TROUBLESHOOTING GUIDE

InsightCM Electromagnetic Interference (EMI)

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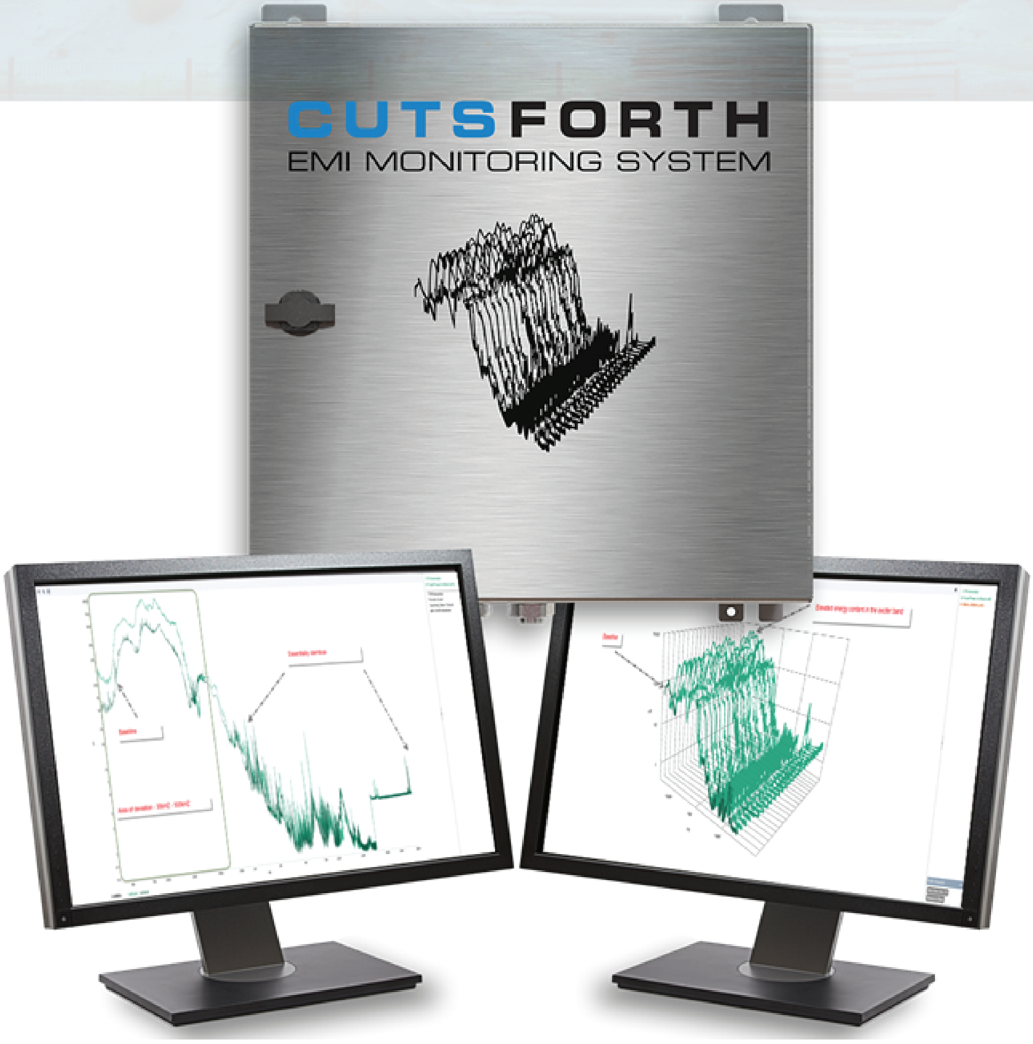

CUTSFORTH
THE POWER OF INNOVATION™

Document #: EZDP-2060 Rev A

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1. About Cutsforth

Cutsforth specializes in developing innovative new technologies and services to support the power generation industry. Cutsforth's patented EASYchange® brush holder design, online truing service, and patented shaft grounding and monitoring systems have been installed across the globe in generators of all sizes and in nearly every industry application, including nuclear, natural gas, coal, wind, and hydroelectric.

Cutsforth's knowledge and commitment to excellence drives our innovative solutions for the changing needs of the power industry. Whether it is a quick response to a critical situation or a new way of solving an old problem, our commitment to quality ensures that our customers receive the best-in-class products and services—Cutsforth is the Power of Innovation.

Cutsforth, Inc. started back in 1991 as a small company focused primarily on making replacement brush holders for generators and exciters. Today, after 25+ years in business, Cutsforth's experience and innovative designs have brought its best-in-class excitation brush holder and shaft grounding replacements and collector ring services to some of the world's largest power companies.

1.1. Cutsforth Products

- EASYchange® Removable Brush Holders
- EASYchange® Brush Condition Monitoring
- Cutsforth Shaft Grounding Systems
- Rotor Flux Monitoring
- Electro-Magnetic Interference Monitoring

1.2. Cutsforth Field Services

Cutsforth provides comprehensive product installations for all product offerings as well as on-site training after the installation. We work efficiently during your outage to ensure a smooth upgrade to our innovative solutions such as Product Installations, Online Collector Ring and Commutator Truing, Spiral Groove Restoration, and Consulting and Emergency Services.

1.3. Cutsforth Electrical Contractor Services

In addition to our Field Service installation services, Cutsforth offers turn-key services including the electrical contractor scope of work as an additional service in select regions within the US. With this service offering, Cutsforth can greatly simplify the process of monitoring product installation from beginning to end.

2. Legal Information

2.1. Limited Warranty

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For a period of ninety (90) days from the date of invoice, Cutsforth warrants that (i) its software products will perform substantially in accordance with the applicable documentation provided with the software, and (ii) the software media will be free from defects in materials and workmanship. If Cutsforth receives notice of a defect or non-conformance during the applicable warranty period, Cutsforth will, in its discretion: (i) repair or replace the affected product, or (ii) refund the fees paid for the affected product. Repaired or replaced Hardware will be warranted for the remainder of the original warranty period or ninety (90) days, whichever is longer. If Cutsforth elects to repair or replace the product, Cutsforth may use new or refurbished parts or products that are equivalent to new in performance and reliability and are at least functionally equivalent to the original part or product. You must obtain an RMA number from Cutsforth before returning any product to Cutsforth. Cutsforth reserves the right to charge a fee for examining and testing Hardware not covered by the Limited Warranty.

This Limited Warranty does not apply if the defect of the product resulted from improper or inadequate maintenance, installation, repair, or calibration performed by a party other than Cutsforth; unauthorized modification; improper environment; use of an improper hardware or software key; improper use or operation outside of the specification for the product; improper voltages; accident, abuse, or neglect; or a hazard such as lightning, flood, or other act of nature.

THE REMEDIES SET FORTH ABOVE ARE EXCLUSIVE AND THE CUSTOMER'S SOLE REMEDIES, AND SHALL APPLY EVEN IF SUCH REMEDIES FAIL OF THEIR ESSENTIAL PURPOSE.

WARNING REGARDING USE OF CUTSFORTH SHAFT MONITORING EQUIPMENT: CUSTOMER IS ULTIMATELY RESPONSIBLE FOR VERIFYING AND VALIDATING THE SUITABILITY AND RELIABILITY OF THE PRODUCTS WHENEVER THE PRODUCTS ARE INCORPORATED IN THEIR SYSTEM OR APPLICATION, INCLUDING THE APPROPRIATE DESIGN, PROCESS, AND SAFETY LEVEL OF SUCH SYSTEM OR APPLICATION. PRODUCTS ARE NOT DESIGNED, MANUFACTURED, OR TESTED FOR USE IN LIFE OR SAFETY CRITICAL SYSTEMS, OR ANY OTHER APPLICATION IN WHICH THE FAILURE OF THE PRODUCT OR SERVICE COULD LEAD TO DEATH, PERSONAL INJURY, SEVERE PROPERTY DAMAGE OR ENVIRONMENTAL HARM (COLLECTIVELY, "HIGH-RISK USES"). FURTHER, PRUDENT STEPS MUST BE TAKEN TO PROTECT AGAINST FAILURES, INCLUDING PROVIDING BACK-UP AND SHUT-DOWN MECHANISMS. CUTSFORTH EXPRESSLY DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY OF FITNESS OF THE PRODUCTS OR SERVICES FOR HIGH-RISK USES.

CUTSFORTH DOES NOT WARRANT, GUARANTEE, OR MAKE ANY REPRESENTATIONS REGARDING THE USE OF OR THE RESULTS OF THE USE OF THE PRODUCTS IN TERMS OF CORRECTNESS, ACCURACY, RELIABILITY, OR OTHERWISE. CUTSFORTH DOES NOT WARRANT THAT THE OPERATION OF THE PRODUCTS WILL BE UNINTERRUPTED OR ERROR FREE. INCIDENTAL AND CONSEQUENTIAL DAMAGES, INCLUDING LOSS OF USE, ARE SPECIFICALLY EXCLUDED FROM THIS WARRANTY; THE MAXIMUM VALUE OF A WARRANTY CLAIM CANNOT EXCEED THE ORIGINAL VALUE OF THE ASSEMBLY OR COMPONENT.

2.2. Copyright

2.3. Patents

Please send patent information requests to patents@cutsforth.com.

3. Safety Information

Following is important safety information. For safe installation and operation of this equipment, be sure to read and understand all cautions and warnings.

3.1. Safety Conventions

Additional information.

Indicates an action or specific equipment area that can result in personal injury or death from an electrical hazard if proper precautions are not taken.

Indicates a hazardous situation that, if not avoided, could result in minor or moderate injury or equipment damage.

Indicates a hazardous situation that, if not avoided, could result in death or serious injury.

Indicates possible injury from rotating parts.

Indicates a hazardous situation that, if not avoided, will result in death or serious injury.

3.2. General Safety Instructions

Only qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid injury should work with Cutsforth products. Among the many considerations are the following:

- Avoid contact with energized circuits.
- Avoid contact with rotating parts.
- Never install any component that appears not to be functioning in a normal manner.
- Always ensure proper installation of the holder assembly and rope refresh kit.

Before working on the generator, de-energize, lock out, and tag out all power sources to the generator, shaft, and accessory devices. Electric shock and death may result due to failure to heed this warning.

High-voltage and rotating parts can cause serious or fatal injury. Installation, operation, and maintenance of this product must be performed only by qualified personnel, in accordance with all applicable safety regulations and guidelines.

4. Introduction

This guidebook is intended to provide details on how to recognize common waveform patterns measured in the RF spectrum between 30 kHz and 100 MHz and give guidance on how these signatures can be used to identify expected results vs. defects including location and type being detected in the machine.

The common waveform patterns are arcing, corona, partial (gap) discharge, micro-sparking, and random noise. Some waveforms are combinations of the common patterns.

5. Background

This section provides some information about Electromagnetic Signature Analysis.

5.1. Electromagnetic Waves

When a flow of electrical energy occurs in one of the ways listed below, some of the energy is converted to electrical and magnetic fields that are transmitted through the air in the form of electromagnetic waves:

- Full conductor-to-conductor current flow
- Partial conductor-to-conductor current flow
- Discharge in air
- Man-made conductor or antenna

Low-frequency electromagnetic fields, such as house current at 60 Hz, are attenuated very rapidly in air and require very high voltage and current levels to impact surrounding equipment (such as high-current transmission lines). High-frequency electromagnetic fields, such as radio and television carrier frequencies, travel much longer distances in the air and require less energy to impact surrounding equipment.

These electromagnetic waves are absorbed in surrounding conductors that are sometimes many miles away.

If the energy flow is controlled, it can be used as information transmission from place to place (for example, radios). If the release is uncontrolled, the emissions can interfere with the controlled transmission of information and the operation of electrical equipment near the uncontrolled release.

5.2. FCC and CISPR Standards

The Federal Communications Commission (FCC) and Comité International Spécial des Perturbations Radioélectriques (CISPR) have developed Electromagnetic Compliance standards that equipment manufacturers must adhere to for both:

- Manufacturing equipment to detect high-frequency emissions from electronic equipment
- The amount of emissions that are allowed from electronic equipment.

NOTE

Generator manufacturers and electric utilities do not have to adhere to these emission standards for low-frequency equipment, such as 60 Hz generators.

5.3. Electromagnetic Signatures

Electromagnetic (Interference) Signature Analysis (EMSA) is the capture and analysis of both controlled and uncontrolled electromagnetic emissions absorbed by electrical utility equipment (generators, motors, transformers, switchgears, etc.) to determine if any uncontrolled sources of discharge are being emitted from within the electrical utility equipment.

NOTE

The term Electromagnetic Signature Analysis (EMSA) was coined by an Electric Power Research Institute (EPRI) User's Group so the process was not confused with Electromagnetic Compliance (EMC) process.

In the early 1980's, two Westinghouse engineers wrote a paper discussing the possibility that using low-frequency equipment could potentially help detect defects in high-frequency equipment. This paper was based upon the fact that energy discharges (such as arcing, lightning, partial discharge, etc.) generate a broadband high-frequency emission pattern.

When he was working at American Electric Power (AEP), Jim Timperley read that paper and started using some CISPR-compliant equipment to detect emissions coming from generators, motors, switchgears, and transformers from the 10 kHz to 100 MHz frequency bands.

In his 1990's paper "The Basics of EMI (electromagnetic interference) Analysis," Jim Timperley introduced five basic types (plus a combination of the five) of electromagnetic signatures that he found in his experience using EMSA for detecting electrical defects in both rotating and stationary high-voltage (greater than 2000 volts) utility equipment.

Based on Jim Timperley's paper, the electromagnetic signatures are:

- Arcing (page 10)
- Corona (page 11)
- Gap Discharges (page 11)
- Micro-Sparking (page 11)
- Random Noise (page 12)
- Combinations (page 12)

5.3.1. Arcing

Arcing is a low-voltage electrical discharge involving lower frequency current that is several orders of magnitude greater than that produced by Partial Discharge (PD). Arcing is rich in low-frequency harmonics, extending through a wide range of the radio frequency spectrum. Arcing is characterized by discharges with measurable rise and fall times when displayed in real time on an oscilloscope.

Arcing results from the loss of continuity in conductors, loose-bolted or crimp joints, broken conductors in stator coils, or broken bars in rotors. Frequent sources of arcing are sliding contacts like shaft grounding brushes, exciter commutator brushes, or slip ring brushes.

The detected audio component is usually erratic due to the intrinsic instability of the source. Depending on the source, the discharges may or may not be synchronized with the power frequency.

5.3.2. Corona

Corona is an electric current discharging into a gas or liquid that appears during both positive and negative half cycles. In air, corona can be found on clean conductors operating above 2,000 volts to ground and at frequencies below 10 MHz. If the media is oil or pressurized hydrogen, this voltage can be higher.

Low-frequency corona is a common signature for asphalt mica-flake insulated machines, which is the same pattern detected by PDA techniques as internal insulation voids. Machines with modern VPI synthetic resin insulation systems often have corona activity only above 2 MHz. Dirty and contaminated windings can produce corona even with 2.3 kV machines.

The detected audio component has a sound similar to bacon frying.

5.3.3. Gap Discharges

A gap discharge (partial discharge) is produced when two surfaces separated by a gap are at different potentials sufficient to spark over the gap and generate a current pulse. A gap discharge can occur one or more times during each half of the power frequency cycle because the rise and fall time of each discharge is extremely fast. Usually the pulse repetition frequency (PRF) is fixed at 1 to 15 events per half cycle at any location and is synchronized with machine phase voltage.

The PRF and amplitude of gap discharge vary as a function of gap dimensions, impressed voltage, insulation quality of the surrounding gas, and the RF impedance of adjacent conductors. EMI generated from gap discharge is rich in broadband harmonics characterized by high amplitude throughout the RF spectrum.

The detected audio component has a popping or rasping sound depending on the source PRF.

5.3.4. Micro-Sparking

Micro-sparking is similar to a gap discharge except the gap is extremely thin, usually in the order of 0.4 mm. The discharge PRF is 15 to 30 pulses per each power frequency half cycle compared to gap discharges which occur at PRF of 1 to 15. Each micro-spark has a very short duration.

The EMI produced is usually found to be above 20 MHz. Often, transmission-line hardware micro-sparking is measured at the generator neutral. Micro-sparking is often intermittent due to the very thin gap involved that can be contaminated with dirt, chemical residue, oil, or rust.

The detected audio component is a buzzing sound that is a function of the PRF.

5.3.5. Random Noise

Random noise is similar to the white or pink noise used to test audio circuits. It results from the contamination of high-voltage insulation with conductive material. This white noise can be broadband or centered at one to three specific frequencies with a spectrum response similar to a signal transmitter but with a much wider bandwidth.

When surface contamination on the insulation is involved, ambient humidity changes may influence discharge activity. Contamination in the insulation (for example, wet stator bars) also produce random noise. Random noise is not a partial discharge. Detection by PDA systems has not been verified.

The detected audio component sounds like an AM radio receiver or television set when tuned between stations.

5.3.6. Combinations

Most EMI signatures are a combination of the five basic types, and they are always combined with a variety of man-made noise sources. Gross problems such as broken or shorting conductor strands are obvious and easy to detect. Other problems such as loose phase rings, contamination, and internal corona are more subtle and harder to isolate particularly when deterioration is in the early stages.

6. Identifying Areas of Interest and Levels of Concern

When you have an increase in the EMI level on a piece of equipment, you can take these steps to evaluate whether the situation is of major concern.

1. Compare the spectrum that generated the alarm with a previous "baseline."
2. Contact the plant site (if possible) to determine any changes in plant condition (rain, power level, voltage level, plant modification, etc.) that could have contributed to the increase in EMI.

   The plant conditions can help determine if an increase in magnetic or electric fields contribute to the EMI increase. An increase in magnetic fields can lead to more movement of components while an increase in electric fields can indicate a weakness in the insulation structure.
3. Determine which frequencies have increased over the baselines and the possible plant conditions that could have contributed to the EMI increase. Label these frequencies as "Areas of Interest."

   The Areas of Interest can help determine the subcomponent of the generator or motor that may be causing the EMI increase.
4. Determine how much the level has increased and whether it is over multiple frequencies ranges or localized in nature. Label these as "Levels of Concern."

After identifying the Areas of Interest and Levels of Concern, you can focus on the type of defect in the subcomponent by evaluating the demodulated waveform associated with the carrier frequencies in the Areas of Interest.

With the demodulated waveform and the plant condition evaluation, you can focus on the type and location of maintenance that may be needed to repair the anomaly.

6.1. Evaluating Areas of Interest

During the capture of the frequency domain data, look for humps and spikes of energy that stand out against the backdrop of general EMI noise levels. Record the frequency of these areas, and capture the associated demodulated time domain signal. By examining the characteristics of the demodulated waveform and knowing which frequency the demodulated waveform is associated with, you can make some educated guesses about where and what type of defect could be causing the EMI signature.

For generators, four features have been developed to correlate the frequencies associated with the areas of interest to specific generator equipment. These features were developed from case studies and observations of signals over the last 20 to 30 years.

Frequency	Anomalies related to	Predominant failure modes
30 kHz – 500 kHz	Exciters or excitation components	▪ Diode pulse trains (missing diode pulse in the tone pattern) ▪ Dirt tracking ▪ Loose connection arcing
500 kHz – 5 MHz	Stator slot components	▪ Spark erosion ▪ Insulation breakdown ▪ Core arcing ▪ Partial discharge ▪ Loose wedging
5 MHz – 30 MHz	End winding structure components, although the region can be affected by anomalies in both the next higher and next lower frequency bands.	▪ Loose end basket structure ▪ Corona due to end winding spacing issues ▪ Connection issues between connection rings ▪ Bushings
30 MHz – 100 MHz	Generator output bus components: ▪ Isolated Phase bus ▪ Segmented bus ▪ Non-segmented bus ▪ Cable bus components	▪ Loose connections at the flex links ▪ Cracked insulators ▪ Dirty insulators ▪ Water or moisture intrusion in the bus

However, sometimes processes (especially with random noise or static) increase the whole level of the spectrum without any specific sub-frequency band increasing any more than another.

This situation often occurs where the contamination levels were very high inside the generator. For example, a cooler leak had been going on for a very long time, and the unit was elevated across the frequency bands. After the cooler leak was fixed and the generator's interior cleaned, all frequency bands decreased in activity.

For large motors, the lower frequency range (30 kHz – 500 kHz) and upper frequency range (30 MHz – 100 MHz) are not relevant unless the motor is a synchronous motor. Induction motors do not have an excitation system, so signals of interest do not occur in the lower frequency area. Also, since there is no output bus from a motor, the high frequency range is not relevant either. In fact, for many years the signals were only monitored up to 10 MHz for motors because nothing had ever been detected above that.

For large transformers, higher frequency areas tend to be relevant to the generator output bus. Unlike with generators, not enough data has been gathered to be able to correlate specific frequency ranges to physical areas of the transformers, so only the power spectrum of the whole frequency band (30 kHz – 100 kHz) is monitored for changes.

6.2. Troubleshooting with Demodulated Waveforms

After identifying an area of interest, tune the interference analyzer to a specific carrier frequency to get a demodulated waveform, which checks for any pattern that aids in the interpretation of the signature. Jim Timperley (in his paper) and other EMI analysts have noticed the following patterns:

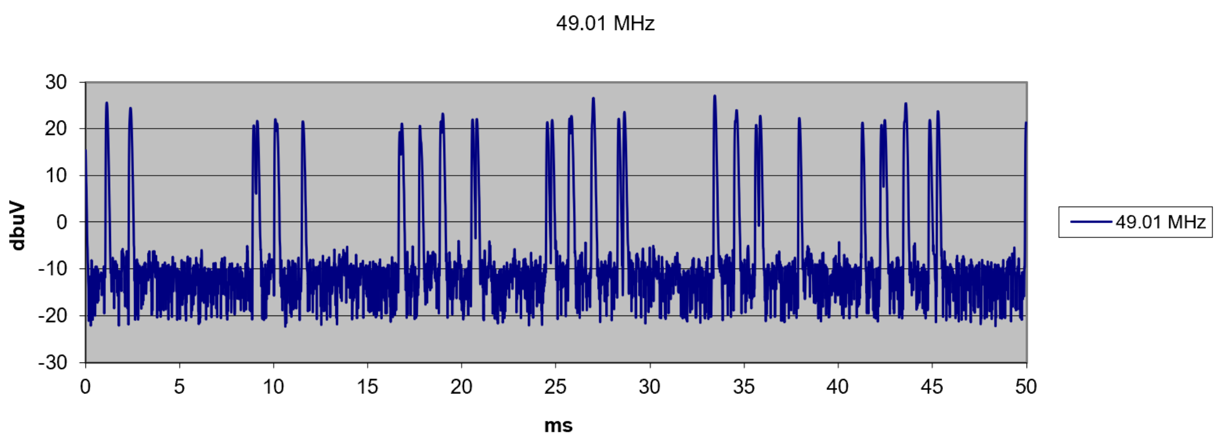
- Arcing (page 15)
- Corona (page 16)
- Gap discharges (page 18)
- Micro-sparking (page 19)
- Random noise (page 21)
- Tones (page 22)
- Radio signals (page 20)
- Combination (page 24)

NOTE

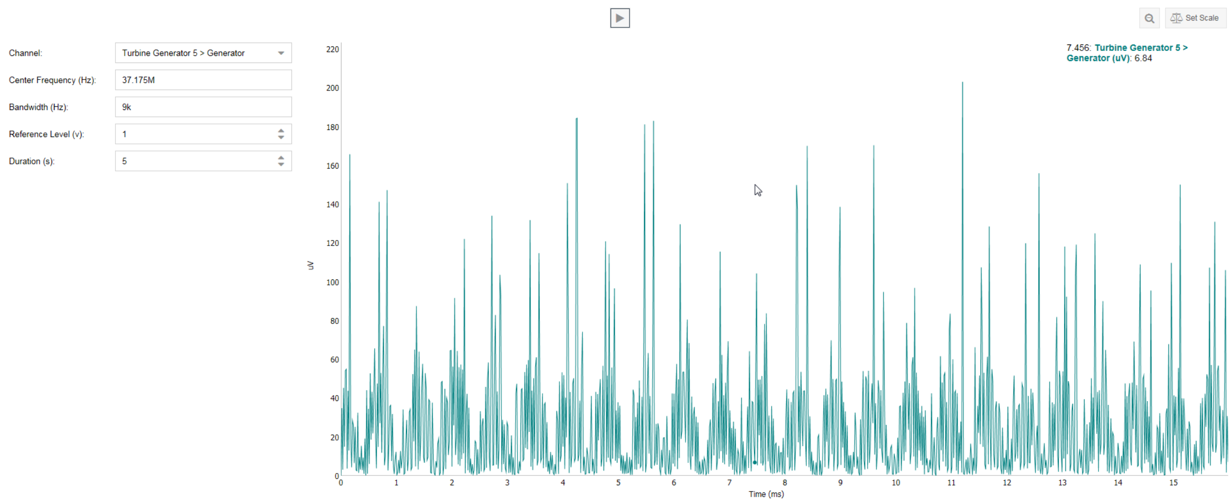
Although other patterns may be found, specific failure modes may not yet have been identified for them. Many signatures are man-made signals (such as radio signals, voltage-regulator diode patterns, etc.) that tend to fall into the tonal patterns. So you should listen to the signal along with visually inspecting it to see if "sound" gives any more insight into the interpretation.

6.2.1. Arcing Demodulated Waveforms

Arcing is one of the most destructive processes associated with Electromagnetic Interference analysis. It is a relatively high-energy discharge of current and is seen many times in combination with lower-level discharge types such as gap discharge and corona. It's primary characteristic is a high-energy discharge with a broad base rather than a sharp peak with a narrow base.



Arcing is sometimes interpreted as gap discharge because in many cases, the arc is across a conductor gap. However, arcing tends to be more erratic than a pure gap discharge signature and has more energy content. As the system deteriorates, the arcing patterns can get very close together.



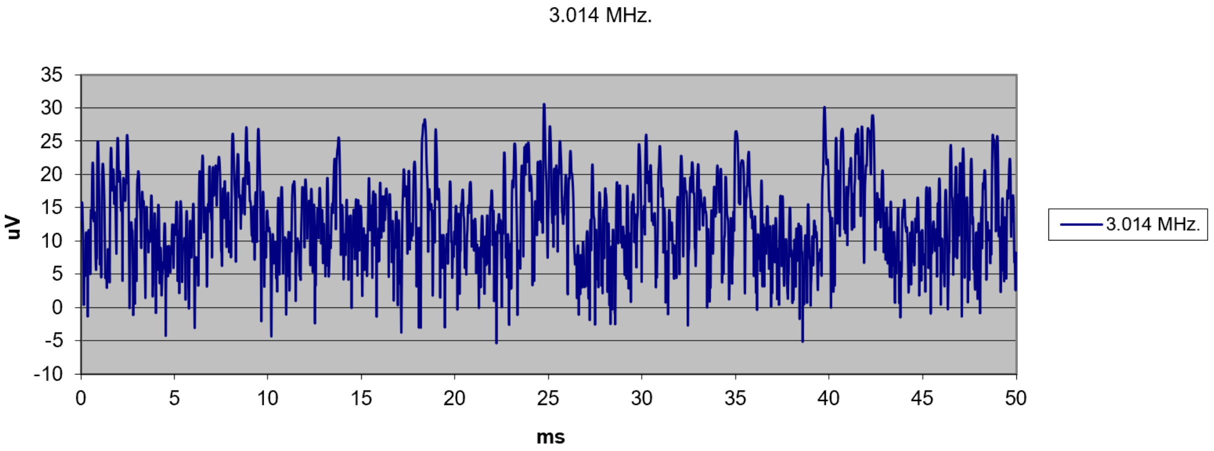
This type of signature, seen quite often in the higher frequency bands, are attributed to issues in the Generator Output Bus (Isolated Phase bus, Segmented Bus, Non-segmented Bus, Cable Bus) and can be due to bad connections at the bus transitional areas (flex links, bolted connections).

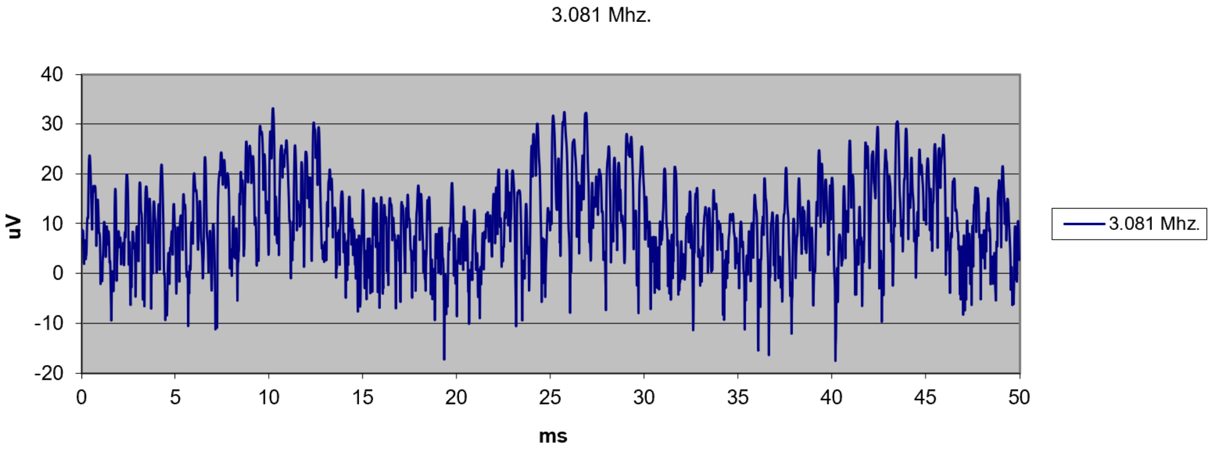
If this arcing signature is seen in the lower frequencies, it could be attributed to loose connections on power rectifier circuits and exciter connections.

If this arcing signature is seen in the middle frequencies, it could be attributed to cracked strands, bad braze joints, and bad connections on internal phase connections. It is rare to see this signature in the middle frequencies, and it would be high concern for the health of the generator internals.

6.2.2. Corona Demodulated Waveforms

Corona is caused by a discharge in the air or hydrogen space associated with generator end windings. It is rarely seen in hydrogen machines and is indicative of either surface contamination on windings or improper spacing between high voltage windings. It is characterized by random noise process superimposed on a 60 Hz sinusoidal pattern.





This type of waveform is seen in the middle frequency bands and tends to be in the end winding structure or very close to the end of the core. Bad gradient paint / tape structure on the windings as they exit the core structure can cause this type of signature.

It usually is not very destructive in nature. White powder (ozone deposits) can be found during visual inspection (or black if oil is present), and it should be cleaned and the insulation structure under the indication should be inspected to determine if insulation is being deteriorated by the corona or being etched by the ozone deposits from the coronal discharge.

Repairing the gradient structure and filling the offending air gap with an epoxy resin have been some repair processes used in the past to prevent corona, but many machines operate for long periods of time with evidence of corona on the windings without failing. Repair of degraded insulation may need to be done but that usually does not prevent corona. However, it does extend the life of the insulation structure.

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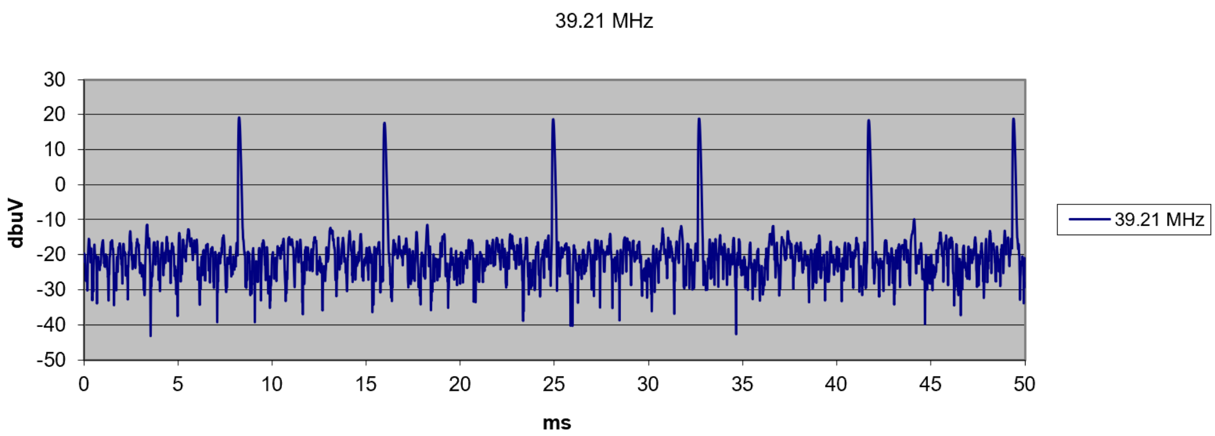
6.2.3. Gap Discharge Demodulated Waveforms

Gap Discharge or Partial Discharge is a discharge activity across an insulation void or an air gap in a connection point. Mica insulation is very robust against partial discharge but cross-link polyethylene structures (such as cable insulation) are very susceptible to further damage from the partial discharge process itself. For discharges across a pit in a connection point it can escalate into an arcing pattern as the connection point gets deteriorated by the discharge action over time.



If the frequency band in this signature is noted in the low (exciter) frequency, it could be a normal diode firing pattern (depending on the number of spikes per sine wave structure). This can usually be listed in the "tone" pattern and the spikes will modulate based upon the voltage regulator control pattern.

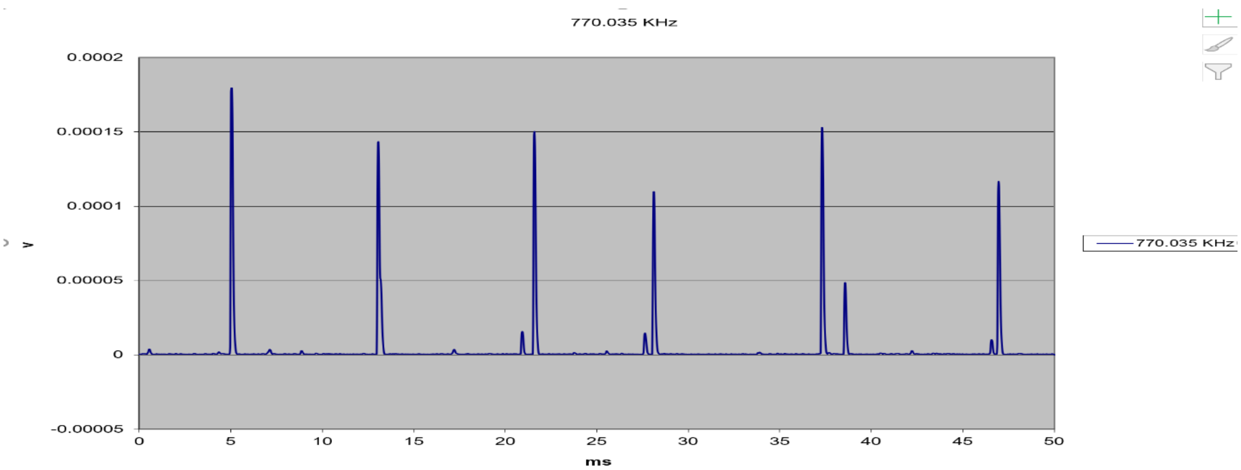
If in the higher frequency band (as in the above signature), it could be developed by a gap in the ceramic insulator structure (bolt gap, insulator crack, space between the conductor and the insulator, etc.).

It could also be the start of a connection problem. Trend this pattern over time to see if it degrades into a multi-gap discharge pattern or arcing pattern.

The discharge noted can be stable or inconsistent, single or multiple discharges.

If the discharge is single and stable, then it is indicative of a minor pit or single void. Multiple and stable indicate multiple pits or voids but this is still a stable condition. Monitor these conditions to determine if it is degrading over time into a stronger multiple discharge pattern or an unstable signal.

If the discharge is unstable, then it is indicative of a condition such as a loose connection, loose bolt, insulation gap movement, or other condition that causes the gap structure size to change.



In the above case the motor appears to have a very low-level start to a connection gap discharge. The level of the frequency of interest was less than 100uV so no action was taken. But it was a type of signal we would monitor to see if the energy levels of the interference increased over time.

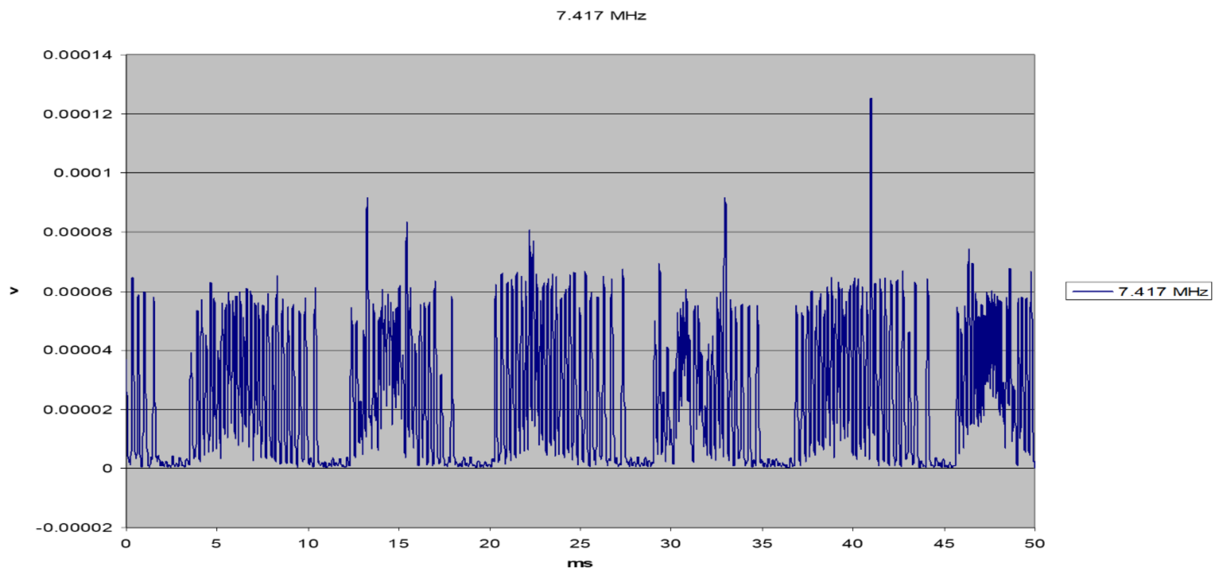
6.2.4. Micro-Sparking Demodulated Waveforms

Micro-sparking has a similar pattern to the tones noted below but the pattern is voltage related. It appears as a burst of spikes with gaps between the bursts.

These anomalies are usually developed from very small gaps in the conduction path such as pitting or frosting of connections. In some cases, the anomaly deteriorates into more damaging conditions (arcing).

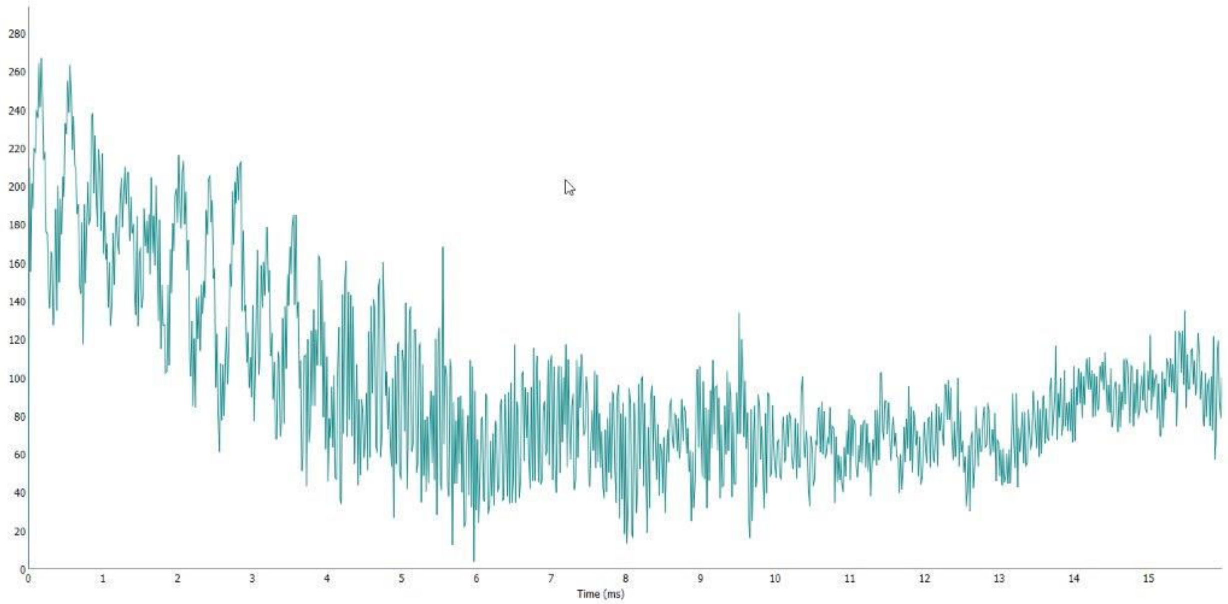
This condition is not seen very often and is of concern if the values of the EMI are high. Perform an inspection to find and repair the location of the defect causing the signal as soon as reasonably possible.

This signal sometimes sounds like a growling sound when the audio is listened to.

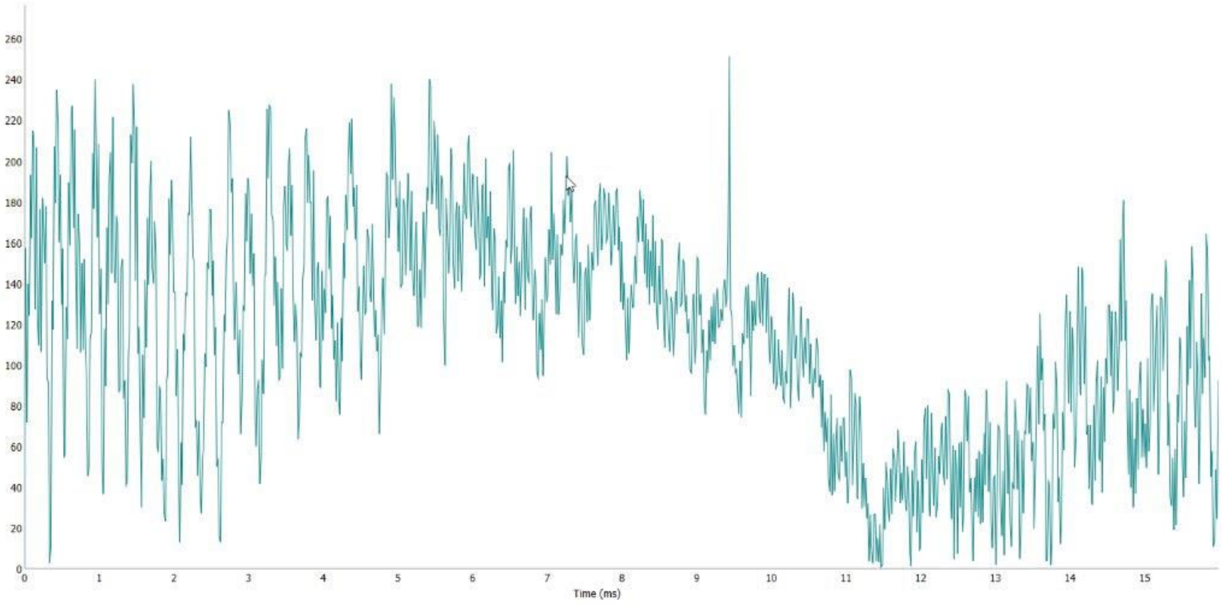


6.2.5. Radio Signal Demodulated Waveforms

Radio signals are usually very recognizable because they look really weird (very scientific term). They go from a random noise, to a burst of signal, to an envelope type signal.

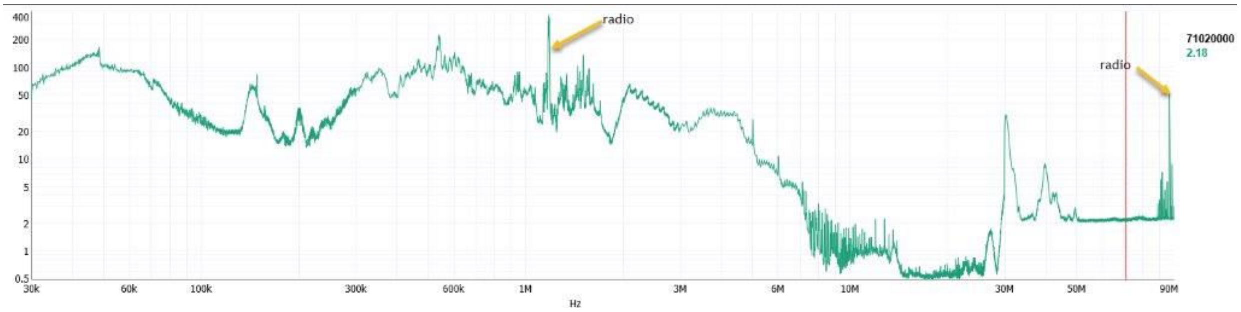


Once you see it and listen to it, the signal becomes pretty easy to recognize.



These signals are used to monitor for other signals of interest interfering with the radio content. If a radio signal is swamped by some interfering noise signal, that is usually a sign of a defect becoming stronger or worse.

Radio signals have a very narrow frequency band and can usually be recognized on the spectrum by a spike in the spectrum in the AM and FM radio frequency bands. Other tones, such as diode patterns, are not as narrow a frequency band, but some man-made communication signals can also have very narrow bandwidths.

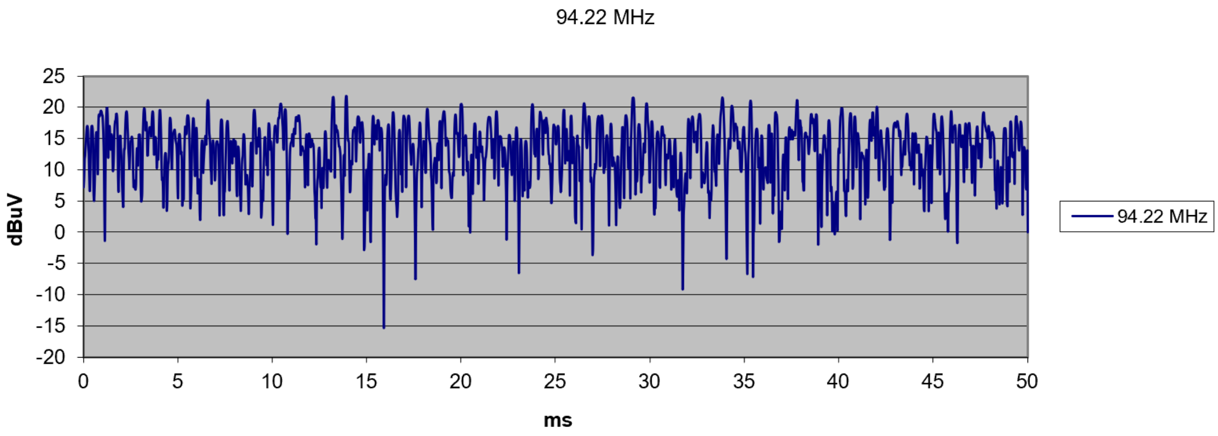


6.2.6. Random Noise Demodulated Waveforms

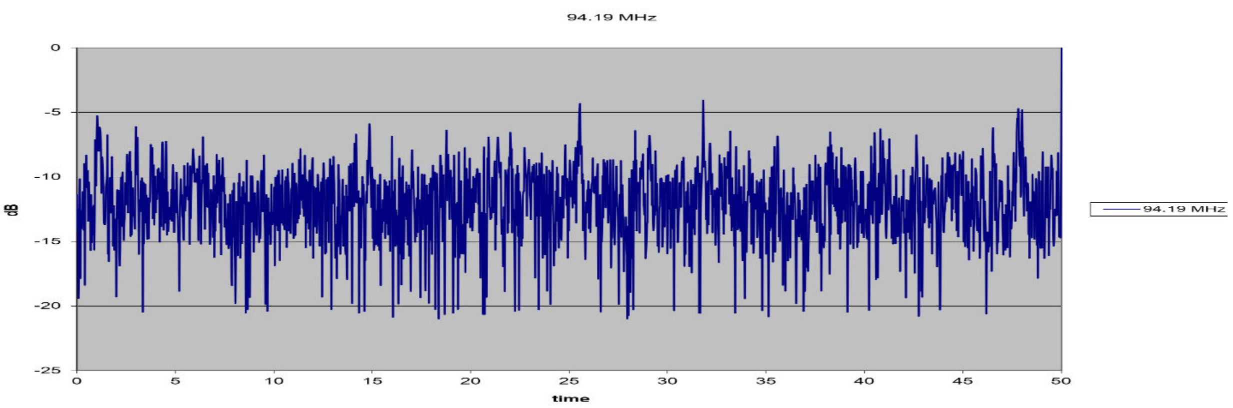
In general, random noise is created by contamination of some kind.

For example, in a motor, random noise developed due to salt contamination on the windings, and in a generator, it was from water/algae contamination. In the motor example, only the middle two bands were affected. For the motor, survey data was only taken up to 10 MHz. In the generator example, all frequency bands were affected due to the severe nature of the contamination.

For random noise events you generally get a broad area of interest.



In general, there is no voltage dependence (i.e. sine wave pattern like corona).



In some cases, in the excitation frequency band, you need to be aware of the random noise process that is between the exciter SCR/Thyristor spikes. As dirt and contamination builds on the voltage regulator/exciter diode area, the random noise levels between the diode pulses increase. This Indicates that the excitation area should be cleaned in an upcoming outage.

Monitor Liquid Level detector usage to help determine if this signal is caused by water leakage into the component.

While this condition may seem to be benign, the contamination can lead to insulation degradation which leads to full insulation failure.

6.2.7. Tones Demodulated Waveforms

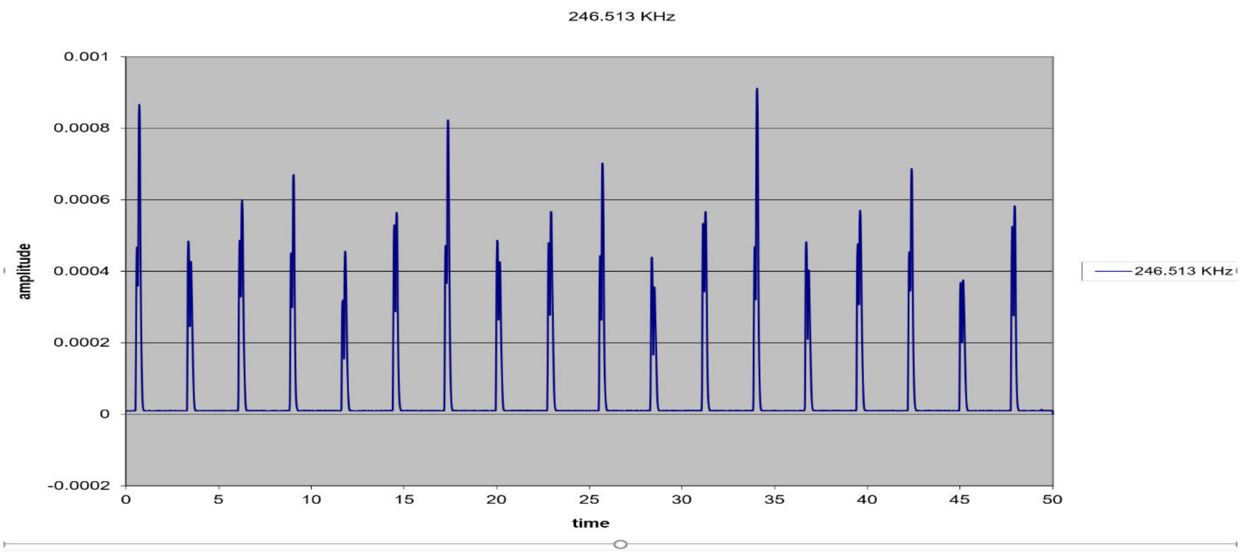
In most cases, tones are man-made signals. The excitation system will give you a tonal quality when you listen to it. If contamination builds you can sometimes hear a static noise interfering with the tone.

The pattern is a pulse train that is not voltage dependent but steady across the whole time of capture.

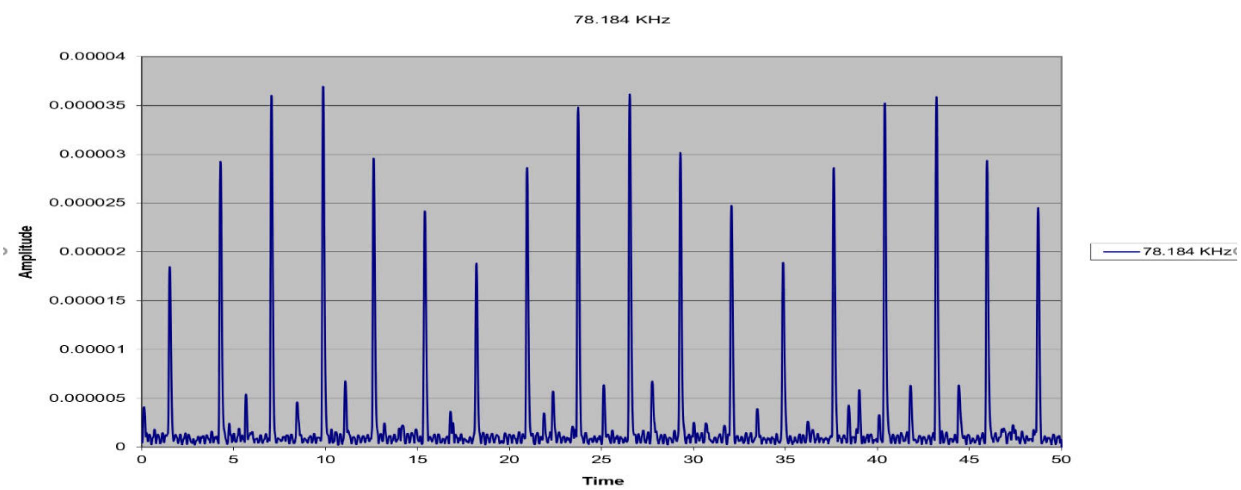
Tones are indicative of transmission line communication systems, variable frequency drives, and the like. They are captured by the antenna effect of the structure being monitored.

These tones can be very informative as trending indicators over time. If the tone starts to be swamped out by random noise or another waveform process, then there is a defect that is getting bad enough to develop a stronger signal than the man-made signal.

This tonal pattern is seen many times from a normal exciter/voltage regulator pattern. The pulse heights are modulated by the voltage regulator controls and there is no noise pattern in the gaps between the thyristor pulses.



The next example has a nice diode pulse train but it also has the start of some random noise process between the pulse pattern. If you are listening to the audio for this, you might hear a popping sound or static along with the tonal sound.

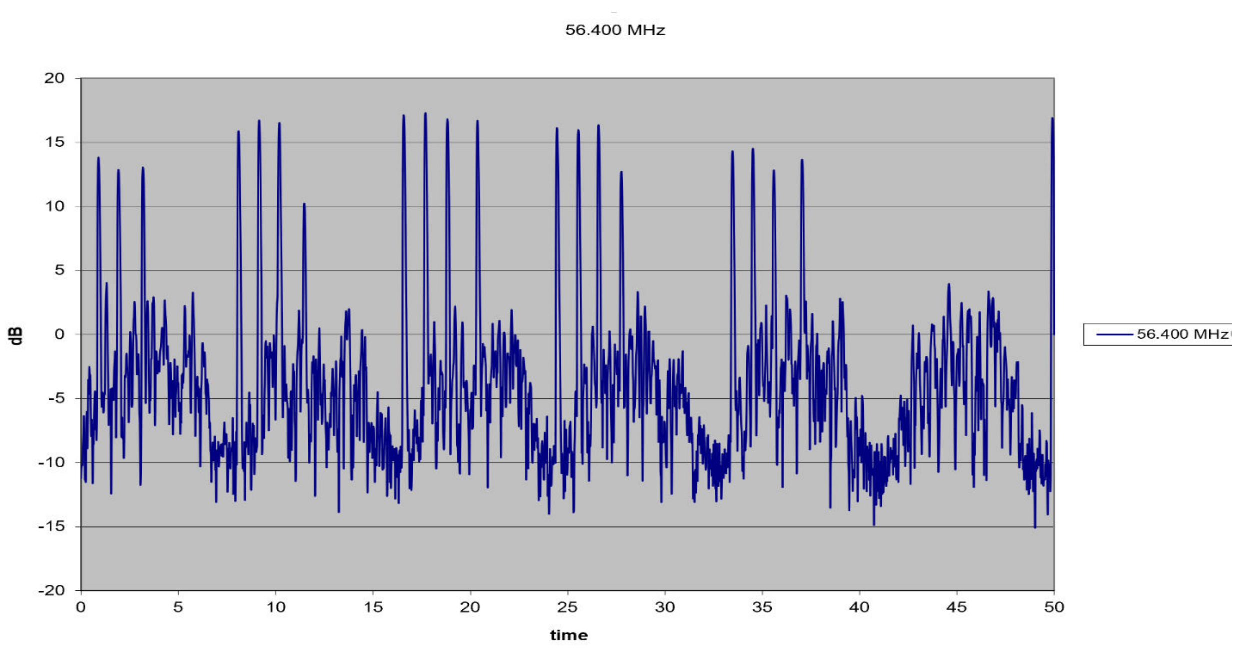


In this case, the larger pulses are not the "defect" but a man-made required component. The troubleshooting associated with these patterns is associated with the noise levels detected in the baseline of the signal. A clean baseline is indicative of a clean system requiring no maintenance. If the baseline becomes spikey or very noisy, then it is indicative of dirt contamination of the diode pack or some other defect.

If a "pulse" is missing from the pulse train, then it is indicative of a diode / thyristor misfiring.

6.2.8. Combination Demodulated Waveforms

Since all signals can be seen in combination with each other, it may be difficult to determine exactly what defect or signal style you are dealing with. As in the field, you may have multiple defects or anomalies occurring at the same time. If you have very strong signals and they are multi-pattern combinations, you should show a little more concern (especially if the arcing pattern is present).



This demodulated waveform, taken at higher frequencies, has a very distinct corona pattern with some gap discharge. The gap discharge is not consistent, indicating that the gap is likely not consistent (like a loose connection).

In the tones discussion, we showed a good diode pattern and a good diode pattern with additional random noise. That case developed a recommendation to clean the static excitation system power rectifiers in the next outage. The unit is a coal unit. The diode bank is contaminated with coal dust. The rectifiers have filters, but some stuff still gets through filters.

7. General Troubleshooting Techniques

This section describes other methods to help with troubleshooting EMI issues.

7.1. Establishing Baselines from Frequency Bands Initial Scan Readings

When the first EMSA scans are taken, look at the frequency scan for humps or spikes of higher-level frequencies. Record the higher readings for future comparison.

For the permanently installed units, the Power Spectrum of the frequency bands are captured and trended in InsightCM. The overall EMSA spectrum is saved on a company/IT determined frequency for comparison.

For periodic monitoring, capture the peak values and frequencies for comparison as more data is captured for trending purposes.

Currently, neither method automatically captures the demodulated time-domain waveforms. However, you should capture the demodulated time-domain waveforms for all the areas of interest to compare with similar data in the future.

7.2. Comparing Similar Patterns at Different Frequencies

In the demodulated data from the areas of interest, sometimes the same patterns are seen at different frequencies. However, there may be some changes to the patterns that may be of interest:

- The addition of random noise, corona patterns, etc.

- The strength of the signal is changing

These indications may help indicate to which frequencies the defect is mostly attributed.

7.3. Initial Scan Readings for Levels of Concern

NI-9770 card trends and periodic measurements have different levels of concern. The NI-9770 card uses the Power Spectrum, which is more sensitive to developing problems and can more easily detect issues that have not developed signals stronger than the local radio stations. The periodic measurement process uses the peak scan voltage.

The NI-9770 card has the following levels of concern for the areas of interest:

- Below 1000 uV : Generally no concern.
- Between 1000 uV to 10,000 uV: Should have a long-term inspection and repair plan.
- Greater than 10,000 uV: Should have a shorter-term plan with more aggressive inspections.

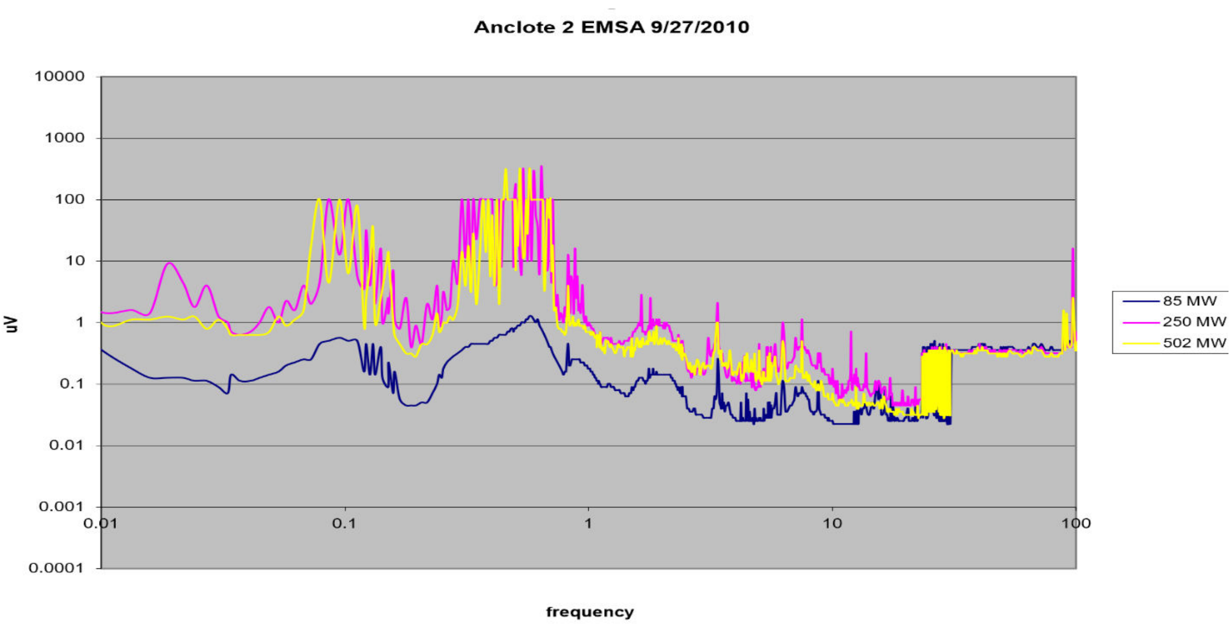
Recently, a generator was above 10,000 uV for about five years. A step change in level from 13,000 uV to 16,000 uV (Power Spectrum: 30 MHz – 100 MHz) was noted approximately three months before the unit tripped on stator ground. The issue was found in the Isolated Phase Bus: some cracked insulators and significant dirt contamination on other insulators.

For the periodic Instrument (Agilent E-7402), peak values of the spectrum are:

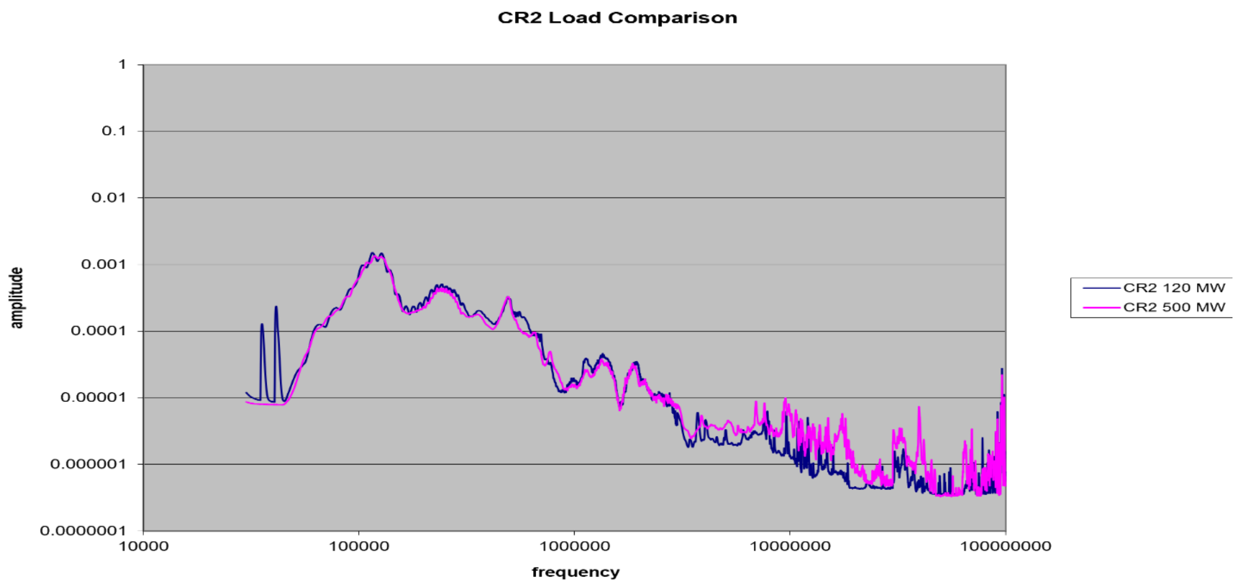
- Below 100 uV: No concern in this area.
- Between 100 uV and 1000 uV: Monitor and trend this area.
- Between 1000 uV to 10,000 uV: Area should have a long-term inspection and repair plans.
- Greater than 10,000 uV: Area should have a shorter-term plan with more aggressive inspections.

7.4. Comparing Loads

If very high values occur when the unit is at high loads, it may be worthwhile to take another scan at low load values. Signal strengths decreasing significantly at the low load values indicates loose components in the monitored equipment. Loose wedge systems or loose end winding ties will be moving more at high loads and cause the discharge signals to increase.



In other cases, the unit is tight and does not show different EMI signatures with load.



Note the area of frequency to determine the location of the loose component.

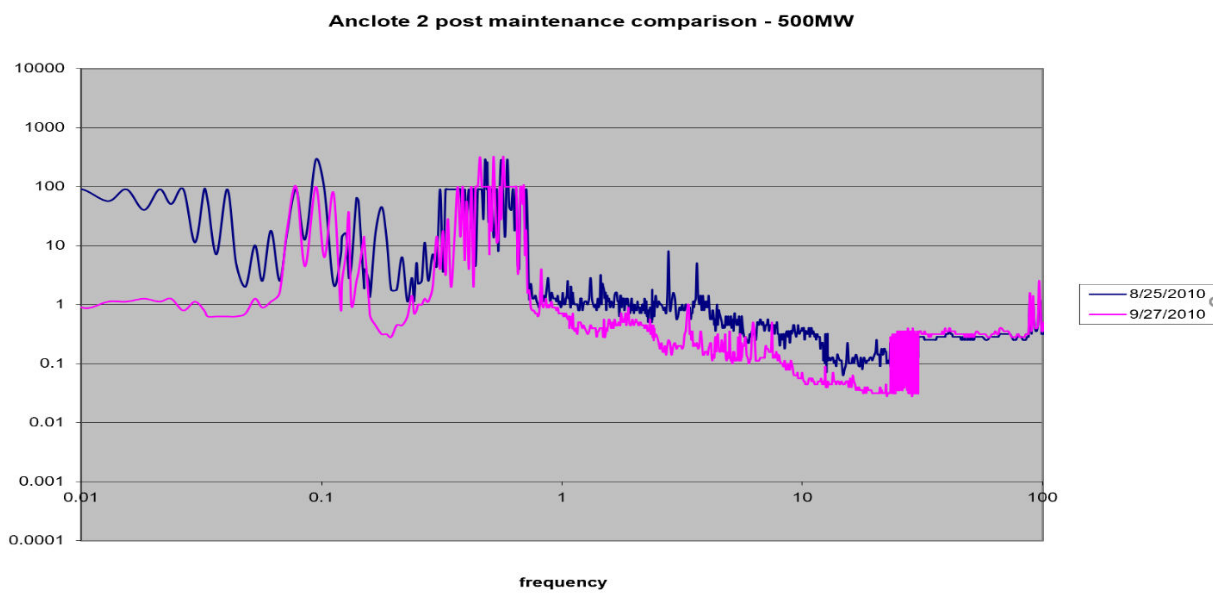
7.5. Comparing Pre- and Post-Maintenance Signals

One of the strengths of EMI Monitoring is the ability to trend the data over time. The signal strength usually increases long before the defect causes the plant to trip. However, this is not always the case, especially if the defect deteriorates rapidly or is caused by some rapid phenomena such as water or rain intrusion.

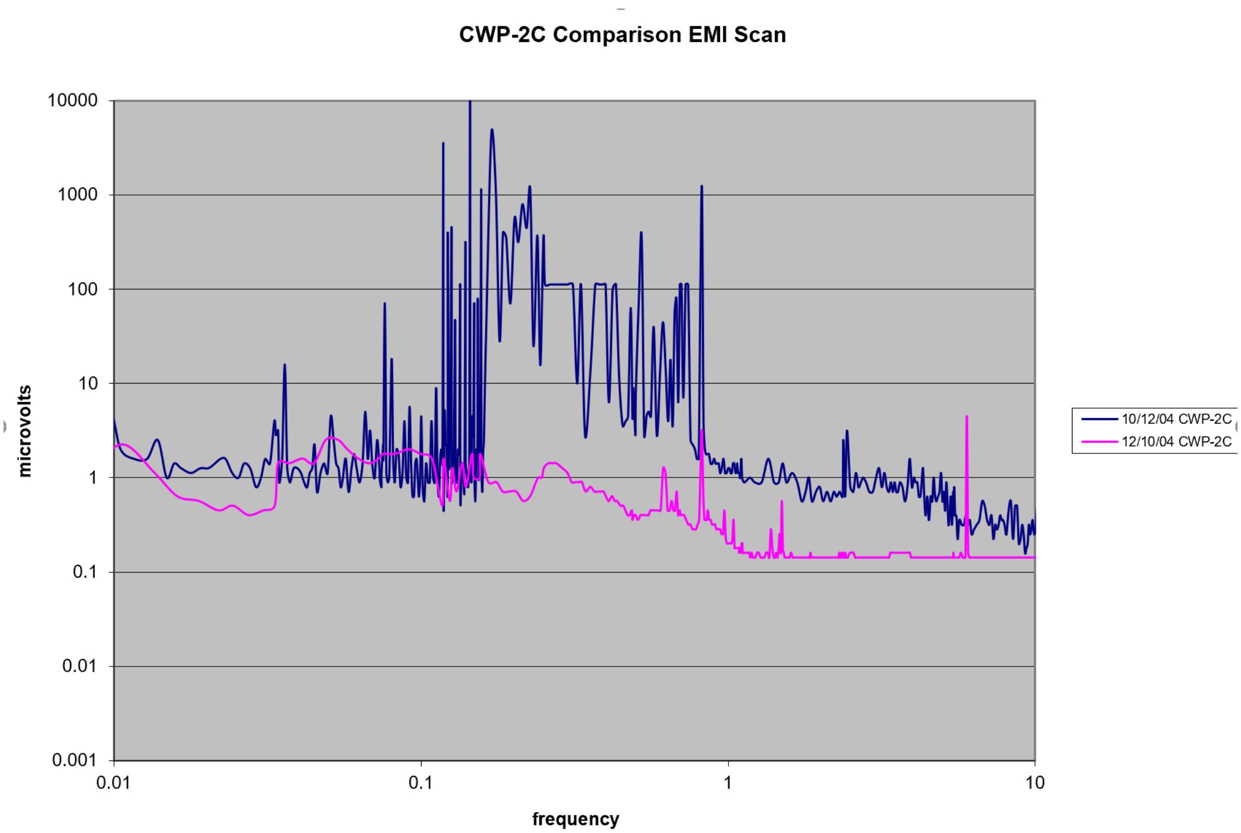
Comparison of the spectrum over time or trending the Power Spectrum values over time usually gives adequate time to develop an inspection and repair plan.

It is also good to do before and after maintenance comparisons.

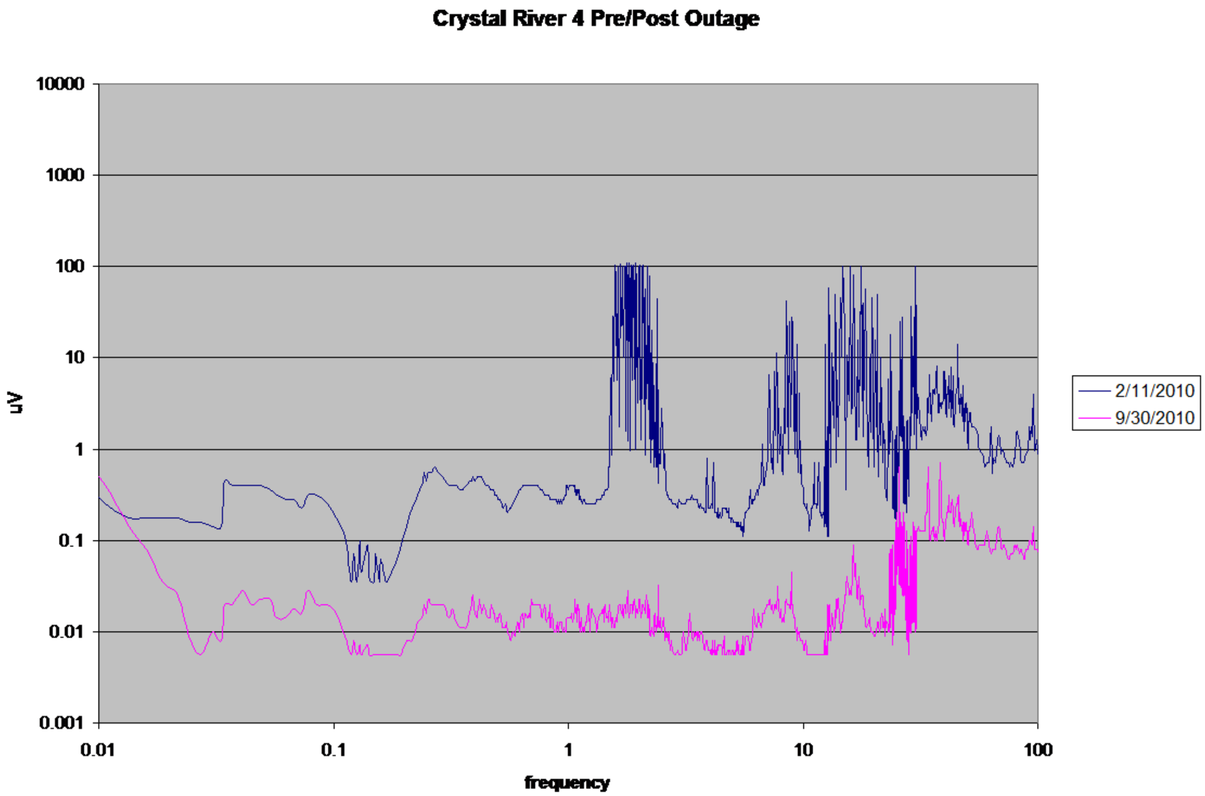
Example 1: The demodulated waveforms in the lower frequency band showed that the excitation system might have a loose connection. Although these values were still low, the unit had a Not in Demand period, and the new air-cooled power rectifiers were examined. Loose hardware was found on the disconnect switch associated with rectifiers. The snapshot below shows the before and after maintenance scans.



Example 2: When the motor was sent out for cleaning, it was found to have salt contamination. The snapshot below shows the before and after maintenance scans.



Example 3: Four major water clip leaks were found and repaired. The unit had a wet bar that was dried after the repairs were completed.



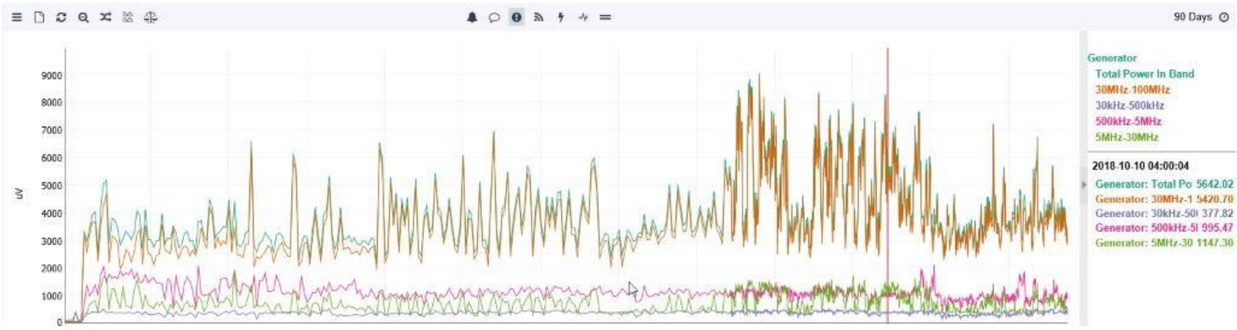
7.6. Comparing Trends

InsightCM has the capability of trending features extracted from the EMI overall scan.

For Generators, the trends for the Power Spectrum values of the overall scan and four sub-bands are used.

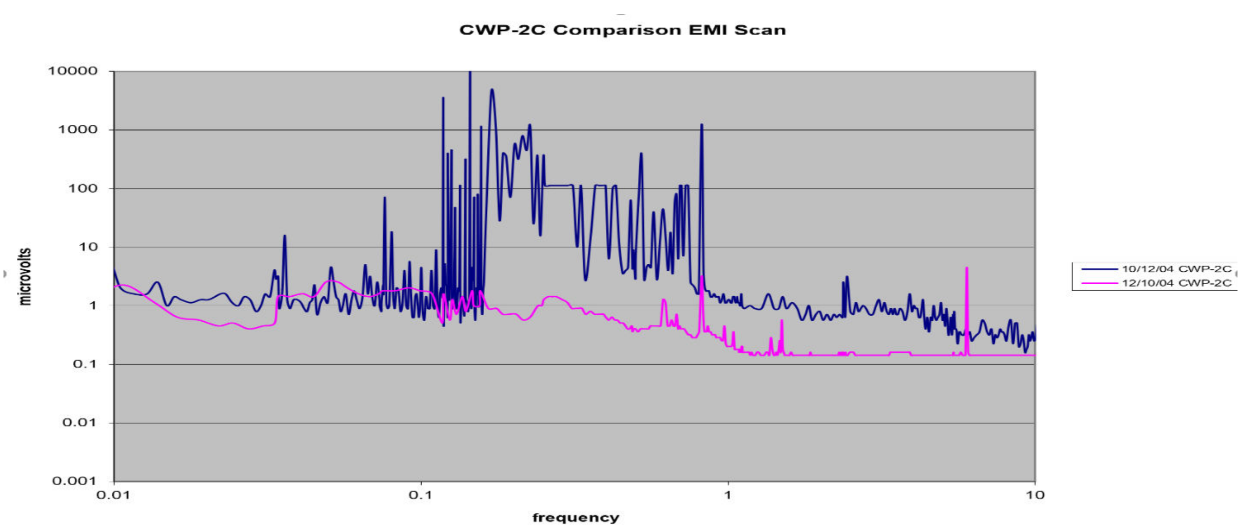
- Total power (30 kHz – 100 MHz): Overall power of the total spectrum, the band that the levels of concern usually bounce against.
- Low-frequency (30 kHz – 500 kHz): Anomalies are usually found in the generator's exciter area, such as voltage regulator diodes, static exciter, brushless exciter, power rectifiers, etc.
- Low mid-frequency (500 kHz – 5 MHz): Anomalies are usually found in the generator's core/slot area, although sometimes the upper frequency bands can also be affected by internal generator defects.
- Upper mid- frequency (5 MHz – 30 MHz): Anomalies are usually found in the generator's end winding area, although it is sometimes difficult to distinguish issues between the two mid-frequency band areas.
- Upper frequency (30 MHz – 100 MHz): Anomalies are usually found in the Isolated Phase bus (Generator Output bus) area. There are many case studies to support this conclusion.

The sub-bands are compared to the total power band to help validate the defect regions of interest. In the snapshot below, the upper frequency band contributed the most to the total power in band values and the defects were found in the Isolated Phase Bus area.



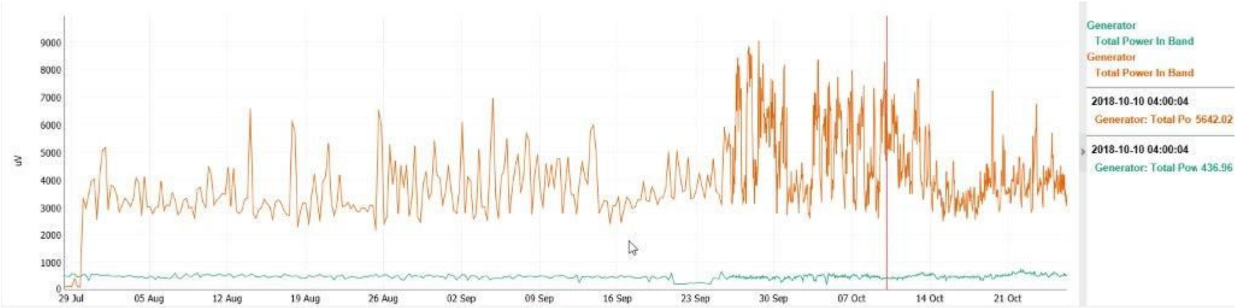
For Transformers, only the Power Spectrum for the total power in band (full scan) is used. There is not data or case studies to make any conclusions about defect location based upon frequency range yet. However, research is currently being performed to try developing a similar categorization as the generator area.

For Motors, only scans from 30 kHz to 30 MHz (sometimes only 10 MHz) are used. The upper frequencies have never detected any motor issues, which makes sense because motors do not have an Isolated Phase bus structure. For induction motors, the lower frequency band does not have much relevance either because they do not have an excitation system. The scans may be appropriate for Synchronous motors. Although there is not much data associated with synchronous motors, they are similar to generators, so those areas are still monitored. The scan below shows an induction motor with severely contaminated motor windings.

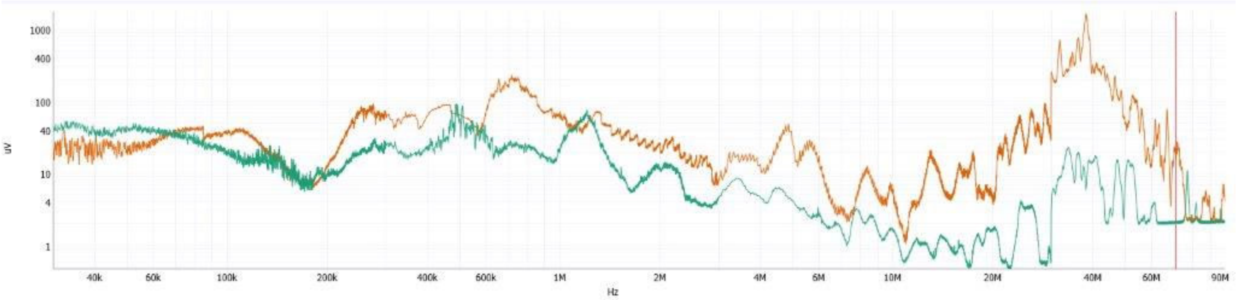


7.7. Comparing Sister Units

Comparing sister units can be useful in troubleshooting, but you must make sure that the comparisons are valid.



You can compare both the feature values and the spectrum signatures.



However, many other things can affect the signatures when comparing like machines.

- Regional and local area EMI conditions

  At each site the environment is different: different radio stations, different carrier signals, and different equipment emitting EMI noise that affects the background signatures. Research is currently being done to determine if the subtraction of an offline baseline would be appropriate to enhance the comparison between like units at different sites.

- Different CT locations on same piece of equipment

  While you hope that the installer would locate the EMI sensor (RFCT) in the same location for like units, sometimes they do not. In one case, four sister units at the same site had one or more CTs located differently, which affected the ability to compare the unit signatures.

  Also, no two "ground" locations are the same. Take care to inspect the ground connection pattern to locate the RFCTs in similar locations (upstream of a Tee vice downstream of a Tee, etc.).

- Different equipment manufacturing dates

  While OEMs tend to have the same base equipment in the same model numbers, sometimes minor changes are implemented as the model number manufacturing progresses. These changes in the structure can affect EMI signature patterns.

7.8. Using an EMI Sniffer and Acoustic Ear Scan

To help localize EMI sources, use an EMI sniffer or ultrasonic acoustic monitor.

An EMI sniffer is a broad band radio with two antenna and three different ranges. It has a gain dial that allows desensitization enough to aid location of the source. It is especially useful for bearing electrolysis issues, brush rigging issues, and shaft ground connection issues.

The Acoustic ear, used by PdM technicians for many years for bearing issues, can also be used for PD detection and for localizing the source of EMI signatures. It is especially useful for connection issues on the high side bushing of large GSU transformers.

7.9. Monitoring Partial Discharge with RTD Leads and Slot Couplers

For many years, Partial Discharge (PD) monitoring has been done with Resistive Temperature Detectors (RTDs) and slot couplers (small antenna embedded between the top and bottom windings in the core).

NOTE

RTD leads and slot coupler antennas are available for generators and some motors.

Slot coupler antennas can also be used for monitoring EMI signals. However, they are the least sensitive because they are shielded from many sources by the windings and the core. The antennas tend to be very localized in their monitoring capabilities. Many PD monitoring folks have gravitated toward the bus couplers for this reason and because a rewind is needed to install them. However, if there is no other good location, the antennas can be used.

7.10. Monitoring the Neutral Ground Transformer

The Neutral Ground Transformer (NGT) conductor can be monitored in two ways: around the conduit that houses the conductor before it enters the NGT cubicle or around the conductor itself within the NGT cubicle. If the conductor from the WYE connection on the generator's neutral side is either a bus arrangement until it gets inside the NGT cubicle or a bar conductor with no conduit protecting it, the CT can be placed around the conductor itself. However, the conductor needs to be properly insulated for the rating of the generator itself.

When the CT is around the conduit and the conductor, it can detect signals from the antenna effect of the windings and the shielding effect of the generator frame. This is one of the more sensitive points to detect as well as the preferred location. If the CT is only around the conductor itself, you only get the antenna effect of the windings, so it is slightly less sensitive. If many units are being monitored, it may be the appropriate location to be able to compare similar units.

Comparing units with the CT around the conduit to units with the CT around the conductor only can be done but the sensitivity of the location should be accounted for.

NOTE

A motor may not have any access to the neutral connection at all. So, in most cases this method is not used for motors.

Transformers have multiple winding arrangements available: delta-delta, delta-WYE, WYE-delta, two winding, three winding, etc.).

For the most part, the ground cable coming from one of the WYE terminations is used, which can lead to more noise from the system if the WYE is from the switchyard side of the unit, like most Generator Step-up Transformers (GSU). Comparison between a switchyard side WYE location with a plant side WYE location is be very difficult and not recommended.

If trying to compare like units care, be sure CT locations are the same.

7.11. Using Frame and Case Grounds for Troubleshooting

Frame and case grounds are used on many Combustion Turbine units, motors, and transformers. They use the shielding effects of the frames and the casing structure to absorb the EMSA signal and port it through the ground conductor that the RFCT is around.

Because the industry does not have a standard for grounding a unit, there are many different grounding configurations. Even sister units at the same facility can have different grounding configurations.

When comparing like units, make the location of the RFCT as similar as possible (same end (exciter vs. turbine), etc.). In some cases, multiple components (generator output bus and generator frame) are tied to the same ground conductor.

8. Effects of Different RFCT Locations

The transfer mechanism of the RF emitted from the "defect" to the EMI sensor location is a very complex mechanism to explain and to model. Very little research has been done in that area, and consequently, very little information has been documented about it. There is some research associated with the sensitivity and effect both defect location and RFCT location have on the signature associated with transformers. Most of the data gathered for the generator rules of thumb have been empirical in nature and reflective of information gathered in the field over many years of data gathering.

However, here are the basics:

1. Any time there is a flow of electrons, an electromagnetic process is developed (Maxwell's Equations).
2. At the point of generation, the process can be transmitted through the air in the form of radio frequency emissions or through conductors and emitted via an antenna effect.
3. At the point of reception (RFCT), the current transformer detects the current flow through a conductor attached to something that can have an antenna effect or a shielding effect. For example, generator windings have an antenna effect while the generator frame has a shielding effect.
4. Three basic locations of RFCTs have been used over the years for both EMI signature analysis and PD capture:
    - Neutral ground (NG) conductor
    - RTD leads and slot coupler antennas
    - Frame or casing grounds

9. Glossary

AWG	American Wire Gauge
Current Transformer (CT)	A device used to measure alternating current (AC).
Electromagnetic Interference (EMI) Analysis	The capture and analysis of both controlled and uncontrolled electromagnetic emissions absorbed by electrical utility equipment (generators,motors, transformers, switchgears, etc.) to determine if any uncontrolled sources of discharge are being emitted from within the electrical utility equipment.
Generator Step-Up Transformer (GSU)	A transformer that takes the voltage from the generator and brings it up to the proper transmission voltage.
Neutral Ground Transformer (NGT)	A device used to provide a path to ground in an effort to bring the system ground and system neutral to equal potentials.
Partial Discharge (PD)	According to IEC 60270 standard: *Partial discharge (PD) is a localized electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor.*
Resistance Temperature Detector (RTD)	A device that measures temperature by detecting the changes in resistance of an internal thermometer element.

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