CASE STUDIES IN ONLINE AND OFFLINE MOTOR ANALYSIS

David L. McKinnon, PdMA Corporation, *Member, IEEE*

***Abstract*—In this paper we present three case studies using online and offline motor analysis to prevent catastrophic motor failures. The online and offline analysis in our case studies use a battery of standard electrical tests including Current Signature Analysis (CSA) and Demodulated Current Spectrum Analysis (DCSA).**

***Index Terms* — Current Signature Analysis (CSA), Demodulated Current Spectrum Analysis (DCSA), Rotor Influence Check (RIC), DC Motors, Armature, Field, Motor Testing, and Measurement.**

I. INTRODUCTION

Current Signature Analysis (CSA) has become the standard for detecting broken rotor bars by analyzing the sidebands around line frequency. Another useful tool is Demodulated Current Spectrum Analysis (DCSA) that enhances the ability to detect broken rotor bars especially on two pole motors. Our first case study will present a situation where CSA and DCSA were used to detect broken rotor bars on a two pole motor.

The Polarization Index (PI) is a standard measurement in the IEEE 43-2000 standard for insulation testing. PI is a ratio of the measured resistance at ten minutes divided by the resistance measurement at one minute. This ratio can be used for analyzing the general health of the insulation system of the motor. In our second case study, we present a modification to the standard polarization index test. By plotting the resistance measurement every five seconds, a graph called a Polarization Index Profile (PIP) is obtained. The resulting PIP profile can then be used for additional analysis of the insulation system that cannot be obtained from the standard polarization index.

Power Quality is a measure of the quality of the voltage and current supplying a motor or other load. By analyzing the harmonics, voltage and current unbalance, over or under voltage, and over current conditions a technician can determine what may be causing nuisance trips, voltage swells or sags, and other power system related situations as we will examine in our third case study.

II. CASE STUDY 1 – BROKEN ROTOR BARS

Motor Specifications: 3500 HP, 2 Pole, AC Induction, 4160 Volts, 3590 RPM.

Problem

During routine EMAX testing in June 2003, it was observed that the peak dB level of the pole pass sideband was 0.7419 dB, which exceeded the alarm set point of 0.3 dB (Figure 1). Rotor bar problems were suspected, however, when vibration analysis was performed the results indicated a healthy motor. Due to the conflicting indications between the EMAX and vibration tests, the decision was made to monitor the motor and trend the test results.

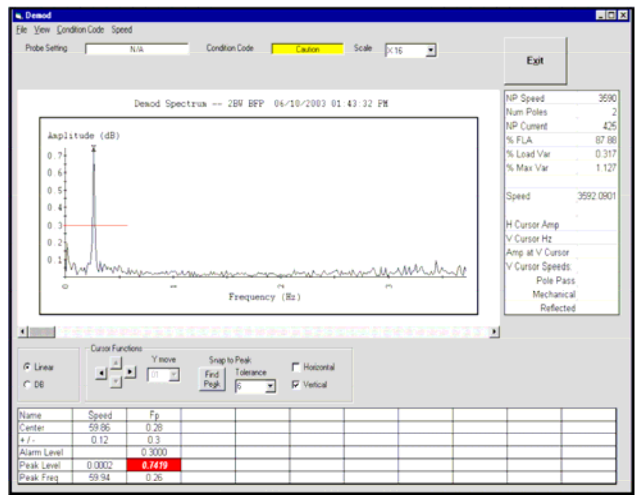


Figure 1 – Demodulated Current Spectrum showing the Pole Pass Sideband at 0.7419 dB.

Action Taken

The motor was retested periodically until 5/12/2004, at that time it was removed from service. The trended data indicated a 1420% increase in the peak level of the pole pass sideband from 0.1814 dB at a running speed of 3591 RPM on 8/15/2001 to 2.5851 dB at a running speed of 3592 RPM on 5/12/2004 (Figure 2). Trending the data from tests taken between 2001 and 2004 showed an exponential increase in the pole pass peak levels, which is typically indicative of at least one or more broken rotor bars. Additionally, there was a 275% increase in the load variation, from 0.855% in 2001 to 2.345% on 5/12/2004 (Figure 2). The load variation should be constant from test to test under normal operating and motor conditions. The Current Spectrum (Figure 3) of test data taken on 5/12/2004 showed an increase in sideband activity around the fundamental frequency, which also indicated broken rotor bars.

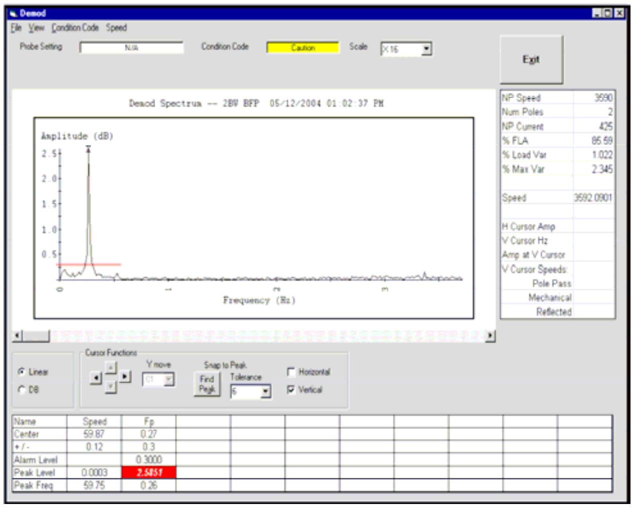


Figure 2 – Pole pass sideband of 2.5851 dB at a running speed of 3592 RPM.

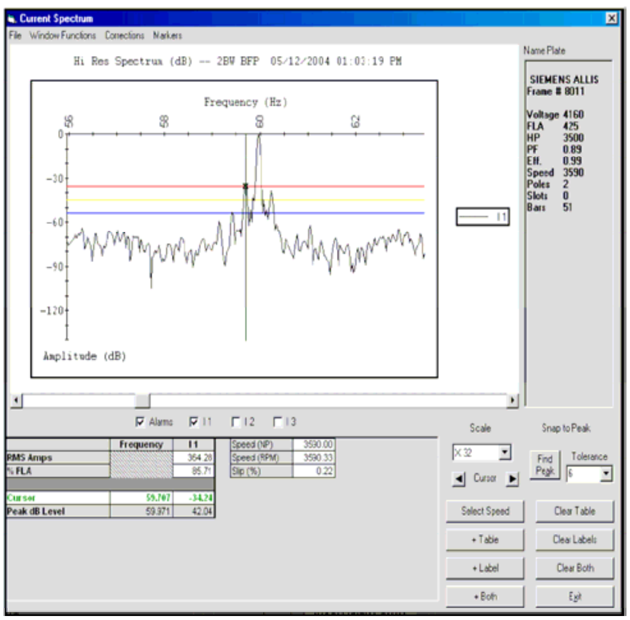


Figure 3 – Hi Resolution Current Signature Spectrum centered around line frequency.

All EMAX test results indicated broken rotor bars in the motor. The motor was pulled and a RIC test was performed, which also indicated a rotor anomaly (Figure 4). The motor was sent to the motor shop, where it was disassembled. A visual inspection found 22 of 51 rotor bars were broken or cracked (See Figure 5).

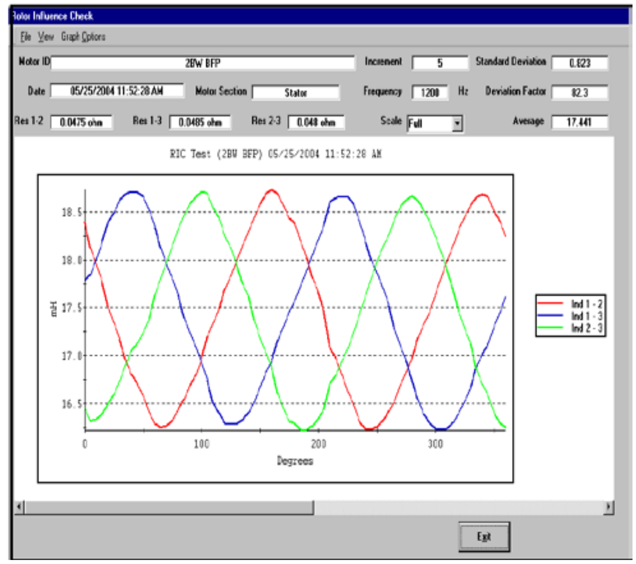


Figure 4 – Rotor Influence Check (RIC) test of the motor before disassembly. Notice the repeated variations in the inductance waveforms, which are indicative of broken rotor bars.

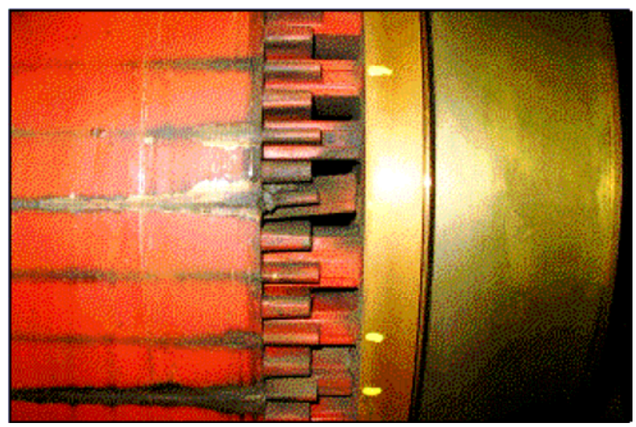


Figure 5 – Some of the broken rotor bars found using online and offline tests.

Root Cause

It was determined that bad braze joints between the bars and end rings from a rotor repair performed in 2001 caused the broken and cracked rotor bars.

Savings

Cost to repair the motor was $90,000 (repair $60,000 plus $30,000 planned plant downtime). Had the motor run to failure the cost would have been $370,000 ($170,000 cost of new motor plus $200,000 unplanned downtime). Total savings were $280,000.

III. CASE STUDY 2 – POLARIZATION INDEX PROFILE

In March 2005, a PIP test was performed on an Induced Draft (ID) fan motor resulting in the PIP shown in Figure 6. Notice the low PI value and fast initial rise-time of the resistance to a relatively low value overall. These are indicative of an insulation system containing a significant amount of moisture. IEEE 43-2000 recommends an insulation resistance of no less than 100 Megohms and a PI value of >2.0 for this motor.

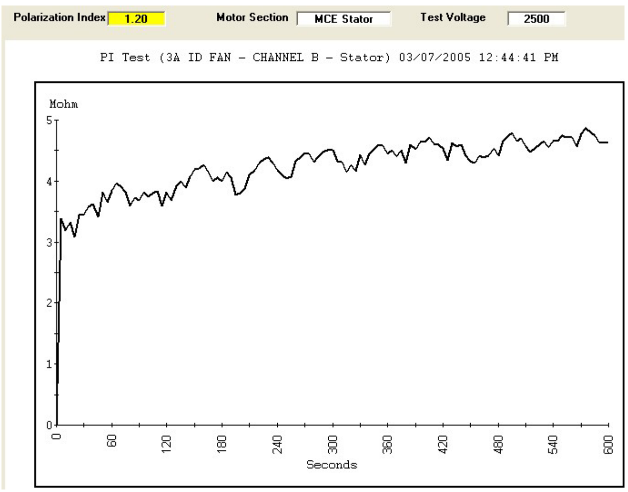


Figure 6 – Polarization Index Profile (PIP) of an insulation system containing a significant amount of moisture.

Figure 7 shows the moisture around the power cable entrance that caused the low overall PIP and low PI value.

Figure 7 – Condition that caused the unacceptable PIP.

The moisture was dried from all cables, components, etc., and another PIP performed a few days later. Figure 8 shows the resulting PIP after the dry-out. This PIP is indicative of a motor with a healthy insulation system.

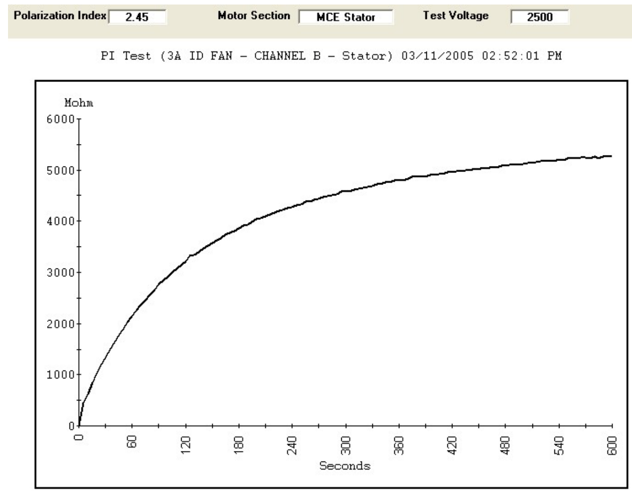


Figure 8 – Polarization Index Profile of a healthy insulation system.

When insulation systems become contaminated with debris such as dirt, carbon dust, etc., the PIP will have a significant amount of spiking in the profile throughout the test as shown in Figure 9.

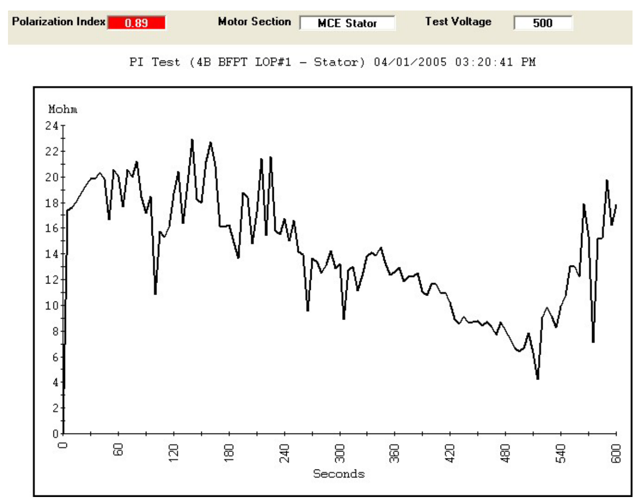


Figure 9 – PIP of a motor that has a contaminated insulation system.

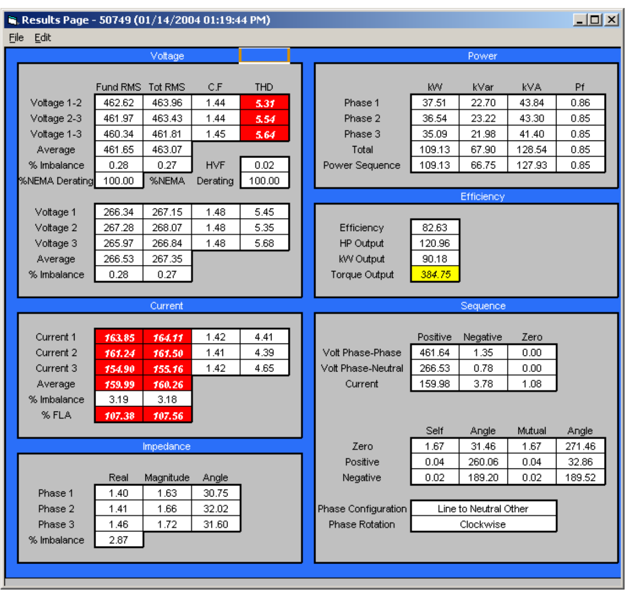
Figure 10 shows the contamination on the stator windings of the motor.

Figure 10 – Stator of the motor containing the contaminated insulation system.

IV. CASE STUDY 3 – POWER QUALITY

Problem

Initial test data on a winder motor indicated the voltage harmonics are greater than 5% and Full Load Amps (FLA) at 107% as seen in Figure 11.



Results Page - 50749 (01/14/2004 01:19:44 PM)

File Edit

Voltage

	Fund RMS	Tot RMS	C.F	THD
Voltage 1-2	462.62	463.96	1.44	5.31
Voltage 2-3	461.97	463.43	1.44	5.54
Voltage 1-3	460.34	461.81	1.45	5.64
Average	461.65	463.07		
% Imbalance	0.28	0.27	HVF	0.02
%NEMA Derating	100.00	%NEMA	Derating	100.00
Voltage 1	266.34	267.15	1.48	5.45
Voltage 2	267.28	268.07	1.48	5.35
Voltage 3	265.97	266.84	1.48	5.68
Average	266.53	267.35		
% Imbalance	0.28	0.27		

Current

Current 1	163.85	164.11	1.42	4.41
Current 2	161.24	161.50	1.41	4.39
Current 3	154.90	155.16	1.42	4.65
Average	159.99	160.26		
% Imbalance	3.19	3.18		
% FLA	107.38	107.56		

Impedance

	Real	Magnitude	Angle
Phase 1	1.40	1.63	30.75
Phase 2	1.41	1.66	32.02
Phase 3	1.46	1.72	31.60
% Imbalance	2.87		

Power

	kW	kVar	kVA	Pf
Phase 1	37.51	22.70	43.84	0.86
Phase 2	36.54	23.22	43.30	0.85
Phase 3	35.09	21.98	41.40	0.85
Total	109.13	67.90	128.54	0.85
Power Sequence	109.13	66.75	127.93	0.85

Efficiency

Efficiency	82.63
HP Output	120.96
kW Output	90.18
Torque Output	384.75

Sequence

	Positive	Negative	Zero
Volt Phase-Phase	461.64	1.35	0.00
Volt Phase-Neutral	266.53	0.78	0.00
Current	159.98	3.78	1.08

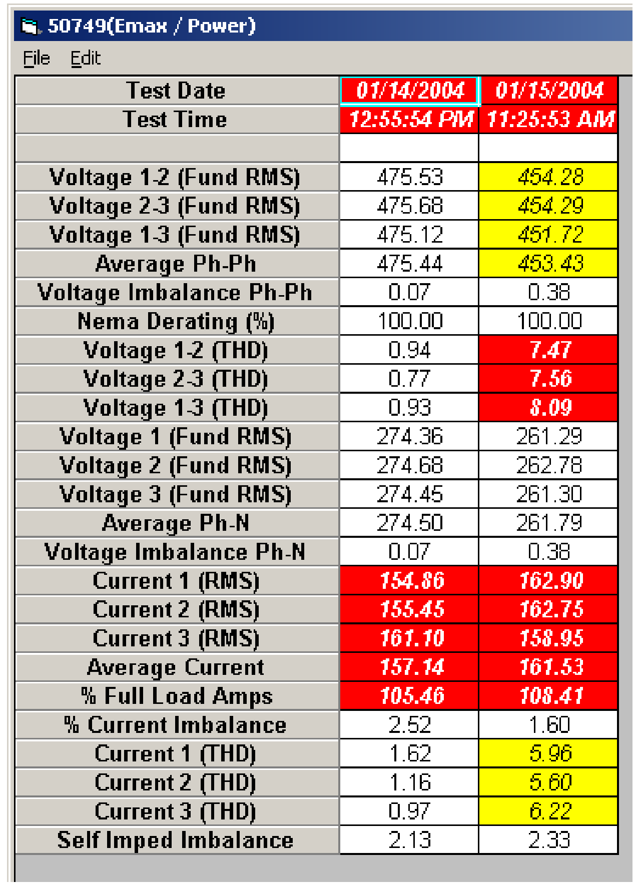
	Self	Angle	Mutual	Angle
Zero	1.67	31.46	1.67	271.46
Positive	0.04	260.06	0.04	32.86
Negative	0.02	189.20	0.02	189.52

Phase Configuration	Line to Neutral Other
Phase Rotation	Clockwise

Figure 11 – Test results page with the winder running.

Action Taken

The power distribution system to MCC M4-50 was researched to identify what might be causing the harmonics. Transformer #31 a 13.8KV to 480 Volt, 2500 KVA transformer is the feed for the MCC M4-50's 460 Volt service. There are eight motor line ups and five DC drives on the system. This is unique to this power distribution system. All of the other DC Drive power transformers supply power only to the DC drives and are not used in combination with AC motors. This suggested the power quality issues may be generated by the DC drives themselves.



50749(Emax / Power)

File Edit

Test Date	01/14/2004	01/15/2004
Test Time	12:55:54 PM	11:25:53 AM
Voltage 1-2 (Fund RMS)	475.53	454.28
Voltage 2-3 (Fund RMS)	475.68	454.29
Voltage 1-3 (Fund RMS)	475.12	451.72
Average Ph-Ph	475.44	453.43
Voltage Imbalance Ph-Ph	0.07	0.38
Nema Derating (%)	100.00	100.00
Voltage 1-2 (THD)	0.94	7.47
Voltage 2-3 (THD)	0.77	7.56
Voltage 1-3 (THD)	0.93	8.09
Voltage 1 (Fund RMS)	274.36	261.29
Voltage 2 (Fund RMS)	274.68	262.78
Voltage 3 (Fund RMS)	274.45	261.30
Average Ph-N	274.50	261.79
Voltage Imbalance Ph-N	0.07	0.38
Current 1 (RMS)	154.86	162.90
Current 2 (RMS)	155.45	162.75
Current 3 (RMS)	161.10	158.95
Average Current	157.14	161.53
% Full Load Amps	105.46	108.41
% Current Imbalance	2.52	1.60
Current 1 (THD)	1.62	5.96
Current 2 (THD)	1.16	5.60
Current 3 (THD)	0.97	6.22
Self Imped Imbalance	2.13	2.33

Figure 12 – Test results with the winder down (1/14/2004) and with it running (1/15/2004).

Further testing was performed to compare the test results when the winder was not running and when it was running. As shown in Figure 12, when the winder was not running (1/14/2004), current harmonics (THD) were <2%, voltage harmonics were <1%, full load current of 105% of rated current, and the system voltage was 475 volts. With the winder running (1/15/2004), current harmonics (THD) > 5%, voltage harmonics >7%, full load current of 108% of rated current, and a system voltage drop of 21 volts.

These power quality issues were reported to the appropriate department managers and then filed away. Earlier this year, the E/I Supervisor came to the E/I Reliability office to ask about the Power Quality report on MCC M4-50. A new microprocessor based dock lock system for their eight bay tractor trailer loading dock had been purchased and a new power feed for the controllers had been provided by the E/I supervisor's crew. The system had been installed by the vendor and was under warranty. The system worked fine most of the time, but at other times the locks would open and close on their own. The controller manufacturer's field service group including their design engineer had made several trips to the mill. They replaced several electronic cards and two complete controllers.

The E/I supervisor's crew got the power for the new feed from MCC M4-50. The E/I supervisor now remembered the report and asked if the Power Quality issues might still be on the supply from M4-50.

Figure13 – Line filters installed on a new controller.

After a review of the report, line filters were installed on all of the new controllers as shown in Figure 13. The problem for the dock lock controller disappeared.

IV. SUMMARY

Three case studies were presented; broken rotor bars, polarization index profile, and power quality. Broken rotor bars can be detected using a battery of online and offline testing. Online testing includes demodulated current and current signature analysis. Offline testing includes a rotor influence check, which graphically depicts broken rotor bars.

In our second case study, a modification to the standard polarization index test provided a very good benefit in analyzing the health of insulation systems.

In our last case study, power quality was used to analyze a power system and correct harmonic issues caused by the installation of motor drives.

David L. McKinnon received his BS in Electrical Engineering from New Mexico State University in 1991 and an MBA from the University Of Phoenix in 2002. He has worked in the field of magnetics for over 14 years. During the past four years, he has worked for PdMA Corporation as a Project Manager for hardware and product development of motor test equipment.