THE NEW GENERATOR CONDITION MONITOR AND ITS APPLICATION TO THE PROTECTION OF TURBINE GENERATORS

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ABSTRACT

Continuing improvements in the Generator Condition Monitor, in use for over a decade for the protection from hot spots of turbine generators, have increased its reliability and "user friendliness." These improvements include automatic alarm verification and optional computer interface connections for remote monitoring of generator status.

Tests indicate that heating of the gas, used in some installations to inhibit alarms due to oil contacting hot surfaces inside the generator, can result in reduced sensitivity to a real alarm.

INTRODUCTION

With the major reduction in building new generating plants that has been occurring over the past ten years or more, an increasing amount of the world's electric power is becoming dependent upon aging generators. Downtime of a major unit can cost hundreds of thousands of dollars a day, making it imperative for utilities to improve reliability and reduce downtime.

The Generator Condition Monitor (GCM) is a sensitive real-time detector of submicrometer particles created by the incipient thermal decomposition of coatings and insulation. Also referred to as a "Core Monitor" because it was originally designed to respond to core overheating caused by circulating currents between laminations, the Monitor's applications have been extended to provide early warning of all forms of overheating sufficient to produce thermal degradation.

DESCRIPTION AND THEORY

Particle detection is by means of an ionization chamber (1) through which the hydrogen cooling gas is circulated by the pressure produced by the generator fan. The ion chamber detector (ICD) consists of an ionizing section and an ion collecting chamber contained in a pressure housing. The gas first passes through the ionizing section which contains a low level alpha source (Thorium 232). The resulting ions then pass with the gas to the ion collecting chamber in which there is an electrode maintained at –10 volts. Because the ions are extremely small, they have a high ratio of charge to mass, giving them a high mobility when placed in an electric field. The –10 volt potential is sufficient to cause most of the ions to be attracted to a collecting electrode, where they produce the output current.

When particles are present in the gas, some of the ions will become attached to them. These particles, even though invisible under a microscope, are many times larger than the ions. Therefore, the charge to mass ratio of the particle-ion combination is very much reduced (by a factor of a thousand or so), and the mobility is very low. This means that only very few are now attracted to the collecting electrode, resulting in a reduced output current.

Ion chamber detector theory is present in (2), from which the following simplified relationships can be derived. (These relationships are approximations, involving some empirical test data, and are not dimensionally exact. They apply to air at atmospheric pressure):

[1] Io = Qe q/?

[2] ? I = QerZ/4?

[3] ?I/Io = rZ/4 ??q

(? I/Io < 0.4)

Io = ICD output current, no particles (Amperes)

Q = volumetric flow (M1 Sec $^{-1}$)

e = electronic charge (1.6 x 10 $^{-19}$ Coulombs)

q = ion birth rate (Ion-Pairs M1 $^{-1}$ Sec)

? = ion loss due to recombination (1.6 x 10 $^{-6}$ Ion-Pairs M1 Sec)

?I = change in ICD output current due to particle concentration Z (Amperes)

r = particle radius (Cm)

Z = particle concentration (M1 $^{-1}$)

The volume of the ionizing section of the ion chamber is made large enough to establish ion-particle equilibrium, which requires several seconds. Total source strength is less than 0.1 Microcurie, far less than is used in home smoke detectors.

A typical GCM is shown schematically in Figure 1. In this arrangement, a differential pressure (? P) gage which monitors the pressure drop across the ion chamber is used to indicate flow. A true volumetric flow sensor, such as the turbine type, would be more appropriate since ion chamber performance is based on volumetric flow. However, this would increase complexity, and experience has shown the ? P gage to be very adequate.

Ion chamber output current is amplified by an electrometer developed for this application to withstand the environmental conditions likely to be encountered. The amplified current is displayed on a meter and/or recorder, and is also used to activate alarm contacts. The usual operating procedure is to adjust the flow to a given ? P indication, and then to adjust electrometer gain to produce an output of 80%. The alarm sensing circuit will switch the alarm contacts when ion chamber output drops below 50%.

When an alarm is produced the operator can insert the filter by activating its associated solenoid valve. By comparing ion chamber output for filtered and unfiltered hydrogen, a decision can be made as to whether an alarm is real or due to equipment malfunction.

Switching of the alarm contacts will also open the solenoid valve ahead of the collector for a pre-set time interval, allowing a fixed volume of gas to flow through the collector. The collector contains three stages: A coarse filter or trap relatively large particles, a filter to trap submicrometer particles, and a vapor adsorbing section (3). The collector can be removed and the trapped materials analyzed to determine their source.

A test particle source which generates submicrometer particles can be used to test ICD response and filter effectiveness. The source consists of a vertical, heated filament, the lower end of which passes through a reservoir containing an organic compound that is a solid at normal temperature. When the filament is heated some of the compound melts and moves up by capillary action, forming the particles. The source contains enough material for a hundred or more tests, and can be easily replaced when depleted. In order to activate the source, as well as provide access to other adjustments, a cover must be opened. This automatically inhibits activation of the collector system.

The diaphragm assembly of the differential pressure gage is in an all metal sealed enclosure, with diaphragm motion transmitted by a magnetic linkage. All GCM controls are solid state, encapsulated, and all contacts and switches are hermetically sealed.

Typical ion chamber output current and volumetric flow as functions of hydrogen pressure, with the differential pressure maintained at 76 Mm of water, are shown in Figure 2. Because volumetric flow is inversely proportional to the square root of gas density (for constant ? P), the flow drops with increasing pressure, which causes a reduction also in output current. There probably is also an increase in ion recombination losses at higher pressures because the alpha particles travel a shorter distance, creating higher ion concentrations in a smaller volume, to reduce further the current at higher pressures. As pressure is reduced below about 2 Bar the current again drops. This is because the lower gas density increases the alpha paths so that some strike the walls of the chamber and do not create ions. The change in output current with pressure is not normally of concern because most generators operate over a narrow pressure range. If the pressure does vary, however, there is a compensating effect because the change in generator fan differential pressure is in a direction to vary the flow in a manner to oppose the change in current.

APPLICATIONS

In use since the early ‘70s, hundreds of GCM’s have been installed at power stations throughout the world. Spectacular successes have been reported whereby major outages have been avoided by prompt operator actions (4). The monitors are standard for many new generator installations, and are often supplemented by other diagnostic systems such as vibration detectors, and radio frequency monitors for arc detection (5). The usefulness of the Generator Condition Monitor has been enhanced by the development of sacrificial coatings (6). These compounds are designed to particulate at a lower temperature than the normal materials used in the generator, and, therefore, give an even earlier warning of overheating. The use of several different coatings, along with the ability to trap the particles in a collector, can aid in locating the area being overheated.

Due to relative simplicity, absence of moving parts, and no critical adjustments, many GCM’s have given continuous service for ten or more years with little or no maintenance. Where problems have arisen the cause has usually been traced to less than ideal generator operating conditions resulting in particulate or liquid contamination of the hydrogen.

Earlier GCM’s used the floating vall (rotameter) type of flowmeter, and if there was dirt in the hydrogen, deposits would build up in the flowmeter tube, resulting in erratic flow indication. This problem has been eliminated by the differential pressure gage. Because no gas flows through the gage, it cannot become contaminated. In addition, transparent plastic or glass components are not required in the pressurized hydrogen flow system, and the ? P gage can be provided with a contact to activate a remote low flow warning.

In some installations alarms were caused apparently by excess moisture in the hydrogen. These were eliminated by installing a low wattage band heater on the ICD housing to maintain the temperature slightly above ambient, and a band heater is now standard on all Monitors.

In some generators, particularly at high load levels, a GCM alarm can be produced if a malfunctioning hydrogen seal oil system allows oil to contact a part of the internal structure of the generator which is at elevated temperature due to eddy current heating. These alarms can be inhibited by operating the ICD at temperatures of up to 140 C (4). Another method is to heat the hydrogen by a preheater just before it enters the ion chamber. The advantage of the latter approach is tht the ICD temperature is lower, resulting in reduced thermal effects on seals and insulators.

TESTS

Tests were conducted in air in which epoxy-glass generator insulation was heated inside a one cubic meter chamber, and the resultant particles detected by an ICD and Condensation Nuclei Monitor (CNM). The CNM measures submicrometer particle concentrations by causing water to condense on the particles to make them large enough to be counted by an optical system.

In the first series of tests, the insulation was heated on a hotplate to 250 C, which created a particle concentration of about 10^6 per Ml. Filtered air was then introduced into the chamber to vary the concentration. A new sample was used for each test. ? I/Io for the ICD as a function of particle concentration, with the preheater cold and at 140 C, is shown in Figure 3. The alarm level corresponds to ? I/Io = 0.375 (50% alarm, 80% Io). For this ion chamber, Io was 3.3 Picoamps at a volumetric air flow of 10 LPM. The data show that with the preheater off the alarm corresponds to a particle concentration of 105K mer Ml, while with the preheater at 140 C, the concentration is about 230K mer Ml, a greater than 100% reduction in sensitivity. Equations 1 and 3 can be used to determine equivalent particle diameter, which was found to be 0.056 Micron, based on the data for the preheater off. If a particle density of 1 Gm/Ml is assumed, the particle mass at alarm level is 9.6×10^{-9} Gm/Liter which, for a generator with a volume of 5×10^4 Liters, means that 0.5 Milligram of total particle mass within the generator will produce an alarm. In contrast, for 20 Micron dust particles, barely visible to the unaided eye, a total particle mass of 64 Grams would be required to produce an alarm. Therefore, the GCM is not affected by relatively large dust particles that may be created inside a generator by abrasion. Tests on a generator have shown that the GCM will alarm when an area as small as 69 square Centimeters of core lamination is heated to discolor the coating (7). These same tests confirmed that the submicrometer particle concentration in a normal generator is essentially zero.

A second series of tests was conducted in which particles produced by a burning match were introduced into the test chamber. In this case, ICD sensitivity as compared to the CNM was the same, with the preheater off and at 140 C. This indicates that the ICD particle sensitivity is unaffected by gas temperature, but that elevated gas temperatures can reduce the size of, or vaporize completely, particles produced at lower temperatures.

Another series of tests was conducted in which particle levels were monitored while the sample was being heated. Test results for the preheater off are shown in Figure 4. Typical of most materials, there is no particle production until a specific temperature is reached, in this case about 140 C. Based on the volume of the test chamber, sample area, and rate of signal rise, the particle production rate per second is about 3.9×10^8 particles per square Centimeter of sample area.

Figure 5 is a repeat of the same test with a new sample, with the preheater at 140 C. In the data in Figure 4, the GCM alarm level is reached at a sample temperature of 164 C, while in Figure 5, with the preheater on, sample temperature is 187 C at the alarm level. Another test using a lower rate of temperature rise gave essentially the same results. These results would indicate that, with the preheater (or heated ion chamber) at 140 C, insulation temperatures must be 20 to 25 C higher to produce an alarm than if the gas is not heated. This would reduce some of the benefits of sacrificial coatings, which are intended to produce particles at lower temperatures than normal insulation.

As was pointed out earlier, these tests were conducted in air, at atmosphere pressure. With hydrogen at typical generator pressures the absolute values may be different, but the relative effects should be similar. For comparison, the output current, Io, for this ICD with hydrogen at 3 Bar (45 PSIG), at a volumetric flow of 10 LPM, was found to be 33% higher than for air at the same flow. This indicates that equation 1 is 33% higher for hydrogen at 3 Bar than it is for air at atmospheric pressure.

The conclusion to be drawn from these tests is that the preheater or hot ion chamber should not be used indiscriminately, but only in very special cases, and with the understanding that reduced sensitivity may result where particles are produced at lower temperatures. Sensitivity for high temperature produced particles, created by arcing or melting core material, should not be affected.

AUTOMATIC ALARM VERIFICATION

A logical approach to reduce the dependence upon correct and prompt operator response in verifying an alarm is to automate the process. This has led to the development of the GCM Auto Alarm. Designed to be compatible with existing GCM's, it fits into the same panel space as the earlier Remote Panel, and can use the same wiring.

With the Auto Alarm, a drop in ICD output to 50% causes the filter in the GCM to be inserted. After a time dely to allow the ion chamber to stabilize, the output current level is stored, and the filter removed. After another delay, the output current for unfiltered hydrogen is read, and compared with Io. If ?I/Io is greater than .17 a verified alarm is produced. If the ? I/Io ratio is less than .17, a GCM fault is produced. The comparison circuit will also produce a GCM fault in the event of a continuous drop in ICD output, such as on generator shut-down.

From equation 3 the ration ? I/Io is independent of the flow, therefore changes in flow will not affect the alarm decision, as would be the case if ? I only were used. The verification sequence takes about 40 seconds, and the collector is activated only for a verified alarm, which prevents inadvertent activation upon generator shut-down.

The Auto Alarm has provisions for manual activation of the filter, test particle source, and collector. It will produce a warning indication if ICD output drops below 70% or increases above 95%, or if the flow drops below a preset level. A test switch permits testing of warning, fault and alarm functions, the latter by automatically simulating a verified alarm sequence.

The GCM Auto Alarm system has been designed to minimize effects of operator errors or inattention. For example, when in the test mode the verified alarm contacts will not switch, making it possible to connect them so as to remove generator load or initiate shot down automatically without fear that this would be done inadvertently. The collector system also will not be activated under these conditions. If the switch should be left in the test mode, a warning indication is produced. If the cover which provides access to GCM adjustments and controls is opened, alarm inhibit and warning indicators are produced, and the alarm sequence will not be initiated. The collector in the GCM is made easily removable by self sealing quick disconnect couplings. These seal and the collector, protecting the sample, and also prevent the release of hydrogen in the event the collector is not replaced and the system is activated.

COMPUTER COMPATIBILITY

The Auto Alarm provides a 4 to 20 Milliampere output of ICD current, a standard level for many processor based data handling systems. In addition, it can be provided with a computer interface port through which GCM and generator status can be monitored by a computer, allowing the GCM to become an important part of the increasingly sophisticated diagnostic systems now becoming available.

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