Why generators fail

By William G Moore, PE, National Electric Coil

Planned outages for gas-turbine-based peaking, cogeneration, and combined-cycle plants are scheduled based on the inspection and maintenance needs of the gas turbine/generator as prescribed by the OEM (original equipment manufacturer). Owners of machines in regular use often schedule two outages yearly—spring and fall, when the market for power is soft. Others opt for one major outage annually. For peaking turbines in limited use—say a couple of hundred hours per year of operation—the time between overhauls may stretch from two to four years.

Outages typically focus on the engine; generators sometimes are taken for granted—until a problem arises. It's understandable that inspection and maintenance activities must be prioritized and optimized given the limited resources and shrinking budgets that plant managers are forced to live with today. But be sure that the work plan for your next outage gives the generators the respect they deserve. It doesn't take much effort to check them thoroughly and verify their safe working condition.

The pictures presented here will help you identify the onset of problems that could compromise safety and lead to a forced outage—including foreign object damage, partial discharge, rotor winding distortion, overheating, contamination, fatigue and stress corrosion cracking, vibration, and loose wedges. Share this report with your key staff to build awareness and knowledge of generator failure mechanisms. CCJ

Foreign object damage

Problem: A generator operates in a carefully controlled environment. Entrance of objects into the machine can be disastrous. Such objects can come from external sources or failure of internal components. Once inside the machine, objects can gain energy from the spinning rotor and do extensive damage. Fig 1 shows coil insulation damage caused by a fan bolt that corroded and flew off into the winding.

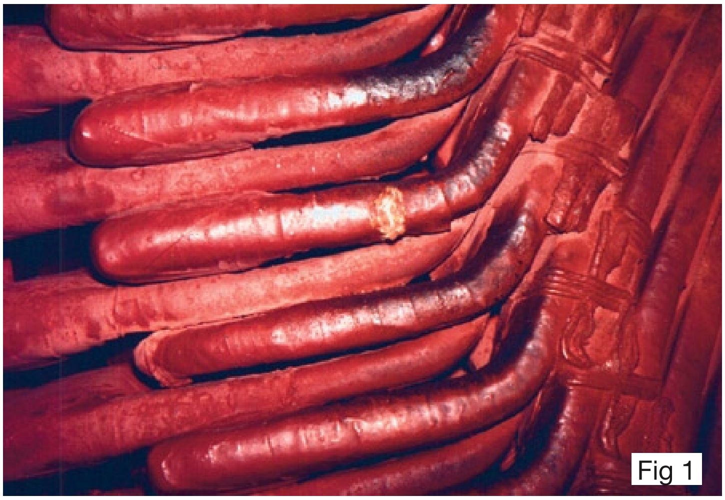

Fig 1

Prevention: Inspect, on a regular basis, all internal parts that are prone to failure or can be dislodged—such as rotating fan blades, balance weights, and pantleg washers. Damage to stator core iron in Fig 2 was caused by a balance weight that came off the rotor.

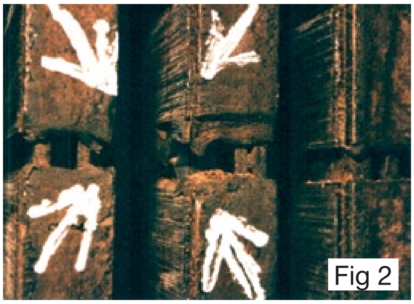

Fig 2

Remember, too, there is always potential danger from items left inside the generator during inspection, testing, and maintenance. When inspecting for damage, consider a combination of visual examination and final crawl through, along with ultrasonic or magnetic particle tests on rotating components.

Partial discharge

Problem: Partial discharge, sometimes called *corona,* is quite common in air-cooled generators. It is caused by a partial voltage breakdown within the generator coil insulation, in gaps between the coil and the stator core, or in the end turns when the coils are in close proximity. Because it is not a complete breakdown of the insulation system, it doesn't cause a full electrical ground. Over time, however, these discharges can "eat" at the insulation, causing its deterioration until a full ground does occur and the unit trips offline.

Evidence of partial-discharge (PD) activity often is visible to the eye, appearing as a white powder dusting the surface of the stator winding (Fig 3). Severe PD damage on the outside surface of a stator coil is shown in Fig 4. This was attributed to a lack of semiconductive coating on the surface of the coil in the slot portion.

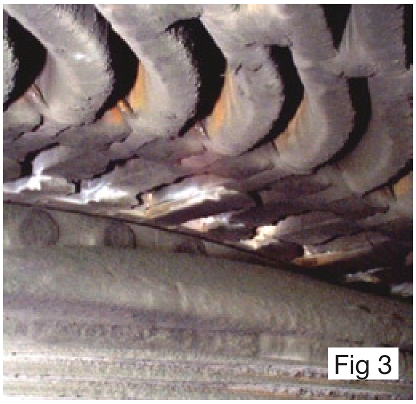

Fig 3

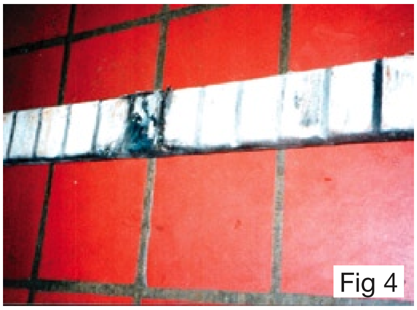

Fig 4

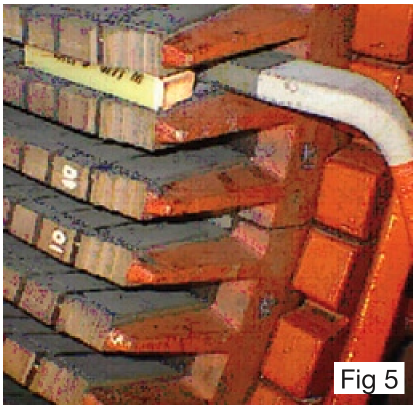

Fig 5

Prevention: Special equipment is needed to detect PD activity. Stator slot couplers can be inserted under the stator wedge to monitor magnitude and frequency of the discharges. It is important to trend PD activity over time because different machines have different baseline values.

Doubling of PD levels over a period of six months is cause for concern. The machine should be opened up and inspected visually. Special corona suppression treatments can be applied to coil surfaces to minimize some types of PD activity. Fig 5 shows special cell- and corner-section corona suppression treatment for a stator coil. Other types of shielding arrangements can be used as well, especially for phase-to-phase discharges.

Rotor winding distortion

Problem: Air-cooled rotors sometimes develop severe rotor winding distortion and displacement, which result in shorted turns or an electrical ground. Distortion can be caused by poor design of the end-turn blocking supports or by top-turn elongation of the rotor coils. Top-turn elongation often is caused by an inadequate slip plane between the end turns and the retaining ring. Distortion of rotor end-turn coils is illustrated in Figs 6 and 7.

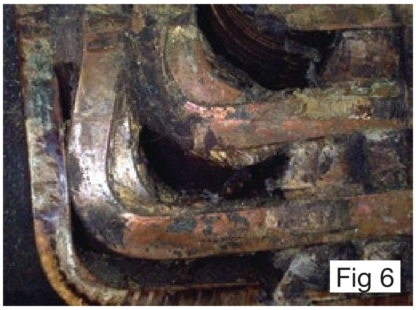

Fig 6

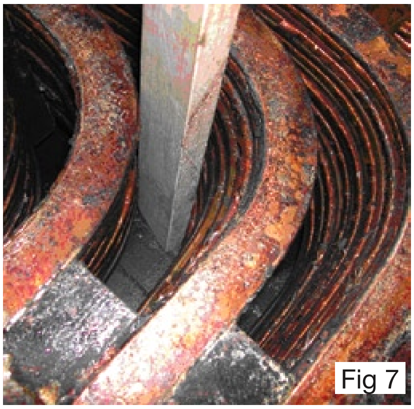

Fig 7

Prevention: Proper design of the rotor coils, and bracing to support the coils under axial loads, are essential. Upgrading of the existing blocking design can provide improved coil support. In some instances, if only the top turn is distorted, it can be placed back into its proper position.

Rotors should be tested for turn-to-turn shorts with a flux probe at operating speed.

Retaining-ring ground insulation should include a Teflon surface so the coils can expand and contract with temperature.

Overheating

Problem: Overheating of the rotor or stator can lead to insulation loss of life, shorting of turns, and eventual ground faults. The tendency to overheat can result from problems in the original design or abnormal operation. Darkened areas on the rotor surface in Fig 8 show typical areas of overheating caused by abnormal operation.

In other cases, short-term overheating results from blocked ventilation passages caused by shifting insulation components or slot wedges.

Prevention: Make sure rotor wedges with cooling vents are securely in place to prevent their migration and blockage of the cooling passage. Slot liners and fillers also should be locked in place to prevent axial migration and the blocking of ventilation holes.

Always operate the unit within the generator capability curve.

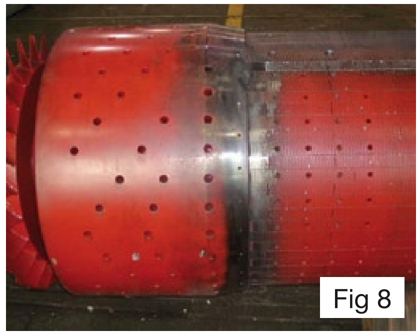

Fig 8

For all rewinds, specify Class F insulation and components.

Contamination

Problem: Contamination from dirty oil or other chemicals can wreak havoc on a turbine/generator. Gas purity is critical to the efficient operation and cooling of hydrogen-cooled generators. Oil leaking into the generator reduces hydrogen purity, sometimes to the point where the machine trips offline. Dirt and dust are more of a problem for air-cooled machines; electrical grounds are relatively common.

Prevention: Good maintenance practices prevent contamination. For example, don't forget to check these regularly: hydrogen dryers, replacing the desiccant when needed; leak detectors, for signs of oil or water leakage; and filters for air-cooled machines, cleaning when necessary.

Polarization Index tests provide a good indication of the rotor winding's overall cleanliness.

Fatigue cracks

Problem: Many generator components are susceptible to fatigue stresses that can initiate cracking. To illustrate: Low-cycle fatigue cracking caused by cyclic operation can occur in rotor-forging tooth tops and fluted areas, slot wedges, and retaining rings. Keep in mind that the failure of a forged component can completely destroy a generator and even cause loss of life. Fig 9 shows cracks in the rotor winding attributed to low-cycle fatigue stresses in the copper.

Rotating fan blades are more susceptible to high-cycle fatigue cracking as shown in Fig 10. Here, the failure occurred in the blade base area, not in a weld joint.

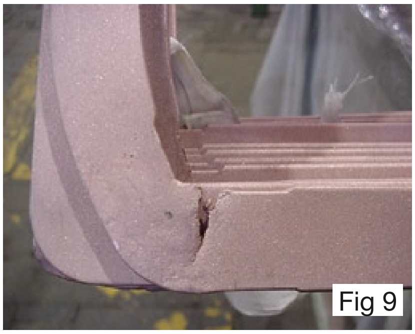
Fig 9


Fig 10

Prevention: Regular nondestructive examination (NDE) helps you find cracks early, before a failure occurs and the component can be repaired or replaced. Inspection method depends on material, accessibility of parts, and other criteria. Select from among ultrasonic, wet fluorescent magnetic particle, eddy current, and simple dye penetrant testing.

Retaining ring SCC

Problem: Stress corrosion cracking occurs on non-magnetic retaining rings—particularly those made from 18Mn-5Cr alloy steel. The presence of high stresses (retaining rings usually are the most highly stressed component on a generator), and moisture or chlorides, will initiate cracking and pitting in this material. Laboratory tests have shown that when conditions are ideal for cracking, cracks can grow as fast as 0.001 inch per hour.

Prevention: SCC can be prevented by keeping the retaining rings dry. This can be difficult, especially on air-cooled generators, which, unlike hydrogen-cooled machines, are influenced by ambient air conditions. Regular NDE, particularly ultrasonic and dye penetrant testing, can detect cracking early as shown in Fig 11.

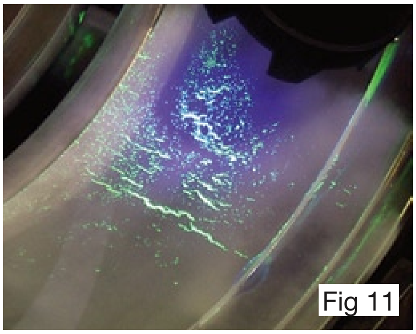
Fig 11

An alternative is to replace the 18Mn-5Cr retaining rings with ones made of 18Mn-18Cr, a material that is considerably less susceptible to SCC. However, this is expensive.

Vibration

Problem: Stator-winding end-turn vibration can wear away coil insulation, precipitating a ground fault or it can cause coil strand breakage, which results in overheating. It is caused by double-frequency operating forces that loosen the end turns over time. Fig 12 shows the tell-tale greasing between coils indicative of end-turn vibration. The relative motion of coils wearing away insulation, plus the mixing of the insulation particles with entrained oil, causes the greasing. In companion Fig 13, dusting, caused by the relative movement between the stator-coil end turns and the support bracket, shows up as a white powder where the bracket and the end-turn surge ring meet.

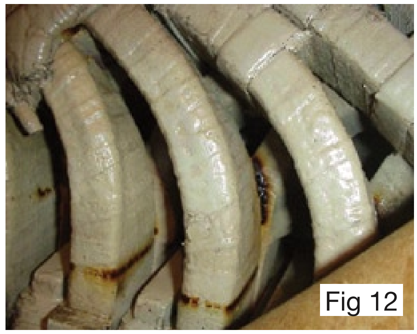
Fig 12

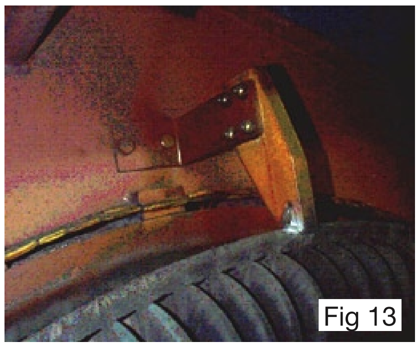
Fig 13

Rotor vibration problems are not usually catastrophic, but they have been responsible for many forced outages. Most often, they are caused by shorts, blocked ventilation passages, electrical grounds, mechanical imbalance, wedge stick-slip, coil stick-slip, loss of balance weights, overheating, and bearing wipe.

Prevention: A "bump" test can tell if stator windings are near 120-Hz resonance, which would make them prone to vibration problems. For the rotor, good vibration monitors and alert operators are essential. Accurate instrumentation signals impending problems and knowledgeable operators can take appropriate action to prevent damage.

Stator wedge looseness and failure

Problem: Wedges are essential for holding stator coils tight in their slots and for minimiz-

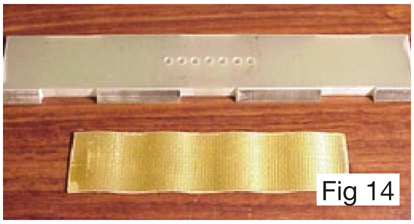
Fig 14

ing vibration from steady-state related excitation forces. When wedges loosen, coils can vibrate, wearing ground-wall and turn insulation. Such wear leads to ground failure or turn-to-turn shorts. Note that when a wedge becomes completely dislodged, damage to both the winding and core can be extensive.

Prevention: Proper design and installation minimize the potential for wedge movement and vibration. Top, bottom, and side ripple springs preload the coil and maintain compression under all normal operating conditions. Conduct periodic checks during regular maintenance activities to verify wedge tightness. Be aware too, that by preventing oil seepage into the machine you can prolong wedge tightness and insulation life. A typical stator wedge and top spring are shown in Fig 14. Wedge has gauge holes for measuring ripple-spring deflection.

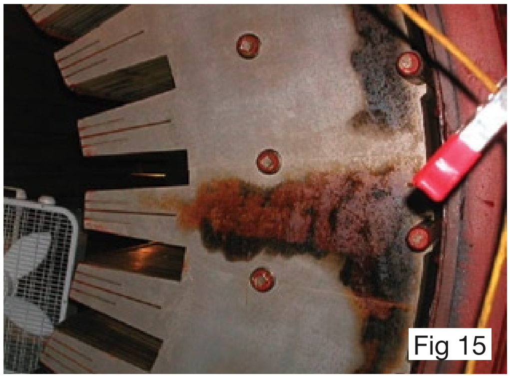
Fig 15

Stator core damage

Problem: Stator-core looseness can occur over time as pre-tensioned through bolts relax. A loose core is conducive to coil and lamination damage. If laminations vibrate relative to one another, they can wear surface insulation. Such wear leads to shorts, core hot spots, and eventually, core-to-core or coil-to-core failure. Note that in Fig 15, arc damage on lamination surfaces was not visible until after the core was unstacked.


Fig 16

Prevention: Though some engineers doubt that retorquing can tighten the core, inspection of through-bolt tightness is recommended at regular intervals. Regular EL CID (for electromagnetic core imperfection detection) tests or loop test inspections of the stator core also can verify its continued integrity. The knife test illustrated in Fig 16 is a simple way to check for stator core looseness.

COMBINED CYCLE Journal

Gas turbines • HRSGs • Steam turbines • Auxiliaries

• Engineering solutions for gas-turbine-based powerplants •

• Plus, analysis and perspective of critical business and regulatory issues •

You qualify for a ***FREE*** subscription to the **COMBINED CYCLE Journal** if you have engineering, supervisory, management, or executive responsibility for the design, construction, operation, and/or maintenance of combined-cycle and simple-cycle electric generating facilities or gas-turbine-based industrial cogeneration plants.

☐ **YES,** start my ***FREE*** subscription to the **COMBINED CYCLE Journal**

☐ No, I do not want to receive this professional journal

Signature ______________________________ Date ______________________________

ALL QUESTIONS MUST BE ANSWERED TO QUALIFY FOR A FREE SUBSCRIPTION

Name ______________________________ Title ______________________________

Company ______________________________ E-mail ______________________________

Address ______________________________ Address is: ☐ Home; ☐ Business

City ______________________________ State______________ Zip ______________

Phone ______________________________ Fax ______________________________

1. Type of company or organization (check ONLY one):

☐ A – Electric generator (regulated utility or unregulated IPP, merchant, etc.)
☐ B – Industrial generator (pulp and paper, refinery, etc.)
☐ C – Institutional/commercial generator
☐ D – Engineer/constructor, consultant
☐ E – Equipment manufacturer/plant services provider
☐ F – Regulatory agency, law firm, financial services
☐ G – Other (specify) ______________________

2. Primary job function (check ONLY one):

☐ A – Plant management (including O&M)
☐ B – Construction management
☐ C – Engineering management
☐ D – Engineering, plant O&M, plant services
☐ E – Other (specify) ________________

You may receive renewal reminders via e-mail. If you do not want to receive other business-related third-party e-mail offers from the publisher—including messages from supporting user groups—please check here ☐

Please also start subscriptions for these other qualified personnel at this address:

Name ______________________ Title ______________________ E-mail______________________

Name ______________________ Title ______________________ E-mail ______________________

Name ______________________ Title ______________________ E-mail ______________________

FAX to 702-869-6867