PREFAULT MONITOR FOR AIR COOLED GENERATORS

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ABSTRACT

In recent years a major portion of all new generating capacity has been provided by small to mid-size air-cooled generators. Generator manufacturers and utilities have recognized the need for monitoring equipment that can be used to assess the condition of insulation in these air-cooled machines.

This paper will discuss two different technologies that have been tested as prefault monitors for air-cooled generators. These tests were designed to simulate insulation overheating in an operating air-cooled generator and to illustrate that both technologies are capable of detecting the overheating.

INTRODUCTION

A clear trend in new electric power generation installations has emerged, away from large central generating plants and towards smaller power plants. These plants are being built and operated by independent power producers, cogenerators, and even by large utilities.

Practically all of these smaller power plants utilize gas turbine/generators, either as stand alone units or as part of a combined cycle plant. Many of the associated electric generator manufacturers are placing major emphasis on the design and development of air-cooled generators suited to these applications.

For over two decades large hydrogen cooled generators have been protected against overheating by Generator Condition Monitors, or Core Monitors. Both devices use an ion chamber detector through which hydrogen coolant is circulated. Overheating generator insulating materials create large quantities of submicrometer particles which cause the output current of the ion chamber detector to drop, triggering an alarm.

Providing similar protection for an air cooled generator would require a somewhat different approach. For one thing, particle concentrations for a given fault would be lower, particularly for open ventilated systems, because of signal dilution caused by the large volume of air. Also, because the coarse filters used in the ambient cooling air supply do not remove submicrometer particles, a high background concentration could cause an unwanted alarm.

To assess the background problem, preliminary tests were conducted on an air cooled generator using a cloud chamber type particle detector to detect overheated submicrometer particles. The cloud chamber will detect smaller particles, at higher sensitivity, than the ion chamber. The intent of the test was to assess background particulate levels of the ambient air and generator cooling air. During the test, the generator developed a ground fault which produced particle signals from the generator cooling air fifteen times greater than the ambient air. The cloud chamber detected a problem prior to any other indication. These same tests also pointed out the necessity of background compensation when welding operations produced large signals in both the ambient and generator channels.

Based on these earlier tests, two different prototype monitors were designed and built. One uses dual ion chambers to monitor ambient and generator air. The other uses a cloud chamber which sequences at fifteen second intervals between ambient and generator air.

To evaluate the designs, additional tests were conducted at the Edison Generating Station of Public Service Electric and Gas, on a 46.5 MVA combustion turbine generator. The generator cooling is single pass, at a rate of 50,000 CFM. Several power resistors (Ohmite type 270), rated at 100 watts were coated with insulating paints and enamels used by two generator manufacturers. Thermocouples were epoxied to the outside surfaces of the resistors, and the resistors were attached to the generator inlet air screens. Probes consisting of drilled 1/2" I.D. PVC pipe were installed in the exhaust air ducts to provide the generator signal. Ambient air was monitored down-stream of the ambient air filters. The resistors were energized one at a time with enough current to bring their temperatures to the range of 277 to 400 C. In each case good signals were obtained on the generator channels of both the ion chamber and cloud chamber detectors.

Whether ion chamber or cloud chamber detection is used, the generator fault alarm would be based on an increase in particle concentration above ambient, so that an increase in ambient particles alone would not result in a fault alarm. A separate level alarm on both ambient and generator signals would be provided to warn of possible detector saturation.

EQUIPMENT DESCRIPTION

The tests involved equipment using two different kinds of particle detection principles - cloud chamber and ion chamber. A single cloud chamber detector was employed, with a sequencing valve that alternately selected generator air and ambient air. Because the ion chamber has a slower response, two ion chambers were used to sample simultaneously generator and ambient air.

Cloud Chamber

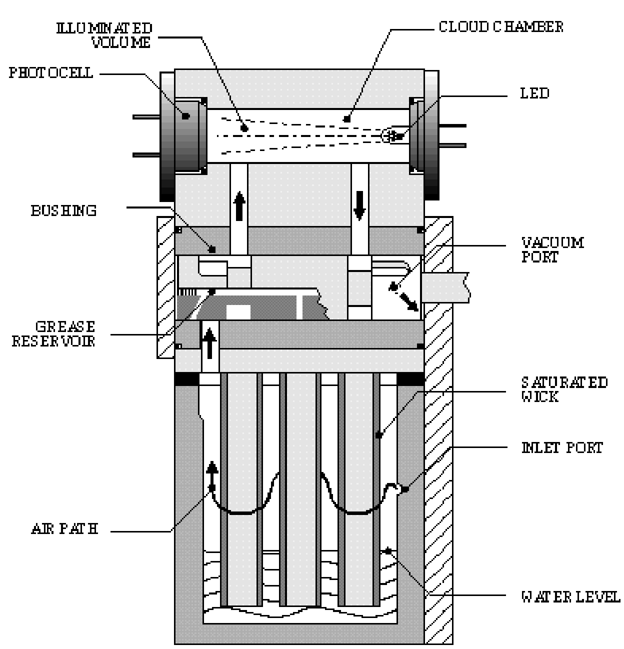
In the cloud chamber the humidified air sample is expanded adiabatically, producing a reduction in air temperature of up to 20 C. With no particles in the sample the expanded air will remain super-saturated, and there will be no condensation. With particles present they will act as condensation centers, and a water droplet will form around each particle. A .01 µm particle will grow to a 4 µm water droplet in about 50 milliseconds, an increase of 160,000 times in cross sectional area. However, because the original particle is much smaller than the wavelength of light, it is virtually invisible, while the 4 µm droplet can be readily detected by a simple and reliable optical system.

The expansion induced amplification is noise-free in that one, and only one droplet is formed on each particle, and where there are no particles, no droplets are formed. Because of this, the cloud chamber detector has a wide dynamic range, able to reliably detect particle concentrations ranging from a few hundred to over one million per ml, without resorting to exotic circuit techniques.

The cloud chamber design is shown on Figure #1 , with the flow schematic and valve sequence on Figure #2. A pump provides a vacuum of 200 mm of mercury, resulting in a supersaturation of about 300%, sufficient to detect particles as small as .002 micrometer in diameter. The cloud chamber is about 50 mm (2 in.) long, with a LED light source at one end and a photocell at the other.

The periodic expansion of the sample air in the cloud chamber at a rate of once per second, causes a cyclic attenuation of the light on the photocell. The resultant electrical signal is peak detected and converted to a 0-10 volt analog DC voltage. The overall detector configuration is similar to that employed for the monitoring of phase bus cooling air. A blower is used to draw in sample and ambient reference air samples, and solenoid valves sequence between the two inputs at fifteen second intervals. The circuit compares the difference between sample and reference signals, and will provide an alarm if either this difference, or the actual level, exceed a pre-set value. The detector is microprocessor controlled, and it is monitored by a diagnostic system which warns of any trouble.

FIGURE 1 - CLOUD CHAMBER



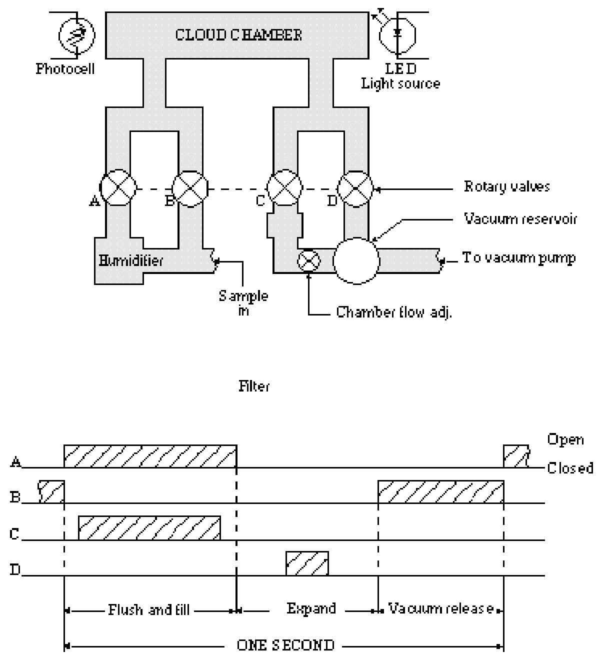


FIGURE 2 - CLOUD CHAMBER DETECTOR FLOW SCHEMATIC/VALVE SEQUENCE

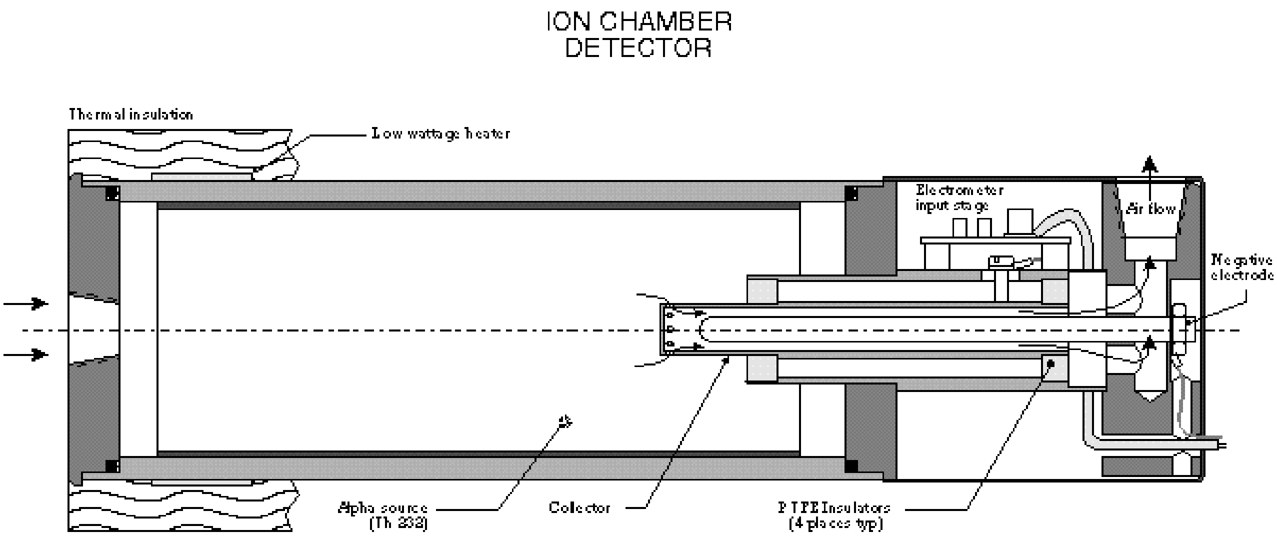


FIGURE 3 - ION CHAMBER DETECTOR

Ion Chamber Detector

The design of the ion chamber is based on that used in the Generator Condition Monitor for hydrogen cooled generators. It is shown on Figure #3 and consists of an ionizing section and an ion collection chamber. The air first passes through the ionizing section which contains a low level alpha source (Thorium 232). The resulting ions then pass with the air to the ion collecting chamber in which there is an electrode maintained at a negative voltage with respect to ground. 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 negative potential is sufficient to cause most of the ions to be attracted to a collecting electrode, where they produce a current amplified by the electrometer.

When particles are present in the air, 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 current to the electrometer.

Because high pressures are not involved, the ion chamber housing can be much lighter than that used in the GCM. Also, the electrometer input stage is part of the ion chamber assembly, eliminating the need for a co-ax cable. A low wattage heater is used to maintain reduced relative humidity in the ion chamber and electrometer input stage housing.

The prototype Dual Ion Chamber Overheat Monitor flow schematic is shown on Figure #4 . Because the presence of particles results in a reduction of ion chamber current, an absolute zero filter is provided to permit initial gain adjustments based on clean air. The gain set valves are set so that the ion chamber is filtered, and the electrometer gain adjusted to a level close to full scale (9 volts for these tests). The valves are then set so that signal and sample air passes through the ion chambers. The ion chamber flow is also

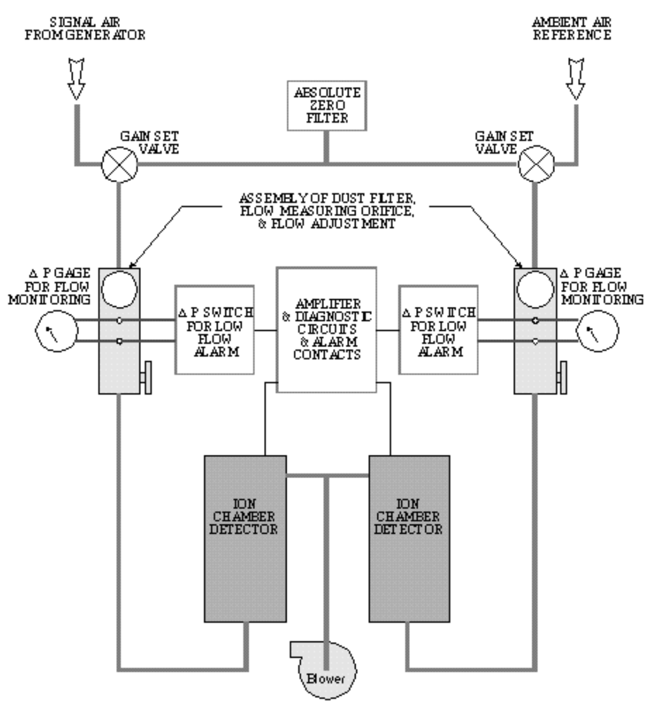


FIGURE 4 - DUAL ION CHAMBER OVER-HEAT MONITOR

adjusted, using an orifice and differential pressure gage.

The circuit will produce warning and alarm indications when the electrometer output voltage drops below pre-set levels. For these tests the warning levels were 7 volts, and the alarm levels 6 volts. The prototype monitor did not incorporate a comparison circuit, but one can be easily added. A diagnostic system produces a trouble indication in the event of low flow, gain set valves in filter position, or electrometer failure.

Background Test

Background tests were conducted for 4 months at the Edison Generating Station, from 30 July to 1 Dec. 1992. Dual channel strip chart recorders were used to monitor the outputs of the cloud chamber and ion chamber detectors. The two channels of each monitor tracked background variations quite closely. As expected, the cloud chamber, with its higher sensitivity to submicrometer particles, showed greater fluctuations in ambient background. Differences between day and night, primarily due to traffic, were very apparent.

The gain of both ion chamber electrometers was adjusted for outputs of 9 volts with clean air, with the generator running. When the generator was shut down, the ambient air output went to 9.4 volts, and the generator sample air dropped to 8.6 volts. This was due to changes in the pressure drops of the inlet air filters and discharge duct. With the generator shut down there was no drop in the inlet air filters, so that the pressure at the ambient sampling heads increased slightly, which produced a slight increase in the ambient ion chamber flow. At the probe sampling generator air the pressure went down, because there was now no drop in the discharge duct, and the signal ion chamber flow was reduced. It is not expected that this effect will create any problems. If a comparison circuit is used, the alarm level will have to be set low enough to prevent an unwanted alarm at shutdown. Also, ion chamber tests have shown that the effect of flow on ion chamber current can be reduced by operating at a higher flow.

The data for 28 Aug. show two periods of particle production within the generator while it was shut down. On the cloud chamber, the signals went to 6 volts against a background of about 2.5 volts. On the ion chamber the output dropped to 7 volts from a background of 9.5 volts. These were probably due to the operation of thermostatically controlled heaters inside the generator. The heaters had not operated for some time and dust had deposited on them, so when power was applied to the heaters particles were produced from the accumulated dirt.

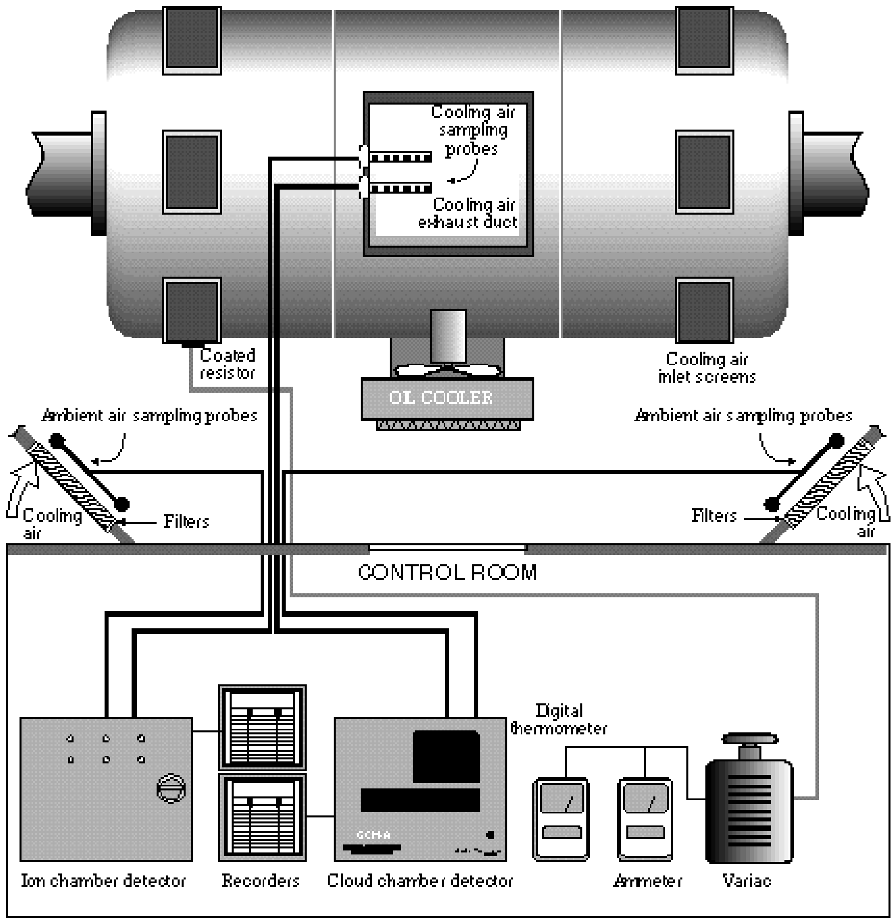


FIGURE 5 - TEST SETUP

On a few occasions there were simultaneous cloud chamber signals of about 3 volts above background, and ion chamber output drops of about 2 volts, coinciding with generator start-up or shutdown. The largest signal, above 10 volts on the cloud chamber, and an ion chamber drop to 1.2 volts, was observed at about 13:30 on 29 Aug. while the generator was operating. Signal duration was about 20 minutes. The cause is unknown, although the station log refers to an emergency trip at 13:37.

Results/Discussion

Both the cloud chamber and ion chamber monitors operated satisfactorily throughout the tests, and except for chart problems with one of the recorders there were no malfunctions. Other than recorder chart paper changes maintenance on equipment based on these designs would be minimal - addition of distilled water to the cloud chamber every few months, and possibly gain and flow adjustments, with dust filter change if required, for the ion chamber monitor at 6 month intervals. Both detector types demonstrated the capability of detecting particulates produced in the generator, with the cloud chamber having higher sensitivity.

Head Location

As shown in Figure #5 , the tests were conducted with the ambient air heads downstream of the inlet air filters, and the signal air obtained from probes in the cooling air discharge duct. Initial tests conducted with the signal air obtained where the cooling air is discharged to atmosphere produced negative results. It was thought that the outdoor signal pick-up resulted in dilution, and for this reason the cooling duct probes were added.

Further analysis indicates that the negative results were probably due to the resistor location (discussed later), and that the outdoor discharge signal pick-up would be satisfactory if properly installed. It would have the following advantages:

1.When the generator is shut down, any particles produced by the internal generator heaters would be diluted by ambient air, and there would be less likelihood of an unwanted alarm. With the generator operating, if the pick-up head is located so that it is completely bathed in the generator discharge air, there will be no dilution.

2.The effect on the signal ion chamber flow rate due to generator operation would be eliminated. Further, the effect on the reference ion chamber flow rate would also be eliminated if the ambient air pick-up is placed upstream of the inlet air filters.

Resistor Location

Preliminary tests with the over-heat resistors located some distance from the generator inlet screens produced negative results. Although all particles produced by the resistors eventually passed through the generator, the particle concentration was low due to the low air velocity over the resistors.

When the same type of resistor was heated in a test chamber in still air, the particle production rate was determined to be about 109 particles/cm2/second. For these tests, with the resistors fastened to the cooling air inlet screens, particle production has been estimated at about 1011 particles/cm2/second. This difference is due to the high air velocity over the resistors. When particles are produced in high concentrations they coagulate very rapidly, with a resultant decrease in number. The coagulation rate is reduced if the particle concentration can be diluted by high velocity air, resulting in an overall larger total number of particles.

Because of the effect of air velocity on particle production, it is very likely that an internal generator fault would produce a relatively higher particle concentration for a given heated area because the internal air velocity would be higher than that over the test resistors.

Resistor Burn Test

To simulate generator overheating a thin layer of insulating epoxy paints and enamels were applied to several 100 watt, 5 ohm, ceramic power resistors. Each resistor had a surface area of approximately 102cm. A type “T” thermocouple was attached to the center of the resistors to measure the surface temperature.

To establish a current through each resistor, a 0 to 140 volt, 10 amp variac was used. An ammeter was used to measure the current and a digital thermometer was used to measure the resistor’s surface temperature (Figure #5).

A current varying from 7.5 to 9.0 amps was fed through each resistor producing a surface temperature of between 277 C to 400 C.

Preliminary tests were carried out to determine the optimum location for the sampling probes and test resistors. As stated earlier the sampling probes were first located where cooling air exits the exhaust duct above the roof. Because there was no response by either detector, the sampling probes were then mounted in the exhaust duct nearest to where the cooling air exits the generator. The resistors were also relocated from a point several feet from the generator to being attached to one of the cooling air inlet screens.

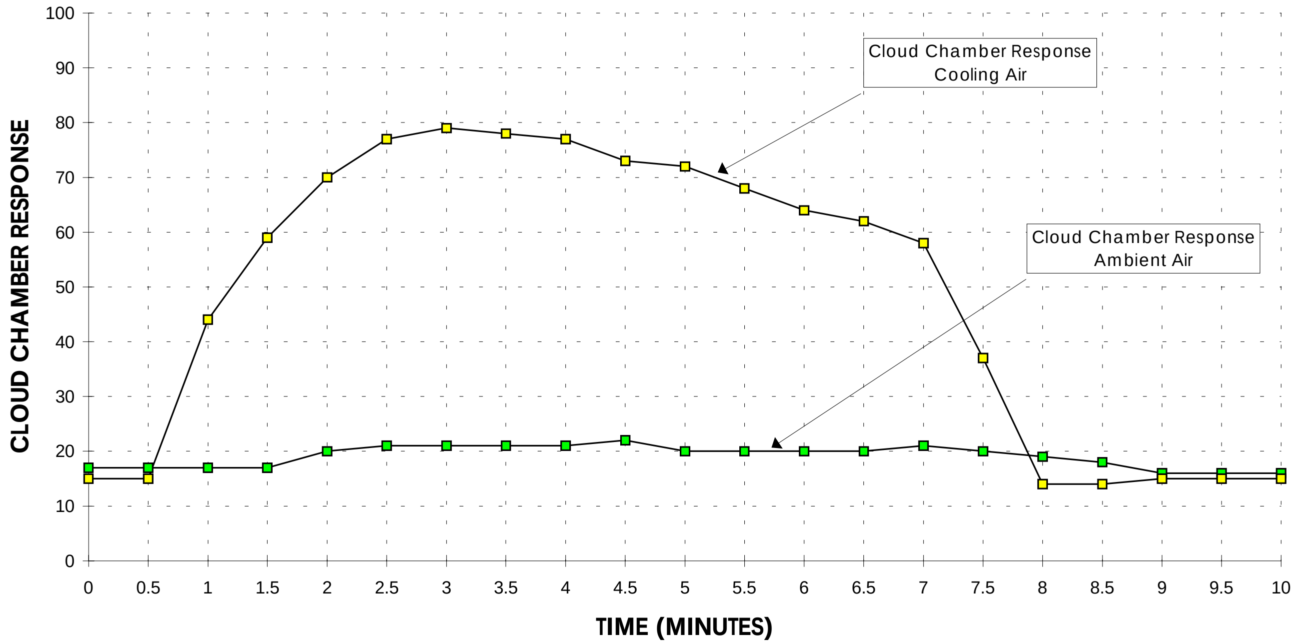
After proper locations for the sampling probes and resistors had been determined, two burn tests were performed. Figure #6 shows that both detectors responded to the overheated resistors; however the cloud chamber was more sensitive.

Conclusions

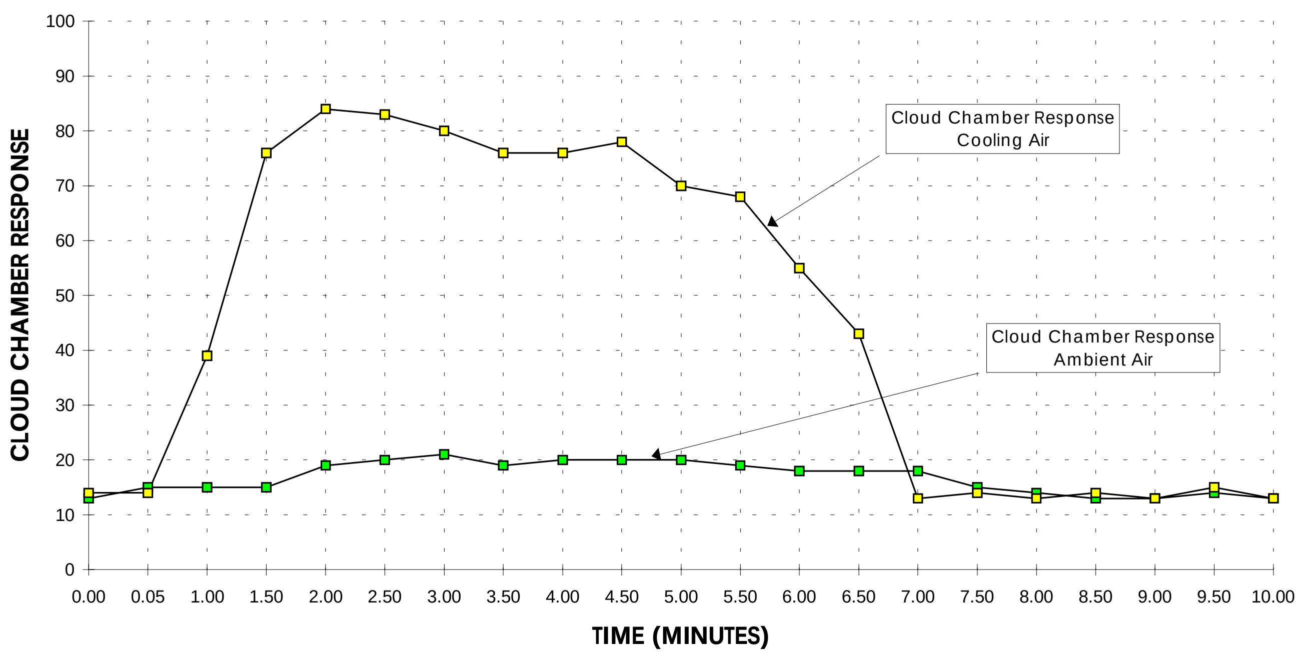
The tests confirmed that, even for a single pass air cooling system, internal generator overheating sufficient to damage insulation can be detected by monitors using either cloud chamber or ion chamber detectors. Cloud chamber sensitivity is higher, but also produces higher background signals. The reason for this may be due to the extremely small particle size threshold for the cloud chamber, versus the .01 micrometer minimum detectable size for the ion chamber.

It is expected that higher particle concentrations will be produced by a given fault in a generator with a closed cooling air system because of the reduced dilution. It is also expected that higher particle concentrations would have been produced by the resistors if they had been located within the generator housing due to the greater cooling air velocity.

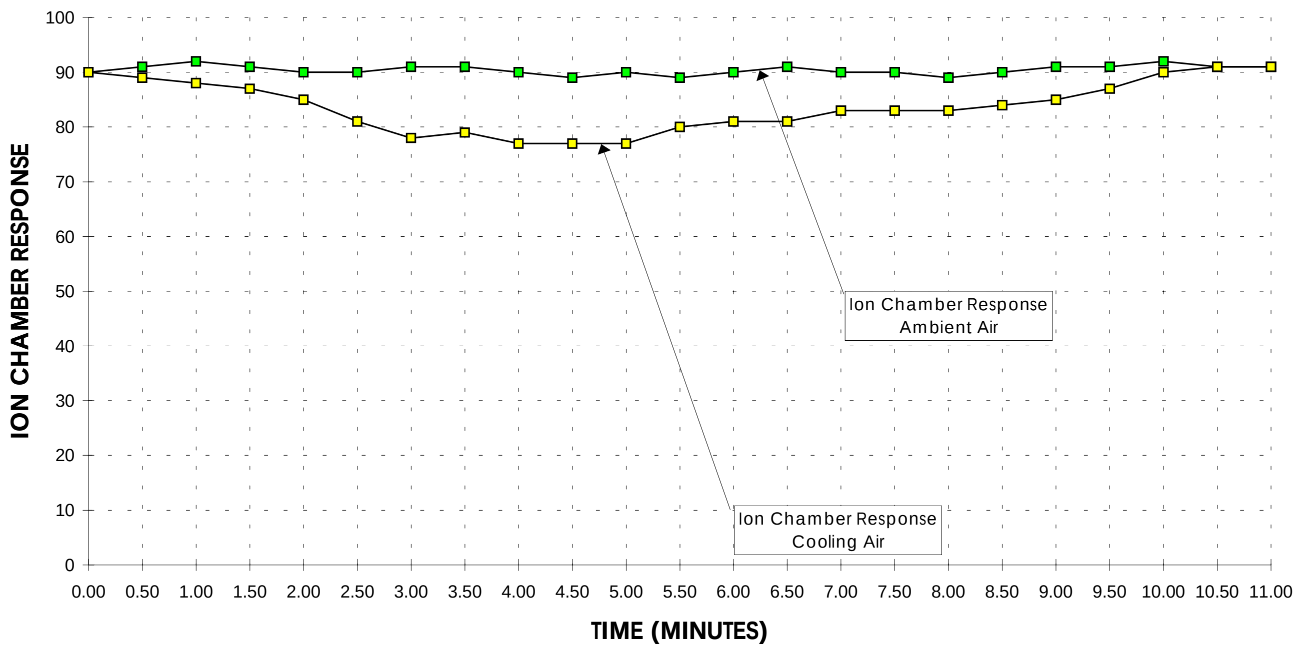
TEST #1 - 100 WATT RESISTOR - CLOUD CHAMBER



TEST #2 - 100 WATT RESISTOR - CLOUD CHAMBER



TEST #1 - 100 WATT RESISTOR - ION CHAMBER



TEST #2 - 100 WATT RESISTOR - ION CHAMBER