Transient Noise and Impedance of a Grounding Electrode

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Abstract

High speed electronics today allow us to see distant planet, map the human genome, fly drones thousands of miles away, deploy semi-autonomous vehicles and have mobile access to the internet, video and audio at the palm of our hand. Electronic systems such as super computers, data servers, routers and switches are all interconnected through a network of cables, optical fiber and RF links. Data centers, mobile and public telephone switching offices, satellite earth stations, radio communications, cell sites and control centers are large installations that are part of the total network prone to transient noise. High speed electronics are very sensitive devices that are prone to damage caused by transient noise. The use of surge protection devices and installation of a good grounding system in these installations are ways to mitigate damages caused by transient noise. A grounding system starts at the grounding electrode with a low resistance to earth. Low transient earth resistance results in lower transient noise voltage, making these electronic systems more robust. Transient behavior of the grounding electrode is critical in minimizing the impact transient noise has to the electronic systems. This paper will present and contrast the performance of two (2) electrode types when subjected to transient noise.

Introduction

Distant lightning strikes and direct strikes impose transient noise voltage onto power lines, RF cables, control cables and other conductive objects. Lightning imposed transients have fast rise time and slow decay. High frequency (HF) components occur at the fast rise time while the low frequency (LF) components occur in the slow decay time of the pulse. The lightning transient model has a rise time of 1.2 µS and a decay time of 50 µS. A 1.2 µS pulse has a fundamental frequency of 833 KHz.

Other forms of transients, mostly a ring wave transient, are generated by the electric motors, welders, switching power supplies, and electric appliances. A ring wave transient model has a fast rise time of 0.5 µS or a fundamental frequency of 2 MHz. Transient voltages can cause equipment failures. A well designed grounding system with low resistance to earth along with surge protection devices are ways to mitigate equipment failures due to transient or surges.

Earth resistance measurements of a grounding electrode are mostly done at frequencies of less than 150 Hz to closely characterize the electrode at power line frequency. Because measurements are done at LF, earth resistance at HF is not known. Ideal grounding systems have low impedance at LF and HF.

Transient noise voltages in a grounding system with distributed inductive and capacitive components create a complex voltage response. In general transients are larger in inductive systems compared to a purely resistive system. Capacitance in the system can generally reduce transient voltages. Distributed inductance and capacitance of the grounding system become a factor in HF.

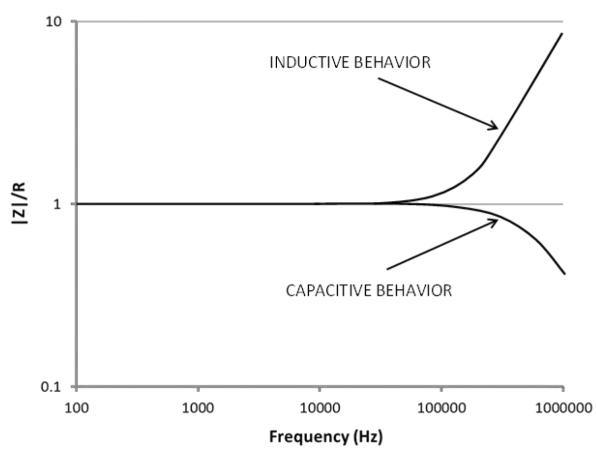


Figure 1. Frequency dependence of impedance to ground.

The behavior of a grounding electrode as it relates to soil resistivity and configuration is discussed in [1]. Figure 1 from [1] shows two frequency ranges where the characteristic impedance do not change (LF range) and where it becomes inductive or capacitive (HF range). Capacitive electrodes tend to have lower impedance at HF. It is therefore advantageous to have a capacitive electrode to minimize transient voltage.

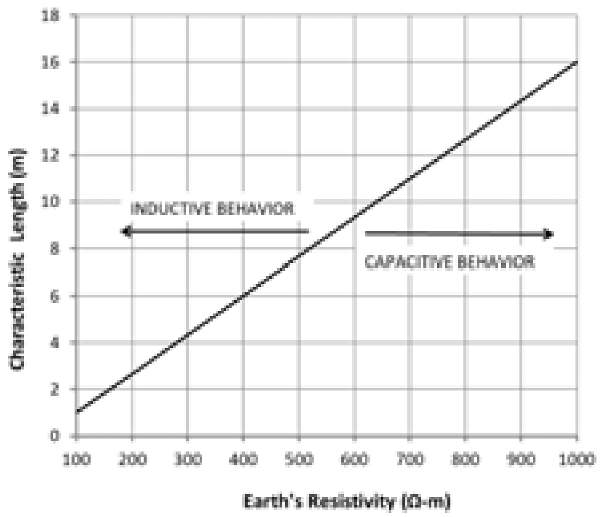


Figure 2. Regions of inductive and conductive grounding behavior of an electrode.

Two (2) types of electrodes were used in the test. A ½ in. x 3 ft. rod and a 2 in. x 4 ft. XIT rod. The ½ in. rod was driven 3 ft. into the ground making contact with native soil. The XIT rod was buried 3 ft. deep in an 8 in. x 42 in. well filled with Lynconite II®.

Figure 2 from [1] shows the relationship of the electrode characteristic length to earth resistivity. The soil resistivity at the test site was measured, and the result ranged between 50 to 100 Ohm-m. Using the graph in Figure 2, a 3 ft. electrode in soil with 100 Ohm-m resistivity is expected to have a capacitive behavior.

Electrode Resistance to Earth

The Fall-of-Potential test method utilizes a special purpose meter and two auxiliary probes spaced out at specific distances, one remote current probe and one potential probe, and a connection to the ground system being tested. The meter establishes a low frequency current between the grounding system and the remote current probe and the voltage potential between the grounding system and the potential probe is measured and graphed. The test was conducted using standards set forth by IEEE Standard 81.

Two types of Fall-of-Potential tests were performed to determine the LF resistance and HF impedance of the electrode. A DET 2-2 was used to measure the LF resistance (earth resistance). The transient pulse method was used to measure the HF impedance. A transient pulse contains low and high frequency components. From a single transient pulse you can determine the LF resistance and HF impedance of the electrode. Figure 3 shows the LF resistance comparison between the two electrodes using the DET 2-2. Notice the improvement an XIT rod has over the driven rod. The earth resistance of the ½ in. driven rod is 2.4 times higher than the XIT rod.

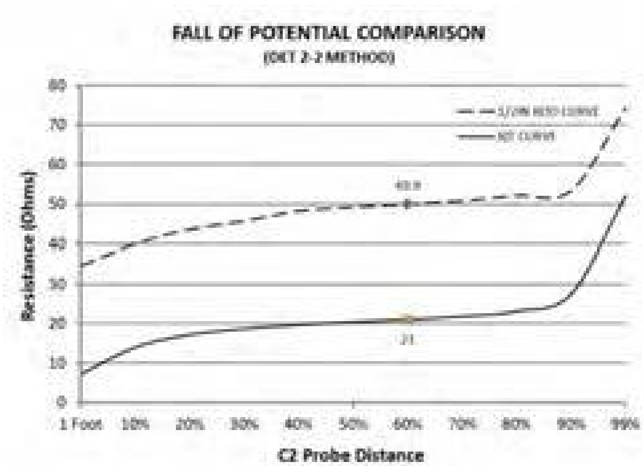


Figure 3. EUT Fall-of-Potential test using the DET 2-2

Dynamic Behavior

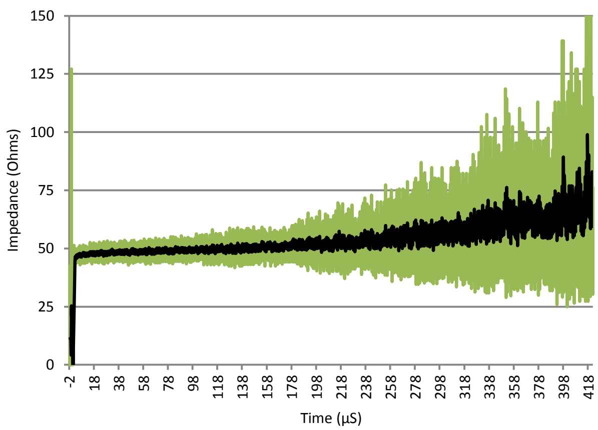
The dynamic behavior of an electrode is characterized by its low frequency resistance, transient impedance and impulse impedance. Measurements performed using the DET 2-2 gives you the LF resistance of the electrode. Low frequency resistance is defined in [2] as $R = V/I$, where V is the voltage feed point and the remote neutral ground and I is the injected current.

Transient impedance is defined in [2] as: $Z(t) = V(t)/I(t)$, where $V(t)$ is the electric scalar potential at the feed point in reference to the remote neutral ground and $I(t)$, the injected current pulse. Transient impedance measurement data are shown in Figure 4, and Figure 5.

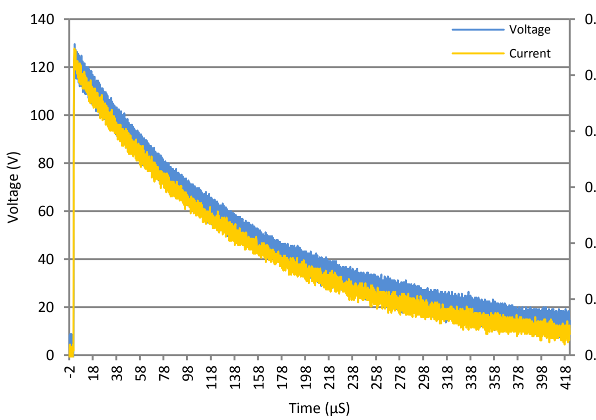
Impulse impedance is defined in [2] as: $Z = Vm/Im$, where Vm is the peak voltage of the potential pulse $V(t)$ and $I(m)$ is the peak value of the injected current pulse $I(t)$.

of the pulse. The impedance between 2 to 500 µS resembles the LF resistance. Poor signal to noise ratio due to low signal levels measured after 200 µS distort the resulting LF resistance measurement. Higher signal levels between 0 to 200 µS result in a consistent measurement.

The transient impedance of the XIT electrode is also shown in Figure 5. Comparing the transient impedance trace in Figure 4 and Figure 5, shows the XIT's LF resistance is significantly lower than the driven rod. The difference follows the results shown in Figure 3.

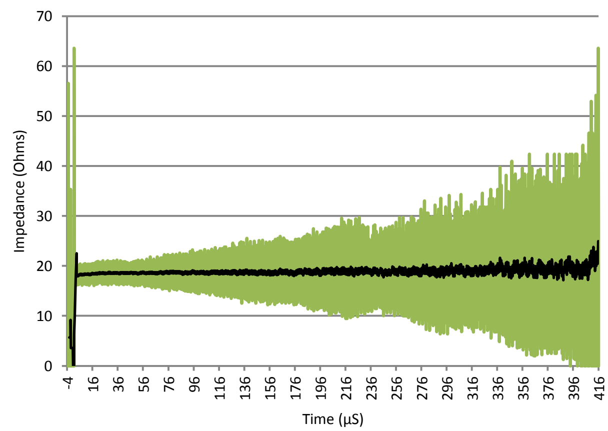


(a)

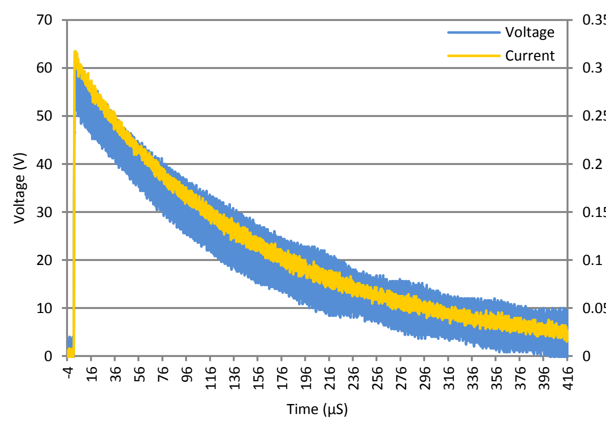


(b)

Figure 4. Driven rod transient impedance (a) and signal (b).



(a)



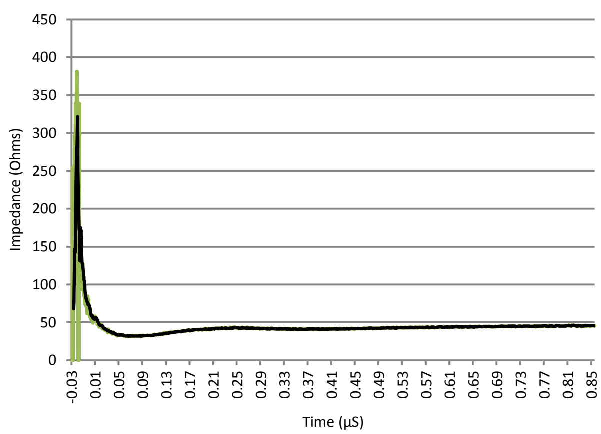
(b)

Figure 5. XIT rod transient impedance (a) and signal (b).

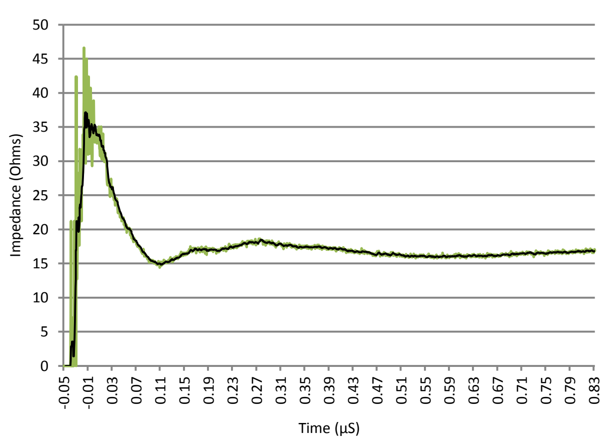
Notice the driven rod transient trace in Figure 4. Figure 4a shows both the peak (green) and average (black) transient impedance. Peaks occur within 2 µS

Measurements at <1 µS were performed to improve horizontal resolution of the trace and enable us to see the electrode's dynamic behavior at high frequency

(Figure 6). The peak transient impedance of the driven rod (Figure 6a) is 7.5 times higher than its measured LF resistance. The peak transient impedance of the XIT rod (Figure 6b) is 2.2 times higher than its measured LF resistance. Despite having a better earth resistance than the driven rod, the XIT rod was unable to maintain the same earth resistance at HF. This shows, what might be considered as a good earth resistance at LF does not guarantee a good earth resistance at HF. One more thing to note, the transient impedance of the driven rod is 7.8 times higher than the XIT rod. The XIT rod is consistently better than the driven rod.



(a)



(b)

Figure 6. Transient impedance of a driven (a) and XIT (b) rod at <1µS span.

As defined above transient impedance $Z(t) = V(t)/I(t)$. The proportionality of the transient impedance to voltage and current dictates that larger transient impedance meant higher transient voltage at the grounding electrode. To expect an electrode with a low earth resistance at LF to dissipate high transient noise is misguided if the transient impedance of the electrode is high. A summary of the dynamic behavior at <1 µS is shown in Table 1.

EUT	R (Ohms)	Z(t) pk	Z
Driven rod	49.9	375.0	44.6
XIT	21.0	48.0	16.9

Table 1. Dynamic characteristics of EUT

Conclusion

The XIT rod showed a better performance at both LF and HF compared to the driven rod. The XIT's earth resistance is 58% lower than the driven rod. Its transient impedance is 87% lower than the driven rod. The XIT's transient noise headroom is greater than the driven rod. This is significant in reducing transient or high frequency noise in the system.

References

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