APPLICATION NOTE

AC-Synchronous Generator

Note 1301

Design Description

AC Generators come in two basic types – synchronous and non-synchronous. Synchronous generators lock in with the fundamental line frequency and rotate at a synchronous speed related to the number of poles similar to that of AC Synchronous motors. Synchronous generator stator windings are similar to a three-phase synchronous motor stator winding. Synchronous generator rotor fields may be either salient or non-salient pole. Salient Pole (also called spider or projected pole) means the rotor has distinct pole windings mounted on the rotor shaft using dovetail joints as seen in Figure 1. These pole windings are wound around field poles. Salient Pole rotors are most commonly used in slow speed applications and tend to be at least six poles. Salient pole rotors typically have damper windings to reduce rotor oscillations (caused by large flux changes between the individual poles) during operation.

Figure 1: Salient Pole Synchronous Rotor

Non-salient pole rotors (also called turbo-rotors or drum rotors) typically have fewer poles and are generally used in higher speed applications. These rotors are made from solid forged steel and have slots milled axially along the rotor for the field windings as seen in Figure 2. Damper windings are not used with solid rotors due to the more even distribution of flux.

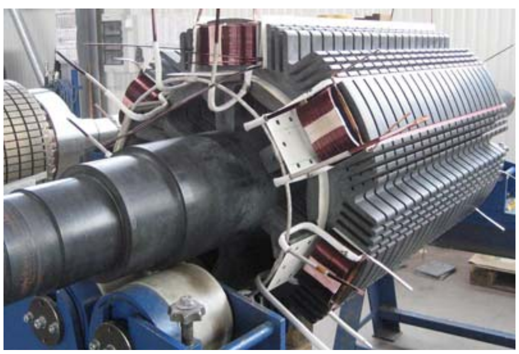

Figure 2: Turbo Synchronous Rotor

Test Description

The MCE® test equipment performs de-energized testing to identify faults or anomalies in the Power Circuit, and Insulation integrity of the Stator and Rotor. The MCE® tester provides the user with a variety of tests for this analysis; Stator and Rotor Standard, Polarization Index, Step Voltage tests. The MCE® test results provide a comprehensive picture of the electrical condition of the motor/generator. Some of the MCE® tests provide enough information to call a motor/generator good or bad, based on results from one test. Other MCE® tests provide data, which is best suited for trending and comparison. *Trending* means comparing sequential test results for the same motor/generator over time. *Comparison* means comparing individual test results on one motor with test results from an identical motor/generator operating in a similar environment.

The **AC Standard** test provides the following:

- Measured and temperature corrected resistance-to-ground in megohms (phase 1-to-ground)
- Capacitance-to-ground in pico-farads (phase 1-to-ground)
- DC resistance phase-to-phase in ohms (phase 1-2, 2-3, and 3-1, % resistance imbalance)
- Inductance in millihenries (phase 1-2, 2-3, and 3-1, average inductance, % inductance imbalance)

The resistance-to-ground (RTG) measurement indicates the cleanliness and health of the insulation system. Temperature correction is necessary since the resistance of insulation decreases significantly as its temperature increases. To compare readings obtained today with readings obtained six months from now, it is important to compare like results. The way to do that is to calculate the resistance to a given temperature, MCE® uses 40^{o} Celsius. The capacitance-to-ground (CTG) measurement is indicative of the cleanliness of the windings and cables. An increasing trend indicates that the motor/generator needs to be cleaned. Phase-to-phase resistance is the measured DC resistance between phases of the stator in an AC motor/generator and between polarities of the rotor in a synchronous generator. The phase-to-phase resistance values of the stator and rotor are used for trending and comparison with identical units. A change in these values can indicate high resistance connections, coil-to-coil, phase-to-phase, or turn-to-turn current leakage paths, open windings, etc. The % Resistance Imbalance is calculated from the three individual phase-to-phase resistance readings. Phase-to-phase inductance in AC stators indicates the condition of the stator winding with regard to phase-to-phase and coil-to-coil current leakage paths. In DC rotors inductance changes indicate current leakage paths in the windings. Both the stator and rotor inductance values can be used for trending and comparison with identical units. % Inductance Imbalance is calculated from the three phase-to-phase inductance readings.

The **Synchronous** test provides the following:

- Measured and temperature corrected resistance-to-ground in megohms (phase 1-to-ground)
- Capacitance-to-ground in pico-farads (phase 1-to-ground)
- Measured and temperature corrected DC field resistance in ohms
- Field Inductance in millihenries

The **Polarization Index (PI)** tests indicate the condition of the insulation system under test. The PI is calculated from the 10-minute megohm reading divided by the 1-minute value. IEEE 43-2000 recommends a minimum PI value of 1.5 for Class A insulation and 2.0 for B, F, & H insulation. The DA ratio is calculated from the 1-minute megohm reading divided by the 30-second value, a value of greater than 1.5 is recommended.

The **Step Voltage** or Leakage Current vs. Voltage testing of insulation systems is a process of applying a DC test voltage for discrete periods of time and recording the leakage current at scheduled times for a series of voltage steps up to a predetermined level of voltage. The level and steps of voltage applied and the amount of allowable leakage current are set prior to beginning the test. Maximum voltage applied during the test is normally well above the AC peak voltage. Moisture and dirt in the insulation are usually revealed at voltages far below those expected in service. The effects of aging or mechanical damage in fairly clean and dry insulation may not be revealed at such low voltage levels. When the voltage is increased in steps to produce electrical stresses, which approach or exceed those in service, local weak spots in the insulation will be observed in the insulation resistance. Advanced technology has basically eliminated the term “infinity” with respect to leakage-to-ground resistance. Advanced testers reach the teraohm range, 10^{12} or 10 million million ohms. The newer test capabilities and computerized data collection have given the technician the ability to evaluate new motor/generator insulation systems. These advancements in data collection provide legitimate, repeatable data that can be recorded and used for trend evaluation.

The EMAX test equipment performs energized testing to identify faults or anomalies in the Power Quality, Power Circuit, Stator Windings and Rotor Field Poles. The EMAX tester provides the user with a variety of tests for this analysis: Power test, Rotor Evaluation, and In-Rush/Start-Up. EMAX test results provide a comprehensive picture of the electrical condition of the motor/generator. Some of the EMAX tests provide enough information to call a motor/generator good or bad, based on results from one test. Other EMAX tests provide data, which is best suited for trending and comparison.

The **Power** test provides the following:

- Three phase voltage measurements and voltage imbalance
- Three phase current measurements and current imbalance

- Voltage and Current Total Harmonic Distortion (%THD)
- Impedance Imbalance
- Power Factor
- Real, Reactive, and Apparent power being delivered by the generator

The Power test indicates balance and amplitude of the voltage and current being delivered by the generator. Increases in voltage imbalance could be indicative of stator winding defects or voltage regulation issues. Voltage imbalance delivered by a generator will be distributed to each load connected to the generator output. NEMA MG-1 recommends a reduced HP rating for motors running on elevated voltage imbalances and does not suggest a motor be operated at 5% or greater voltage imbalance. The power test can also deliver the power quality (%THD) of the voltage and current signals being delivered by the generator. Power quality data should be compared to the IEEE 519 standard for acceptable values of distortion. NEMA MG-1 also recommends a horsepower de-rating for excessive voltage distortion as well. Power factor should be monitored for changes unrelated to load as an indication of possible field anomalies.

The **Rotor Evaluation** test provides the following:

- Current Spectral Plot
- Three phase current RMS measurements and current imbalance
- High resolution time domain plot of the three phase currents

The Rotor evaluation test can be used to monitor load fluctuations and provide high frequency spectral analysis. Increases in current fluctuations could be load driven, but could also be related to regulation.

The **In-Rush/Start-Up** test provides the following:

- Six channel voltage and current RMS envelope
- Six channel voltage and current time domain
- Peak detection

The In-Rush/Start-Up test is an ideal process analysis tool that can display either RMS or raw data. In RMS envelope mode it provides ideal trend information on load changes over time. In time domain mode each phase of current and voltage can be compared to identify voltage or current spikes, swells or sags.

Test Considerations

- In some generators, it may be difficult for the tester to resolve resistance readings due to the magnetics of the generator windings preventing the stabilization of the test signal. This instability is identified as large changes in resistance or resistive imbalance values in back to back tests. If you feel the resistance test is not stabilizing, contact PdMA® technical support for further clarification. The empirical data available for the development of this application note was acquired on generators up to 30MW in size with no issues in resistance stability. Special attention should be given to the resistance imbalance values when testing generators, but especially generators greater than 30MW.
- Generator windings have a very high voltage storage capacity and may require a significant grounding period to discharge the DC voltage applied during ground wall insulation testing. This is very noticeable following a Polarization Index test.
- Ensure the winding temperature is stabilized prior to taking measurements as changing temperatures will dramatically affect the winding resistance.
- If the neutral leads are brought out of the generator separately, make sure they are solidly connected together in the proper configuration (typically Wye). Ensure that the stator windings are isolated from

ground by disconnecting any neutral grounding systems (i.e., solid ground, grounding transformer, high resistance ground, etc.).

- When testing rotor fields ensure the rectifier banks and any associated control circuitry are disconnected from the field windings.
- Capacitance to ground (CTG) readings below the minimum measurable by the test equipment may indicate an invalid or improper ground distribution.
- Ensure any surge and/or power factor capacitors are removed from the circuit prior to performing a baseline test.

Data Analysis

Color coordinated default caution and alarm levels are established throughout the MCEGold® software to assist the analyst in assessing the health of the assets being tested. These alarm set points have been established through years of testing experience by PdMA® as well as existing industry standards such as IEEE and NEMA®. Some of the following analysis suggestions may not apply to every type of AC-Generator. Contact PdMA® Technical Support for more information.

Power Circuit

Inspect all the connections in the power circuit. Clean and re-torque as needed. Re-test to verify repair integrity. If the high resistance is internal to the generator, inform the repair facility immediately. Running a generator with a high resistive or voltage imbalance could cause large negative sequence currents to develop and overheat insulation systems.

Insulation

Correlate Resistance-to-Ground (RTG), Polarization Index (PI), and Insulation Resistance Profile (IRP) test data. Most low voltage (<600v) machines should have either a value of the PI or a value of the IRP (at 40^{o} Celsius) above the minimum recommended values for continued operation or overvoltage tests. Machines above 10,000 kVA should have both the PI and the RTG above the minimum recommended values for operation or further overvoltage testing.

Per IEEE 43, if the one minute insulation resistance is above 5000 Megohm, the calculated PI may not be meaningful. See IEEE 43 for more details.

A significant increase in the capacitance-to-ground reading indicates that the insulation may have elevated levels of surface contamination. If the resistance-to-ground reading shows a large decrease at the same time, a PI and IRP should be performed to determine what level of insulation breakdown may have occurred.

Catastrophic failure of the windings may occur under the right conditions.

Stator

Changes in Inductive imbalance could be a result of the rotor, stator, or air gap. Performance of a Rotor Influence Check (RIC) is necessary to determine which of the fault zones could be influencing the change in inductive imbalance.

Compare voltage, current, impedance, and resistive imbalances:

Low voltage and resistive imbalances (<1%), and higher than normal current and impedance imbalances can result from early stages of stator defect. If a high resistive imbalance is present, look for high resistant connections downstream of the MCE® connections. A high current imbalance will correlate with a high resistive imbalance as the high resistance fault becomes more severe. Early stages of a high resistance fault may be correlated with infrared thermography.

If the source of the inductive imbalance is determined to be the stator through consistent separation in phase inductance, then immediate action should be taken to repair or replace the generator. Stator problems can quickly become catastrophic.

Rotor/Field

Large reductions in field inductance or changes in field resistance strongly suggest a shorted field pole. Loss of, or poor voltage regulation could occur with shorted field windings. Additional correlation with an AC drop test may provide some quantitative values of degradation.

Air Gap

The RIC test should be performed for a baseline comparison test of the stator winding inductance values. Varying peaks of inductance and inductive imbalance values in future tests compared to the baseline test indicate the possibility of an air gap offset. Larger journal bearings can naturally show a slight air gap due to the shaft settling on the bearing face. Correlate with vibration analysis.