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Short communication

Remote monitoring of VRLA batteries for telecommunications systems

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Abstract

This paper describes a remote monitoring system that can be set up in an operating center to monitor the state of valve regulated lead acid batteries (VRLA) used as a backup power supply for telecommunications. This system has a battery voltage monitoring function, a lifetime prediction function based on ambient temperature, and a discharge circuit diagnosis function. In addition, the system can be equipped with an internal resistance measurement function and an electrolyte leakage detection function to further insure power-supply reliability. Various states of batteries observed with the system are transmitted to the remote operating center by a remote monitoring function. This function enables obtaining immediate information about the condition of batteries and helps to avoid unexpected failures.

Keywords: Remote monitoring; VRLA battery; Electrolyte leakage; Lifetime prediction; Internal resistance

1. Introduction

Preserving the integrity of the telecommunications infrastructure, even in the event of a power failure, is critical in today's highly information oriented society. To supply electric power to communications equipment during emergencies, a backup power supply unit is needed. Lead-acid batteries are used for short-term backup units, and emergency generators are used as long-term backup of telecommunication power supplies. Lead-acid batteries are also used for starting the engines of the emergency generators. Therefore, lead-acid batteries play an extremely important role.

The NTT group currently uses about 15,000 sets of assembled lead-acid batteries. Valve regulated lead acid batteries (VRLA) have been used because they require less maintenance work (such as adding water), the installation direction is not restricted, and they offer a longer lifetime [1,2]. At present, 99% of NTTs installed lead-acid batteries are VRLA batteries. The nominal capacity of the VRLA batteries ranges from 150 to 3000 Ah.

As the NTT group recently consolidated its maintenance operations so that these activities are conducted from only two locations, improved efficiency and improvements in the monitoring functions were required. Measurements of voltage and internal resistance are considered essential to the maintenance of VRLA batteries. Previously, a device with these functions has been reported [3]. However, a more efficient and accurate maintenance method was required for VRLA batteries set up in a remote location.

VRLA batteries deteriorate with the lapse of time, so we needed a means of knowing when batteries needed to be replaced. In addition, VRLA batteries were subject to electrolyte leakage. If electrolyte leakage is not repaired, it can cause a fire by forming a short circuit, so a means to detect electrolyte leakage was also necessary.

Based on this background, we have developed a system that can remotely monitor the conditions of VRLA batteries. The system can predict battery lifetime, monitor battery voltage, diagnose discharge circuits, detect electrolyte leakage, and measure internal resistance and the results of these functions can be obtained with a remote monitoring function. The following sections describe and explain this system.

2. Maintenance and management of VRLA batteries for telecommunications systems

VRLA batteries for telecommunications are always kept fully charged and prepared for discharge after they are set up. Moreover, they must discharge effectively during their designed

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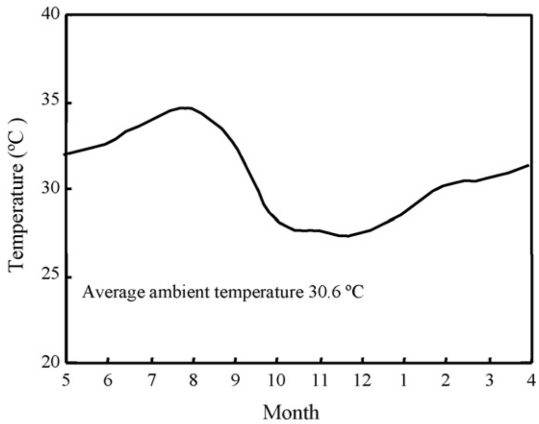

Fig. 1. Example of temperature transition in telecommunications building.

lifetime. Therefore, regular maintenance work to confirm their operational condition is needed.

The condition of VRLA batteries cannot be determined by the specific gravity measurement that is used for flooded lead-acid batteries. Therefore, the regular maintenance required in this case consists of voltage and internal resistance measurements to check battery condition.

To compensate self-discharge, VRLA batteries for telecommunications are continuously charged with a low current. As batteries are charged over a long term, capacity gradually decreases due to corrosion of the positive grid. The ambient temperature greatly influences the deterioration of batteries. When their capacity reaches 70% or less of initial capacity, the batteries are replaced. The discharge test is performed to check battery capacity.

Fig. 1 shows an example of temperature transition in a telecommunications building. The ambient temperature of batteries varies through the year. Therefore, an effective method for efficient maintenance is to predict battery lifetime in advance based on the ambient temperature. In addition, the VRLA batteries must be monitored remotely as maintenance workers are no longer stationed at each site because of the consolidation of our maintenance bases in recent years.

Defective manufacturing and manufacturing scattering cause some problems with VRLA batteries. Fig. 2 shows a VRLA battery burnt by an electrolyte leakage from jar cracks generated by organic solvent. Since the initial electrolyte leakage does not

Fig. 2. VRLA battery burnt by electrolyte leakage.

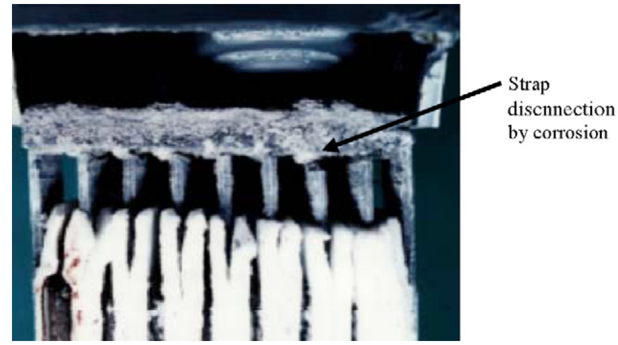

Fig. 3. VRLA battery strap corrosion.

cause a drop in the cell voltage, this failure cannot be detected by monitoring cell voltage.

When a VRLA battery is used where the temperature and humidity are high, nonconductive corrosion may occur between a terminal and a connecting bar. This corrosion interferes with the battery discharge during an electrical blackout. Another failure that prevents a battery from discharging is a disconnection caused by strap corrosion (Fig. 3). These incidents are difficult to find with cell voltage and internal resistance measurements, so an effective countermeasure has been requested for detecting the unexpected incidents and determining the replacement of the batteries.

Table 1 lists the items mentioned above that must be monitored with regard to the VRLA battery.

3. VRLA battery monitoring for telecommunications

3.1. System configuration

We designed a VRLA battery monitoring system to ensure the reliability of these batteries when used in telecommunications and to lower the cost of battery maintenance. The system has four main functions: lifetime prediction, cell voltage monitoring, discharge circuit diagnosis, and remote monitoring. Fig. 4 shows the system configuration. Functions for measuring internal resistance and detecting electrolyte leakage can be added as necessary.

The VRLA monitoring system is composed of the battery management unit (BMU), the information transfer unit, and

Table 1
VRLA battery monitoring items

	Item	Monitoring function
Daily maintenance	State of charge	Voltage measurement and internal resistance measurement
Replacement planning	Forecast of replacement and decision of replacement	Lifetime prediction and capacity test
Failure detection	Leakage detection, terminal corrosion and strap corrosion detection	Leakage detection and circuit diagnosis

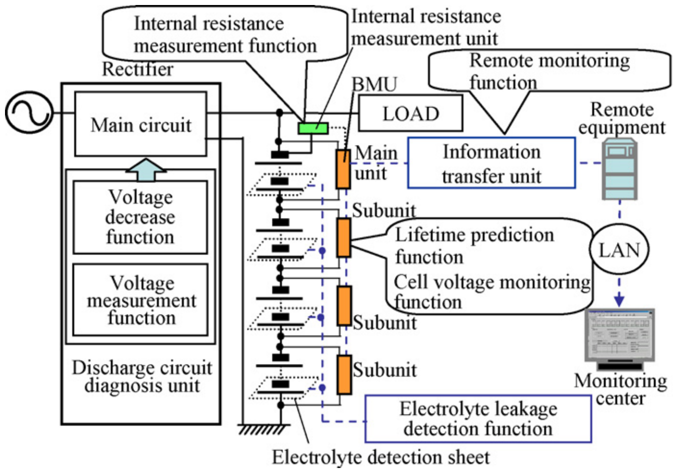

Fig. 4. Configuration of system for remote management of VRLA batteries.

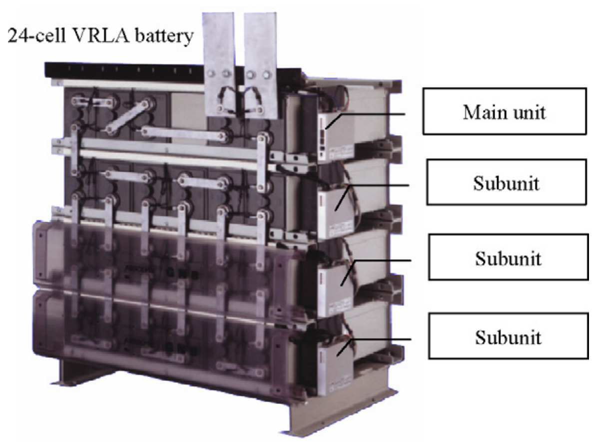

Fig. 5. Installed battery management unit (BMU).

the functions installed in the rectifier and uninterrupted power source (UPS). The BMU is installed directly on a metal battery frame. Fig. 5 is a photograph showing its appearance, and Table 2 lists its specifications. We incorporated the functions for lifetime prediction and the cell voltage monitoring (battery failure detection) in the BMU. In addition, we installed the discharge circuit diagnosis function in the rectifier and the UPS.

We installed the internal resistance measuring function in the measurement unit, and the unit has a constant-current discharge circuit. The unit that detects electrolyte leakage is composed of a leakage detection sheet and a detector. The detection sheets

Table 2
Battery management unit specifications

Item	Specifications
Power source	40–60 V DC
Temperature measurement	−10 to 50 °C
Voltage measurement	1.8–2.5 V DC ±1%
Operating temperature	(−20 to 80) ± 2 °C
Output interface	RS422
Dimensions	28 (*W*) mm × 155 (*H*) mm × 145 (*D*) mm
Configuration	Main unit × 1 + subunit × 3
Capacity	24 cells maximum

Table 3
Information transfer unit specifications

Item	Specifications
Power source	30–60 V DC
Temperature measurement	−10 to 50 °C
Power consumption	10 W
Output communication interface	
To BMU	RS422
To transfer equipment	LAN
To local PC	RS232C
Dimensions	400 (*W*) mm × 215 (*H*) mm × 76 (*D*) mm
Capacity	24 BMU maximum
Housing	Metal

are mainly placed under the batteries. The alarm signal of the electrolyte leakage detection unit can be sent to the BMU.

A BMU set is composed of one master unit and three sub units, and it can monitor up to 24 cells corresponding to a set of batteries used for a −48 V DC telecommunications backup. The BMU can also monitor a set of batteries for a UPS that consists of more than 24 cells by increasing the number of BMU sets. The remote monitoring function enables communication with the monitoring center through a LAN connected to the information transfer unit (Table 3).

3.2. Lifetime prediction

The VRLA batteries that the NTT group uses for telecommunications backup gradually lose their capacity due to positive grid corrosion caused by trickle charging and arrive at the end of their useful life. The degree of corrosion on the positive grid greatly depends on the ambient temperature. When the temperature becomes higher, it promotes the corrosion.

Battery lifetime prediction is a function used to determine when a battery should be replaced. It works by automatically measuring the ambient temperature periodically and applying the correlation between battery lifetime and ambient temperature. According to the Arrhenius' equation, a 10 °C rise in ambient temperature reduces the battery lifetime by half, so its lifetime can be predicted through the following equation based on measured ambient temperature:

$$L_{\mathrm{T}} = L_{25} \times 0.5^{(T-25)/10}$$

where L_{25} is the designed and expected lifetime at 25 °C (years) and L_T is the expected lifetime at T °C (years).

To confirm the validity of this method, we did a temperature accelerated life test on a 2–200 Ah VRLA battery at three levels (40, 50, and 60 °C). Fig. 6 shows the test results [4]. Expected lifetime L_{25} of the battery used in our company is examined beforehand with the high temperature accelerated life test, and this value is written into the memory of the BMU. The lifetime prediction is accomplished by transforming durations under actual use and subtracting the transformed durations from the designed lifetime duration. The temperature variations at a telecommunications building are reflected to transform an actual calendar time to a converted time at 25 °C. An alarm occurs

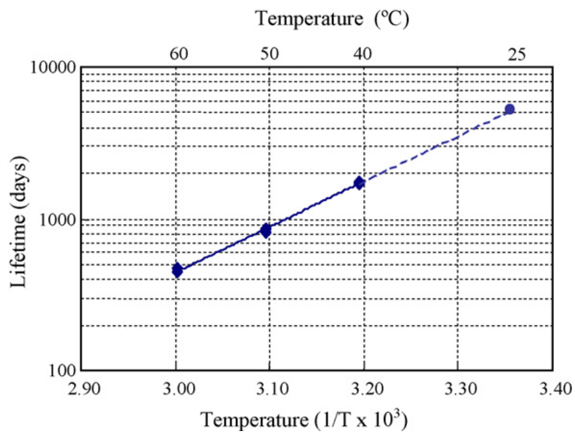

Fig. 6. Correlation between battery lifetime and ambient temperature.

when the lifetime prediction function of the BMU judges that the battery has arrived at the end of its life.

3.3. Battery voltage monitoring

The proper floating charge voltage for a VRLA battery is determined depending on the electrolyte's specific gravity. The VRLA batteries used for telecommunications in the NTT group are charged at the voltage of 2.23 V ±1%. Their lifetime is shortened by the overcharge if they are charged with a voltage higher than the above-mentioned voltage range. Moreover, their lifetime can be shortened by a poor charge state if they are charged with a voltage lower than the range given above.

The first function of battery voltage monitoring is that of continuously observing the total voltage of each battery and to generate an alarm when floating charge voltage deviates from the proper range. Manufacturing defects, such as internal short-circuits or a lack of air tightness can cause battery voltage to drop sooner than expected. The second function of voltage monitoring is that of allowing observation of each cell's voltage during floating charge to detect any defective batteries at an early stage and thus ensure string battery reliability.

3.4. Discharge circuit diagnosis

The discharge circuit diagnosis function checks whether the circuit is operating normally according to the string battery voltage and the duration of a specified short discharge by decreasing the floating charge voltage of the power supply to a level that does not affect the load. Fig. 7 shows this function schematically. As output voltage control and the changeover from the regular power supply to batteries are necessary, we installed this function in the rectifier and UPS. This function is programmed to execute automatically every 3-month.

An automatic program executes this diagnosis, usually once every 3 months. The total voltage and the cell voltage are measured by the BMU while discharging, and the normality of the battery is confirmed. When a defective cell exists in a set of batteries, or there is an insulating material in the circuit, and the discharge is disturbed, the BMU detects the abnormal voltage drop.

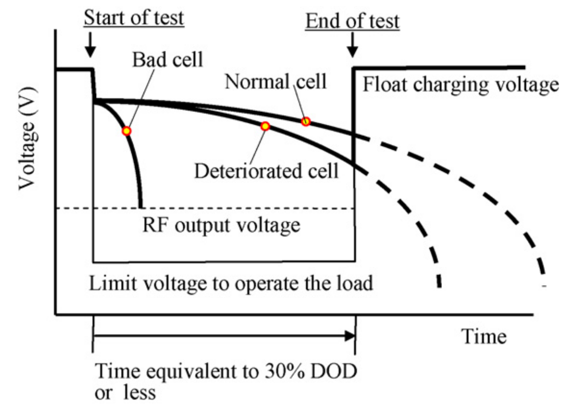

Fig. 7. Outline of discharge circuit diagnosis function.

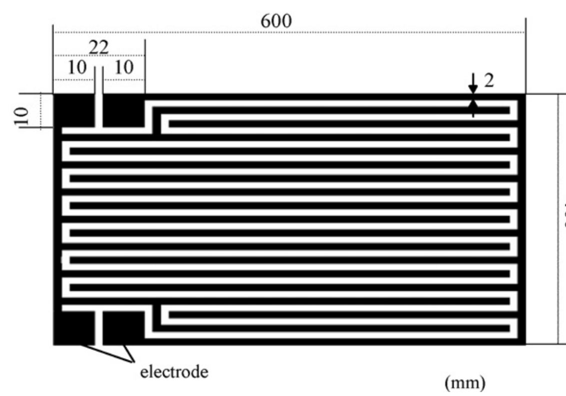

Fig. 8. Copper-foil electrode pattern in detection sheet.

3.5. Electrolyte leakage detection

The electrolyte leakage detection sensor is composed of a detection sheet and a detection circuit. The detection sheet consists of three layers: a flame-resistant PET film, a pair of copper-foil electrodes, and a special coating material that does not react and dissolve in water, but does react and dissolve in sulfuric acid. To detect efficiently the sulfuric acid dropped on the sheet, the pair of copper-foil electrodes is configured in a mosaic pattern. Fig. 8 illustrates an example of the copper-foil electrodes arranged in the sheet.

Fig. 9 describes the detection circuit that is composed of an amplifier, a relay, resistance, and a fuse. Constant DC voltage is

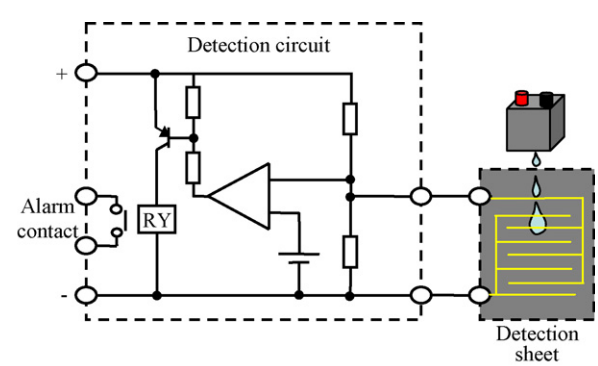

Fig. 9. Electrolyte leakage detection circuit diagram.

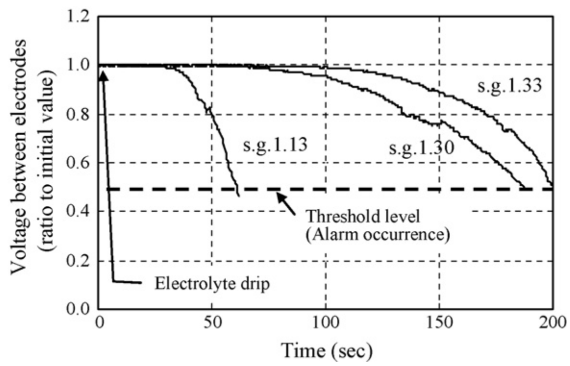

Fig. 10. Electrolyte leakage detection by electrolyte leakage detection unit.

fed continuously between the electrodes by the detection circuit, and any resistance change is detected by measuring the voltage between the electrodes. The detection sheet is usually set up under the battery or on the battery cover near the posts.

The electrolyte dripping onto the sheet will melt the coating and yield conductivity between the electrodes. The detection circuit monitors the change in resistance between the electrodes of the detection sheet as a change in applied voltage, and when the applied voltage falls below a threshold, the alarm contact operates and a warning is sent. We connected the detection sheet and the detection circuit to examine the coating reaction of sulfuric acid. We dropped sulfuric acid onto the detection sheet and measured the voltage between the detection sheet electrodes and the time before the alarm was given. Three sulfuric acid concentrations (specific gravity: 1.13, 1.30 and 1.33) were used.

The electrolyte concentration for the examination was assumed to be the following three concentration levels, normal (before discharge), diluted (after discharge) and enriched (after moisture permeation). Fig. 10 shows test results. The alarm was given within 1–3 min for all of the sample sheets exposed to sulfuric acid when the voltage decreased, so we are confident that this function can detect electrolyte leakage within about 3 min. This data also shows that the detection time tended to become shorter as the specific gravity of the electrolyte decreased. Furthermore, we found no symptom of a voltage change between electrodes when we dropped water on the sheet, and the alarm did not occur.

3.6. Internal resistance measurement

The approximate lifetime of the VRLA battery used by the NTT group for telecommunications purposes is known because the high temperature accelerated life test has been executed prior to introduction, and we can accurately forecast the appropriate time for battery replacement from the correlation between ambient temperature and expected lifetime. The internal resistance measurement function was added for improving the accuracy. Battery capacity has been shown to be correlated with internal resistance. We found that 30% of cell capacity was lost when internal resistance increases to 1.5 times [5]. Therefore, the internal resistance measurement is a function that can forecast lifetime by regularly measuring internal resistance, and observing the tendency of any change in it.

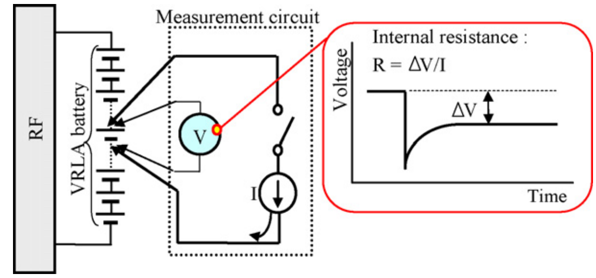

Fig. 11. Circuit for measuring internal resistance with short time discharge method.

Two methods are conventionally used to measure a battery's internal resistance. One is to discharge a battery for a short time and the other is to add an alternating signal to a battery [6]. We have selected the discharge method in this system. In this method, internal resistance is calculated from the battery voltage change ΔV and the discharge current measured when the battery discharges to an externally connected resistance at a constant current. Fig. 11 is a schematic of the measurement circuit for the short-time discharge method.

To determine the proper conditions for measuring the battery internal resistance, we examined the internal resistance measurement with a discharge current and duration as parameters; i.e., we measured the internal resistance of a 2 V VRLA battery while varying the discharge duration at different discharge current levels. Fig. 12 is a graph of the measurement results of the sample 2 V–150 Ah VRLA battery's internal resistance.

Though the measurement value was greatly influenced by the discharge current when the discharge duration was short, when the discharge duration was sufficiently long, a definite internal resistance value was obtained that meets the value measured by the AC impedance measurement apparatus. We found the test current of 5–75 A (0.03–0.5 CA) to be applicable for the 2 V–150 Ah VRLA battery. This experimental result suggests the discharge current rate ranging from 0.02 to 0.5 CA is applicable for the internal resistance measurement in the method. Therefore, even if a single discharge current is selected, multiple kinds of VRLA batteries can be subjected to internal resistance measurement, so long as the selected current is within the applicable range for the VRLA batteries. Therefore, we selected 50 A as the discharge test current for the VRLA batteries with a capacity ranging from 150 to 500 Ah.

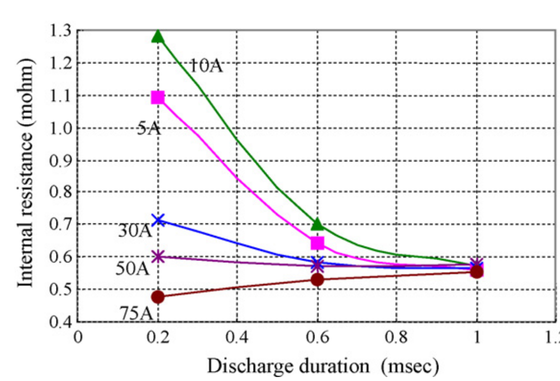

Fig. 12. Internal resistance dependency on measurement conditions.

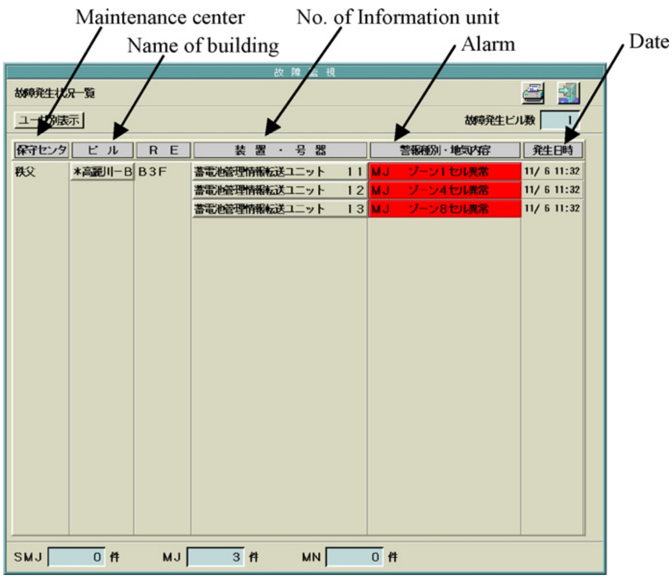

Fig. 13. Example of monitoring center displaying cell malfunction.

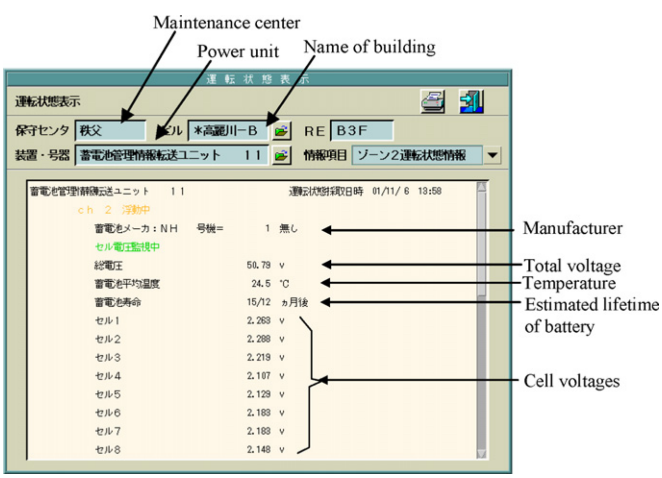

Fig. 14. Example of monitoring center displaying battery status.

After the installation of this function, internal resistance is measured once a month, automatically.

3.7. Remote monitoring

The information transfer unit periodically receives the measurement information and alarm (if any) from the BMU; they are connected through an RS422 interface. This unit notifies the monitoring center after it detects an alarm sent from the BMU. Fig. 13 shows one example of the monitoring center display in the event of a cell malfunction. An operator can confirm the following at once: name of building, number of information unit, alarm information and the date. In addition, when the operator requests information from the monitoring center on the status of the selected string battery, information such as the total voltage, each cell's voltage, average temperature, the appropriate time for battery replacement, and an alarm (if any) is sent back and displayed on the monitor at the center. Fig. 14 shows an example of the monitoring center display regarding the battery status requested by an operator. The operator can learn immediately battery conditions such as each cell's voltage, total voltage, and manufacturer. Thus, knowing the state of the VRLA batteries is possible whenever necessary. The BMUs have worked well in many telecommunications buildings and no system failure has occurred to date.

4. Summary

The VRLA battery remote monitoring system automatically measures each cell's voltage and ambient temperature, reports the appropriate time for battery replacement, and transmits these data to an operating center located elsewhere through the application of the following functions: lifetime prediction, cell voltage monitoring, discharge circuit diagnosis, internal resistance measurement, electrolyte leakage detection, and remote monitoring.

This remote monitoring system represents an upgrade in VRLA battery surveillance because it not only monitors their status, but it also detects malfunctions. We are planning to check the system's effectiveness continuously and to improve its functions taking into consideration the opinions obtained from maintenance personnel.

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