EARLY WARNING OF FIRE AND HYDROGEN GAS THREATS IN BATTERY SPACES

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INTRODUCTION

The quantity and type of battery applications has increased in recent years. Several factors have led to this increase:

- Increased need for uninterrupted power for control of critical processes where even momentary power interruption results in highly-detrimental or even catastrophic circumstances, in such diverse applications as manufacturing, power generation, chemical production and refineries.
- The proliferation of data centers in support of mobile and on-line internet services.
- The recent surge in development of renewable energy sources such as solar and wind turbines, which depend on Grid Energy Storage for proper and timely distribution of energy on the Power Grid.
- Smart Grid development initiatives
- Improved battery energy density, making battery storage more practical and feasible

The amount of fixed energy storage is expected to surge in the next 5 years according to SBI Energy with a forecast of 26 percent annual growth rate in the US through 2015. These will be primarily Grid Energy Storage (GES) systems, supporting wind and solar generation facilities, but many of them also will provide backup power and peak-shaving reserve for large users and communities. These GES units frequently will be located in and around urban populations, critical infrastructure such as data centers, or production plants in order to serve users effectively.

FIRE AND EXPLOSION RISKS AND CONSEQUENCES

Battery rooms and GES system enclosures typically are densely packed with racks of storage batteries and frequently contain supporting electrical equipment such as inverters, switchgear and controls. The high density of stored energy and electrical equipment pose a risk that faulty workmanship or equipment malfunctions may result in excessive heat generation, leading to fires. Also, batteries may vent or leak combustible and toxic gases into their environment. The costs of such events are numerous and potentially ominous:

- Equipment replacement
- Loss or interruption to daily operations and production
- Injury to surrounding populations of residents and workers
- Bad publicity

Manufacturers of battery storage systems are keenly aware of these risks, as evidenced by the safeguards that are built into their system designs. However, certain risks remain which cannot be handled by these built-in safety features:

- Faulty workmanship during field installation such as loose electrical connections
- Adverse environmental conditions
    - Water intrusion caused by natural perforations, defects or aging of the enclosure or building
    - Condensing moisture from humidity
- Thermal events or migration of fires from adjacent structures
- Vandalism and sabotage
- Force majeure (Hurricanes, seismic activity, tornadoes, war)

RISK MITIGATION

Very Early Warning Detection

The inability to design systems for every possible risk scenario and the magnitude of consequences related to fires and hazardous gas release point to the need for detection of overheating components and hazardous gases in battery storage systems. The sooner such events are detected and acted upon, the less potential for injury, property damage and disruption. Detection systems therefore, should be designed to provide the earliest possible warning without compromising reliability. In other words, they should provide the highest possible sensitivity without risk of unwarranted “false” alarms.

Detection System Objectives

The ultimate objectives of any detection system are:

- Safety to human life
- Property protection
- Continuity of operations
- Reduction of liability
- Public relations (stay out of the 6 o’clock news)

Available Fire and Gas Detection Technologies

Fire detection technologies are categorized based upon the parameters they are designed to sense:

1. Heat Detection
2. Radiant energy (flame) detection
3. Smoke detection
4. Multi-criteria detectors (combination of the above parameters)

Over many years of evolution, products in each of these categories have been developed and improved, such that each type can claim to perform reliably and effectively. However, Figure 1 depicts a typical fire growth curve and the stage at which each of these detector types can be expected to perform.

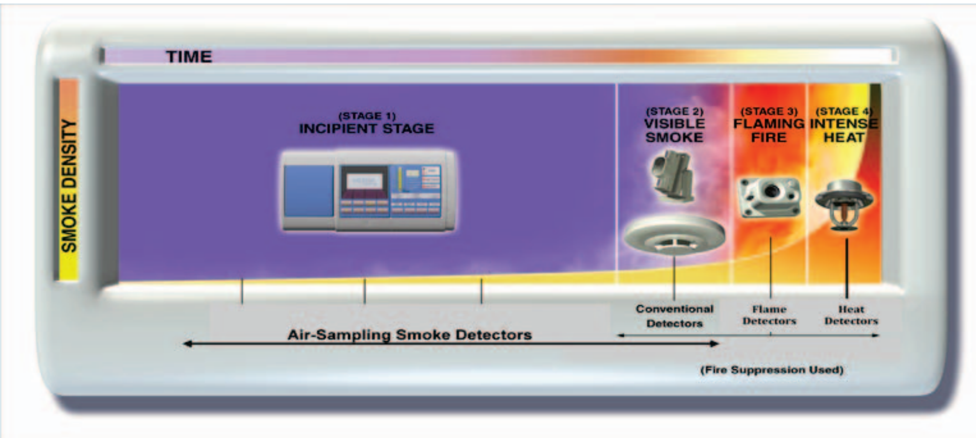

Figure 1 – Typical Fire Growth Curve and Detection Types

It should be noted here that not every fire will follow this idealized curve. While each detector type may perform well at its intended fire stage, smoke detection provides the earliest possible detection. Smoke particles are the first detectable parameter in an overheat condition that could lead to an actual fire, practically speaking. Heat and flame are not present in detectable quantities in the initial stages, and their path to detection devices may be impaired by electrical enclosures, equipment, air currents, or the distance between the overheating equipment and the detector. Additionally, the ventilation system can be a serious impediment by removing the heat at a rate that prevents its detection.

Most of the components of a battery storage system contain materials that will exhibit an incipient stage generating detectable smoke particles when heated, prior to generation of detectable heat and flame. These materials include:

- wire insulation
- molded plastic relay and circuit breaker enclosures
- electronic components
- circuit boards
- paint coatings

Smoke particles are migratory, following air movements created by thermal currents and ventilation systems. Opportunistic smoke detection system designs take advantage of this migration by positioning detection devices in the expected smoke migration paths. For this reason, most smoke detection systems in homes and commercial spaces position the detectors on the ceiling or high on the walls of the protected area. This is based on a design scenario in which thermal currents from an overheating event will carry the smoke particles to the ceiling, and is generally very effective for those environments.

Smoke Detection in Battery Storage Systems

Before deciding that smoke detection is the best method for battery storage systems based on its early-warning capability, it is necessary to evaluate the different types of smoke detection technologies available and their performance in the range of applications and environments that will be encountered. Battery systems are deployed in a wide variety of environments, with factors that influence behavior and suitability of traditional point-type smoke detectors:

- Extremes of temperature – smoke detectors are typically listed and approved for use in environments between 32 and100 degrees Fahrenheit, and should not be subject to temperatures outside of their listed range.
- Airborne dust and dirt – may contaminate the detection chamber, and may frequently causes false alarms. Dust and dirt may be introduced from sources outside the protected enclosure, brought in by fresh air intakes from HVAC systems.
- High air flow from ventilation systems – will carry smoke toward return air grilles or exhaust fans, which may prevent smoke from reaching a smoke detector.

The types of smoke detectors available are of three major types:

1. "Spot-type" detectors – these are the detectors normally used in residential and commercial occupancies and are generally located on the ceiling or high on a wall.

Figure 2 – Spot-Type Smoke Detector

2. Projected beam smoke detectors – these detectors measure the intensity of a light beam that is projected across the protected space, near the ceiling. If the beam is partially blocked (presumably by smoke particles) then an alarm is generated.

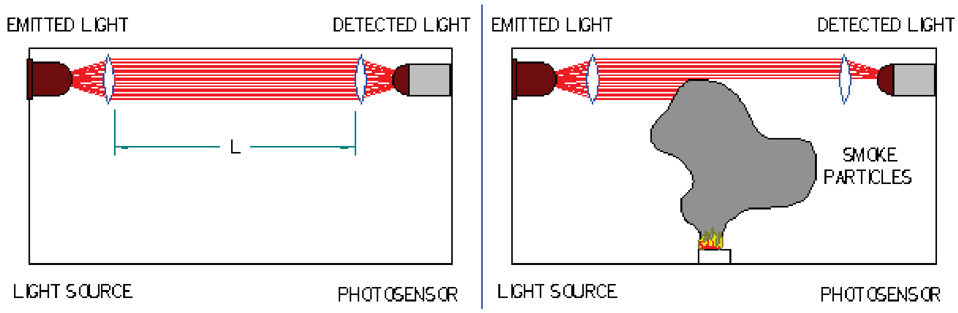

Figure 3 – Projected Beam Smoke Detector

3. Air-sampling smoke detectors (ASD) – these detectors continually draw air from the protected space, via a pipe network, back to a central detector which continually monitors for traces of smoke.

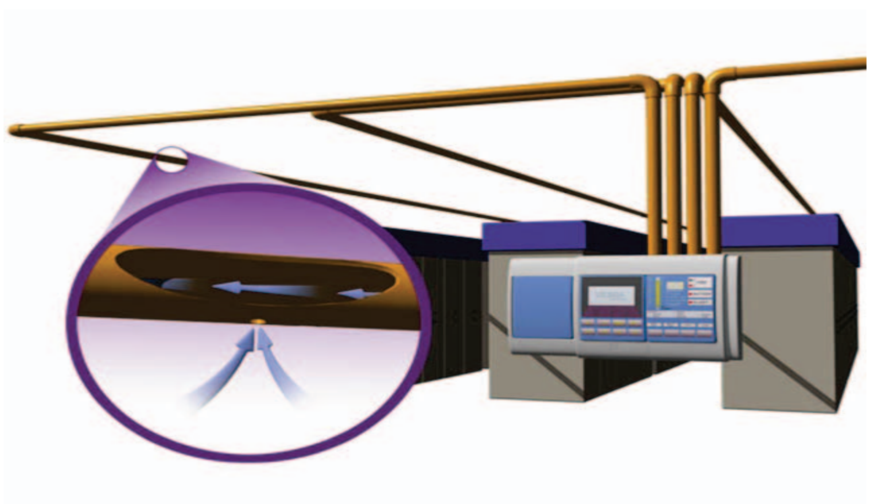

Figure 4 – Air-Sampling Smoke Detector

An evaluation of the impact of environmental conditions on the performance of each smoke detector type is useful in deciding which type, if any, will be suitable:

Temperature extremes

Spot-Type and Projected Beam Smoke Detectors will not function properly outside of their listed temperature range, typically between 32 and 100 degrees F. Air-Sampling Smoke Detectors will not function properly outside of their listed temperature range, but the detectors can be located outside of the protected area in a suitable environment. Only the sample pipe is subjected to the temperature extremes, which means <u>effective smoke detection can be provided in extreme temperature environments</u>.

Airborne dust and dirt

Spot-Type Detectors – will become contaminated, leading to false alarms or reduced detector sensitivity

Projected Beam Detectors – the lenses of the light source and photo sensor will become coated with airborne particles, leading to false alarms or reduced sensitivity.

Air-Sampling Detectors – typically employ filters that remove dust and dirt in the sampled air before it enters the detection chamber. The smoke particles are smaller and pass readily through the filters for effective early-warning detection.

High Air Flow

High air flow, usually caused by HVAC systems, prevents smoke from accumulating in sufficient quantity to be detected by spot-type and projected-beam smoke detectors. Air-sampling smoke detection can be configured at much higher sensitivity levels than other detection types, so that less smoke is needed to cause an alarm. Also, the sample pipe can be located in HVAC air flow paths to capture smoke more effectively. In high air flow applications, sampling pipe is typically located at return air grilles, and may also be placed in close proximity of protected equipment. One particularly effective means of capturing smoke in high air flow environments is to draw air samples directly from within electrical equipment cabinets. A single air-sampling detector can sample from multiple equipment cabinets for effective early warning detection. Detection at these discrete levels is not practical with either spot-type or projected beam smoke detectors.

Hydrogen Gas Detection in Battery Storage Systems

Depending on the type of batteries used, gas may be emitted from cells under normal or abnormal conditions. Some gases are known to be flammable or toxic, and one of the most prevalent gases of concern is hydrogen. Hydrogen is highly flammable and will burn explosively at concentrations as small as 4 percent by volume. For this reason, battery rooms often are equipped with fan-driven ventilation to prevent hydrogen from accumulating at explosive concentrations.

Ventilation is an effective means of preventing hydrogen accumulation, but should not be the only safety method employed for three very important reasons:

1. If a ventilation system is the only safeguard against hydrogen gas accumulation, there should be some way of knowing that the system is actually operating properly. Rotating mechanical equipment eventually will fail, or filtration may become clogged to the point that there is inadequate air flow.
2. Ventilation systems consume energy, and continuous, round-the-clock operation is not energy efficient design. Also, the fresh air that is drawn into the space must be heated or cooled, which adds to unnecessary energy consumption.
3. Continuous ventilation, which in some cases may be unfiltered, introduces unnecessary pollutants into structures housing batteries subjecting control systems, processing systems and other critical infrastructure components to exposure, potentially threatening their reliability and shortening their service life.

The most effective means of addressing these three concerns is to provide an early-warning hydrogen gas detection system. Hydrogen gas detection can be used to control the ventilation system so that it operates only when needed, for maximum energy efficiency and air quality considerations. Also, there is positive assurance that hydrogen gas concentration is maintained at a safe level. If two levels of hydrogen gas alarms are employed, then a high level may be used to alert personnel that urgent action is required.

Hydrogen gas detection systems traditionally have employed individual “stand-alone” sensors placed at strategic locations where it is believed that hydrogen gas is most likely to accumulate – usually near the ceiling. Hydrogen gas is much lighter than air and will tend to rise to the highest possible level in the protected space. However, air currents in the space introduce uncertainty about where the gas may accumulate. This can be overcome by placement of multiple gas detectors in the room, but this increases cost without positive assurance that the detectors are in the best locations for the earliest possible detection of gas concentration levels prior to reaching explosive levels.

A novel approach is to utilize recently emerged detection technologies which work off the principle of air-sampling, similar to that of air-sampling smoke detection technologies, which has gained much recognition over the last decade. In-fact, these new technologies leverage the same pipe network allowing for detection of both smoke and gas. The air-sampling pipe network can be installed throughout the protected space, and in air flow paths such as return air grilles. A pervasive network of sampling pipe insures that hydrogen gas anywhere in the room will be actively sampled and transported to the gas sensor. Adverse conditions such as temperature extremes, airborne dust and high air flows can be handled in the same way as discussed previously for air-sampling smoke detection, providing early warning gas detection in a wide variety of environments.

Combined System

As previously mentioned, the air-sampling pipe network can be used for both smoke and gas detection. This combined approach can often times result in lower capital expenditure than conventional point-type gas and fire detection counterparts. Air-sampling systems also are simpler and less costly to maintain than their conventional counterparts, since the detection devices can be mounted in accessible locations rather than near the ceiling or over sensitive equipment. The air-sampling detectors provide analog and digital signals that can be used to control HVAC equipment based on hazardous gas concentrations and smoke, thereby minimizing energy consumption.

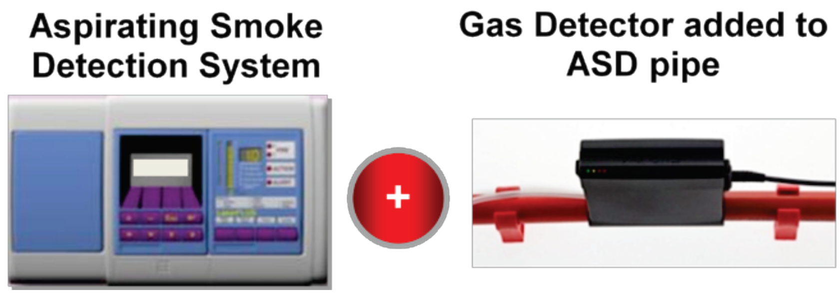

Figure 5 – Combined ASD Smoke and Gas Detection on a Single Pipe Network

CASE STUDY

In-Situ tests were conducted December, 2009 at a precast telecommunications Base Transceiver Station. The structure was equipped with two Bard HVAC systems, a Bard MC3000 controller, equipment racks fitted with various BTS gear for simulation, a bank of VRLA batteries, one thermal rate of rise heat detector and one Kidde ionization smoke detector model i12020 manufactured March 11, 2009 with a sensitivity rating of 0.5-0.83%/FT. There were various cable penetrations into the space. One exterior door is provided and equipped with a weather seal. Space interior dimensions are approximately 19 x 11 x 9 ft.

Figure 6 – Smoke and Hydrogen Detection Test Structure

Both ionization smoke and heat spot-type detectors were present in the space and were presumed new and un-operated up until the point of the tests. A hydrogen spot-type detector was provided for comparison testing and was mounted per manufacturer's recommendation on the ceiling above the battery bank. This detector was new out of the box and first had power applied the day of testing. The HVAC systems present at the site were 5 ton units with a 2000cfm capacity positioned side by side, and were provided with two return air grilles measuring approximately 20x36 inches, and two supply air grilles measuring approximately 10x36 inches.

A bank of 12 VRLA 2VDC 1000Amp/hr batteries was present in the structure in a corner opposite the entry door and just below a return air grille. It was understood that battery bank locations could change from site to site so for that reason hydrogen dispersion apparatus was equipped to simulate off-gassing at various locations in the structure.

One aspirating smoke detector was fitted to the wall between the two return air grilles. The sampling pipe network associated with the detector provided coverage of the ceiling, return and supply air grilles.

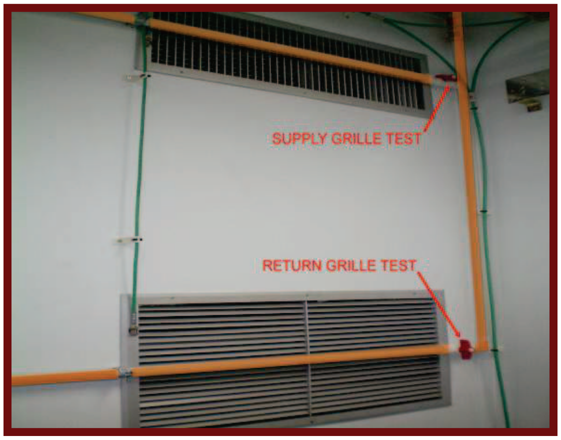

Figure 7 – ASD System Inside Test Structure

A total of four hydrogen ASD units were strategically placed at positions along the pipe network to provide isolated indication as to where hydrogen was likely to accumulate. The data collected from these four sensing units would help determine best placement for a single unit. Placement for the tests was as follows:

Unit 1: At inlet of the air-sampling detector which would collect samples from all sample points within the pipe network.

Unit 2: At right of pipe tee on pipe branch covering HVAC supply/return air grilles. This location would collect samples only from the sampling points covering the return/supply air grilles.

Unit 3: At left of pipe tee on pipe branch covering ceiling. This location would collect samples only from the sampling points covering the ceiling.

Unit 4: On ceiling pipe network prior to last sampling point directly above battery bank. This location would collect samples only from the last sampling point and would be representative of a point type detector, with the exception that the sampling point is aspirated.

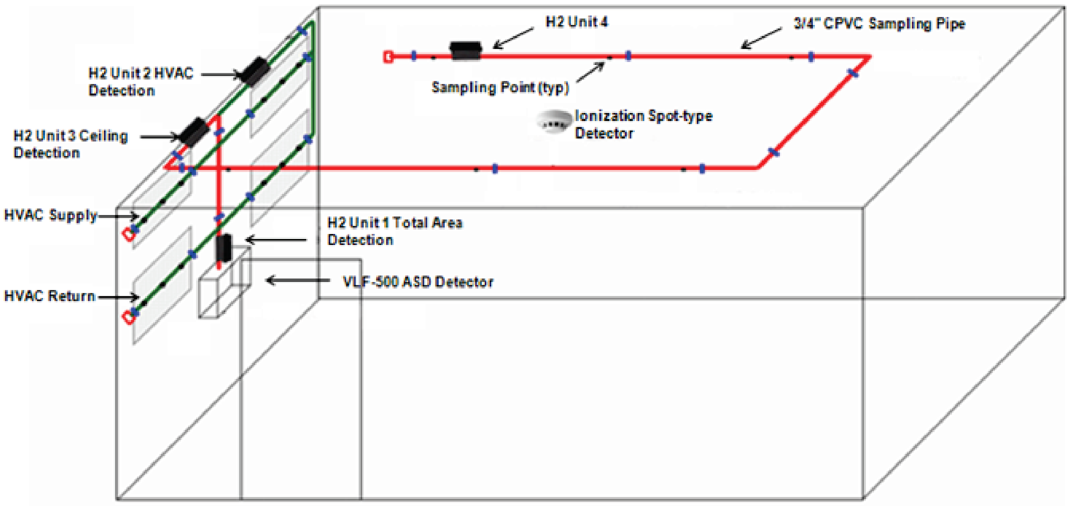

Figure 8 – Test System Layout

Testing apparatus for smoke detection consisted of test apparatus similar to that described in the appendix of NFPA 76 or BS6266 hot wire burn. Materials included a regulated 6 VDC power transformer fitted with positive/negative posts, an on/off switch and timer. Fuel source consisted of 72 in. lengths of 22 AWG PVC coated solid core wire. This test is designed to simulate a small amount of smoke, barely visible, that would be created in the early smoldering stages of an electrical overload in electronic equipment or cables, generally much less that 1kW. The test is intended to be repeatable and representative of an actual event a BTS structure may experience.

Presentation and Interpretation of Test Data:

Still Air Tests

The aspirating smoke detector consistently signaled alarm conditions within seconds from the initiation of each smoke test while the ionization spot-type detector only went into alarm 212 seconds later. This test demonstrates that with no airflow present, a low energy smoldering event rises towards the ceiling where it accumulates and propagates outward. Unless directly above the source of ignition, a spot-type detector is not likely to detect a low energy smoldering event until such time that the smoke density has accumulated at the detector and in a concentration equal to its sensitivity threshold. ASD detection technology with multiple holes distributed at the ceiling has the advantage of accumulating smoke from multiple points, thus increasing the smoke concentrations within the detection chamber.

Hydrogen ASD unit #2, covering the HVAC supply grilles, recorded the lowest gas readings for all still air tests. This can be attributed to the fact that this detector is monitoring the space below the ceiling and any hydrogen present would be diluted from the mixing of air within the space. The data collected suggests that positioning a detector to monitor gas concentrations at the supply air grilles would not provide adequate gas monitoring for the space.

Hydrogen ASD unit #3, covering the ceiling, demonstrated the most consistent and repeatable results of all tests performed. The average gas concentration measured during still air tests was 27% Lower Explosive Limit (LEL) with a maximum variance of 3% LEL. Low alarms would have been activated in each of the still air tests. This test validates the assumption that hydrogen gas vented by the batteries would rapidly rise and spread across the ceiling under still air conditions.

Hydrogen ASD unit #4, mounted and sampling directly above the battery bank, demonstrates that the exact location of hydrogen gas collecting at the ceiling cannot be predicted and reinforces the assumption that pockets of hydrogen accumulation can form. The average reading of this detector during still air tests was 15% LEL with a maximum variance of 12% LEL. Low alarm levels were exceeded in one out of 4 still air tests.

The hydrogen spot-type detector alarmed in three out of four tests. Low alarms were activated twice and a high alarm was activated once. Test one did not active the 25% LEL low alarm and test 4 activated the 50% LEL high alarm indicating that the minimum variation between still air tests was at least 25% LEL

Recirculation Air Test

The results of smoke tests while the HVAC system was operational were as expected. The ASD detector consistently signaled alarm conditions within seconds from the initiation of each smoke test while the spot-type detector never went into alarm, even with the test apparatus directly below it where greater density of smoke was released. This test demonstrates that with airflow present, smoke from a low energy event is carried by air currents towards the HVAC return air grilles, through the HVAC system and re-circulated back into the space.

Due to the positioning of HVAC supply grilles, smoke accumulation at the ceiling was unlikely. This partially explains why the spot smoke detector never alarmed. During one particular test, where the smoke concentration level measured well above the spot detector's sensitivity threshold, the detector still failed to alarm. One possible explanation is that a void existed at the ceiling which kept smoke from accumulating where the ionization detector was located. It is also possible that with an air exchange rate of about 70ACH while HVAC systems are operating, the airflow exceeds the spot detectors working range, especially if placed close to the HVAC supply.

All hydrogen detectors showed similar results during the recirculation air tests. None of the detectors reached the 25% LEL level, which is typically the threshold for low level alarm. This was expected due the fact that the HVAC system mixes the hydrogen gas with the entire room air volume and therefore reduces the average hydrogen concentration in the space. IMPORTANTLY, however, the hydrogen ASD units provide adjustable thresholds so that the low level and high level alarms can be configured to accommodate the dilution effects of the HVAC system. In this way, a single hydrogen ASD unit with a distributed pipe network on the ceiling will deliver better area coverage than a single point or spot hydrogen detector that could miss formation of explosive pockets altogether.

SUMMARY

Air-sampling smoke and hydrogen gas detection provide faster response than discrete, separate sensors. This is because of 2 primary reasons:

1. Air-sampling occurs at ports throughout the protected space, while discrete sensors are positioned in fewer locations. If smoke and hydrogen gas do not migrate to the discrete sensors, it will not be detected.
2. The alarm thresholds are field-adjustable to the specific environment, for the earliest possible warning. Discrete sensors typically are preset to a fixed value.

Air-sampling hydrogen gas detection typically requires fewer sensors, because the sampling pipe network is distributed throughout the protected space. This may reduce the total cost of the detection system, while providing more effective protection.