



Winding Stress Detection with Electrical Signature Analysis

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Abstract: Low voltage and VFD driven electric motors will often have voltage stresses between conductors. In cases where this is severe, it is detectable as discharges in the airgap of the machine. In this paper we will review one of the applications associated with turn faults stresses in stator windings of induction. The discovery was originally made in laboratory testing in 1988 but was confirmed during special testing of electric machines that operate in a vacuum by MotorDoc LLC.

Introduction

The ability to detect winding faults was first confirmed by William Thompson in 1988¹ in a laboratory test. The associated theories have been re-published in a variety of IEEE and white papers since 2015, also performed in laboratory testing. In 2018 and 2019, MotorDoc LLC performed the testing in low voltage VFD applications in a vacuum, VFD applications and wind generator stators and rotors (Doubly-Fed Inverter Generators – DFIG). In this paper we will discuss the vacuum application with future white papers addressing other applications including wind generation.

The fault signatures associated with winding faults in stators have two distinct features: 1. An impedance unbalance that shows as current unbalance (direct short); and, 2. Harmonic related signatures that relate to (eq. 1) for winding stress and shorts.

$$f_{st} = f \left[\left(\frac{n}{p} \right) (1 - s) \pm k \right] \quad (\text{eq. 1})$$

Where:

f_{st} = Signature/Sidebands, Hz
 f = Supply frequency, Hz
 $n = 1, 2, 3, \dots$
 $k = 1, 3, 5, \dots$
 p = pole-pairs (ie: 2-pole = 1, 4-pole = 2)
 s = slip

At the time of this paper, faults and stresses are detected, but the time from fault detection to failure, using Electrical Signature Analysis (ESA) is still being evaluated. Presently, additional testing such as motor circuit analysis and offline partial discharge can be used following online detection in order to project severity of turn fault conditions.

¹ Thompson and Culbert, Current Signature Analysis for Condition Monitoring of Cage Induction Motors: Industrial Applications and Case Histories, IEEE, Wiley & Sons, Inc., 2017

VFD and Stator in a Vacuum

A special application with significant fast rise time pulses at 480 Vac, 500 kW, 4-pole machine design, and operating frequencies from 100 Hz to 300 Hz with a vacuum encapsulated winding and a vacuum pressure of 5 mmHg. Offline partial discharge was performed on a sample stator in a laboratory environment showing significant inter-turn winding stresses at 5 mmHg, which increased through to 1 mmHg.² At the application site surge comparison testing in vacuum and EMPATH™ ESA were utilized to evaluate operating systems as shown in Figure 1.



Figure 1: EMPATH System collecting data on 500 kW 480 Vac flywheel technology

The data using a sine wave filter is shown in figure 2 (related to expected winding stress) and a standard dV/dt filter in Figure 3.

² Penrose and Dreisilker, Evaluation of Offline Partial Discharge in Vacuum Environments, 2019 IEEE Electrical Insulation Conference, Calgary, AB, June 2019

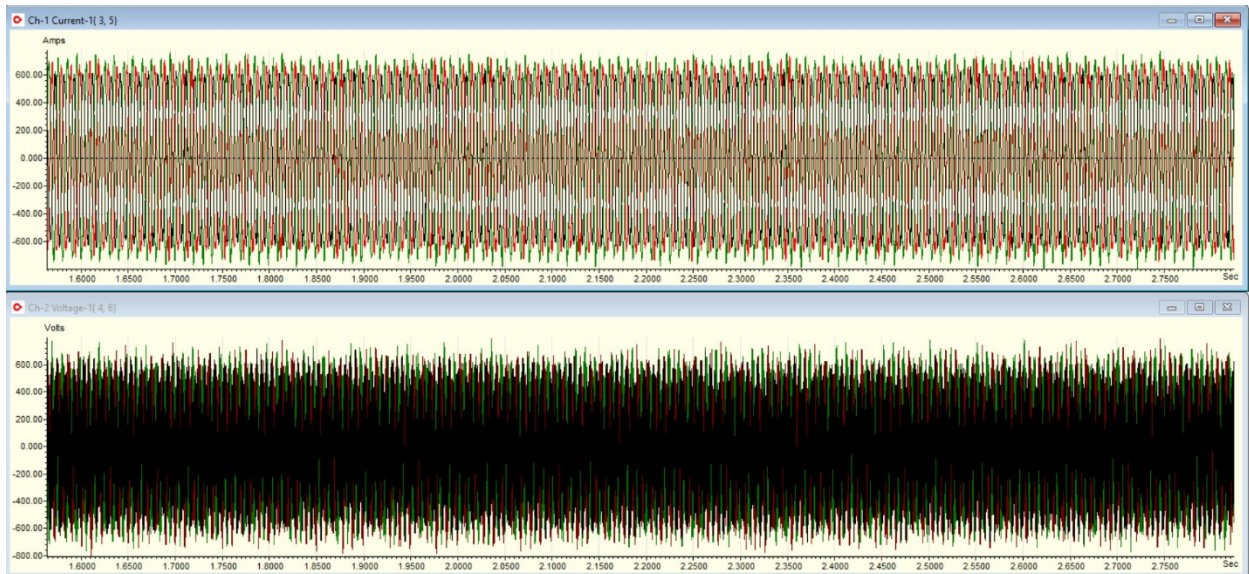


Figure 2: Voltage (bottom) and Current (top) waveforms are relatively balanced using a sine wave filter



Figure 3: FFT of Voltage (bottom) and Current (top) with most of the expected peaks associated with inter-turn stress being low

When evaluating the two signatures from the sine wave filter system as shown in Figures 2 and 3, the voltage and current waveforms were relatively balanced and winding stress related peaks are relatively low when comparing voltage peaks to current peaks. If most of the peaks are in current versus voltage, and the peaks are higher in current (lower value in -dB), then this would represent significant winding stress. In this case, surge comparison testing and offline partial discharge testing identified low turn to turn arcing at values just above the operating voltage were possible. With the sine wave filter application shown in Figures 2 and 3, there is some inter-turn stress which would require additional tuning of the filter. However, the values are low and mostly associated with power electronics.

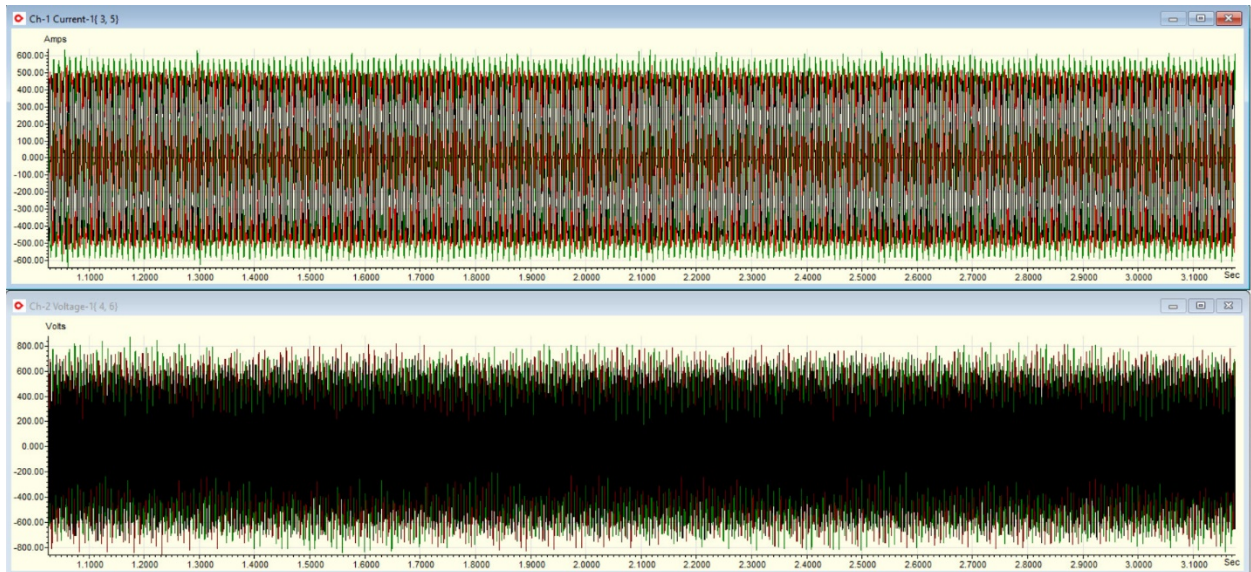


Figure 4: Slight current unbalance with dV/dt filter (top)

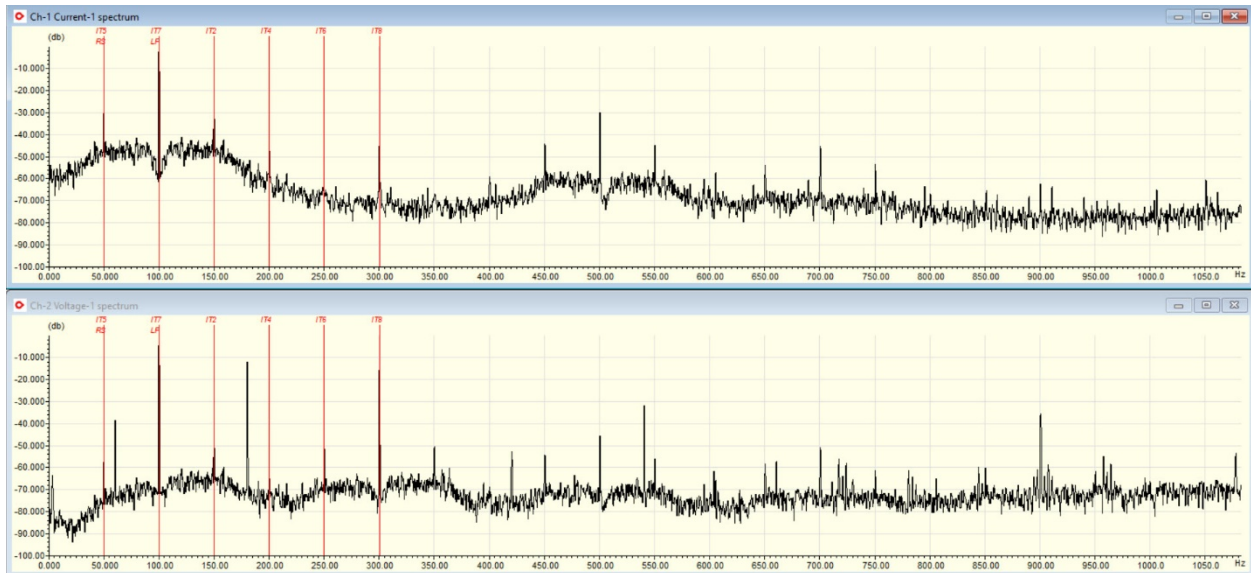


Figure 5: Key indicating peaks at 150 Hz and 300 Hz are higher in Current than Voltage

Figure 4 indicates a current unbalance on the VFD application. The winding design is balanced, so the unbalanced current would be primarily related to either drive, connection or winding issues. In Figure 5, the peaks at 150 Hz and 300 Hz are higher in current than voltage indicating winding stress. In this application, the original machines failed turn to turn in less than 40 hours of operation. By identifying the winding stress issue and its source, an improvement to potential insulation life can be accomplished, including verification of the drive filter and setting impacts on the winding.



Conclusion

Experiments associated with stators in vacuum environments provided the ability for MotorDoc® LLC to identify the ability for ESA using EMPATH™ technology to confirm stresses in stator windings. This confirmation of work performed in laboratories in 1988 and 2015, as well as MotorDoc and Dreisilker research in 2018 and 2019, has been applied to other applications including VFDs in atmosphere and wind generation (stators and rotors) with success (future white papers).

In this paper we evaluated the built-in EMPATH analysis system which includes the (eq. 1) and current unbalance analysis on machines in a special application. In addition to the detection of winding stress conditions, the measurements were found to be useful for evaluating the stresses of different control configurations. At this time, MotorDoc is performing a study using previously collected data with known machine conditions to determine usefulness in normal atmosphere.

Bio

Howard W Penrose, Ph.D., CMRP is the president of MotorDoc® LLC and the past chair of the Society for Maintenance and Reliability Professionals. He is the leading researcher in Electrical and Current Signature Analysis. For more information on EMPATH and Motor-System Diagnostic Services contact us at info@motordoc.com or 800 919-0156.