Paper

Maintenance of Lead-acid Batteries Used in Telecommunications Systems

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Abstract—The article presents numerous problems with standby batteries used in telecommunications systems, with a particular emphasis placed on the assessment of their real capacity. The methods used to evaluate the technical condition of batteries and to measure their real capacity are presented. Also, the a new test device which measures the actual battery capacity is presented. The said measurement is based on the discharge test method and is performed with the use of a new TBA-A automated test unit. The article is targeted for electronic designers, managers and telecommunications hardware maintenance personnel, as well as for other telecommunications systems experts.

Keywords*—*battery capacity measurements, maintenance, telecommunications systems.

1. Introduction

Nowadays, a high degree of reliability is an aspect of key significance in the delivery of telecommunications services. This means that telecommunications systems should remain powered even if a mains failure occurs. Lead-acid batteries are the most popular back-up energy source and it is expected that such batteries will remain in use for a long time to come, in spite of introduction, to the market, of new battery types and new reserve power source chemistries. The above means that the problem of maintenance of good lead-acid batteries still remains an issue of high importance.

2. Batteries Used in Telecommunications Systems

Telecommunications systems should ensure continuous availability of services. This applies both to commercial services offered to the general public, and to emergency services supplied over critical infrastructure networks. That means that telecommunications systems should be powered without any interruptions.

Telecommunications systems are powered by installations relying on rectifier-based power systems (PS) and a number of batteries connected in parallel. The batteries should be able to provide backup for a given telecommunications system for a few hours or more. When the mains voltage is present, PS supply energy to the telecommunications equipment and to the batteries associated therewith. Under such conditions, the rectifier provides float voltage (about 54 V) to the batteries, preventing their self-discharge.

Figure 1 shows three basic configurations of power systems dedicated to use on telecommunications sites. The simplest structure, and thus the least reliable, is presented in Fig. 1a. In the case of a mains failure, the powered equipment (PE) is supplied from the battery until either the battery discharges or the mains voltage is restored. Additionally, it should be borne in mind that if rectifier or battery maintenance is performed, an additional, transportable backup power source has to be connected. The configuration shown in Fig. 1b is more reliable due to the added redundancy. It allows to disconnect one rectifier unit or one battery without any disturbances to the PE supply. The configuration shown in Fig. 1c is the most reliable, but at the same time the most expensive. It relies on two independent power systems and two independent mains networks.

In order to increase the level of AC voltage supply reliability even further a backup diesel generator may be connected to the system via an automatic switch [1], [2]. Batteries are the source of power during mains failures. Therefore, their key features should include long battery life, low overall costs of purchase and operation, as well as safety of use.

It should be noted that battery weight is not an important factor in this particular case. Hence, lead-acid batteries fulfill all the requirements mentioned above. They are characterized by high power density of up to 0.1 kWh/kg and by low internal resistance. Despite of advanced technologies relying on other battery chemistries, i.e. NiCd, NiMH, Li-Ion and Li-Po, lead-acid batteries remain the primary standby source of energy in telecommunications power supply systems.

3. VLRA Batteries

Flooded lead-acid batteries have been used in the telecommunications sector for about 100 years now. Because of their open design, they must be installed in separate, ventilated and secured rooms. The first leak-proof, valve-regulated lead-acid (VRLA) batteries first appeared in the 1960s in the USA, but they only began to be used on a wider scale in Europe in the 1990s. It is difficult to say if VRLA batteries are significantly superior to the flooded variety, but they offer certain advantages which have contributed to their widespread use. VRLA batteries have a shorter lifetime, but their maintenance cost is lower. They do not require separate, special rooms, but there is a need to provide float voltage thermal compensation. VRLA units can be installed in rooms used by staff or other electronic equipment, but in a designated area. Adequate room must be

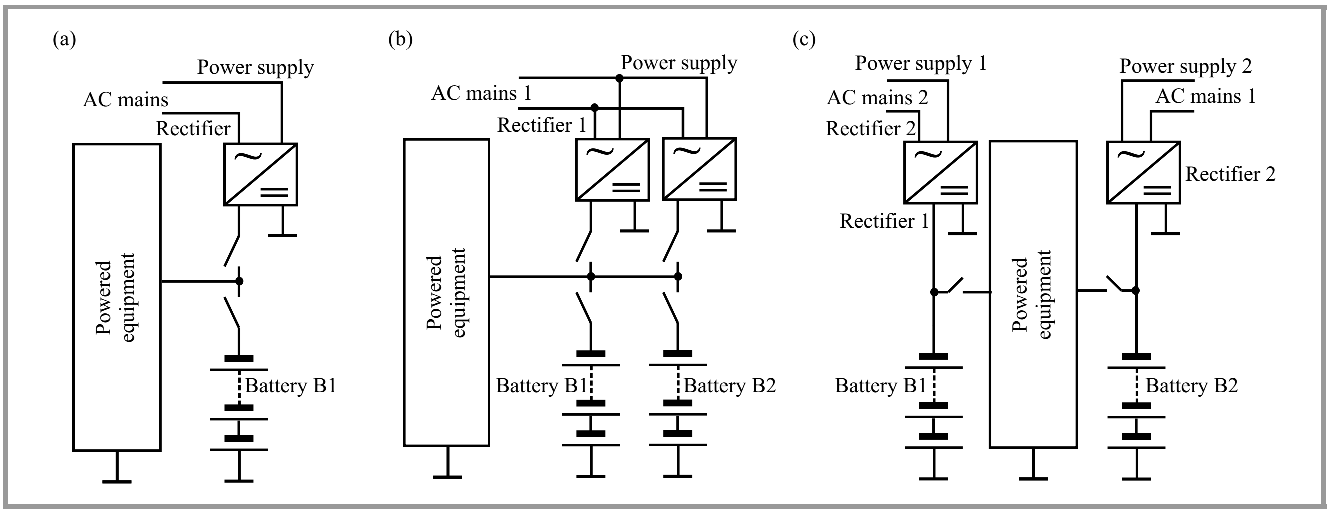

Fig. 1. Examples of power system configurations.

provided around the battery system to allow maintenance, including the exchange of blocks/cells. The area required for installation of VRLA batteries can be smaller than in the case of their flooded counterparts. The battery can be placed vertically or horizontally and can be stacked with the use of a dedicated rack enclosure.

All lead-acid batteries have a defined maximum storage time of six months at the temperature of 18–30°C. By the end of that period, batteries should be either installed or charged. Therefore, it is important to schedule the delivery of batteries to the site and their date of production as close as possible to the date of actual installation.

Two primary types of VRLA batteries exist, relying on gel and AGM technologies. In the case of the gel technology, silica dust is added to the electrolyte, forming a thick putty-like gel. The Absorbed Glass Mat (AGM) technology employs a fiberglass mesh between the individual battery plates. The mesh absorbs and retains the electrolyte. Both technologies offer similar advantages and disadvantages in comparison to conventional battery types.

4. Battery Condition Monitoring

To improve operational functionality of batteries and to protect them against damage, the use dedicated equipment is required. A relevant device can be integrated within the power supply system, may constitute a part of the battery itself, or may be installed as additional, stand-alone test equipment [3], [4]. The following parameters can be monitored with use of this equipment:

- battery voltage,
- charging/discharging current,
- ambient temperature,
- all cell/block voltages and temperatures,
- AC ripple current and voltage.

Voltage and temperature measurements pertaining to all cells/blocks enhance assessment of battery cell balancing and help detect damaged cells. Comparisons of battery string temperatures, in turn, allow for detection of thermal runaways.

Specialized circuits are used in order to improve cell voltage balancing. They reduce cell voltage if it is higher than the prescribed limit value while the battery is charging. Balancers are also used in which the cells with the lowest voltage levels are charged with higher current in order to manage cell voltage more effectively [3], [5], [6].

Generally speaking, monitoring systems are capable of indicating the actual condition of the batteries, but do not reflect their actual capacity.

5. Key Parameter Measurements

All battery manufacturers recommend periodic check of batteries condition including:

- leaks,
- verification of cell interconnection resistance,
- battery capacity measurements.

Battery maintenance always requires that periodic site visits be paid (even on unmanned sites), but attempts are made to minimize the maintenance time. It is recommended that only a few measurements be made to evaluate the condition of a battery, with a particular focus on its capacity and the remaining lifetime. With the accuracy of all crucial parameter measurements, the time and cost of tests, as well as the need to mitigate test-related risks taken into consideration, one may conclude that no single method meeting all the requirements exists [4], [7], [8]. Therefore, internal resistance measurements and discharge tests are among the most commonly used procedures. The properties of such methods are described in detail below.

6. Internal Resistance Measurement

The common internal resistance measurement procedure is cheap, fast and safe, and usually does not require that the battery undergoing the test be disconnected from the power system. It relies either on the analysis of DC pulses or on resistance measurements performed with the use of AC signals [5], [9]. The resistance reflects not only the battery capacity, but also:

- grid corrosion,
- loss of active material from electrodes,
- possible sulfation,
- temperature increase,
- internal short circuit,
- other cell failures.

Measurement equipment manufacturers recommend that a principle be adopted in line with which a 20% loss of battery capacity is related to a 25% increase in the resistance of each cell. It is also estimated that the loss of battery capacity is related to only 40% of the total internal resistance (for the entire battery). Additionally, internal battery resistance may vary by approximately ±10% for the same type. Therefore, it is recommended to measure each cell and the entire block separately, and directly at battery terminals. If the measurements are performed periodically under the same conditions, i.e. temperature and charge level, it is possible to identify deterioration of the cells based on historical data analysis. Unfortunately, research fails to prove that the internal resistance test may be considered an equivalent of the battery capacity measurement that relies on the discharge test. Hence, it is not commonly used to actual battery capacity assessment.

7. Discharge Test

The discharge test is the only reliable method used to evaluate actual battery capacity with a high degree of accuracy. It takes a long time to perform – even up to 20 hours. While the measurements are performed, the battery needs to be disconnected, which results in a considerable depletion of the amount of reserve energy available on site. A few test procedures and equipment setups may be employed, which can provide results characterized by a varying degree of accuracy. The cost of the measurements performed may vary as well. Examples of the test procedures are presented below.

7.1. Discharge Test Built into the Power System

Modern DC power systems offer an advanced functionality enabling the efficient use of energy from VRLA batteries, referred to as the “battery test”. This function is capable of controlling the powered equipment based on priority levels assigned (e.g. critical equipment and non-critical equipment). The test may be run periodically, e.g. after a prolonged mains failure, or on-demand. Charging voltage may be boosted or reduced.

The test is based on a simultaneous, partial discharge of all batteries (up to 50% of the batteries’ design capacity). During the test, the output voltage of the power system’s rectifier is temporarily reduced to the pre-programmed value, e.g. 44 V. If the batteries manage to keep the telecommunications equipment powered up, over a pre-defined period of time, with the voltage remaining higher than the rectifier-provided value, the test result is deemed positive. If the battery voltage drops below the rectifier-fed value, over a period of time that is shorter than specified, the test result is considered negative.

Power consumption of modern telecommunications systems remains constant. Therefore, the amount of energy drained from batteries can be measured quite easily. Interpretation of test results is much easier when cell voltage of all batteries is monitored. This solution is simple and cheap to implement, but the capacity of batteries available at the final stages of the test is unpredictable. Therefore, the real battery capacity is unknown.

7.2. Discharge Test Using Battery Discharger

In order to determine the real capacity of a battery, a discharge with the current of 0.1 C is usually performed [10]–[12]. There are many types of battery dischargers, but in general, all of them are passive and rely on the transformation of power into heat. The majority of modern battery dischargers are equipped with monitoring circuits that measure the following parameters: battery voltage, individual cell voltage, discharging current and battery temperature. Hence, they are capable of working out the battery capacity. It is possible to set threshold values for the parameters referred to above, and to program the discharger to discontinue the test if one of them is reached. This simplifies the entire test procedure and allows to protect the battery from damage caused by excessive discharge. An example of the discharger unit that can sink up to 120 A

Fig. 2. Battery discharger with nominal current of 120 A.

Fig. 3. Stand-alone battery ATE: (a) up to 160 A and (b) up to 50 A.

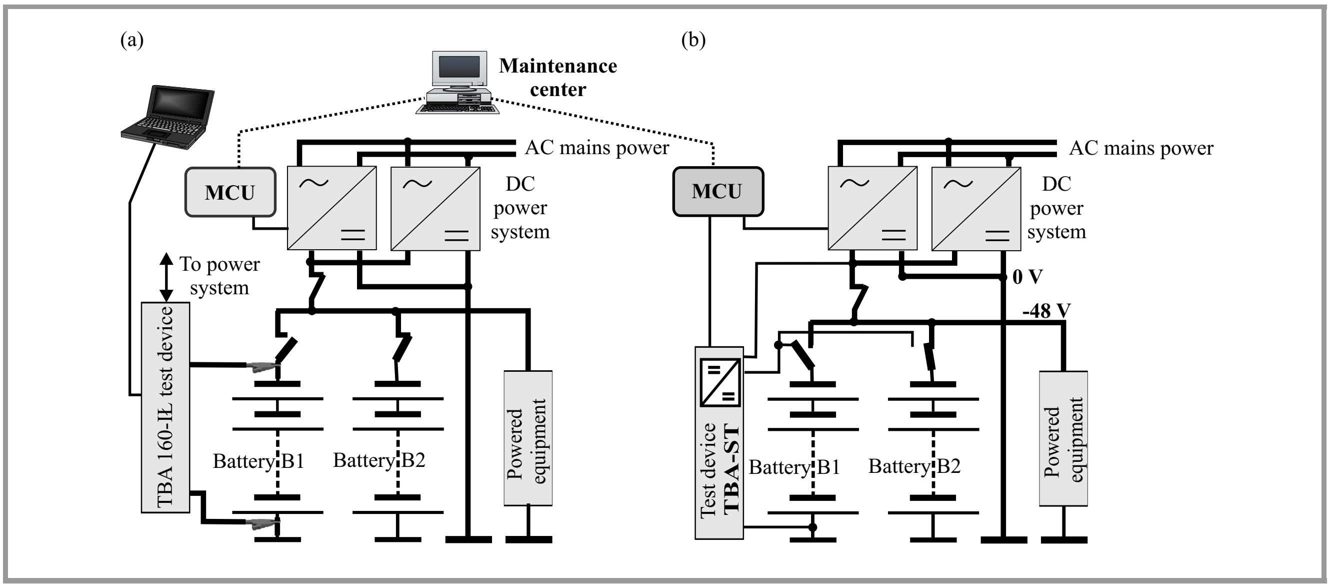

Fig. 4. Power system with ATE (a) stand-alone TBA160-IŁ and (b) built-in test functionality (TBA-ST).

from 48 V batteries is presented in Fig. 2 [13]. However, tests performed with the use of such devices are time consuming, as the full test procedure requires that several steps be completed:

- disconnecting the battery to be tested from the power system,
- charging the battery to its full capacity,
- discharging the battery,
- re-charging the battery to restore its operational parameters,
- reconnecting the battery to the power system.

Unfortunately, the return charging process is not monitored and battery energy efficiency cannot be assessed. Each stage of the process requires that battery connections be altered, and that the measurements be activated manually. One full battery test cycle takes approximately one day to complete, which means that in the case of sites with two batteries, the power system operates with a reduced energy capacity for two days. Therefore, often only partial discharges are performed.

It needs to be added that large amounts of heat are dissipated in the course of the test, which increases ambient temperature in the room and, of course, the battery temperature. The above means that not only all discharge energy is lost, but that air conditioning systems in use on the site consume more power as well.

7.3. Battery Test Automation

The entire battery test cycle can be automated, thanks to the use of sophisticated testers, either of the stand-alone variety, or ones that are built-in to the power supply system. TBA-IL is an example of a stand-alone portable device designed to measure real capacity of batteries at telecommunications sites (Fig. 3). The device can be connected to the battery and the power system via universal flexible cables, or with the use of a dedicated terminal box. As mentioned above, the battery undergoing the test needs to be disconnected from the power system. TBA160-IŁ was developed within the framework of a project titled “The new generation of VRLA battery control devices for telecommunications power systems”, and was subsidized by the European Union under the Innovative Economy Operating Program [14].

The test unit can operate in a full automatic mode (Automated Test Equipment) – Fig. 4a. All input parameters and measurement results are stored in its memory and may be transferred to a local or remote PC by means of the LAN-WAN interface. The unit presented in Fig. 3 is very efficient – energy discharged from the battery is returned to the power system and less than 5% energy is dissipated in the form of heat. The enclosure of the device is also smaller than that of a typical resistive discharger.

The ATE test device may be integrated with the power system, as shown in Fig. 4b. In this case, it is supervised by a power system controller and managed by the maintenance center. In such a case, the ATE comprises only a bidirectional power converter and relevant sensors. Therefore, the built-in test device can be a few times cheaper than the stand-alone version. Automated battery switch-off functionality is another of the advantages of this particular configuration. No manual operation is required, and the switching-off process is initiated by the power system controller. However, there are certain restrictions inherent in this solution. The only drawback is the fact that the built-in unit is capable of controlling batteries with the maximum capacity of 1000 Ah.

8. Universal Module for Charging/Discharging Batteries

The National Institute of Telecommunications (ITL) boasts extensive experience in designing devices for testing batteries used at telecommunications sites. ITL cooperates with the Electronic Power and Market (EP&M) company. A consortium led by ITL won a contract from the National Centre for Research and Development for designing a “Control systems for telecommunications site energy reserve solution - SKOT”. TBA-A with the module shown in Fig. 5 was developed within the framework of this project, which can serve as a TBA-ST device integrated with the power system. There are similar solutions available on the market, i.e. [15], but ITL TBA-ST ATE offers optimized functionality. The TBA-ST is dedicated for medium size telco sites and it is capable of driving/sinking current of up to 50 A. When combined with the TBA-W control unit, the TBA-A module forms another ATE unit. Its firmware was also developed under the project in question.

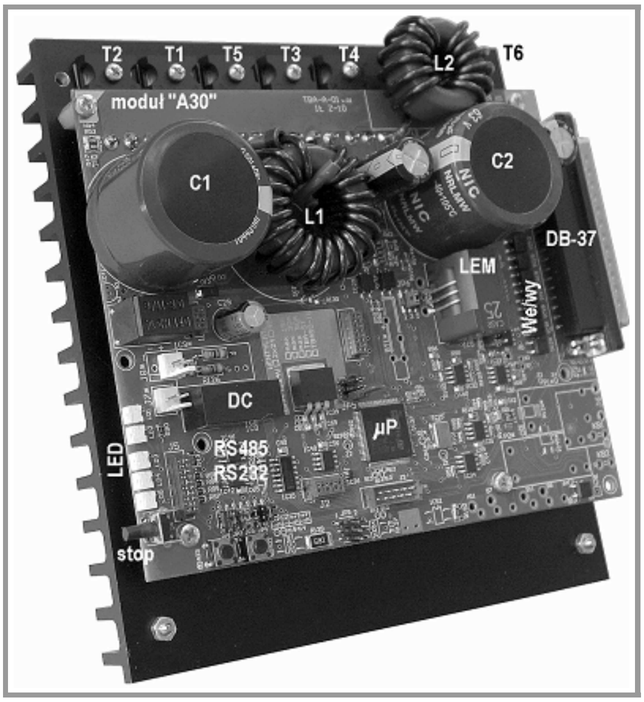

Fig. 5. Universal battery charging/discharging module.

The core of the TBA-A has the form of a bidirectional additive/subtractive power converter based on T1–T4 switching transistors, L1 inductor and C1–C2 capacitors. The switching process is controlled by the PWM circuit at the fixed frequency of 35 kHz, enabling output voltage to be regulated, and the energy from the tested battery (either Battery 1 or Battery 2) to be transferred to the power system or in the reverse direction. The charging and discharging current is stabilized by using a high accuracy LEM current sensor. The input and output voltage is monitored for exceeding threshold values. The power conversion is controlled by the STM32F103VE 32 bit microcontroller. It generates PWM waveforms, reads battery voltage, power system voltage, each cell/block voltage and charging/discharging current from the LEM transducer. It also offers an external communications interface. All parameters and operational modes can be transferred remotely via the RS232/485 interface. The serial port is used also for downloading the measurement results. The TBA-A is also equipped with an additional RS232 port used for servicing. More details are presented in Fig. 6 and in [16].

The firmware of the device presented above constitutes is core component, as it controls the bidirectional converter. It was developed based on the authors’ extensive experience. The first power converter dedicated to charging/discharging batteries was developed by ITL 15 years ago and weighed approximately 10 times more than the current solution [6], [17]–[19]. The use of fast MOSFET transistors with internal diodes, the 32-bit ARM-based microcontroller and sophisticated firmware has enabled to develop a very small, light and powerful unit.

Voltages of the batteries (B1 and B2 in Fig. 6) and cells (a1…a4, b1…b4) are measured with the accuracy better than 1%. The real capacity calculated in relation to the capacity at 20°C is saved with the accuracy 2%. In addition, the device calculates works out the energy of the discharged battery. The test device offers high energy efficiency. About 95% of the discharged energy is returned to the power system to supply telecommunications equipment. As no heat is generated, the measurement conditions remain very stable. The room itself and especially the battery are not exposed to any additional heat, which means that the air conditioner operates under stable ambient conditions. The TBA-ST ATE device was developed under the “Monitoring system for telecommunications site

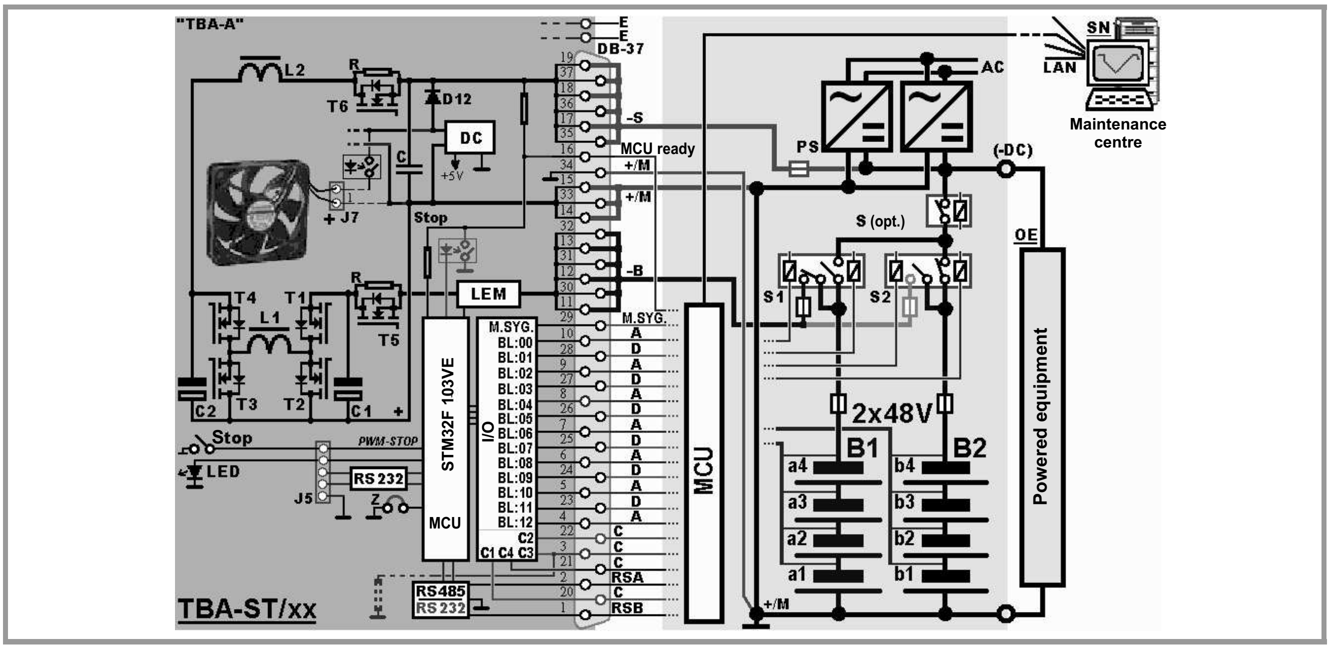

Fig. 6. TBA-A block diagram and its connection to the power system.

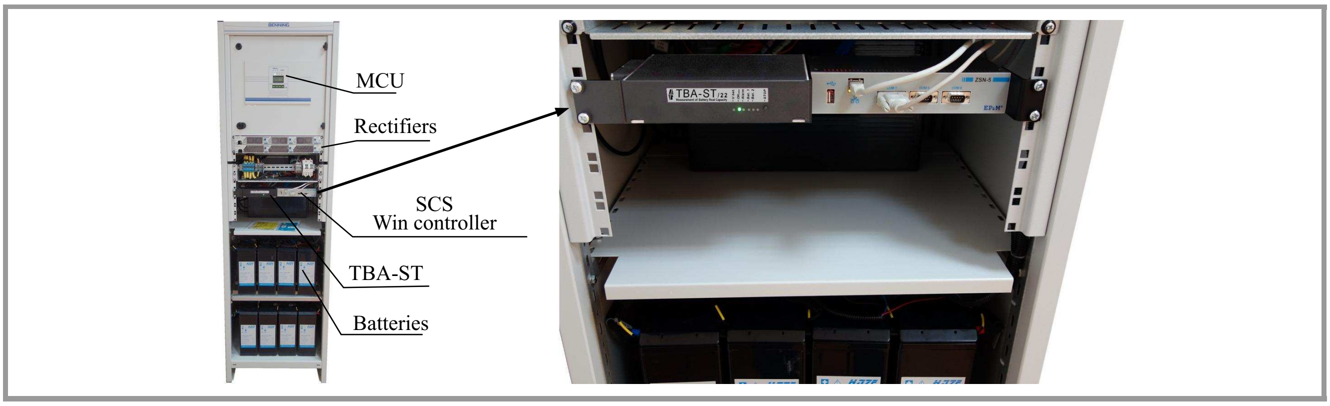

Fig. 7. Power system with a built-in universal battery testing module.

energy reserve solutions – SKOT” project. The project was implemented by the National Institute of Telecommunications and the EP&M company, and was co-financed by the European Regional Development Fund under the Innovative Economy Operational Program.

9. Deep or Partly Battery Discharge

The primary objective of the study is to evaluate the energy reserves stored in the battery. It is usually assumed, in the case of telecommunications power systems, that the battery remains operational if its capacity (Q) is not lower than 80% of rated value at the discharge current of 0.1 C. That is why the designed battery capacity is 20% greater. It enables to achieve the required capacity within the power system at the end of the battery’s lifetime declared by its manufacturer. Due to the adverse operating conditions, some batteries fail to achieve the average declared life expectancy, but a significant portion of them remain operational until the end of the specified period. It should be noted that the efficiency of each battery is determined by the condition of its weakest cell.

Figure 8 shows the results of checks performed on various batteries rated at 48 V/1000 Ah after operation lead times. The drawings present cell voltages during the discharge and charge test under the same conditions. The cell discharge cut-off voltage was set at 1.80 V. If the voltage of any of the tested cells drops below that value, the battery discharge stops.

The initial charging current was set at 0.1 C (100 A), the final charging battery voltage was 56.00 V, and the highest cell voltage was set at 2.38 V. If either the voltage of the battery reaches 56.00 V or any the voltage of any of the cells is equal to 2.38 V, the charging current is decreased and the charging process is stopped.

The discrepancies between cell voltage characteristics shown in Fig. 8 tend to increase with time of use, and with the reduced battery capacity. It can also be noted that

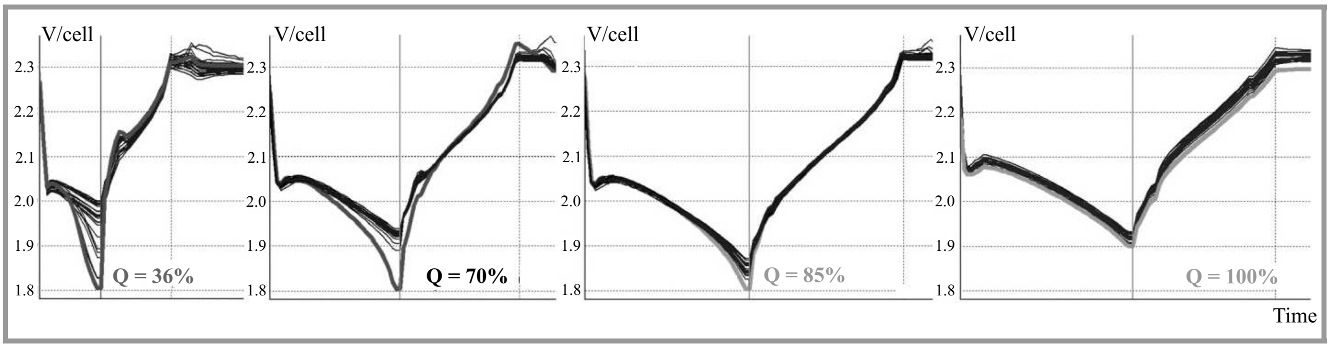

Fig. 8. The results of inspection of various 48 V/1000 Ah batteries.

in the first stage of the discharging process, cell voltages are usually similar and do not suggest a failure of any of the cells. Moreover, the voltage of smaller capacity cells recorded during the first stage of discharge process may be higher than that of higher capacity cells. Such a case is presented in Fig. 9. The cell with the lowest voltage in the final stage of the discharge phase (after 360 minutes) has the smallest capacity. But in the first stage of the discharging process, the voltage of this particular cell was good, and no evidence enabling to predict its reduced capacity existed. This means that is not easy, or even impossible, to evaluate battery parameters, especially its capacity, based on the cell voltage chart during the first stage of the discharge process. The National Institute of Telecommunications [20] has performed research focusing on this particular issue, but no effective algorithm to predict the battery capacity based on short discharge results only has been developed yet.

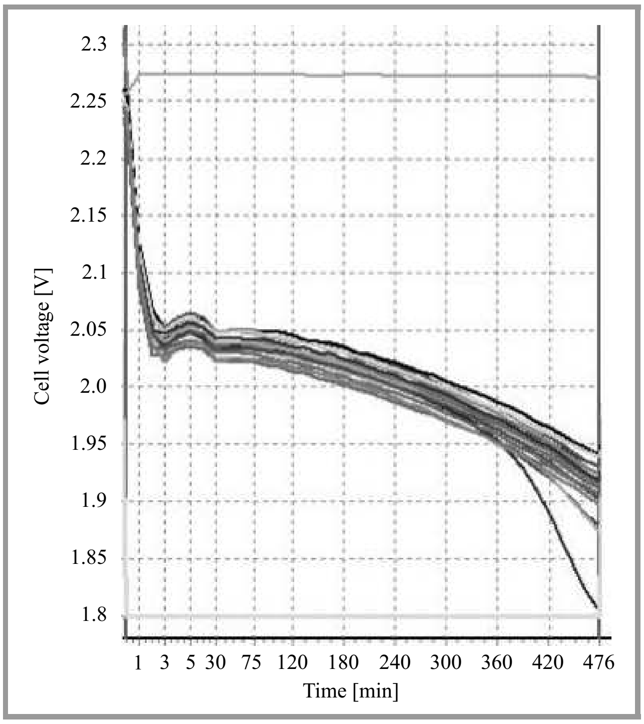

Fig. 9. Detailed discharge characteristics of a 700 Ah battery.

10. Conclusions

Currently, the discharge test method remains the only reliable way to evaluate the real capacity of batteries. Such a measurement method renders results with the accuracy of ±2%, a level that is unattainable in the case of remaining methods. Unfortunately, measurements made with dischargers or stand-alone testers are expensive and time consuming. The use of a measurement module that is integrated with the power supply system can significantly reduce the cost of testing batteries to the level that is competitive with alternative solutions.

The method presented and the ATE testers do not reduce the measurement lead time, but offer the opportunity to stop the test at any given moment, e.g. if the continuity of power supply is jeopardized. Once the test is completed, the battery is reconnected to the power system and the reserve power is increased.

The measurement module enables also to disconnect the battery remotely, should a need arise.

These benefits make the application of the ATE system very profitable in the case of remote telecommunications facilities.

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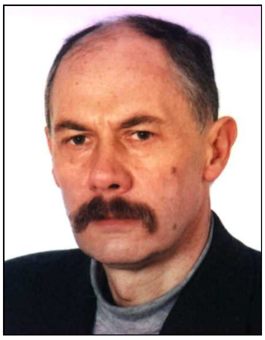

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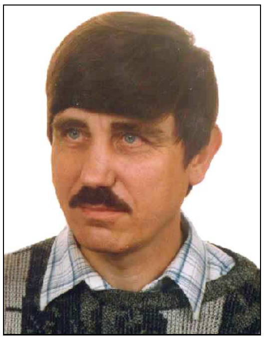

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