<u>Electrical Equipment “Screams” For Attention!</u>

Decoding High Frequency “SOS” Calls

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<u>ABSTRACT</u>

In many parts of the country, the current winter has once again put into focus the absolute value of a reliable electrical infrastructure and supply to both home and business. Many areas have experienced extended outages due to supply lines becoming overwhelmed with snow and ice, succumbing to the weight and failing. This is the most visible effect of bad weather, and it impacts many facilities, large and small alike. It is not, however, the only concern in a modern world demanding steady, clean electricity necessary for day-to-day operations or basic needs such as heating and refrigeration. The utility supply notwithstanding can be highly reliable, but a failure of any kind within an individual facility can create disruptions that, although on a smaller scale, can be as disruptive as the impact of an area-wide loss of service.

This can be devastating to the individual on many levels when the unexpected does occur. This paper will discuss several instances where ultrasonic testing clearly uncovers hidden failures certain to cause interruptions if failure stage is achieved. Preventing equipment failures and outages may help avoid an impact on the most simple of conveniences, such as the internet receiving email, all the way to life or death scenarios, such as critical care units in hospitals malfunctioning, or worse, failing altogether and patient care being compromised. The following examples illustrate why diligence is demanded when approaching an effective program that achieves the goals of reliability and safety.

<u>INTRODUCTION</u>

Electrical equipment has condensed in size over the years, making traditional maintenance methodology and inspection frequency a thing of the past. As a result, new techniques and procedures are required, which present unique challenges along with some risks. Any manager will agree that managing risk provides an intangible savings by keeping employees safe and productive. The means to manage these risks are more plentiful today than in times gone by. With the advent of acoustic listening devices such as the Ultraprobe, redundancy in these ever important procedures continues to increase and further reduce risks that employees face.

The ancillary benefit to safety procedures and risk reductions is identifying faults and potential faults within the electrical components. More and more we are realizing earlier detection, and utilizing techniques combined with existing technologies to become more precise.

Our organization has always used ultrasonic testing as a safety protocol; however, it has matured into a fantastic “diagnostic” tool as well. In spite of much initial resistance from the personnel using the device, more and more of the technicians throughout the Network are learning the value of ultrasonic testing on electrical components, regardless of voltage classes. As everyone is aware, this instrument is particularly useful on high voltage items, but more frequently we are identifying faults in components 600 volts and below. This is interesting because not too long ago, the consensus among industry professionals was that ultrasonic anomalies below 1000 volts could not exist. However, there is a different opinion today resulting from the many instances where arcing, tracking, vibration, or mechanical looseness was found to be detrimental to equipment health.

This paper looks at several electrical examples which include both high and low voltage classes, but illustrates once again that ultrasonic faults can manifest in <u>*any*</u> voltage class if one knows: **a**) what they should be both “listening *and* looking” for when servicing components, **b**) which attachment of the instrument to select for the application, **c**) which frequency setting works best, and **d**) the proper method of analyzing the recordings in the Spectralyzer. We will examine these considerations in this paper and illustrate why a comprehensive program is necessary in today's complex systems to ensure the highest degree of reliability and longevity.

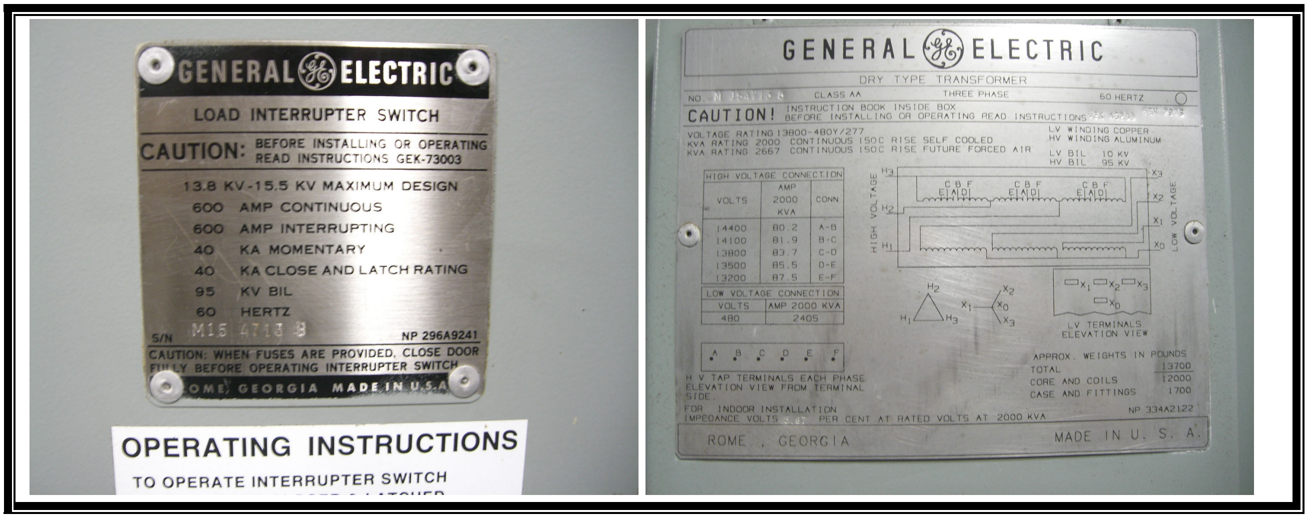
EXAMPLE #1

During a July 2009 inspection at a Charleston, South Carolina hospital, technicians were tasked with nearly 400 components, which included everything from the 13,800 volt incoming utility supply transformers and switches, all the way down to the 480 volt switchgear, motor control centers, transformers, panels, and lighting circuits. This was nothing new to the seasoned technicians, as they had been diligently applying our services for 5 years in this area.

As the inspection progressed, Morgan Fowler, lead technician at this time from Transworld Inc., contacted TEGG Corporation personnel to seek opinions of a recording he had secured on one of the 13.8 KV load break switches. This particular switch was one of two identical arrangements that featured the utility feed, a dry 2000 KVA transformer stepping the voltage down to 480/277 volts for distribution to facility equipment. Additionally, this configuration was mirrored on the opposite side of the electrical room to provide redundant supply in the event of an interruption of either of the unit substations. The image in Figure #1 below gives the perspective of the physical lay-out of the one sub:

Figure #1

(Directly opposite of this is an exact duplicate configuration of the illustration above.)



Load Interrupter Switch and Transformer Nameplate Information

Upon receiving the recordings, and after discussions with Morgan regarding the analysis in the Spectralyzer software, it was determined to be an electrical fault known as “destructive corona”. If you recall from the paper last year at Ultrasound World IV entitled “What you can’t hear can hurt you!”, corona in its natural state is a normal phenomena due to the expanding and collapsing magnetic fields present in systems where voltage levels are >1000 VAC. Corona becomes destructive when the stresses become too large and nitrates are released, mixing with the moisture content in the air, which when combined forms nitric acid and destruction of dielectric insulating systems will begin.

Reviewing what “destructive corona” looks like using the FFT and time domain tools in the Spectralyzer software can be seen below in Figure #2:

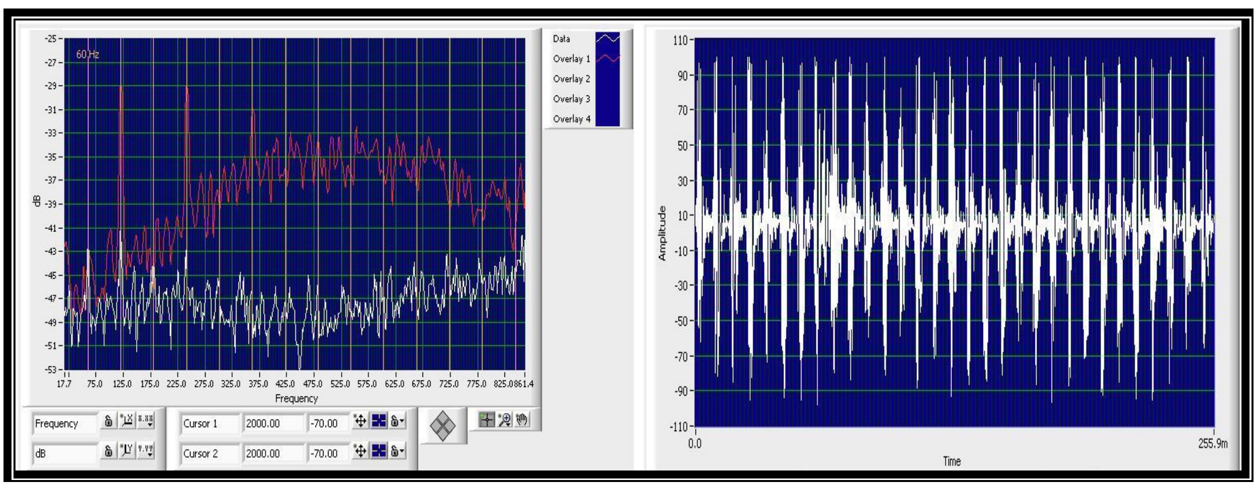


Figure #2

The white trace in the FFT illustration is the known sample of destructive corona, and in the time domain on the left, the same event is displayed. FFT demonstrates pronounced 60 Hz “fault frequencies” only in the beginning part of the spectrum, with a drop-off as it moves further along the spectrum. This is unlike “nuisance” corona in which the 60 Hz “fault frequencies” are predominant throughout the spectrum. Both instances of this type of corona will also have an abundance of noise content in between each harmonic frequency.

The time domain shows a very uniform, linear pattern in which the excursions from the expected broadband of “white noise” throughout the recording are fairly even in spacing (time) and amplitude. This is due to the fact that the ionization process occurs at the negative peak of each electrical sine wave where the potential is at its highest. The 16 ms time base of 60 Hz AC is very predictable and consistent. With Morgan’s anomaly, it was very similar in nature, as can be seen in the spectrums below in Figure #3, although there were not as many “fault frequencies” in the view. The tonal quality, however, was indicative of an electrical fault, and that was factored into the decisions moving forward.

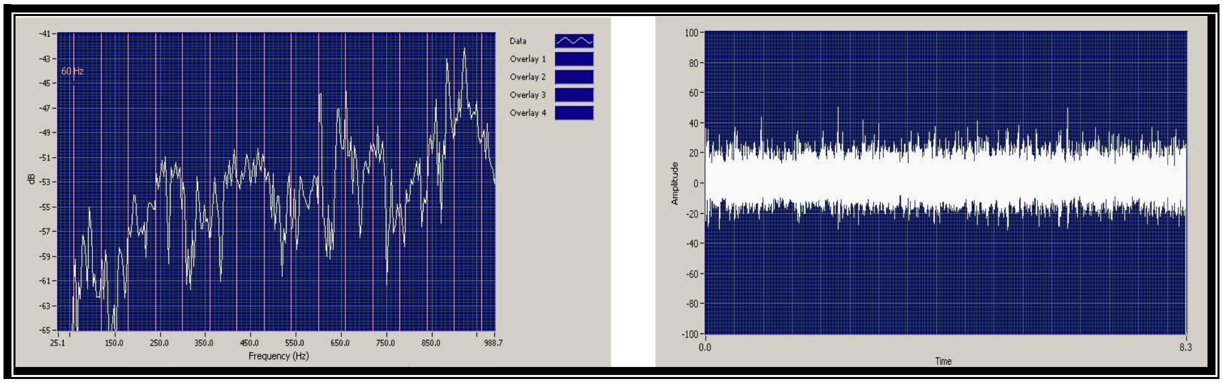
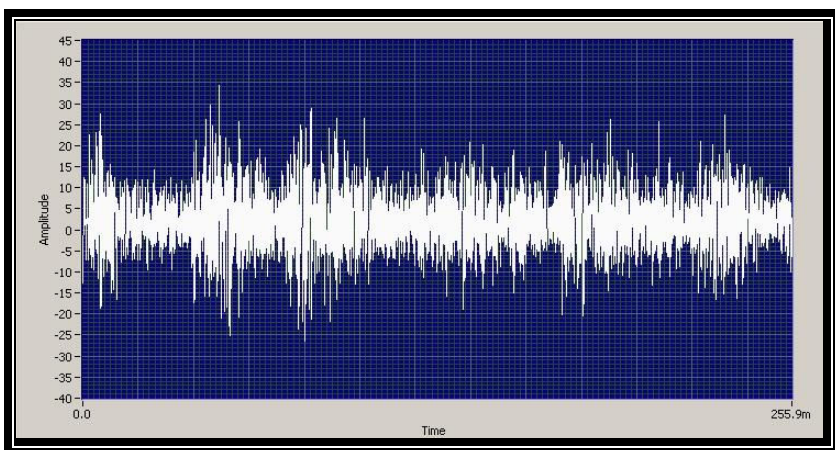


Figure #3

Here is the “cropped” or “sliced and diced” view of a smaller time frame showing the non-uniform timing and amplitude



Combining the tonal quality, FFT and time domain view, a scope of work regarding possible repair actions was developed and passed up the chain of command at the hospital. Between July and September 2009, frequent visits were made to the hospital for other maintenance needs, and the switch was checked to determine if there was any progression of the anomaly relative to severity.

Finally, on September 2, 2009, unrelated training was taking place at Transworld’s office on a power quality data logger to further enhance the capabilities of the technicians in the workplace and better meet customer needs. During this training, a recommendation was made that we visit the hospital to take advantage of the time and assess the current condition of this switch.

When we arrived on site, we met with the maintenance engineer who willingly accompanied us to the electrical room containing the switch. The room in this particular instance was not only on the 6th floor of the hospital, but should the switch fail (and possibly destroy the transformer, switchgear and opposite line-up of the same equipment), there would be no easy method of installing replacement units in the same location, save for the option of excavating a hole in the block wall to expose the outside of the hospital. Illustrated below are the spectrums of the recording made during this visit two months after the initial identification of this concern in Figure #4:

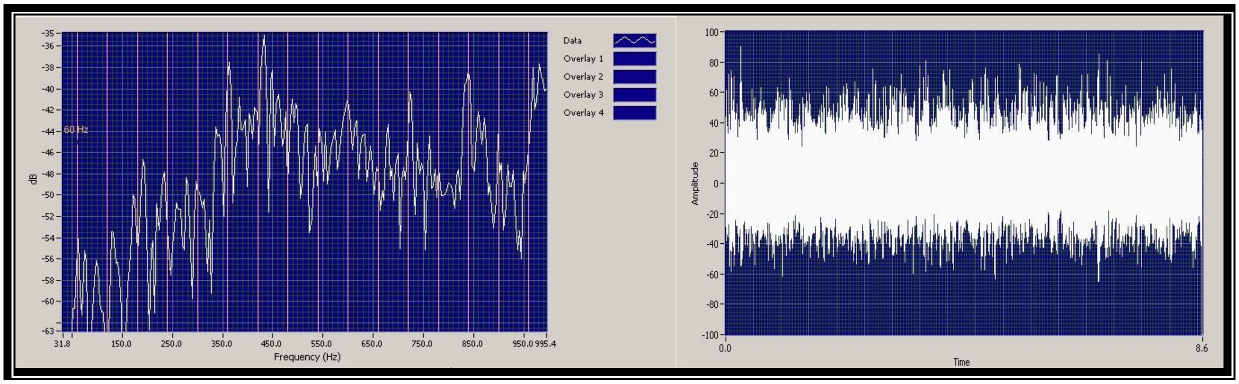
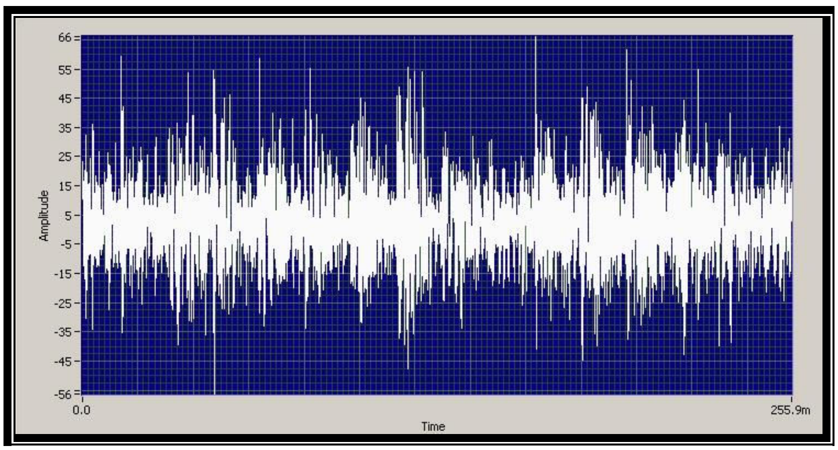


Figure #4

Here is the "cropped" or "sliced and diced" view of a smaller time frame showing the non-uniform timing and amplitude



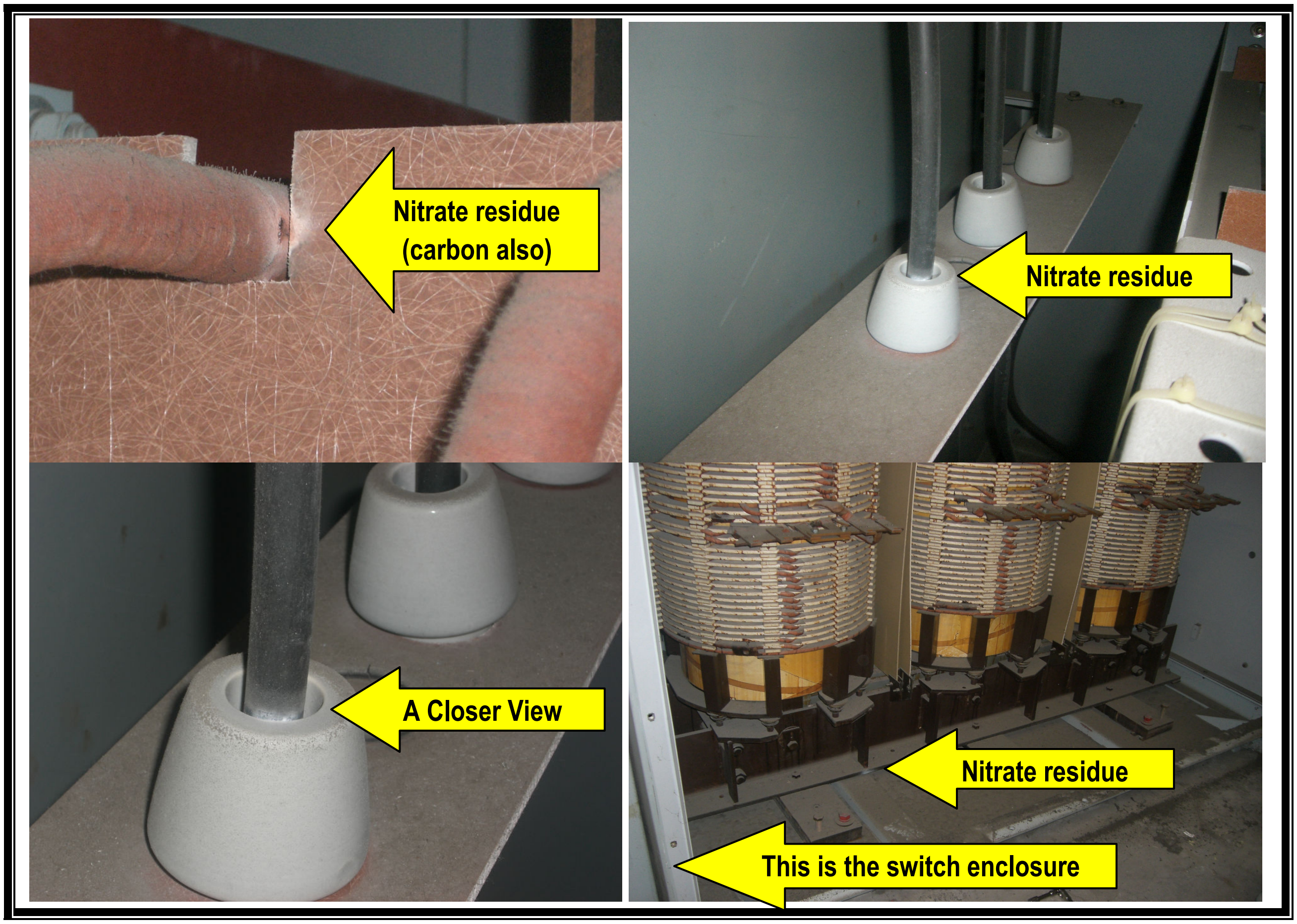
(Notice the increase in amplitude and frequency of occurrences)

The qualitative differences in the two recordings' tonal quality, as well as the spectral content, left no doubt in our minds that the deficiency was indeed degrading in severity, and it was only a matter of time before the device would experience a failure.

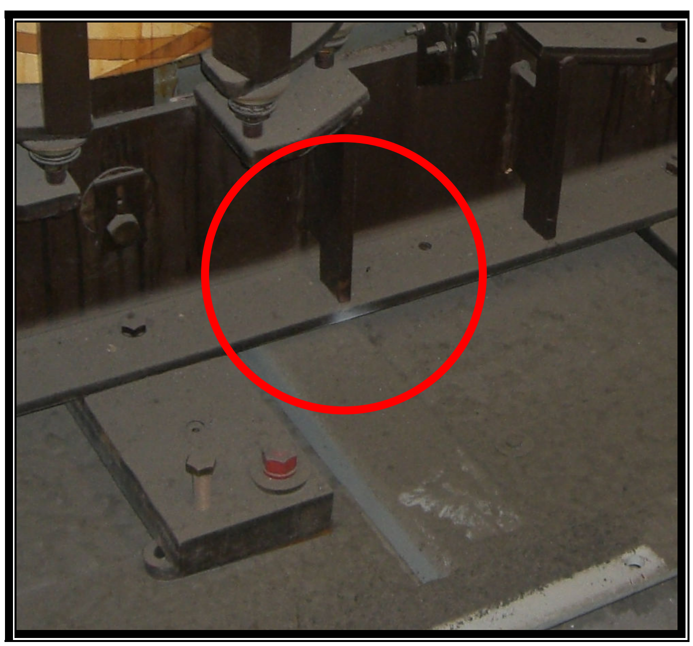
Armed with this new data on the fault, we prepared and presented a report of findings to the facility engineer, expressing our concern that maintenance must be done, or the switch most likely was going to fail. Obtaining approval for a shutdown in any hospital proves monumental in scope, as the coordination issues to ensure no critical support systems are interrupted have many built-in redundancies that are checked and re-checked. There are no energized types of maintenance tests on this style of switch other than ultrasonic and visual inspections that yield actionable data. Infrared is not effective due to the line-of-sight issues, and there were no infrared windows installed on this unit. (There is a proposal to install these now under consideration with hospital management.)

Finally, after a couple of weeks of planning for the outage, all the coordination was addressed and approved, September 25, 2009 arrived, and the unit substation was isolated, locked out, tagged out, verified as deenergized, and opened for inspection. The window of opportunity to complete this inspection was terribly narrow, so time was of the essence to prove that our suspicions were correct and analysis accurate. It did not take long to find what we were looking to see. After analysis, the suspicion was "destructive corona," so one would reasonably expect to see the nitrates typically associated with this fault.

These images illustrate the results of the visual inspection of the switch:



Here is a closer view of the transformer bracket where the nitrates are also visible in the image above:



The visual evidence was indisputable and confirmed beyond any shadow of a doubt that the initial and subsequent analysis and suspicions were correct. The switch conductors and insulators were in fact deteriorating rapidly and in need of maintenance. Due to the curtailed allotment for repairs, a complete replacement of the conductors and insulators was not possible during this visit. The customer agreed to allow Morgan to clean the items as much as reasonably possible, work on the procurement of replacement components, and schedule another visit to complete permanent repairs.

Given the close proximity to the backup equipment supplying power from another source and the logistical challenges of any replacement of these items, the identification of this fault surely prevented a larger failure, cost, and problem for the hospital. It is not known if infrared windows would have identified any deficiencies on this particular example, however, the customer is budgeting to install these items on equipment over 1000 volts to allow for more comprehensive inspections in the future.

EXAMPLE #2

Another transformer example from Birmingham, United Kingdom is next in our examples. This unit is a 2500 KVA ABB, 11,000 KV primary/417 volt secondary with forced air cooling, running at a steady 4500 amps with an internal core temperature of 88 degrees Celsius.

The customer called in the local TEGG contractor due to the equipment apparently experiencing structural movement of some sort, resulting in the bus duct/trunking and supports becoming distorted. This can be seen below in Figure #5 with the visual evidence of movement:

Figure #5

Upon arriving on site, Mick Lamburn, Lead Field Technician for ADI, Ltd., conducted an infrared inspection of the bus duct, which revealed nothing noteworthy. Subsequent to that inspection, Mick performed both an airborne and contact ultrasonic inspection of the duct in question to determine if there were issues inside the cast resin unit in need of attention. The initial recordings made in December 2009 revealed what Mick described as “boiling/cooking water or fat”.

Technicians in the TEGG Contractor Network are trained to associate aural sounds with certain deficiencies. Although a technician would never deem an anomaly deficient on the tonal quality alone, it is the first step in classifying a possible problem. The characterization of this emission was typical and consistent with either arcing and/or tracking in electrical equipment. Mick knew right away that what he heard differed dramatically from what one would expect on this type of equipment, so the recordings were made and sent to the support staff at TEGG Corporation.

As you can see below in Figure #6, there was not much detail in the FFT, however; the time domain had tell-tale signs of a tracking event:

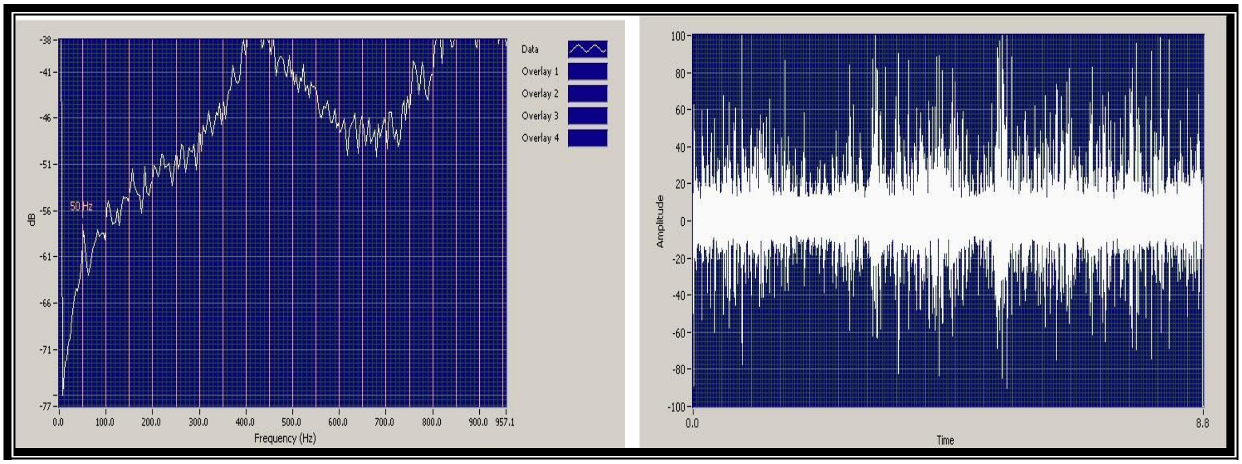
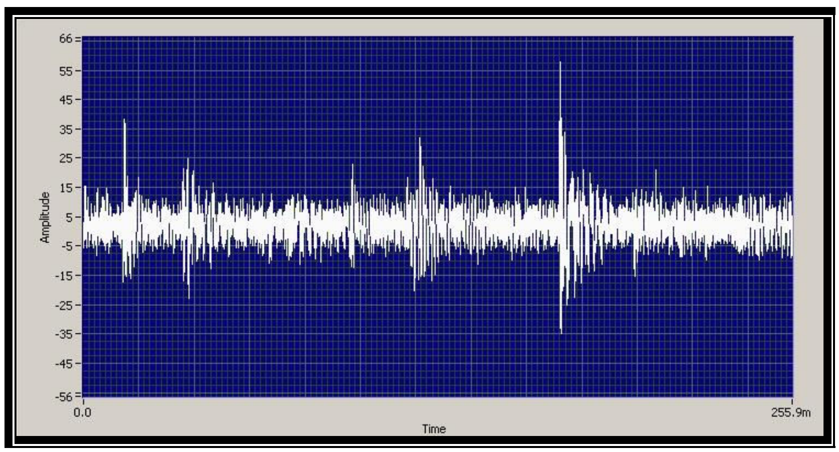


Figure #6



(Time view sliced)

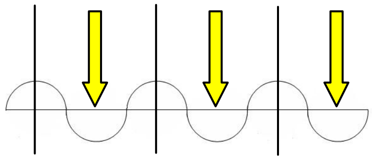
Frequency analysis had no pattern to discern and notably no fault peaks in the spectrum. The time domain over the 8.8-second recording does have “footprints” of a typical tracking event. This means there are three main factors that distinguish this anomaly:

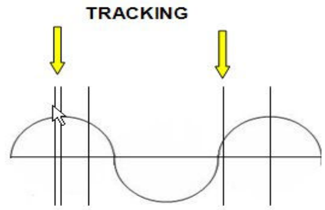
1) *Broadband of “white” signal noise throughout the recording*
2) *Variations in amplitude of the excursions throughout*
3) *Variations in the “timing” (spacing) of the excursions*

These variations in Items #2 and #3 are key, as this indicates discharges of energy along insulating materials that are not uniform in spacing (time) or amplitude (intensity).

This is due to the erratic nature on where in the electrical sine wave this is occurring, and is unlike corona, for example, where ionization takes place at very specific intervals in the time domain relative to the peak potential of the voltage. Tracking is not created due to stresses alone. It is also due to weaknesses in the insulating medium that allow the mini arcs which create the time domain patterns we see. Visualizations of these two phenomenons are illustrated below in relation to where they manifest on an electrical sine wave:

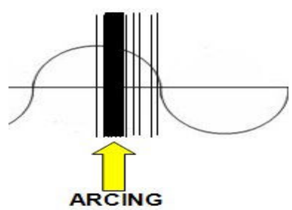
Corona Discharge Points



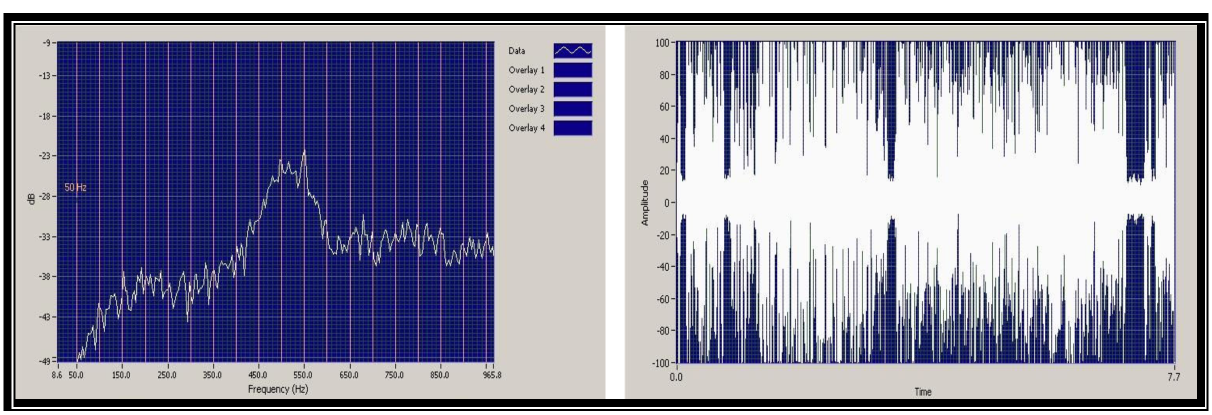


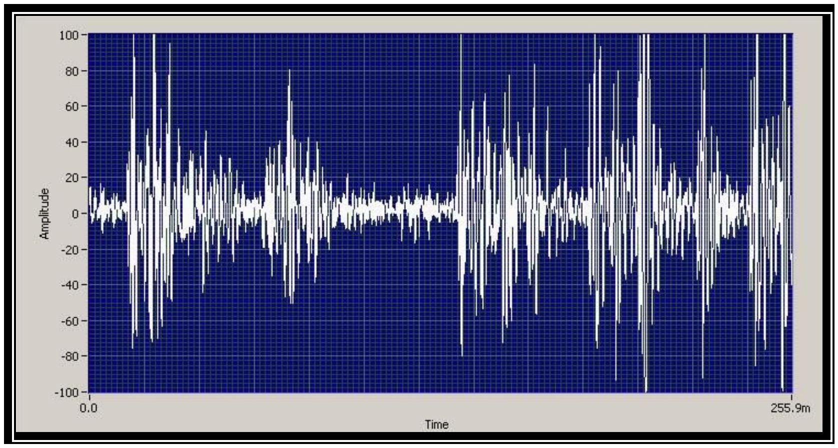
Although these examples are from the paper in 2008, they truly represent where the discharges with tracking take place as compared to the ionization on negative peaks of the same sine wave with corona. It is for this reason that the time domain is so useful when used to identify the presence of electrical faults, as the time and amplitude axis in the tool tends to “mimic” the above anomalies. This means you can better understand the variations in the spacing and amplitude of the excursions when dealing with tracking. It also explains the signature with corona in that the same broadband of white noise is present, however; there is very uniform spacing and amplitude of the excursions due to the consistency of the 50/60 HZ electrical sine wave which repeats every 15 ms/16 ms respectively.

Even with arcing, the same concept applies when characterizing this failure stage event. One still has the broadband of white noise; the excursions vary in both amplitude and timing as a result of the violent nature of going from total silent to full intensity discharge, then back to silent when it is extinguished. This is very important to understand because the FFT tool can easily confuse arcing and tracking due to the similarities in fault frequencies and noise content. When time domain is used in conjunction with it, there can be no mistaking the two very different faults:



This was very apparent in Mick’s recordings, as the FFT did not represent any discernable footprint that could be linked to an electrical fault. The time domain tells a different story, as it fits the profile of tracking as listed above. A decision was made to come back the following month to see if the condition had further deteriorated. The graphs below indicate what was present in January 2010:





(Again, variations in time and amplitude)

Once again, the FFT spectrum yields any useful data with respect to frequency faults or content. The time domain indicated an increase in the intensity of the discharges while taking the measurements at the exact same location on the unit, with the same attachment, frequency setting, sensitivity setting and environmental conditions. (Noteworthy is the “chopping” of the peaks in the time domain. This is remedied by reducing the sensitivity setting on the instrument to avoid signal overload and square-waved displays inhibiting data analysis.)

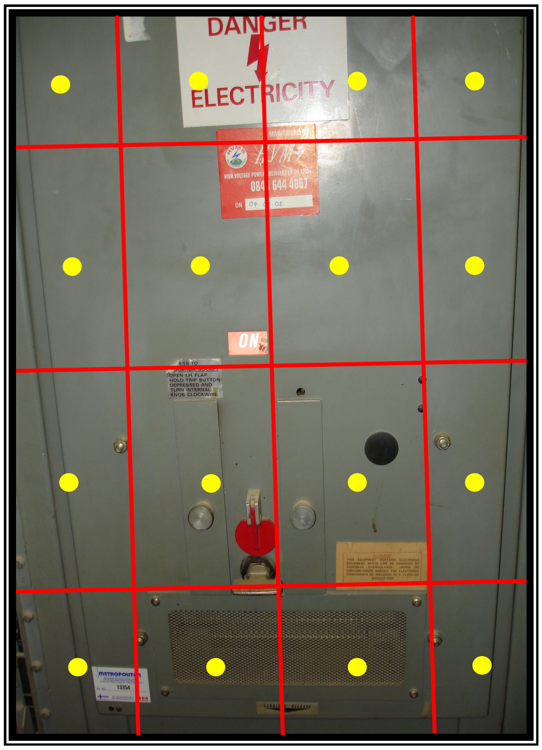
This suggests that the anomaly had degraded in nature and became worse from a severity point, which altered the action plan and options. The customer was seeking maintenance and testing records on the unit to aid in developing this plan. At the time of this writing, the outcome is still pending, however, the suspicion is that structural movement of the unit and/or bus bar assembly had placed the low voltage connections under stress and possibly damaged the internal structure of the transformer insulating system. This scenario would almost certainly lead to an arcing/tracking event due to compromised insulation and allowing voltage discharges to occur. Results of subsequent testing and inspections will be forthcoming in the near future.

EXAMPLE #3

The next example comes again from the United Kingdom and the greater London area. Gavin Lingham, TEGG Service Manager from Metropolitan Electrical Services Limited, was at a customer’s site in which two 1600 amp main circuit breakers tied together with a bus splice were tasked for maintenance. The customer would not permit the removal of the covers for service, so the infrared portion would not prove very effective in this case.

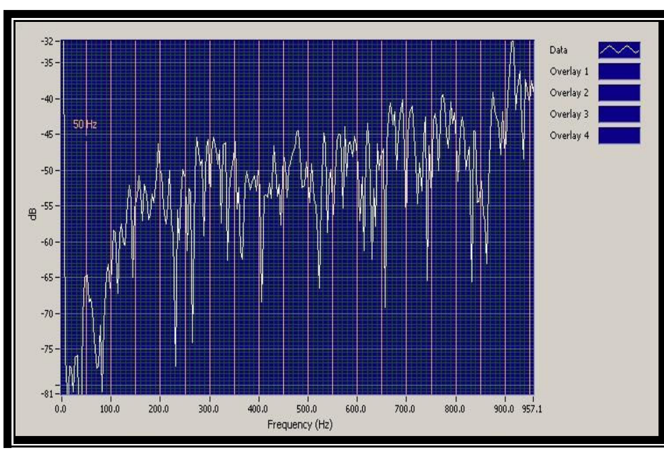
As infrared is only one tool in the arsenal which *must* be complemented with other technologies to maximize inspection precision, the Ultraprobe again was deployed. To the naked eye and ear, there was nothing that alarmed Gavin as he began the service. Upon employing the ultrasonic scan with the airborne module, it was evident that not much was present in the way of emissions. Once the contact module was used, a different picture emerged.

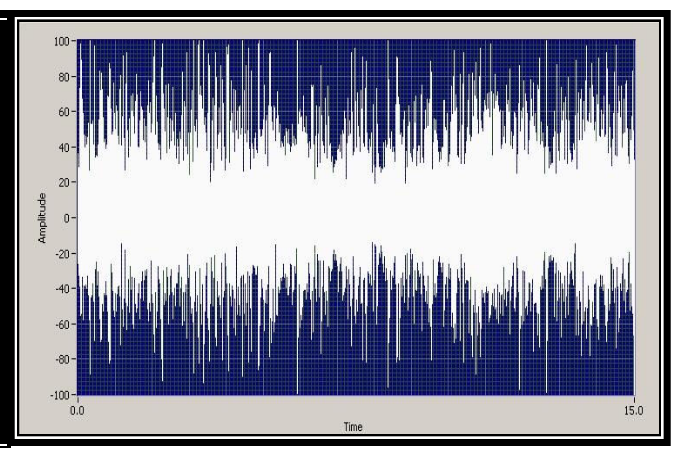
Several positions were selected physically on the exterior of the device to utilize the contact module. An emission was detected, and the recommended procedure of quadrant testing was followed to determine the highest intensity of the anomaly. Below is a picture of the circuit breaker in question, as well as the quadrants from which measurements would be obtained:

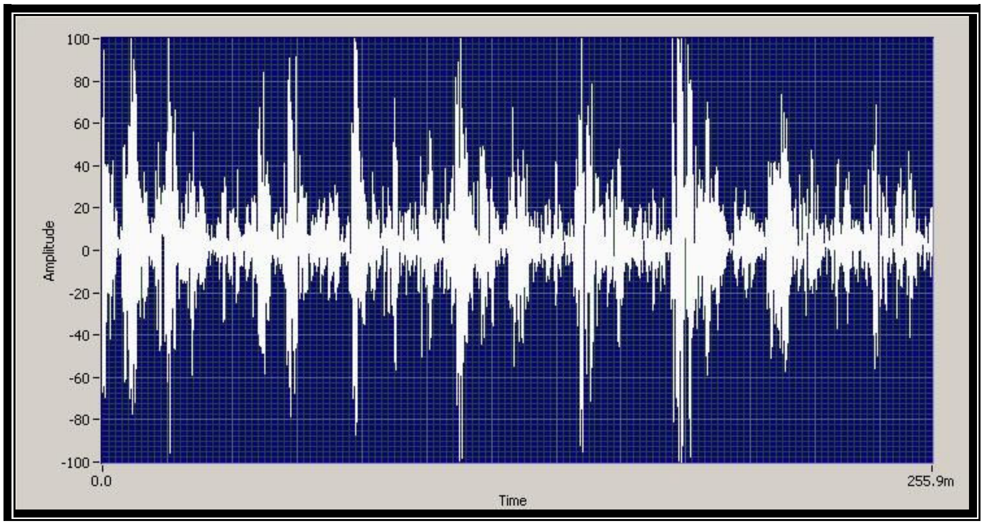


The airborne scan around the door seals indicated that something was taking place inside that was not audible to the human ear. Because the ultrasonic sound waves at 40 kHz are only a fraction of an inch, the directional nature of the wave and the sonic deflection made it easy to identify. The addition of the rubber focusing cone had the added benefit of narrowing the listening field of view to around 5 degrees and shielded any competing ultrasonic emissions in the area. (Fluorescent lighting ballasts that are aging are infamous for generating competing signals that can fool the inspector due to the sonic deflection.)

Below are the spectrums generated from the recordings where the signal intensity was highest, in this case near the bottom of the device where the ventilation screen is located:







(Here once again the illustration of non uniform timing and amplitude)

The FFT this time indicated some degree of frequency faults present at the 50 Hz harmonics, including a greater abundance of activity within each harmonic (frequency noise content). The time domain also had the characteristic "footprint" one would be in search of relative to a tracking event. The broadband of white noise throughout the recording was accompanied by non-uniform time and amplitude of electrical discharges. This again reinforces the theory that arcing and tracking *cannot* be identified without the use of both FFT and time domain analysis. The FFT tool allows us to determine if it is electrical or mechanical in nature, where the time domain tool tells the real story as to which electrical event we have taking place.

Based on the fact that analysis revealed a high probability that tracking was occurring somewhere in the circuit breaker, planning is in place to perform a closer, more detailed inspection of the circuit breakers and bus connections this August during a scheduled shutdown of the facility. Efforts are also under way to procure a replacement breaker to be retrofitted and installed at the same time.

EXAMPLE #4

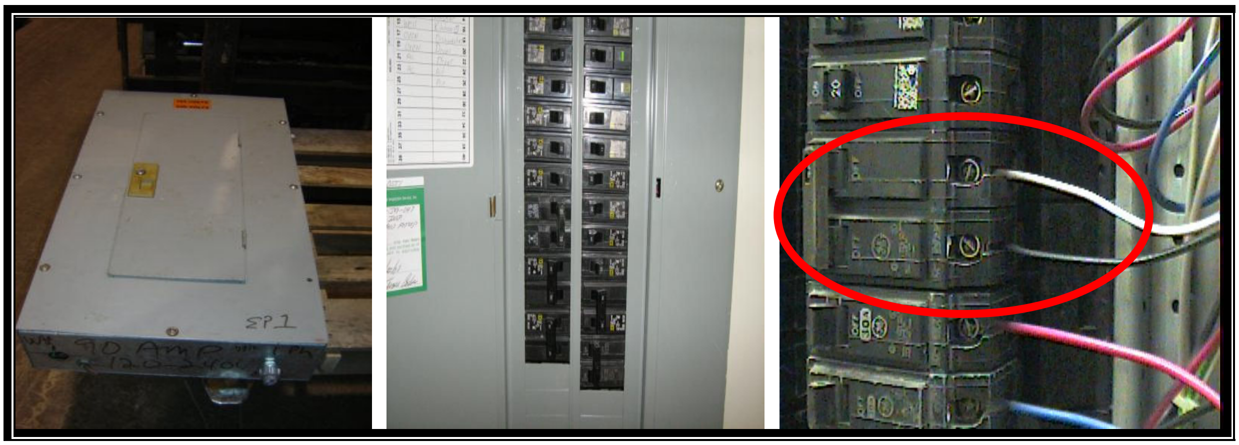
The last example for this paper is on a much smaller scale. During a first-year visit to complete a maintenance agreement at an Indianapolis facility, Jarod Pauley from Enterprise Electrical and Mechanical was the lead technician on this assignment. The components were varied in type, both large and small, including items such as a 1600 amp main switchgear, motor control centers, distribution panels, lighting controls, and branch circuit breaker panels. The facility had conveyor systems, battery charging areas, high bay lighting, computer rooms, multi-bay garage door controls, outdoor area lighting, and back-up generation, to name a few loads.

As with any other service, the intent was to ascertain the health of the equipment under normal operating conditions, determine which items may present problems with reliability and longevity, and develop an action plan for repairs to the equipment based on the findings. The typical facility, depending on age and condition of maintenance, will have a mixed bag of problems that encompasses infrared, ultrasonic, voltage, current, code and safety issues. This facility was no different.

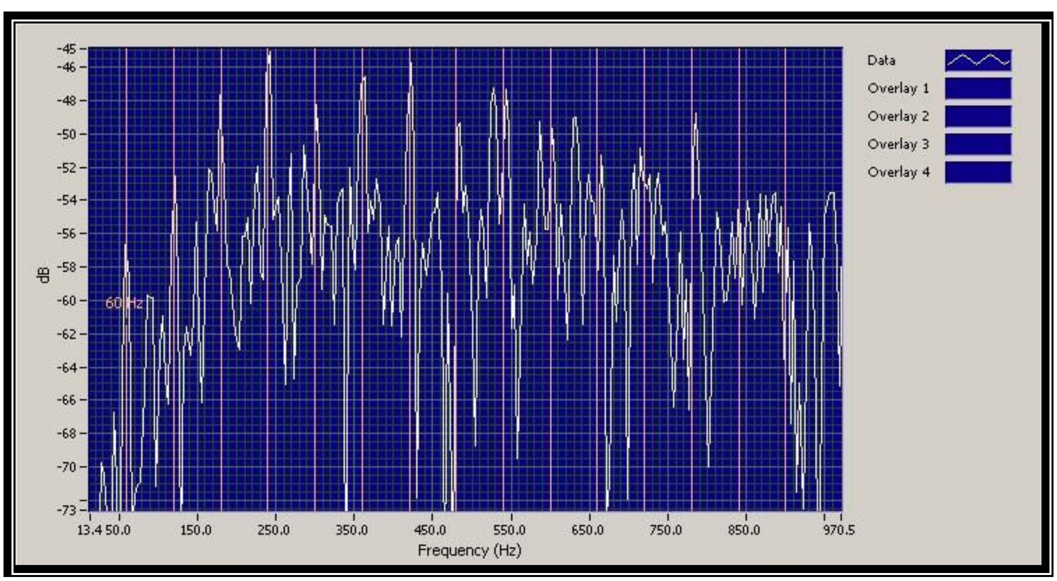
Throughout the three days of service, many deficiencies were identified on both large and small equipment. The second day yielded the ultrasonic anomaly on a component that most would consider least likely to have an ultrasonic issue. A 30 amp, double pole circuit breaker with a 208/120 voltage supply caught our attention during a routine training exercise. Technicians would normally use only the airborne module on equipment of this type; however, in the interest of training, the decision was made to practice with the contact module.

Of course this involves altering certain set-up parameters on the instrument to accommodate the attachment and be an integral part of the exercise. Technicians are trained and aware of which electrical components usually have some type of ultrasonic emission, such as transformers, motors, contactors, variable speed drives, etc… and which should have total silence. Small molded case circuit breakers like this one certainly fit the latter mold. The lesson progressed on this particular panel, and you could see by Jarod's facial expression and the rise of his eyebrows that something caught his attention.

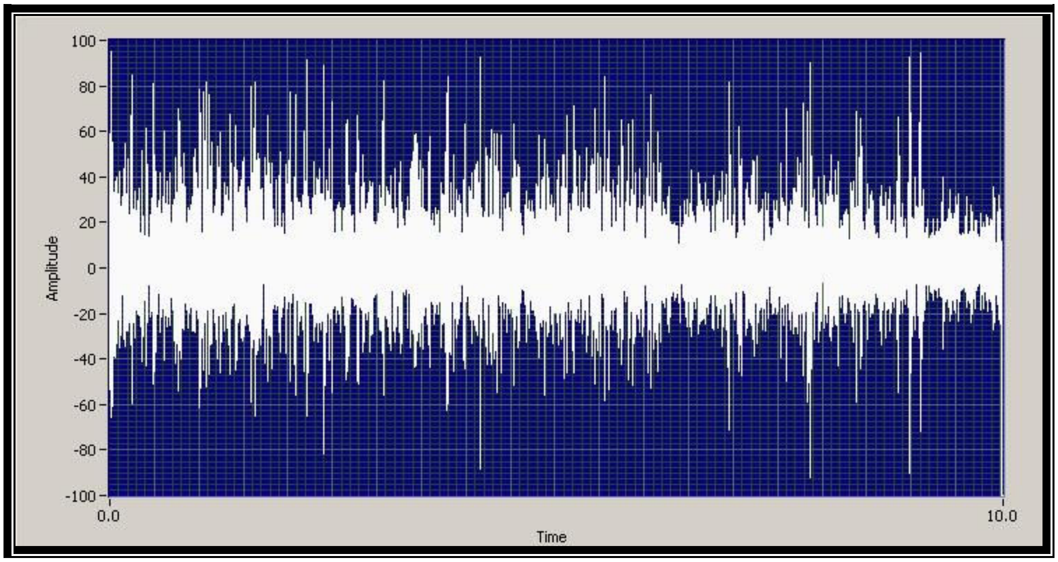
He described a sound in the acoustic isolators (you know them as headphones) that he felt should not be present. The "snap, crackle, pop" characterization came to mind, and he immediately allowed his thought process to drift to tracking as the suspect. The next step was to make a quality recording of the emission and download it to the laptop computer where it could be analyzed with Spectralyzer. Any component that shouldn't have an emission or a tonal quality concern on those that do have some type of ultrasound warrants analysis right there in the field when it is located. An image of the panel type and the actual circuit breaker is seen below:

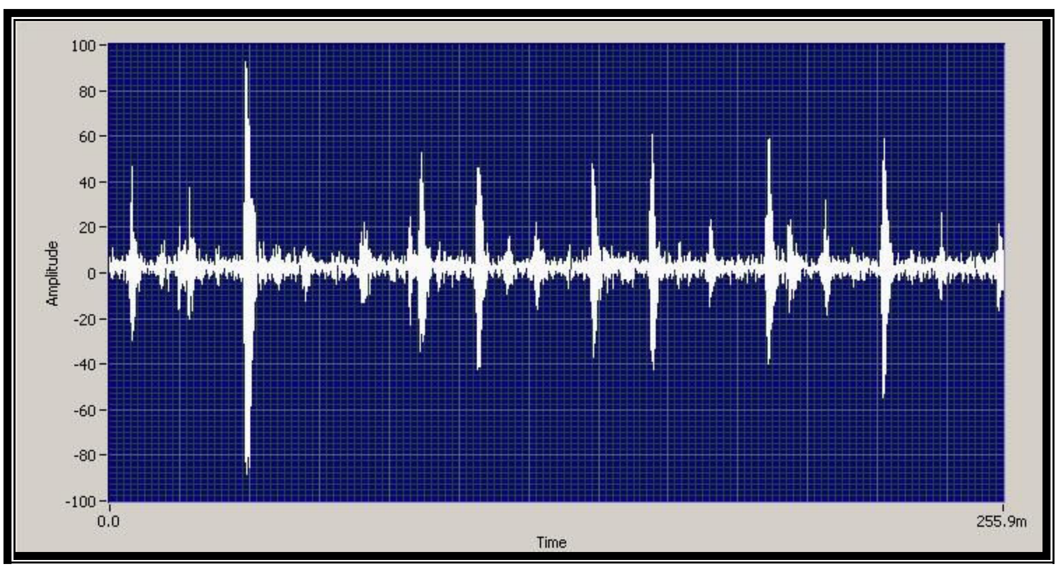


Aside from the fact that there was a code violation with the use of a "white" conductor as a current-carrying conductor, the ultrasonic emission was cause for alarm. Although one would not believe a simple 30 amp double pole breaker is important enough to justify the efforts, one must take into consideration and investigate what load is served with a given circuit. In this case, the circuit was found to be supplying a central air conditioner unit. But this was not a unit simply for comfort - it serviced the data center in the facility to ensure proper ambient temperatures for operation of the computer networks. This fact added credence to the need to analyze correctly. Once loaded into the software, all the earmarks of a tracking event reared its head. The illustrations below demonstrate once again how both tools clearly expose what is taking place and remove any doubt:



The respective time domain graphs are the proverbial “icing on the cake” for the analysis. All the hallmarks of an electrical tracking event manifest with great clarity and solidify identification of this fault, which degrades with each passing day. The first graph is the entire 10 seconds of recorded tracking, the second a snapshot at the 4-second mark:





(Great visualization of the footprint exhibiting total non-linearity)

The intriguing aspect of the above two views relates to the method in which tracking discharges take place along the entire 360-degree electrical cycle. If you recall from Example #2 in which tracking was graphically portrayed, these discharges occur anywhere on a given electrical cycle. As the discharges become more frequent (ergo more severe in nature), you will see the number of excursions increase and become more compacted, suggesting greater numbers of tracks per cycle. This is clearly evident in the first image above displaying the full 10 seconds of recording time.

The second image is a 255 millisecond slice to demonstrate a "magnified" view of this concept. Notice that both the amplitude and spacing of the discharges have no distinct pattern, meaning the intensity and timing are non-linear and present throughout each electrical cycle. Clearly and without reservation, this breaker was deemed to be in the failure mode due to the tracking taking place internally, and was recommended for replacement to avoid a future interruption. The outcome relative to repairs is still pending. The results of the inspection were already presented to the customer, and they will ultimately decide which direction to proceed and with whom. Certainly the customer cannot dispute the value received by this service, professionalism exhibited by the technicians in the application, and the final product report outlining all deficiencies. This is what "service" should be about.

SUMMARY

No one would argue that today's thirst for reliable, abundant electrical supply will only widen as technology expands and businesses diversify. This growing need only exemplifies the demand for regular predictive and condition-based maintenance programs. On top of that, the majority of the programs and tasks will have to be accomplished while the equipment is still in service and without interrupting the loads. The "run to failure" mindset *was* a great philosophy, if there was a contingency plan in place. Many organizations have adopted a new, modern philosophy of "lean manufacturing" and "just in time" delivery, which results in reduced inventory of spare parts on hand.

The modern world and global economy mandated adjustments in the methodology of conducting business to stay competitive. Cost reductions were necessary to accomplish this, and typically maintenance, inventory, and workforce personnel are the first to experience cuts. Although it does impact the bottom line, this approach bears short-term fruit, however, as it does nothing to reduce the stresses of the electrical system components. Ignoring routine maintenance only perpetuates failures which are sure to come.

Any competent facility manager is cognizant of this and will be proactive in their maintenance applications. They will also seek out the most technologically advanced, state-of-the-art instruments to achieve the objective of lowering downtime, increasing revenue, and maximizing equipment life. To not utilize all of the tools available for a given task is derelict. There are many great tools that make the modern maintenance or service electrician's life much easier. Conscious of the fact that there is no one tool that is limitless in capability, identifies **every** deficiency, and provides root cause analysis, a multi-faceted approach to maintenance relative to the tools and instruments becomes an absolute necessity.

Insomuch as we rely on the electricity that impacts every aspect of our lives, we must be diligent in our efforts, precisely analyze potential faults, prioritize repairs to deal with problems on our terms as opposed to allowing equipment to dictate repairs, and take every tool possible to extend the life and reliability of every component within the electrical system that serves our everyday needs. Ultrasonic testing *MUST* complement any relevant maintenance program that aims to achieve those objectives. At a minimum on electrical systems, infrared thermography, ultrasonic testing, voltage/current diagnostics, and visual inspections by trained, licensed, and certified electricians would have to be the key components of any program.

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