Evaluating Motor Condition With Advanced Diagnostics

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Introduction

Up to this point, we have discussed the traditional and customary methods of testing AC induction motors while they are running or de-energized. In the next two articles, we will discuss three 'modern' methods of evaluating the condition of the insulation system including the two methods of Motor Circuit Analysis (MCA) and surge comparison testing. Each of these methodologies operates differently in how they evaluate the condition of the insulation to ground and the inter-turn insulation system of an electric machine.

As we progressed through the previous articles, you will have noticed that the primary part of the insulation analysis focused on the ground-wall insulation system. In the March, 2007, Uptime article, we discuss the operation of the insulation system, itself, and how high voltage ground-wall insulation test instruments work. However, the greatest number of electrical failures in a motor winding actually occur between conductors or coils with only 17% of insulation failures ending with an insulation to ground fault.

Because of the reactive nature of turn and coil insulation breakdown, DC resistance readings from phase to phase will not detect them at any stage up until conductors break or somehow come into direct contact with each other. This means that you must either detect insulation weakness or insulation degradation. The technologies we are going to discuss in these articles insulation weakness (surge comparison testing) and insulation degradation (MCA) by looking at the reactive components of the system. We will also explore the three major players in these technologies: ALL-TEST Pro, Baker Instruments and PdMA and how they use these technologies, in combination with some of the other testing we have discussed in this series, to provide motor diagnostics and condition-based solutions. In this article, we will discuss low voltage testing and in the next article we will discuss high voltage testing methods.

Motor Circuit Analysis

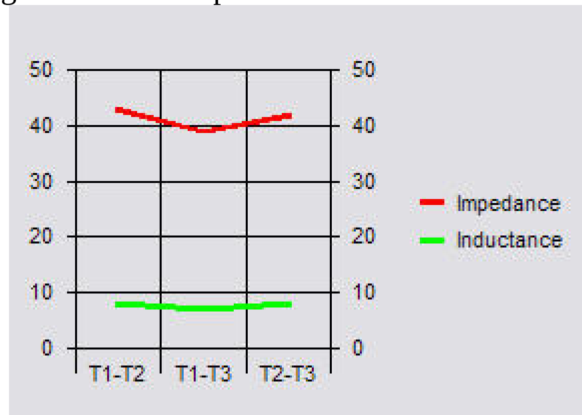
Modern MCA devices use low voltage sinusoidal outputs designed to excite the insulation system dipoles and surrounding magnetic steel dipoles as well as other DC insulation tests in order to obtain a more complete view of the condition of the insulation system. There are several key benefits to this approach: Size and voltage rating of the machine being tested do not matter; in many instances, specific pass/fail criteria can be applied for phase to phase comparisons; and, Degradation can be trended over time without any adverse effects on the existing condition.

Detection of Winding Contamination

There are several ways to detect winding contamination using MCA. These methods include: The traditional insulation resistance test; Polarization Index and Dielectric Absorption Tests; Capacitance; and, Impedance and inductance comparison.

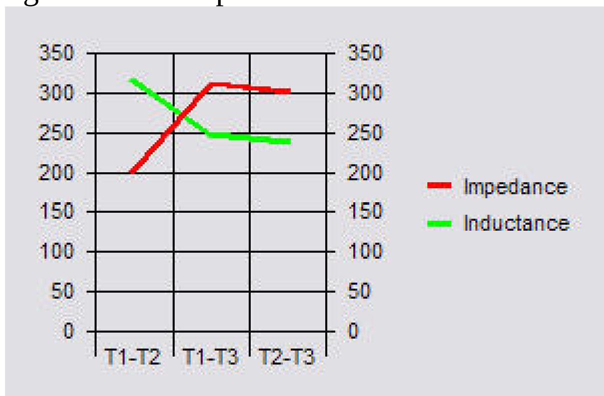
Due to the fact that one of the last measurements to change due to a winding fault is inductance (L), a test result of L can be used as a comparative baseline. This is important as the relative position of the rotor in an assembled machine will effect the reading due to mutual inductance. When considering the stator as the primary in a transformer and the rotor as the secondary, the number of turns, in relation to each other, will give slightly different readings. In each rotor position of an induction motor, the ratio of turns will be slightly different in each phase, causing a slightly different value of inductance.

Figure 1: Good Impedance and Inductance Pattern



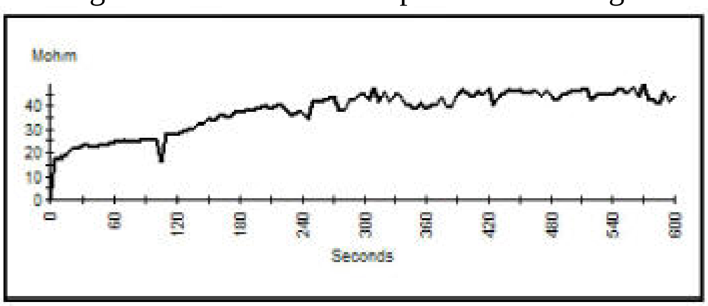
Winding contamination causes changes to the capacitance of the winding circuit due to the polarization of the contaminants (ie: moisture). When referencing the simple impedance formula, it identifies that a change in capacitance will have a negative impact on impedance. Also, with instruments that use very low voltages, the capacitive reactance has a more significant impact on the impedance as the capacitive value is more dominant. The result, using a relatively low frequency and sinusoidal output, is a collapse of impedance towards inductance in the phase which has the greatest impact from contamination or moisture. In cases of high humidity, the insulation has to have fissures or defects in order to cause the change. However, it is able to detect inter-turn, inter-coil and coil end contamination.

Figure 2: Bad Impedance and Inductance Pattern



Another impact will be on trended circuit capacitance. When compensating for the ambient humidity, on machines that have cooled to ambient temperature, and testing temperature, which also has a direct impact on capacitance-only measurements. The level of sensitivity of this type of measurement is a double-edged sword. While it has the sensitivity to ambient temperature and humidity changes from test to test, it can also detect changes very early, making it an excellent trendable test. Users with limited experience should consider additional testing prior to making a call based on this measurement. This measurement can also detect inter-turn, inter-coil and coil end contamination.

Figure 3: PI Curve and Capacitive Discharges



The Polarization Index (PI) and Dielectric Absorption (DA) will detect when contaminants build up between the conductors and ground. As mentioned in the February, 2007, edition of Uptime Magazine in “Keeping Up Resistance,” the ratio of the 10 minute to 1 minute insulation resistance reading for PI and the 1 minute to 30 second ratio for DA will detect most contamination issues when trended. However, for single PI or DA testing, a different approach can be taken. In this approach, the curve is monitored for the whole time. If the winding is clean and dry, the curve will be smooth. However, if there are sudden dips in the curve, it identifies capacitive discharges that indicate winding contamination.

Overloaded Windings

Overheated windings have a similar impact as winding contamination. The difference is that the insulation is thermally degrading causing increased resistance to dipolar action. In this case, the capacitance value will change causing a decrease in impedance in one or more phases.

In both winding contamination and overloaded winding conditions, the end result will be a winding short. Winding contamination can be corrected through a clean, dip and bake, if detected and corrected in its early stages. However, once changes occur that allow for the detection of a winding fault, the winding will have to be replaced. If the issue is an overloaded winding, the corrective action is a rewind.

Winding Shorts

One of the keys to proper MCA testing is that inductance is not used as a primary method of detecting developing shorts. Instead, two specific measurements are used in combination to determine the type and severity of the defect. These measurements are the circuit phase angle and the current/frequency response method.

When a defect occurs in the winding, it changes the effective capacitance of the complete circuit. The change in capacitance will directly effect how the low level current lags behind voltage with the usual result being an increase in capacitance and a reduction of the phase angle in the effected phase. Once the fault becomes more severe, it will begin to effect the surrounding phases. This normally occurs when the defect exists in one coil or between coils in the same phase. A very small change in capacitance within the circuit can be detected, allowing the detection of single turn faults and pinhole shorts when using very low frequencies.

A second method of fault detection uses a current ratio, similar in method to the frequency response test used for transformer testing. However, the low voltage current is measured, then the frequency is exactly doubled and a percentage reduction in the low-level current is produced. When the frequency is doubled, small changes to capacitance between conductors or phases are amplified, causing a change to the percentage reduction when compared between phases.

The combination of phase angle and current/frequency response allow for the detection of winding shorts and the type of short being detected in any size machine. Also, due to the use of low voltage and the result that only a small change to circuit capacitance is required to detect the faults, early winding defects can be detected quickly and trended to failure.

Another method of detecting late-stage winding faults is to perform a rotor inductance test. At the completion of the test, if one phase is significantly shifted from the other phases, it either indicates a significant phase unbalance or a winding short. If the motor had been previously tested, a shift would indicate a winding short.

Rotor Testing With MCA

MCA inductance readings can be used to determine if rotor bar faults exist in the electric motor. The MCA device excites the core steel based upon the amount of current available to the circuit and reacts across the airgap. The direct relationship to the ability to detect the rotor circuit across the airgap depends upon the distance across the airgap, the area of the steel magnetized and the length of the stator core. In longer cores, the effect will carry across the airgap and excite the rotor core and induce the instrument frequency into the rotor circuit. In large machines, the amount of energy available from an MCA device allows for the detection of rotor defects only above the area immediately surrounding each coil side.

This produces multiple effects:

1. The mutual inductance changes as the rotor position changes as a direct result of the change to the transformer ratio between the primary (stator) and secondary (rotor). A good rotor will show a repeating pattern, a bad rotor bar will change the transformer ratio and a defect will appear as a non-repeating pattern.
2. Fractures will be readily detected as the induced energy is relatively low and the oxides on the surface of the defect will block the low-level current with the same result as a bad rotor bar, as above. Whereas, in higher voltage rotor tests, the energy may be significant enough to pass through the defect.
3. In rare instances, the airgap may be too significant and very little to no variation of the mutual inductance occurs. In this case, larger defects, such as multiple fractures or a broken bar, will show as a variation in a straight line.
4. MCA technology has the ability to detect wound rotor, synchronous rotor field and other wound-rotor defects across the airgap. Because of the impedance ratio between the primary and secondary, rotor winding defects will show as a change to phase angle and current/frequency response and will vary based upon rotor position.

The ALL-TEST IV *PRO* 2000™ MCA Instrument

The MCA device manufacturer ALL-TEST PRO, LLC, provides lower cost, hand-held, MCA devices. This device uses two test leads, much like a multi-meter, and a 500 data-set memory that can be uploaded to proprietary software. The software system uses simple rules to evaluate the condition of the winding for the user and to trend data.

The types of data collected by the unit include:

- ☑ A DC milli-Ohm test that is compared for balance phase to phase. This allows for a percentage resistive unbalance that does not require temperature correction. It is basically used to detect gross loose connections, broken conductors or other resistive faults.
- ☑ Circuit impedance at frequency selections of 100, 200, 400 and 800 Hz that the instrument picks based upon proprietary logic.

- ☑ Circuit inductance.
- ☑ Phase angle readings at the same frequency as impedance.
- ☑ Current/Frequency readings with the base frequency the same as impedance.
- ☑ An insulation to ground test to 100 MegOhms at a selectable 500 or 1,000 Volts.

The primary purpose of the ALL-TEST IV PRO 2000 is to detect insulation defects indicating developing winding shorts, existing winding shorts, winding contamination and rotor faults. The resistance and insulation to ground tests are used to detect significant resistive and ground-wall insulation faults.

The PdMA MCE Instrument

The MCA device manufacturer PdMA provides a laptop and case unit device. This device is able to connect to all three phases and ground during the testing cycle and the data is entered directly into the included laptop. The software provides alarms and trending capabilities to detect faults.

The types of data collected by the unit include:

- ☑ A 4-wire Kelvin bridge DC resistance test. This value is temperature corrected for trending and phase to phase comparison.
- ☑ AC testing performed at 300 or 1200 Hz.
- ☑ Inductance testing for phase to phase inductance balance comparison.
- ☑ Circuit capacitance testing for trending.
- ☑ Insulation resistance testing with temperature correction and the ability to perform a PI and/or DA test. The PI and DA tests produce the curves in order to detect capacitive discharges.
- ☑ A higher voltage insulation test system is available as an option to allow for up to 5,000 Volt test values and higher PI and DA tests.

The primary purpose of the MCE is to detect insulation to ground defects, rotor faults and later stage winding shorts.

Conclusion

In this article we have discussed Motor Circuit Analysis technologies and how they are used to detect winding degradation and rotor condition with induction electric motors. The discussion outlined detection of winding contamination, overloaded windings, developing and shorted windings and rotor faults. The two primary MCA devices offered from ALL-TEST Pro, LLC and PdMA are similar but one focuses primarily on early winding short detection and the other on ground-wall insulation systems and rotor condition.

In our next article, we will discuss high voltage insulation testing followed by a discussion of the test limits for each of the technologies.

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