The Critical Angle of Ultrasonic Electrical Inspection of Transmission Lines and Enclosed Systems

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Abstract:

Electrical Ultrasound Inspection is one of the most unique applications as it is not dependent on decibel levels as much as the patterns the anomaly produces. However, limited approach restrictions can make it difficult to get the truest form of the Incident Sound Wave for pattern identification.

White Paper

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Why does Critical Angle Matter?

Historically, electrical systems have been scheduled for an annual inspection as mandated by insurance companies. Sometimes, it is simply because the facility does not have the personnel to perform inspections and the inspection is outsourced. Sometimes, it is the mentality of the management and planners that these assets are not as critical or that it takes too many man hours to inspect these assets. When using ultrasound, the inspector scans the seams and openings in equipment to figure out if there is an anomalous condition that needs to be investigated further. With the invention of IR Windows and Ultrasound ports, the time it takes to perform electrical inspections has been dramatically reduced. The IR Windows and Ultrasound Ports allow for a safer process of inspecting these critical assets while in their energized state. The facility can inspect their assets monthly if they wish because there is no need to wear an arc flash suit or remove the panels to perform these inspections.

When it comes to ultrasound testing of electrical assets, there is no limit to what equipment class it can be used on. Everything from transmission lines to breaker panels can be inspected. Ultrasound has always been relegated to scanning the seams and vent holes of switchgear with some success. However, the inspector cannot always achieve the Critical Angle due to diffraction of the sound wave making it difficult to record the truest sound of the anomaly. This can lead to limited harmonic indications when trying to analyze the Fast Fourier Transform (FFT) of the waveform in a sound analysis software. The harmonic topic will be covered more in depth in a future paper.

Often, while performing Electrical Inspections, the inspector may find that they hear the sound characteristics change as well as the amplitude (dB) as they move around the target location. When the sounds from the anomaly are recorded from different angles, the inspector can see different signatures of the same event in the FFT while the Time Signal can still show similar harmonic indications. This is because there is only one Critical Angle of the anomaly and as such it has a limited field of reception.

The Critical Angle of electrical inspections is the angle at which one records the best sound characteristic and amplitude (dB level) of the anomaly. Sound Analysis is critical in ultrasonic electrical inspections and the decibels can only be used to guide the inspector to best angle to capture the sound wave. Decibels are only to be used as a guide to find this angle and not a measure of severity. Sometimes the Critical Angle maybe pointing directly away from the inspector and the Critical Angle cannot be achieved from their position.

The Critical Angle is much like riding in a car listening to the radio. The radio signal that it receives is strong when the car is in line with the transmission. However, when the car enters a valley or is behind a mountain, the radio starts to lose signal clarity as the signal becomes distorted. Some of the signal can still be heard but some of it is missing. As the car comes back in range of the radio signal, the Critical Angle is restored and the occupants can enjoy the radio program.

The car radio experience can occur with ultrasound inspections of electrical equipment. The inspector can hear an electrical anomaly and record that anomaly for sound analysis. Analysis of that recording shows that the FFT does not always show a 60 Hz harmonic marking but the 60 Hz harmonic markings do show up in the Time Series visualization of the waveform. This observation occurs when the captured sound waves are not at the Critical Angle. It is not the truest form of the incident wave because there is resolution loss due to distortion of the signal. The inspector will still be able to see some indications within the Time Signal as it is not dependent on any translation of the signal into the frequency domain.

Here are some examples of sound images showing the achievement of the Critical Angle.

Critical Angle Achieved:

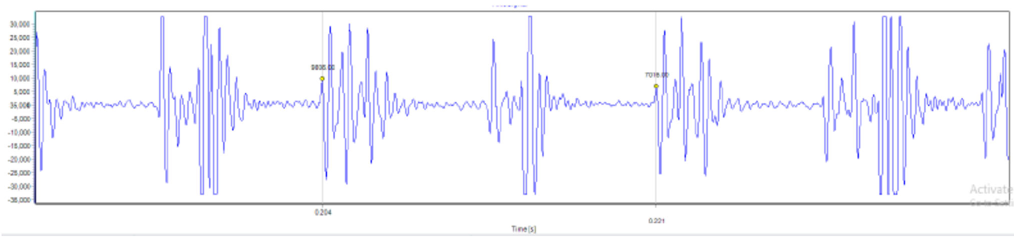

Figure 1 Time Signal clearly shows peaks within 0.0167 seconds which indicates 60 Hz

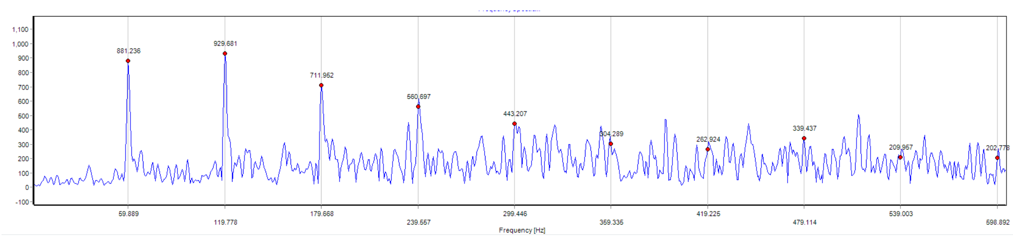

Figure 2 FFT Shows the 1st, 2nd, 3rd and 4th occurrence of a 60 Hz Harmonic Marker indicating the Critical Angle was achieved for this anomaly.

With clear indications in both the Time Signal analysis and in the FFT, the inspector can confirm they have achieved the Critical Angle of the ultrasound emission and determined the existence of treeing (tracking). The inspector was able to make the correct diagnosis of the ultrasound emission by confirming the existence of a .0167 seconds harmonic in the Time Signal and 60 Hz Harmonic in the FFT.

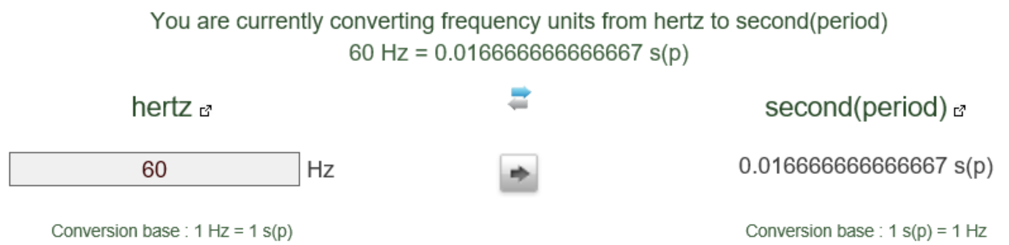

Figure 3 60 Hertz Electrical system have a Period of 0.167 seconds

With other advances in sound wave analysis like Spectrogram and 3D Surfacing, the inspector can look more in-depth to see issues at hand as well as produce stunning reports that help visualize the evidence to management or clients.

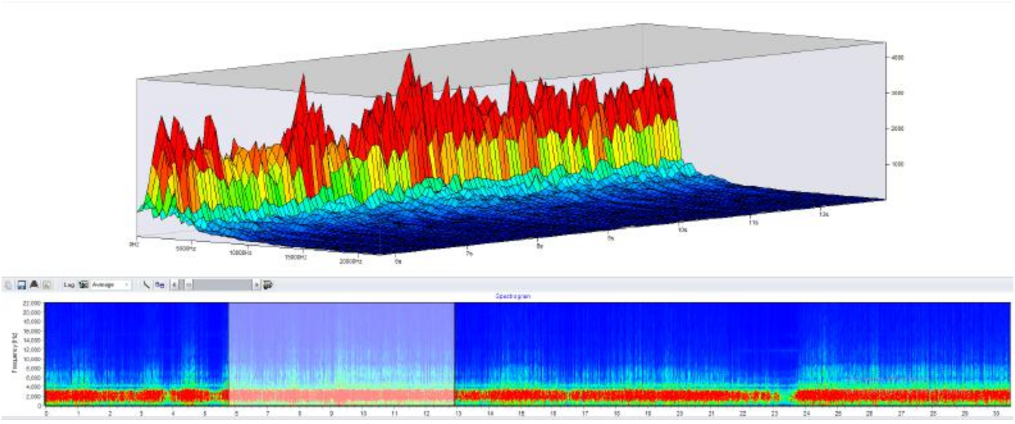

Figure 4 3D Surfacing representation of Sound Wave

These indicators show that this event is Treeing (Tracking). What is Treeing? When Electrical treeing occurs, it begins to sprawl outwardly across a dielectric material that is stressed over a period of time by highly divergent electrical fields. Electrical treeing generates a distinct ultrasound signature and can be caused by impurities, gas voids, or mechanical defects.

Treeing can cause gases to ionize around the event creating small electrical discharges. A pollutant or defect may even result in a partial breakdown of the dielectric material. This anomaly will also produce ultraviolet light and ozone from these partial discharges (PD). It will also react with the nearby dielectric material, furthering the breaking down of its insulating value and accelerate the PD process.

Electrical treeing can occur in high voltage equipment just prior to equipment failure. During a Root Cause Analysis (RCA), the treeing can be used to track down the source of the failure. There are 2 common types of treeing that can be produced when equipment starts to fail:

1. **Bow-tie** trees start to grow from within the dielectric insulation and grow outward towards the electrodes. As it starts inside the insulation, it does not have a supply of air which would allow the continuous support of partial discharges. Hence these trees have limited growth and do not usually result in a failure in the insulation or ability to sprawl out to the nearest electrodes.

2. **Vented trees** initiate at an electrode insulation and sprawl out towards the opposite electrode. Being exposed to atmosphere is a key for its growth. These trees will continuously grow until they are able to bridge the electrodes which will result in the failure of the insulation.

Treeing has actually been used to create some amazing artwork where you can clearly see how this electrical event got its name. The use of this in art work is known as Lichtenberg Figures and there are some amazing images created when electricity is applied to the medium.

Next, we will look at what happens when the Critical Angle was not achieved on this same treeing anomaly.

Figure 5 A Lichtenberg Figure as Art

Critical Angle Not Achieved:

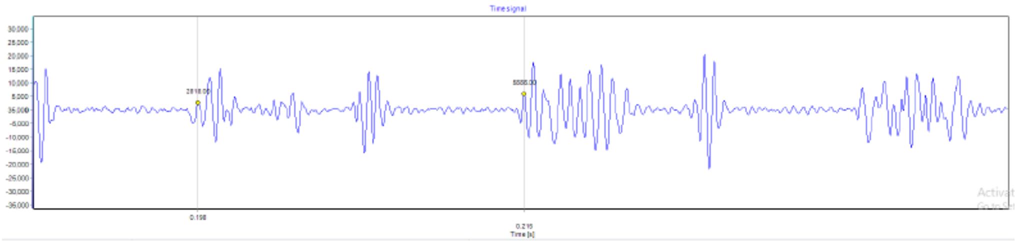

Figure 6 A Period of 0.167 seconds clearly shows up in the Time Series.

Notice in Figure 7 below, the lack of rich 60 Hz harmonics in this treeing occurrence. There is a small indication at 60 Hz and another one at the 120 Hz Harmonic value but it quickly disappears. The Critical Angle was not achieved in this recording and as such we do not have the signal strength to show rich 60 Hz harmonic intervals.

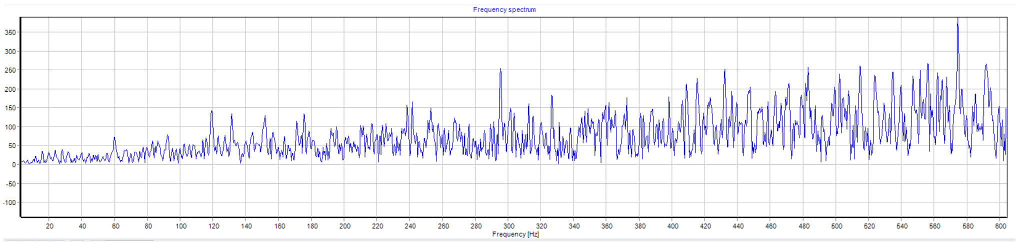

Figure 7 FFT Does not show clear indications of a 60 Hz Harmonics.

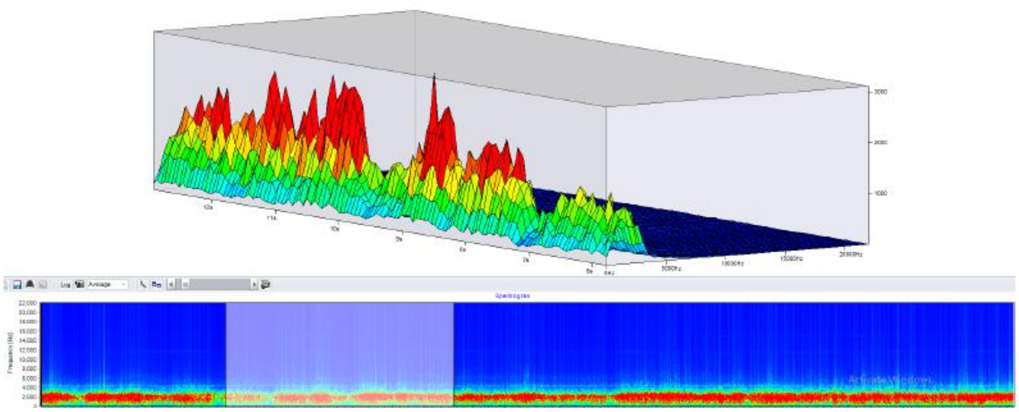

Figure 8 Lack of Repeating Amplitude in the 3D Surfacing & Spectrogram

Note that Figures 1, 2, 4, 6, 7, 8 and 9 were generated using the Sonus Vue Pro desktop analysis software from IRISS. When using the Sonus Vue Pro software, the inspector can also use the overlay feature in both the Time Signal analysis and the FFT to simultaously compare multiple sound waves. This allows the inspector to quickly see the difference between different anomlies and help determine if they achieved the critical angle.

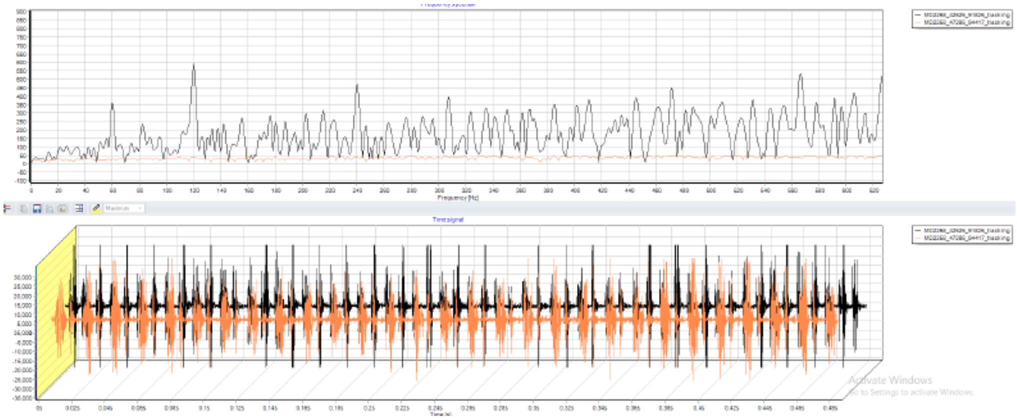

Figure 9 Top image shows the FFT sound waves from Figures 1 (black) & 6 (orange) while the lower image represents the sound waves from Figures 2 (black) & 7(orange) in 3D.

These are splendid examples of treeing when we listen to them. However, only when we run them through the Sonus VUE PRO software can the inspector verify that they have achieved the Critical Angle of these treeing events. Therefore, it is very important to walk around and listen as you move to try to find the Critical Angle of these ultrasound anomalies. The key is using your decibels only as an indication of increased strength of signal. Decibels should never be used for gauging severity of electrical anomalies. Decibel levels only indicate that the inspector is in line with the critical angle.

Enclosed Assets:

When it comes to enclosed systems like switchgear or the terminal chamber of a transformer, diffraction of signal can also affect the ability of the inspector to achieve the Critical Angle during the electrical inspection. The inspector is left to trace the seams around the asset's panels and change their positioning of the airborne module when something is heard to try to achieve a higher intensity of the emission.

What is Diffraction? Diffraction is what happens to a sound wave when it encounters an obstruction or an opening. As the sound wave bends and bounces off the material it is interfacing with, it is intensity can vary. Just like testing open air assets, the inspector can see a harmonic appear in the time signal and FFT if the Critical Angle has been achieved. Due to the diffraction of the signal as it exits the equipment seam, it will lose a sizable part of the emission's energy needed to produce a clear signal for exact translation into the FFT.

When inspecting equipment with ventilation openings, the inspector can sometimes get a better angle through theses openings. By simply changing the positioning of the module, the inspector can try to pinpoint the area where the emission is originating from. If the asset is totally enclosed and there are no ventilation openings, the use of a dedicated Ultrasound Port (e.g. IRISS VP-12-US) or and Infrared Window with an Ultrasound Port (e.g. IRISS CAP-ENV-PD Series) will insure the truest form of the emission can be recorded with minimal diffraction. These ports are significantly more effective than scanning the seam on enclosed systems.

Figure 10 Dedicated Ultrasound Ports and IR Windows with Embedded Ultrasound Ports

Some electrical assets have hermetically sealed cabinets and the use of an Infrared Window with a built in Partial Discharge Sensor like the IRISS CAP-CT-PDS or CAP-ENV-PDS Series is the best choice. With a transducer mounted inside of the cabinet, the inspector can eliminate antagonistic ultrasound from nearby defective lighting ballasts, ultrasonic motion sensors for lighting & security and from other sources generated by the everyday noises in production areas. Adapter cables allow a handheld Ultrasound tester to plug into the PDS ports are available.

Figure 11 IR Windows with Built in Partial Discharge Sensors can be used to gather Ultrasound Data on Closed Systems

In conclusion, it is very important that the inspector takes the time to pay attention to his surroundings as they conduct their audit. We can easily get distracted looking at the sound source and forget to watch our footing. In addition to focusing on the sound and recording it, the inspector needs to also look at the display screen and see what the data shows.

About the Author: Drew Walts has 15 years' experience as an ASNT Level 2 Airborne & Structure Borne Ultrasound Instructor in the industrial segment. He carries IR Level 2 certifications in LETA & ANST and has 30 years of experience with IR in the military, fire service, and industrial segments.

To contact Drew please find him on LinkedIn or email him at d.walts@iriss.com and he will be glad to discuss anything related to this article or anything else related to Ultrasonic detection applications.