Electrical Signature Analysis for Generators

Howard W Penrose, Ph.D., CMRP
MotorDoc LLC, Lombard, Illinois
hpenrose@motordoc.com

Introduction

Taking a comprehensive look at a generator in operation in order to evaluate its electrical and mechanical condition can be labor intensive. This includes challenges with ensuring loading is the same during each test or, in the case of variable speed generators, at the same speed. Electrical Signature Analysis (ESA) is not load or speed dependent.

Conditions in ESA are related at speed multiplied by various components and the amplitude of the peaks on FFT spectra in relation to the peak voltage and current line frequency. This peak changes depending on loading or output and the associated peaks remain relative to those peaks. There are few exceptions to this rule, but the condition still remains, even when the amplitude of the peaks change slightly.

Steps in Data Collection

Data collection is not limited to just collecting voltage and current, but the requirement to obtain information related to the machine being tested and what it drives, as well as any controls, such as Variable Frequency Drives (VFDs). This information includes:

- Complete machine nameplate especially the horsepower/kilowatt, base RPM, Voltage and Current;
- Rotor bars (or slots) and stator slots;
- Bearing information;
- Type of coupling;
- For gearboxes:
  - Gear teeth or ratios for each shaft; and,
  - Bearings and which shafts/locations.
- For direct drive pumps and vans – the number of blades;
- For belted applications:
  - Sheave sizes;
  - Belt information; and,
  - Center to center distance of the shafts.
- Control information; and,
- Any other component application attached electrically or mechanically to the system.

Why is this important? Because everything that will be detected will be related to the speed of the machine multiplied by the appropriate 'number.' For instance, stator related issues will be related to the number of stator slots times the RPM.

How the data is presented is up to the analyst. Some prefer to use of Hertz and some prefer RPM/CPM, either method is valid. The analyst can determine frequencies they were interested in before collecting data should be associated software not assist. In effect, the more information that is available, the better.

Data collection is performed by using voltage probes and current clamps. Alternately, a pre-installed plug may be connected to jack the instrument in for data collection. In each case, for full analysis, both voltage and current data must be collected. Safe methods of data collection must be followed as exposed energy is probable. The collection of data from CTs and PTs is acceptable, but it should be considered that it may not be as accurate in frequency and amplitude.

<u>Basic Data Analysis</u>

The first step in analysis of any machine is to review the voltage and current applied. The RMS and wave form of both can tell you a significant amount about how the equipment is operating. For instance, cyclical loads will definitely appear, problems with VFDs, and other issues will be quickly apparent. This data is viewed as voltage and current.

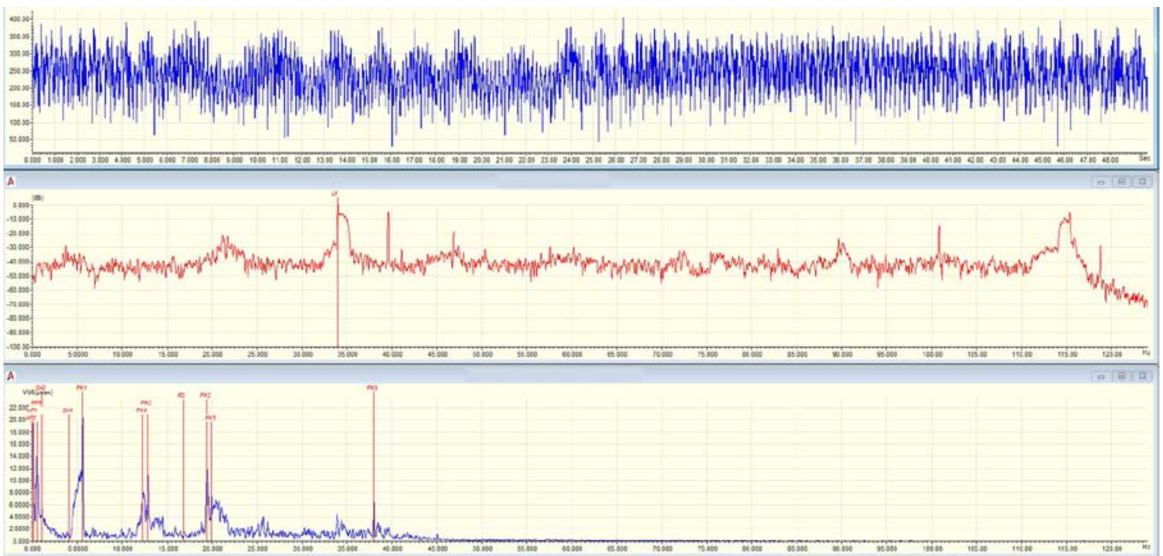

Figure 1: Low Frequency Data

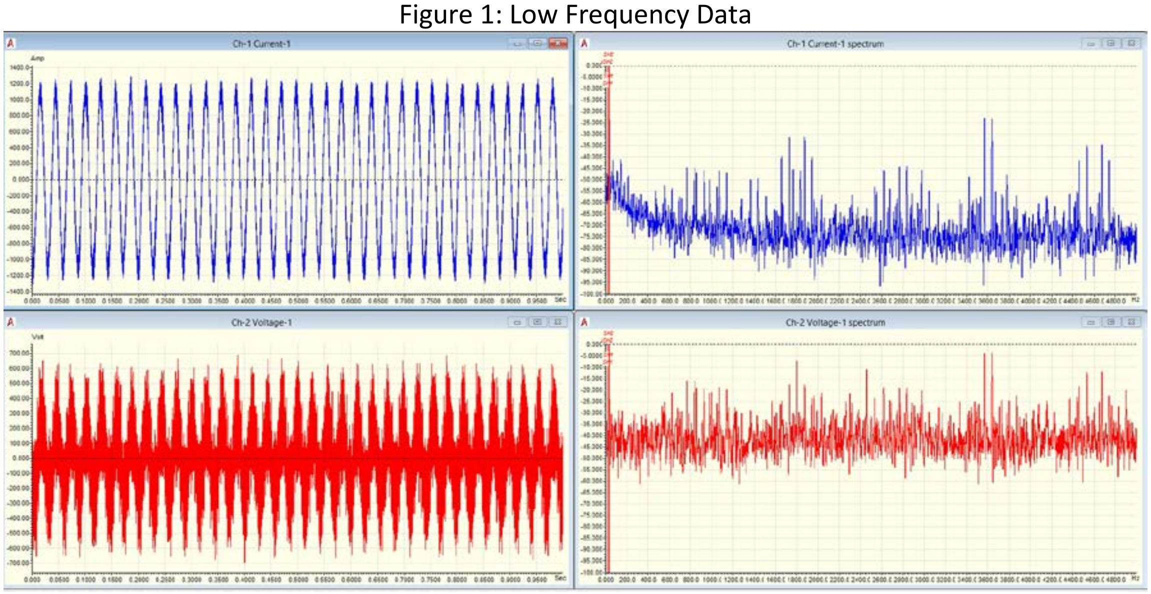

Figure 2: High Frequency Data

In the higher resolution spectra around the line frequency voltage and current will relate directly to conditions effecting the rotor and driven equipment. Some bearing, fan, impellor and gear issues show up in this range. Normally the data is viewed in dB measuring from the peak voltage and current (0 dB) to -100 dB. This provides a relationship in the relative 'force' associated with the frequency being evaluated. These peaks will mirror each other on either side of the line frequency.

Demodulated voltage and current are related directly to these mirrored peaks. This data is often presented in voltage and current frequencies without the actual line frequency peak. This information can assist in determining the RPM and which peaks to look for in the low frequency spectra, but is not normally used for determining alarm conditions.

Higher frequency data is used for looking at harmonic conditions and higher frequency faults, such as stator and eccentricity. At these higher frequencies points of analysis are formed as twice line frequency pairs.

Waterfall Analysis

Depending on the system used, a waterfall analysis of the data can be very important to see what is going on, especially when frequency peaks have broad bases. These can be indicators of looseness, changes in speed, or torsional issues. The waterfall analysis provides a 'z-axis' view such that the analyst can look over changes versus time. The front-on 'X-Y axis' view is a layered or average view over the time data was collected.

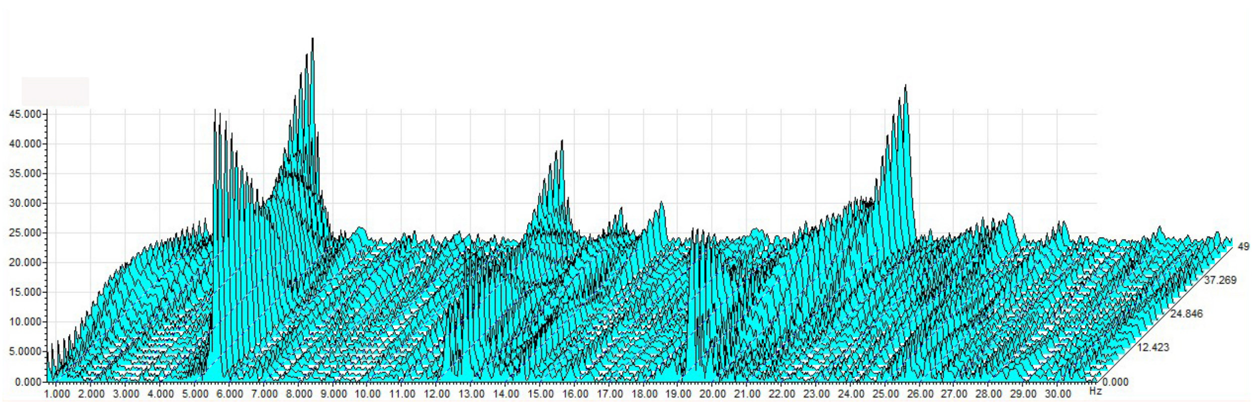

Figure 3: Waterfall Data

When cyclical issues exist, there will be a rise and fall across the Z-axis. Looseness will be indicated with a 'fluttering' across time. This data can be viewed in either the electrical value or dB.

Torsional Analysis

Torque ripple can be a valuable part of a machine analysis. While very difficult to detect with vibration analysis or requiring expensive strain gauges mounted on rotating components, the use of ESA lends itself to direct detection of torque ripple. The frequency, if significant, will also show as peaks in the low frequency and demod spectra. The torque ripple is used to detect the associated frequency and the dB down from the peak voltage or current determines the severity.

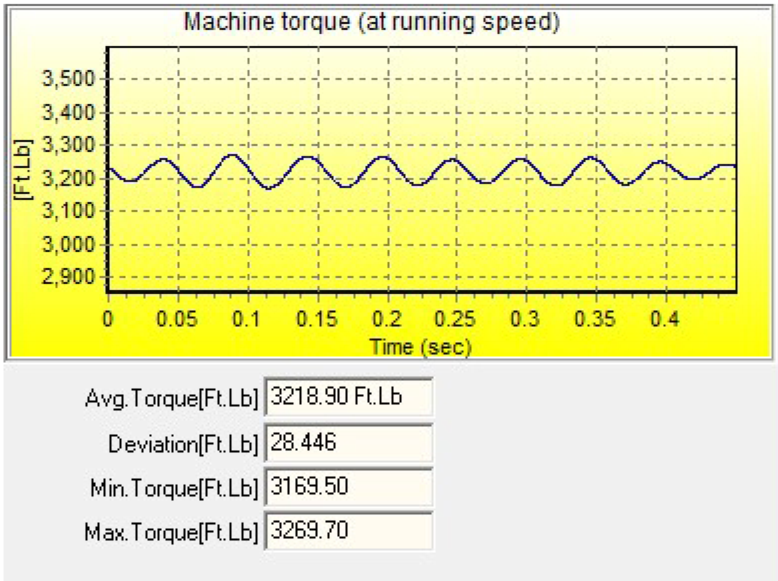

Figure 4: Torque Ripple Data

Torque ripple will provide data on the driven equipment, coupling or even the controls. For instance, a VFD will have some amplitude of ripple with greater severity resulting in coupling faults, shaft failure, or driven equipment failure.

Other Information

ESA provides additional information such as power factor, efficiency, phase balance, harmonics and other power quality data that can be valuable when performing analysis. No one set of data, alone, can view the complete system and must be viewed holistically.

Evaluating Generators

The full approach and settings to perform a generator analysis is proprietary. However, it is fairly straight-forward once viewed correctly. Just as with induction machines, the transducer for the generator is also the air gap. Small variations due to rotor vibration cause changes in the magnetic field which are detectable by ESA. The data rides on the voltage and current waveform which is an amplitude modulated signal.

Data on a generator must be taken from the stator before any transformers or other devices are in the circuit, as these will block the signature to be inspected. As all existing ESA devices, with the exception of the ALL-TEST Pro OL, have a 600 Vac limit, the ATPOL has a 750 Vac limit. Any system with voltage higher than the limit of the instrument must be evaluated using CTs and PTs.

It is important to remember that data taken with CTs and PTs, unless they are specifically selected for ESA testing, will cause some damping and possibly even a small phase shift requiring an experienced analyst to pay close attention. For proper analysis of a generator, it is critical that all three phases of data are taken in both voltage and current. When one conductor of many are used, or if CTs are used, a CT ratio must be entered or considered for evaluating proper loading.

Limitations

If bearing signatures are present, regardless of amplitude, they must be considered significant. It takes a significant amount of damage to the bearing races or balls to cause the rotor to vibrate enough to be detectable. ESA should be considered a secondary method for bearing fault detection.

Conclusion

While the details of generator analysis using ESA are proprietary, the capability of generator analysis is significant. In analysis of variable speed generators to synchronous generators, it requires significant data on the machines being tested. When prime mover data is also provided, then the entire power train can be analyzed. While bearings can be a challenge, they also seem detectable in later stages of failures. Overall, ESA can detect conditions through the entire generator power train from the prime mover to the generator load.

Biography

Howard W Penrose, Ph.D., CMRP is the President of MotorDoc LLC (formerly Success by Design), web-editor-in-chief of the IEEE Dielectrics and Electrical Insulation Society, and Secretary of the Society for Maintenance and Reliability Professionals. He is the author of the Foreword Book of the Year, "Electrical Motor Diagnostics: 2nd Edition." Contact him at hpenrose@motordoc.com for more information on ESA for generators.