Gas Sensor for Monitoring Stationary Storage Batteries

Hiroki KOBAYASHI*, Tetsuya FUKUNAGA, Satoru SEMBAYASHI, and Junya TAKAGI

The use of renewable energy is expanding to achieve carbon neutrality, and there is a growing demand for stationary battery energy storage systems (BESS), which are essential technologies contributing to the stable supply of energy when combined with generation facilities. Most storage batteries used in BESS are lithium-ion batteries (LiBs). Recently, there has been an increase in fires caused by LiB abnormalities, not only in countries where LiBs were introduced earlier but also in Japan. As a result, safety standards have been established both overseas and domestically. In Japan, the corresponding standard is JIS C4441:2021. To comply with the standard, it is necessary to have a system that detects gas and fire generated when an abnormality occurs in the BESS (such as during LiB thermal runaway) and issues an alarm externally, which is one of the requirements. Nissin Electric Co., Ltd. has developed a sensor for detecting gas generated when an abnormality occurs in LiBs, as a component of BESS. In this report, we introduce the features of this device and examples of its use in the field.

Keywords: gas sensor, storage battery, LIB, JISC4441

1. Introduction

In recent years, the growing adoption of renewable energy and increasing demand for backup power sources have heightened the need for stationary battery energy storage systems (BESS).*1 The global BESS market is projected to grow tenfold in installed capacity, from 30 GWh in 2019 to 370 GWh in 2030 and 3,400 GWh in 2050, expected to expand to an estimated value of up to 47 trillion yen.[1]

The domestic BESS market is also expanding annually, with approximately 6,200 MWh installed as of 2021.[2] Lithium-ion batteries (LiB)*2 are the mainstream choice for the type of storage battery used, due to their high energy density and high number of charge/discharge cycles.

2. BESS Incident Cases and Safety Standards

Overseas, primarily in the United States and South Korea, over a dozen BESS fire and explosion incidents occur annually. Such incidents have also occurred domestically. On March 27, 2024, a fire broke out in a BESS installed adjacent to a mega-solar power generation facility in Isa City, Kagoshima Prefecture, injuring four firefighters during firefighting operations. In response to this incident, the Ministry of Economy, Trade and Industry issued a notice on April 26, 2024, titled “Thorough Implementation of Safety Measures for Battery Storage Equipment Installed at Power Plants, etc.” On the same day, the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications also issued a notice titled “Notes on Firefighting Activities at Electrical Facilities, etc.”

BESS systems have the characteristic that once a fire starts, combustion tends to continue due to the large number of battery modules housed within containers.[3] Common BESS firefighting methods include installing firefighting equipment inside the container and injecting water from outside the container. However, even with these methods, there are cases where the entire system is completely destroyed due to fire. Additionally, concerns exist regarding the generation of contaminated water during firefighting operations. Consequently, recent priorities emphasize the prompt evacuation of nearby residents over aggressive fire suppression efforts. In response to the increase in BESS fire and explosion incidents, the international standard “IEC 62933-5-2:2020,” which specifies safety criteria for BESS, was published in 2020. The domestic equivalent, “JIS C4441:2021,” was published the following year in 2021. According to this standard, regardless of the voltage class of the BESS, non-aqueous electrolyte batteries (e.g., LiB) are used as the battery type 2 and if there are people permanently stationed in surrounding buildings, a system to detect the generation of flammable gases must be installed in the same location as the BESS. Furthermore, if combustible gas is detected, it must be communicated to the operator via audible alarms and visual signals. In other words, to comply with BESS safety standards, a device capable of detecting combustible gas and providing a contact output is required.

Figure 1 illustrates the process by which thermal runaway in a LiB cell, the smallest unit of a LiB, generates

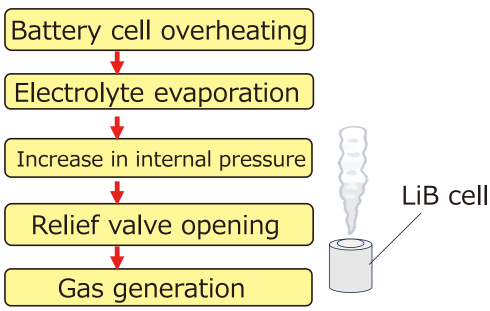

Fig. 1. Thermal runaway process of LiB cells

flammable gas. Overheating of the cell causes the electrolyte to evaporate, generating gas. As the internal pressure within the cell rises, the relief valve activates, releasing the accumulated gas. The main components of this gas are combustible gases such as hydrogen, hydrocarbons, and carbon monoxide. Since flames may be present when the relief valve activates, it is necessary to detect and report these combustible gases at an early stage to minimize damage from fire.

3. Gas Detection Sensor MES-92/93

We introduce the gas detection sensor (MES-92/93) developed by Nisshin Electric Co., Ltd. Photo 1 shows the exterior view, and Table 1 provides an overview of the specifications. This device was developed as one model in the composite environmental sensor lineup.

The sensor installed on the front panel detects gases generated during LiB abnormalities. It enables measurement of the gas sensor output and provides a contact output (LiB abnormality detection) when the gas sensor output rises.

Photo 1. Gas detection sensor MES-92/93

Table 1. Specifications overview of MES-92/93

Item	Specifidations	
	MES-92	MES-93
Dimensions/weight	W50 × H80 × D120 mm / ≤ 250 g	
Contol power supply	AC80-264 V • DC80-143 V	
Measurement items	Gas sensor output / temperature	
Data logger	Records 40,000 data points	
Device settings / data collection	Performed by connecting the USB port to a computer	
Contact output	a contact (when gas sensor output rises)	
Remote communication function	Wired (RS-485)	wireless (920 MHz band multi-hop)

4. Distinctive Features of the Gas Detection Sensor

The sensor used in this device was selected based on the following criteria:

1. Reliable detection of gases generated during LiB abnormalities
2. Ensuring long-term continuous operation performance
3. Consideration for maintenance
4. Cost and availability

As a sensor satisfying these requirements, a semiconductor gas sensor was selected. This sensor has extensive usage experience in air purifiers and similar applications, is relatively inexpensive, and can be operated with a simple detection circuit. The detection circuit is shown in Fig. 2. When a semiconductor gas sensor detects the target gas, its internal resistance decreases. This decrease in resistance can be detected by the voltage rise across a series-connected measuring resistor. The semiconductor gas sensor is used under conditions where it is heated to around several hundred degrees Celsius by a heater.

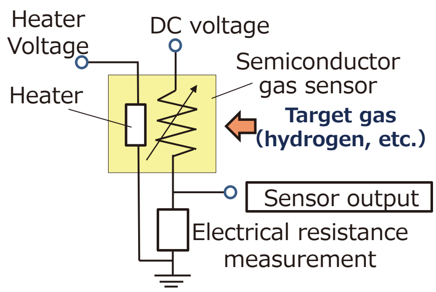

Fig. 2. Gas detection circuit

4-1 Reliable detection of target gases

Semiconductor gas sensors come in various types depending on the gas types they detect. Comparative analyses, including simulated LiB cell failure tests, were conducted on multiple semiconductor gas sensors. As a result of these analyses, a semiconductor gas sensor with a wide detection range for combustible gases such as hydrogen, hydrocarbons, and carbon monoxide, which are generated during LiB abnormalities, was adopted for this device.

4-2 Ensuring long-term continuous operation performance

The semiconductor gas sensors used in this device have a proven track record of durability through extensive long-term use. However, it is necessary to consider their temperature characteristics, individual variation, and changes over time.

Regarding temperature characteristics, the influence of temperature was minimized by correcting the gas sensor output based on measured temperature values.

Furthermore, evaluating the gas sensor output as a relative value rather than an absolute value reduces the impact of individual sensitivity variations and aging effects. The specific LiB anomaly detection algorithm is shown in Fig. 3.

The gas sensor output remains nearly constant when the LiB is normal, but increases when gas is generated during an abnormality. In such cases, LiB abnormality is determined by whether the ratio of the “current value” to the “moving average value from 1 to 2 hours prior to the current value” exceeds a threshold. The threshold represents the increase factor of the gas sensor output compared to its normal state, initially set at 3 to 5 times. This detection algorithm reduces the impact of individual sensitivity variations and changes over time. The threshold can be modified using the integrated application, which is the shared display setting software for the composite environmental sensor lineup.

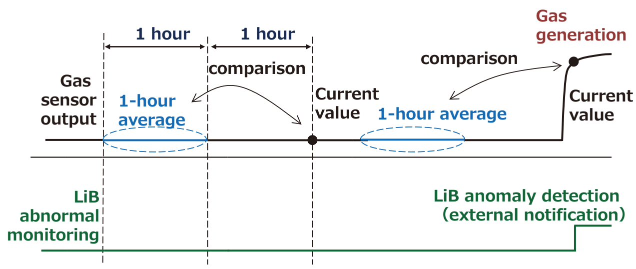

Fig. 3. Detection algorithm

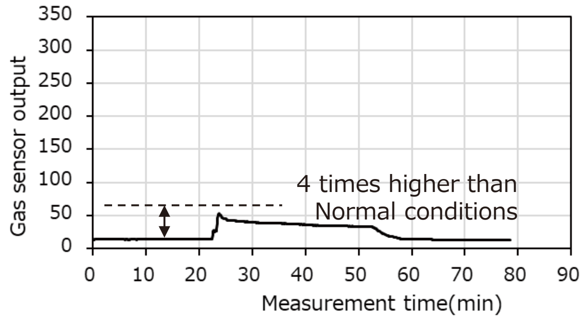

Fig. 4. Example 1 of anomaly simulation test

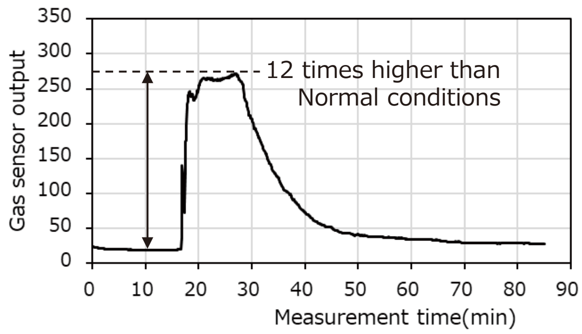

Fig. 5. Example 2 of anomaly simulation test

4-3 Maintenance considerations

As described in Section 4-2, the relative evaluation of LiB abnormality detection eliminates the need for periodic calibration of this device.

However, similar to fire detectors, periodic inspection of this device is preferable. Inspection can be easily performed by using a commercially available hydrogen gas spray to reproduce an abnormal state and confirming that the LED lamp indicating gas detection on the main unit is flashing or illuminated.

Furthermore, this device is a plug-in type designed for socket mounting. Replacement due to end-of-life or other reasons can be performed easily without requiring tools or special skills.

5. Abnormal Condition Simulation Test

A thermal runaway simulation test was conducted by placing the LiB cell and this device in a sealed test chamber and heating them using an external heater. The gas sensor output measurement results when gas was generated from the LiB cell are shown in Figs. 4 and 5.

In both cases shown in Figs. 4 and 5, the test chamber volume is roughly equivalent to that of a 40-foot container typically used as a BESS. The device was positioned at a sufficient distance from the thermally runaway LiB cell, demonstrating reliable detection even when the generated gas was sufficiently diluted. The reason the ratio of the gas sensor output increase during gas generation is larger in Fig. 5 than in Fig. 4 is likely due to the difference in LiB cell capacity.

Figure 6 plots the ratio of the gas sensor output increase on the vertical axis and the cell capacity / test chamber volume ratio (as a relative value) on the horizontal axis for multiple simulated failure test results, including those mentioned above.

As the cell capacity / test chamber volume ratio increases, the gas concentration after dilution becomes higher, resulting in a higher gas sensor ratio of the gas sensor output increase. Therefore, when monitoring new electrical equipment using this device, it is possible to estimate the gas sensor output increase ratio during LiB cell abnormalities based on the cell capacity / test chamber volume ratio, enabling the setting of an appropriate threshold for LiB abnormality detection.

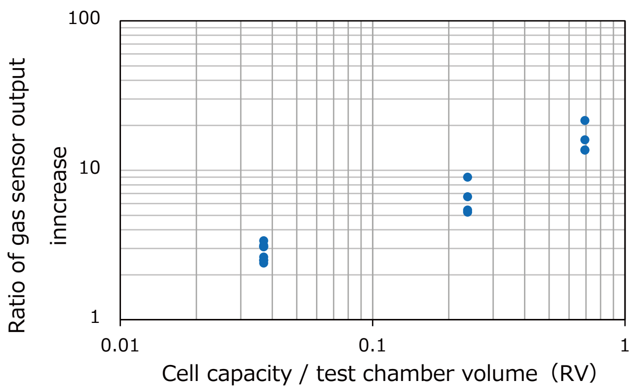

Fig. 6. Ratio of the gas sensor output increase for test conditions

6. Operational Equipment Monitoring Results

This device was installed to monitor an outdoor BESS. Photo 2 shows an exterior photo, and Fig. 7 shows the acquired monitoring data. The measurement period was from November 1, 2023, to February 29, 2024.

Figure 7 (a) shows the maximum gas sensor output value per hour, (b) shows the average gas sensor output value per hour, and (c) shows the gas sensor output increase ratio calculated by dividing (a) by (b) from one hour prior.

Photo 2. Installation conditions

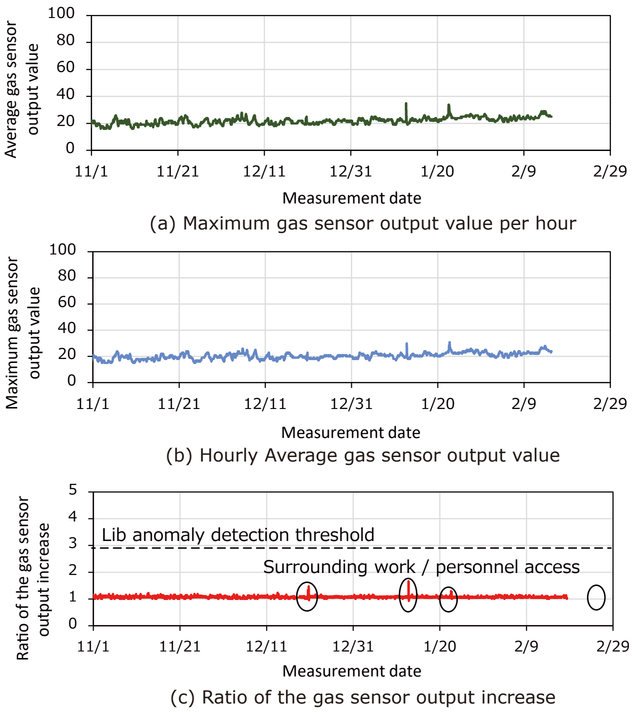

Fig. 7. Monitoring data

Both the maximum and average gas sensor outputs showed fluctuations, while the gas sensor output increase ratio remained approximately 1 × for most of the period. During the observation period, no gas that could be attributed to LiB abnormalities was actually generated, confirming normal monitoring was maintained. Furthermore, the gas sensor output increase ratio rose to approximately 1.5 several times during the observation period, but it was confirmed that surrounding work or personnel access occurred during these periods. Unnecessary detections due to output increases caused by these factors can be prevented by setting the LiB abnormality detection threshold sufficiently high. Similar continuous monitoring is currently being implemented at multiple facilities. Table 2 shows the maximum gas sensor output increase ratios observed at each monitoring facility. In all monitoring cases, the gas sensor output increase ratio was 1.7 or less.

Therefore, it was confirmed that for the equipment monitored this time, setting the LiB anomaly detection threshold to 3 times or higher enables LiB anomaly monitoring without unnecessary detections.

Table 2. Facility monitoring results

Facility	Monitoring period	Maximum gas sensor output increase ratio
Facility A	2023/10/21-2024/4/26	1.67
Facility B	2024/4/10-2024/4/26	1.33
Facility C	2024/4/10-2024/4/26	1.33
Facility D	2024/4/10-2024/4/26	1.25
Facility E	2024/4/10-2024/4/26	1.67
Facility F	2024/2/19-2024/4/25	1.43

Setting the LiB anomaly detection threshold and monitoring data can be easily performed using the integrated application. Figure 8 shows an example of an individual screen when connected to MES-92/93. This application can be downloaded from the website of Nissin Electric Co., Ltd.

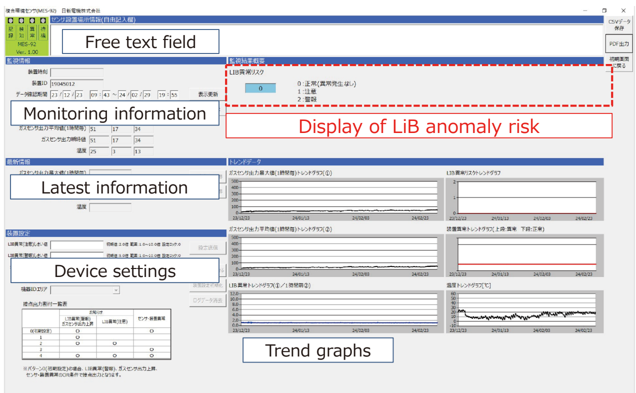

Fig. 8. Integrated application screen

7. Introduction to the Sensor Lineup

The sensor lineup, including the newly developed MES-92/93, is shown in Table 3.

Table 3. Sensor lineup

No	Model number	Photo	Sensing	Control	commnication
1	MES-61		• Temperature • Humidity • Insulation resistance	SH control 10A × 2	Not available
2	MES-52/53		• Temperature • Humidity • Insulation resistance • Vibration resistance	SH control 3A × 1	Available
3	MES-32/33		• Dust accumulation • Insulation resistance • Temperature	Notice 3A × 1	Available
4	MES-42/43		• Corrosion risk (hydrogen sulfide) • Temperature	Notice 3A × 1	Available
5	**MES-72/73** ***New product**		• Local temperature (3 points)	Notice 3A × 1	Available
6	**MES-82/83** ***New product**		• Temperature distribution (64 points)	Notice 3A × 1	Available
7	**MES-92/93** ***New product**		• Generated gasses (H2, CO, and hydrocarbons)	Notice 3A × 1	Available

It enables monitoring of sensing items such as temperature, humidity, dust, corrosive gases, and overheating to meet the needs for monitoring electrical equipment. The common product features of the composite environmental sensor lineup are as follows.

(1) Communication Function

Measured data can be automatically collected and remotely monitored via communication functions. The communication method can be selected from wired or wireless types (except for the MES-61).

(2) Data Logging

Measured data can be recorded in the internal memory for 30,000 to 40,000 data points (equivalent to 3 to 4 years of data logging once per hour) depending on the sensor type (for MES-82 / 83: 7,200 data points). Recorded data can be transferred to a PC via a USB cable using the integrated application.

(3) Easy Installation

The sensor unit is lightweight and compact, mountable on a DIN rail.*3 Its universal socket facilitates easy installation and replacement.

By using the composite environmental sensor lineup individually or in combination, and analyzing the results, it is possible to evaluate the impact on electrical equipment and propose improvements.

8. Conclusion

Nissin Electric Co., Ltd. has developed the gas detection sensor (MES-92/93) as a component for systems that detect gases generated during LiB abnormalities in BESS and issue external alarms. This device features a semiconductor-type gas sensor, enabling measurement of the gas sensor output and providing a contact output function that activates when the gas sensor output rises. Going forward, as demand for BESS increases, awareness of ensuring their safety will grow, making compliance with the safety standard JIS C4441:2021 all the more critical. Given this context, we anticipate an increase in demand for this device.

Nissin Electric Co., Ltd. continues its efforts to develop a comprehensive environmental sensor lineup and accumulate know-how through field testing, aiming to advance and streamline electrical equipment maintenance. We intend to further promote product development and diagnostic technology improvements, contributing to achieving the SDGs and advancing the smart transformation of electrical safety.

9. Acknowledgments

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Technical Terms

*1 Stationary Battery Energy Storage System (BESS): A system that stores generated electricity in batteries and supplies it when needed.

*2 Lithium-ion Battery (LiB): A rechargeable secondary battery that can be used repeatedly. Charging and discharging occur through the movement of lithium ions between electrodes. While rechargeable secondary batteries offer the advantage of high energy density, there is a risk of heat generation and the possibility of fire, necessitating ongoing research to improve safety.

*3 DIN Rail: A metal rail for easily mounting electrical components such as relays, timers, and circuit breakers within control panels or distribution boards, using a standardized method. This rail conforms to the German Industrial Standard (DIN).

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