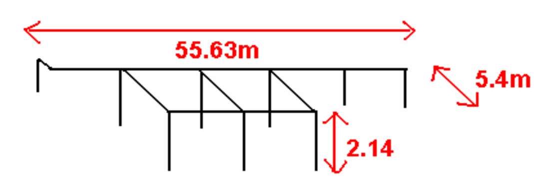
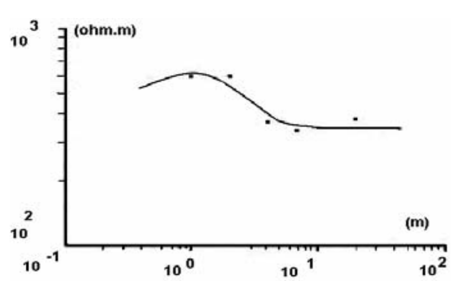
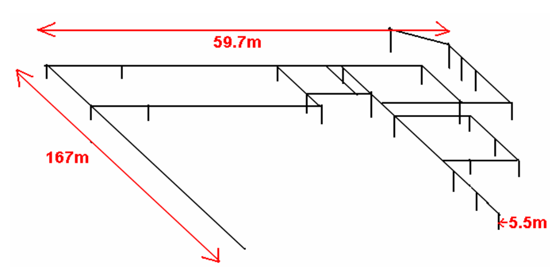
The arrangement for the impulse tests on earthing systems consists of an impulse generator, voltage and current transducers, and earthing systems. Figures 1a and 1b show the test arrangement of impulse tests. Since the impulse tests were conducted on live/operating stations, the voltage levels of only up to 6kV were used. A combinational waveform impulse generator with voltage level of up to 6kV produces a standard lighting response of 1.2/50µs. A fast response voltage probe with a ratio of 1000:1 was used for voltage measurement. Fast transient current measurement was obtained with a commercially available current transformer, with a sensitivity of 0.1V/A and a response time of 20ns. The voltage and current signals were captured on a WaveRunner Lecroy, 500MHz Digital Storage Oscilloscope (DSO). A 'Scope Explorer' was utilised for data acquisition and analysis. The remote/reference earth consisting of a single rod is placed at 80m away from the earth grid for the study of

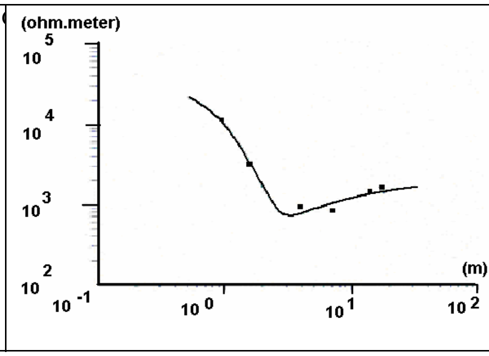
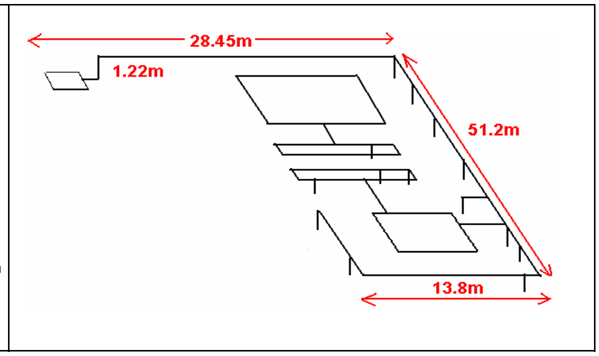
i) the characteristics of live/operational stations
ii) correlation between AC earth resistance and earthing systems characteristics

However, for the study of the effect of distance of remote earth, the remote/reference earth are placed at a number of locations away from the earth grid, where different sizes of rods were used.

TABLE I

RESISTIVITY PROFILES, EARTH CONFIGURATION/DIMENSIONS AND CALCULATED EARTH RESISTANCES.

Sites/Location (Resistances (Ω))	Soil Resistivity Profiles	Earth Configuration /Dimensions
Building A (9.92)		
Microwave Station (2.69)		

Microwave Station ((3.25)		

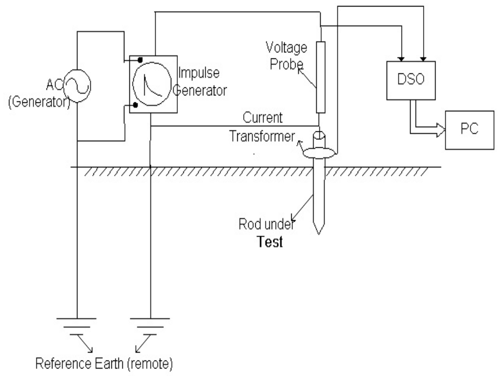


Figure 1a: Impulse test circuit

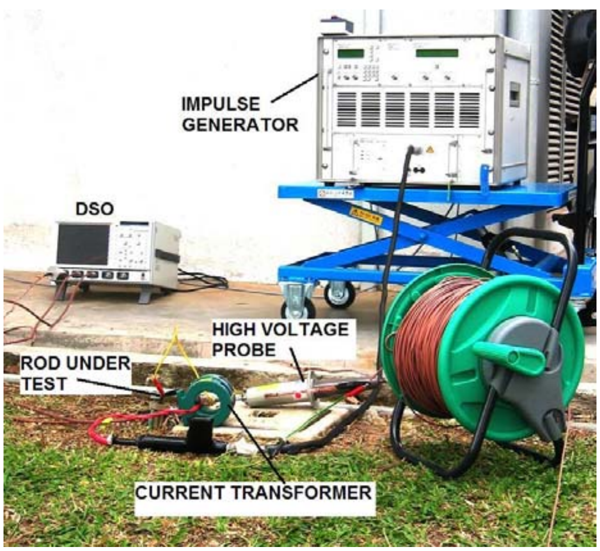


Figure 1b: Impulse test arrangement at field site

IV. IMPULSE TEST DATA

Impulse tests were conducted at three field sites; earthing systems of a building and two telecommunication systems, in order to determine the earth impedance values. When impulse voltages up to 6kV were injected into the live/operational earthing systems, no flashover or damage on the equipments was observed. Figure 2 shows typical voltage and current traces obtained for site A. Impulse voltages and currents for sites B and C are found similar to Figure 2. The figure shows the voltage peak occurred before current peak. It was also observed that the current trace of all earthing systems exhibited a significantly slow time to current peak (has slow rise time). There is also initial overshoot/spike on the measured voltage trace, which could be due to the inductive effects in combination with the capacitive effects of the earthing systems.

It can also be seen from the figure that the voltage decays faster than the current, and at current peak, the voltage is at its zero which shows that the earthing systems are mainly inductive under impulse conditions. In this study, it was also observed that the voltage trace swung negative before completely discharged to zero. This could be due to a poor remote earth, since it only consisted of only a single earth rod, thus the voltage and current do not discharge to the ground effectively.

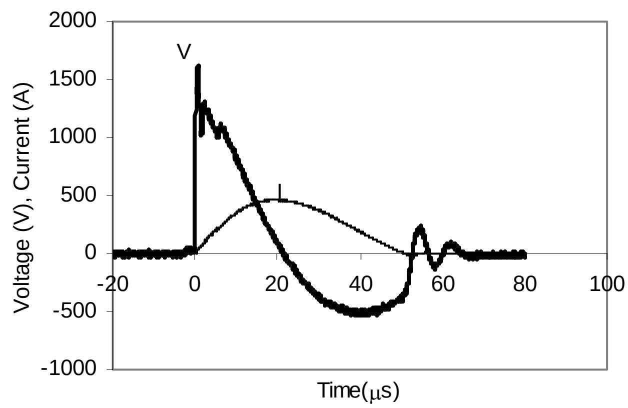


Figure 2: Voltage and current traces for existing earthing systems at charging voltage of 3kV, with remote earth consisting of a single rod at 80m away from the existing earthing systems.

A. *Correlation between AC Earth Resistance and Earthing Systems Characteristics under Impulse Conditions.*

The AC earth resistance values of the earthing systems used in this study range between 2.7-9.2Ω. Since the voltage and current traces of all sites obtained in this study are found to be similar, it is therefore no significant correlation between the AC earth resistance and the characteristics of earthing systems is observed. This could be due to low voltage levels used, which are only up to 6kV. This is to avoid damages on the equipments at the station. However, the authors feel that these correlations are important, and further analyses to address these effects are still required. Such effects are still under study, and the results are hoped to be published in the next publication.

B. *Effect of Distance of Remote Earth*

As part of the main contributions of this paper, the effects of the distance of remote earth are also investigated in the study. Impulse tests were conducted on the existing earthing systems of the telecommunication station (site C), where the remote earth consisting of

i) a single rod buried at 80m away from the station, of which the results have been discussed earlier (section IV of this paper),

ii) a single rod buried at 5m away from the station

iii) a single rod buried at 40m away from the station

iv) a newly constructed earthing systems with a dimension of 5m x5m square grid, located at 80m away from the existing earthing systems.

Having various locations of the remote earth, it allows the studies on the effects of the distance of the remote earth to the earth electrode under test, which have never been addressed before.

Figure 3 shows typical voltage and current traces obtained for existing earth grid (site C) when impulse tests were applied into it, with the remote earth is a single rod buried only at 5m away from the electrode under test. The figure shows that the voltage peak occurred before current peak. It was also observed that the current trace exhibited a significantly slow rise time, which was thought to be due to the inductive effects. It can also be seen that the voltage decays faster than the current. However, unknown characteristics of earthing systems were observed, where the voltage trace was found to highly swing to negative before returning to zero and the voltage trace was found to be negative at peak current. These behaviours may not show the real characteristics of earthing systems, which are expected to be predominantly inductive.

Voltage and current traces similar to Figure 2 were observed when a single rod buried at 40m away from the existing station and a 5m x5m square grid, located at 80m away from the existing earthing systems are used as the remote earth.

Even though the remote earth at 40m away from the earth grid is only made of a single rod, the earth grid's characteristic is found to be similar to when the remote earth is 80m (5mx5m). This finding shows that it is important to place the remote earth at least 40m away from the electrode under test.

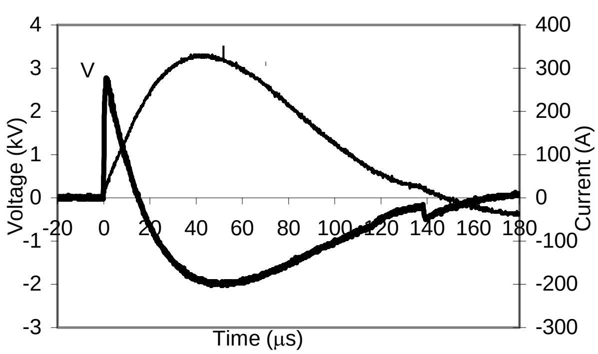


Figure 3: Typical voltage and current traces for existing earthing systems at charging voltage of 3kV, with remote earth consisting of a single rod located at 5m away from the existing earthing systems.

V. CONCLUSIONS

There is no flashover or damage was observed on the equipment in the stations. The study also offers the knowledge on the performance of earthing systems under impulse conditions. The impulse impedance values obtained with the voltage level up to 6kV were found to be predominantly inductive. There is no correlation between the AC earth resistance and the characteristics of earthing systems under impulse currents are observed. The results also reveal that the remote earth should be placed at least 40m away from the electrode under test.

VI. ACKNOWLEDGEMENT

The authors wish to thank Mohd Noorfallah Md. Isa for his assistance in carrying out the experiments.

VII. REFERENCES

[1] R. Kosztaluk, M. Loboda, and D. Mukhedkar: 'Experimental Study of Transient Ground Impedances', IEEE Transactions on Power Apparatus and Systems, Vol. PAS 100, No. 11, pp. 4653-4660, Nov. 1981.

[2] P. L. Bellaschi, R. E. Armington, and A. E. Snowden: 'Impulse and 60-Cycle Characteristics of Driven Ground Rods-II,' AIEE Transactions on Power Apparatus and Systems, Vol. 61, pp.349-363, 1942.

[3] S. Sekioka, H. Hayashida, T. Hara, and A. Ametani: 'Measurement of Grounding Resistance for High Impulse Currents', IEE Proceedings Generation, Transmission and Distribution, Vol. 145, pp. 693-699, 1998.

[4] M. Takeuchi, Y. Yasuda, H. Fukuzuno: 'Impulse Characteristics of a 500kV Transmission Tower Footing Base with various Grounding Electrodes', 24th International Conference on Lightning Protection, pp. 513-517, Birmingham (UK), 14-18 September, 1998.

[5] A. Morimoto, H. Hayashida, S.Sekioka, M. Isokawa, T. Hiyama, H. Mori: 'Development of Weatherproof Mobile Impulse Voltage Generator and Its Application to Experiments on Nonlinearity of Grounding Resistance', Transactions Institute Electrical Engineering Japan, Vol 117, No. 5, pp.22-33, (in English), 1997.

[6] T. Sonoda, H. Takesue, S. Sekioka: 'Measurements on Surge Characteristics of Grounding Resistance of Counterpoises for Impulse Currents', 25th International Conference on Lightning Protection, pp. 411-416, Rhodes (Greece), 18-22 September, 2000.

[7] User's Primer CDEGS (Current Distribution, Electromagnetic Interference, Grounding and Soil Structure Analysis), Revision level: Version 11 year 2004.

[8] ANSI/IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.

[9] ANSI/IEEE Std 142-1991, IEEE Recommended Practice for Grounding Industrial and Commercial Power Systems.

[10] ANSI/IEEE Std 80-2000, IEEE Guide for Safety in AC Substation Grounding.

[11] J. Ma, F. P. Dawalibi, W. Ruan, R. D. Southey, R. Waddell, J-K. Choi: 'Measurement and Interpretation of Ground Impedances of Substation Grounding Systems Connected to Ground Wires and Metallic Pipes', Proceedings of the 60th American Power Conference, Vol. 60, pp. , Chicago (USA), 14-16 April, 1998.

VIII. BIOGRAPHIES

Nurul Aishah Idris was born in Malaysia on 1975. She received her degree in Electrical Engineering from Universiti Teknologi Malaysia in 1998. She joined Telekom Malaysia in Research and Development Division in 1998. Currently she is attached to Lightning Protection & EMC Unit.

Annuar M. Ramli received his B.Eng. (1993) and M.Eng. (1999) in Electrical Engineering from Universiti Teknologi Malaysia. He is a Senior Researcher in Lightning Protection & EMC Unit, in Telekom Research & Development Sdn. Bhd., Kuala Lumpur, Malaysia. He is a member of the Institute of Electrical & Electronic Engineers (IEEE) and Electromagnetic Compatibility (EMC) Society.

Normiza Mohamad Nor was born in Malaysia, on June 73. She received her degree in Electrical and Electronic Engineering from University of Wales, College of Cardiff, UK in 1996. She obtained the Ph. D degree in Electrical Engineering from the same university, in 2001. She is currently a Lecturer of Electrical Engineering at the Multimedia University, Malaysia. Her research interests include high voltage, earthing systems and lightning protection.

Hussein B. Ahmad is a professor at Faculty of Electrical Engineering, Universiti Teknologi Malaysia. He obtained his B.Sc. and M.Sc. from the University of Strathclyde, Scotland in 1977 and 1981 respectively and Ph.D. degrees from University of Manchester, UK in 1986. He has wide research experience in insulation performance under adverse condition and lightning protection and grounding, Currently he is the Head Department of Electrical Power Engineering of the faculty since 1998.