Low Voltage Vs High Voltage Testing

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Introduction

Since the mid-1980's, new technologies have been introduced that perform low voltage non-destructive evaluation of your electrical rotating machinery. Prior to this introduction, high voltage test method manufacturers would commonly caution users about the potential destructive tendencies of their technologies. After this period, the story changed as the low voltage technologies took market share. The result? Marketing became the driving force with engineering the victim.

It is the purpose of this paper to discuss some of the myth and misdirection presented, and to re-affirm the direction of the industry. For de-energized Motor Circuit Analysis (MCA), the capabilities include: Cable faults; Winding shorts; Insulation to ground faults; and, Rotor/Airgap issues.

"It is as possible to damage the insulation with the surge tester as it is with a DC or AC hipot, and caution should be exercised accordingly."[1]

Motor Circuit Analysis Technology

Motor Circuit Analysis (MCA) technologies are designed to evaluate the electrical health of an electric motor system. This normally includes, when testing from a motor control center, or disconnect, the cable between the point being tested, through the windings and including the rotor windings. This means that the MCA test is able to evaluate for cable faults, winding faults, insulation to ground faults, air gap problems and rotor bar problems.

Most recently, research has been underway to evaluate MCA trending methods to develop a means to estimate time to failure after a fault is detected. The research involves dozens of motors in actual application, as opposed to a laboratory environment, and has been successful in detecting and tracking faults months in advance. The length of time to failure has been well known for years:

"Studies have shown that many motor failures begin as turn-to-turn shorts within a single winding. These turn-to-turn shorts then create hot spots which in turn degenerate the insulation in adjacent turns until the entire winding fails. The mechanism of this type of failure may take three to six months, or more, depending upon the operating parameters of the motor."[2]

The MCA study incorporates this into three stages of winding failure:

> "The stages of a winding short are:
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> 1. Stage 1: The insulation between conductors is stressed, causing a change to the resistive and capacitive values of the insulation at the fault point. High temperatures and similar reactive faults result in carbonization of the insulation at that point. Carbonization may also occur due to tracking across the insulation system. MCA values of phase

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[1] Schump, David, President, Baker Instrument Company, "An Introduction to the Testing of Insulation Systems in Electrical Apparatus," 1986 International Coil Winding Association Refereed paper.

[2] Schump, David, President, Baker Instrument Company, "An Introduction to the Testing of Insulation Systems in Electrical Apparatus," 1986 International Coil Winding Association Refereed paper.

angle and I/F will be effected at this point.

2. Stage 2: The point of fault becomes more resistive. A mutual inductance occurs between the 'good' portion of the winding and the shorting turns. I^2R losses increase at the point of fault due to the increase in current within the shorting turns, increasing the temperature at that point and causing the insulation system to carbonize quickly. The motor may start tripping at this point, although it may be able to run after a short cooling period.
3. Stage 3: Insulation breaks down and the energy within the point of the short can cause an explosive rupture in the insulation system and vaporization of the windings. Inductance and sometimes resistance, may be able to detect the fault at this point."[3]

In an attempt to refute this work, information was presented that a winding fault would only last about 20 to 40 seconds from inception to completion of the failure mechanism. The 'experiment' used to come up with these numbers involved two electric motors, a 1 horsepower, 4-pole, 480 Volt motor and a 5 horsepower, 4-pole, 480 Volt motor. The 1 horsepower motor was started 40 times in one hour (125% of allowable starts) at loads between 100% and 140% of its rating. The 5 horsepower motor was first shorted using a surge comparison tester then subjected to 42 starts in one hour (125% of allowable starts) at 140% of load. These were presented within the un-refereed white paper as standard operating conditions.[4] It is well known that operating an electric motor well outside of its operating design will cause it to fail rapidly.

MCA technologies use electronic level evaluations of the changes to capacitance, resistances, impedances, reactance, and more to detect faults using energy levels well under the capabilities of the motor insulation to fail. It is, literally, non-destructive and similar to using an MRI or Ultrasound to detect the health of your tissue versus a high powered X-Ray to only see your bones while having potentially undesirable effects if used repeatedly.

Is High Voltage Testing Non-Destructive?

One of the primary issues has been the post 1986 claims that high voltage testing is now, miraculously, non-destructive. However, as late as 2001, the Electrical Apparatus Service Association (EASA) has noted the potential problems involved in high voltage testing:

"To avoid excessive stressing of the insulation, repeated application of the high-potential test voltage is not recommended. Machines to be tested must be clean and dry."[5]

"AC or DC high-potential current should be limited by impedance or instantaneous trips to limit damage when breakdown occurs."[6]

Evaluations used to present that high voltage surge or high potential testing is non-destructive have always been demonstrated on brand-new motors with clean, dry insulation systems. In the real world, this is most often not the case. Winding contamination, general insulation wear and age will all add up over time so that a high potential test will finish the equipment off. Once that occurs, the 'party line' is "It was going to fail anyways, we just detected the insulation problem." Unfortunately, this puts the end-user in a bad spot as the decision to operate the equipment until a suitable spare can be found has been taken away from you. A test instrument has now put you into breakdown

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[3] Penrose, Howard W, Ph.D., "Estimating Motor Life Using Motor Circuit Analysis Predictive Measurements," IEEE EIC Refereed paper, EIC/EMCW Conference, 2003.

[4] Wiedenbrug, E, et.al., "Impulse Testing as a Predictive Maintenance Tool," Baker Instrument Company commercial white paper (not refereed).

[5] ANSI/EASA AR100-2001, Recommended Practice for the Repair of Rotating Electrical Apparatus

[6] ANSI/EASA AR100-2001, Recommended Practice for the Repair of Rotating Electrical Apparatus

mode, urgently looking for a spare or losing capital.

"Repeated electrical strength testing [High potential testing and surge testing]: Repeated testing may impair the strength of the transformer or insulation system."[7]

"The test itself [surge testing] is destructive."[8]

Motor Circuit Analysis Standards

MCA technology is non-destructive and uses the following means to evaluate a winding:

- ✓ Resistance: Normally used to detect loose connections, broken wires and severe winding shorts.
- ✓ Impedance and Inductance: Used to detect phase unbalances, severe winding faults and rotor and air gap condition. Combined, the readings can detect winding contamination and overheated insulation systems. Impedance includes capacitance, inductance, phase angle, frequency and resistance. If the tests show a consistent pattern (ie: readings are low, medium, high, regardless of value) in both impedance and inductance, then any phase unbalance is related to rotor position or condition and not winding condition. If the pattern does not match, then winding contamination or overheating exists.
- ✓ Phase Angle: The timed measurement of voltage and current angle presented in degrees. Winding shorts, capacitance changes between conductors indicating insulation breakdown, and similar conditions will cause the phase angle balance to change between phases. The tolerance in an assembled motor is +/- 1 degree from the average reading.
- ✓ Current/Frequency Response: An example of a variable frequency test includes the current/frequency response test. Current is measured at one frequency (normally in the mill- or micro-amp range) then the frequency is doubled. The percentage reduction in current is measured. As insulation changes values of capacitance and resistance between conductors, minute changes in impedance occur that are amplified by the change in frequency. The tolerance in an assembled motor is +/- 2 degrees from the average percentage.
- ✓ Insulation Resistance: Evaluation of insulation resistance to ground.

These tests follow published IEEE and other recognized standards:

- ✓ IEEE Standard 43-2000 was reissued in May of 2000. It is the "Recommended Practice for Testing Insulation Resistance of Rotating Machinery" and covers the recommended limits for insulation testing. An interesting point to note is that the new issue downplays Polarization Index and Dielectric Absorption tests, noting that to perform such tests on insulation systems reading over 5,000 MegOhms is pointless (the wording is not far off). The standard was almost re-written in the form of a paper, stating that new insulation systems polarize much more quickly than pre-1970 insulation systems. As a result of these changes, there are new limits to insulation resistance tests:
    - o 1 MegOhm + 1 MegOhm/1000 Volt rating of equipment for insulation systems prior to 1970
    - o 5 MegOhms for random wound motors under 600 Volts
    - o 100 MegOhms for form wound motors, motors over 600 Volts and armatures

- ✓ IEEE Standard 56-1977, the "IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery." This standard provides guidelines for testing and inspection of insulation systems on motors. Insulation test methods follow the

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[7] IEEE Standard 388-1992, IEEE Standard for Transformers and Inductors in Electronic Power Conversion Equipment.

[8] IEEE Standard 389-1996, IEEE Recommended Practice for Testing Electronics Transformers and Inductors.

testing methods used by MCA devices for insulation to ground evaluation.

- ✓ IEEE Standard 118-1978 is the "IEEE Standard Test Code for Resistance Measurements."

- ✓ IEEE Standard 120-1989 is the IEEE Master Test Guide for Electrical Instruments in Power Circuits. This standard discusses and outlines a number of issues important to MCA, including: Section 5.6 – Bridge methods used for data collection; Section 7.4.2 – Alternating current sources used for evaluation; and, Section 8.1.5 – Data Analysis.

- ✓ IEEE Standard 388-1992 is the "IEEE Standard for Transformers and Inductors in Electronic Power Conversion Equipment." Outlined in Section 5 are the electrical tests: Section 5.2 – Inductance and Impedance unbalance testing. Describes how to test and evaluate; Section 5.4.2 was interesting and supported our statements from the past concerning repeated high voltage testing for preventive and predictive maintenance – "Repeated electrical strength testing [ie: Hi-Pot and Surge Testing]. Repeated testing may impair the strength of the transformer or insulation system."; and, Section 5.6.1 discusses the inductive bridge method of measurement for phase balance. The presentation of Standard 388 allows itself to cover other equipment including electric motors and coils.

- ✓ IEEE Standard 389-1996 is the "IEEE Recommended Practice for Testing Electronics Transformers and Inductors." This is one of the more important standards relating to MCA. Table 1 of the standard provides the recommended tests and specifications for transformer and inductor groups. It also covers impedance and reactance limits as well as conductor resistances. Then, discussed under General Test Methods – Surge Testing -"The test itself is destructive." Section 6 discusses simple DC resistance tests and limitations. Sections 8 through 11 cover the meat of MCA testing: Section 8.1.1 – calculating winding ratios with inductance. This section was interesting as we had issued a test procedure for transformer testing which required the user to short and ground all of the leads opposite of the side being tested. Standard 389 specifically outlines the same procedure; Section 8.1.2 – Transformation ratio with by impedance measurements; Section 8.3 – Impedance unbalance methods and limits; Section 8.4 – Phase balance tests and limits; Section 10 – Inductance measurements by impedance bridge method; and, the truly interesting find – Section 11.1 – The transformer frequency response, which outlines test methods that validate the Current /Frequency (I/F) test method.

Capability Comparison of MCA to Surge Testing

There are very distinct differences between MCA and surge testing technologies.

As advertised, the surge test is only capable of detecting turn or coil shorts a few turns into the phase windings of an electric motor. The deeper the fault, the more difficult to detect the fault, if at all. MCA can evaluate the condition of the winding completely, with no dampening of the signal used. This was again supported by the EPRI 2003 Advanced Electric Motor Predictive Maintenance Project conclusions on evaluating turn shorts.[9]

Additional capabilities of MCA include the ability to see problems within the rotor, and to compensate for the rotor without having to move the shaft (with some MCA technologies). This is important for testing electric motors in place, as well as the ability to test without having to disconnect from the control or from a variable frequency drive, with the exception of insulation to ground testing.

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[9] EPRI, Advanced Electric Motor Predictive Maintenance Project, EPRI, 2003.

"Surge comparison testing will not detect all the potential faults in a coil winding with multiple parallel conductors. For example, an open wire or poorly soldered connection will be difficult to detect..."[10] With high voltage equipment, the size of the tester increases with the size of the equipment to be tested with weights starting from about 30 pounds on up.

MCA technologies are not limited to testing only the electric motor circuit. They can be successfully applied to transformers, alternators, DC motors, servo equipment and any other equipment that uses coils as a means to operate. This can be done with a unit as small as a hand-held instrument which can be applied to equipment from fractional horsepower to hundreds of mega-watts.

Applications of MCA

Low voltage, non-destructive testing using MCA allows a great many applications:

- ✓ Commission new and repaired electric motors – 81% of motor repair shops modify windings during the repair process. Motor repair shops can use MCA to show that they do not change the parameters of the motors they repair as a sales and customer service tool; Manufacturers use MCA as a QA device for new electric motors; and, end users can be assured that their electric motors are electrically healthy.
- ✓ Quickly troubleshoot and find not only what is faulty, but what is not faulty. Why replace an electric motor when you do not have to?
- ✓ Allow for long term trending by reliability engineers.

Conclusions

As we leave the dark ages of motor testing, putting motor windings through the torture of high voltage surge testing and other potentially destructive test methods, new technologies offer faster and safer methods to evaluate electric motor health. It has been well known within industry, by the users of both older and modern technologies, that high voltage testing is potentially destructive. Prior to 1985, though, most of the high voltage test equipment was required to evaluate winding condition as newer, non-destructive technologies were not possible due to limitations in electronics technology. In the modern world, advanced MCA technology allows for an accurate view of the condition of your rotating machinery and other windings without the danger of having decisions taken from you by a test instrument.

About the Author

Dr. Penrose joined ALL-TEST Pro in 1999 following fifteen years in the electrical equipment repair, field service and research and development fields. Starting as an electric motor repair journeyman in the US Navy, Dr. Penrose lead and developed motor system maintenance and management programs within industry for service companies, the US Department of Energy, utilities, states, and many others. Dr. Penrose taught engineering at the University of Illinois at Chicago as well as serving as a Senior Research Engineer in the Energy Resources Center performing energy, reliability, waste stream and production industrial surveys. Dr Penrose has repaired, troubleshot, designed, installed or researched a great many technologies that have been, or will be, introduced into industry. He has coordinated US DOE and Utility projects including the industry-funded modifications to the US Department of Energy's MotorMaster Plus software in 2000 and the development of the Pacific Gas and Electric Motor System Performance Analysis Tool (PAT) project. Dr. Penrose is the Vice-Chair of the Connecticut Section IEEE (institute of electrical and electronics engineers), a past-Chair of the Chicago Section IEEE, Past Chair of the Chicago Section Chapters of the Dielectric and Electrical Insulation Society and Power

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[10] Schump, David, President, Baker Instrument Company, "An Introduction to the Testing of Insulation Systems in Electrical Apparatus," 1986 International Coil Winding Association Refereed paper.

Electronics Society of IEEE, is a member of the Vibration Institute, Electrical Manufacturing and Coil Winding Association, the International Maintenance Institute, NETA and MENSA. He has numerous articles, books and professional papers published in a number of industrial topics and is a US Department of Energy MotorMaster Certified Professional, as well as a trained vibration analyst, infrared analyst and motor circuit analyst.