# Next Generation Wireless Battery Monitoring System (Gen.2)

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## 1 Abstract

The lead acid battery used for backup use is adopted in communications equipment for the use of UPS, such as cell phone base station. The UPS needs are especially growing for the use in large scale sites requiring high reliability, as in data centers, which are increasing their size continuously. On the other hand, the lead acid battery of the staff and the maintenance of the automation to measure were expected very much. Therefore, we develop a monitoring system in the next generation called Gen.2 in substitution for the system which was developed before being called Gen.1. This paper takes a flow and next generation monitoring system called Gen.2.

## 2 Characteristics of the New Product (Gen.2)

- We adopted a configuration in which a slave monitoring device installed in the lead acid battery automatically measures the voltage, impedance, and temperature of (or near) the battery. The measurement data is then transmitted wirelessly to a master monitoring device. This configuration, in which the battery conditions can be monitored on a cloud server, is provided as a basic option. However, some customers might want to restrict communications with outside devices because of security concerns. To handle such a situation, we also provide an optional configuration that works in the same way as Gen.1, and enables operation by installing a higher-level PC.
- The master monitoring device incorporates a function that enables communication by switching between multiple antennas, and a function that changes frequencies if a communication abnormality occurs. These functions improve the reliability of wireless communications between the master and slave monitoring devices.
- This configuration enables measurements of impedance values at low frequencies in addition to measurements of regular internal resistance, and also enables improvements in the state-detection function, such as for capacity estimates of discharge characteristics.
- This configuration also enables a balancing function that can stabilize the battery state by equalizing the battery voltage.

## 3 Background of the Development

Industrial lead acid batteries for backup use are widely employed in various fields: such as for landline phones, cell phone base stations, communications infrastructures of backbone networks, DC power supply of power plants and buildings, and the power supply to data centers.[1), 2)] Higher reliability of lead acid batteries is desired as data centers increase in size because of various factors: in particular, the spread of e-shopping (web-based businesses), the computerization and globalization of transactions, and the spread of smartphones[3)]. In addition, requirements for equipment used for social infrastructure, such as communications and electric power, are that remote personnel must be able to verify whether a battery used for backup power is in a normal state and that, when a disaster occurs, the remote personnel must be able to check whether the battery is usable. As a method for detecting battery abnormalities, trend management by measuring the temperatures, voltages, and internal resistance values of the battery is often used. In addition, automation (the need to change from conventional manual measurements to status monitoring by automated measurements) is becoming increasingly important. Furthermore, upgrading lead acid battery equipment requires both money and time, and there is a need to precisely grasp the timings for such upgrades. Therefore, when we developed the Gen.1 wireless battery monitoring system, we applied automated measurements to large-scale lead acid battery equipment. This enabled safety-oriented automated measurements, which reduces installation work, simplifies harnesses, and avoids insulation breakdowns due to harness contact. In addition, automated measurements made it possible to provide a calendar function that indicates when it is time to upgrade a battery. Furthermore, IoT has become widespread in recent years. To handle

IoT and to enable remote monitoring of data at multiple installation sites, we decided to develop Gen.2. Gen.2 is designed on the premise of continuous remote monitoring by using cloud servers. In addition, we decided to support single-cell measurements (not supported by Gen.1), and to enhance communication reliability.

## 4 Details of the Technology

**Figure 1** shows an example of the usage period of a backup battery, and the typical characteristics of the internal resistance and trickle current. As shown in the figure, the internal resistance and trickle current gradually decrease after use of the lead acid battery starts, and then gradually increase in the end-of-life period. Then, if a lead acid battery continues to be used beyond its end-of-life period, the internal resistance and trickle current increase sharply. Continued use of the battery under such conditions may result in heat generation and smoke.[4] Therefore, we need to have adequate controls that detect sharp rises and to report that a battery upgrade is required. Note that the relative ratio of the usage period is the relative value when 100% is set as the designed service life.

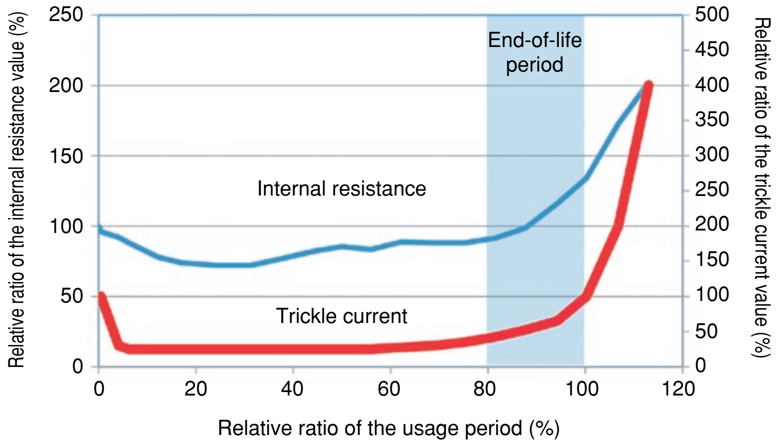
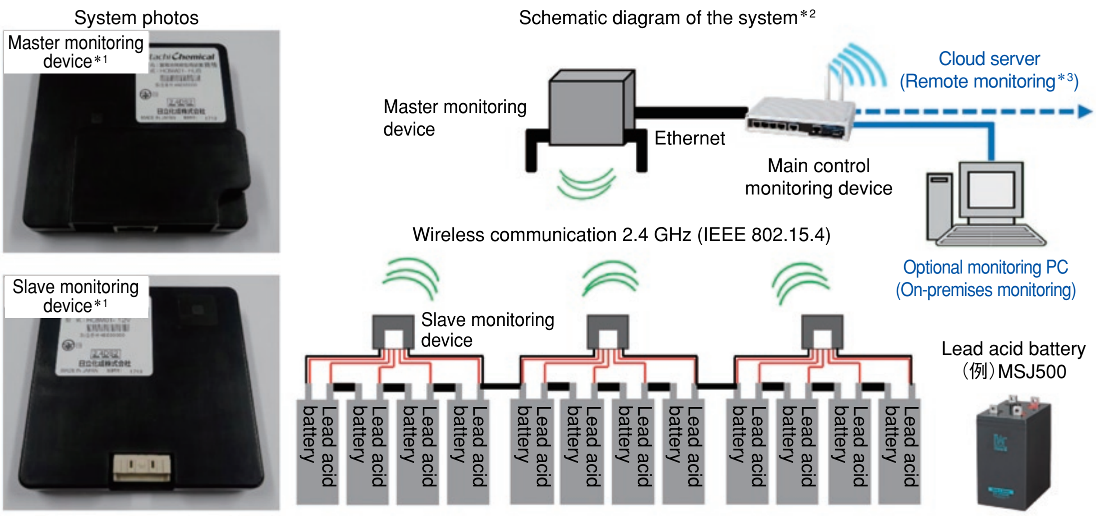



Figure 1 Typical characteristics diagram of impedance and trickle current

Gen. 1 and Gen. 2 wireless battery monitoring systems are designed to report the standard battery upgrade times based on the usage period, and to confirm the soundness of a lead acid battery by continuously monitoring trends in its voltages, temperatures, and internal resistance values.

**Figure 2** shows the equipment configuration for a wireless monitoring system of storage battery states. **Table 1** shows the specifications of the developed system.




*1 Built-in antenna
*2 Installation with existing battery equipment is also possible.
*3 Proven IoT platform services are adopted, and high security is ensured.

Figure 2 Equipment configuration of wireless monitoring system of storage batteries states

**Table 1** shows the specifications of the developed system.

Table 1  Specification of the developed system

| Item | Description | | |
|---|---|---|---|
| Component devices | Basic configuration | Master monitoring device, slave monitoring device, main control monitoring device | |
| | Optional | Cloud server, higher-level controller | |
| Wireless communication system | IEEE 802.15.4 (2.4 GHz) | | |
| Supported battery | Mono-block type | 12 V series | UP, HSE/MSE/MSJ |
| | | 6 V series | HSE/MSE/MSJ |
| | Unit cell type | 2 V series | MSE/MSJ  MU series |
| No. of batteries that can be monitored (per main control monitoring device) | Mono-block type (6 V or 12 V types) | 2,160 (8 master monitoring devices x 270 slave monitoring devices x 1 battery/slave monitoring device) | |
| | Unit cell type (2 V type) | 8,640 (8 master monitoring devices x 270 slave monitoring devices x 4 batteries/slave monitoring device) | |
| Monitored items | Voltage, temperature, internal resistance (impedance: multiple frequencies) | | |

The Gen.2 system includes a wireless slave monitoring device, wireless master monitoring device, main control monitoring device, and cloud server or higher-level controller. The wireless slave monitoring device is connected to the battery to measure temperatures of (or near) the battery, battery voltage, and internal impedance, and transmits the data to the master monitoring device wirelessly. The data is transmitted by an Ethernet connection to the main control monitoring device, where the data is stored. After that, the data is transferred to the cloud server or higher-level controller. The cloud server or higher-level controller manages the measurement data, and uses trend and threshold management to determine whether the battery is in a deteriorated or abnormal state. The system we developed for Gen.2 is based on a cloud server, and enables data to be shared between the customer and our service (administration) department. However, some customers might want to restrict communications with outside devices because of security concerns. To handle such a situation, we also provide an optional configuration that enables operation by installing a higher-level controller.

**Table 2** compares the existing system (Gen.1) with the newly developed system (Gen.2).

Table 2  Comparison between Gen.1 and Gen.2

| No. | Item | | | Existing system (Gen. 1) | Developed system (Gen. 2) |
|---|---|---|---|---|---|
| 1 | Equipment performance | Communication method | | Wireless 2.4 GHz band IEEE 802.15.4 | Wireless 2.4 GHz band IEEE 802.15.4 |
| 2 | | Battery to be measured | | ・12 V or 6 V mono-block battery<br>・2 V battery (to be measured with three or four batteries connected in series)* | ・12 V or 6 V mono-block battery<br>・2 V battery |
| 3 | | No. of data items for batteries to be measured | | 1,620 or below | 2,160 or below (6 V or 12 V batteries)<br>8,640 or below (2 V batteries) |
| 4 | | Voltage | Range (V) | 4.0～15.5 | 1.5～15.5 |
| | | | Accuracy (mV) | ±200 or below | ±50 or below |
| 5 | | Temperature | Range (℃) | −10～60 | −10～60 |
| | | | Accuracy (%) | ±1.5 or below | ±1.5 or below |
| 6 | | Internal resistance | Range (mΩ) | 0.1～20 | 0.1～30 |
| | | | Accuracy (%) | ±3.0 (FSR) | ±3.0 (FSR) |
| 7 | | Current consumption (slave monitoring device: mA) | | 2 or below on average | 2 or below on average |
| 8 | Extra features | Abnormality detection | | Voltage, temperature<br>Internal resistance, communication | Voltage, temperature<br>Internal resistance, communication |
| 9 | | Prediction of lifetime | | Refer to the designed service life. (Without temperature compensation) | Refer to the designed service life. (With temperature compensation, under development) Predictive-indicator diagnosis (Under development) |
| 10 | | Estimation of high ratio service capacity | | Not supported | Under development |
| 11 | | Voltage balancing | | Not supported | Under development |
| 12 | | Remote monitoring | | Not supported | Supported |
| 13 | | Communication stability | Antenna diversity | Not supported | Supported |
| 14 | | | Ch change, timing control | Not supported | Supported |

*The 2V battery is monitored as a pseudo mono-block battery with three or four batteries connected in series.

**Figure 3** shows an internal block diagram of the Gen.2 wireless slave monitoring device (for unit cells).

Gen.1 was able to measure the voltage and internal resistance of only one battery, by using one slave monitoring device.

To measure the voltages and impedances of a unit cell, the Gen.2 slave monitoring device carries out measurements with ADC by switching terminal voltages of multiple cells with the multiplexer (MUX). In addition, Gen.1 adopts a commercial wireless communication module equipped with a chip antenna. However, as shown in **Figure 4**, Gen.2 adopts an on-board wireless circuit unit to reduce costs, and the antennas are pattern antennas. Note that the wireless master monitoring device of Gen.2 has a configuration in which two pattern antennas use different half wavelengths, which enables communication by both antennas. This improves the reliability of communications.

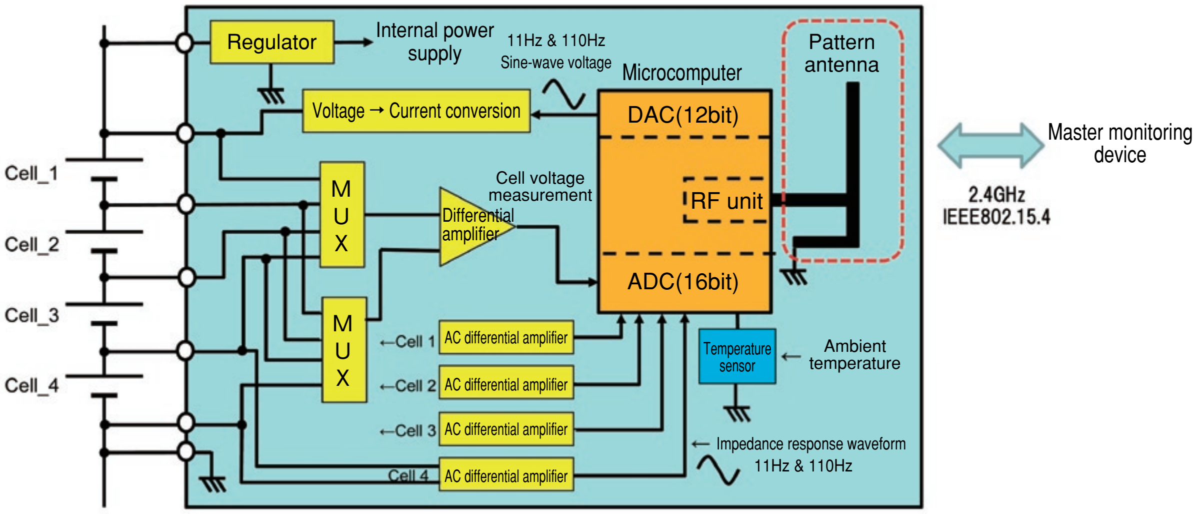



Figure 3  Block diagram of the Gen.2 wireless slave monitoring device

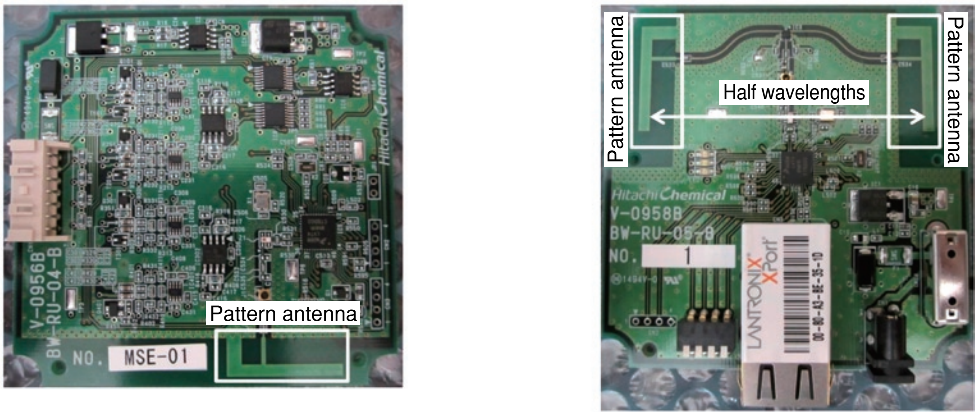



Figure 4  Photographs of wireless slave monitoring device (left) and master monitoring device (right)

**Table 3** shows the specifications of the slave monitoring devices. Multiple types of slave monitoring devices are used this time. More specifically, there are types for unit cells and types for mono blocks. The types for unit cells assume an assembled battery in which multiple unit cell batteries are connected in a series as one item, and measurement is conducted for each unit cell. Although it is possible to install a slave monitoring device for each unit cell, such installation increases the number of slave monitoring devices, thereby increasing costs, congestion during wireless communication, and radio-wave interference. Therefore, we adopted the previously described configuration. Furthermore, taking radio-wave interference into account, we equipped the master monitoring device with a function to enable communication by switching between the two antennas, a frequency-switching function that varies the frequency during a communication abnormality, and a function to adjust communication timing in order to prevent redundancy of communications between the master monitoring device and multiple slave monitoring devices. **Table 4** shows the specifications of the wireless master monitoring device. One master monitoring device is capable of monitoring up to 270 slave monitoring devices. **Table 5** shows the specifications of the main control monitoring device. Up to eight master monitoring devices can be controlled.

Table 3 Specification of slave monitoring device

| Item | Unit cell | | Mono-block | |
|---|---|---|---|---|
| | 3 cells | 4 cells | 6 V type | 12 V type |
| Voltage range monitored (V) | 1.400～3.000 | 1.400～3.000 | 4.20～9.00 | 8.40～18.0 |
| Temperature range monitored (℃) | −10.0～60.0 | −10.0～60.0 | −10.0～60.0 | −10.0～60.0 |
| Monitored internal resistance range (mΩ) | 0.100～10.000 | 0.100～10.000 | 1.00～30.00 | 1.00～30.00 |
| Input voltage (V)(DC) | 4.2～12.0<br>(To be supplied from a battery) | 4.2～12.0<br>(To be supplied from a battery) | 4.2～18.0<br>(To be supplied from a battery) | 4.2～18.0<br>(To be supplied from a battery) |
| Current consumption (mA) | ≦2.0 | ≦2.0 | ≦2.0 | ≦2.0 |
| Outside dimensions (mm) | W:86.0×H:86.0×D:13.0 | W:86.0×H:86.0×D:13.0 | W:86.0×H:86.0×D:13.0 | W:86.0×H:86.0×D:13.0 |

Table 4 Specification of master monitoring device

| Item | Common to each type |
|---|---|
| Max. number of slave monitoring devices connected (units) | 270 |
| Input voltage (V) | DC:4.5-5.5 |
| | 100 V AC (compact UPS)<br>Power is from an AC adapter. |
| Current consumption (A) | 0.5 |
| Outside dimensions (mm) | W:86.0×H:86.0×D:13.0 (excluding protrusions) |

Table 5 Specification of main control monitoring device

| Item | Common to each type |
|---|---|
| Max. number of master monitoring devices connected (units) | 8 |
| Input voltage (V) | DC:12.0～20.0 |
| | 100 V AC (compact UPS)<br>Power is from an AC adapter. |
| Current consumption (A) | 3/12V |
| Outside dimensions (mm) | W:117.0 ×H:92.0×D:35.0 |
| Ethernet port | RJ45 (10BASE-T, 100BASE-TX) |

The features of the software are described next:

( i ) To ensure the reliability of communications of the master and slave monitoring devices, we implemented a system in which the master monitoring device communicates with the slave monitoring device by continuously switching between two antennas, and can switch communication frequencies during communication abnormalities.[5), 6)] In addition, to enable communication with multiple slave monitoring devices, we used a method in which the master monitoring device controls the communication timing.

( ii ) To equalize cell voltages, for the software for unit cells, we provided a function to control the balancing circuit for each unit cell; for the software for mono-blocks, we provided a function to control balancing by using a function to measure internal resistance.

( iii ) To shorten the hours needed to develop the software, we adopted a general-purpose Linux gateway for the main control monitoring device.

( iv ) By using the general-purpose IoT platform, connections to the cloud server can be established with security ensured, while using (public) mobile communications.

( v ) The main control monitoring device adopts the Modbus TCP specifications for communication, which enables the main control monitoring device to communicate data as a slave device. By developing software that runs as the master for the Modbus TCP, it is also possible to use an existing monitoring system.

( vi ) We provided a function to report the replacement timings of lead acid batteries. The function measures the temperature of the battery or of the surrounding area, and converts the temperatures to the usage period of the battery, based on Arrhenius's rule.

( vii ) We enhanced the resistance of impedance measurements to noise.

Feature (vii) of the software is explained next. In practical use, ripple voltage may affect the measurement values of internal impedance. This depends on the types of UPS and DC power supplies used, and the size and frequency components differ according to the type of power supply.[4), 7)] With Gen.2, we decided to measure the impedance at frequencies of 110 Hz and 11 Hz, taking into account the noise[7), 8)] from commercial power sources. Note that we plan to provide a function to obtain the value at 1 kHz, for compatibility with past measurement data.

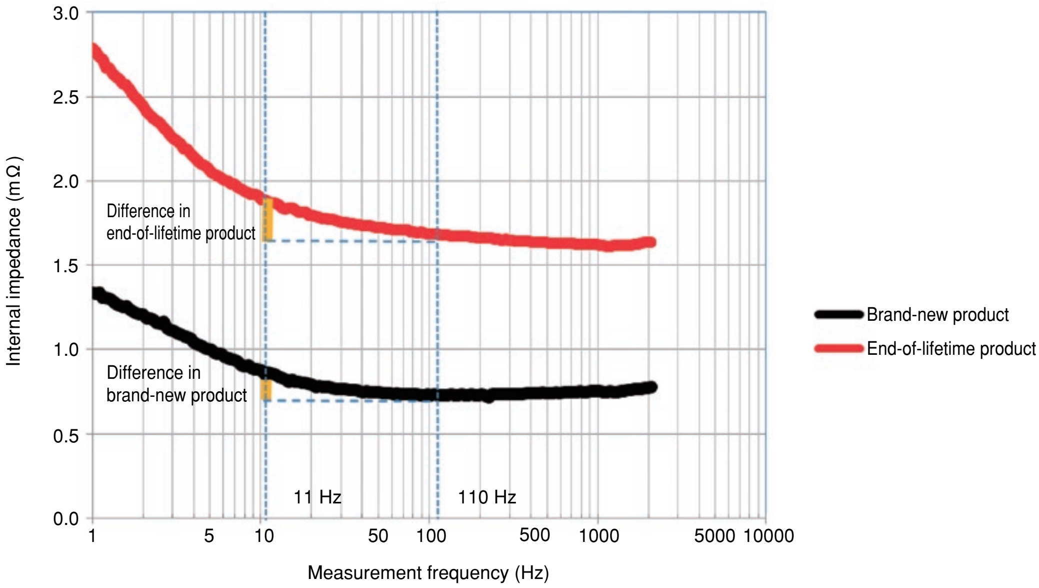



Figure 5 Typical characteristics diagram of impedance and measurement frequency

The impedance at lower frequencies from 5 Hz to 100 Hz is explained next. It is known that the high-rate discharge characteristics of a lead acid battery are dependent on the effective reaction surface area of the negative electrode,[9), 10)] and the indices for this include the electrical double-layer capacity and the charge-transfer resistance. The difference between the impedance of low frequencies in the range from 5 Hz to 100 Hz to be measured with Gen.2 (11 Hz at this time) and the impedance of high frequencies is equivalent to the charge-transfer resistance of the previously mentioned negative electrode; therefore, discharge characteristics at a higher rate than the value can be expected.

As described above, for Gen.2, we adopted specifications that enable measurements of impedance values at low frequencies, which is effective for the assumption that there is high-rate discharge. In addition, the specifications take into account compatibility and continuity with Gen.1 and with the impedance value of 1 kHz, which is the standard in the lead acid battery industry.

## 5 Future Business Development

- Commercialize the products.
- Further improve reliability.
- Increase the precision of predictions of the lifetime of, and predictive-indicator diagnosis for, lead acid batteries
- Take action to handle overseas requirements (wireless authentication and conformance to laws and regulations).

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