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# Investigation of Spherical Electrode Grounding System Under High Impulse Conditions with Different Polarities

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**Abstract.** There have been many studies in the pasts, which showed that under high impulse conditions, soil ionization process around the electrode would occur, which results in lower resistance and lower transient voltage on the electrode. Several factors have also been found to affect the ionization process in soil such as; soil types and its grain sizes, moisture contents in the soil, earth electrode configurations, impulse polarity, the location of the injection point, the shape of response time, etc. In this paper, spherical electrodes grounding is used to study the ionization process in the grounding system under different impulse polarity of the current. The experiment was done by field measurement using a commercially available impulse current generator. It was found that lower earth resistance was seen to decrease with increasing current magnitudes for both impulse polarities. In addition, it was found that at low impulse current with negative polarity has a higher resistance than that of positive polarity. This paper is, therefore, to investigate towards improvement on grounding electrode's design, which would consider soil ionization process

Keywords: Ionization process, lightning impulse, grounding electrodes, impulse resistance

## 1. Introduction

One of the most significant facilities required in the world is the electrical power system. Therefore, grounding systems need to be well designed in order to ensure the continuity of the supply to achieve its objectives, since it is important to effectively dissipate the fault current to the ground irrespective of the type of fault that can be triggered either by internal faults or by external sources [1]. In protecting electrical devices during electrical overload, grounding is very important. It will help regulate the voltage levels and prevent a risk from occurring. In the safe and reliable operation of the power system [2], the efficiency of grounding systems subject to high impulse current is important. To allow the fault current to dissipate into the ground through the grounding systems [3], the grounding resistance must be engineered with low-magnitude earth impedance.

Many research studies have been carried out to investigate the soil ionization phenomenon in the grounding systems during high impulse current [1-7]. Soil ionization occurs when the lightning current leaking into the earth is high enough to produce electric field intensity greater than a critical value and contribute to the decreasing of the ground impedance [7]. There are several factors that affect the soil ionization such as types of soils, impulse polarity, grain size, and type of electrodes [8-13]. Research in [14] discussed the behavior of earth resistances under high impulse currents, where the phenomena causing the decrease in the earth resistance and the effectiveness of giving to the earth electrodes the



properties of edges or points were explained. The electrode with spikes has lower resistance in comparison to the electrode without a spike. The electrodes are suggested to be shaped with their surfaces area with high intensities at low voltage to content the theoretical and experimental verification. Based on finding in [14], an improvement in the grounding electrodes can be considered in the future considering the ionization process in soil.

In this work, the effectiveness of spherical grounding electrode was studied under different impulse polarity regarding the soil ionization process.

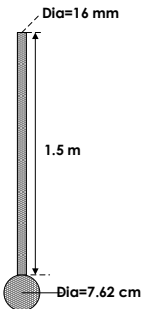
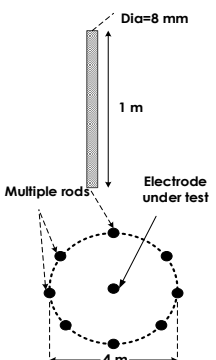
## 2. Methodology

The experimental study of the effectiveness of spherical grounding electrodes under different impulse polarity can be divided into two categories: details of the earth electrode and the test set-up.

### 2.1. Details of Earth Electrode

For these tests, there are two built earthing systems, the primary electrode being tested, and the auxiliary/remote electrodes, which are specified in Table 1. The principal electrode is a copper rod electrode of a single sphere type with a length of 1.5 m and a diameter of 16 mm. The diameter of the sphere of the principal electrode is approximately 76.2 mm. At a depth of 0.3 m, the rod is submerged in the soil and the remainder of the rod is eventually left visible to the surface of the earth for copper tapes to be attached during the impulse inspection. In the experiment, 8 vertical rod electrodes were used to build an auxiliary/remote earthing system. Each of the rods used is 1 m long and 8 mm in diameter. Then a 5 mm diameter steel wire is laid and connected by clamps to the multiple rods to form a ring configuration, as shown in Table 1. A similar auxiliary/remote earth experimental setup configuration can be found in [15-16].

**Table 1** Main and Remote/Auxiliary Earthing Systems

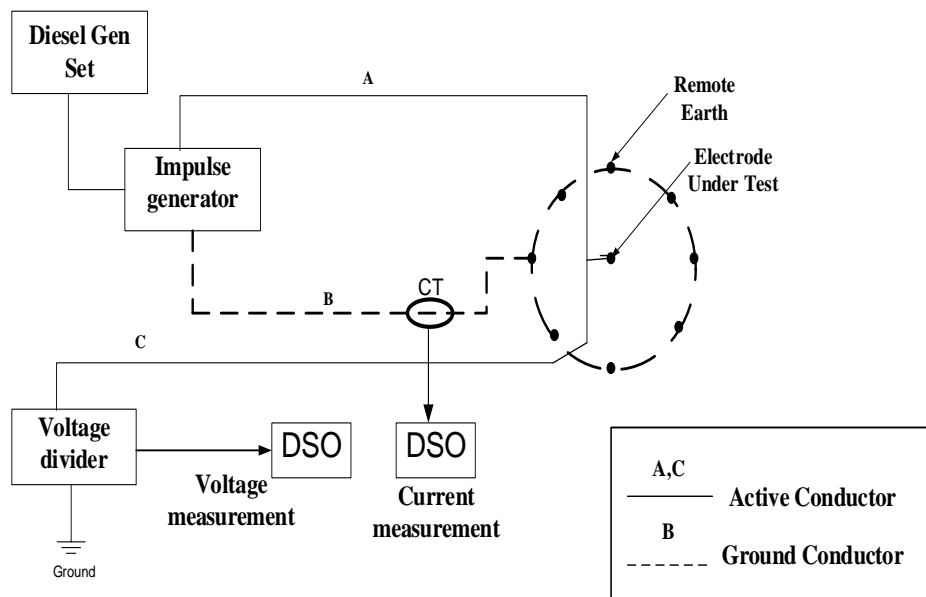
No.	Details of configuration	Layout
1	<p>Main earth electrode under test:</p> <p>Spherical Rod: 1.5 m length copper and 16 mm in diameter. The sphere diameter is 7.62 cm</p>	
2	<p>Auxiliary/remote earth electrode:</p> <p>Ring electrode of 4 m diameter constructed using 8 vertical copper rod electrodes (Per rod is 1 m long and 8 mm in diameter.).</p>	

It is highlighted in IEEE Standard 81:2012[22] during impulse testing, it is essential to have a return path for the release of high impulse currents from the impulse generator to the earth. Moreover, it is explained in [22] that the resistance of the return or auxiliary ground path should be lower than that of the test electrode. The effectiveness of the lower ground resistance of the remote earth compared to that of the electrode under test has also been discussed in [23]. Consequently, the ring earthing system is constructed like a supplementary earthing system that is larger in size and is therefore expected to have a lower earth resistance value [15].

This experiment uses the high voltage impulse generator shown in Figure 1 with the capacity to generate up to 300 kV via a three-stage capacitive discharge circuit. For voltage measurement, a 3890:1 ratio resistive divider is used, whereas for current measurement, a current transformer (CT) with a sensitivity of 0.01 VA-1 and a response time of 20 ns is used. The Digital Storage Oscilloscope (DSO) records the voltage and current signals through two separate 350 MHz/1 GS/s. The data gathered from the oscilloscope was translated to a Microsoft Excel and MATLAB file using the built-in DSO program. Figure 2 displays the experiment's circuit structure. Impulse experiments have been carried out at various voltage ranges, from 30 kV to 210 kV.



**Figure 1** Three-Stage, 30 kV to 300 kV Impulse Generator.



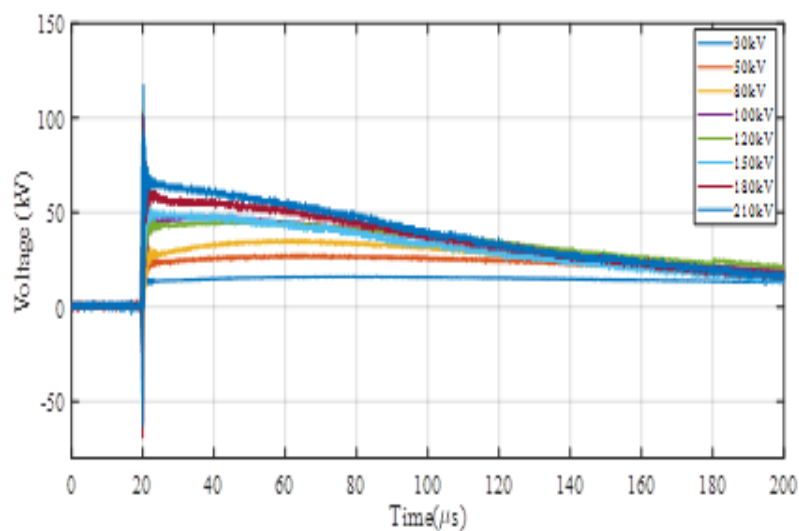
**Figure 2** Circuit Arrangement for the Impulse Test Experimental Set-up.

### 3. Results and Discussion

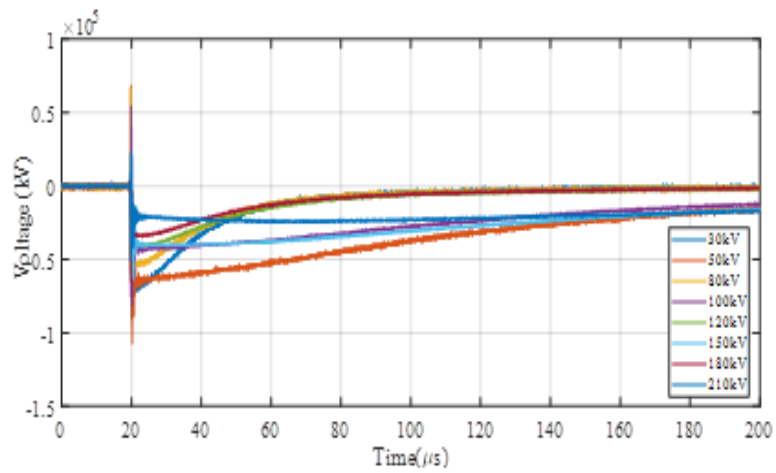
Based on voltage and current traces captured during the tests, the effects are analysed and discussed in this section. In addition, the results of a calculated impulse earth resistance are presented at the end of this section.

#### 3.1. Details of the Earth Electrode

Figures 3 and 4 present the spherical rod electrode earthing device current and voltage traces measured at various applied voltages and with both positively and negatively impulse polarities, respectively. It can be seen from Figure 3(a) and 3(b) that the voltage traces for positive and negative charging voltages have a similar fast rise time. A similar situation can be seen in Figure 4(a) and 4(b).

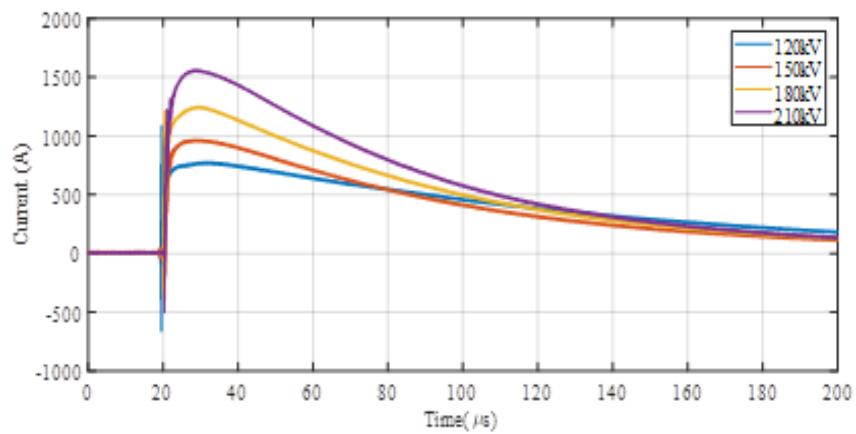


(a) Positive Charging Voltages

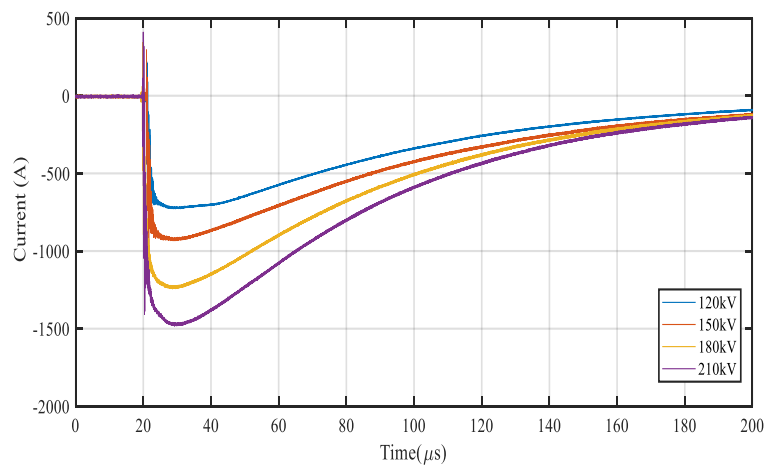


(b) Negative Charging Voltages

**Figure 3** Impulse Voltage Traces for the Spherical Single Rod at Different Charging Voltages



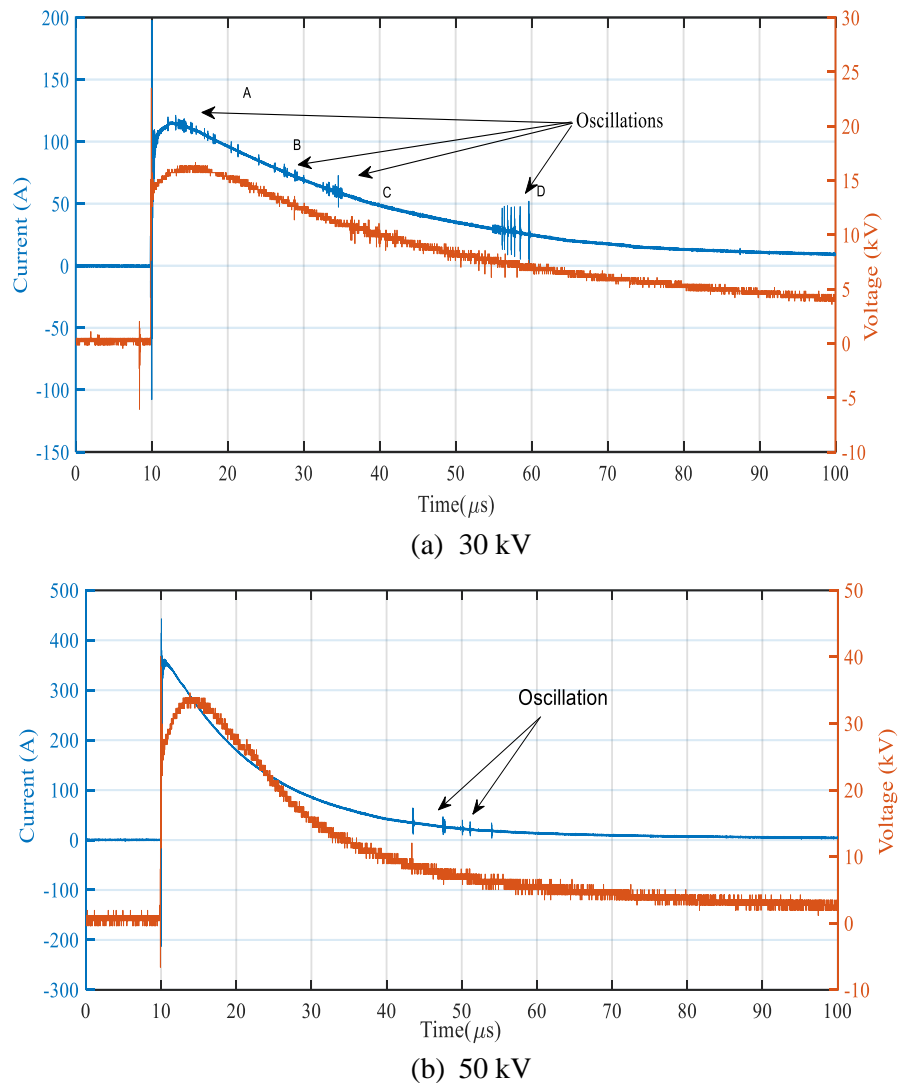
(a) Positive Charging Voltages



(b) Negative Charging Voltages

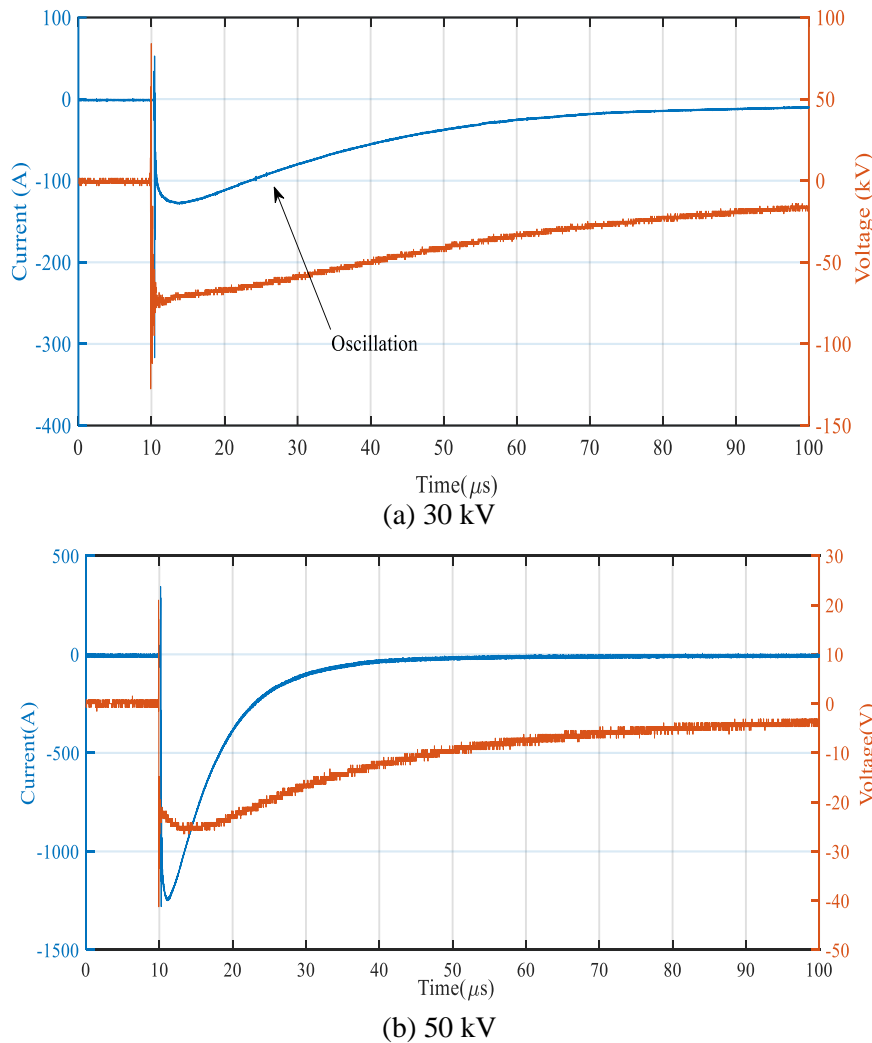
**Figure 4** Impulse Current Traces at Different Charging Voltages for the Spherical Single Rod

All voltages shown in Figure 3(a) unveiled almost the same decaying trends. However, in Figure 3(b), it was observed that some of the voltages decayed much rapidly than the others. It can be seen that voltage traces of 50 kV, 80 kV, 120 kV and 210 kV decayed much faster than voltage traces of 30 kV, 100 kV, 150 kV and 180 kV, respectively. In Figure 4, it can be seen that all current traces showed similar decaying trend for both positive and negative polarity of impulse voltages. Furthermore, it was also observed in Figure 4(a) that some of the current traces decayed much slower at the middle of the time than compared to other current traces.



**Figure 5** Voltage and Current Traces at (a) 30 kV, and (b) 50 kV Applied Voltage Positive Polarity

Some oscillations on the current track at the upper and lower current levels have been found in Figure 5. For 30 kV instances (point D), the appearance of the oscillation is clearly seen. It is believed that these oscillations are due to certain capacitive effects between the soil grains and the contact between the soil and the rods in the soil.



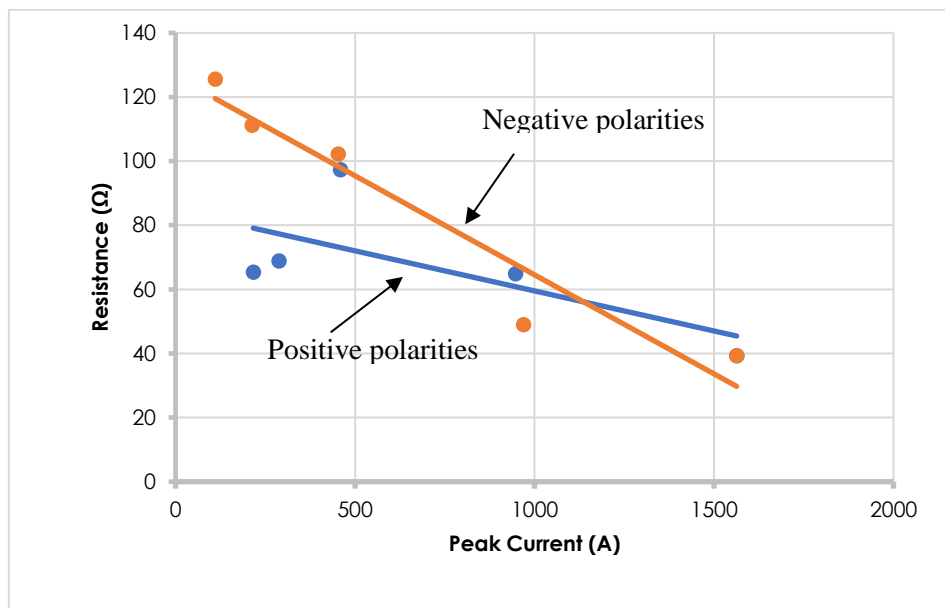
**Figure 6** Voltage and Current Traces at (a)30 kV, and (b)50 kV Applied Voltage Negative Polarity

As seen in Figure 6(a), in case of negative polarity, all current traces have similar impulse shapes as voltage trace with respect to the front and tail times. There is also a small oscillation occurs as shown in Figure 6(a). The current decays quicker at greater charging in Figure 6(b), which may be influenced by the generally resistive nature of the earthing systems implemented at higher voltage/current rates.

Impulse resistance  $R_{\text{impulse}}$  is the impulse resistance measured by two DSOs from the voltage and current signals collected. Equation (1) is used to obtain the  $R_{\text{impulse}}$  value, so it is possible to minimize inductive effects [17-19].  $V$  at  $I_{\text{peak}}$  is defined as the voltage taken at the time when the current is at its peak in this method.

$$R_{\text{impulse}} = (V \text{ at } I_{\text{peak}} / I_{\text{peak}}) \quad (1)$$

Impulse resistance values were measured at various current magnitudes. Earth resistance values for various magnitudes of impulse current are seen in Figure 7. As the present magnitudes for both positive and negative polarities rose, a substantial decline in impulse resistance was observed. The maximum impulse resistance was also observed at 30 kV for negative polarity and 30 kV for injection positive polarity voltages. For both injected voltages, it was found that the lowest impulse resistance calculated is around 39  $\Omega$ . From this graphic, as predicted, it can be shown that impulse resistance decreases as the current magnitude grows. This is similar to those findings in publications [17-19].



**Figure 7** Values of earth resistance with increasing currents.

Based on the results of the study in [11 - 19], through the tests that have been conducted, it was found that the reduction of impulse resistance is related to thermal and ionization processes. Thus, the effect of polarity is thought to occur on disposal in the soil. The findings from the study conducted are supported by studies conducted by [12 - 14,20], which prove that the characteristic properties of the soil are influenced by the polarity of the impulse. In [20–21], the author explains that for a voltage subjected to a positive polarity, the current distribution starts from the test electrode to the ground, while for the applied voltage a negative polarity, the current begins to propagate from the ground to the test electrode. Therefore, poor soil release due to the dispersion of some bands and the negative polarity conduction process is predicted to appear relative to the positive polarity, resulting in the development of lower currents in the negative polarity. Again, the effect of this polarity indicates that when the earthing system is exposed to high pulse conditions, the process of ionization of the soil will take place in the soil.

#### 4. Conclusion

Impulse tests were performed on the sphere electrode under both impulse polarities. It was found that the resistance reduced with increasing currents under both conditions. It was also found that lower earth resistance was seen to decrease with increasing current magnitudes for both impulse polarities. In addition, it was found that at low impulse current with negative polarity has a higher resistance than that of positive polarity.

#### 5. Acknowledgement

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