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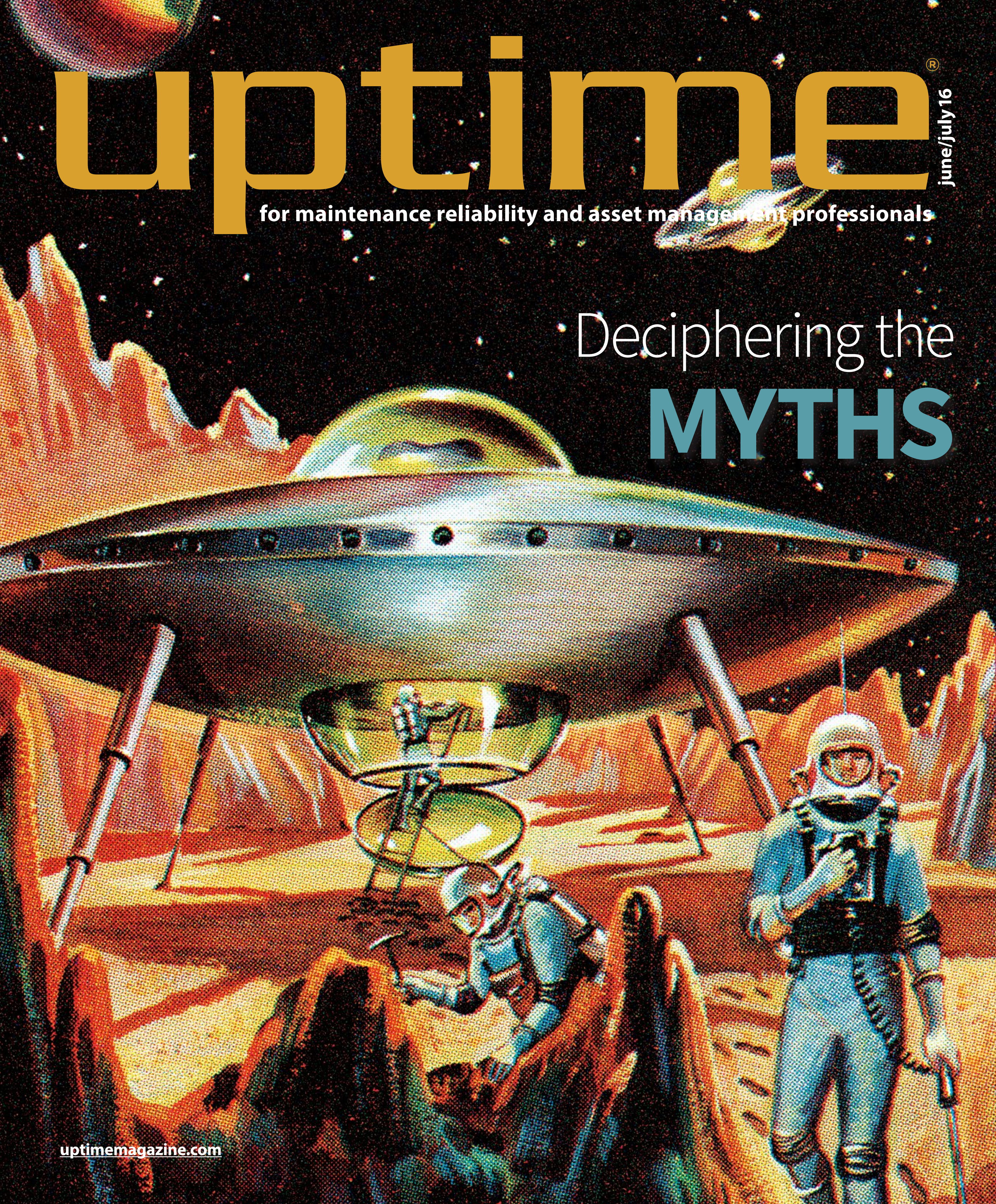

Deciphering the MYTHS

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Evaluation of Medium and High Voltage Machines with Motor Circuit ANALYSIS

by Howard W Penrose

Low and high voltage motor circuit analysis (MCA) methods have existed since the 1950s, with low voltage MCA technology becoming commercially viable in the 1980s. Since the mid-1980s, MCA technologies have become more prevalent as part of predictive maintenance and motor diagnostics programs across all industries. While the descriptions of these technologies are high and low voltage, they describe the types of outputs from the instruments, not the types of electric machines tested. This article explains the concurrent application of low and high voltage MCA on 4160 volt induction machines through 13.8 kV synchronous motors.

The technologies studied include:

- Amprobe 5 kV Insulation Resistance Tester (AMB55) for insulation resistance, polarization index, dielectric absorption, dielectric discharge, rotor test and capacitance to ground.
- ALL-TEST PRO 5™ for resistance, inductance, impedance, phase angle, current/frequency response, insulation resistance, capacitance to ground and dissipation factor. Other than resistance and insulation to ground testing, the circuit tests are frequency based.
- Electrom iTIG II D12 for resistance, inductance, impedance, phase angle, capacitance, Q-factor, rotor influence test, insulation resistance, polarization index, dielectric absorption, high potential test, surge comparison testing and PD surge.

The goal of the study was to determine how the test results and findings compared between technologies, as well as their accuracy. Each of the technologies studied is designed for field application, as well as in the original equipment manufacturer (OEM) and service industries. The low voltage MCA devices are relatively lightweight across all voltages, while the high voltage instruments increase in size and weight as the voltage and machines being tested increase.

4160 Volt Induction Motor

The types of motors tested in the study were open, drip proof (ODP), varied in size from 300 to 4500 horsepower, 900 to 1800 RPM form wound induction and synchronous machines. Each machine had power factor correction capacitors that need to be disconnected for either low or high voltage testing. While testing can be performed at these leads, since the tests would evaluate the cables and motors in parallel, the motor leads were disconnected in order to evaluate the motor insulation system only.

The first machine evaluated was an ODP 300 horsepower, 885 RPM, 4160 Vac, form wound electric motor that had some visual level of contamination. While no specific test results indicated the contamination was an issue, the unbalanced partial discharge (PD) levels may be an early indicator of insulation degradation.

The low voltage MCA results in Table 1 show a balanced winding with good insulation resistance results.

Table 2 and Figure 2 are the low voltage and high voltage MCA tests. The data was balanced with the exception of PD, which was measured in picocoulombs and unbalanced. Off-line PD tests involve trending and/or comparison of phases or like motors to determine if there are changes or unbalances. In this case, the average PD from other machines was under 20,000 pC and relatively balanced. Therefore, it was determined that a polarization index and insulation resistance profile (IRP) reading would be performed. The motor also passed a surge test, indicating that any issues are early in nature and should be trended, or the motor should be removed, cleaned and put through a short cycle vacuum pressure impregnation (VPI) to fill in any cracks or surface voids.

The IRP was performed at 2500 Vdc and resulted in only a few small capacitive discharges. Therefore, the final conclusion was to plan an overhaul within the next three to six months.

Figure 1: A 300 horsepower, 885 RPM, 4160 Vac, form wound motor

Table 1 – Low Voltage MCA Test Results (ATP5)

	T1-T2	T1-T3	T2-T3
Resistance (Ohms)	1.15	1.15	1.15
Impedance (Ohms)	43.7	43.8	43.7
Inductance (mH)	69.5	69.7	69.5
Phase Angle (degrees)	81.2	81.2	81.1
I/F (percent)	-46.8	-46.9	-46.8
Insulation Resistance (1000V)	>999 Megohms		
Capacitance	35.7 nF		
Dissipation Factor	1.13%		
Test Frequency	100 Hz		

Table 2 – High and Low Voltage MCA Tests (iTIG)

	T1-T2	T1-T3	T2-T3
Resistance (Ohms)	1.1530	1.1528	1.1526
Impedance (Ohms)	369.3	369.0	367.9
Inductance (mH)	58.47	58.43	58.26
Phase Angle (degrees)	84.2	84.3	84.3
Q Factor	9.85	9.93	9.89
Partial Discharge (pC)	24460	16306	16306
Insulation Resistance (1000V corrected to 40°C)	8,333 Megohms, 0.03 uAmps		
High Potential Test	10,300 V, 1.54 uAmps		
Capacitance	0.128 nF		
Capacitance D Factor	0.437		

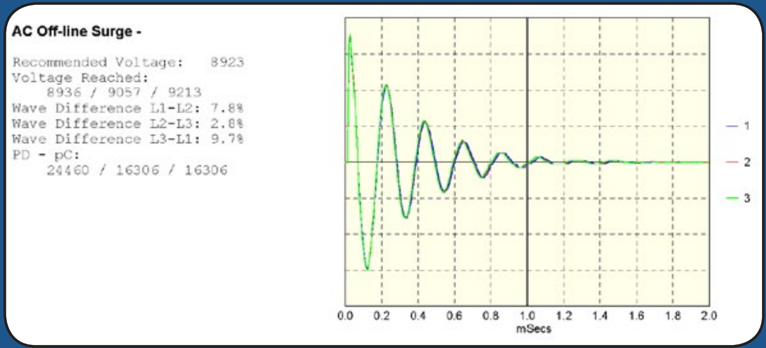

Figure 2: Surge comparison test and PD test of the 300 horsepower motor

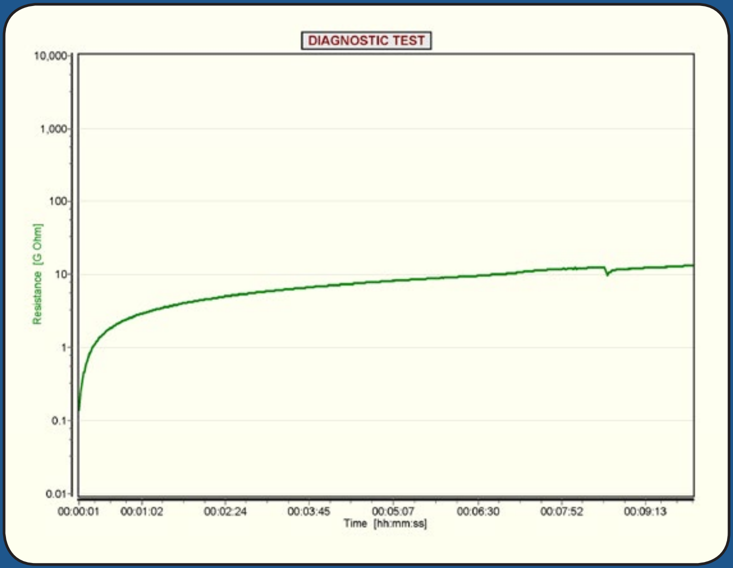

Figure 3: IRP with small discharges starting at about seven minutes, indicating an aging insulation system

Table 3 – High and Low Voltage MCA Tests Stator (iTIG)

	T1-T2	T1-T3	T2-T3
Resistance (Ohms)	0.7195	0.7186	0.7204
Impedance (Ohms)	519.2	437.7	437.7
Inductance (mH)	81.23	68.77	76.42
Phase Angle (degrees)	79.4	80.8	79.9
Q Factor	5.35	6.19	5.62
Partial Discharge (pC)	21,742	10,871	8153
Insulation Resistance (1000V corrected to 40°C)	25000 Megohms, 0.01 uAmps		
High Potential Test	0.62 uAmps at 11,000 V		
Capacitance	0.051		
Capacitance D Factor	-0.701		

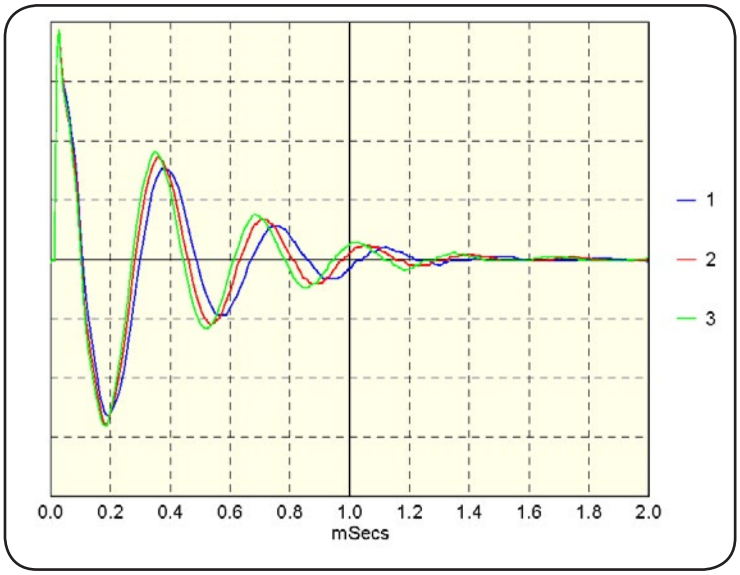

Figure 4: Surge test results show unbalance due to rotor position

13,800 Volt Synchronous Motor

A series of 4500 horsepower, 1800 RPM, 13.8 kV synchronous motors were evaluated as part of the study. It was determined that the rotor would be evaluated with an insulation resistance test prior to performing any other testing. As the values appeared to be relatively low, the team decided to use low voltage MCA and IRP to evaluate the rotor.

Since there were surge arresters in the machine connection boxes, they were disconnected. Additionally, the rotor leads were disconnected for testing both the stator and the rotor to reduce the influence the rotor had on the stator and to protect the rotor electronics. When possible, both the low and high voltage MCA devices are able to adjust for rotor position. In the case of these machines, such an effort was not time-effective.

The condition of the stator was known to have moisture and oil contamination and there was corona and partial discharge problems with the windings. The PD unbalance, shown in Table 3, would be expected from these conditions.

The stator had been tested four months prior to using low voltage MCA, allowing for a comparison between the previous and present data. Table 4

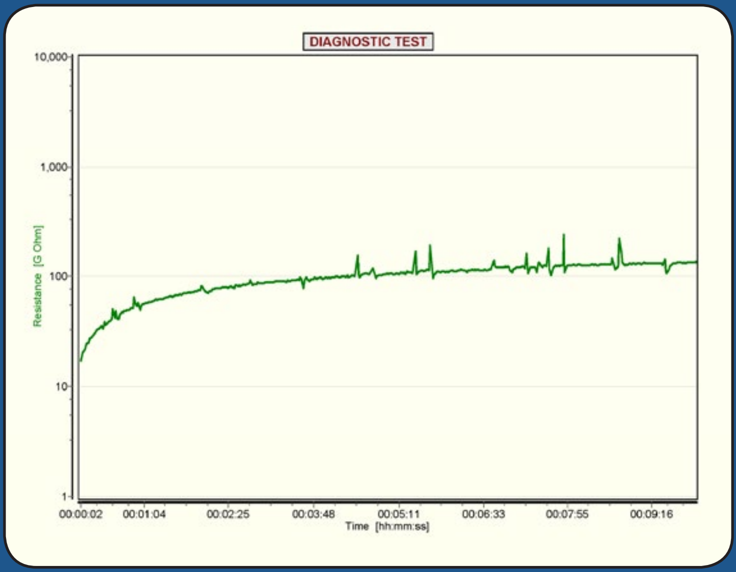

Figure 5: IRP of rotor at 500 Vdc indicating aged insulation system

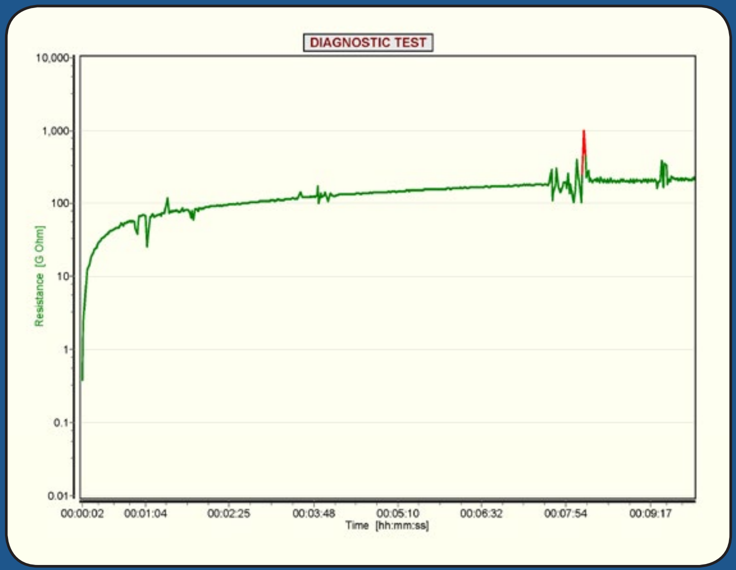

Figure 6: Rotor four months later after the motor was idle for several weeks

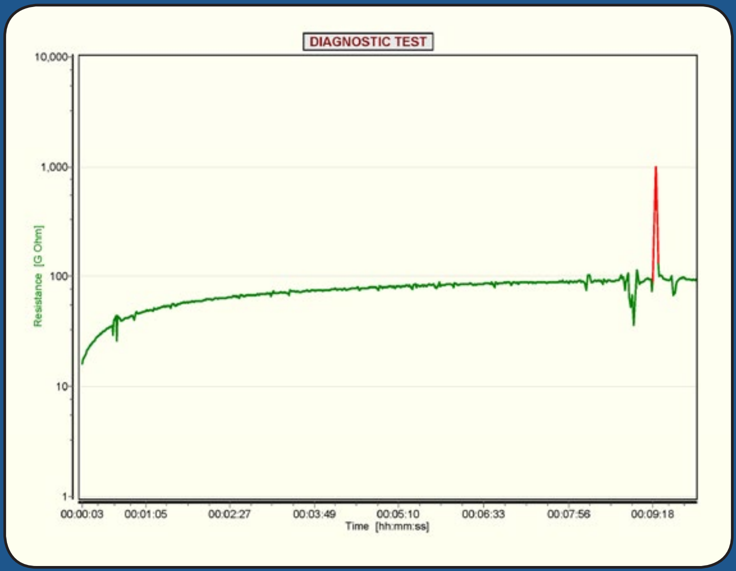

Figure 7: Rotor after attempting to start the machine

Table 4 – Low Voltage MCA Test Results on Stator 4 Months prior (ATP5)

	T1-T2	T1-T3	T2-T3
Resistance (Ohms)	0.726	0.727	0.724
Impedance (Ohms)	55.4	54.3	54.7
Inductance (mH)	88.2	86.4	87.1
Phase Angle (degrees)	78.7	76.8	76.6
I/F (percent)	-47.1	-46.2	-46.0
Insulation Resistance (1000V)	>999 Megohms		
Capacitance	170 nF		
Dissipation Factor	1.38%		
Test Frequency	100 Hz		

Table 5 – Low Voltage MCA Test Results on Rotor Comparison Between Present and 4 Months Prior (ATP5)

	Present	Prior	Difference
Resistance (Ohms)	0.171	0.153	0.018
Impedance (Ohms)	42.0	45.8	3.8
Inductance (mH)	33.4	72.9	39.5
Phase Angle (degrees)	70.9	63.4	7.5
I/F (percent)	-41.2	-39.1	2.1
Insulation Resistance (500V)	727 Mohms	>999 Mohms	Reduced
Capacitance	9.60 nF	9.80 nF	0.2
Dissipation Factor	1.12%	1.23%	0.11
Test Frequency	100 Hz	100 Hz	N/A

represents the data taken the first time and Table 5 is the second set of data used to determine how quickly there is degradation of the insulation system in order to make reliable time to failure estimations.

Previous data identified some issues with the condition of the rotor insulation. While there are conditions with the stator, in this case, the rotor is the weakest part of the chain. Additional work was performed to evaluate the condition of the rotor insulation.

The changes, in particular where inductance and impedance are concerned, identify the potential for a winding short in the rotor. Additional testing would be necessary to confirm the condition of the rotor.

The increase in discharges in Figures 5, 6 and 7 indicates the synchronous motor rotor is rapidly decaying. The reasons for degradation were found following the second round of testing, with those findings outside the scope of this article.

The challenge in this case is that the high voltage MCA device could potentially "finish off" the rotor, thus removing the decision to continue operating the machine from the user. In this case, the use of low voltage MCA and IRP was invaluable because the problem was found and the user had the option of continuing usage without the potential of finishing off the insulation system.

Conclusion

The use of low and high voltage MCA testing provided similar results. One of the primary differences was found with the synchronous motor rotor, where high voltage tests may have finished off the insulation system. Another concern was the need for a "booster" to meet the surge and high potential voltages necessary for the 13.8 kV system. The use of 11,000 volts versus the 18,500 volts that should have been used was based on previous predictive

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maintenance tests. In both cases, the high voltage MCA device required access to an outlet with a reasonable output voltage. The instrument used for this study has a built-in power conditioner that reduces the impact of power quality issues on the test results.

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